Liang Emlyn Yang · Hans-Rudolf Bork
Xiuqi Fang · Steffen Mischke *Editors*

Socio-Environmental Dynamics along the Historical Silk Road

GRADUATE SCHOOL AT KIEL UNIVERSITY
human development in landscapes

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Foreword I

The Graduate School of Human Development in Landscapes at Kiel University is an advanced school engaged in studying and teaching interdisciplinarily the interactive development of past human society and physical landscapes. Since it was established 11 years ago, I have been involved many times in its project reviews, advisory issues and have noticed its significant progress. A remarkable aspect is its young researchers who explore human development from various perspectives, including the lead author of this book Dr. Yang who I was impressed by when I first heard him talk in November 2016 at the School. It is a promising direction that he and others have taken to investigate the adaptation and resilience of human society (both successfully and unsuccessfully) in facing of the past climate changes with the target to inform the present global climate problems.

This new book "Socio-Environmental Dynamics along the Historical Silk Road" continues this direction as well as other aspects of climate-related social–environmental changes, including landscape, water, disaster, population, empire, civilization, culture and heritage. It is often challenging to discuss on such large-scale and long-term social development issues in one book. However, the concept Silk Road is a natural framework for these topics and thus perfectly links the international contributions to this book. Especially, several chapters in the book focused on the Central Asia area with the ever existed Han Dynasty (Chap. 3), Sogdiana civilization (Chap. 9), Saljūq Empire (Chap. 13), Oxus civilization (Chap. 14), which collectively evidenced certain interactives between physical environment and social systems.

It has been widely agreed that human migration and cultural exchanges in the Eurasia hinterland existed much earlier than the traditionally recognized start time of the Silk Road around the end of third century BC. Culture is rooted in the local environment and associated living habits, but cultural change involves many external factors, among which the exchange with others is a most significant one. The Scythians of the Eurasia steppe in seventh century BC was formed like this, where nomadic confederations developed either symbiotic or forced alliances with agriculture peoples—in exchange for animal produce and military protection. While the rise of the Silk Road networks subsequently facilitated those exchanges, the integration and coexistence of cultures from the West and the East of the Eurasia continent performed more pronounced in Central Asia.

The editors and authors have made great efforts in putting together an important body of knowledge in this book. It is very important because it reveals partially the history of man as well as human development. We have to learn how cultures developed in the past to understand why we have certain processes today. Learning from the past experience will help us understand these exchanges and integrations at the systematic level. For instance, the current problem of climate change is not a problem only of today, but was faced by many societies in the past. These societies' experiences and lessons, the development of unique social and cultural systems, the power of religions, tolerance and intolerance to each other should never be forgotten. Against this backdrop, the book includes state-of-the-art research on socio-environmental dynamics, integrates knowledge on multiple aspects of social-cultural exchanges, and highlights case studies on and references for human development. Today, more than ever, we need sharp research like this.

The book is a collaborative venture. The chapters provide an interdisciplinary perspective and document emerging and innovative knowledge of the past environmental conditions and its links to social-culture development. Such knowledge based on solid analysis of data, materials and proxies in the field is indispensable as we move forward. We are still a long way from understanding the essential mechanisms of the socio-environmental interactives in various scales and periods. This book is a welcome addition to the literature.

Berlin, Germany
June 2018

Hermann Parzinger
President, Professor Prussian Cultural
Heritage Foundation

Foreword II

The long history of human–environment interactions has attracted and is attracting a large number of investigations by international scholars, and it is also a major research field that I and my research team explored for many years. Our studies in Western China, Central Asia and other alpine Asian sub-regions have been focusing on the paleoclimate records of loess sections and lake sediments to reveal climate changes in the late Quaternary, especially in the Holocene, in the Westerlies-dominated region. Exciting geo-archaeological studies revealed the linkages between dramatic environmental changes in the past and prehistoric human activities at regional scale. We have found that the cultural exchange was certainly influenced by geographic setting and environmental changes, and the proliferation of crops and agricultural technologies along the prehistoric Silk Road from the west promoted human adaptation and living at the Tibetan Plateau during the late Holocene. These findings initiated extensive discussions in the global academic community.

Recently, we are supporting and increasing integrative geoscientific research in the Pan-Third Pole Region. One of the focal themes is the relationship between the cultural history and the environmental and climatic changes along the Silk Road territory, and the implications to the formation and development of contemporary China and the Eurasian societies. Five years ago, the Chinese President Xi Jinping proposed “The Belt and Road Initiative” to strengthen economic ties and cooperation between China and neighbouring countries in Central and West Asia. The initiative is increasing development opportunities for the countries and the region in general, and at the same time, brings major opportunities for scientific research focusing on this vast area. Traditionally, resources and environmental conditions of the Pan-Third Pole Region are key constraints for the development of West China and the countries along the ancient Silk Road. Therefore, the studies of the human activities, environmental changes and the rise and fall of the Silk Road civilizations as well as their mutual relations at different historical stages in the Pan-Third Pole Region are of urgent and great significance to understand the human–environment interactions in science, and to enhance the regional eco-environment sustainability and socio-economic development in practice.

I was excited to learn about the international workshop on the socio-environmental issues of the historical Silk Road area that was organized and conducted by the authors of this book in 2017. The theme of the workshop fits well with our research interests, and I am happy to see that some of my colleagues participated in the workshop and contributed to the book. The lead author Dr. Yang has a similar research philosophy as I have: investigating the past social-climate relationships with a present geographical perspective. This may not be a perfect combination in terms of scientific research, but it starts from the present social–environmental challenges and seeks answers from the complex historical experiences and lessons. This perspective often helps since the long human history has rich stories to tell but only targeted researchers can comprehend the meaningful implications. I think this is one of the reasons why the workshop was very successful.

The publishing of this book "Socio-Environmental Dynamics along the Historical Silk Road" is of cause the biggest success, in which the editors and authors put great efforts and invested long time. It is a wise integration of expertise from different disciplines, including climatology (Dr. Yang), geo-archaeology (Prof. Bork), geography (Prof. Fang) and geology (Prof. Mischke), and additional disciplines represented by the authors of the chapters. Organizing contributions from such various disciplines and integrating them into a thematic book is certainly challenging, but the editors successfully framed them within a logic chain including landscape evolution, environmental disasters, climate impacts, social resilience and culture connections.

The chapters cover a broad research area, the historical Silk Road area in the hinterland of the Eurasia. It naturally involves the diversity of natural landscapes and environmental characteristics, while the diverse aspects are linked by one essential factor: water. Water was related to agriculture development and population growth during water-rich periods, but the scarcity of water also caused disasters that forced social system changes as described in case studies in Parts II and III of the book. However, human societies were not always transformed when climate and environmental stresses were faced. As the chapters in Part V indicate, social resilience existed (human–water relationships in Chap. 16) and human knowledge was advanced (Karez Systems in Chap. 17), so that those societies maintained their functions and developed into the present. The exchange of goods, culture and ideas along the Silk Road was an important power that promoted the mutual understanding and peaceful coexistence of different groups of people, as well as sharing the experience living with tough natural conditions.

The book is a further research step to answer the grand question "Why collapsed some civilizations while others persisted?" from the perspective of climate/environment changes. Though it does not provide a clear answer (maybe, no clear answer may exist!), research in this direction will provide more case studies and will improve our knowledge to inform a better strategy of social development in this critical region. Especially in recent years, the revival and reconstruction of exchange pathways and trade routes between the East and West of the Eurasia continent call for better understanding of the evolution rules of coupled social–environmental systems. This is the true value of studies such as those presented in the book, reaching beyond academic research. From this point of view, this book could not come at a better time.

The effort of the editors and authors demonstrated in achieving this book is a good sign that the "old" science is very alive and attractive to especially young researchers. I hope that this fresh body of knowledge captured hereinafter will reach an audience beyond the paleo-science communities and by doing so undoubtedly become useful to everyone in the broader environment and development community.

Beijing, China
July 2018

Fahu Chen
Director, Professor
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Foreword III

Over the last decade, interdisciplinary efforts directed on past societies and their environments are broadening our view on socio-environmental dynamics and have opened exciting new perspectives on old archives. Among the key areas that demonstrated these dynamics in the past and therefore attracted intensive investigations in the recent are the northeast Mediterranean, Middle East, Central Asia and the Eurasia Steppe, which are linked by the modern concept Silk Road.

The Silk Road is one of the oldest routes of international trade in the world. It is first reported to have been used during the Han Dynasty (206 BC–220 AD) in China, but recent archaeological evidence indicates that trade managed by the ancient steppe societies across the central Asian deserts began as early as 5000–6000 years ago. In several millennia, territory along the Silk Road has been both, a home to ancient civilizations and a hot spot of environmental hazards. Therefore, it is a key region through which we may disentangle the interwoven forces of long-term interaction between humans and the environment. Managing risks, maintaining livelihoods and promoting development were unavoidable tasks for local communities in the long past. Until now, however, there have been few attempts to bring different archives together to form an integrated long-term narrative of the interactions between humans and the environment in the region.

In early 2017, Dr. Yang proposed the International Workshop “The Rise and Fall: Environmental Factors in the Socio-Cultural Changes of the Ancient Silk Road Area” and raised this specific and significant research question. The workshop brought together experts from 12 countries with 19 presentations and enabled to produce this book as a proceeding volume. The book “Socio-Environmental Dynamics along the Historical Silk Road” is a manifestation of the research progress in the field and an achievement made by the four editors, more over 30 (co-)authors and over 50 reviewers. Both the workshop and the book were sponsored by the Graduate School Human Development in Landscapes at Kiel University (GSC 208/2) and the Past Global Changes project (PAGES) and are considered among the most fruitful initiatives by young researchers at the school and through the project.

The GSHDL and Johanna Mestorf Academy (JMA) strive to promote international partnerships as a means of advancing education and research in the field of past socio-environment. The global theme of human development in their cultural and natural environment is linked to the detection of cross-linkages between different factors: the influence of man on nature and vice versa. With this integrative background, the GSHDL/JMA offers a favourable opportunity to understand the highly dynamic spatial–temporal processes that join interdisciplinary expertise in palaeoclimatic, palaeoecological, palaeodemographic, as well as cultural research. Though the processes involved may be of global character and may apply to the entire human history, case studies concentrate on the Holocene and mainly in Europe and adjacent regions. I think, this unique feature of the school contributes an important part to the success of the workshop and book about the Silk Road.

In many cases, research questions arise in highly specialized fields, and progress is accompanied by increasing specialization and divergence of research fields. However, to gain an integrated understanding of the multifaceted phenomenon of human development in an ever-changing environment, a multidisciplinary approach uniting the full width of philosophical, social and natural sciences is needed. The book using Silk Road as the geographical scope and inspirational concept and striving to provide such a frame to address the human-environment interactions has well handled this challenge and is absolutely successful.

Our new Cluster of Excellence ROOTS aims to explore archaeological and historical places in a diachronic perspective, covering a wide range of socio-environmental constellations, under the basic assumption that humans and environments deeply shaped each other, creating social, environmental and cultural connectivities. As planned, the ROOTS programme will introduce new and long-term research perspectives, expanding the existing broad interdisciplinary expertise and extending strengths to the central and eastern areas of the Eurasia continent. This book is certainly a pioneer effort in this large and foreseen vision.

I would like to express my gratitude and appreciation to the editors, authors, reviewers, workshop conveners and assistants, the GSHDL, PAGES and all those who have collaborated to support the workshop and the publication of this book. I trust that this book will provide a useful knowledge base and tool for future students and researchers to comprehend the mounting challenges in human development and to explore innovative approaches to promote human–environmental harmonious and sustainability.

Kiel, Germany
July 2018

Johannes Müller
Director, Professor
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Acknowledgements

On behalf of the other editors, I wish to express our appreciation to the organizations and individuals who contributed perspectives, ideas, contents and offered support throughout the course of this book's development. This book emerged as a result of the International Workshop "The Rise and Fall: Environmental Factors in the Socio-Cultural Changes of the Ancient Silk Road Area", which was held at the Kiel University during 27–28 September 2017. Both the workshop and the book received joint financial resources from the Graduate School "Human Development in Landscape" (GSHDL) at Kiel University (GSC 208/2) and the Past Global Changes project (PAGES).

We thank the workshop Organizing Committee, particularly Prof. Josef Wiesehöfer, Ms. Milinda Hoo, Mr. Faraz Nikpour Arani for all the help during the conference, and Dr. Silvia Balatti for early preparation of the workshop. Nineteen experts from twelve countries participated to discuss the importance of the past climate–environment–society relationships at this workshop. We are also very grateful to Prof. Johannes Müller for his welcoming words at the beginning of the workshop. Full support by PD Dr. Mara Weinelt throughout the long process from proposing the workshop to publishing the book is very much appreciated.

We would like to take this opportunity to thank all the chapter authors for their important insights, hard work, prompt return of manuscript drafts and revisions, and continued eagerness to make sure our ideas reach a broader audience. Our appreciation is also extended to the 51 reviewers (a list is included in the book) who took time to read the chapters and made valuable and constructive comments to improve the manuscripts, which guaranteed the high academic quality of the volume. Mr. Michael Spate, Mr. Stephen Pow and Dr. Rosalind Gillis provided their kind and free support to the book by proofreading some of the manuscripts and individual chapters at critical times. Open Access publication of this book has been made possible through financial supports from GSHDL and Dr. Bertil Mächtle's group in Heidelberg, besides the book editors. Especially, contributions of forewords from Prof. Hermann Parzinger, Prof. Fahu Chen and Prof. Johannes Müller are noted with great gratitude. Together with various interested and cooperating experts, they contributed to the book's success and helped to gain a high level of attention. Our gratitude also goes out to the Springer editing and producing team, especially Dr. Johanna Schwartz, Ms. Claudia Mannsperger, Ms. Dörthe Mennecke-Bühler, Ms. Sujitha Shree Duraisamy, and Mr. Boopalan Renu for making this publication such an enjoyable process.

Personally, it has been my honour and pleasure to take the leadership in convening the workshop and editing the book. Working on these for one year and a half has been a very creative, inspiring and rewarding process. Writing and publishing this book took a lot of effort and could not have been done without the co-editors of the book, Prof. Hans-Rudolf Bork, Prof. Xiuqi Fang and Prof. Steffen Mischke. Personal thanks go to them for their valuable input and great contributions in terms of science, organization, review, editing and time. I would further like to express my gratitude and appreciation to the GSHDL that hosts and supports my research initiative on the long-term socio-environmental interactions in China, Central Asia and South Asia, which is the very origin of both the workshop and the book.

Kiel, Germany
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Part I
Introduction

Chapter 1
On the Paleo-climatic/Environmental Impacts and Socio-Cultural System Resilience along the Historical Silk Road

Liang Emlyn Yang, Hans-Rudolf Bork, Xiuqi Fang, Steffen Mischke, Mara Weinelt and Josef Wiesehöfer

Abstract This chapter introduces, by literature reviews, the issue of the links and processes behind climate change, environmental change, and socio-culture change in the past at the ancient Silk Road region. Analyses of the changes of the socio-environment system in this area enhance our understanding on the regular patterns of coupled natural and social evolution, and is thus of important theoretical and practical significance. We argue that the cross-cutting theme has been to reach beyond simple explanations of environmental or human determinism, but social resilience under environmental impacts. Studies indicate both that climate conditions significantly influence human socio-cultural systems and that the socio-culture systems are certainly resilient to climate impacts. This chapter also summarizes the scope of all chapters in this book by illustrating the specific topics, research areas, focused periods and their inner relationships. The conclusion further summarizes the recent research states on past socio-environmental dynamics and the findings achieved in this book, as well as some outlooks.

Keywords Paleo-climate change · Environmental stresses · Natural hazards Social resilience · Socio-culture system · The Silk Road

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1.1 Introduction

The Silk Road is a modern concept for an ancient network of trade routes that for centuries facilitated and intensified processes of cultural interaction and goods exchange between West China, Central Asia, the Middle East, and the Mediterranean (Elisseeff 2000). The term derives its name from the lucrative trade in Chinese silk carried out along its length. The Silk Road flourished when the Han Dynasty explored Central Asia around 139 BC and thrived throughout Antiquity and far into Middle Ages under the Islamic and Mongol Empires. However, the Silk Road network also often covers other earlier or regional routes, e.g. the Persian Royal Road established during the Achaemenid Empire (550–330 BCE) as well as the maritime connections between China and the West (Frankopan 2015) that are not involved in this chapter and the book.[1] Though silk was certainly the major commodity, many other goods were traded, and religions, syncretic philosophies, and various technologies, as well as cultural influences, also spread along these networks. Trade and contacts on the Silk Road played a significant role in shaping the societies and cultures of ancient China, as well as those of the Mongols, Iranians, Arabs, Mesopotamians, Syro-Anatolians, Greeks and Romans, opening long-distance political and economic relations between various peoples and cultures (Bentley 1993; Frankopan 2015).

Along the ancient Silk Road, empires, dynasties and the associated institutions, social structures, and economic systems changed for several reasons. There is increasing discussion that climate and environmental factors might have also played a significant role in fostering economic and socio-cultural changes along the Silk Road as well as in a broader area (Zhang et al. 2011; Clarke et al. 2016). For instance, favorable environmental conditions may have boosted agriculture and animal husbandry, thus increasing the availability of resources necessary to support a powerful empire, while adverse conditions may have undermined the level of production and the living conditions of human society or exacerbated social stresses which eventually may have led to severe crises or collapse of socio-culture systems (Yang et al. 2017). In fact, coherent patterns and synchronous events in history suggest certain links between the social upheaval and climate forcing (Issar and Zohar 2004; Clarke et al. 2016), and environmental factors have been claimed as multipliers that accelerated socio-culture changes in some cases (Zhang et al. 2005; Rosen 2007).

However, it is also argued that many analyses over-emphasized the deterministic mechanisms (Gemenne et al. 2014). Research on climate change and social consequences primarily focuses on a few accessible regions, biasedly states the links between both phenomena and cannot explain the absence of social crisis in the face of climate risks (Adams et al. 2018). Indeed, archive-based studies of socio-economic responses to climate variability in colonial Mexico illustrate that vulnerability to change can lead to improved understanding of risks and increased adaptive capacity (Endfield 2012). At the same time, the possibility that social transitions themselves may have been responses/resilience strategies to abrupt climate events has also been

[1]The term Silk Road in this chapter thereafter and in the whole book indicates the overland Silk Roads as illustrated in Fig. 1.1, if not otherwise stated.

under exploration (Clarke et al. 2016). Studies also provided evidence that diverse ethnics, religions, industries, business activities and physical environments supported the resilience of a port city development through long history along the North Coast of Java in Southeast Asia (Ariestadi et al. 2017). Increasingly in recent literature, studies on civilization resilience (Dunning et al. 2012), mountain resilience (Tinner and Ammann 2005), coastal resilience (Adger et al. 2005), urban resilience (Ernstson et al. 2010), community resilience (Gunderson 2010; Wilson 2014), etc., also indicated certain resilience capacities of human societies with various perspectives from the past to present, and at the same time, emphasized the significance of understanding resilience in a historical and holistic way.

Societal responses to external forces are nonlinear in nature (Leroy 2006), meaning that in the archaeological and historical records, any hypothesized direct linkages between cultural transition and environmental forcing must be treated with caution. Purely environmental explanations of societal collapse, including climatic explanations, remain less than convincing and are still controversially discussed to make a general conclusion (Endfield 2012). Different societies might pursue different adaptation strategies when faced with similar changes in climate, depending on existing environmental and cultural factors. Resilience and adaptation frameworks therefore help us move away from deterministic models of human-environment interaction and beyond existing causal models of climate-induced collapse (Brooks 2012). Bearing this in mind, links between climatic, environmental, economic, societal and cultural changes manifested themselves differently in different places and times and often remain unclear.

This chapter reviews, compiles and analyses published literature, environmental proxies alongside archaeological records, and strives to illustrate the state-of-the-art in the field of socio-environmental interactions along the historical Silk Road areas. The introduction also briefly discusses the scope of other chapters in this book by illustrating the specific topics, research areas, focused time periods and their inner relationships to each other. We aim to highlight the complexity of the relationships between climatic and socio-cultural changes, and therefore encourage further investigations, for instance, of the concept of climate resilience that links both the climate impact and social response into one framework.

1.2 Paleo-climatic/Environmental Changes and Impacts along the Historical Silk Road

1.2.1 The Physical Geography and Environmental Conditions

The overland Silk Road is often recognized as a combination of the Desert Silk Road, Steppe Silk Road and the Southern Silk Road (the Tea-Horse Road) and covers a broad region of the Eurasian hinterland (Fig. 1.1). The most significant environmental characteristics of the region are dry sand deserts and Gobi (gravel desert), with

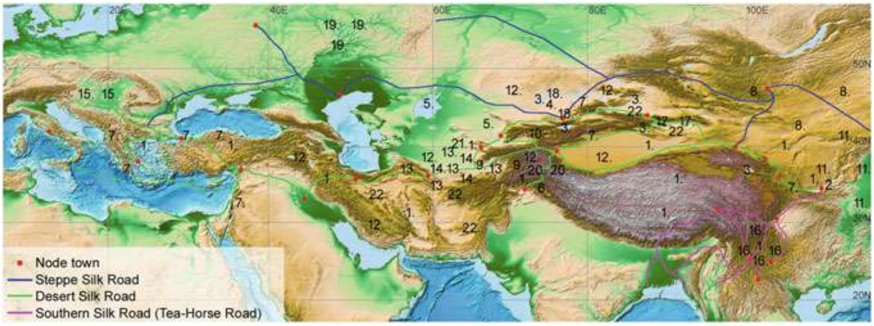

Fig. 1.1 Map of the historical overland Silk Road areas with rough representation of the road networks and node towns. Every number (chapter number in the book content) in the map indicates the main geographical location of the studies of a certain chapter in this book

high mountains including the Pamir, Tian-Shan, Karakoram and Hindukush. Another landscape characteristic of the region are the snow-fed rivers and oases that served as major places for human activities.

Geographically, the eastern areas of the Tian-Shan Mountains, mainly in the contemporary China, are complex with various local landscapes, including mountains, basins, deserts, Gobi, grasslands and oases (Yao et al. 2013). The Kunlun Mountains and Qilian Mountains at the northern margin of the Tibetan Plateau supported the predominant possibility for human exchanges along the foot hills in the east-west direction. There are only two possible pathways to go across the Tian-Shan Mountains, one is the southern foot hill line that passes over the Pamir at its western end, and another is the northern foot hill line that is a much longer alternative. The western side of the Tian-Shan Mountains represents typical grasslands in its north and deserts in the south (Hu et al. 2014). The grasslands compose a part of the Eurasia Steppe together with the Eastern European grasslands, while the deserts connect to the Iranian dry plateaus in the southwest. The Tarim River, Amu Darya, Syr Darya, and several lakes like the Lop Nur, Bosten, Balkhash and the Aral Sea form the main inland water bodies of the vast expanse of the drylands. Many oases fed by snow melting from the surrounding mountains are the major human settlement areas and provide stations for travelers. Due to the impacts of global climate warming and increasing human demands, most of the water bodies were shrinking significantly (Sorg et al. 2012).

The Desert Silk Road linked with the existing road networks in the Persian Plateau and further west-toward the Mesopotamia Basin and Anatolia (Frankopan 2015). The Persian Plateau and Anatolia are both surrounded by high arid mountains with sharp valleys. The central part of the Persian Plateau is a vast inland basin with dry salt marshes and deserts. The fertile Mesopotamia plain is surrounded by deserts, mountains and the Persian Gulf, where the Euphrates and Tigris Rivers flow almost in parallel from northwest to southeast and feed the alluvial plain (Fisher 2013).

The Steppe Silk Road was formed at the north of the Aral Sea, Caspian Sea and the Black Sea, linking mainly local nomad people. The steppe belt covers wide temperate grasslands, savannas, and shrublands, where the relatively few and mobile nomad people did not develop large human settlements in the ancient times, and thus the trading roads were erratic (Christian 2000). The Southern Silk Road or "Tea-Horse Road" is an ancient Chinese commercial road network comparable to the traditionally known Silk Road (Forbe and Henley 2011). It is located in the Hengduan Mountains and the Tibetan Plateau and includes the Yangtze River (Jinsha River), Minjiang River, Nujiang River, Lancang River (Mekong River) and the Yarlung Zangbo River. The road networks originated from the Sichuan Basin of the ancient Chinese Empire and the major tea producing areas in Yunnan, and extended to Lhasa in the Tibetan Plateau and south to India across the Himalaya.

Generally, the natural environment at the historical Silk Road areas is very difficult for human living and traveling. The environmental conditions can be felt today and somehow also be imagined from ancient poems "yellow sands and dry grasses linking the land and sky"[2] and traveling records "no flying birds, no walking animals, no living grasses".[3]

1.2.2 *Paleo-climatic/Environmental Changes and Social Impacts*

Over the ~12 millennia period of the Holocene, the climate in arid Asia has fluctuated. It has experienced the early Holocene warming period (11700–8500 years BP (Before Present)), the mid-Holocene warm period (8500–3000 years BP), and the late Holocene cooling and drought period (from 3000 years BP to present). Chen et al. (2008) confirmed that during the early Holocene most of the lakes in the region experienced very low water levels or even dried out before ca 8000 years BP. The study based on loess grain-size changes of loess sediments in the Ili Basin by Li et al. (2011a) also recorded the warm and dry period of 11000–8000 years BP.

Small climate fluctuations in each large period are still relatively consistent. Several cold climate periods around 8200, 5000, 4200, 3100 and 600 years BP occurred in almost every sub-region (Mayewski et al. 2004), which generally showed significant continental and arid climatic characteristics in Central and West Asia. As a result of paleo-environmental syntheses based on several types of proxy data, it is accepted that the mid-Holocene drought reached its peak between 3800 and 3500 years BP (Arikan 2015). However, some humid periods occured in middle to late Holocene as evidenced by loess records in Xinjiang (Chen et al. 2016) and Iran (Chen et al. 2017), which had a profound impact on the development of human civilization in the inland dry areas in Asia.

[2]Cen Shen, Remember Duling at Jiuquan. 岑参,《过酒泉, 忆杜陵别业》.

[3]The biography of Master Sanzang. Tang Dynasty. 沙门慧立本, 释彦悰笺. 《大慈恩寺三藏法师传》, 10 卷.

Overall, the traditional Silk Road area has a distinctive semi-arid climate with hot, cloudless, dry summers and moist, relatively warm winters in the south and cold winters with severe frosts in the north. Precipitation throughout most of the region has a spring maximum (Lioubimtseva and Henebry 2009). Records of stalagmites from Kesang Cave demonstrate that precipitation history in the region exhibits a processional rhythm over most of the past 500,000 years (Cheng et al. 2012). Based on the early-to-mid-Holocene reconstructions, the arid zones of Central Asia may become moister as a result of global warming, due to an expected southward shift and probable intensification of the westerly cyclones (Lioubimtseva and Henebry 2009). However, due to the very high uncertainty in such studies, it is important to further understand the mechanisms of precipitation changes and climate in general.

Oasis systems play a dominant role in supporting human activities in the arid Asia, but they are fragile to large-scale climate change and also human influences. For instance, the eco-environment of the oasis systems in the southern part of the Tarim Basin has taken great changes during the recent 2000 years, which are characterized by the evolution and desertification of oasis and led to many famous ancient cities having been abandoned (Zu et al. 2003; Liu et al. 2016). However, research based on analyses of lake sediments from Lop Nur in the eastern Tarim Basin also shows that the Loulan Kingdom decline resulted from a man-made environmental disaster rather than from changing climate, because lakes in adjacent regions recorded rising levels and relatively wet conditions during the same period (Mischke et al. 2017). Analyses on the distribution and evolution of oases show that environmental changes are partly due to the aridization of climate before the 20th century but mainly attributed to the human activities in the 20th century.

The environments in the Silk Road areas are complex and diverse, and the climate is sensitive and variable. The development of regional cultures was deeply influenced by the natural environment and its evolution (McMichael 2012). Tree ring-based reconstructions of European summer precipitation and temperature variability over the past 2500 years revealed human susceptibility to climate variability (Buntgen et al. 2011). The direct manifestation of climate impacts may be in terms of its resource utilization and economic shape of human society, while the extensive influences can contribute to the development, migration, spreading and the rise and fall of cultures. Abrupt climate change events, such as the widespread droughts around 8200, 5200 and 4200 years BP, are suggested to be the result of altered subtropical upper-level flow over the eastern Mediterranean and Asia (Staubwasser and Weiss 2006).

In monsoonal Asia, drastic swings in moisture availability, notably megadroughts associated with monsoon failure, interacted with socio-political and technical institutions to spur the disintegration of the 14th century Khmer Kingdom at Angkor (Hessl et al. 2017). The late 16th and early 17th century experienced a period of drought and the collapse of the Ming Dynasty in China, while most of the regions across Southeast Asia saw great unrest and rapid realignment during one of the most extended periods of drought (Buckley et al. 2014). New paleo-proxy records and the incorporation of historical documentation are expected to further improve the understanding of these disruptions in regional societies.

Looking at the natural environment and cultural development of late Holocene period in the Silk Road areas, we could see the following salient features:

- First, when the climate developed toward dry-cold or warm-humid, the vegetation belt in Eurasia moved southward or northward accordingly (Li et al. 2011b; Zhao et al. 2017; Dallmeyer et al. 2017). In most cases, the climate shifts drove people of different economic modes move to the south or north as well. As a result, a boundary line between agriculture (oasis regions) and pastoralism groups (steppe areas) was formed. In China, the line was stretched to a belt region approximately equivalent to the position of the Great Wall (Shi et al. 2017).
- Second, the north-south movement of human groups is often accompanied by wars and conflicts, especially between the agricultural and non-agricultural groups (Cosmo 2002; Zhang et al. 2007). As a result, cultures and blood was often exchanged between both regions.
- Third, the social development model associated with local environment was also formed over long periods of time, for example, the oasis agriculture mode and the steppe pastoralism mode (Porter 2012). These modes were formed and developed relatively slowly but were compatible with the harsh natural environment.
- Fourth, in several extreme climatic periods of the last 5000 years, the different socio-economic modes and their coping strategies have brought about distinctly different results in terms of society, economy and culture that some successfully transformed and some collapsed (Fang and Zhang 2017).

In general, the development level of culture and productivity in arid Asia was limited during most of the Holocene period. However, human societies were always learning to adapt to environmental changes and influences. Similar to results of Tol and Wagner (2010) for Europe, the relationship between social conflicts and climate varies weakens in the industrialized era, and is not robust to the details of climate conditions in many contemporary societies. It often seems that human beings were passively adapting to nature, but essentially it might also be a process of continuous learning and active response.

1.3 Socio-Cultural Dynamics and Resilience in a Historical Perspective

1.3.1 Socio-Cultural Features and Exchanges along the Silk Road Areas

Cold mountains, dry deserts and seasonal grasslands composed the complex and diverse landforms of most areas along the historical Silk Road, which are tough conditions for human activities in ancient times. However, our ancestors were not isolated by the unfavorable geographical conditions. There are often rivers flowing down from the snow-capped mountains on the edge of the deserts, which irrigated oases and served as cradles of local socio-cultural development and exchange places of different civilizations. The Silk Road connected these places and people and major civilizations in the Eurasian continent, including the Confucian in Eastern Asian, Buddhism-Hinduism in Southern Asian, Islam civilization in Western Asian, and the Greek-Roman civilization in Europe (Beckwith 2009). Its strategic and historic position around the East-West axis and the major trading routes guaranteed a steady influx of ideas and conflicting notions of tribalism and traditionalism, and stimulated a variety of cultures such as the Buddhism, Mongols, Persians, Tatars, Russians and Sarmatians (Liu 2010).

From the 2nd century BC to the 2nd century AD, four empires juxtaposed along the historical Silk Road from west to east. That is, the Roman Empire in Europe (30 BC–284 AD), the Parthian Empire in West Asia (247 BC–224 AD), the Kushan Empire in Central Asia (30–375 AD), and the Han Dynasty of East Asia (206 BC–220 AD). The four empires were in a period of prosperous states around the 1st year AD and were actively expanding outward. Their pioneering efforts directly connected the East and West worlds and enhanced the mutual exchanges and influences between the four ancient civilizations of China, India, Persia and Greece (Beckwith 2009). Since then, the development of any civilization has not been carried out in isolation.

The ancient Silk Road contributed greatly to the cultural exchange between China and the West. From the 2nd century BC to the 15th century AD, splendid cultures among China, India, Greece, Persia and Rome were exchanged along this famous trade route, making the route a great "Cultural Bridge" between Asia and Europe (Foltz 2010). Religion is of great importance in most places, but this is especially true in the Silk Road areas where the culture cannot be separated from religious beliefs and practices. In the 1st century AD, Manicheism and Christianity penetrated from the Near East to Central Asia and further to China. Islamic doctrine might have been brought by warriors of Arabian caliphates in the 7th century but its distribution along the Silk Road was carried out peacefully. At the same time, the Silk Road was also the route for Buddhist monks who went from India to Central Asia and China (e.g. the most known monks Zhu Shixing, Fa Xian, and Xuan Zang) (Liu 2010), as well as the route for Christian doctrine dissemination. The most significant religion in the Silk Road areas, by far, is Islam that dominants in the southern and western parts, while the northern steppe areas are more related to the Russian Orthodox Church (Foltz 2010). The Southern Silk Road regions had a significantly different culture reflecting a mixture of Chinese Buddhism, Tibetan Buddhism and many local religions.

Central Asia was once the center of multiple nomadic empires and tribes, including the Scythians, Mongols and Turks. The invasions and migrations of nomads were an important force in history that greatly affected all parts of Eurasia and also influenced the traditions and cultures of many Silk Road sub-regions to the present day. A big shock occurred from the 2nd century BC when the Xiongnu nomadic tribes raised and moved from the east to west in the steppe (Wu 1983). This movement led to a series of nomadic intrusions into the farming empires such as the Chinese Qin-Han Dynasties, the Indian Kushan Empire and the Western Roman Empire. In the 13th century, another big wave of the impact of the nomadic world on the farming world broke out, when the Mongols and Turkic people attacked the whole region along the

Silk Road from East Asia to Central Europe (Wu 1983). The interaction between farming civilization and nomadic civilization was an important way to promote the development of civilization in Eurasia. So dynamic were the steppes that vast empires could rise and fall within a generation (Invictus 2006). In the modern era, with the ultimate decline of nomadic cavalry and the rise of maritime trades, the nomadic Eurasia gradually lost its military superiority to the surrounding farming civilizations.

The Silk Road was not only the source of goods but also information on their making, i.e. technologies, in particular, the breeding of silkworms, silk spinning, paper making, printing with movable types, the making of gunpowder, porcelains and lacquers, and the invention and use of the compass. Material culture exchange was also underway on this long trade road (Liu 2010). A large number of products of the West flowed into China, such as grapes, walnuts, carrots, peppers, spinach, cucumbers, pomegranates, medicinal materials, flavorings and jewelry. Also, along with spreading goods, cultural developments in the applied art, architecture, wall painting, music and dances enriched the intercultural exchange along the Silk Road (Elisseeff 2000). The cultural exchange between China and the West offered mutual benefits and achieved common progress, which greatly sped up the development of the Eurasia world.

1.3.2 Resilience of the Socio-Cultural Systems

Climatic change has certainly influenced socio-culture characters in the long (pre-)history of the Eurasian continent, while it can also be a factor of technological innovations in order to compensate difficulties and to maintain a certain threshold of vital yields for the whole population, such as moving to new ecological areas and adapting new irrigation or planting techniques (Clarke et al. 2016; Flohr et al. 2016). Actually, the diversity of cultures, livelihoods, and political formations indicated that relationships between climate, ecosystems, and societies are non-linear, complex, and variable over time (Endfield 2012). Examples of human-environment interactions in the monsoonal and arid Central Asia suggested that societies have adjusted to climate variability in diverse and (mal)adaptive ways over the last three millennia (Hessl et al. 2017).

It has recently been emphasized that the concept of social resilience can be usefully deployed in some historical contexts (Haldon and Rosen 2018). Among the five patterns of the impacts of climate change on civilization summarized by Fang and Zhang (2017), only one is socio-cultural collapse while the other four are different types of resilient continuous cultures and transformations of socio-cultural systems. It is a normal phenomenon in the Silk Road areas that a group of people (e.g. nomadic tribes) migrate to another area after consuming the resources of one area. This kind of migration is not a manifestation of social system collapses. On the contrary, it is the performance of the social system with resilience and adaptability.

History and archaeology have a well-established engagement with issues of pre-modern societal development and the interaction between physical and cultural environments; together, they offer a holistic view that can generate insights into the nature of cultural resilience and adaptation (Haldon et al. 2018). The so-called 9.2 and 8.2 ka events were among the most pronounced and abrupt Holocene cold and arid events in the Northern Hemisphere and especially in Southwest Asia. However, a thorough study did not show evidence for a simultaneous and widespread social collapse, large-scale site abandonment, or migration at the time of the events, instead, there are indications for local adaptation (Flohr et al. 2016). This result could lead to the conclusion that early farming communities were somehow resilient to the abrupt, severe climate changes.

Modeling tools have the advantage to represent the process of human responses under climatic and environmental stresses. An agent-based model indicated that highly interconnected social systems without mobility are less effective in adaption to climate impacts, while they jointly as a larger social unit can be more resilient than the individuals (Rogers et al. 2012). The case analysis at Gordion in central Turkey implicated temporal and spatial mismatches as a cause for local environmental degradation, and increasing extra economic pressures as an ultimate cause for the adoption of unsustainable land-use practices (Marston 2015). Integrated analyses of palaeoclimate proxies and model simulations also reveals the limited extent in which climate trends determine patterns of socio-economic activities in complex historical societies (Xoplaki et al. 2018). These analyses suggest that a research approach which integrates environmental archaeology with a resilience perspective has considerable potential for explicating regional patterns of agricultural change and environmental degradation in the past.

Still, it is often unclear which characters a social system must have to be resilient. Peregrine (2017) examined 33 archaeologically known societies bracketing 22 catastrophic climate-related disasters and concluded that societies allowing greater political participation appear to provide greater resilience to catastrophic climate-related disasters, which generally supports the predominant perspective in recent disaster response studies. Another opinion is that human societies gained increasing abilities and productivities to not only adapt but also "reform" the natural environment since the traditional farming technologies emerged from the 3rd–4th century BC in China (The Warring States Period) (Han 2008). In other words, this also means that human impacts on the natural environment have significantly increased. For instance, many oasis grasslands were changed into farmlands when the Han Dynasty attached Xiongnu and opened the Desert Silk Road, which brought irreversible damages to the natural desert-oasis environment.

Apparently, discussions of significant climate impacts on social systems so far have focused on ancient agricultural and pastoral societies because these societies are more sensitive to climatic and environmental conditions. On the contrast, very few studies discussed climate-society relationships after the Industrial Revolution or in industrialized countries. A broad consensus is that technology and economic development can increase the resilience and resistance of human social systems and mitigate the negative impacts of climate change (Adger et al. 2009). As the correlation between climate and society is weakening and even negative, it appears that global warming would not lead to an increase in social conflicts in warmer climates

(Tol and Wagner 2010). It can be assumed that as long as the climate conditions do not undergo large-scale dramatic changes, the socio-cultural systems would unlikely be completely destroyed at one time. Social and cultural characteristics (e.g. stability of core territory and the main ethnic groups) can thus still achieve cumulative development. However, in comparison with the topic of climate impacts on society, societal responses to climate changes have far less been explored. This is right the direction that this chapter and the book are dedicated to.

1.4 Book Overview and Key Messages

1.4.1 Coverage of the Book

Independent studies on the natural environment and social development of the Silk Road region began in the early 20th century. So far, the academic community has basically defined the routes network and the areas along the Silk Road, and built up a general understanding of the natural environment and social conditions. There are also a number of studies investigating local specific human-environment relations. Despite this state of research, there is still a lack of comprehensive research focusing on the social and environmental development of the entire Silk Road area in its long past. Therefore, the core purpose of this book is to discuss the socio-cultural changes that took place in the Silk Road area where climate/environmental proxies indicate rapid and/or high amplitude changes and impacts.

The book has 22 chapters. Versions of most of the chapters were initially prepared for the international workshop entitled "The Rise and Fall: Environmental Factors in the Socio-Cultural Changes of the Ancient Silk Road Area", which was convened at the Kiel University during September 27–28, 2017. Each chapter has a specific topic focusing on a specific geographical region, and as a whole the book covers most of the overland Silk Road areas (Fig. 1.1). The chapters are divided into six parts based on the related topics. An overview of each part and associated key messages are provided below.

1.4.2 Key Messages from the Book

The first part of the book is this introduction paper (Chap. 1; Yang et al. 2019). It first reviewed the state-of-the-art on socio-environmental dynamics in the historical Silk Road areas and then introduced the scope of all chapters in this book by illustrating the specific topics, research areas, focused time periods and their inner relationships to each other. The introduction further summarizes the findings achieved in this book, as well as some outlooks. The chapter also discusses some key concepts and definitions that are deemed useful for examining resilience and vulnerability from an archaeological perspective.

The second part includes five studies on landscape evolutions in the human-environment system (Chaps. 2–6). The concept of landscape has for quite a long time been important to geo-scientists and environmental scientists in understanding human-environment systems, which is well reflected in the chapters about drying lakes in western China (Fei et al. 2019; Mischke et al. 2019). In Central Asia, hydrogeological systems evidenced human colonization, and the impacts of water extractions on tributaries of large river and lake systems are suspected as the main causes of water level regressions in the Ili River Delta (Deom et al. 2019) and the Aral Sea (Sala 2019). The chapter of Spate (2019) synthesized past archaeological and climate data in Kashmir and concluded that differentiated landscape patterns may have resulted from long-term adjustment and reorganization as a response to climate pressures.

Part III of the book consists of a series of four papers (Chaps. 7–10) that are arranged under the topic of natural disasters and impacts. The Silk Road areas overlap well with the earthquake and mountain fault belt that runs from China to Italy, and thus many local earthquake-resistant techniques were developed in sub-regions (Kázmér 2019). The study on climate-related dryness, famine and diseases in the Eastern Turkic Empire suggested that the climatic factor did have an impact on the historical processes that took place in the nomadic territories (Ganiev and Kukarskih 2019). As we stated before, dryness is the major natural threat for most of the Silk Road areas especially over the last millennium when human activities have increased dramatically (Opała-Owczarek and Owczarek 2019; Chen et al. 2019).

The book includes a major part investigating climate impacts on social systems (Part IV, Chaps. 11–15). Analysis of global climate simulations over the last 6000 years indicate that 10% more precipitation may have provided the climatological foundation for the golden era of Silk Road trades (Hill 2019). Even in adverse climate conditions, social adaptation activities helped to avoid hardship and expanded the capabilities for the continual development of the Chinese civilization (Fang et al. 2019). In Central Asia and Western Asia, inferences of Turkic tribes' migration in Saljūqs period reach beyond climatological determinism and provide more socio-political explanations (Frenkel 2019). And, Luneau (2019) argues that the present data do not support a drastic climate change during the first half of the 4th millennium BP as a responsible factor for the fall of the Oxus civilization. Pow (2019) also questions the climatic and environmental effects on the Mongol Empire's withdrawal from Hungary in 1242. A common message from these articles is that climate impacts are recognized but not considered as a dominant factor in the development of social events.

The fifth part of the book includes four papers of social adaptation and resilience to environmental stresses (Part V, Chaps. 16–19). Experience of extreme climate conditions can increase opportunities for learning and innovation, e.g. local people developed hydraulic systems of water-sediment separation at the mountainous Tea-Horse Road region that effectively mitigated flood hazards (Xu et al. 2019), and the Karez system in the dry Asian regions is a great human creation that survives social development for thousands of years (Mächtle et al. 2019). The study from Panyushkina et al. (2019) shows that Saka people of the Iron Age employed extensive ravine agriculture on alluvial fans and that they were able to apply simple flow control structures, which certainly reduced water constrains to agricultural expansion in the Lake Balkhash Basin. The steppe landscape in the Middle Volga region was also transformed by cultivation, wood extraction, and the expansion of pastures and road networks in the past 2500 years (Vyazov et al. 2019). These examples from the past might help inform the degree to which societies can develop strategies to deal with environmental perturbations at different scales and highlight that social breakdown and collapse are not an inevitable result of transformation.

The last part of the book discusses three environment-related socio-cultural issues (Part VI, Chaps. 20–22). Studying early rock carvings in the Karakoram Ranges gains insight into the roots and spread of early Buddhism in the extreme dry-cold-high environment (Aerde 2019). The chapter by Marten-Finnis (2019) reveals how ecological zones and their division into steppe and sown, nomadic and sedentary people, helped Russian ethnographers to understand the heritage and urban neighborhood principles of Bukhara. In addition, Abudu et al. (2019) review the Karez systems from the perspective of the cultural heritage, and argue that Karezes should be protected as indigenous human heritage and utilized to enhance water resilience under changing environments.

Overall, human societies have always been living with and adapting to a variable climate and environment. It is clear from studies in this book that climate has certainly influenced human societies while societies have also shown increasing resilience and capability in coping with adverse climate impacts. The Silk Road areas are richly endowed with information on human and environmental history, which makes it suitable for exploring interactions between climate, environment and humans over a variety of time scales. As historians, archaeologists, geographers, paleo-environmentalists and paleo-climatologists, we often seek to contribute to a better understanding of this complex topic. This book is an important step in this direction.

The concept of social resilience has gradually become an important topic in scientific communities (e.g. Climatology, Geography, Socio-ecology, Geoarchaeology, and Sustainability). In fact, increasingly sophisticated detection and attribution studies already suggest that societies have largely persisted and developed continuously in hazard-prone areas and climate-change periods. Findings and discussions of chapters in this book make evident that many challenges remain which are connected to even more complex questions for forthcoming research:

- Are there clear cases of social resilience to climate changes in the past societies? If so, what are the general environmental-socio-cultural patterns?
- What are the key factors and features for a social system to be resilient in face of climate variation? In other words, how can resilience be maintained in key sectors, e.g. agriculture, nomadism, livelihood, population and urbanization?
- How did social resilience change and evolve in response to climate changes? What are the scope, thresholds and tipping points for the dynamics of social resilience?

- What can we learn from the experience and lessons of the past resilient and/or "un-resilient" societies? Are these learnings up-scalable to explanatory theories?

These are open questions that some chapters in this book addressed but which were not deeply investigated yet. In order to both forecast and adapt to future conditions we need to advance our understanding of interactions between cases of socio-cultural resilience to climate change in time and space, and to utilize the knowledge in supporting sustainable development at local, regional and global levels.

1.5 Summary and Outlook

The development of the Silk Road has supported a great leap of long-distance, large-amount cultural exchange across the Eurasian continent, and has had a profound impact on the overall development of human society. Studies on the rise and fall of the Silk Road have shown some principles of human-climate relationships. Climate conditions can lead to the abandonment of villages or castles but that does not necessarily mean a collapse of the human society. People are active and social systems are able to migrate or adapt. Migration is not a manifestation of the collapse of the socio-cultural system, on the contrary, it shows the resilience of the system.

Today, the Silk Road has become a road of friendship for economic and cultural exchanges between Asia, Europe, Africa and even further areas. The Silk Road was declared a World Heritage Site by UNESCO in 2014. China's recent "Belt and Route Initiative" further promotes attentions to the traditional Silk Road areas. On the one hand, the Silk Road has become a popular word through cinema, television and other popular media. On the other hand, however, the Silk Road has so far majorly been discussed in politics and business themes from the East side (e.g. China's business attempts) while its reception in sciences are less targeted. It remains a challenge for research to overcome the chronological, regional, linguistic, and disciplinary fragmentation of Silk Road research. However, the fact that the term is a modern construct, makes it a fruitful, organizational concept for the scholarship. By constructed definition, it could also allow and promote transnational, superregional, intercultural and interdisciplinary approaches to research and comprehension.

The Loulan Kingdom at Lop Nur region used to be an ancient country with animal husbandry and oasis agriculture in the center of the Silk Road areas. Sima Qian wrote in his "Historical Records" (1st century BC) that "Loulan is rich of jade, reed, poplar trees and white grass. The people often move to where there are water and grasslands".[4] However, when Xuan Zang passed by this area in the Tang Dynasty (7th century AD) he saw only "remains of towns and castles, but no people anymore".[5] This tragic change happened with both impacts from natural environment change and human activities. Research on the environmental changes, social development,

[4]Sima Qian, 91 BC. Historical Records. 司马迁在《史记》中记载: "楼兰出玉,多葭苇、柽柳、胡杨、白草,.

[5]Xuan Zang (talk), Bian Ji (write), 646 AD. Great Tang Records on the Western Regions. 《大唐西域记》: "城郭岿然，人烟断绝".

the rise and fall process, and their interactions along the Silk Road can provide important historical experience and decision-making basis for regional sustainable development in present times, and is thus of theoretical and practical significance.

A growing network of multi-millennial, multi-proxy records from multiple sub-regions would help reveal climatic contexts for more important historic events which emphasize the diversity of human-environment interactions. Future efforts in this field will need to account for the diversity of economic, political, and cultural features that filter, dampen, and amplify the effects of climate change on society. This chapter and the book hold the concept of "taking history as a mirror", and hope to promote more studies on the evolution process of environmental-social interactions, in both the Silk Road areas and other regions.

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Part II
Landscape Evolutions in the Human-Environment System

Chapter 2
Evolution of Saline Lakes in the Guanzhong Basin During the Past 2000 Years: Inferred from Historical Records

Jie Fei, Hongming He, Liang Emlyn Yang, Xiaoqiang Li, Shuai Yang and Jie Zhou

Abstract This study reconstructed the possible existence of saline lakes in the Guanzhong Basin during the past 2000 years. Using Chinese historical literature as well as stone inscriptions, a total of five historical saline lake bodies which had existed in this region were documented: Lakes Yanchize, Xiluchi, Dongluchi, Zhuyanze and Xiaoyanchi. Lakes Zhuyanze, Yanchize, Xiluchi, Dongluchi, and Xiaoyanchi desiccated respectively at some point during 1076–1701 AD, 1584–1735 AD, 1666–1791 AD, 1666–1791 AD, and 1712–1906 AD. The lakes in the west of this region possibly desiccated relatively early, and the lakes in the east desiccated relatively late. Most of the lakes desiccated during a cold climate period. It seems that the dry period of the 15th–17th centuries overlapped with the periods that some of the lakes desiccated. All the five lakes desiccated during periods of increased soil erosion. The main causes of the degradation and desiccation of Lakes Yanchize, Xiluchi and Dongluchi were flood irrigation and silt sedimentation. The degradation and desiccation of Lake Yanchize and Lakes Dongluchi and Xiluchi corresponded to periods of population explosion when land was heavily cultivated in Fuping and Pucheng Counties. The existence of historical saline lakes indicates that the remains of the Sanmen Paleo-Lake existed in the Guanzhong Basin during the past 2000 years.

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Flood irrigation · Silt sedimentation

2.1 Introduction

Analysis of the evolution, degradation and desiccation of saline lakes during the past 2000 years will help us to better understand the geographical distribution and evolution of saline lakes. There are more than 1500 modern saline lakes in China (Zheng et al. 1993). Knowledge of the historical saline lakes is not as advanced as geographical and historical value suggests it should be, since historical saline lakes contain information about local hydrology, regional environmental change and salt resources.

No saline lakes exist in the Guanzhong Basin in modern times (Williams 1991; Zheng et al. 1993; Wang and Dou 1998; Zheng et al. 2002). Here, the possible existence of historical saline lakes in this region during the past 2000 years is examined. We deduce the dates of their desiccation, and discuss the relationship with environmental change and human activity.

2.2 Regional Setting

The Guanzhong Basin lies in the middle Shaanxi Province, China, and sometimes it is also referred to as the Weihe River Plain (Fig. 2.1). The Weihe River is the largest tributary of the Yellow River. The total length of the river is 818 km, and it flows through the Guanzhong Basin from west to east. However, the Weihe River Plain does not correspond exactly to the Guanzhong Basin because there are several patches of undrained depressions in the basin, and these depressions are exactly where saline lakes could exist.

This region is well known as a major cradle of ancient Chinese civilization. Xi'an and its vicinity formed the national capital city of China during the Western Zhou Dynasty (1046–771 BC), Qin Dynasty (221–206 BC), Western Han Dynasty (206 BC–25 AD), Sui Dynasty (581–618 AD) and Tang Dynasty (618–907 AD). This region is tectonically a graben basin between the Loess Plateau and Qinling Mountain. The basin extends about 400 km from west to east, and about 30–80 km from south to north. It occupies an area of 19,000 km^2, and the altitude is 325–900 m above sea level.

The climate in the region is mostly a semi-arid temperate East Asian monsoon type, with a few patches of sub-humid type in the southwest part. The annual mean temperature is 11–14 °C, and the monthly mean temperatures of January and July are −2 to −1 and 25 to 27 °C, respectively. The annual precipitation ranges from 500–720 mm, and decreases from southwest to northeast (Liu and Guo 2008; Chen and Dong 2009). Although the distribution of saline lakes is related to precipitation, temperature and net evaporation (Williams 1991), the limit at which saline lakes can exist is about equal to the 500 mm line of annual precipitation (Zheng 2010), and therefore saline lakes could have existed in some areas of this region. When the precipitation is significantly higher than 500 mm, desalination occurs; when precipitation is too low, desiccation occurs.

Lacustrine sediments were identified in some isolated depressions of this region, which indicated that lakes had existed during the past several million years (Yan 1988; Zhao and Zhang 1994). A previous study obtained the quasi-continuous lake sediments over the past 34,000 years in the Lupotan Flats (‘lu’ means saline, ‘po’ means Lake, and ‘tan’ means Flats). However, sediments during the past 2000–3000 years were partially eroded and disturbed by human activities, thus hampering a reliable

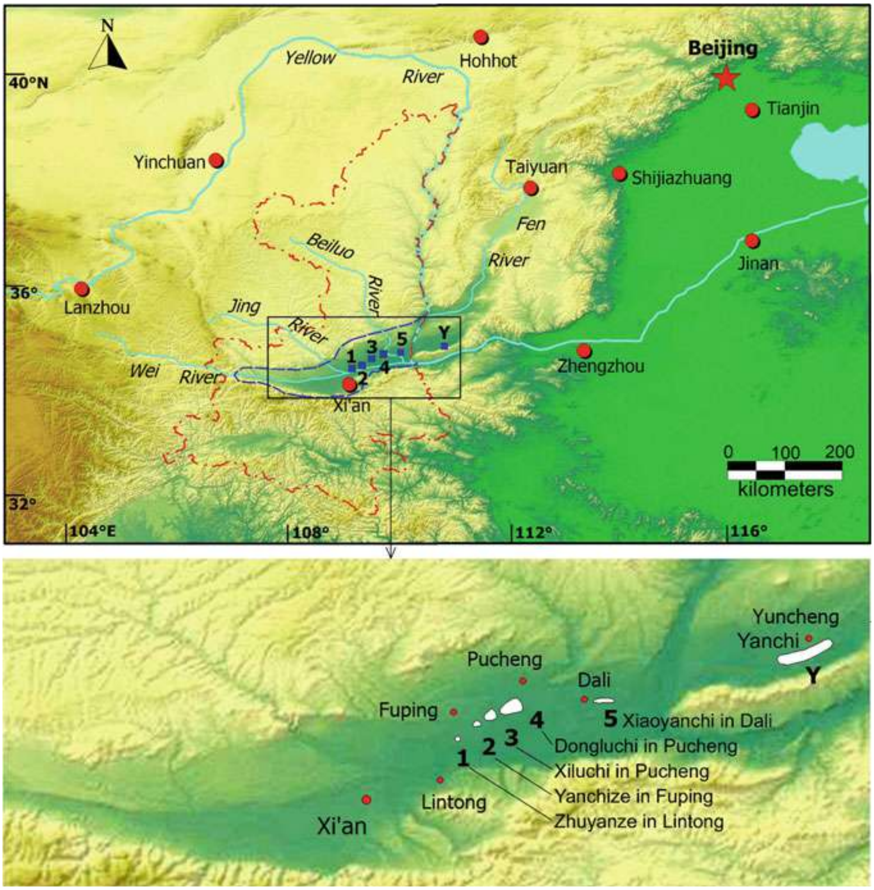

Fig. 2.1 Schematic map showing the recent topography of the Guanzhong Basin (upper panel) and the estimated locations of ancient saline lakes in the basin (lower panel). The Guanzhong Basin at the west of the Yellow River is indicated by blue dashed line, and the Shaanxi Province is in red dash-dotted line

interpretation of the limnological information (Yan et al. 2016). Historical records, supplemented by archaeological evidence, are very reliable and effective.

2.3 Materials and Methods

Historical literature has been proven to be a critical source of information for gathering data on lake evolution during the past 2000 years (Brooks 1923; Dixey 1924; Nicholson 1999; Nicholson and Yin 2001; Fang 1993). The Guanzhong region is well known for its long history of civilization and abundant archives of historical literature. For this study, we examined the Chinese historical literature as well as archaeological materials (stone inscriptions), and investigated whether saline lakes existed in this region during the past 2000 years.

Various kinds of historical literature were examined, and relevant records were found in the historical local chronicles of the Fuping, Pucheng, Lintong and Dali counties and cities, historical chronicles of Shaanxi Province, dynastic histories, historical geography books, and stone inscriptions.

The data of population and cultivated lands of the relevant counties are scattered through the Chinese local historical chronicles. A systematic literature survey was conducted, and those of the Fuping, Pucheng, Lintong and Chaoyi counties are carefully examined. The population data were converted into population density data. With regard to the data of cultivated land, we employed a Cultivated Land Ratio (CLR), which was defined as the ratio between the cultivated land area and the total land area.

2.4 Results

After an exhaustive literature survey, nearly a hundred records concerning saline lakes were discovered. A synthesis of these records pointed to the existence of five historical saline lakes in the Guanzhong Basin, i.e. Lake Yanchize in Fuping County, Lakes Dongluchi and Xiluchi in Pucheng County, Lake Zhuyanze in Lintong County, and Lake Xiaoyanchi in Dali County (former Chaoyi County, Fig. 2.1). The five lakes will be discussed separately in the following sections.

2.4.1 Lake Yanchize in Fuping County

2.4.1.1 Prior to the 13th Century

Historical records on Lake Yanchize in Fuping County may be traced back to the Northern Wei Dynasty (386–534 AD). It was recorded in the History of the Northern

Wei Dynasty that, '*there was a salt lake in the Pinyang County* (modern Fuping County. Wei 554).'

In the Yuanhe Reign Period General Geography (Li 813), it was recorded that, '*Lake Yanchize was located 25 li from the southeast of the administrative centre of the county (Fuping County). The circumference of the lake was 20 li.*' Because the circumference was about 20 *li* (1 *li* ≈0.5 km), i.e. 10 km, the area of the lake is estimated to have been about 4–8 km^2. Similar records were also found in the New History of the Tang Dynasty (Song and Ouyang 1060), Chronicle of Chang'an (Song 1076) and Revised Chronicle of Chang'an (Luo 1296).

The earliest record is that which recorded the history of the Northern Wei Dynasty (386–534 AD). The latest record is that in the Revised Chronicle of Chang'an, which recorded the history prior to 1296 AD. Based upon the above sources, we inferred that Lake Yanchize was a saline lake with an area about 4–8 km^2 between the late 4th and 13th centuries.

2.4.1.2 14th–16th Centuries

Two records were found in the Chronicle of Fuping County (Liu and Sun 1584),

> The Lupotan Flats, was also known as the Mingshuitan Flats ('Mingshui' means water covered) and East Flats (Dongtan). The flats did not dry up in winter or summer, and the water could be boiled for extracting salt (Liu and Sun 1584).
>
> Lake Yanze (i.e. Yanchize) lies in the east of the county, and looked like a lake (Liu and Sun 1584).

It may be inferred that Lake Yanze was still a saline lake during the 14th–16th centuries. However, the name of the lake was changed from *ze* (lake) to *tan* (flat), which possibly indicated that the lake had become significantly reduced in size.

2.4.1.3 17th–18th Century

Two brief records were found within two local chronicles which were printed in 1735 and 1740 AD respectively.

(1) *'The Lupotan Flats lay in the east of the county, and now it was silted up.'* (Liu and Shen 1735. As indicated by the reference, 'now' probably refers to the early 18th century.)
(2) *'The Lupotan Flats, also known as the Mingshuitan Flats and East Flats. It was just the ancient Yanchi of Pinyang County. Now it dried up.'* (Qiao 1740; Wu and Hu 1778; Fan and Liu 1891. As indicated by the references, 'now' probably refers to the early 18th century.)

In addition, two official reports of the Lupotan Flat were recorded in the Draft Chronicle of Fuping County (Fan and Liu 1891),

> 22nd Day, 7th month, 56th year, Qianlong Reign Period (21st Aug. 1791), the county head reported that 'there was no saline lake in Fuping County. But there is Luopotan Flat in the east of the county extending 6-7 li from east to west. The area is low and contains saline and alkali (that is, it contains NaCl and Na_2SO_4). When the weather is favourable, local people collected the surface soil, put it into water, and boiled it to extract salt. The salt is brackish (because it contains Na_2SO_4). When it rained too much, the flat was covered by water.
>
> 16th day, 11th month, 56th year, Qianlong Reign Period (16th Dec. 1791), the county head reported that 'the Lupotan Flat in our county was in all probability the Lake Yanchize in the chronicles… however, it dried up.

2.4.1.4 19th Century

An official investigation of the Lupotan Flats was conducted in the autumn of 1886 AD.

> The Lupotan Flat in our county was the ancient Yanze Lake, and extends from Fuping to Pucheng. It was a saline land, local people took the saline soil after rains and boiled for Xiao (glauber's salt, i.e. Sodium Sulfate Decahydrate).
>
> The flats in Fuping County extended 3-4 li from east to west, and 2-3 li from north to south… The area was full of weeds and contained no saline waters, and the areas that still possessed salt production extends to less than 1 square li (1 square li $\approx$ 0.25 km^2)… there were only five or six small ponds that were producing salt, other areas were wastelands and were overgrown with weeds (Fan and Liu 1891).

According to the investigation, the flats in Fuping County were dry by the late 19th century. In addition to the official report of the investigation, a few related materials were recorded in the Draft Chronicle of Fuping County. In conclusion, the above records indicate that Lake Yanchize in Fuping County (also known as the Lupotan Flats) had desiccated at some point during 1584–1735 AD.

2.4.2 Lakes Dongluchi and Xiluchi in Pucheng County

Lakes Dongluchi and Xiluchi lay in the south of the Pucheng County. Here, 'dong' means 'east', 'xi' means 'west', and 'luchi' means 'salt lake'. Historical records on Lakes Dongluchi and Xiluchi in Pucheng County are numerous and very detailed.

2.4.2.1 Prior to the 13th Century

As early as 2000 years ago, the History of the Western Han Dynasty (Ban et al. 80) recorded that 'Emperor Xuandi (reign in 91–49 BC) was trapped in Luzhong, Lianshao County… There was a salt lake in the Lianshao County, and it extended over 10 *li* from north to south. The local people called it Luzhong.' The Lianshao County during the Han Dynasty lay near the modern Lupotan Flats (Tan 1982), and

Lake Luzhong should be the possible predecessor of Lakes Dongluchi and Xiluchi, as well as the modern Lupotan Flats.

No relevant historical records are available concerning the Three Kingdoms Period (220–265 AD), but archaeological evidence has been identified. Archaeological research unearthed two official seals, one is ‘Lianshao Lu Xian Du Yin’ (Seal of the Lianshao Governor of Salt and Alkali Industries), and the other is ‘Lianshao Lu Du Yin’ (Seal of the Lianshao Governor of Salt Industry) (Luo 1987). The seals support the idea that there was salt production during the Three Kingdoms Period, which thus possibly indicates the existence of one or more salt lakes in this region, as there are no salt mines or dry lake salt crusts in this region.

Detailed historical records become available again from the Tang Dynasty (618–907 AD). The Luchi Lakes (including the Dongluchi and Xiluchi lakes) of Fengxian County (modern Pucheng County) were recorded as one of the salt production places in the History of the Tang Dynasty (Liu 945), New History of the Tang Dynasty (Song and Ouyang 1060) and the Collection of Material on the Lives of Emperors and Ministers (Wang 1013).

2.4.2.2 14th–17th Centuries

Detailed records are available concerning the Ming and Qing Dynasties (1368–1644 AD, 1644–1911 AD). In the History of the Ming Dynasty (Zhang 1739), it was recorded that ‘there were Xiluchi in the west Pucheng County and Dongluchi in the south Pucheng County, and salt was produced previously.’

A poem titled ‘*Bing qi ri ji* (Sunshine on the ice covered salina)’ was recorded in the Continued Chronicle of Pucheng County (Wang and He 1714). The date of the poem was sometime during the Ming Dynasty. The poem probably refers to the Xiluchi Lake or the Dongluchi Lake, as there were only two saline lakes in Pucheng County. This poem indicated that saline lakes and salt production existed in Pucheng County during the Ming Dynasty (1368–1644 AD).

Within the Chronicle of Pucheng (Deng and Li 1666), three records are identified:

(1) *‘There is a saline lake looking like a mirror in the south of the county.’*
(2) *‘East Luchi Lake lies 20 li to the south of the city centre of the county, and it was also called Anfengtan Flats. Salt was formed naturally in the 12th year of Dali Reign Period (777 AD). After that, salt production in the salt lake was forbidden, but alkali production went on.’*
(3) *‘West Luchi Lake lies 40 li to the southwest of the city centre of the county… it did not dry up even in droughts. The local people boiled the lake water and extracted salt. Recently, salt production was given up because of the high cost.’*

2.4.2.3 18th Century

In the Draft Chronicle of Fuping County, a detailed report on the Lupotan Flats, entitled *Hui Kan Lu-po-tan Bin* (Report of the joint investigation of the Lupotan Flats), was provided (Fan and Liu 1891; Li and Wang 1905).

The Lupotan Flats included the former East Luchi, West Luchi, and Yanchize lakes. The report was based on an official investigation of the Lupotan Flats in autumn 1791 AD.

> It was said that the Lupotan Flats extended 50-60 li from east to west. The East Flats extended 5-6 li. The middle part of the Lupotan, extending 30-40 li, was a wasteland. The West Flats extended about 10 li. The end part of the Lupotan, extending a little more than 1 li, was overgrown with weeds. Apart from the middle and end sections, the flats extended a little more than 10 li. Ever since the Tang Dynasty, salt production left numerous deserted ponds, and saline water dried. There were salt production operations only in a few square li of the flat now.
>
> We investigated the East Flats and learned that saline water existed in the middle of the East Flats, and was surrounded by wheat fields… we criticized that they were producing salt illegally, and it was told that it was not salt but mirabilite. They told us that of the products in the flats, 90% was mirabilite, and 10% was salt.
>
> Then, we investigated the West Fats. They lie between Pucheng and Fuping counties, and mostly in Pucheng. We walked for two days, and saw no people, but only desert and weeds. The ponds were old and long abandoned.

According to this report, the East Flats, i.e. the former East Luchi Lake, desiccated before 1791 AD; The West Flats, i.e. the former West Luchi Lake and the Yanchize Lake, also completely desiccated. Inferring from the print dates of the literature, both the East and West Flats probably desiccated during the years 1666–1791 AD.

2.4.2.4 Late 19th Century and Early 20th Century

Maps recorded the lakes of Pucheng County in the Shaanxi Provincial Atlas (Wei 1899) and the New Chronicle of Pucheng County (Li and Wang 1905). The West Luchi Lake was drawn as Lupotan (Saline Lake Flats) in these maps. A road was drawn in the Lupotan (Xiluchi Lake) in the map in the New Chronicle of Pucheng County, thus providing evidence that the Xiluchi Lake probably desiccated around 1890–1910.

An atlas was made in 1915 AD by the Japanese Territorial Geodesy Department (1938). According to the atlas, the west and middle areas of the Lupotan Flats were dry in 1915. The east part of the Lupotan Flats also desiccated except for several ponds scattered around the flats.

It may be inferred from these sources that the Lupotan Flats, including Xiluchi Lake, Dongluchi Lake and Yanchize Lake, desiccated earlier than the late 19th century and early 20th century. This is consistent with the above inference that the lakes desiccated during the period 1666–1791 AD.

2.4.3 Lake Zhuyanze in Lintong County

Lake Zhuyanze lies in Lintong County. The earliest record of this lake was identified in the Yuanhe Reign Period General Geography. It was recorded that,

> Lake Zhuyanze lies 15 li to the south of the Yueyang County. The lake's water contains a lot of salt. People boiled the water and extracted salt during the Fuqin Period (350-394 AD). The circumference of the lake was 20 li. (Li 813)

A similar record was found in the Chronicle of Chang'an (Song 1076) which was compiled in the late 11th century. The New History of the Tang Dyansty contains a chapter that recorded the lakes that yielded salt, and Lake Zhuyanze was one of them. It was recorded that, *'there was a Lake Zhuyanze in the Yueyang County.'* (Modern Yueyang Town of Lintong County) (Song and Ouyang 1060) 600 years later, the Chronicle of Lintong County repeated this record, and added one more sentence, '*the water in the Zouma village was salty now. A lake is supposed to have existed here* (Zhao 1701).' Because the Chronicle of Chang'an was printed in 1076 AD, and the Chronicle of Lintong County was printed in 1701 AD, the date of the desiccation of the lake should be sometime in the period 1076–1701 AD.

2.4.4 Lake Xiaoyanchi in Dali County

The earliest record of Lake Xiaoyanchi in Chaoyi County[1] was found in the History of the Tang Dynasty which listed *Lake Chaoyi Xiaochi* as a salt production place (Liu, 945).

In the New History of the Tang Dynasty, it was recorded that *'salt was manufactured in Lake Xiaochi, Chaoyi County'* (Song and Ouyang 1060). In the *Chronicle of Tongzhou Prefecture* (Zhang and Ma 1625), it was recorded that

'*Salt was produced in Lake Xiaoyanchi during the Tang Dynasty. Now, salt was not manufactured regularly, and the output was very limited.*'

It was then recorded in the Continued Chronicle of Chaoyi County (printed in 1712 AD. Wang 1712) that

> The water of the area gathered in Lake Xiaoyanchi. It was extremely arid in this area. By boiling the water, salt was extracted…. When it was rainy, salt could not be produced… The basin extended more than 20 li, and the soil was saline. Crops could not grow, whereas wild grass grew everywhere.

In addition, it was recorded in this chronicle that there was illegal salt production, whereas salt production was officially organized in the Wanli Reign Period (1573–1620 AD).

These records indicate that Lake Xiaoyanchi was still a salt lake in the early 18th century. However, in the Chronicle of the Chaoyi County, it was recorded that Lake

[1] Chaoyi County was merged into Dali County in 1958.

Table 2.1 Historical saline lakes in the Guanzhong Region[a]

Name	Location	Size (km^2)	Type	Desiccation
Yanchize	Fuping County	4–8	Chloride and sulphate	1584–1735 AD
Xiluchi	Pucheng County	Several	Chloride and sulphate	1666–1791 AD
Donglu Chi	Pucheng County	Several	Chloride and sulphate	1666–1791 AD
Zhuyanze	Lintong County	Several	Chloride	1076–1701 AD
Xiaoyanchi	Dali County	Several	Chloride	1712–1906 AD

[a]The sizes of the lakes are estimated according to the circumferences and relevant records. The types of the lakes are based on the historical records of salt production and Xiao (Glauber's salt. $Na_2SO_4 \cdot 10H_2O$) production

Xiaoyanchi was abandoned in later times. The area occupied by Lake Xiaoyanchi was called 'Yanchiwa', which means a flat called Yanchi (Zhu 1906). The lake, by this time, probably desiccated and was possibly reduced to an inland salt marsh.

According to the timing of the chronicles compiled, we infer that Lake Xiaoyanchi desiccated and was possibly reduced to an inland salt marsh sometime in the years 1712–1906 AD.

In summary, the evolution of the five historical saline lakes is reconstructed using historical records (Table 2.1). Historical records about the three Lupotan lakes were found to be numerous, whereas records on the Zhuyanze and Xiaoyanchi lakes are relatively rare. All the saline lakes lie in the relatively arid northeast part of the Guanzhong Region. Among them, Lakes Dongluchi, Xiluchi and Yanchize lie in an area commonly known as the Lupotan Flats where lacustrine sediments were identified, indicating the existence of saline lakes during the past several million years (Yan 1988; Zhao and Zhang 1994).

2.5 Discussions

2.5.1 Causes of the Degradation and Desiccation of the Saline Lakes

Despite the presence of historical records and the plethora of evidence they contain, a fundamental question remains to be ascertained. What is the cause of the disappearance of these lakes? The causes of the drying up of saline lakes maybe complicated, and various causes need be considered.

2.5.1.1 Climatic Change

Climatic change is commonly considered a major force behind lake evolution (Fang 1993; Ma et al. 2010). Here we discuss the climatic background of the saline lake evolution in the Guanzhong Basin.

With regard to precipitation, we employed the six-grade data set of drought or flood of Shaanxi Province (Yuan 1994). The data set is based on various historical records, and the starting point is 580 AD. Droughts and floods are classified into six grades according to their respective severity. We calculated the decadal arithmetic mean of the grades of droughts and floods as an indicator of precipitation (Fig. 2.2d) (Yuan 1994).

It seems that the dry period of the 15th–17th centuries overlapped with the periods that the lakes Yanchize, Xiluchi and Dongluchi possibly desiccated. We compared the lake evolution with a recently updated set of chronology for temperature changes in China based on multiple sources (Fig. 2.2e) (Ge et al. 2013). A comparison with temperature change chronologies indicates that Lakes Yanchize, Dongluchi, Xiluchi and Xiaoyanchi desiccated in the cold period of 14th–19th centuries, but the relationship is not very clear.

As a whole, the desiccation of the historical saline lakes usually occurred in relatively dry periods. A possible explanation is that the humid summer monsoon was weak during the Little Ice Age (Zhang et al. 2008).

2.5.1.2 Silt Sedimentation

A previous study indicated that sediment accumulation caused the filling of lake basins and contributed significantly to the drying up of lakes in the lower reaches of the Yellow River Plain (Fang 1993). The middle reaches of the Yellow River are well known for severe soil erosion. Figure 2.2c shows the sediment outputs of the upper and middle reaches of the Yellow River, which illustrates how many tons of silt and sand were transported by the Yellow River. About 90% of the sediment outputs come from the middle reaches. Therefore, the erosion of the middle reaches of the Yellow River increased over time during the last 2000 years (Xue 2001; Shi 2009).

Is silt sedimentation the cause of the desiccation of Lakes Dongluchi, Xiluchi and Yanchize in Pucheng and Fuping counties? The Draft Chronicle of the Pucheng County recorded,

> The East and West Luopo Flats lay in the south of the county (Pucheng County)… The salt lake in Pucheng had a poor fate. Ever since the times of antiquity, no one protected it, and no one developed it. Every year it was flooded by the mountain floods, whereby sand and silt were deposited. Year after year, it was further reduced to dry flats. (Institute of Pucheng County 1946)

An earlier source also briefly recorded the cause of the desiccation of the Lupo Flats. It was recorded that *'The Lupo Flats lay in the east of the county* (Fuping County)*, and it was silted up now.'* (Liu and Shen 1735). The records on Lake

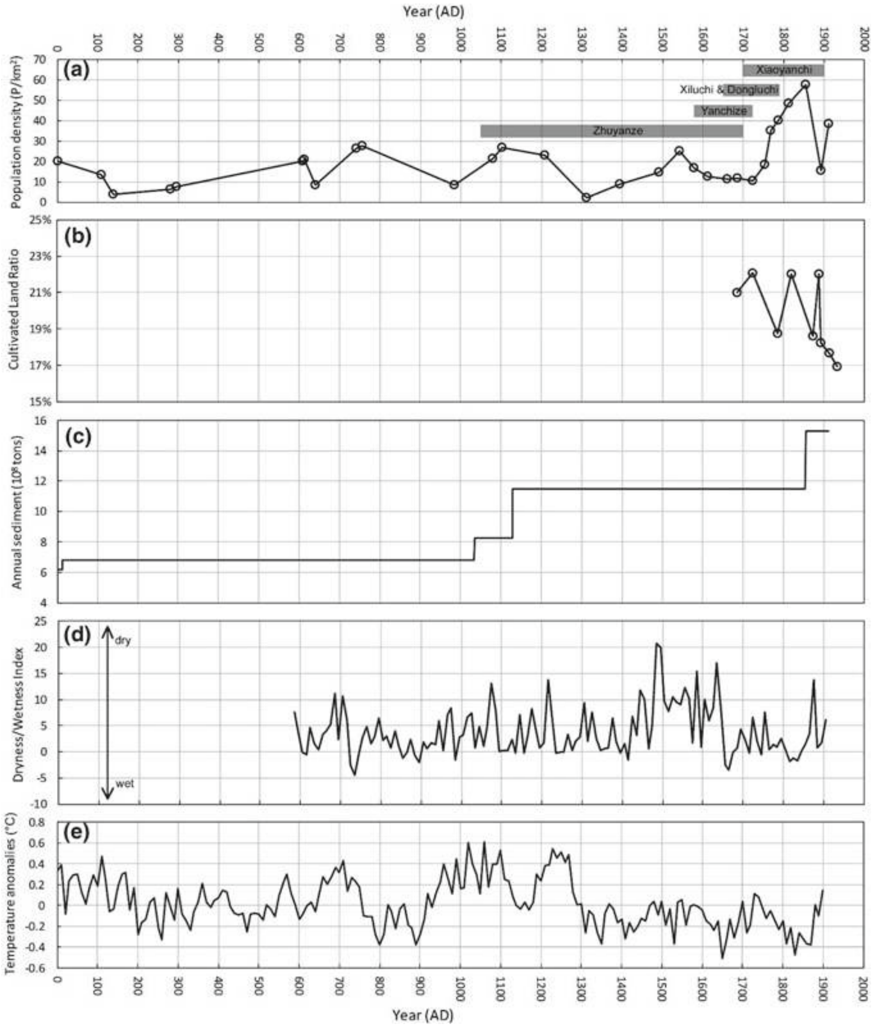

Fig. 2.2 **a** Evolution of the population density of Shaanxi Province during the past 2000 years (Xue 2001). The bars denote the approximate dates that the lakes desiccated. **b** The cultivated land ratio of Shaanxi Province (Ge et al. 2004). **c** The annual sediment outputs from upper and middle reaches of the Yellow River (Shi 2009). **d** The dryness/wetness index change of Xi'an and Yan'an (Central Meteorological Administration of China 1981). **e** The annual temperature anomalies in China (Ge et al. 2013). Edited by Liang Emlyn Yang

Zhuyanze are relatively terse, and it is difficult to determine precisely when it desiccated. The topography might have contributed to the desiccation of the lake. Lake Zhuyanze was very close to the channel of the Weihe River, which frequently caused flooding during the past 2000 years (Yin et al. 2005). River flooding and the resulting silt sedimentation are a potential cause of the desiccation of Lake Zhuyanze.

Lake Xiaoyanchi evolved from a saline lake to a salt flat during the 18th–19th centuries. This lake was very close to the channel of the Beiluo River, which flooded and migrated frequently over the past 2000 years of history (Wang 2005). Therefore, the evolution and shrinking of the lake is possibly also related to the river flooding and the resulting silt sedimentation.

However, historical records concerning Lakes Zhuyanze and Xiaoyanchi are relatively brief, and no sources clearly recorded that these two lakes were directly flooded by the Weihe and Beiluo Rivers. The link between the evolution of the two lakes and river flooding remains inevitably hypothetical.

2.5.1.3 Population Density and Cultivated Land Area

In an agricultural society, increased population causes expanding areas of cultivated lands. Population pressure and cultivated lands were discussed on both provincial and national levels. The population and cultivated land changes at the county level offer a detailed relationship between specific saline lake evolutions and population and cultivated land changes. The saline lakes' basins were enclosed drainage basins, and these lakes were small and only occupied certain parts of the counties. The comparison of population change on countywide levels would be more informative than other approaches.

The population data were divided by the area data and converted into population density, which is helpful to understand historical population pressure. Previous researches have integrated the data sets of the historical population and cultivated land of Shaanxi Province (Xue 2001; Ge et al. 2004). Among them, Xue's (2001) data set of the historical population sizes of Shaanxi Province during the past 2000 years is of good quality. We used this to indicate the population density change there. The population density of Shaanxi Province fluctuated during the 1st–17th centuries, and increased dramatically since the 18th century (Fig. 2.2a).

Historical records of cultivated lands are less detailed in comparison to those of population, and that of Ge et al. (2004) is the only available data set of the cultivated land data of Shaanxi Province in historical times (Fig. 2.2b). The Lakes Yanchize, Dongluchi, and Xiluchi desiccated sometime during the years 1666–1791 AD, and Lake Xiaoyanchi desiccated during 1712–1906 AD, which corresponds to the population explosion in Shaanxi Province during the 18th–19th centuries (Fig. 2.2a). Concerning the CLR of Shaanxi Province during the past 400 years, its relationship with the saline lake evolutions is not very significant (Fig. 2.2b).

We compared the population density and CLR of Lintong County, Fuping County, Pucheng County, and Chaoyi County (Fig. 2.3) with the dates of the desiccation of Lakes Zhuyanze, Yanchize, Dongluchi-Xiluchi, and Xiaoyanchi, respectively. The population density and CLR in this region in historical times were very high. It is clear that the desiccation of Lake Yanchize and Lakes Dongluchi-Xiluchi corresponds to periods of population explosion and elevated CLR in Fuping and Pucheng Counties (Fig. 2.3). The desiccation of these lakes is apparently related to the mas-

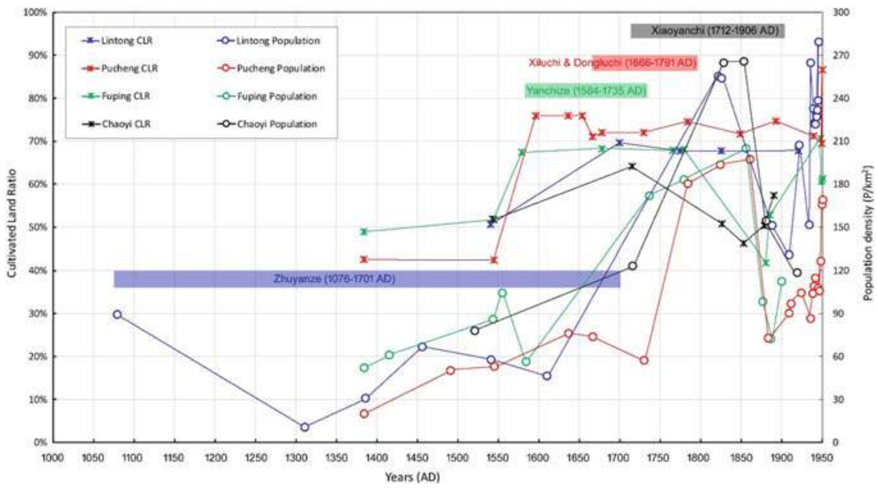

Fig. 2.3 The Cultivated Land Ratio (CLR) and population density of the four counties Lintong, Pucheng, Fuping and Chaoyi during the years 1000–1950 AD. The bars denote the approximate desiccation dates of the five lakes with the bar colour indicating the lake locations at the counties. Edited by Liang Emlyn Yang

sively increased population pressure on the region's natural environment, leading to increased soil erosion, increased sediment accumulation and lake reclamation.

With regard to Lake Zhuyanze in Lintong County and Lake Xiaoyanchi in Chaoyi County (Fig. 2.3), the relationship with population and cultivated land are not clear. In particular, the time that Lake Zhuyanze desiccated was deduced to be in the range of 1076–1701 AD, which is too long and difficult to be discussed in detail.

In addition, population pressure also caused the destruction of forests. A qualitative study suggested that the forests on the Loess Plateau reduced gradually during the past 2000 years, which resulted in an increase of the rate of soil erosion and accelerate the silting up of lakes in the region (Shi 2001).

2.5.1.4 Flood Irrigation and Reclamation

A map engraved on a stone in Fuping County, Shaanxi Province, recorded that the silty flood carried by the gully stream, Zhaolaoyu, flowed to the saline flat Lupotan and made it reclaimable (Fig. 2.4). The map was engraved in 1670 AD, thus the map was drawn during the period that the three lakes, Yanchize, Xiluchi and Dongluchi, in the Lupotan region were shrinking or about to shrink. It indicates that the silt carried by flood irrigation was possibly related to the desiccation of these lakes.

Some researchers argued that the flood irrigation possibly had a history of 2000 years in the Guanzhong Basin, though the historical records and evidence are brief and ambiguous (Ye 1991, 1992; Chang 1997). Few historical records are

Fig. 2.4 Part of the geographical map of Fuping (Fuping yuditu. Shen Qiqian, 1670. The map was engraved on a stone, and the stone is archived in the Fuping County Library, Shaanxi Province, China). The letters A, B, C, D are added by the authors. 'A' denotes the text that reads 'Lupotan (a saline flat)'. 'B' denotes the text that reads 'the silt carried by the gully stream deposited in the flat and made it reclaimable'. 'C' denotes the text that reads 'Zhaolaoyu (a gully stream).' 'D' denotes the boundary between Fuping and Pucheng counties

available concerning unambiguous description of flood irrigation, and no evidence indicates that it was extensive and long-lasting in this region prior to the Qing Dynasty (1644–1912) (Ye 1991, 1992; Chang 1997).

2.5.2 Relationship with the Sanmen Paleo-Lake

During the Pliocene (5.3–2.6 Ma BP) and Pleistocene (2.6–0.01 Ma BP) epochs, there was a large Sanmen Paleo-Lake in the modern plains of the Weihe and Fenhe rivers (Anderson 1923; Wang et al. 1999). The area of the Sanmen Palaeolake varied during the Quaternary Period, and the maximum extent was about equal to the modern plains.

Stratigraphical research indicates that it was most probably a saline lake which was drained about 0.15 Ma BP, when the mountain to the east of the lake was cut through by the paleo Yellow River, thus forming the modern Yellow River (Wang et al. 2001, 2004; Zhang et al. 2004; Liu et al. 2006; Jiang et al. 2007). The Yellow River flowed through the modern Sanmenxia Gorge and eventually drained into the sea. The Sanmen Paleo-Lake shrank and resolved into several relatively small lakes. There is Lake Yuncheng Yanchi (Yuncheng Salt Lake), along with a few small saline lakes in the lower reaches of the Fenhe River, even in modern times, which comprise the remains of the Sanmen Paleo-Lake.

Previous researchers suggested that the remains of the Sanmen Paleo-Lake had existed as several isolated saline lakes in the Guanzhong Basin during the Pleistocene Epoch (Yan 1988; Zhao and Zhang 1994) and early Holocene (Yan et al. 2016). In particular, late Quaternary and early Holocene lacustrine sediments were identified in the Lupotan region (Luopotan Flats), an isolated depression where Lakes Yanchize, Xiluchi and Dongluchi existed (Yan 1988; Zhao and Zhang 1994). Recent research confirmed the quasi-continuous existence of lake sediments in the Lupotan Flats, and the paleolake possibly desiccated ca. 4600 years ago (Yan et al. 2016). The sediments during the past 4600 years were disturbed by increasingly intense human activities, and the lake evolution history of this period remains uncertain.

Regarding Lake Zhuyanze in Lintong County and Lake Xiaoyanchi in modern Dali County, there is no doubt that these regions were parts of the Sanmen Paleo-Lake before the middle Pleistocene, but no stratigraphical research has been done concerning the lake evolution in the late Pleistocene and the Holocene. Because lake remains most probably exist, our inferences at least support the evidence for smaller remaining lakes of the Sanmen Paleo-Lake in historical times.

Our inference on the existence of historical saline lakes suggests that the remains of the Sanmen Paleo-Lake still existed in the northeast part of the Guanzhong Basin during the past 2000 years. This result improves the understanding of the temporal and spatial history of the Sanmen Paleo-Lake.

2.6 Conclusions

There are no saline lakes in the Guanzhong Basin in modern times. Using Chinese historical sources and archaeological materials, we inferred the existence of five historical saline lakes in the region during the past 2000 years, i.e. Lakes Yanchize, Xiluchi, Dongluchi, Zhuyanze and Xiaoyanchi.

Lakes Zhuyanze, Yanchize, Xiluchi, Dongluchi, and Xiaoyanchi desiccated sometime during 1076–1701 AD, 1584–1735 AD, 1666–1791 AD, 1666–1791 AD, and 1712–1906 AD, respectively. Most of the lakes desiccated during cold climate conditions. The dry period of the 15th–17th centuries overlapped with the periods that some of the lakes desiccated. However, the relationship is not very clear.

The lakes in the west of this region possibly desiccated relatively early, and the lakes in the east desiccated relatively late, but the reasons remain unknown. All the five lakes desiccated during periods of increased soil erosion. Flood irrigation and silt sedimentation were probably the main causes of the desiccation of Lakes Yanchize, Xiluchi and Dongluchi.

The desiccation of Lake Yanchize and Lakes Dongluchi and Xiluchi correspond to periods of population explosion and more land was cultivated in Fuping and Pucheng Counties. Population pressure, increased levels of cultivated lands and soil erosion are the potential causes of the desiccation of these historical saline lakes.

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Chapter 3
Landscape Response to Climate and Human Impact in Western China During the Han Dynasty

Steffen Mischke, Chengjun Zhang, Chenglin Liu, Jiafu Zhang, Zhongping Lai and Hao Long

Abstract The Chinese empire experienced a large expansion to the arid regions in the west during the Han Dynasty (206 BCE–220 CE). The Hexi Corridor, the Yanqi Basin, the southeastern part of the Junggar Basin and the Tarim Basin became part of the empire. The expansion of the Han Dynasty was accompanied by the significant intensification of irrigation farming along rivers draining the Qilian, Tianshan and Kunlun Mountains. Sedimentological and geochemical analyses and dating of lake sediments and shorelines revealed that four large lakes in the region experienced falling levels, or were almost or completely desiccating. The level of Zhuyeze Lake was falling rapidly ca. 2100 years before present (a BP), and the accumulation of lake sediments was replaced by an alluvial fan setting in large parts of the basin. Lake Eastern Juyan desiccated ca. 1700 a BP. Lake Bosten experienced low levels and increasing salinities at ca. 2200 a BP. Lake sediments in the Lop Nur region were mostly replaced by aeolian sands during a period of near-desiccation at 1800 a BP. In contrast, records from fifteen lakes farther in the west, north or south of the Han Dynasty realm indicate relatively wet climate conditions ca. 2000 years ago. Thus, dramatic landscape changes including the near and complete desiccation of large

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lakes in the arid western part of today's China probably resulted from the withdrawal of water from tributaries during the Han Dynasty. These changes likely represent the earliest man-made environmental disasters comparable to the recent Aral-Sea crisis.

Keywords Central Asia · Xinjiang · Inner Mongolia · Gobi Desert
Lake desiccation

3.1 Introduction

The climate conditions in the Chinese section of the ancient Silk Road during the Han Dynasty have not been addressed by many studies so far. Climate change research usually focussed on longer time scales such as the Holocene, or on recent global change (Liu et al. 2008, 2015a; Tao et al. 2010; Yang and Liu 2014). The work on Holocene climate records is often motivated by the need to understand climate-controlled environmental change since the last ice age with special emphasis on the rapidness and amplitude of environmental change during times of natural climate changes without human impact but with comparable climatic controls of the Earth's orbital parameters (Wünnemann et al. 2012; Fan et al. 2014). As a result, periods of maximum moisture and temperature of northwestern China have been proposed in the early and middle Holocene (Liu et al. 2015a; Chen et al. 2016). However, the climate and environmental conditions in northwestern China specifically during the Han Dynasty deserve more attention of the palaeoclimate community because the Han Dynasty expansion of the Chinese empire had caused a large population migration towards the west accompanied by significant land use changes (Zhang et al. 2003, 2011; Yang et al. 2006; Lü et al. 2009; Qin et al. 2012). A recent study by Mischke et al. (2017) showed that water withdrawal from the tributaries of the large ancient Lake Lop Nur in the eastern Tarim Basin for irrigation farming caused not only the near-desiccation of the lake ca. 1800 years before present (a BP) but eventually also the abandonment of the Loulan Kingdom upstream of Lop Nur. Thus, human impacts on environments along the Silk Road apparently already reached a significant magnitude during or shortly after the Han Dynasty. We follow and extent the approach of Mischke et al. (2017) here by assessing and comparing the available palaeoenvironment and palaeoclimate records from northwestern China and surrounding regions with special emphasis on the Han Dynasty period. Which environmental and climate conditions can be inferred for northwestern China and surrounding regions during the Han Dynasty? Are there spatial differences in environmental and climate conditions, and if so, can these differences be linked to changes in westerlies or summer monsoon precipitation? Alternatively, were spatial differences in environmental conditions possibly caused by man?

3.2 Previous Research

The Holocene climate history of northwestern China and surrounding regions was addressed by relatively many studies in the last decades. Studies often focussed on the Holocene "Climatic Optimum" in China, i.e. the identification of the warmest and wettest period of the Holocene (Zheng et al. 1998; An et al. 2000; Chen et al. 2008). Ca 2–4 °C warmer conditions synchronously in different regions of China between 9000 and 6000 a BP were postulated by Zheng et al. (1998). In contrast, An et al. (2000) suggested that warmest and wettest conditions culminated at 11,000, between 10,000 and 8000 or 10,000 and 7000, between 7000 and 5000, or at 3000 a BP in different regions of China. Highest lake levels along the eastern section of the Silk Road in the Hexi Corridor region occurred mostly between 10,000 and 7000 a BP. Chen et al. (2008) and Wang et al. (2010) argued that the arid regions of Central Asia or the area influenced mainly by the East Asian Summer Monsoon experienced wettest conditions during the middle Holocene whilst the more humid part influenced by the Indian Summer Monsoon received higher precipitation in the early Holocene. Relatively dry conditions during the early Holocene were also reported for locations along the ancient Silk Road in Xinjiang (Bosten Lake, Aibi Lake, Wulungu Lake, Balikun Lake) or further to the east in the Hexi Corridor of Gansu (Lake Zhuyeze; Liu et al. 2008; Tao et al. 2010; Zhang et al. 2010; Wang et al. 2013; Mischke et al. 2016). The Han Dynasty climate was not specifically addressed in these studies. However, the lake records from Aibi, Wulungu and Balikun suggest relatively wet conditions ca. 2000 a BP whilst Lake Bosten and Lake Zhuyeze experienced falling lake levels.

In contrast to studies of the Holocene climate conditions in northwestern China and surrounding areas in general, archaeological investigations of Han Dynasty sites in northwestern China included discussions of the specific climate conditions as potential drivers of oases evolution and abandonment during and after the Han Dynasty. For example, Qin et al. (2012) described that the Loulan Kingdom and intensive farming in the eastern Tarim Basin was established during a climatically favourable wet period between 2100 and 1700 a BP and that its abandonment was apparently a result of climatic aridification of the region afterwards. Similarly, the oasis Yuansha in the Keriya River region at the southern margin of the Tarim Basin was thriving during relatively wet climate conditions before 2200 a BP and eventually abandoned 1600 a BP following a first avulsion of the Keriya River at 2200 a BP and a drought at ca. 1900 a BP (Zhang et al. 2011). Zhou et al. (1994) also discussed the natural diversion of rivers, drier climate and social unrest as possible causes that may have led to the decline of oases in the Keriya River region. Zhang et al. (2003) described that warm and wet climate conditions between 2800 and 1900 a BP led to significantly larger water resources in the Tarim Basin and flourishing desert oases which were abandoned due to deteriorating climate after 1800 a BP. Yang et al. (2006) reconstructed the extent of irrigated farmlands in the Tarim and Yanqi Basin (including Bosten Lake) during the Han Dynasty. They concluded that irrigation farming was widespread between 2200 and 1500 a BP and that changing climate probably caused the termination of the oases in the Tarim Basin. Thus, climate deterioration was mostly assumed as the main cause of the decline of local kingdoms and desert oases along the ancient Silk Road between 1900 and 1500 a BP.

3.3 Discussion of Climate Records from Northwestern China and Surrounding Regions

3.3.1 Lake Records from the West

Three lake records were analyzed from the Pamir Mountains in the westernmost part of the discussed region: records from Sasikul, Karakul and Karakuli lakes (Figs. 3.1, 3.2, Table 3.1). The records were obtained from alpine lakes at more than 3600 m above sea level (asl) representing relatively small catchment areas. The $\delta^{18}O$ values of fine-grained carbonate from Sasikul Lake are generally high during the Han Dynasty period but also high during the 300 a before (since the start of the record) and in the following centuries (Lei et al. 2014). Consequently, relatively dry conditions are inferred from the high $\delta^{18}O$ values of the closed-basin lake. Relatively comparable $\delta^{18}O$ values of fine-grained carbonate were provided for the closed basin of Lake Karakul 150 km north of Sasikul Lake. Here, $\delta^{18}O$ values are highest during the middle of the Han Dynasty but decreasing towards the end of the Han and later on too (Mischke et al. 2010; Fig. 3.2). Increasingly wet conditions existed at Lake Karakul during the Han Dynasty and in the subsequent centuries. The study of Aichner et al. (2015) applied compound-specific stable isotope analysis to the sediments of Karakuli Lake which is 150 km to the southeast of Karakul Lake. The δD values for terrestrial biomarkers decrease throughout the Han Dynasty and remain low in the centuries afterwards, and increasingly wet conditions during the Han are inferred from Karakuli Lake too (Fig. 3.2).

Two lake records are available from the central Tianshan Mountains in the northeast of the Pamirs (Fig. 3.1). Son Kol Lake is an open-basin lake at 3016 m asl and Issyk-Kul is a closed basin lake at 1607 m asl. The catchment areas of both lakes are relatively small in comparison to the lake surface areas, representing relatively local conditions similar to the Pamir lakes (Savvaitova and Petr 1992). Lauterbach et al. (2014) used $\delta^{15}N$ values of organic matter in lake sediments as proxy for winter snowfall in the Son Kol Lake catchment. Increasing winter precipitation during and after the Han Dynasty is inferred from the $\delta^{15}N$ increase (Fig. 3.2). The low δD values for a terrestrial biomarker ($\delta D_{n\text{-}C29}$) during the Han Dynasty suggest wet climate conditions whilst decreasing δD values in the following centuries indicate diminishing summer precipitation. However, high winter precipitation during the centuries following the Han Dynasty probably maintained generally wet climate conditions in the region. Stable oxygen isotope values for ostracod (micro-crustacean) shells from Issyk-Kul Lake were highest before the beginning of the Han Dynasty and slightly lower afterwards (Ricketts et al. 2001; Fig. 3.2). The timing of the $\delta^{18}O$

Table 3.1 Records from northwestern China and surrounding regions, locations, numbers and types of dating samples, used proxies and references. The number of dating results is given for the last 5000 years of the record. Proxies marked bold were used as representative indicators of moisture conditions here. For locations 4, 14, 15 and 19, a combination of proxies was assessed to draw a relative lake level curve

No.	Location and type	Latitude °N	Longitude °E	Altitude m	Dating	Proxies	References
1	Uluu-Too Cave	40.38	72.35	1490	24 U/Th	**δ^{18}O**, δ^{13}C, µXRF	Wolff et al. (2016)
2	Sasikul Lake	37.70	73.18	3816	5 ^{14}C	**δ^{18}O**, δ^{13}C, GC, GS	Lei et al. (2014)
3	Karakul Lake	39.01	73.49	3928	6 ^{14}C	**δ^{18}O**, δ^{13}C, GC, MS, XRF, GS, P	Mischke et al. (2010)
4	Balkhash Lake	46.00	74.00	338	^{14}C[1]	XRF, XRD, O, D, GS	Sugai (2012)
5	Karakuli Lake	38.44	75.06	3650	17 ^{14}C, ^{210}Pb/^{137}Cs	**δD**, δ^{13}C	Aichner et al. (2015)
6	Son Kol Lake	41.84	75.14	3016	23 ^{14}C	**δ^{15}N**, δ^{13}C, δD, µXRF, P	Lauterbach et al. (2014)
7	Issyk-Kul Lake	42.40	76.70	1607	5 ^{14}C	**δ^{18}O**, δ^{13}C, TE	Ricketts et al. (2001)
8	Sayram Lake	44.58	81.15	2072	4 ^{14}C	**P**	Jiang et al. (2013)
9	Guliya ice core	35.30	81.50	6200	ALC	**δ^{18}O**, SA	Yang et al. (2004)
10	Kesang Cave	42.86	81.75	2000	5 U/Th	**δ^{18}O**	Cheng et al. (2012)
11	Aibi Lake	44.97	82.76	200	6 ^{14}C	**P**	Wang et al. (2013)

(continued)

Table 3.1 (continued)

No.	Location and type	Latitude °N	Longitude °E	Altitude m	Dating	Proxies	References
12	Manas Lake	45.75	86.00	251	4 ^{14}C	$\mathbf{\delta^{18}O}$, $\delta^{13}C$, XRD, GS, P, D	Rhodes et al. (1996)
13	Bosten Lake	41.94	86.76	1048	3 ^{14}C	$\mathbf{\delta^{18}O}$, $\delta^{13}C$, GS, XRD, GC	Zhang et al. (2010)
14	Wulungu Lake	47.23	87.21	479	4 ^{14}C	GS, GC, P	Liu et al. (2008)
15	Lop Nur Lake	40.21	90.30	790	3 OSL	GS, $\delta^{18}O$	Mischke et al. (2017)
16	Balikun Lake	43.64	92.79	1581	7 ^{14}C	**P**	Tao et al. (2010)
17	Dunde ice core	38.10	96.40	5325	ALC	$\mathbf{\delta^{18}O}$	Yao and Thompson (1992)
18	Hurleg Lake	37.24	96.86	2812	6 OSL, 1 ^{14}C	**SD**	Fan et al. (2014)
19	Hala Lake[2]	38.29	97.58	4078	9 ^{14}C	XRF, GC,	Wünnemann et al. (2012)
20	Qinghai Lake	36.90	100.20	3194	6 OSL	**SD**	Liu et al. (2015b)
21	Eastern Juyan Lake	41.89	101.85	892	2 ^{14}C	**P**	Herzschuh et al. (2004)
22	Ulaan Lake	44.51	103.65	1110	4 OSL	**GC**, XRF	Lee et al. (2013)
23	Zhuyeze Lake	39.05	104.10	1291	14 OSL	**SD**	Long et al. (2012)

[1]no number given; [2]for cores HHLS 21-2 and H8; ALC annual dust layer counting, D diatoms, GC geochemistry (total inorganic carbon, total organic carbon, carbonate content), GS grain size, MS magnetic susceptibility, O ostracods, P pollen and spores, SA snow accumulation, SD shoreline dating, TE trace element ratios of ostracod shells, XRD X-ray diffraction, XRF X-ray fluorescence, δD stable hydrogen isotope ratios of n-alkanes

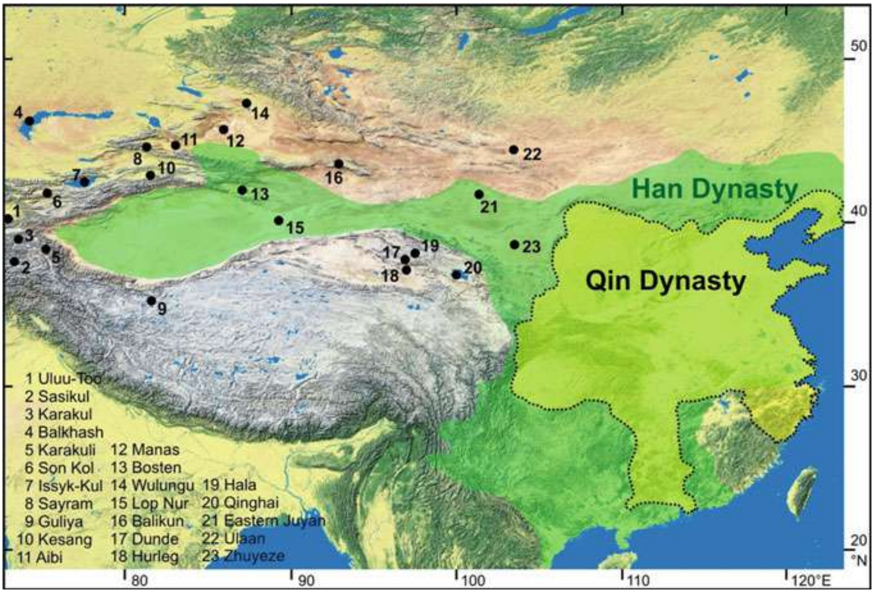

Fig. 3.1 Location of the reviewed climate records from northwestern China and surrounding regions. Extent of Qin Dynasty (light green and dotted line) and of Han Dynasty (green) empires marked. (References provided in Table 3.1)

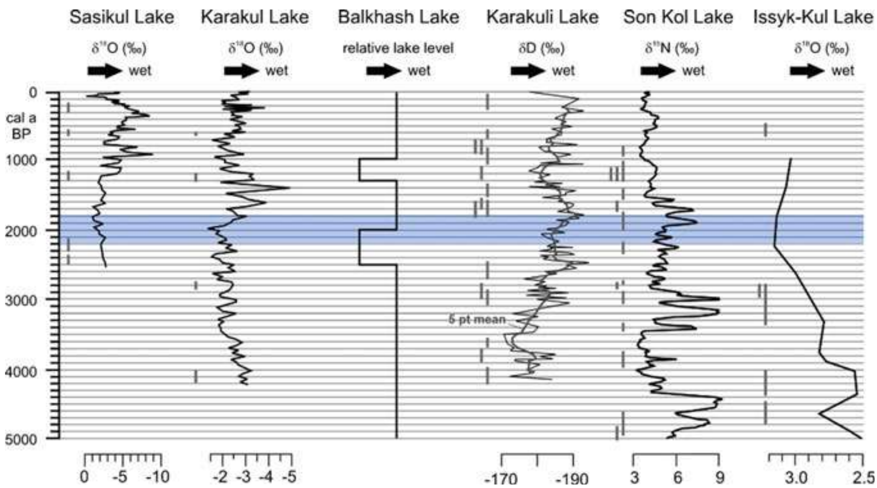

Fig. 3.2 Lake records from the western section of the discussed region. Vertical grey bars at left of records indicate calibrated ^{14}C ages with 2σ error ranges. Duration of Han Dynasty marked by blue bar. (References and additional chronological information provided in Table 3.1)

record is not well constrained for the period of the Han Dynasty due to the absence of radiocarbon data between about 3000 and 500 a BP but relatively low changes of the sediment accumulation rate might be expected for a large and deep lake such as Issyk-Kul (Fig. 3.2). Interpolated sample ages between dated stratigraphic levels in the obtained sediment core are probably relatively robust. However, the decrease of $\delta^{18}O$ values over the Han period probably represents a rising lake level which led to overflow conditions and a lake level at least 16 m higher than present between 1400 and 1200 a BP. Thus, increasingly wet conditions were inferred from the lakes Son Kol and Issyk-Kul in the central Tianshan Mountains.

Balkhash Lake in the northern foreland of the Tianshan Mountains lies at ca. 340 m asl. The closed-basin lake drains a large catchment area of 501,000 km^2 including the northern ranges of the Tianshan Mountains and the Dzungarian Alatau (Chiba et al. 2016). Palaeoclimate signals from the lake are therefore expected to integrate local peculiarities and should represent regional climate conditions. However, late Holocene climate records from the lake presented in previous years often cover only the last 1000 or 1800 a BP and do not include the period of the Han Dynasty (Endo et al. 2010; Narama et al. 2010; Chiba et al. 2016). The rough assessment of relative lake level changes of Sugai (2012) includes two periods of low lake levels between 2500 and 2000 a BP and 1300 and 1000 a BP (Fig. 3.2). Correspondingly, a low-lake-level period between 2500 and 1800 a BP was described by Akhmetyev et al. (2005). Relatively dry conditions existed in the catchment of Balkhash Lake during the early half of the Han period or the entire Han time, which subsequently gave way to wetter conditions in the region.

3.3.2 Lake Records from the Central Region

One additional lake record is available from relatively high altitude in the eastern Tianshan Mountains. Pollen data were reported from Sayram Lake which is surrounded by steppe vegetation (Jiang et al. 2013). The setting of the lake with relatively dense vegetation in its vicinity and its moderate size (453 km^2) suggest that the pollen record mostly represents local and regional vegetation. Pollen transported over far distances contributed probably to a minor degree to the recorded assemblages. The *Artemisia*/Chenopodiaceae (A/C) ratio was used as a moisture indicator to discriminate between steppe (higher A/C ratios) and desert (lower A/C ratios) vegetation (Jiang et al. 2013). The A/C ratio is increasing continuously from ca. 2500 a BP to 800 a BP, and increasingly wetter conditions are inferred over the period of the Han Dynasty (Fig. 3.3).

Three lake records were presented for the Junggar Basin between the Tianshan Mountains in the south and the Altai Mountains in the north (Fig. 3.1). Aibi Lake is a closed-basin lake in the southwestern part of the Junggar Basin 150 km east of Sayram Lake. Pollen data from the desert environment of the lake probably represent regional vegetation changes. The pollen concentration as a measure of vegetation density and the A/C ratio increase from 3600 to 1400 a BP (Wang et al. 2013). Increasing moisture availability is inferred for the Han Dynasty period in the Aibi Lake region (Fig. 3.3). Manas Lake 250 km further northeast of Aibi Lake was a terminal salt lake until the

1960s before the lake turned into a salt-covered playa as a result of the diversion of the entering Manas River for agricultural purposes (Rhodes et al. 1996). Lake and river sediments were recovered in Holocene sediment cores from near the former lake's centre. Phases of lake formation regarded as wetter climate periods existed from 4500 to 2500 a BP and from 2000 to 1000 a BP. The $\delta^{18}O$ values for carbonate increase during the initial period of lake formation after 2000 a BP as a result of the evaporative enrichment in a stagnant water body. $\delta^{18}O$ values from the river period before the lake phase are not regarded as good climate proxy here because they likely represent a mixed signal of detrital carbonate grains from Mesozoic limestones in the upper reaches of the Manas River, reworked carbonate from earlier deposited lake carbonates in Manas Lake, and possibly authigenic carbonate formed in the slowly-flowing river. However, a transition from drier to wetter conditions is reflected during the Han Dynasty through the replacement of river sediments by lake sediments at about 2000 a BP (Fig. 3.3). Wulungu Lake 180 km further northeast receives water from the southern slopes of the Altai Mountains. A multiproxy record of grain size, geochemistry and pollen data from the terminal lake was used by Liu et al. (2008) to construct a lake level curve for the Holocene. The surroundings of the lake are characterized by desert vegetation and the pollen record is regarded to reflect regional vegetation changes. The authors recorded a high lake level during the Han Dynasty and a change from desert steppe to steppe vegetation in the region (Fig. 3.3). Thus, relatively wet conditions were recorded for the northern part of the Junggar Basin.

A $\delta^{18}O$ record of authigenic carbonate from Bosten Lake in the Yanqi Basin between the Junggar and Tarim basins was provided by Zhang et al. (2010). Although Konqi River is the outflow of Bosten Lake, the lake probably behaves like a semi-closed lake due to the close location of the in- and outflows at its western margin (Mischke and Wünnemann 2006). As a result, a significant W-E oriented salinity

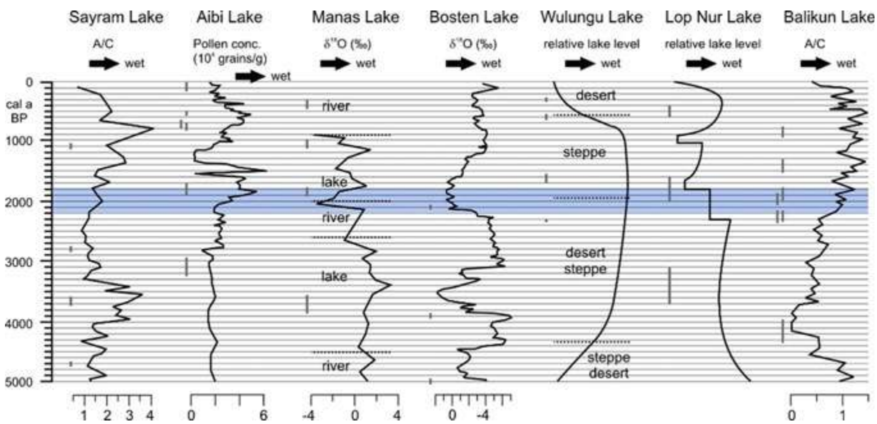

Fig. 3.3 Lake records from the central section of the discussed region. Vertical grey bars at left of records indicate age data with 2σ error ranges. Duration of Han Dynasty marked by blue bar. (References and additional chronological information provided in Table 3.1)

gradient from 0.5 to 2.5‰ exists in the lake (Jin et al. 1990). The $\delta^{18}O$ values rapidly increase at the beginning of the Han Dynasty as a result of a reduced inflow in comparison to evaporation. The $\delta^{18}O$ values remain high during the Han period and in the subsequent two centuries (Fig. 3.3). Rapidly decreasing moisture availability with a significantly reduced inflow to the lake in the early part of the Han Dynasty and dry conditions afterwards are suggested based on the Bosten Lake data.

Lop Nur Lake 350 km further to the southeast of Bosten Lake was a terminal lake before its desiccation in the late 1930s or early 1940s. The lake represented the base level for the Konqi and Tarim rivers. Stable isotope data of carbonate and grain-size data of detrital sediments from a dug section in the centre of the dry lake basin were discussed by Mischke et al. (2017) who argued that a first period of massive aeolian sand deposition in the lake basin occurred 1800 a BP and caused the near-desiccation of the lake. A relative lake level curve based on the earlier presented data includes two periods of rapid lake-level lowering before and at the end of the Han Dynasty (Fig. 3.3). Thus, diminishing moisture availability during the Han period is indicated by the record from Lop Nur.

Another mountain foreland lake record was provided from Balikun Lake some 430 km in the northeast of Lop Nur (Tao et al. 2010). The A/C ratios for a Holocene lake sediment core increase steadily over the Han Dynasty period with a minor drop recorded following the termination of the Han time (Fig. 3.3). However, A/C ratios increase from the middle Holocene at about 4000 a BP to the late Holocene at about 1000 a BP, and relatively wet conditions are inferred for the Han Dynasty period.

3.3.3 Lake Records from the East

A lake record from the large Qaidam Basin between the Qilian Mountains in the north and the Kunlun Mountains in the south, and two records from intramontane basins in the Qilian Mountains represent climate archives from relatively high altitude in the eastern part of the examined region. Hurleg Lake is an open-basin lake in the eastern Qaidam Basin with a moderate catchment area of 12,600 km^2 (Fan et al. 2014). Shoreline deposits above the present lake level were dated using optically stimulated luminescence (OSL) dating and used as proxies of higher lake levels during wetter periods. The proposed high lake-level period between ca. 2200 and 1400 a BP suggests that the time of the Han Dynasty was a wetter period in comparison to today's conditions in the region (Fig. 3.4). Hala Lake 130 km to the northeast is a terminal lake which was studied as a climate archive in detail by Wünnemann et al. (2012). Their multi-proxy data were synthesized in a relative lake level curve (Fig. 3.4). Rising lake levels starting a few centuries before the beginning of the Han Dynasty and continuing a few centuries afterwards suggest increasingly wet conditions during the Han time. Qinghai Lake 270 km to the southeast of Hala Lake is also a closed-basin lake (Fig. 3.1). OSL dating of shoreline deposits suggests that relatively low levels existed before the Han Dynasty, rising levels during the period of the Han, and high levels at its end and in the subsequent centuries (Fig. 3.4; Liu et al. 2015b). Thus, relatively wet conditions are inferred from Qinghai Lake for the Han time too.

Two lake records were presented from the northern foreland of the Qilian Mountains. Eastern Juyan Lake was a terminal lake 600 km north of Qinghai Lake. The lake was fed by the Hei River which flows towards the northwest in the Hexi Corridor. The river formed one of the largest alluvial fans of the world covering an area of 30,000 km^2 in the west of the Badain Jaran Sand Sea. An abrupt change from lake carbonates to sands in the top of an 8 m thick Holocene sediment sequence suggests the desiccation of the lake 1700 a BP (Herzschuh et al. 2004). The modern vegetation in the former lake region consists of semi-desert and desert plant communities, and the pollen record from the lake sediments is regarded to represent regional vegetation changes. Lowest precipitation in the region was reconstructed in the centuries preceding the Han Dynasty, and a slight increase in moisture availability was recorded during the Han time (Fig. 3.4). However, the rapid onset of dry conditions is implied by the desiccation of the lake 1700 a BP. The second lake record from the Qilian Mountains foreland originates from Zhuyeze Lake 380 km to the southeast of Eastern Juyan Lake. The lake is the terminal lake of the Shiyang River which drains the northeastern part of the Qilian Mountains and the eastern section of the Hexi Corridor. Most of the lake basin is dry today due to water withdrawal from Shiyang River for irrigation farming upstream. The remaining Baijian Lake is a salt swamp in the eastern part of the former lake basin. Dating of shoreline and lake deposits was conducted by Long et al. (2012) who draw a relative lake-level curve for the Holocene history of the basin. Continuously decreasing lake levels since the middle Holocene were reconstructed (Fig. 3.4). Higher levels before the Han Dynasty and lower levels afterwards suggest that relatively dry conditions prevailed during the

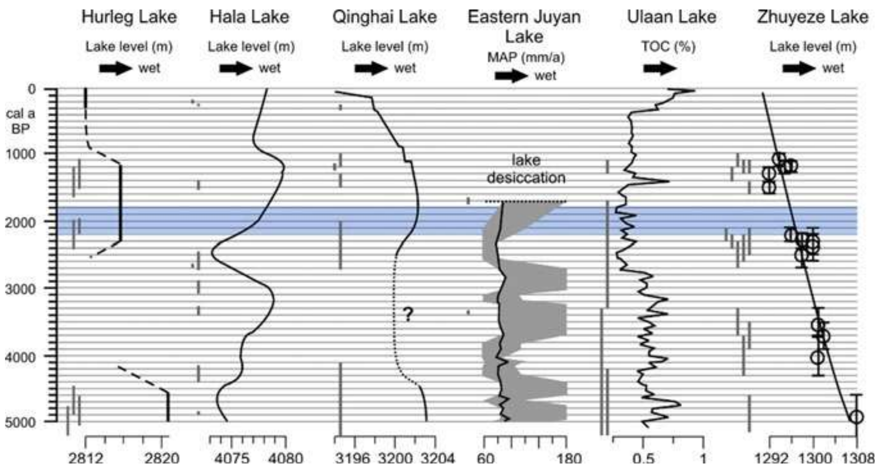

Fig. 3.4 Lake records from the eastern section of the discussed region. Vertical grey bars at left of records indicate age data with 2σ error ranges. Duration of Han Dynasty marked by blue bar. (References and additional chronological information provided in Table 3.1)

Han time. The western part of the former lake basin (Qingtu Lake) fell dry 2100 a BP at the section location QTL02 investigated by Mischke et al. (2016).

Ulaan Lake is a terminal lake 600 km to the north of Zhuyeze Lake. The lake is dry since the mid 1990s until it was fed by the Ongin River from the southeastern ranges of the Khangai Mountains in central Mongolia. Total organic carbon (TOC) contents of lake sediments of a Holocene core were used as proxy of summer monsoon precipitation and warmer and moister climate by Lee et al. (2013). Before, during and after the Han Dynasty, very low TOC values indicate dry conditions and predominantly accumulation of detrital particles in the lake (Fig. 3.4). Thus, generally dry conditions were recorded at Ulaan Lake during the Han Dynasty. However, the obtained OSL age data have large uncertainties and more studies are required to understand climate conditions in southern Mongolia during the last millennia (Fig. 3.4).

3.3.4 Speleothem Records

Two speleothem records are available for the region, the Uluu-Too Cave record from the western Tianshan Mountains and the Kesang Cave record from the eastern part of the mountain range. Relatively low $\delta^{18}O$ values for the speleothem record from Uluu-Too Cave during the Han Dynasty suggest relatively wet conditions (Wolff et al. 2016; Fig. 3.5). Higher values 200 a before the beginning of the Han time and also soon afterwards indicate relatively dry conditions. The $\delta^{18}O$ pattern is different at Kesang Cave 800 km further to the northeast. The $\delta^{18}O$ values are moderate during the Han period with lower values indicating wetter conditions before and mostly higher values suggesting relatively dry conditions afterwards (Cheng et al. 2012; Fig. 3.5). Thus, the two speleothem records from the Tianshan Mountains do not provide a consistent reconstruction of the climate conditions in the region. The Uluu-Too Cave record shows some similarities with the δD record from Karakuli Lake which is 320 km to the southeast of the cave location. Low $\delta^{18}O$ values of the cave carbonates and low δD values for terrestrial biomarkers from Karakuli Lake were recorded at 3000 a BP or shortly before, at 2500 a BP and at the end of the Han Dynasty 1800 a BP (Aichner et al. 2015; Wolff et al. 2016; Figs. 3.2 and 3.5). Similarities with the closer Karakul Lake in Tajikistan (170 km in the southeast of Uluu-Too Cave) are less obvious. Sayram Lake is the closest lake record for Kesang Cave, but the wetness proxies from both sites show unrelated patterns apart from possibly corresponding wet conditions inferred from Kesang Cave 600 a BP and at Sayram Lake 800 a BP. There are significant altitudinal differences between the cave and lake locations, and it is not clear whether stable isotope or pollen records from lakes reflecting catchment-wide climate conditions or regional vegetation changes can be easily compared with more site-specific speleothem records. The $\delta^{18}O$ records of the speleothems mainly reflect the stable isotope composition of precipitation above the caves which is mainly determined by $\delta^{18}O$ changes of water vapour in upstream regions and the pathways of air masses. Air mass trajectories for Uluu-Too Cave in 2014 show a large variability of moisture source areas ranging from

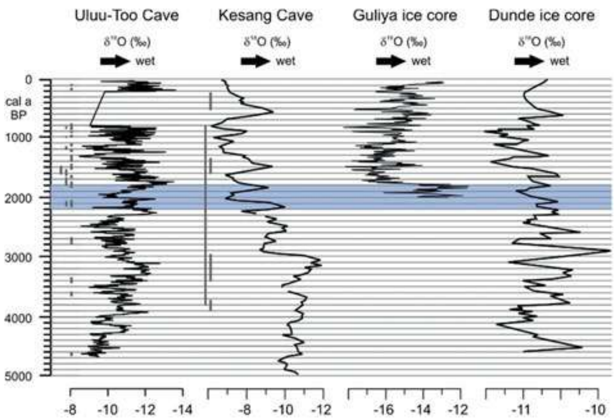

Fig. 3.5 Speleothem and ice core records from northwestern China. Vertical grey bars at left of cave records indicate U/Th ages with 2σ error ranges. Duration of Han Dynasty marked by blue bar. (References and additional chronological information provided in Table 3.1)

the Atlantic Ocean off northwestern Africa to the Barents Sea in the Arctic Ocean (Wolff et al. 2016). Besides trajectories and moisture sources, seasonality changes and snow melt contribution were regarded as most significant factors controlling the $\delta^{18}O$ signal of the Uluu-Too Cave record (Wolff et al. 2016). Snow melt might be partly controlled by local wind strength and direction. The Uluu-Too Cave region in the central Tianshan Mountains is dominated by winter and spring rainfall whilst Kesang Cave in the eastern part of the Tianshan Mountains and at 500 m higher altitude mainly receives spring-summer precipitation. Slight temperature changes in the past may have caused changes in precipitation seasonality. Thus, it remains open to which degree long-term changes of $\delta^{18}O$ values at the caves reflect changes in precipitation amount or changes in dominating air mass trajectories and moisture source areas, seasonality or other factors.

3.3.5 *Ice Core Records*

Ice cores from the Guliya ice cap in the western Kunlun Mountains and the Dunde ice cap in the Qilian Mountains may provide additional evidence for climate conditions during the Han Dynasty. High resolution $\delta^{18}O$ data for ice accumulated during the last 2000 a BP at Guliya were presented by Yang et al. (2004). The $\delta^{18}O$ values are high during the second half of the Han Dynasty (2000–1800 a BP) and shift to significantly lower values afterwards (Fig. 3.5). Thus, warmer and wetter conditions during the Han time are indicated by the Guliya ice core data with an abrupt cooling and aridification after its termination.

Comparison of the Guliya ice core data with lake records from the region is not straightforward due to its large distance to nearest lake records. The closest lake record was provided from Karakuli Lake which is located 670 km to the northwest of Guliya. Increasingly wet conditions were recorded at Karakuli Lake and also at Son Kol Lake during the Han Dynasty (Lauterbach et al. 2014; Aichner et al. 2015; Fig. 3.2). In contrast to the abrupt shift to drier conditions after the termination of the Han observed at Guliya, gradual and long-term transitions to drier conditions were recorded at the two lakes (Yang et al. 2004). The reconstruction of wetter conditions in the centuries after the Han Dynasty at Sasikul, Karakul, Balkhash and Issyk-Kul lakes is contrary to the inference of drier climate conditions from Guliya (Ricketts et al. 2001; Mischke et al. 2010; Sugai 2012; Lei et al. 2014; Fig. 3.2). However, distances between these regions are large and spatial differences in climate conditions are possibly reflected at the individual locations.

The $\delta^{18}O$ data from Dunde ice cap are relatively moderate and less variable during the Han Dynasty in comparison to the preceding 2400 a and the subsequent 1800 a BP (Yao and Thompson 1992; Fig. 3.5). Relatively moderate and stable climate conditions are suggested by the Dunde ice core record. The Dunde ice cap is located 100 km to the west of Hala Lake and 100 km in the north of Hurleg Lake (Fig. 3.1). Moderate and increasingly wet conditions inferred from Hala Lake possibly correspond to the moderate $\delta^{18}O$ values from the Dunde ice core record. Similarities in both records are also the inference of relatively wet conditions 2900 a BP and during the most recent centuries, and of relatively dry climate 4100 and 900 a BP (Figs. 3.4 and 3.5). Similarities exist also between the Dunde ice core and the Hurleg Lake records: relatively wet conditions are inferred at 4500 a BP, during the Han Dynasty and in the most recent centuries, and relatively dry conditions 4100 and 900 a BP. However, the temporal resolution of the shoreline age data from Hurleg Lake does not allow a detailed comparison with the $\delta^{18}O$ data from Dunde. Moderate and wetter conditions at the Dunde ice cap 4500 a BP and during the Han Dynasty apparently correspond to higher lake levels at Qinghai Lake 350 km to the southeast of the ice cap. In contrast, the inferred period of low lake levels at Qinghai Lake (4500–2500 a BP) does not correspond to relatively high $\delta^{18}O$ values of the Dunde ice cap record.

Inconsistencies between ice core and lake records may not only arise from spatial heterogeneities of climate conditions but also from dating uncertainties of OSL ages for shoreline deposits, and poorly constrained chronologies of ice core data (missing annual layers due to removal of snow by wind or ablation, multiple dust layers in years with several severe storms or missing dust layers in less stormy years). In addition, lake records may not only reflect climate conditions but also local human impact in contrast to ice core records. For example, wetter conditions inferred for the most recent centuries at Dunde were also inferred at Hala Lake and Hurleg Lake. The lake-level fall at Qinghai Lake during most recent centuries corresponds not to the inferences from Dunde ice core and Hala and Hurleg lakes, and possibly results from water withdrawal from the lake's tributaries for farming purposes (Fig. 3.4).

3.4 Lake Records Which Indicate Significant Drying During or After the Han Dynasty

The majority of the lake records indicate either increasing moisture availability during the Han Dynasty (Balkhash, Karakuli, Son Kol, Issyk-Kul, Sayram, Aibi, Manas, Balikun and Hala lakes) or generally wet conditions (Wulungu, Hurleg and Qinghai lakes; Figs. 3.2, 3.3 and 4). A significant decrease of moisture available and drier conditions during the Han period or shortly afterwards were recorded at Bosten, Lop Nur, Eastern Juyan and Zhuyeze lakes (Figs. 3.3 and 3.4). Generally dry conditions during the Han time and in the centuries before and afterwards were recorded at three lakes (Sasikul, Karakul and Ulaan lakes; Figs. 3.2 and 3.4).

Different types of evidence were provided for the four lakes which apparently experienced distinctive reductions in moisture availability during the Han time or in the subsequent centuries. The desiccation of the Eastern Juyan Lake at 1700 a BP is probably the most significant evidence for dramatic landscape change (Herzschuh et al. 2004). However, the record of predominantly aeolian sands in the Lop Nur Lake region at 1800 a BP for the first time since sediments were accumulated in the investigated sequence at 9000 a BP is also strong evidence for a significant decrease in moisture availability and the near desiccation of the lake (Mischke et al. 2017). $\delta^{18}O$ values of lake carbonates increased by 4‰ at Bosten Lake between 2300 and 2100 a BP, and a major reduction in moisture availability and inflow was reconstructed (Zhang et al. 2010). Shoreline deposits higher before the Han Dynasty and ca. 4 m lower afterwards were recorded at Zhuyeze Lake (Long et al. 2012). Thus, the accumulated evidence for drier conditions at these lakes during the Han time and shortly afterwards is robust.

The four lakes are all located in the forelands of high mountain ranges. The catchment areas are generally large, ranging from >500,000 km^2 for Lop Nur Lake to 41,600 km^2 for Zhuyeze Lake (Long et al. 2012). Thus, the four lakes represent relatively large regions and do not reflect local hydrological peculiarities. Tributaries of the four lakes originate at high altitude in the Tianshan and Qilian Mountains. The main tributaries of Bosten and Lop Nur Lake are the Kaidu, Konqi and Tarim rivers which flow through the transitional belts between the mountains and the deserts in the basin centres which are mostly used for agriculture today. Similarly, most of today's intensively farmed fertile Hexi Corridor in the northern foreland of the Qilian Mountains is drained by the tributaries of the Eastern Juyan (Hei River) and Zhuyeze (Shiyang River) lakes. Thus, all four lakes are characterized by catchment areas which include significant portions along the foot of large mountain ranges intensively used as farmlands today. Another characteristic in common with the lakes that experienced a change to significantly drier conditions during the Han Dynasty or in the following centuries is that these lakes are situated within the area of the Han Dynasty expansion of the Chinese empire (Fig. 3.6). All other examined lake records originate from regions in the west, north or south of the Han Dynasty realm.

The spatial pattern of a change to significantly drier conditions during or shortly after the Han Dynasty at the four lakes and mostly increasingly wetter or generally

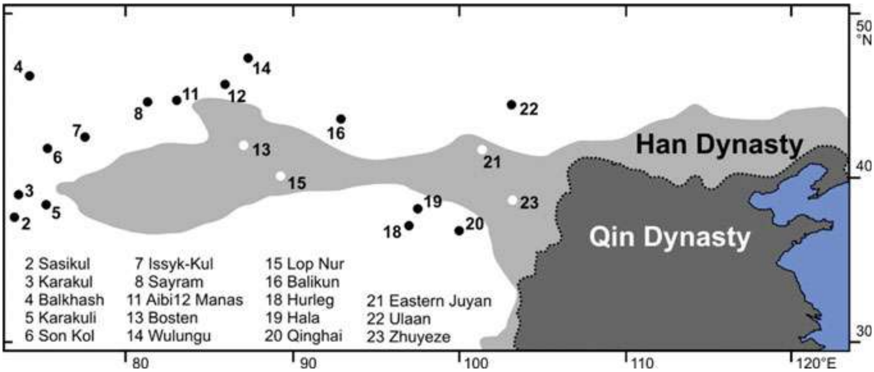

Fig. 3.6 Lake records from northwestern China and surrounding regions which experienced a significant decline in water level during or shortly after the Han Dynasty (white dots) or relatively stable or relatively wet conditions (black dots). (References provided in Table 3.1)

relatively wet conditions in adjacent regions of the Han empire cannot be explained by regional climate change. Instead, the coincidence of (1) lake basins situated within the expansion realm of the Chinese empire, (2) large catchment areas with significant portions in regions along the foot of mountain ranges appropriate for irrigation farming, and (3) recorded decreases of moisture availability during the Han time or in subsequent centuries, suggests that the water balance of these lakes was affected by human activities. Appropriate regions for irrigation farming are located in the middle reaches of the catchment areas of these lakes, and are used for intensive irrigation farming today. Thus, water withdrawal from the tributaries of the four lakes must have caused the desiccation of the Eastern Juyan Lake, the near desiccation of Lop Nur Lake, the lake-level drop of Zhuyeze Lake and reduction in inflow of Bosten Lake. Yang et al. (2006) compiled historical data for the oases agriculture in the Tarim and Yanqi basins in the Han and Qing (17–20th centuries) dynasties and concluded that the area of cultivated land was significantly larger during the Han Dynasty. They argued that land-use practices and climate change caused the transformation of the large Lop Nur Lake in the Han Dynasty to a group of small lakes in the Qing Dynasty. However, they also claimed that "It is somehow unlikely that the irrigated area [in the Korla region, northeastern Tarim Basin; information added] at that time [i.e., during the Han time; information added] was larger than at present." More geological, geomorphological and archaeological research is required to better understand human impact on the landscape during the Han Dynasty.

However, resulting landscape change in and near the lake regions must have been dramatic due to the flat topography of the lake basins in mountain foreland regions and the large areas affected. Several ten thousands of square kilometres of open water surface were probably turned into barren desert or salt marshes due to human activities already ca. 2000 a BP. The former area of Lop Nur Lake is estimated as 17,000 to 50,000 km^2 of which most was probably dry during the near-desiccation state 1800 a BP (Yang et al. 2006). Eastern Juyan Lake may have covered 320 km^2

before its desiccation (Hartmann et al. 2011). The drying of the western sub-basin of Zhuyeze Lake, the Qingtu Lake Basin, probably left some 500 km^2 of previous lake area dry. The areal changes of Bosten Lake are not inferred in a straightforward way from the stable isotope data but the observed 1.5 m lake-level difference between the years 1980 and 2000 caused a change of lake area by ca. 650 km^2, which shows that a relatively minor lake level fall results in a significant lake area reduction (Wang et al. 2003). Thus, substantial areas were apparently turned into barren desert or salt marshes in the four lake regions as a consequence of water withdrawal from tributaries during the Han Dynasty and in the subsequent centuries.

Whilst regional changes of climate conditions are ruled out here as potential drivers of lake desiccation or lake-level decrease during and after the Han time, hydrological changes may have contributed to the desiccation of the Eastern Juyan Lake. Active channels of the Hei River on its large alluvial fan in the north of the Hexi Corridor may have become inactive due to the rapid filling of channels by fluvial sediments and formation of new channels, or due to blockage of active channels by dunes moving over the fan surface. Thus, the terminal Eastern Juyan Lake on the distal margin of the fan is not only controlled by regional climate conditions and discharge under natural conditions, and by water withdrawal upstream in the Hexi Corridor, but also by channel avulsion processes in a flat-lying terrain. However, similar processes were probably negligible for the other three lake catchments.

Another yet ignored line of evidence for potential landscape change triggered by man during the Han Dynasty or in subsequent centuries is the change of land-use practices and possible landscape degradation in or near the core region of the Chinese empire. For example, dramatic landscape change ca. 2000 a BP has been reported from the Ulan Buh Desert in southwestern Inner Mongolia at the margin of the Qin Dynasty realm preceding the Han Dynasty (Li et al. 2015). Tectonic activity and climate change were suggested as causes of aridification in the Ulan Buh Desert so far (Li et al. 2015). Further to the east and within the Qin Dynasty realm, sand mobilization and dune formation occurred apparently already as a result of a massive migration of people and farming intensification in the Mu Us Desert region during the earlier half of the Han time, the Western Han (206 BCE–9 CE; Sun 2000). Here, man's impact was clearly identified. Further in the southeastern part of the Mu Us Desert, studies by Li et al. (2011) and Liu and Lai (2012) implied a drastic change from long-term sediment accumulation to rapid incision of the Salawusu River by 60 m since 2000 or 1750 a BP. Other rivers on the Chinese Loess Plateau have late Pleistocene and older terraces, and apparently significantly lower erosion rates (Qiu et al. 2014). Thus, it remains open to which degree intensified land use or changing practices during the prosperous Han Dynasty may have contributed to landscape change in the core region of the Chinese Empire too.

3.5 Conclusions and Perspectives

The comparison of lake, speleothem and ice core records from northwestern China and surrounding regions for the Han Dynasty period and subsequent centuries shows that relatively wet climate conditions were mostly inferred for areas immediately to the west, north and south of the Han Empire realm. In contrast, the available four lake records from within the Han Empire region witnessed decreased moisture availability and significant landscape change ranging from substantial decreases in lake level and open-water surface areas (Bosten and Zhuyeze lakes) to near (Lop Nur Lake) or complete desiccation (Eastern Juyan Lake) of lake basins. The spatial pattern of lake records indicating drier conditions during the Han time or shortly afterwards cannot be explained by climate change due to mostly wetter conditions inferred from nearby locations which are outside the Han Dynasty region. Thus, man-made impact on surface waters must already have reached an order of magnitude during the Han Dynasty which was sufficient to cause large-scale landscape change. Water withdrawal from the tributaries of the lakes for irrigation farming was most likely the main driver of landscape deterioration downstream.

The timing of landscape response is not very consistent and partly not well constrained for the four lake basins. Significant reductions in inflow are recorded at Bosten and Lop Nur lakes as early as 2300 a BP and more significantly at Lop Nur Lake 1800 a BP whilst the desiccation of the Eastern Juyan Lake occurred 1700 a BP. The underlying radiocarbon and OSL chronologies are likely not precise due to problematic materials used for dating (e.g., bulk organic matter for radiocarbon dating potentially biased by lake-reservoir effects; Mischke et al. 2013) or uncertainties in post-depositional water content assessments for OSL dating. The lowering of the level of Zhuyeze Lake during the Han Dynasty is also not precisely constrained due to the dating of higher shoreline deposits with ages preceding the Han time and dating of lower deposits formed after the Han Dynasty (Fig. 3.4). Thus, it remains open whether man exerted significant impacts on local hydrological systems already as early as the beginning of the Han Dynasty or even before, or whether significant impacts occurred only after the initial Han Dynasty expansion to the west. Better constrained chronological control is required to answer such questions in the future.

Our conclusion that man impacted the landscape already in a very significant way as early as the Han Dynasty clearly calls for an assessment using other lines of evidence. Archaeological field evidence for intensive irrigation farming during the Han Dynasty such as remnants of artificial channels, dams and reservoirs, soils and farmlands buried beneath aeolian sands, and ruins of desert oases from Han times could be assessed in future studies in addition to the screening of written historical documents. Detailed geological, geomorphological and archaeological studies are required to better understand early human impact on fragile landscapes in the arid and semi-arid regions of Central Asia.

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Chapter 4
The Ili River Delta: Holocene Hydrogeological Evolution and Human Colonization

Jean-Marc Deom, Renato Sala and Anne Laudisoit

Abstract Extensive survey of paleocourses of the Ili delta discovered archaeological findings that, chronologically attributed and systematized, allowed the historical reconstruction of the human occupation of the delta. Until recently the colonization was believed to have begun only during medieval times. We argue it began much earlier at the start of the Bronze Age of Kazakhstan (second half of the III millennium BC) under the impulse of new economical activities based on stockbreeding and bronze metallurgy. The basic method of research consisted in surveys, collection of surface finds and documentation of hydrogeological and climatic data. The correlation between the two types of information gives an idea of the factors that influenced the distribution of habitats, mostly represented by winter camps. Their number and concentration change by epoch, pointing to changes in both cultural proclivities and environmental factors. The understanding of the whole historical process requires background knowledge of the hydrological history of the Ili delta, a complex system involving active distributaries and intermittent or inactive paleo-courses, and showing the anticlockwise rotation of 5 successive deltas. Generally speaking, arid climate phases stabilize the delta, pluvial phases favor changes in various directions. Human colonization concerned the two Holocene deltas preceding the modern one: relict terraces of the Uzunaral delta (8–4 ka BP) and terraces of mild active distributaries of the Bakanas delta (4000–250 BP), subject during the last 4000 years to complex geomorphological and hydrological changes that, when reconstructed and correlated with the distribution of finds, explain the location of habitats and allow the mutual chronological attribution of geological and cultural deposits.

Keywords Ili river delta · Geological history · Holocene · Human colonization
Settlement pattern · Pastoralist-metallurgic transhumances

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4.1 Introduction

The Silk Road is not just a system of transport routes but includes also a series of human communities distributed along a longitudinal geographic corridor across Eurasia. In this sense, the Ili valley integrates both aspects: it constituted an important segment of east-west interregional itineraries as well as the historical habitat of important human cultures. It is located at the junction between the transcontinental roads of traders and the meridional Central Asian mountain corridor traveled by mobile pastoralists.

During the initial phase of activity of the classical Silk Road (II BC), the Ili valley was a wealthy political center under the rule of the Saka tribes (Eastern Scythians). These peoples were practicing pastoral vertical transhumances, had a mighty military power and were managing a lucrative horse trade with adjacent settled civilizations. Their importance, attested not only by Chinese accounts but also by the density and size of their funerary monuments (kurgans), which are among the largest in all Eurasia, witness the highly favorable ecological conditions of the region (Deom and Sala 2012; Gass 2016). The foothills of Semirechie enjoy a temperate climate with regular precipitations coming from the Atlantic atmospheric circulation, well watered alluvial fans nourished by snowy peaks, large summer pastures in mountains and, at few km of distance, winter camps in desert: all conditions providing good pastoral resources using short vertical migrations.

This Iron Age economical system derived from a scheme already developed during the Bronze Age[1] and continued to the modern era. The residential pattern consisting of winter camps in semi-desert and desert zones, spring and fall dwellings in foothills, and summer camps in mountains meadows has been extensively documented by the Laboratory of Geoarchaeology during more than 20 years of surveys of these three landscape zones. Settlements and burial grounds of all historical periods occupy the same loci in cultural layers overlapped or next to each other. Concerning the Ili delta, the fact that this territory has been used for millennia as a huge winter camp was not known until recently. Up to now the first and only recorded traces of human colonization of the delta consists of a line of medieval forts marking a caravan road.

The present article communicates for the first time the history of the human colonization of the Ili delta region. It begins with background knowledge about the geography and geological history of the territory (part 1) and about the former archaeological studies and ethnographical reports concerning the cultural processes that happened in the delta region and beyond its borders (part 2). Areas, methods and results of the present research are expounded in part 3. Part 4 provides the preliminary reconstruction of the complex interaction of natural and cultural processes that characterized during the last 4500 years the area of the third and second last deltas of the Ili river.

[1]By Bronze Age and its partitions in early, middle, late and final, we refer to their establishment on the Kazakhstan territory between 2800 and 800 BC.

4.2 The Ili Delta

4.2.1 General Features

The Ili river system rises in Xinjiang and, fed by sources in China and Kazakhstan, develops for 1400 km forming a delta in the Southern Pre-Balkhash region, supplying 70% of the annual inflow to the Balkhash lake.

The last 300 ka saw the succession of 5 generations of Ili river deltas. Under the forcing of sedimentary and tectonic processes, their heads and fronts were gradually displaced northwest and rotated anticlockwise, up to the present Balkhash shore, with their areas reducing in size and largely overlapping each other. In chronological order: (1) Akdala, (2) Bakbakty, (3) Uzunaral, (4) Bakanas, (5) Modern Ili.

Today relict and active channels stretch northwestward for 230 km, starting at the foot of the Tasmuryn mountains at 415 m asl and ending in the Balkhash lake at 341 m asl, with an average slope of 0.30%. The entire territory is clearly composed of 3 very different parts, western, central and eastern: the first consists of the area of the modern delta and the other two of the previous 4 deltas.

The western part, crossed by the active delta distributaries of the modern delta (modern Ili, Topar, Zhideli), is a vegetated wetland of 8000 km^2, covered by tugai forest and reeds. The central part, which is 3 times wider than the first and includes the research area, contains the previous Bakanas and Uzunaral deltas and is today desiccated, covered by sand dunes with bushes and shrubs and cut by dry river channels with rare seasonally moistened segments. Here the most remarkable paleocourses, from west to east, are: the entire Naryn course and the mid-low Orta-Bakanas, which belonged to the second last Bakanas delta; and the upper Orta-Bakanas, the Shett-Bakanas, Ortasu and Akdala, which had been distributaries of the Uzunaral delta and, in segments of their upper course, expose rare traces of erosion by the other two most ancient deltas. The eastern part is the largest, developing further eastwards for more than 300 km until the Karatal river course. It consists of the most arid expanses of the huge Saryesyk-Atyrau desert, which constitutes the area occupied by the oldest Akdala and Bakbakty deltas, today totally invisible under a thick cover of aeolian deposits (Fig. 4.1).

4.2.2 Geological History

The geological history of the Ili delta as reconstructed by Soviet scientists provides the general background of the recent researches implemented in the region (Aubekerov et al. 2009; Dzhurkashev 1972; Sala et al. 2016).

Its establishment is dated around 300 ka BP when the Ili river was diverted northward by the uplifting of the Karoi plateau and started discharging its waters in the Balkhash depression, establishing a system of shallow lakes (Bakanas lake) that were progressively displaced northward by a huge accumulation of sediments (Kostenko 1978; Platonov 1959).

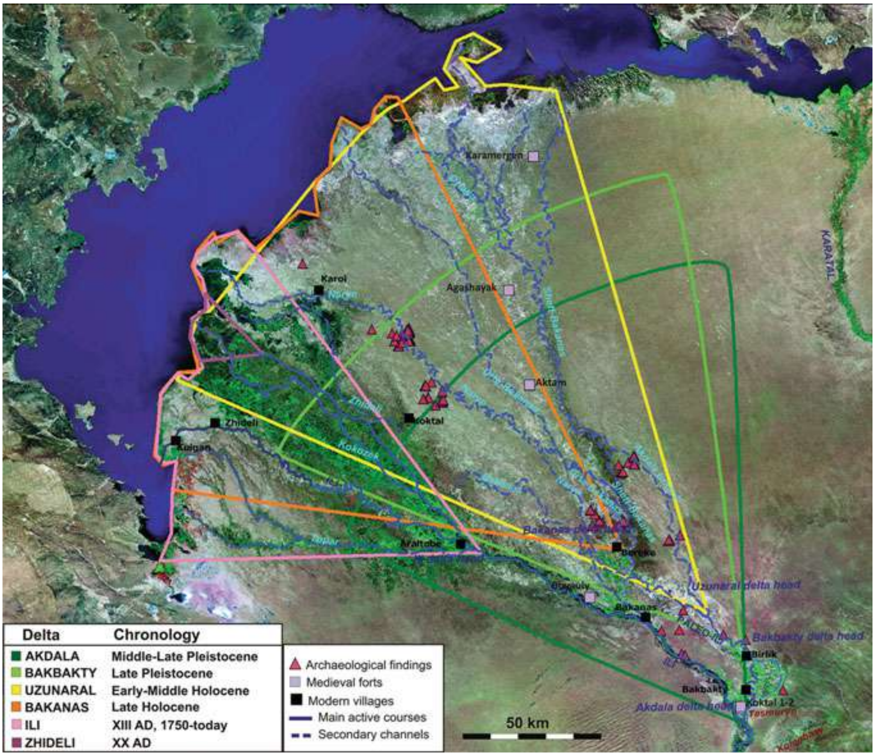

Fig. 4.1 Map of the Ili delta, showing the chronological succession of 5 main deltas and the location of camps and medieval forts. Adapted from Abdrasilov (1993), superimposed on Landsat image

Its subsequent evolution has been a quite complex process across a succession of several deltas. Arid phases, through diminishing the water regimes of delta distributaries, favor the erosion and lowering of the river channels, the formation of terraces and, generally, the stabilization of the existing delta morphology. The establishment of a new delta typically coincides with pluvial phases that enhance the energy levels of the river and promote diversions in various directions. Tectonic and sedimentary processes fix the thresholds that bring to sudden morphological changes and are responsible for the general patterns of the multi-millennial evolution.

Aeolian deposits of different thickness cover most of the region (with the exception of areas like floodplains and proluvia from where they are regularly washed away) so that the dating of their bottom layer by OSL can sort the chronological attribution of the covered surface.

An approximated reconstruction of the area and historical succession of deltaic fans has been produced by Abdrasilov (1993) (Fig. 4.1). For presenting our research, we will draw on this chronology, supplemented with fresh data collected during subsequent research projects (see below Sect. 4.1).

The 300 ky long evolution of the Ili delta can be outlined in 5 phases, in chronological order: (1) Akdala, (2) Bakbakty, (3) Uzunaral, (4) Bakanas, (5) Modern Ili. The heads of the first two deltas were located at the outlet from the mountains and fed by a river segment called Paleo-Ili running on the plain for 10–50 km. During the Middle Holocene, the third delta was formed: the head displaced 30 km NW, its distributaries slightly redirected anticlockwise, and their terminal sediments reaching the line of the present Balkhash shore and building the Saryesik peninsula.

During the Late Holocene, northward and anticlockwise displacements accelerated and the modern Ili river course became established, bifurcating from the Paleo-Ili at the mountain outlet and running parallel southwest of it. At first it proceeded just 50 km NW until the area of the Bakanas village where it formed the fourth delta, the Bakanas delta: smaller than the previous ones and discharging totally in the Western Balkhash basin. During the last 700 years, the modern Ili opened its way 50 km further NW where the head of the modern Ili delta—the smallest—is located (Fig. 4.1).

1. *Akdala delta* (second half of Middle Pleistocene, 300–18 ka BP) is the most ancient. It was a large delta with head at the first outlet from the mountains (Tasmuryn) and distributaries running to NNE and spanning from west of the modern Ili course to the Karatal river course. Today its remains are covered by subsequent aeolian and alluvial sediments and are just barely detectable in the delta head zone.[2]
2. *Bakbakty delta* (Late Pleistocene, 18–8 ka BP). Following the late-glacial reduction of the Balkhash water surface and increased sedimentary processes, the Ili delta migrated 40 km north in the form of the Bakbakty delta. Fed by the Paleo-Ili course, its head was in the Bakbakty region; its distributaries, tectonically forced into anticlockwise rotation, ran to NNW; its front, more advanced, dammed the middle part of the Balkhash lake until 40 km south of the present shore.
3. *Uzunaral delta* (Early-Middle Holocene, 8–4 ka BP), also called Older Bakanas delta, was formed with the first significant moistening of climate occurring at the start of the Atlantic period. The delta head was displaced 30 km NW, half way to the Bakanas village; its distributaries (Uzunaral, Ortasu) ran NNW, its final deposits pushed the lake's coast further north to the modern shores. In that way the Saryesik peninsula has been formed, lying on 100 m thick sediments and separating the W and E Balkhash by the narrow and shallow Uzunaral strait, which is today 5 km wide and 5 m deep. An alternation of dry and pluvial phases marks the transition from the Middle to the Late Holocene, during which the Ili branches cut new narrower beds and wandered to the west of the Uzunaral strait, where in a couple of millennia a new delta was formed.[3]

[2]Preliminary results of OSL dating of terraces located at the head of the Akdala, Uzunaral and Bakanas deltas confirm the channel chronology given in the text and, in the case of Bakanas terraces, antecede the dating of diagnostic Bronze Age sherds. Anyhow, OSL dates are still under study and the final results will be published by Japanese geologists (Sato et al. 2013; Shimizu et al. 2012; Shimizu et al. 2015).

[3]See note 2.

4. *Bakanas delta* (Late Holocene, 4–0.3 ka BP), also called Younger Bakanas, is superposed to the wider Uzunaral delta, fed by a new parallel southern segment of the Ili course (New-Ili) and of lesser extension. The head is now located 30 km NW and all its distributaries, today desiccated, were redirected to the NW discharging their waters in the Western Balkhash basin. According to the Soviet scientists who researched the soil stratigraphy and geomorphological profile of the Bakanas delta (Dzhurkashev 1972; Rybin 1955; Vyatkin 1948), in spite of the anticlockwise rotation of the delta system, the chronological sequence of the main branches of the Bakanas delta went from West to East, from Naryn (oldest and most eroded) to Orta-Bakanas and Shett-Bakanas (which takes active part in 3 successive deltas). Ruins of medieval towns and artificial canals attributed to the VIII–XIII centuries AD are aligned along the Shett-Bakanas and Ortasu distributaries, witnessing some persisting activities of these easternmost courses.[4]
5. *Ili delta* (700–250 BP–now). The switching from the Bakanas to the modern Ili delta happened very gradually during the XIII–XVIII centuries AD, a phase of relative humidity that followed the intense aridity of the Medieval Warm Period (Chiba et al. 2016). At first, a transitional “Bakanas” distributary oriented to the west was activated; then the entire water flow became concentrated in the Ili course that opened its way 50 km further NW towards Araltobe village, establishing here the head of the modern Ili delta. After a few centuries of double course activity and reversals, the Bakanas delta died off completely between the years 1733 and 1785 (Mushketov 1886).[5] This last Ili delta has a much-reduced areal dimension beginning just 125 km far from the shore of the lake, and ramifies in few branches that chronologically succeeded each other from west to east: Topar, Iley, Zhideli.

4.3 Archaeological Data and Ethnographic Accounts Concerning the Southern Balkhash Territory

4.3.1 Archaeological Complex

The southern Balkhash region hosts monuments of all epochs, spanning from the Late Paleolithic to the modern periods (Deom et al. 2009). In particular, in the areas of the delta and in its immediate surroundings, archeological reports preceding the present communication documented the presence of the following monuments.

Late Paleolithic and *Neolithic* stone tools have been documented in 13 loci of the ancient shorelines of the Northern Balkhash and of the Ulken-Araltobe island (Dzhurkashev 1972), and on both sides of the Ili canyon upstream from the delta and

[4] See note 2.

[5] According to the Russian geologist Mushketov, the Bakanas delta dried up between the years 1733 and 1785 as on the Oirat maps preceding this period, the Ili river was drawn with a large branch reaching the Bakanas.

below the Kapchagai dam. No material clearly attributable to the Neolithic period or earlier has been found in the delta (Coque et al. 2000). In the western terraces of the Karatal river finds of Neolithic potteries (which are rare in Semirechie), grinding stone and pestle, lithics (including microliths, blades, scrapers, borers) have been reported (Arkheologicheskaya karta 1960); however, according to the description of the finds, these collections include also ornamented sherds and Bronze objects that seem more related to the Early-Middle Bronze Age.

Bronze Age copper slag and potsherds have been found in all areas spoken above. These sites could belong to the earliest phase of the Bronze Age in the region. Ascribed to this phase are settlement layers dated to the Chalcolithic-Early Bronze in the foothills of the Tienshan, like the pit house floor found in the Talgar fan (3360–3100 cal. BC) (Macklin et al. 2015), and in the upland valleys of the Djungarian Alatau, like the cist burial in Tasbas (2832 and 2492 cal BC) (Doumani 2014).

Contra the formerly accepted view that in Semirechie the Bronze age started in the early II millennium BC with the coming of Andronovo tribes from Central and East Kazakhstan, recent excavations in the Djungarian Alatau (Begash, Tasbas, Dali) and a new campaign of absolute dating of materials resumed from the Zailiski Alatau (Turgen, Kyzylbulak) pushes the chronology of the colonization of the region to the XXV century BC, i.e. the Early Bronze Age (Frachetti et al. 2014; Gass and Goryachev 2016).

Petroglyphs starting from the Bronze Age are present above the delta head in the last small mountain ranges of Kulanbasy and Tasmuryn. Typical Bronze Age cist tombs are found on the northern shore of the Balkhash and on the Tasaral island.

Iron Age kurgans are located on the terraces of the modern Ili course (Marikovskii 1982) and along some paleo-channels at the south of Bakbakty village. No kurgans have been documented further downstream neither in the Bakanas delta.

The *Medieval* period is represented by 8 square forts (*tortkuls*) that have been studied during 4 expeditions (1962–1997) and dated between VIII–XIII centuries AD, from south to north: Koktal 1 and 2, Boyauly, Aktam, Karkaraly, Agashayak, Karamergen and Barkhan (Akishev and Baipakov 1969; Baipakov and Groshev 1993; Baipakov 1998; Baipakov et al. 2001). Karkaraly and Barkhan[6] have been barely identified during 2 different expeditions just on the base of potsherds and slag accumulation, and both lack dimension and precise location. The other 6 had been documented in plan and can be considered as real monuments: Koktal 1–2 and Boyauly are now under rice fields or village houses; Aktam, Agashayak and Karamergen are still visible aligned along the Shet-Bakanas paleocourse (Fig. 4.1).

Around Aktam the ruins of ‘settled agrarian cultures’ were reported on the basis of numerous potsherds, dated at first to the VII–IX centuries AD and ascribed by later publications to the X–XIII centuries AD. The presence of a copper melting workshop has been suspected on the basis of copper slag and fragments of copper vessels. Also SW and W of Aktam, near the Orta-Bakanas course, medieval houses

[6]Concerning Barkhan, a dense deposit of potsherds along a takyr, without visible structures, only makes the presence of ruined ‘houses’ suspect.

and other pottery and metallurgy workshops have been recorded, stretching for 7 km along the main and secondary canals.

In the surrounds of the 3 visible medieval forts, remains initially interpreted as complex irrigation networks consisting of one magistral canal and several secondary channels, sometimes extending for few km till the banks of a main delta branches (from Aktam till Orta-Bakanas, from Agashayak and Karamergen till Shett-Bakanas) have been reported as well as associated to irrigated agricultural fields with identifiable planimetry, supposedly corresponding to the cultivation of 'cucurbitaceae and vineyards'. In 1997 an expedition especially devoted to the pedological assessment of phases of activity of the forts contradicted those hypotheses, revealing that forts were built in a dry environment when no active channels were crossing the area and that the ruins interpreted as 'irrigation systems' were just small aryks (water ditches) using natural paleochannels for bringing water till the forts.

Late Medieval (Ethnographic) period. During the Jungar khanate (1634–1745 AD), the Oirat (Kalmyk) tribes intensively occupied Semirechie and the Ili delta, multiplying winter camps, organizing irrigated agriculture and building forts. They erected 3 walled garrisons in the estuary of the Zhideli branch, later partially eroded by floods, and others near the modern villages of Bakbakty and Bakanas. Most probably they also reused the 3 forts that are clearly visible along the Shett-Bakanas.

These data are supported by toponymic evidence. In the Zhidely estuary, a long stripe of sand dunes paralleling the river is called *Ush-tam* (meaning '3-mounds' or '3-forts') and was previously called *Ush-kalmak* (meaning '3-Kalmyk', i.e. *Bas, Orta, Ayak,* 'Upper, Middle, Lower') referring to 3 Kalmyk groups living in the area (Erofeeva 2008). According to the pedologist M. Vyatkin, the ancient irrigated fields found in areas with resurgent riverbeds (*zabok*) at the Bakanas delta head and in the middle Naryn course were initially built by Kalmyk tribes during the middle of the XVIII century AD (Vyatkin 1948). Kalmyk peoples were also living in the eastern parts of the delta, probably in the 3 medieval forts aligned along the Shet-Bakanas course. In fact, until the end of the XIX century AD, the fort Aktam was called *Durtgut*, which doesn't have any meaning in Kazakh and might refer to the 'Torghuts', a main Kalmyk tribe that settled in the Ili and then moved to the NW Caspian. The Russian geographer N. Palgov reported in 1930 that the Kazakhs considered the 3 '*Aktam*' (referring in this case to Aktam, Karamergen plus Boyauly or another fort north of it) as Kalmyk vestiges "haunted by ghosts" (Palgov 1932).

4.3.2 Ethnographic Accounts

Ethnographic accounts of Russian geographers provide important information on the land and water use within the delta during the XIX century and the start of the XX century.

Concerning ethnic distribution and land use, the driest parts of the delta (3/4 of it) were available for common use, while the relatively moistened lands closer to the Ili banks were belonging to Jalair tribes (Baigaly, Baichigir) from the Karatal valley.

Most of the Jalair clans were living all year round in the delta, though the richest stockbreeders would practice seasonal migration between the best winter camps in the delta and summer pasture in the Djungarian Alatau (Aristov 1894; Vostrov and Mukanov 1968), with horses and camels, because sensitive to mosquitoes, gnats and botflies, all sent during summer to the highlands.

Concerning caravan routes across the delta, significant information was recorded by N. Palgov who carried out the population census of the region in 1930. According to his account, there were several caravan roads linking the Ili delta to the lower Karatal river, with raft ferries helping the cross of active delta branches. The main road, called *Otrau-zhol* (delta road) was following the right bank of the Ili river till modern Karoi village and then turning eastward along the southern shore of the Balkhash lake till the Karatal estuary. It was the most crowded due to the availability of water, it had several yurt villages regrouped around active wells. The second main road, shorter but much harder, called *Tuya-kuduk-zhol* (the road of the camel well), crossed the Bakanas delta in its central part through the ruins of Aktam and a series of often saline wells in a depopulated corridor. These tracks were also used for transporting salt collected in the salt pans on the right bank of the lower Karatal: it was considered the best culinary salt of South Kazakhstan and sold by Kazakh herders in Ushtobe, 100 km upstream, at the price, in 1942, of 1 kg of salt for 1.5 kg of wheat floor (Miller 2014).

It is also recorded that 500 yurts of the Argyn tribe living on the northern shores of the Balkhash lake were grazing in the Ili delta during winter by crossing the iced surface of the lake (Rumyantsev 1913). As soon as ice melted in spring, fishing became an important activity, an expedient surely in use during all epochs.

4.4 Geoarchaeological Study and Chronological Attribution of the Human Occupation of the Ili Delta

4.4.1 Research Projects, Area and Methodology

4.4.1.1 Research Projects

The background of the present research started with the Japanese-Kazakh project (2007–2012), based on the cooperation of 3 institutions[7] and dedicated to the reconstruction of the Holocene environmental changes in the Ili-Balkhash basin. The project implemented studies of the evolution of environmental and cultural aspects of the Balkhash basin: climatic changes and lake water levels, shorelines, alluvial deposits, river terraces and sand dunes, archaeological traces of land-water use, reading of Late Medieval historical accounts and Soviet documents concerning

[7]The 3 institutions are: Research Institute for Humanity and Nature (RIHN), Kyoto; Laboratory of Geoarchaeology, Almaty; K.I. Satpaeva Institute of Geological Sciences, Almaty.

the territory, interviews about post-Soviet pastoral and agricultural activities in the region, and geoarchaeological surveys with documentation and collection of surface archaeological material (Endo et al. 2012; Sala et al. 2016).

Geoarchaeological surveys were undertaken during 4 seasons (2008–2011) along the Balkhash lake shorelines, on the terraces of its tributary rivers (Ili, Lepsy), and in particular on terraces of Ili paleo-deltas. The fieldwork yielded the discovery of an unexpectedly abundant surface material representing a wide chronological frame from Eneolithic to modern times (Deom et al. 2012), giving impetus for further research.

Further work followed in 2011–2013 under the auspices of the British-Kazakh Wellcome Trust Project "Advances in the Prediction of Plague Outbreaks in Central Asia", aimed at studying the percolation of plague in gerbil population by mapping and analyzing their burrows in the area of the Ili delta (Wilschut et al. 2013). Together with the biologist Anne Laudisoit surveying rodents' colonies, we collected surface archaeological findings during 3 seasons.

4.4.1.2 Study Area

The survey areas represent the entire variety of desert habitats at varying distances from the piedmont zone. The upper parts of the entire delta system deserved special geological analyses intended for interpreting the chronological succession of the deltas. The Naryn paleocourse has been privileged as it represents the most relevant and longstanding active or intermittent course during the last 4000 years.

Geoarchaeological surveys focused on the river terraces distributed all along the entire course of the today dry Uzunaral and Bakanas paleodeltas (the area spoken as 'central' in Sect. 2.1), in particular: the terraces of the paleo-Ili and modern Ili river segments upstream from all deltas; the heads of the Bakbakty, Uzunaral and Bakanas deltas; the upper courses of the Akdala, Shett-Bakanas and Orta-Bakanas paleodistributaries; and the entire upper, middle and lower course of the Naryn paleo-distributary.

As a whole, have been surveyed the terraces of 3 regions, focusing on 11 zones (Z-1-11) of 10 × 10 km (marked in Fig. 4.2 and listed in Tables 4.1 and 4.2), where has been detected a total of 70 clusters (areas of 200 × 200 m at mutual distance of >200 m) including a total of 134 loci (areas of around 20 × 20 m characterized by a dense deposition of cultural objects).[8]

The eastern and northeastern borders of the Bakanas delta, at the location of the 4 medieval forts of Aktam, Agashayak, Karamergen and Barkhan, are not yet explored and should be the object of future research. Four archaeological expeditions devoted to the study of the forts and their hydraulic implementations have recorded the surface occurrence of a large numbers of potsherds (exclusively medieval, VIII–XIII

[8]Concerning the repartition of the survey areas between the Japanese-Kazakh and British-Kazakh projects, see Fig. 4.2. Regions, zones, clusters and loci are listed in Table 4.1. Of the total 134 loci, 39 have been found under the first project, 95 under the second.

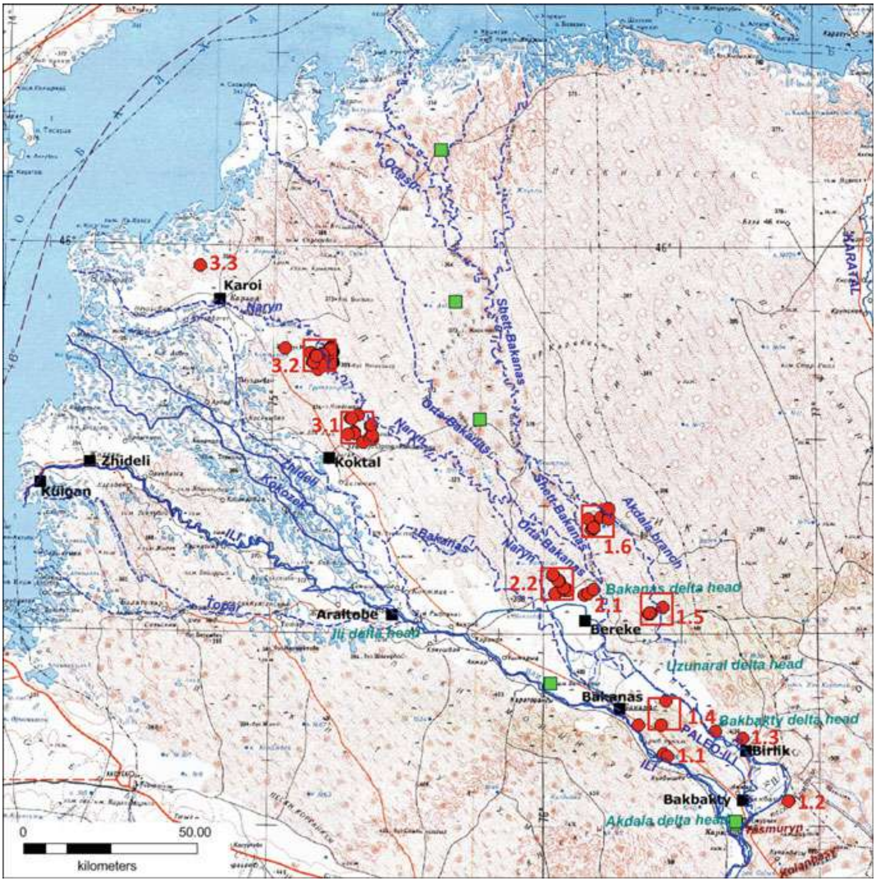

Fig. 4.2 Map of the researched territory. Red dots = loci of cultural findings; green squares = medieval forts; square red perimeters of 10 × 10 km = areas studied under the Wellcome Trust project. Zones are marked by red numbers. Paleo and modern paleo delta heads marked in azure. (Soviet topo map L-43, scale 1:1 million)

centuries AD) scattered around the forts (sometimes within a radius of 7 km) and also in northern areas closer to the Saryesyk peninsula (Baipakov et al. 2001).

4.4.1.3 Methodology

Methodological procedures have been chosen specifically for selecting surveying areas, collecting and analyzing artifacts, fixing a data base and elaborating data by statistical analyses.

Surveys Surveys were implemented through field walking for collection and GPS recording of surface finds. They didn't constitute a systematic grid-based survey

Table 4.1 Ili paleodelta: assemblages of surface finds by zone, material and period

Location and number of sites and finds (microlyths and sherds)										
Location				Finds						
Region	Zone	Clusters n°	Loci n°	Microliths* n°	Sherds					
					by Zone		by Period* n°			
					n°	%**	B	EI	M	KZ
1 Akdala head, Bakbakty head	1.1- Ili upper, R-bank	4	14	11	127	*9.6*	31	64	16	5
	1.2- Akdala delta head	1	2	0	8	*0.6*	8	0	0	0
	1.3- Paleo-Ili (Birlik-N)	2	6	11	38	*2.9*	9	11	6	1
	1.4- Bakbakty delta head	3	12	3	25	*1.9*	9	8	4	1
	1.5- Akdala-mid	5	6	9	16	*1.2*	1	1	0	5
	1.6-Akdaka-low⊥Shett B. upper	12	13	33	132	*10*	34	54	11	0
	Subtotals	*27*	*53*	*67*	*346*	*26*	*92*	*138*	*37*	*12*
2 Bakanas head	2.1- Orta-B. upper	4	7	0	18	*1.4*	3	10	4	1
	2.2- Naryn upper	6	7	3	57	*4.3*	21	18	10	5
	Subtotals	*10*	*14*	*3*	*75*	*5.7*	*24*	*28*	*14*	*6*
3 Naryn mid-low	3.1- Naryn mid	10	20	5	331	*25*	190	107	29	0
	3.2- Naryn low	21	45	0	550	*41.6*	287	191	72	0
	3.3- Naryn final	2	2	0	18	*1.4*	1	6	11	0
	Subtotals	*33*	*67*	*5*	*899*	*68.1*	*478*	*304*	*112*	*0*
TOTALS	**zones: 11**	**70**	**134**	**75**	**1245**	***100%***	**594**	**470**	**163**	**18**
Ratio on total n° of sherds and microliths (1320)				***(5.6%)***	***94.3***		***(45%)***	***(35.65)***	***(12.3)***	***(1.3%)***

* Mc=Microliths (19% Pre-Bronze, 81% Bronze), B=Bronze Age, EI=Early Iron, M=Middle Ages, KZ=Kazakh (Ethnographic) period (last 4 centuries).

** The ratio of finds by zone is calculated on the total number of finds in all zones. Highlights are applied to numbers relatively high by column: azure=very-high, green=high, yellow=average.

aimed at geostatistical analyses, as it has been done fruitfully in other paleodeltas of arid Central Asia (Markofsky 2014) but focused on the terraces of dry paleodelta channels.

Spatial Selection In the frame of the first research project 2007–2012, the strategy of survey was motivated by the aim of gathering chronologically attributed artefacts on terraces of paleochannels where geomorphological profile and sampling for absolute dating were also implemented, in order to correlate geological and cultural chronologies. In this context, the surface collection was done in a perimeter of 1 km around the study site.

The spatial objective of the second project was circumscribed to selected square areas with good satellite image resolution and high density of rodent burrows, which happen to correspond to the areas crossed by the main and most ancient segments of paleodeltas. For plague monitoring, the research area was based on a cartographic division of the territory into primary squares (40 km × 40 km), then each into four

Table 4.2 Ili paleodelta: Assemblage of surface finds by zone, material, period and diagnostic type

ZONE & (n° of loci)	FINDS n°	ASSEMBLAGES BY ZONE, MATERIAL, PERIOD, TOTAL & DIAGNOSTIC TYPES * n° & (%) **							
		Microlith	Sherds by period: Bronze, all types			Early Iron, all types	Medieval, all types	Kazakh, all types	Metal & Stone
			morphology	ornament	textile	diagnostic	diagnostic	diagnostic	
1.1 Ili up, R-bank (14)	127	11 (9%)	31 (25%)			64 (50%)	16 (13%)	5 (4%)	**KZ** iron hanger, iron fragment
			12 (39%)	*2 (6%)*	*0*	*0*	*0*	*0*	
1.2 Akdala delta head (2)	8	0	8 (100%)			0	0	0	–
			0	*2 (5%)*	*0*				
1.3 Paleo-Ili (Birlik N) (6)	38	11 (29%)	9 (24 %)			11 (29%)	6 (16%)	1 (3%)	–
			2 (22%)	*1 (11%)*	*0*	*form 1 (9%)*	*0*	*0*	
1.4 Bakbakty delta head (12)	25	3 (12%)	9 (36%)			8 (32%)	4 (16%)	1 (4%)	–
			0	*1 (11%)*	*0*	*form 1 (12%)*	*0*	*0*	
1.5 Akdala-mid (6)	16	9 (56%)	1 (6%)			1 (6%)		5 (31%)	–
			0	*0*	*0*	*0*	*0*	*form 1 (20%)*	
1.6 Akdaka-low Shett B. up (13)	132	33 (25%)	34 (26 %)			54 (41%)	11 (8%)	0	**B** copper bead
			4 (12 %)	*2 (6%)*	*1 (3%)*	*form 2 (4%)*	*0*	*0*	
2.1 Orta-B. up (7)	18	0	3 (17%)			10 (56%)	4 (22%)	1 (5%)	–
			0	*1 (33%)*	*0*	*0*	*0*	*0*	
2.2 Naryn up (7)	57	3 (5%)	21 (37 %)			18 (32%)	10 (18%)	5 (9%)	slag iron
			1 (5 %)	*0*	*4 (19 %)*		*form 1, deco 2, (30%)*	*form 1(20%)*	
3.1 Naryn mid (20)	331	5 (2%)	190 (57 %)			107 (32 %)	29 (9%)	0	slag (iron?)
			19 (10%)	*17 (9 %)*	*9 (5%)*	*form 6, text 7, (12%)*	*form 1 (3%)*	*0*	
3.2 Naryn low (45)	550	0	287 (52 %)			191 (35%)	72 (13 %)	0	**EI** whetstone, grinding stone (EI); **M?** slag in 2 loci (iron & copper?), crushed iron, copper leaf
			43 (15%)	*16 (6%)*	*27 (9%)*	*form 9, deco 1, text 4, (7%)*	*form 3, deco 1, (6%)*	*0*	
3.3 Naryn final (2)	18	0	1 (6%)			6 (33%)	11 (61 %)	0	–
			0	*0*	*0*	*form 2 (33%)*	*form 2 (18%)*	*0*	
TOTAL (134)	**1320 *(100%)***	**75 *(5.7%)***	**594 *(45%)***			**470 *(35.6%)***	**163 *(12.3%)***	**18 *(1.3%)***	–
TOTAL diagnostic finds***	***209 (16%)***	***61 (81%)***	***164 (28%)***			***33 (7%)***	***10 (6%)***	***2 (11%)***	–
			81 (14%)	***42 (7%)***	***41 (7%)***	***form 21 (4%) deco 1 (0.2%) text 11 (2%)***	***form 7 (4%) deco 3 (2%)***	***form 2 (11%)***	

* Materials: microlith, sherd, metal, stone. Periods: B=Bronze, EI=Early Iron, M=Medieval, KZ=Kazakh. Diagnostic sherds of 3 types, by: morphology, ornament, textile imprints (rows marked in grey).

** For each zone, the ratio of n° of sherds of ***all types*** is calculated on the n° of sherds of all periods within the same zonal assemblage; the ratio of n° of ***diagnostic*** sherds is calculated on the n° of all sherds of the same period within the same zonal assemblage.

*** The ratio of total diagnostic finds is calculated on the above total number of finds.

[a]Materials: microlith, sherd, metal, stone. Periods: *B* Bronze, *EI* Early iron, *M* Medieval, *KZ* Kazakh. Diagnostic sherds of 3 types, by: morphology, ornament, textile imprints (rows marked in grey)

[b]For each zone, the ratio of n° of sherds of ***all types*** is calculated on the n° of sherds of all periods within the same zonal assemblage; the ratio of n° of ***diagnostic*** sherds is calculated on the n° of all sherds of the same period within the same zonal assemblage

[c]The ratio of total diagnostic finds is calculated on the above total number of finds

secondary squares (20 km × 20 km) and these into four sectors (10 km × 10 km), as described elsewhere (Wilschut et al. 2013). The study sites concerned randomly chosen 500 m × 500 m (25 ha) squares spread over 6 sectors (see Fig. 4.2) (Levick et al. 2015).

In the context of these sectors, within 3 seasons (autumn 2011, summer and autumn 2012, spring 2013), 2113 burrow were mapped and most of the surface artefacts were collected. Other finds were gathered when circulating on foot between close squares (within 10 km radius) and during a recognizance survey in the estuary of the Naryn channel. Visual contact with surface archaeological remains occurred predominantly on the ledge of recently dug burrows, around takyr, between dunes, and along the banks of dry paleodelta channels (Photo 4.1).

Collection and Count In each spot with single or multiple finds, the total or a representative amount of archaeological items was collected. Potsherds are by far the most abundant finds, so that in loci with numerous finds, the ones belonging to the same pot and similar sherds were discarded. Among other artefacts, microliths slag, metals and stone tools were systematically collected. Surface finds visually contacted were photographed, georeferenced and packed in labeled bags.

All data were recorded in a database, which includes several entries: exact location, geomorphological setting, amount and type of findings, preliminary chronological attribution, and assessment of buried condition (uplifted, deposited). Subsequent office work based on satellite images added new entries such as elevation and proximity to stream.

Loci and Terraces Most of the loci discovered during the surveys—86 out of the total 134 (64%)—are located on relict or active river terraces, allowing the chronological correlation between cultural and geological data sets. The spatial distribution of the loci corresponds to the orientation of the delta channels and of the dune ridges associated with them, both having, as the dominant wind in the delta, a NNW-SSE direction.

They all consist of surface finds without stratigraphy and are not associated with visible settlement structures or irrigated fields. Most of the surface scatters probably correspond to the original location of occupied sites, but many are located around takyr depression as aggregation from surrounding dunes. Actually, it is almost impossible to distinguish surface and subsurface material being that most of the artefacts might have moved with dune displacement and been uplifted by rodents.

The entire territory of the delta is densely populated by the great gerbil (*Rhombomys opimus*, carrier of endemic plague), which builds burrows with galleries usually running 30–50 cm below the surface while food and nest chambers can be built as low as 5 m underground (average 2.5 m). By digging and cleaning, the rodents constantly excavate and eject to the surface ancient objects, stones, pebbles, vegetation debris, bones and faeces. This is how most of the findings were spotted.

Chronological Attribution of the Surface Material The non-stratified, open site condition of the surface artifacts discourage the possibility of the absolute dating of finds, leaving the chronological information to be retrieved from their typological elements. Out of total 1331 finds, 1320 have been chosen for chronological attribution (Table 4.1).

Sherds have been first of all visually classified according to: (1) shape and thickness; (2) technique of manufacture and firing, hand or wheel made, external and internal color, etc.; (3) paste and inclusions. These elements allow their preliminary partition within 4 periods (Bronze, Early Iron, Medieval and Kazakh-Ethnographic periods). The resulting chronological classification allows the implementation of statistical analyses (see below), at the cost of few ambiguities and potential mistakes.[9]

A way to increase chronological confidence exists: it consists in sorting among the entire bulk of sherds and microliths just the diagnostic samples carrying more precise chronological markers. Diagnostic sherds (16% of their total) are individuated by 3 types of markers: morphological elements (rim, base, spout, handle, etc.), ornaments (incised, applied or colored), and textile imprint (molding technique) (Photo 4.2). The most reliable for chronological attribution are diagnostic sherds with decoration (typical); slightly less reliable are those carrying shape and/or fabric (textile) information. Diagnostic microliths (81% of their total) are individuated by presenting forms classified as characteristic of the Bronze period in several stratified sites of Semirechie.

A disadvantage of this procedure is the reduction of reference samples to 16% and their specific distribution within sites and periods, i.e.: some loci would be empty and disappear from the count and ornamental proclivities would privilege the Bronze period (where diagnostic sherds constitute the 28% of the total) and disfavor the others (Iron Age 7%, Medieval 6%, Kazakh 11%) (see Table 4.2).

On the other side an advantage of referring to diagnostic artefacts is that in some cases they can provide better temporal resolution. This happens for the diagnostics of the Bronze Age pointing to sub-periods and, by being predominantly dated to the Late or Final Bronze, indicates those phases as the ones concerned by largest wave of Bronze Age colonization of the delta.

Assemblages by Loci and Periods The statistical analysis of the ratio of chronological assemblages by zone and period provides precious information about the privileged human habitats during particular phases, under different climate, hydrological regimes and socio-economical scenarios.

In general, zonal and local assemblages include artifacts of different periods and in different ratios, but some sites are characterized by a *dominant* chronological assemblage representing $\geq$50% of the total finds. 6 out of 11 zones follow that category:

[9]For decreasing potential arbitrary attribution, the chronology of collected artifacts was cross-checked by A. Goryachev and K. Dubyagin, archaeologists of the Margulan Institute of Archaeology of Almaty.

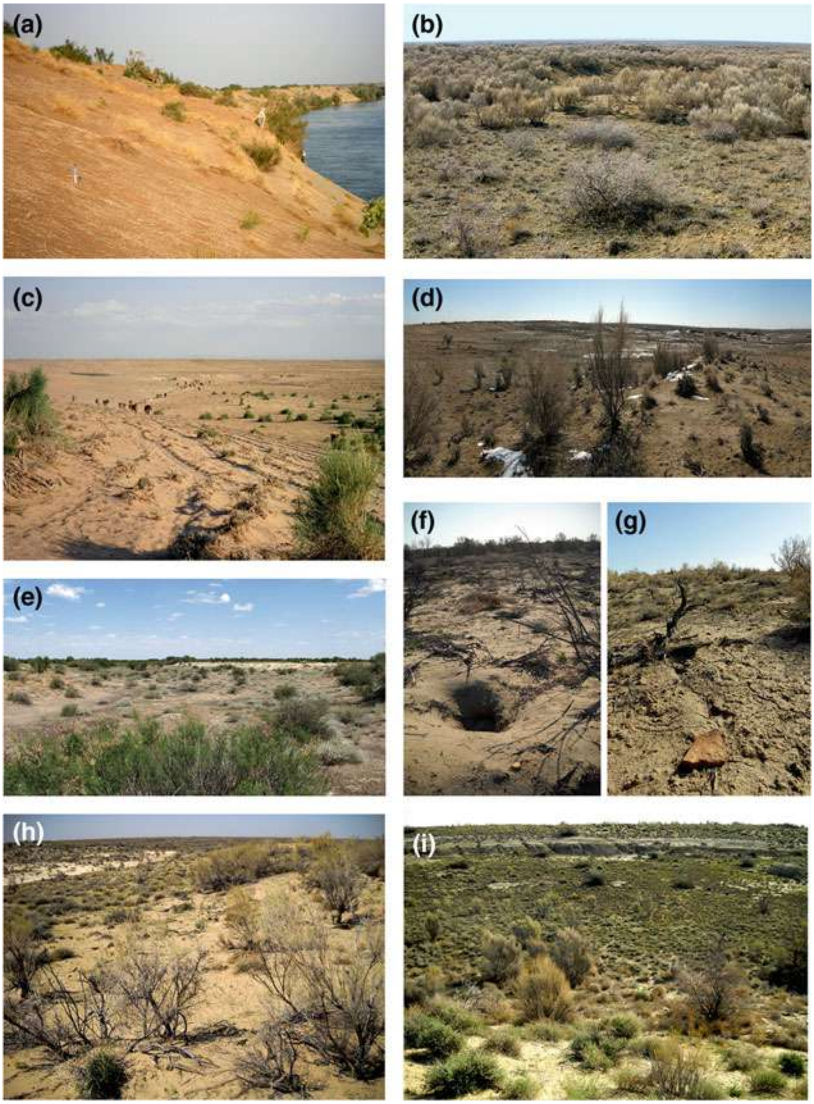

Photo 4.1 View of loci with surface finds in 6 zones representative of the Ili paleo-delta system. **a** Right terrace of the modern Ili river (Z-1.1); **b** Akdala delta head (Z-1.2); **c** Paleo-Ili relict course at Birlik-N (Z-1.3); **d** Bakbakty delta head (Z-1.4); **e** Bakanas delta head in the upper Orta Bakanas (Z-2.1); **f** surface sherd uplifted by great gerbil from burrow; **g** surface sherd at the border of takyr depression; **h** dune ridge stretching NW-SE vegetated by saxaul trees in the Naryn branch (Z-3.1); **i** dry bed of the Naryn paleocourse seen from its western terrace (Z-3.1)

- the Bronze period assemblage is dominant by 100% in the Akdala delta head (Z-1.2), by 57% in mid-Naryn paleo-course (Z-3.1) and by 52% in low Naryn (Z-3.2).
- the Early Iron assemblage is dominant by 50% on the right bank of the upper Ili course (Z-1.1) and by 56% in the upper Orta Bakanas (Z-2.1).
- the Medieval assemblage is dominant in final Naryn (Z-3.3) (Table 4.2).

Quite interesting is the distribution of microliths, which can refer to the Pre-Bronze or Bronze periods. They are mainly found in the upper part of the delta system: the highest number of Pre-Bronze types (11) along the Upper-Ili course (Z-1.1); Bronze types in the Mid-Akadala (Z-1.5) where 9 pieces represent 59% of the local assemblage, and in the Low-Akadala (Z-1.6) where 33 pieces represent 25%.

4.4.2 Research Results

4.4.2.1 Spatial Distribution and Density of Finds

Concerning the number of cultural findings by region, the densest is by far the Naryn-mid-low region including almost half of the total documented loci and more than half of all finds. In general the loci of the middle and lower delta system are more concentrated and include more finds than the loci at the delta heads.

4.4.2.2 Classification of Findings by Type, Area and Chronology

99% of all finds (1331) consist of potsherds [1245 (93.5%)] and stone tools (microliths) [75 (5.6%)]: together they count 1320 pieces providing the data base for statistical analyses. The remaining 11 pieces (1%) consist of iron and copper slag (along the Naryn), metal objects (copper bead, copper leaf, iron hanger, crushed iron), and grinder and whetstone (probably Iron Age), adding some qualitative information (Fig. 4.3).

The chronology of the inventoried material spans from Eneolithic (turn of the IV to III millennium BC) to the ethnographic period (200 BP), evidencing the use of the full extent of the delta from the earliest periods. The most numerous are samples attributed to the Bronze Age (45% of total finds), followed by Early Iron (36%), Medieval (12%), Ethnographic (1%). Tables 4.1 and 4.2 present the systematization of all collected data by zone and period.

Microliths

Most of the lithic material consists of small cores, tools (blades, scrapers, notches, knives) and spalls made of chalcedony, agate, flint, jasper and fossil wood. Lacking laminar and geometrical forms typical of the Neolithic, they could be attributed to both the Eneolithic and Bronze periods, being that in Semirechie and Central Kazakhstan such items are commonly found in the cultural layers and surface sur-

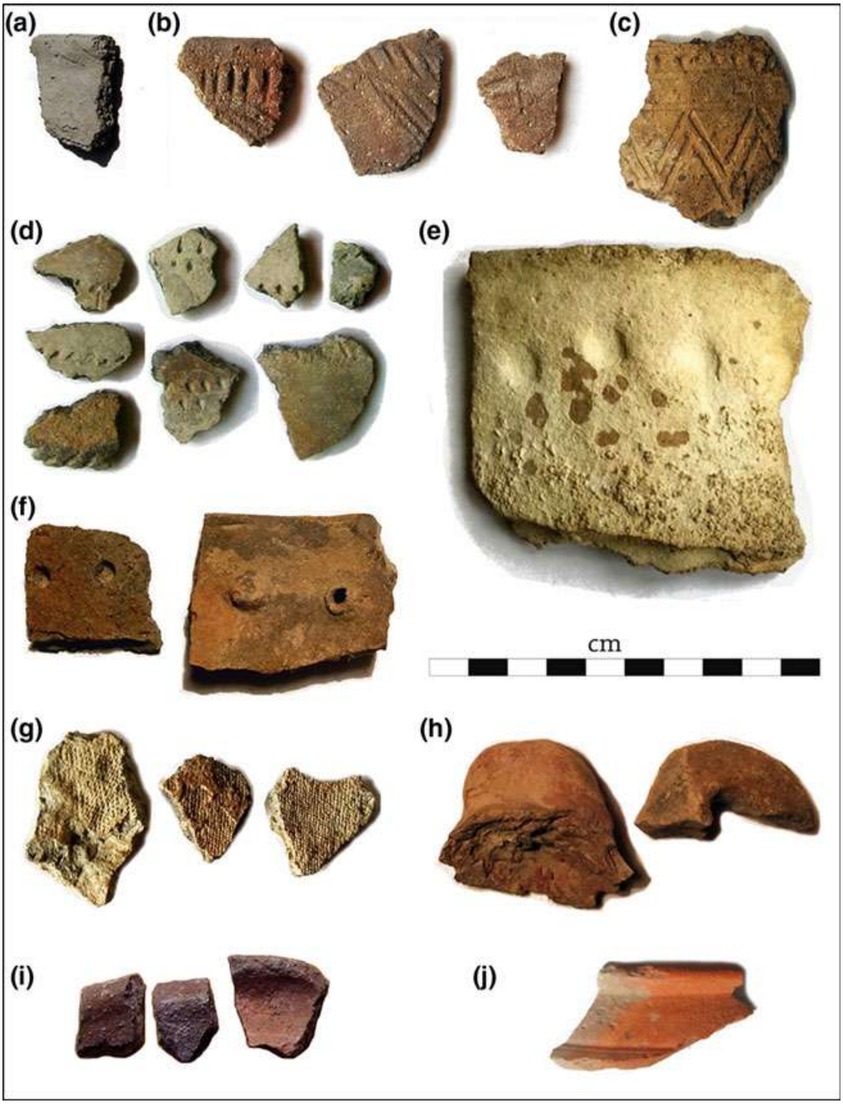

Photo 4.2 Diagnostic sherds. **a**–**e** Mid-Late Bronze Age ornamented sherds (**a**—Paleo-Ili Z-1.3, **b**—Naryn-mid Z-3.1, **c**—Naryn-mid Z-3.1, **d**—Mid-Naryn-mid Z-3.1, **e**—Ili upper right bank Z-1.1), **f** final Bronze applied 'pearl' ornament (Naryn-low Z-3.2), **g** bronze Age with textile mold imprint (Naryn-low Z-3.2), **h** iron age tabbed and disk-shaped lug handles (Naryn-low Z-3.2), **i** medieval rims and bottom (Naryn-mid Z-3.1), **j** ethnographic neck (Naryn-upper Z-2.2)

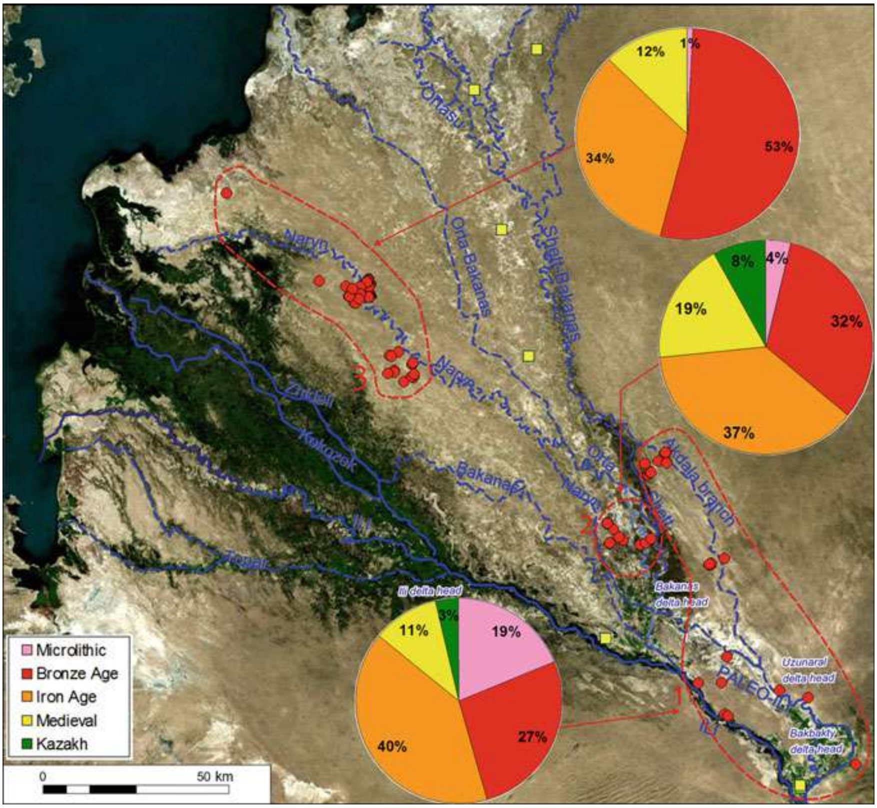

Fig. 4.3 Map and chronological distribution of findings by region (Bing map, 2011)

roundings of Bronze Age settlements.[10] A 20% of roughly flaked tools, some made of porphyry, collected on the right terraces of the modern Ili river, could belong to a pre-Bronze period.[11]

Microliths have been found in all regions, with highest occurrence in the upper parts of the paleo-deltas, nearer to the mountains: in the Akdala and Bakbakty delta heads (Z-1.2, 1.4) (44% of the microlithic collection), on the terraces of the Paleo-Ili in Birlik (Z-1.3) (15%), and in the very dry mid-Akdala branch (Z-1.5) where they constitute up to 56% of the zonal assemblage.

[10]The presence of microliths according to some authors is associated with pre- and early Bronze Age layers and disappears with the second millennium BC; but, according to others, it continues till the end of the Final Bronze Age (A. Goryachev, personal communication).

[11]Stone tools made of porphyry are characteristic of the Upper Paleolithic sites of the Tienshan foothills like Maibulak (Taimagambetov 2009).

Potsherds

The *Bronze Age* is the period most represented, with 45% of the total potsherd finds. These are most abundant in the mid-low Naryn (Z-3.1, 3.2) (80% of the total Bronze Age count) and most scarce in the Bakanas delta head (Z-2.1, 2.2) (4%). The highest occurrence of Bronze Age material within the zonal assemblage is found in the Akdala delta head (Z-1.2) (100%), in the Mid-Naryn (Z-3.1) (57%) followed by the Low Naryn (Z-3.2) (52%).

Bronze Age sherds consist of fragments of handmade (molded, slab joined) coarseware with thick walls, gray and reddish paste with high sand inclusion and generally belonging to open forms (pot or jar shaped) characteristic of the Andronovo and Final Bronze potteries of Semirechie. Diagnostic sherds constitute 28% of the Bronze Age material. Half of them (14%) provide morphological information, the other half are sherds with fabric impressions (7%) or ornaments (7%) consisting of incised patterns (1/3) or applied 'pearls' (2/3).

Among the fragments with incised patterns, some are found almost identical in stratified layers in the Semirechie region dated by absolute chronology. Pieces with bands of striated triangles carved on the neck (Photo 4.2b) and with a crest-shaped groove and nail incisions (Photo 4.2d) are found in the second Bronze Age layer of the settlement Turgen II in the upper Turgen valley (2.285 m asl, 70 km east of Almaty) dated by 14C (fireplace) to the XVIII–XVI centuries BC (Gass and Goryachev 2016). Although, on the basis of Late Bronze finds in the same (very disturbed) layer, A. Goryachev would prefer to date such potsherds to the end of the Late Bronze, at the turn of the XIII–XI centuries BC (Goryachev 2013).

Another fragment with zigzag double line and nail incisions around the rim (Photo 4.2c) has an almost analogical piece in the inventory of the enclosure 8 of Bylkyldak I in the Upper Atasu river valley (Margulan et al. 1966), which constitutes one of the typical mixed Alakul-Federovo monuments dated to the first half of the II millennium[12] (Molodin et al. 2014). The fragment is also similar to potteries from the enclosure I of the Tamgaly I cemetery dated by ESR (pot sediments) to the XIII century BC (Rogozhinskii 1999).

The other, prevailing, group of ornamented sherds consists of applied 'pearl' ornaments or holes around the neck (Photo 4.2f), which in the Semirechie inventory are typical for the Late-Final Bronze period. This decoration typifies the Begazy-Dandybay and Dongal cultures met in the pre-Iron Age layers in numerous sites of the region (settlements Turgen II, Butakty, Oi-Jailau, Tasbas, Tamgaly I, Begash) and radiometrically dated to the XIV–IX centuries BC (Doumani 2014).

Iron Age potsherds are materially different from the previous period by being less coarse, fired at higher temperature, generally thinner and smoother, of predominant orange color, with a wider variety of sizes and forms, often provided with handles,

[12] Although this emblematic Atasu monument still lacks radiometric data, a neighbor burial of the next cultural phase (Begazy-Dandybay) has recently been absolutely dated to the XV–XIII centuries BC (Beisenov 2015).

and with much rarer decoration. They are found in clusters together with the Bronze Age finds, witnessing continuity of habitats between the two periods.

Iron Age material is slightly less represented than Bronze Age material (36% of the total) and found in all zones. By number it is more abundant downstream, but in lesser number than Bronze Age and constituting 35% of all finds of the area; and then closer to delta heads [mainly on the Ili-upper right bank (Z-1.1) and in the upper Orta-Bakanas-upper (Z-2.1)] where it exceeds by number Bronze Age items constituting respectively 51% and 56% of the zonal assemblage.[13]

Iron Age diagnostic sherds are characterized by more morphological features like handles and spouts, quasi absence of ornament (single case of red slip ware), and by textile imprints (11 out of 52 imprinted sherds).

Medieval potsherds are 4 times less abundant than Bronze Age material, although found in all zones, with highest count in the low (44%) and middle Naryn (18%) (Z-3.2, 3.1) and the highest percentage of the zonal assemblage in the Naryn estuary (Z-3.3) (61%) and in the upper Orta Bakanas (Z-2.1) (56%). They are generally found (not always exposed by rodents) on the surface and borders of takyrs (claypan), pointing to new strategies of land and water use; and less on terraces of recently desiccated river branches.

The manufacture of Medieval potsherds carry information about sub-periods. No potsherds dated to the early Turkic period have been identified during our surveys. Characteristic pieces of the Karakhanid period (IX–XII centuries AD) may represent the only medieval demographic peak in the delta, contemporary with the building of a longitudinal network of forts along the Ortasu paleocourse. No trace of post-Mongol occupation has been found. The data quoted above may indicate that during Medieval times habitation was concentrated between piedmonts and alpine pastures, with the delta mainly used as a way station on interregional roads.

Ethnographic (Late Medieval, last 4 centuries) Kalmyk and Kazakh materials dated to the XVII–XIX centuries AD represent a small 1.4% of the finds, with the highest percentage of the zonal assemblage in the Mid-Akdala (Z-1.5) (31%). This was a pluvial period, when the main delta switched to its modern location and as most probably did human habitats, in areas still unexplored to the west of our research polygon.

Slag

Few samples of slag from iron and copper ore are found in 3 zones of the Bakanas delta: at the delta head and in the middle and lower course of the Naryn distributary (Z-3.1, 3.2, 3.3). Slag and a smelting workshop have been recorded in the southeastern outwalls of the medieval fort of Aktam and around the northernmost fort of Barkhan (Baipakov 1998).

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[13] In the upper Orta-Bakanas (Z-2.1) have been collected just 10 pieces of Early Iron potsherds that anyhow constitute the majority of the total 18 finds.

Similar copper slag has been found and studied by geologists at the eastern edge of the Saryesik-Atyrau desert, on the western bank of the Karatal river (Miroshnichenko and Tetryakov 1962). Due to concomitant surface occurrence of Bronze potsherds, both authors link the findings to some Bronze Age campsites found in the area. Their slag analyses revealed a mineral content similar, although specific, to the content found in the major copper deposits at the north (Kungrad, Sayak, Aktogai) and south (Malaisary, Altyn-Emel, Tekeli) of the Balkhash-West Jungar metallogenic belt.

The abundance of fuel—mainly saxaul bushes—might have played a major role in the use of the delta as a favored smelting workshop for metal ore mined in the mountain zone or even on the northern bank of the Balkhash lake.

Other Metal and Stone Objects

In the lower Akdala branch (Z-1.6), in a locus assemblage including a diagnostic Bronze Age sherd, a copper bead (1.1 cm diam.) was found (Photo 4.3g) which is characteristic for the Bronze Age layers of Semirechie (Gass and Goryachev 2016). And in two different loci of the Lower Naryn (Z-3.3) a round copper foil (5 × 5 cm) and a dozen of fairly corroded iron fragments (average of 2.5 cm) were found that are difficult to assign chronologically.

On the right bank of the upper Ili (Z-1.1) a hook-shaped iron accessory (3.5 cm length) looking like a belt hanger and a piece of iron (5 × 3.5 cm) resembling a cauldron fragment were collected. Both iron artifacts, being only superficially corroded, have been dated to the ethnographic period.

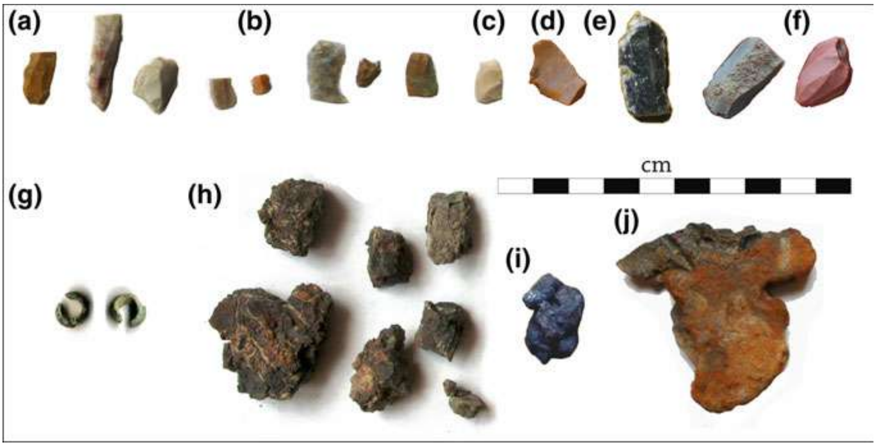

Photo 4.3 Stone and metal finds. **a**–**f** Microliths (**a** Akdala-head Z-1.2, **b**–**c** Akdala-low Z-1.6, **d** Naryn-upper Z-2.2, **e** Naryn-mid Z-3.1, **f** Naryn-low Z-3.2), **g** copper bead (recto-verso, Akdala-low Z-1.6), **h** iron slag (Naryn-upper Z-2.2), **i** iron or copper slag (Naryn-mid Z-3.1), **j** iron slag (Naryn-low Z-3.2)

Among the stone artifacts, fragments of a crescent shaped grinder (10 × 4 cm) and of a triangular whetstone (4.2 × 2 cm), both made from sandstone, were recorded in the Low Naryn (Z-3.2). They have been dated to the Iron Age by analogy to similar artifacts typical for that period in Semirechie.

4.5 Conclusions

The exposed results lead us to discuss the correlation between climate phases, hydrological events and distribution of artefacts and habitats within the central part of the Ili delta system. In that way we will propose a preliminary reconstruction of the process of early human colonization and subsequent historical development in the region.

In arid zones like the Pre-Balkhash region, the evolution of both delta distributaries and human groups largely depends from water availability and climate. Among the climate variables, determinant is the fluctuation of the amount of precipitation, which alternates pluvial and arid phases.

In Central Asia as a whole and in particular in South Kazakhstan, average precipitation values before and after 3000 BP grew from about 280 mm per year to 310 mm per year in average. Most arid phases are detected at 4.6–3.8, 3.3–3.0 and 0.8–1.0 ka BP, followed by 3 pluvial phases (Fig. 4.4). The shift from the Uzunaral to the Bakanas paleodelta (with the activation of upper Ili river course and of the Naryn delta distributary) happens around 4000 BP, and the shift from the Bakanas to the modern Ili delta at 700 BP. Both events are situated at the transition from an arid to a pluvial phase.

The process of colonization of the Ili delta performed in two stages, before and after 2000 BC. It might have started during the transition between the Eneolithic and early Bronze period on the upper part of the delta system (Paleo-Ili river segment and upper distributaries of the most ancient deltas, Z-1.2, 1.3, 1.4) as witnessed by the presence of numerous microliths and very fragmented and abraded undecorated sherds. Following the activation of the Bakanas delta around 2000 BC, colonization spread all along the newly active delta distributaries, in particular the upper and lower Naryn course (Z.3.1, 3.2), becoming predominant in the lower reaches.

Protagonists of the first phase could have been groups of hunter-fishermen and early shepherds, possibly semi-settled in niches of the upper course. The settlers of the second phase (to which the bulk of the Bronze Age sherds is attributed) were groups already acquainted with seasonal transhumances between summer camps in mountain meadows, autumn and spring transitions across piedmonts, and winter camps in the green alluvial plains of the lower part of the delta system. In addition, the presence of permanent settlements and irrigated fields is not excluded. Clear evidences of farming activities with the cultivation of barley, wheat, millet and green peas dated to the second millennium BC have been documented in the mountain meadows of Tasbas (in the Djungarian Alatau, 200 km east of the delta head) (Spengler et al. 2014).

The finding of copper and bronze slag on the western terraces of the Karatal river and around medieval habitats in the central part of the paleodelta testifies the dual activity of such groups, as herder-miners exploiting the summer pastures and mines of the mountain zone and as shepherd-metallurgists using the winter grasses and fuel of the lower delta.

The Bronze Age as a whole (due to its length) and, in particular, the Naryn course (due to its long endurance as first active Bakanas distributary), shows the largest density of cultural remains and human habitats among all the periods and areas under study.

Starting from the first half of the first millennium BC until the turn of our era, there is a rise in precipitation and river flow, and the pastoralist and metallurgist patterns of the former millennium adapt to new very mobile animal assemblages (sheep and horse) and to iron ore. The number of surface artefacts attributed to that Early Iron period is slightly less than the preceding one and their distribution favors the upper regions of the deltas.

We are faced with difficulties explaining why from the start of our era until the Medieval Warm Period (MWP), the number of cultural remains suddenly drops to a third of the Iron Age, pointing to a diminution of human presence in the delta region, in particular in the upper reaches of the deltas. The causes can be variously attributed to economical or climatic factors, probably concomitant: the development in the piedmont area of mixed-farming activities, allowing for demographic concentration and a more settled way of life in these areas; or to climate conditions that reduced the desert biomass or at the contrary and more probably, made it inaccessible by excessive snow cover.

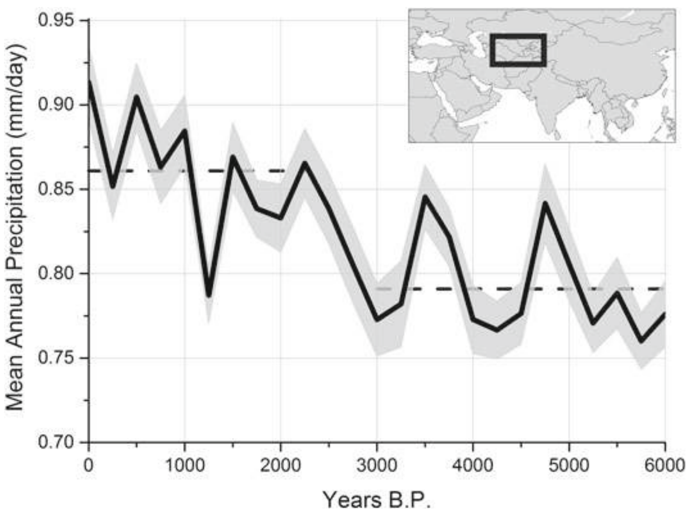

Fig. 4.4 Evolution of precipitation values (mm/year) in West Central Asia during the last 6 ka (Hill 2019)

Certainly the lower reaches of the deltas are again populated, both by camps and interregional caravan routes, during the MWP (900–1200 AD), i.e. at the peak of urbanization of the piedmonts under Karakhanid rule, to which are attributed most of the medieval cultural findings.

The delta seems to be again abandoned in the Post-Mongol period, in spite of the total dismantlement of the urban complexes of the entire Semirechie region and the pastoral conversion that followed. But now such event can find a simple explanation in the decreasing use by a part of the new pastoralist groups of Semirechie, from the XIII century AD to the Kalmyk colonization of the XVIII century AD, of ceramic wares that represent the main markers of our spatiotemporal analysis.

Following the first ethnographic accounts concerning the XVIII century AD, we find again in the delta a complex and detailed scenario of very mobile transhumant stratified pastoralist clans and farming groups of different ethnic attribution: Kazakh, Kalmyk, Jalair etc. Their environmental context is also quite mobile and changeable: the Bakanas delta is at that time desiccated and the modern Ili delta starts its geological evolution.

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Chapter 5
Quantitative Evaluation of the Impact on Aral Sea Levels by Anthropogenic Water Withdrawal and Syr Darya Course Diversion During the Medieval Period (1.0–0.8 ka BP)

Renato Sala

Abstract Paleo-climatic, environmental, archaeological studies and historical accounts concerning the behavior of the Aral Sea during the last 2000 years point to a number of water level regressions similar or deeper than the modern one. This article is focused on the causes of such regressions, which are variously attributed to climatic change, diversion of river courses and anthropogenic water withdrawal. The first factor has been researched by several geo-specialists and its potential impact has been preliminarily evaluated. The second factor has been considered only in the case of the Amu Darya river. The third factor—water withdrawal for irrigation purposes—has been hypothesized, though never deserved specific analysis. The article provides a quantitative evaluation of the total hectares covered by the medieval urban systems of the Syr Darya and Amu Darya river basins, and of the coefficient of water use per hectare of walled towns during the X-XII centuries AD. Estimates of annual volumes of anthropogenic water withdrawal allow the investigation of the complex interaction of the three factors above in determining the hydrological conditions of the Aral Sea. On the basis of the calculation of possible scenarios of water mass balance, the occurrence of transmission losses by medieval diversions of the Syr Darya course has been suspected as the main cause of lake regressions, which is supported by geological considerations, archaeological data and historical accounts.

Keywords Aral Sea · Lake water level change · Water subtraction
Medieval urbanization · Syr Darya course diversion

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5.1 Introduction

Tectonic depression at the modern Aral Sea and Sarykamysh basins formed during the Neogene final stage of the Tethys paleo-ocean evolution. From the Middle Pliocene to the start of the Pleistocene the depression was filled up to +73 m a.s.l. by the Akchagyl and Apsheron transgressions of the Caspian Sea; and, during the Pleistocene, it entered a continental phase characterized by a local erosional river network and shallow saline lakes.[1]

The Aral Sea depression started hosting a small lake around 140 ka BP when reached by the Syr Darya river, and a lake similar to the Aral Sea of year 1960 (Aral-1960[2]) only during the post-glacial period as soon as reached by both the Syr Darya and Amu Darya courses. The modern history of the Aral Sea begins with the Holocene, always concerned by water level fluctuations of high amplitude, with regressions down to total disappearance and transgressions up to 54–56 m a.s.l.,[3] forced by climate change and/or by diversion of river courses. Most significant are switches of the Amu Darya course between the Aral Sea and Sarykamysh basins. (Berg 1908; Maev et al. 1983; Mamedov 1991; Micklin et al. 2014; Sects. 3 and 5)

Accordingly, the reconstruction of the multi-millennial behavior of the Aral Sea requires the consideration of geological events (climate changes and deviations of river courses out of tectonic and sedimentary activity) happening in both the Aral Sea and Sarykamysh basins. Starting from VI century BC,[4] must be kept into account also the anthropogenic water withdrawal from the Amu Darya and Syr Darya rivers (Fig. 5.1).

By the end of the article it will be clear that, in order to reconstruct the historical evolution of the Aral Sea water volumes, such consideration must be extended to all the existing and *highly variable evapo-transpiration spots of the complex hydrology of the Aral Sea basin, inclusive of lakes, lakelets, marshes and…irrigated fields*.

5.2 Regressions of the Aral Sea During the Last 2000 Years

5.2.1 Modern Crisis and Parameters of the Aral Sea and Its Feeding Syr Darya and Amu Darya Rivers

In 1960 the Aral Sea is characterized by high water level stand: an average water volume of 1083 km^3, water surface 67,000 km^2, evaporation 63 km^3

[1] About the tectonic and sedimentary processes driving the geological history of the Aral Sea basin, see: Kes and Klyukanova (1999); Letolle and Mainguet (2003).

[2] In this article, when considering the Aral Sea conditions in a specific year (for example year 1960), the lake will be shortly referred as Aral-1960.

[3] This is the altitude of the divide between the Aral Sea and Sarykamysh basins.

[4] In the present article, centuries will be referred by roman numerals (VI century BC = VI BC) and years by Arabic numerals (1890 year AD = 1890 AD).

Fig. 5.1 The Aral Sea basin in 1960

(940 mm/year), input +63 km^3 [net[5] river inflow 53 km^3 + local precipitation 8.9 km^3 (133 mm/year) + groundwater-infiltration balance +1–2 km^3 (inflow +2–3 km^3, infiltration −1–2 km^3)], water level at +53 m a.s.l. (with lake bottom at −13 m a.s.l., max water depth of 69 m and average depth of 16 m) and coastal salinity 10 g/l. Within the basin the total runoff totaled 114 km^3, irrigated area 4.7×10^6 ha, and annual water withdrawal 61 km^3 (Fig. 5.2).

During the following 50 years, the number of people living in the basin grew by four times, the irrigated area almost doubled to 8×10^6 ha and so did the water withdrawal up to 105 km^3, causing a progressive reduction of annual river inflow that by 2007–2012 dropped to less than 10 km^3, accompanied by a correspondent

[5]River inflow decreased by 8–10 km^3 of water losses in the deltas.

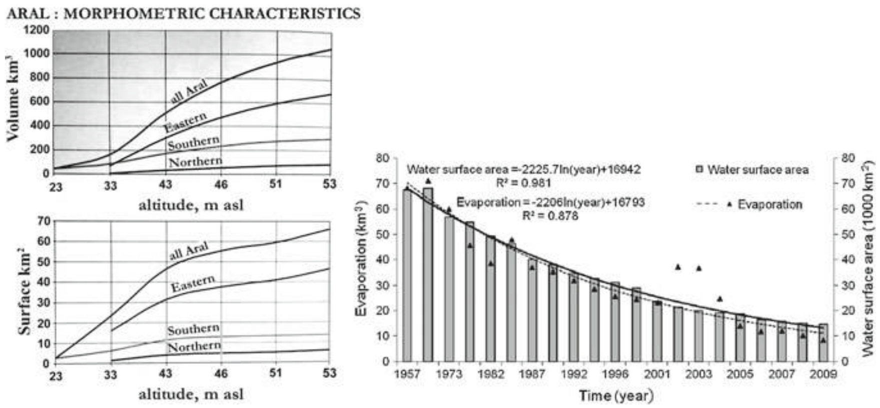

Fig. 5.2 Left: Aral Sea morphometry (*source* Nazionalnyi Atlas Respubliki KZ 2010). Right: evolution of water surface and evaporation volumes, 1957–2009 (*source* Gaybullaev and Chen 2012)

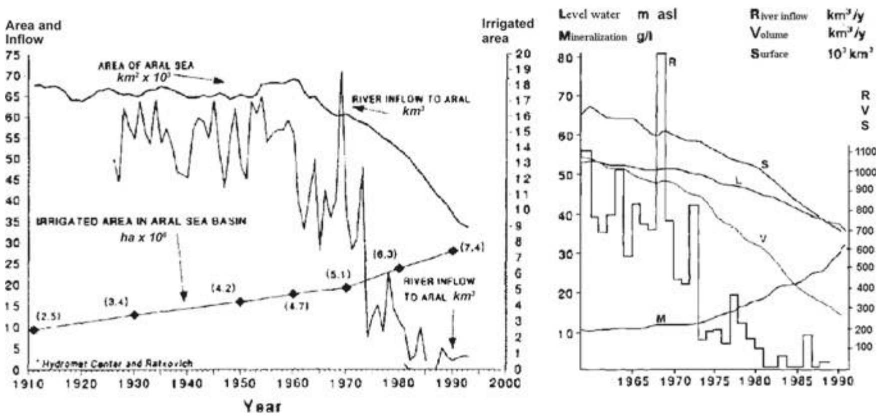

Fig. 5.3 Aral Sea. Left: evolution of water surface, river inflow and irrigated area within the basin (1910–2000) (*source* Micklin and Williams 1996). Right: water volume and mineralization from 1960 to 1990 AD (*source* http://archive.unu.edu/unupress/unupbooks/uu14re/uu14re0a.htm)

huge contraction of the lake water volume (down to 70 km^3) and surface (down to 8000 km^2) (Fig. 5.3).

During the years 2003–2008 the regression trend crossed two topographic thresholds, making the Aral Sea disappearing, first divided into two (Lesser and Greater) and then into three basins: Northern, Eastern and Southern. The northern (Northern Aral Sea, abbr. NAS) and the southeastern (Eastern Aral Sea, EAS) basins, because of infilling with sediments from the Syr Darya and Amu Darya rivers, are both quite shallow with basal elevations at +23 and +24 m a.s.l. respectively. The southwestern basin (South Aral Sea, SAS) is the deepest, with lake bottom at −11 m a.s.l..

The **NAS** is the main recipient of the Syr Darya inflow and is connected with the EAS through the Berg straight at +37 m a.s.l. In 1992, as the Aral Sea water level dropped towards +37 m a.s.l. (which would have cut off the small Aral Sea from the Syr Darya's flow completely), a dam (Kokaral dam) was built in order to catch the Syr Darya inflow, so that by 2006 the NAS water level rose to +41 m a.s.l. (water depth of 18 m).

The **EAS**, the largest basin, is the main recipient of the Amu Darya inflow and is connected to SAS through the Kulandy straight at +27–29 m a.s.l. Deprived of the Syr Darya inflow by the Kokaral dam and of the Amu Darya inflow by extreme water withdrawal, in 2009 the EAS went dry and in the following years intermittently reappeared as a salty pond.

The **SAS**, after becoming in 2006 totally isolated from the EAS and only fed by groundwater, had water levels dropping to +26 m a.s.l. (max water depth of 37 m) and salinity rising above 100 g/l.

The NAS, EAS in particular, and SAS basins are now very variable year by year: in 2017 they respectively present average water volumes of 53.5, 0.9 and 26.7 km^3 and water surfaces of 4.0, 1.0 and 3.3×10^3 km^2 ($\pm 30\%$).

Significant for the present study are some modern hydrological parameters (annual average of 2007–2012) of the Syr Darya and Amu Darya river basins given here.

Amu Darya: total surface runoff within the basin: max 97.4/min 52.8, av. 76 km^3; total irrigated area 5.09×10^6 ha; water withdrawal 72 km^3; terminal inflow 1–2 km^3.

Syr Darya: total surface runoff within the basin: max 72.5/min 18.3, av. 38 km^3; total irrigated area 3.1×10^6 ha; water withdrawal 31 km^3; terminal inflow 4–6 km^3.

As a whole, the Amu Darya has almost twice the values of the Syr Darya in terms of surface runoff, irrigated area, water withdrawal and, until 1980, of terminal inflow in the Aral Sea (in 1960, of the total 53 km^3 of river inflow into the lake, 36 km^3 came from the Amu Darya and 17 km^3 from the Syr Darya). Then, after 1980, on the account of water withdrawal, the annual terminal inflow of the two rivers decreased in different ways: the one of the Amu Darya has been almost nullified, the one of the Syr Darya was reduced to 4–5 km^3.

5.2.2 Historical Water Level Fluctuations of the Aral Sea

An unstable behavior characterized the Aral Sea throughout the Holocene. Regressions down to +24 m a.s.l. and transgressions above +55 m a.s.l. have been recorded by several authors from different disciplines: by climatologists analyzing abiotic and biotic climate and paleo-environmental proxies; by archaeologists documenting settlement patterns; and in historical sources.

Geological, climate and hydrological studies of the evolution of the Aral Sea basin during the last 2000 years have been produced by Soviet scientists such as L. Berg, A. Kes, I. Gerasimov, B. Fedorovich, E. Maev, S. Nikolaev, etc. (summarized in: Sevastyanov et al. 1991); and then have been continued by modern international specialists like P. Tarasov, P. Micklin, R. Letolle, I. Boomer, P. Sorrel, H. Oberhänsli, etc. (summarized in: Krivonogov et al. 2014).

Geomorphological data are still presenting low chronological resolution and contradictions. More robust and integrated data sets for modeling lake behavior are provided by reconstructions based on lithological, chemical and paleo-environmental analyses of proxy samples retrieved through lake coring: climate data (precipitation, seasonal evaporation and river inflow) are inferred from palynological analyses; lake water levels from analyses of abiotic (lithological and mineralogical) and biotic components (dinoflagellate cysts and diatoms) identifying salinity changes and water volumes.

In the present article the main references for paleo-climate and paleo-environmental conditions are the reports concerning the analyses of sediments from the composite core (CH2/1) retrieved in 2002 (Southern Aral Sea water level at +31 m a.s.l.) at the Chernyshov bay in the northern part of the southwestern basin (Sorrel 2006; Sorrel et al. 2006, 2007). The core is 10.79 m long with head at +9 m a.s.l. (water depth of 22 m) and base at −2 m a.s.l., representing a time span of 2000 years (Fig. 5.4).

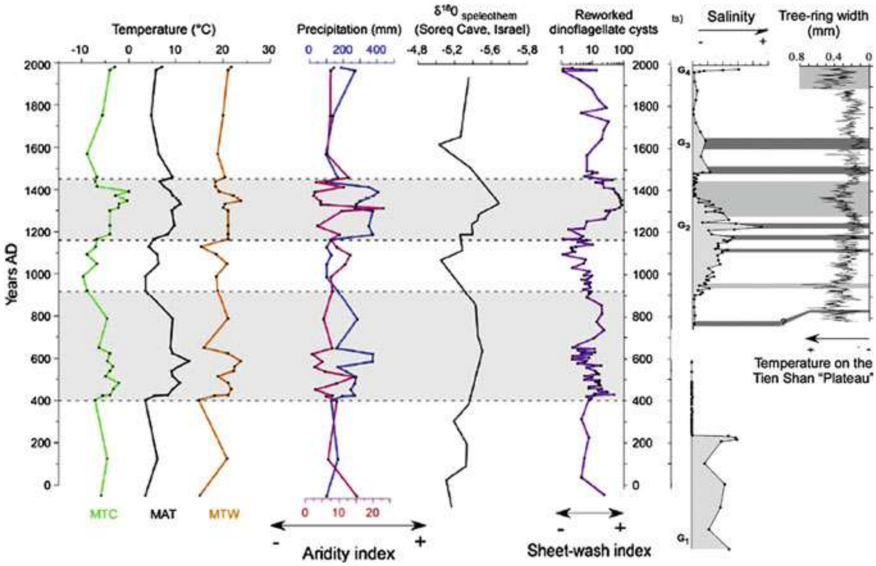

Fig. 5.4 Southern Aral-2002, Chernyshov bay, core section CH2/1: climate parameters T (MTC, MAT, MTW refer to Mean T during Coldest, Annual, and Warmest month respectively) and P, reconstructed from palynological analyses (blue line: Amaranthaceae-Chenopodiaceae; red line: Poaceae); sheet-wash index derived from relative abundance of reworked dinoflagellate cysts; salinity level estimated from relative abundance of L. machaerophorum. Grey shadings represent periods of increased T and P. Sheet-wash index directly points to water levels: low levels are documented at 2.1–0.6, 1.1–0.7, 0.6–0.4, 0.3 and 0.05–0 cal ka BP (*source* Sorrel et al. (2006, 2007). Tree ring record from Tienshan plateau (*source* Esper et al. 2002)

Archaeological surveys of monuments along the lake shore and river delta distributaries began in Soviet times with the works of S. P. Tolstov and continued after perestroika. They provide information about building and abandonment phases and, indirectly, about local paleo-hydrological conditions. Most significant has been the recent discovery of the Kerderi settlement dated to the XIII - early XIV AD, located at +34 m a.s.l. on the NE part of the Aral Sea evidencing a water level regression below +31 m a.s.l. (i.e. the water level of Aral-2002),[6] and the detection of a synchronic phase of inundation of the Sarykamysh lake (Boroffka et al. 2006; Boroffka 2010).

Accounts on the part of medieval Muslim geographers and historians are even more dramatic, quoting the disappearance of the Aral Sea at 1417 AD due to diversions in both the Amu Darya and the Syr Darya courses.[7]

Concerning the last 2000 years there is good agreement among authors in detecting four periods of relevant low lake level stands at: 0–400, 900–1230 (Medieval Warm Period), 1400–1650, and after 1960 AD. The first regression at 0–400 AD, which left peat layers at +10 m a.s.l. in the central part of the SAS lake, has been the most relevant; the second ended at 1250 AD with what seems to be an abrupt short event more extreme than modern, i.e. lake level stands below +26 m a.s.l.; and around 1400 AD the lake level dropped below +31 m a.s.l. Lesser regressions are suspected at 600 and 1800 AD. Regressions are intercalated by transgressive phases at 400–550, 650–900 and 1230–1400 AD.[8] (Boomer et al. 2009) (Fig. 5.5).

Figure 5.6 shows the tentative reconstruction of the evolution of Aral Sea water levels during the last 2000 years by synthesizing and attuning data from several sources and authors, in particular synoptic reconstructions of Aral Sea lake level changes (Boomer et al. 2009; Krivonogov et al. 2014). Lake level trends are compared with temperature and precipitation values from Sorrel et al. (2007).

T and P trends evolve in direct correlation (T amplitude between 4 and 12 °C, P between 100 and 400 mm/y) at the exception of the IX–XII and XVI–XVIII AD intervals where are diverging or converging.

Lake levels are characterized by a long regressive trend between 100 BC and 1600 AD, accompanied by fluctuations only partly correlated with climate, i.e. showing regressions in coincidence with T+P+ and transgressions with T+P−. The regressions in particular present most anomalous characters, witnessing the action of forcing factors other than climate: the strong regression culminating in 400 AD is correlated

[6]In proximity of the Kerderi settlement, satellite images show traces of a paleo-distributary of the Syr Darya delta flowing down to +30 m a.s.l., 100 km west from the shore of Aral-1960 (Krivonogov 2009).

[7]Hafızi-Abru, geographer at the Timurid court of Shah Rokh, in 1417 AD writes about the disappearance of the Aral Sea, which attributes to the diversion of both the Syr Darya and Amu Darya flow into the Caspian Sea (Tolstov 1948, 285). This account has been overseen by L.S. Berg and V. Barthold but hastily considered an overstatement (Krivonogov 2009).

[8]These transgressions are documented by the stratigraphy of shore sediments of the Karaumbet outcrop and the chronology of the Pulzhai settlement in the Aibugir Bay at the SW corner of the lake (Krivonogov et al. 2010, 560) and by the relative abundance of dinoflagellate cysts and freshwater algae from the Chernyshov Bay Core CH2/1 (Sorrel et al. 2007).

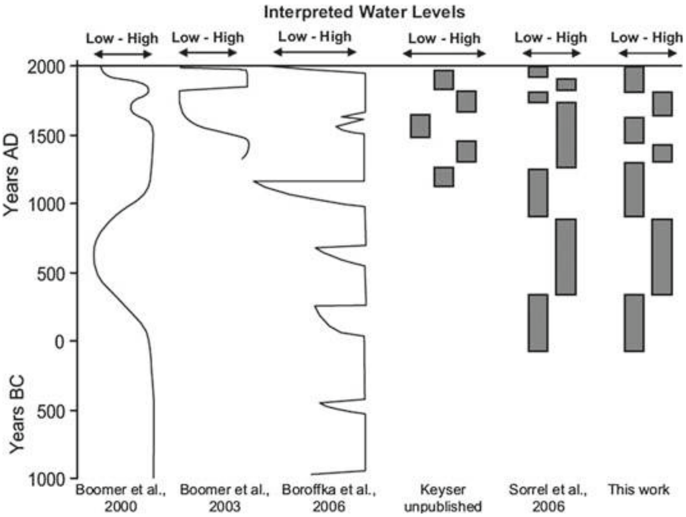

Fig. 5.5 Aral Sea: reconstructions of water level transgressions and regressions during the last 3000 years by different authors (*source* Boomer et al. 2009). The unpublished evaluation of Dietmar Keyser is based on ostracods analyses of two short cores from the Tschebas Bay (Boomer et al. 2009, 82)

with relatively stable T and P trends; the regressions of 1250 and 1300–1450 AD are anomalously related with high T and P values and remarkable by their extreme and abrupt character intercalated by relevant transgressions.

5.2.3 *Causes*

The above reconstruction, like any existing reconstruction of the multi-millennial behavior of the Aral Sea, is preliminary and must be continuously updated by new data. But even more controversial is the determination of the causes of the Aral Sea behavior, and of their interaction within a dynamic model, which constitutes the main subject of this article. The task is made difficult by the lack of data and by the entanglement of several events in the backdrop of the hydrology of the Aral Sea basin, in particular the complex and changeable behavior of tributary rivers exposed to transmission losses by natural and anthropogenic water subtraction.

Extreme Aral Sea regressions have been variously attributed to three different (and certainly concomitant) driving factors: climate change, river course diversion, anthropogenic water withdrawal. During the last 2000 years these three factors are most often acting together, with relative impact varying at different times. Each factor by itself may be able to induce a severe regression: annual precipitation can drop to less than 50 mm (1/3 of the average value) for prolonged periods (which mainly happens during cool phases but occasionally can coincide with rising temperature, like in 900–1200 and 1400–1550 AD), reducing the glacial and nival deposits that

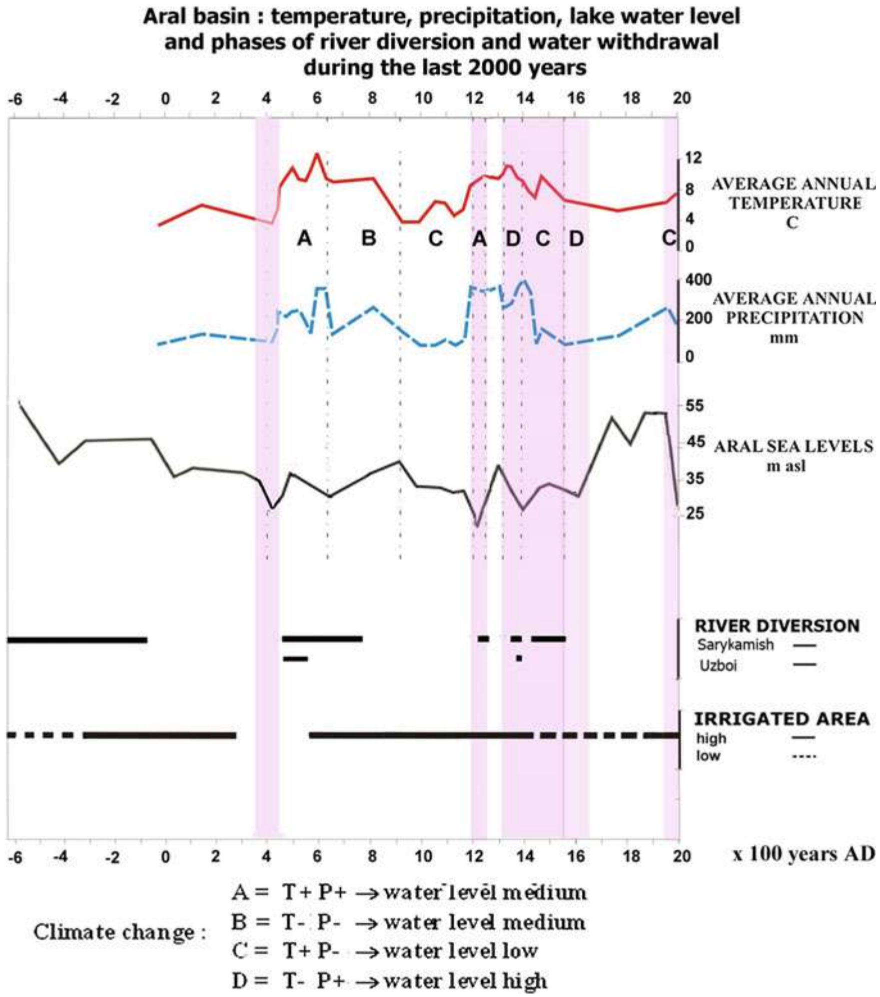

Fig. 5.6 Correlation of temperature, precipitation, lake water levels and phases of river course diversion and anthropogenic water withdrawal during the last 2600 years. A, B, C, D classify four types of climate changes and their potential impact on lake levels. Marked bands: periods of climatically anomalous water level fluctuations. T and P trends adapted from Sorrel et al. (2007); Aral Sea water levels elaborated by R. Sala by synopsis of different sources

constitute the main source of the river runoff; the diversion of the Amu Darya course can be almost total, lowering the river inflow by more than 50%, and relevant diversions probably happen also in the Syr Darya (see below Sect. 5.2); the increasing water withdrawal of the last 60 years has in itself been the determinant cause of the modern disappearance of the Aral Sea.

5.2.3.1 Climate Change to Very Arid Conditions

Climatologists and paleo-environmentalists who detected the severe Aral Sea regressions of the last 2000 years tend to underline their coincidence with negative NAO phases weakening westerly winds and precipitation (Sorrel et al. 2007; Hill 2017). Synchronous with these phases is the establishment of a series of events that all together point to global atmospheric teleconnections: palynological dry phases in the Aral Sea region at 900–1150 and 1450–1550 AD; decreasing tree ring width in the Tienshan and Pamirs ranges (sources of the almost totality of the rivers' runoff) at 1250, 1400, 1500 AD (Fig. 5.4); similar water level fluctuations in other Central Asian lakes like the Balkhash, Issykul, Bosten, etc. (Chen et al. 2008; Endo et al. 2012); and drought in the Near East.

All the above cases seem related to low P values, but the forcing effect of cold phases must be also considered. The regression of the 1450–1650 AD coincides the Little Ice Age when lower T values contributed to the decrease of river discharges in two ways: by lessening atmospheric transport and precipitation and by enhancing ice accumulation in the Tienshan and Pamir mountains (Krivonogov 2009).

5.2.3.2 River Course Diversion

Reconstructions based on archaeological studies and historical accounts tend to explain the most extreme Aral Sea regressions by a diversion at the head of the Amu Darya delta to the west through the Daudan Darya and Darialyk (Kunya Darya) channels into the Sarykamysh basin. The channel cross-section at Daudan Darya and Daryalyk could not carry more than 20–30 km^3 per year, so that the diversion of the Amu Darya flow can never be total and a residual inflow would always reach the southern part of the Aral Sea (Letolle et al. 2007).

The Sarykamysh basin covers an area of 11,000 km^2 with the potential to accommodate, between −38 and +54 m a.s.l., a max. water volume of 250 km^3 (1/4 of Aral Sea at its max capacity at +54 m a.s.l.) exposed to annual evaporation of 11 km^3. In case the Sarykamysh lake water level would grow above +54 m a.s.l., its emissary Uzboi channel would be activated towards the Caspian Sea. The annual discharge of the Uzboi channel cannot be higher than 10 km^3 so that the eventual water excess would be diverted and dissipated in the dunes of the Zaunguz desert (northern part of the Karakum desert). Besides the Amu Darya diversion, geomorphological features indicate that the Uzboi would be activated also in case the Aral Sea would enter into extreme transgressive conditions with water levels at +54–56 m a.s.l. and merge with the Sarykamysh (Tolstov and Kes 1960; Kes and Klyukanova 1999; Letolle et al. 2007).

A longstanding filling of the Sarykamysh lake and activity of the Uzboi channel is documented between 5000 and 2000 BC by the presence of numerous Neolithic sites, after which, due to the damming of the Daryalyk channel for irrigation purposes, Uzboi water regimes started decreasing and ended around IV BC. In subsequent times, except for short abrupt events that left no geological or archaeological traces,[9] the Uzboi was never reactivated and changed into a series of ponds that could host a caravan road but could not support the establishment of large agricultural settlements (Tolstov 1948, 295; Tolstov and Kes 1960).

Amu Darya diversions continued intermittently, filling incompletely the Sarykamysh lake during III–I BC, IV–VIII AD and XIV–XV AD.[10] After VIII AD the lake never reached level stands above +8 m a.s.l. (Krivonogov et al. 2014, 297), whereupon any further diversion of the Amu Darya course would have had just an abrupt and ephemeral character supporting average Sarykamysh lake stands and evaporation losses quite similar to modern.

The Amu Darya diversions of last 2000 years, which saw the anthropogenic embankment of the western distributaries of the Amu Darya delta, were necessarily related to the destruction of dams by natural hazards or wars: undocumented flash-floods or earthquakes at 1208, 1389, 1405 AD (Melville 1980), the Hephtalite Huns invasion during 380–400 AD, the Mongol invasion at 1221 AD, the Timurid wars at 1372–1388 AD.[11]

Besides the lower course of the Amu Darya, the middle and lower course of the Syr Darya are also characterized by a very unstable watershed where sedimentary and/or technogenic factors can easily induce abrupt events of water diversion (see below Sect. 5.2). In the first half of the XIV AD the Arab geographer ibn Fadl Allah al-Omari (d. 1349) heard from oral sources that the "*Seyhun (Syr Darya) flows among reeds and sands below the city of Jend (on the Janadarya) at the distance of three days travel and here it disappears*". (Barthold 1902, 55). As quoted above (note 7), also Hafizi-Abru in the early XV AD describes the Syr Darya delta (or at least its southern branches) merging with the Amu Darya, and both rivers avoiding the Aral Sea and flowing together to the Caspian Sea (Barthold 1902; Boroffka 2010). The Timurid ruler Babur (1483–1530) in his 'Memoirs' speaks about the Djihun (Syr Darya) lost in sands far away downstream from the medieval town of Turkestan (see Sect. 5.2) (Babur 1530, 45; Crétaux et al. 2009, 285).

[9]The Persian geographer Hamdallah Kazwını in 1339 mentions the Amu Darya flowing via the Uzboi to the Khazarian (Caspian) Sea (Tolstov 1948, 285); and in 1392 Zahır-ad-dın al Maraschı describes a trip taking place by ship up the Uzboi (Boroffka 2010, 292).

[10]In 1417 AD Hafızi-Abru wrote about the disappearance of the Aral Sea (see note 7). In 1558 the English merchant and traveler A. Jenkinson, while residing in Sellizure (Vazir) on the shores of the Daryalik channel, witnesses its progressive desiccation due to upstream anthropogenic implementations: "*the water that serveth all that country is drawn by ditches out of the river Oxus, unto the great destruction of the said river, for which cause it falleth not into the Caspian Sea* (in reality the Sarykamish lake) *as it hath done in times past; and in short time all that land is like to be destroyed and to become a wilderness for want of water, when the river of Oxus shall fail*" (Jenkinson 1558). Few years later, Abu al-Ghazi (1603–1663), khan of Khiva, reported that the Amu Darya was flowing to the southwest until the 1573 after which switched its course into the Aral Sea (Tolstov 1948, 285; Boroffka 2010, 293).

[11]All authors tend attributing the Amudaya diversion events of the last 2000 years to the destruction of technogenic dams built across main distributaries of the delta. Historical sources support that hypothesis (Barthold 1902). According to general Gloukhovsky (1893), between 1310 and 1575 AD the dams and irrigation systems of the Amu Darya delta were disrupted at the point of diverting its main current into the Sarykamysh depression and further, through the Uzboi channel, into the Caspian Sea (Boroffka 2010).

5.2.3.3 Anthropogenic Water Subtraction by the Agro-Irrigational Urban Complexes of the Amu Darya and Syr Darya Basins

Concerning the anthropogenic water subtraction by the medieval urban and irrigation systems of the Syr Darya and Amu Darya basins, its possible impact is evident today in the fact that water withdrawal for irrigation purposes has been by far the main cause of the present Aral Sea desiccation; and most of the authors quoted above suspect that, from the III BC to the XX AD, it has always been a concomitant factor, together with climate and river diversion, of Aral Sea water level fluctuations.[12] Referring to historical-archaeological accounts, on the lower Amu Darya the presence of large urban systems and irrigation practices have been documented initially between 300 BC and 300 AD and then again between 600 and 1300 AD. Their presence on the Syr Darya is basically ignored.

If up to now water withdrawal has not been subject of scientific investigation and quantitative evaluation, this is due to three main reasons: absence of a database of the urban systems of West Central Asia, underestimation of their size and potential environmental impact, and lack of geoarchaeological field studies needed for elaborating coefficients of past water use.

This article tries to answer those questions and confronts the problem of the interactive effect of the three casual factors spoken above on the evolution of Aral Sea water levels, focusing on the time span of the Medieval Warm period. Research methods are explained in Sect. 3, research results in Sect. 4. Eventually the quantitative evaluation of annual anthropogenic water subtraction is sorted out, allowing a preliminary reconstruction of the complex interaction of the three forcing factors in determining the Aral Sea water levels during the Medieval Warm Period (Sect. 5).

5.3 Medieval Water Withdrawal: Research Methods

The quantitative evaluation of water withdrawal by the medieval agro-irrigational urban complexes of the Syr Darya and Amu Darya basins and of its impact on Aral Sea water volumes is a difficult task, therefore the present study proceeds through average estimates and extrapolations, leading to approximate and debatable results. The method itself is original, developing through three main steps: documentation of the size of the urban systems of the Aral Sea basin during a specific period (century); elaboration of a coefficient of water use per urban hectare in a specific

[12]"However, the degree of lake level lowering may have been amplified by humans responding to changing environmental conditions. Irrigation systems were probably extended during periods of more arid conditions" (Sorrel et al. 2007). "Therefore a similar effect as the modern one, a major regression of the Aral Sea caused by man, may be presumed especially towards the end of Antiquity, when long-term results of intensive irrigation took effect" (Boroffka 2010). "Irrigation activities were at a maximum between 300 BC and AD 300 (Classical Antiquity) and between AD 800 and 1300 (Medieval Age) and after AD 1960" (Oberhänsli et al. 2007).

region; calculation of the ratio of agro-urban annual water subtraction from the virtual runoff of the Syr Darya and Amu Darya rivers during the chosen period.

Modeling starts analyzing the agro-urban complexes of the Syr Darya basin (Sects. 4.1–4.3) and sorts out hydraulic coefficients concerning the region. Such coefficients are then extrapolated to the Amu Darya region, allowing the evaluation of the total impact of irrigational water withdrawal in the entire Aral Sea basin (Sect. 4.4). In Sect. 5 the insertion of those data within a simplified model of the Aral Sea bathimetry and water balance provides the evaluation of the Aral Sea water levels under two different scenarios, i.e. two different values of terminal river inflow, in absence or in presence of river diversion. In detail:

a. **Documentation of all the walled units of the urban systems of the Syr Darya basin**, with particular focus on their geographical location, size in hectares and chronological attribution of their occupation by century.

The database of these monuments has been elaborated by the Laboratory of Geoarchaeology of Almaty during several research seasons. It includes all the walled towns (and a few very large and visible villages) of the Syr Darya river valley, recorded in archaeological reports and in the *Svod Pamiadnikov Istorii i kulturi Respubliki Kazakhstan.*[13] Small unwalled villages are omitted, by being in general badly explored, most often undetectable, and in any case covering a relatively small total area heterogeneously in different urban regions.

b. **Selection of a particular historical period and of a particular urban region** for documenting the irrigation schemes (general structure, length and profile of canal distributaries) active in that region during that period.

As *historical period*, for this study has been selected the X century AD, due to four convenient characters: (1) it is included within the recession phase of the IX-XII AD, which ends with the extreme low water stand of the early XIII AD; (2) its climate has been evaluated as similar to modern, though slightly cooler and drier,[14] suggesting an estimate of precipitation and evaporation rates and virtual river runoff in the Aral Sea basin as 10% less than in modern times, i.e. 104 km^3, 33 km^3 in the Syr Darya basin and 71 km^3 in the Amu Darya[15]; (3) in the X AD, historical records quote the Aral Sea as receiving the entire discharge of the Amu Darya river,

[13] A large part of the urban units has also been documented by aerial photography and explored by land surveys for filling entries of environmental character. A few tens of urban structures have been discovered anew.

[14] The Sorrel reconstruction of Fig. 5.4 infers for the start of X AD average temperature values 3 °C cooler and annual precipitation 40 mm lesser than modern, and T and P rising to modern conditions by the end of the century and during the following XI and XII centuries. The time span falls within the so-called Medieval Warm Period, which apparently in Central Asia has not been exceptionally warm.

[15] Together with values of virtual river runoff, also values of terminal river inflow into the Aral Sea would be decreased by 10%. This is in agreement with measurements and dating (by archaeological findings and few radiocarbon analyses) of re-deepened river channels in the foothill zone, implemented in Soviet times by E. D. Mamedov and G. N. Trofimov, suggesting for the XI AD a total terminal river inflow in the Aral Sea of 49–50 km^3 increasing in the following century to modern

which excludes anomalies attributable to Amu Darya course diversion and allows inferences about diversions of the Syr Darya course; (4) and, most importantly, the X AD corresponds to the peak of urbanization in West Central Asia, which shows a plateau of homogeneous total urban area between the VI and XII AD.

As *study polygon* for hydraulic analyses has been selected the Otrar oasis, located on the Arys delta at its confluence with the middle Syr Darya (Fig. 5.10), for several reasons: its monumental heritage has been object of several decades of archaeological study and chronological attribution; the oasis shows evidence of six generations of clearly detectable irrigation schemes; and its environment has been object of palynological analyses and paleoclimate reconstruction.

c. **Structural analysis of a significant irrigation scheme**, evaluation of the total volume of annual water withdrawal through the use of specific agro-hydraulic models, and calculation of the coefficient of annual water use by occupied urban hectare.

The hydraulic system under study, the Altyn irrigation scheme of the X–XIII AD, runs in the central part of the Otrar oasis and has been analyzed in the context of the project INTAS/2002-2005. The canals' length, bed width, side slope, bed slope and berm width have been measured in order to reconstruct trapezoidal canal cross sections and calculate their carrying capacity. These data have been simulated into a hydraulic model using the US Corps of Engineers River Analysis System software HEC-RAS 2009. CROPWAT software (UN-FAO) provided additional estimates of water requirements in mm/day based on consideration of crop type, effective rainfall and soil moisture deficit (Clarke et al. 2010).

d. **Extrapolation of the Otrar water use coefficient to the whole agro-urban systems of the Syr Darya**, resulting in the evaluation of the total volume of annual water withdrawal from the entire Syr Darya river basin.
e. **Evaluation the virtual river runoff of the Syr Darya during the chosen period** on the basis of the climate esteems quoted at Sect. 3b, and calculation of the ratio of water withdrawal versus water runoff.
f. **Extrapolation of the ratio of water withdrawal calculated for the Syr Darya to the water runoff of the Amu Darya basin**, and evaluation of the total volume of water withdrawal and residual runoff of both rivers.

The resulting values of water withdrawal are valid without significant error for the X–XII AD. In fact the period under study is the X AD, the total area of the Syr Darya settlements between VI and XII AD is stable (±3.6%) (Fig. 5.8), and the Otrar Altyn irrigation scheme chosen for sorting out hydraulic coefficients has been active from X to XIII AD.[16]

regimes of 56.9 km^3 (Trofimov 2003, Table 3). As a whole, these esteems point for the X–XII AD to an arid climate supporting nival-ice deposits and river discharges slightly lower than modern.

[16]The values of medieval urbanization and correspondent water withdrawal given for the X–XII AD start decreasing only from XIII AD when West Central Asia, following the Mongol invasion, entered a period of pastoralist conversion reducing agricultural activities and a longstanding cooling climate phase lessening water requirements.

By tendency the above procedure underestimates the resulting amounts of water withdrawal: on one hand they are lowered by the discounting of unwalled villages and still undiscovered urban units, and on the other by the extrapolation of values calculated for the Syr Darya to the Amu Darya basin which, being more arid and historically more crowded, would better hold higher coefficients.

5.4 Medieval Water Withdrawal: Research Results

5.4.1 The Urban Complexes of the Syr Darya Basin

The urban system of the Syr Darya basin as a whole develops from the VI to the XX AD (Fig. 5.7) and blossoms during the VI–XII AD. The X AD represents the urbanization peak with around 400 occupied walled towns covering, together with an additional 25% of large unfortified villages, a *total urban area of 2350 ha* (Figs. 5.7 and 5.8).

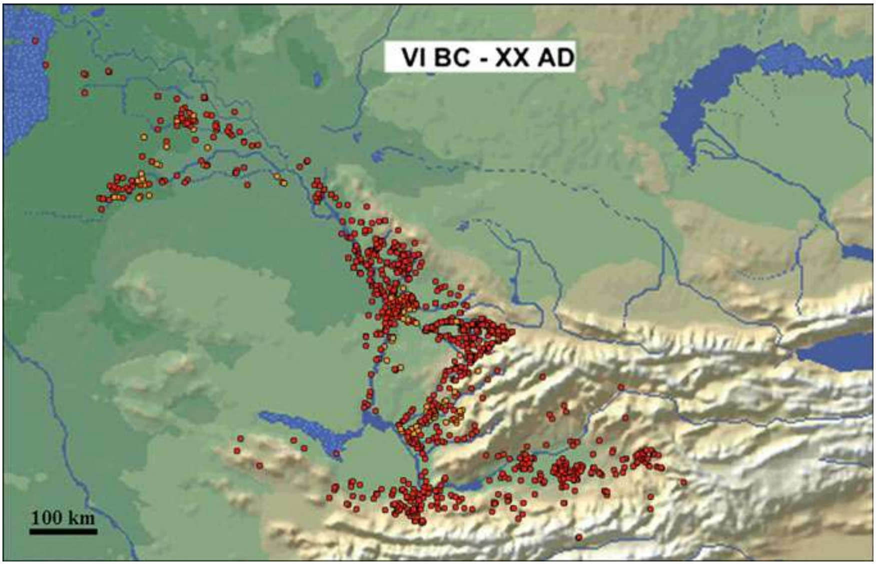

Fig. 5.7 Total urban units in the Syr Darya basin from VI BC to XIX AD. More than 1050 walled towns have been documented, covering altogether around 3500 ha. Red dots = settlement units. Settlements built after the XIX AD are not included

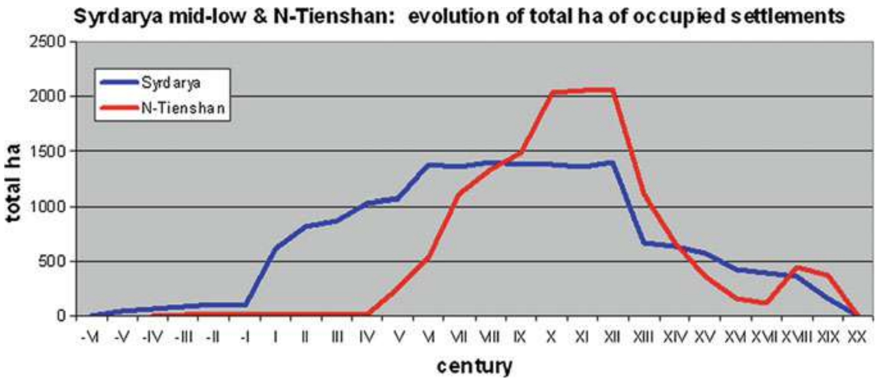

Fig. 5.8 Evolution of occupied urban area (ha) of walled towns in the middle-low Syr Darya basin (Fergana not included) and in N-Tienshan piedmonts from VI BC to XIX AD. Settlements built after the XIX AD are not included

5.4.2 Coefficient of Water Use in the Otrar Oasis in X–XII AD

In the X-XII AD, the central part of the Otrar oasis, covering an area of 15 × 15 km (Figs. 5.9 and 5.10), hosts 12 occupied walled towns totaling an urban area 46.76 ha and watered by a third generation irrigation system, the Altyn scheme, that had been operational during X–XIII AD. By measuring the carrying capacity of the canals' network and the seasonal needs of cultivated crops, "*we calculated peak irrigation water requirements as 7.64 mm/day, equivalent to a continuous canal flow of 0.88 l/s for each hectare of crop at the peak of the growing season*" (Clarke et al. 2010). This corresponds to an annual water subtraction of 0.24 km^3 and a *coefficient of annual water use of 0.0051 km^{3}per urban ha*.[17]

5.4.3 Annual Water Withdrawal in the Syr Darya Basin During the X-XII AD

Volumes. The coefficient of water use of central Otrar, when extrapolated to the 2350 ha of the entire urban system of the Syr Darya during X AD, corresponds to an *annual water withdrawal in the Syr Darya basin of* $0.005 \times 2350\ km^3 = 11.9\ km^3$.[18]

[17]The coefficient of water use could be calculated referring to values other than urban hectares, like irrigated ha or number of inhabitants, which are less convenient objects because of difficult or indirect recognition. Anyhow, these three objects can be put in correspondence: geo-archaeological considerations suggest that, in medieval urban complexes, 1 urban ha averagely corresponds to 400 inhabitants and to 161.63 ha of irrigated agriculture (Clarke et al. 2010).

[18]In Medieval times, this amount of water withdrawal from the Syr Darya basin would correspond to an irrigated area of 0.4×10^6 ha. For irrigating the same agricultural area, the modern surface basin-irrigation systems of the Syr Darya region, thanks to the implementation of sealed canals,

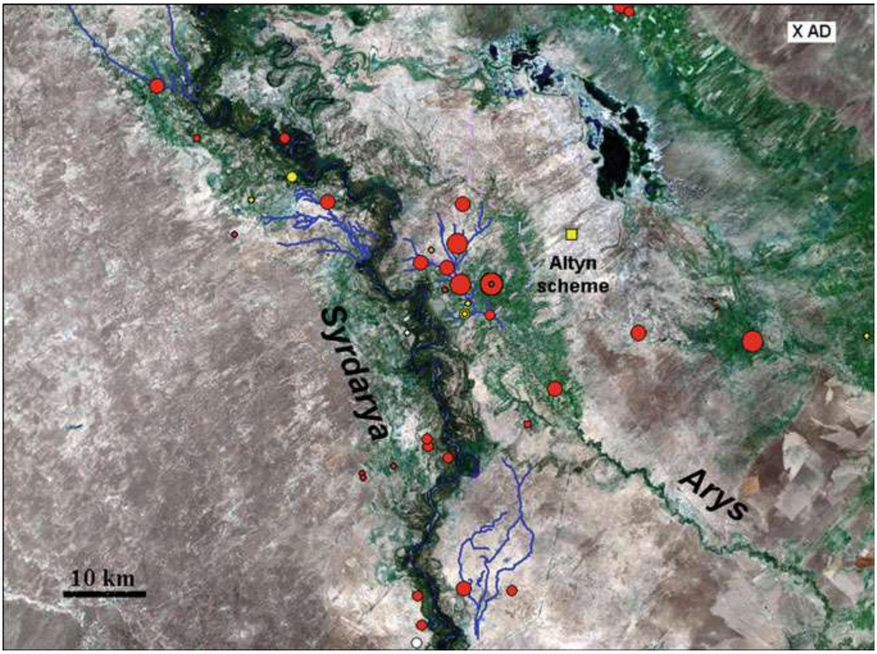

Fig. 5.9 Otrar oasis during the X century AD. Dots = settlements: red = occupied; yellow = newly built after the start of the century; white = just abandoned before the start of the century. Dots' size is proportional to the areal dimension of the urban unit. Blue lines = canals of the Altyn irrigation scheme (center) and, south and northwest of it, of its contemporary Shubara and Ak-Aryk schemes

Ratios. Supposing for the X–XII AD climatic conditions slightly cooler and drier than modern and virtual river regimes 10% lower, the virtual annual surface runoff of the Syr Darya basin would be 33 km^3 (see Sect. 3b), of which the *annual water withdrawal of 11.9 km^3 represents the 11.9 × 100 : 33 = 36.0%.*

5.4.4 Total Annual Water Withdrawal in the Syr Darya and Amu Darya Basins During X–XII AD

Currently, a complete data base of the medieval settlements of the Amu Darya basin is not available. In order to evaluate the anthropogenic water withdrawal within this basin, the same ratio of water subtraction calculated for the Syr Darya has been applied to the virtual surface runoff of the Amu Darya (71 km^3; see Sect. 2b), resulting in an *annual water withdrawal from the Amu Darya basinof 36.0% × 71 = 25.5 km^3*.

water drainage and return flow, would use only half of the water volume calculated here for Medieval times.

Therefore, during the X AD the *total annual water withdrawal from the entire Aral Sea basin (Syr Darya + Amu Darya) would be 11.9 + 25.5 = 37.4 km³*.[19]

A water withdrawal of 37.4 km^3 represents around 1/3 of the total runoff of the two rivers (104 km^3), leaving a total residual river flow of 66.6 km^3, 45.5 km^3 in the Amu Darya and 21.1 km^3 in the Syr Darya. And it corresponds to around half of its value in the 1960,[20] the year that saw the last modern high stand of the lake (+53 m a.s.l.) before the following catastrophic recession.

5.5 Discussion

5.5.1 Controlling Factors of the Aral Sea Water Balance During X-XII AD

The water mass balance equation of the Aral Sea, which is deprived of emissary, is a function of few hydrological variables characteristic of the lake, expressed in water volumes (km^3/year):

$$\mathbf{f}_0\text{:}\quad dV/dt = R_t(v_t - d_t - a_t) + P_t + G_t - E_t$$

where V = lake water volume, t = time, R = river inflow, P = local precipitation, G = groundwater-infiltration balance, E = local evaporation. R is function of virtual runoff (v), river course diversion (d) and anthropogenic annual water withdrawal (a). P, E and v depend strictly on climate. The equilibrium state, where the lake hydrological system is uniform throughout, corresponds to dV/dt=0.

For example, the water balance equation of Aral-1960 is:

$$\mathbf{f}_1 : \ \mathbf{Aral-1960} \quad R[v(114) - d(0) - a(61)] + P(9) + G(1) - E(63) = 0\ \mathrm{km}^3/\mathrm{year}$$

Let's work out the water balance equation of the Aral Sea at X AD (Aral-1000) in two steps, under two scenarios.

[19]In Medieval times, this amount of water withdrawal from both the Syr Darya and Amu Darya basins would correspond to an irrigated area of 1.15×10^6 ha (see note 17), against the 10×10^6 ha of the modern land under irrigation. During Classical Antiquity (IV BC–IV AD), according to Tolstov and Andrianov (1968) and Gerasimov (1978), the network of canals detected in just the Amu Darya basin would 'allow' to irrigate more than 5×10^6 ha (Oberhänsli et al. 2007, 177). In fact, the actual extent of yearly irrigated area was most probably 3–4 times lower (Tolstov 1948) and submitted to fallow cycles longer than modern, in that way approximating the evaluation of irrigated land given above for the entire Aral basin during medieval times.

[20]This double modern value of water withdrawal matches the fact that by 1960 the Soviet regime quadrupled the former medieval irrigated area of the Aral Sea basin from 1.2 to 4.7 million ha, introducing in the same time technical advances as sealed canals, drainage and return flow that improved the performance of the irrigation systems and halved the water requirements per ha.

The two scenarios are similar in supposing the same climate and the same amount of water withdrawal as evaluated above. Climate conditions are slightly more arid than modern,[21] so that precipitation and evaporation rates in/from the lake and run-off values within the basin are evaluated as 10% lower than modern (Sect. 3b). The value of annual anthropogenic water withdrawal (a) is 37.4 km^3, as calculated in Sect. 4.4. The two scenarios differ on values of terminal river inflow R, in absence or in presence of water subtraction by river course diversion.

a. The **first scenario** considers the terminal river inflow as the residual flow of Sect. 4.4: $R = v(104) - a(37.4) = 66.6$ km^3 (45.5 from the Amu Darya and 21.1 from the Syr Darya), i.e. without additional water subtraction by river diversion, i.e. $d(0)$.

A river inflow of 66.6 km^3 corresponds to hydrological parameters of Aral-1000 higher than today, at the top of the lake's bathymetric capacity: water volumes above 1100 km^3, water surface of 75600 km^2, local evaporation volumes 75.6 km^3, local precipitation 8 km^3, and lake level at +55 m a.s.l. Under this scenario the resulting water balance equation for Aral-1000 would be the following:

$$\mathbf{f}_2 : \ \mathbf{Aral-1000(1)} \quad R[v(104) - d(0) - a(37.4)] + P(8) + G(1) - E(75.6) = 0 \text{ km}^3/\text{year}$$

The hydrological parameters related to this first scenario (a river inflow of 66.6 km^3) are in disagreement with the values suggested for the same period by the paleo-environmental reconstructions quoted above: physico-chemical analyses of lake cores indicate for Aral-1000 higher salinity levels and lower water volumes than for Aral-1960 (see Sect. 2.2, Figs. 5.4 and 5.5); and geomorphological surveys of relict channels suggest a much lower inflow of 49 km^3 (see note 16).

b. The **second scenario** considers a river inflow into the Aral Sea of 49 km^3 in agreement with the estimations of river inflow and lake water volumes suggested by paleo-environmental studies. A river inflow of 49 km^3 would correspond to lake water volumes of 820 km^3, water surface of 57,000 km^2, local evaporation volumes of 58 km^3, local precipitation of 7 km^3, and lake-water level at +49 m a.s.l.

But in order that $R = f\ (v - d - a) = 49$ km^3, with values of climate (virtual river runoff) and anthropogenic water withdrawal set as the preconditions spoken above [$v(104)$ and $a(37.4)$], an additional $(104 - 37.4 - 49) = 17.6$ km^3 of water subtraction must be attributed to a still undetected event of river diversion: $d(17.6)$.

$$\mathbf{f}_3 : \quad \mathbf{Aral-1000(2)} \quad R[v(104) - d(\mathbf{17.6}) - a(37.4)] + P(7) + G(1) - E(58) = 0 \text{ km}^3/\text{year}$$

[21] For the start of X AD have been evaluated annual temperature values 3 °C cooler and precipitation 40 mm lower than modern, and T and P trends rising to modern values by the end of the century (see Sect. 1.1, Fig. 5.4, note 14).

Being excluded switches of Amu Darya course (see Sect. 2.3.2), the additional water subtraction of 17.6 km^3 must be attributed to some still undetected transmission losses along the poorly explored course of the Syr Darya river.

When analyzing this possibility, it has been noticed that the Syr Darya has hydrological parameters averaging half of the values of the Amu Darya but at the same time a much more meandering and undefined course, "*frequently changing its bed, forming channels that often lose themselves in the sands, and overflowing its low banks at flood*",[22] ending up in constituting a deltaic floodplain one-and-half times wider and potentially exposed to higher transport losses. Have also been found archaeological data and historical accounts (quoted in Sect. 5.2) testifying the occurrence of medieval switches of the Syr Darya course relevant enough to divert the quasi totality of the 21.1 km^3 residual flow of the river, matching in that way the hydrological scenario inferred by geo-environmental reconstructions and described by the water balance equation $\boldsymbol{f}_3$.

5.5.2 *Water Diversion Events Along the Syr Darya Course*

Significant events of water diversion from the middle and low Syr Darya course during antiquity and, specifically, during medieval times are documented by geological studies, archaeological data, and historical accounts.

Concerning *geological studies*, the susceptibility of the Syr Darya to switches of river course into paleo-beds ending in neighboring depressions to now has been underestimated. Most exposed to diversions are four points of the middle-low course:

- The first diversion occurs from the left bank at the exit of the Fergana valley, feeding the Arnasay lowland and, today, the man-made Aydar-Arnasay lake. It has become very relevant only in the last few decades after been enhanced by Soviet technogenic implementations.[23]
- The second occurs from the left bank of the Chardara river segment towards the sand dunes of the Kyzylkum desert where a relict delta 100 km long with front 60 km wide is detectable. This diversion happened during the period under consideration at a scale that seems to be of medium size.[24]

[22]See: *Syr Darya*, Encyclopedia Britannica 2011.

[23]The Arnasay lowland, formerly a dry salt pan and ephemeral lake (Tokzan lake), in the 60ies started to be used as a flood control basin and grew into a lake with water surface of 3000 km^2 and water volume of 44 km^3 (Aydar-Arnasay lake system). In that way an 'unintentional byproduct of Soviet planning', by subtracting annually 10% of the Syr Darya water flow (3 km^3), became one of the main causes of the subsequent shrinking of the Aral Sea. As a whole, the total water surface of useless Soviet evaporation basins amounts to 10,000 km^2 (Ashirbekov and Zonn 2003, 16). Today, in spite of the fact that only 500 families inhabit the Aydar-Arnasay region, the restoration of the former hydrological conditions is impeded by transboundary water conflicts.

[24]Today the areas paralleling the left bank of the Chardara river segment are concerned by seasonal floods totally harvested within irrigation schemes, so that the Chardara paleodelta itself is almost desiccated. This was not the case between the IX and XII AD when some of its distributaries were

- The third, just at the head of the delta at +154 m a.s.l., is the right bank diversion of the Telikol channel that during the period under consideration, after running northward for 100 km, could have flooded the Daryalyk plain and the Ashikol depression located between the Syr Darya course in the south and the Ulytau mountains in the north, forming the so-called Telikol (or Gorguz) lake (Fig. 5.10).

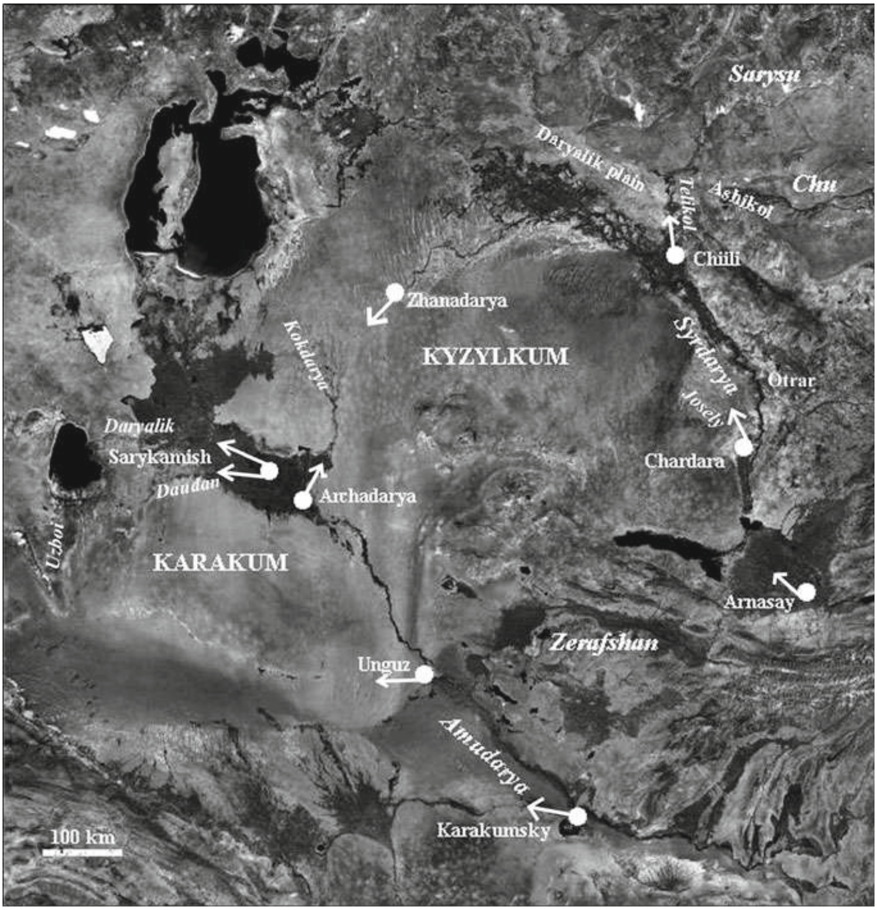

Fig. 5.10 Main diversions of river courses in the Aral Sea basin. The Syr Darya course presents four main points of diversion, from SE to NW: Aydar-Arnasay, Chardara, Chiili, Zhanadarya. Most of these points correspond to large historical and modern irrigation oases fed by catching floodwaters (flood-basin irrigation schemes). The Telikol (Gorguz) lake was apparently covering the Daryalik plain and Ashikol depression. White dot and arrow: point and direction of river course diversion. Background: Bing satellite image, year 2000

surely active, as witnessed by the chronology of the ruins of 6 large villages aligned along the Josely paleochannel (Asylbekov et al. 1994).

- The fourth and only diversion event clearly quoted by historical accounts (note 12) and considered by some authors (Barthold 1902; Boroffka 2010) is the diversion of the Zhanadarya delta distributary into the sands of the Kyzylkum desert. The event occurred together with the reactivation and re-colonization between XII and XVI AD of the formerly dry Zhanadarya course (Fig. 5.12) and is not related to the period under study.

Most significant for the present discussion is the Telikol diversion, due to its chronology, size and location. The Telikol is today an artificial canal, but the existence of a past natural diversion is evidenced by relict paleo-distributaries 100–200 m wide diverging at Chiili from the Syr Darya right bank to the north for 100 km until merging with the Sarysu and Chu river deltas. From there a multi-channel river course established a large lacustrine system in the Daryalyk plain and the Ashikol depression, and then flowed out to the west until merging with the terminal segment of the northernmost distributary of the Syr Darya delta. "*Finally, a curious observation comes from the Memoirs of Sultan Babur (Babur 1530), a solid diary of events in Central Asia at that time, who wrote "in my time, Djihun (Syr) was lost far away in the sands". This would imply that at least a good part of the Syr water did not fetch the Aral. In fact, at the NW of Kzyl Orda, exists a large area of about 50,000 km^2 covered with gypsum and lake sediments, at the past junction of Syr Darya and the Chu river (these lakes are shown on nineteenth century maps), which could have evaporated most of the Syr Darya water. This does not seem to have been investigated in detail, and could have consequences on reconstructions of the past of Aral Sea*." (Cretaux et al. 2009, 285).

Given the geomorphological characters of the plain, the Telikol water basin could only have been a system of lakelets, brackish ponds and evaporation flat and salt playas occasionally gathering into large basins, functionally similar to the Sarykamysh, shallower but much larger by size and evaporation potential.[25] Geological studies concerning the region are scanty and up to now the full extent of the Telikol diversion and lake have not been geologically documented and chronologically attributed.

Better grounded are *archaeological data*. The head of the Syr Darya delta during the VIII-X AD sees the sudden development of the Chiili oasis, with the building of 13 walled towns[26] and a large agro-irrigational system covering around 44,000 ha

[25]The Syr Darya course diversion into the Daryalyk plain would have surely caused, if not a large lake, in any case high transmission losses, which "*are relatively low when flow is confined to the primary channels, but increase at higher stages as lesser channels and the floodplain are activated…exacerbated here by the exceptionally long distance and unusual multichannel form of the channel/floodplain system*" (Knighton 1994, pp. 137–142).

[26]The medieval walled towns of the Chiili oasis are in number of 13 and cover all together an area of 44 ha. Signak, the largest (26 ha), is dated to the VI–XIX AD, 3 other towns to the VIII–XII AD, and 8 to the X–XIV AD. Eight additional large villages covering together around 10 ha appeared between the XIV–XVI AD. The Telikol channel has surely been active from the VIII until the XII–XIV AD, after which is documented an enhance regime of the Zhanadarya distributary and of the main course of the Syr Darya delta (Kerderi branch) in the context of low lake level stands (Krivonogov 2009).

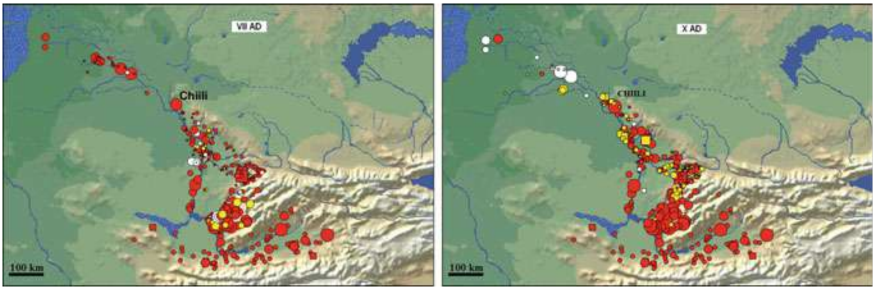

Fig. 5.11 Walled towns along the Syr Darya during VII (left) and X (right) AD. Dots = towns: red = occupied; yellow = newly built after the start of the century; white = just abandoned before the start of the century

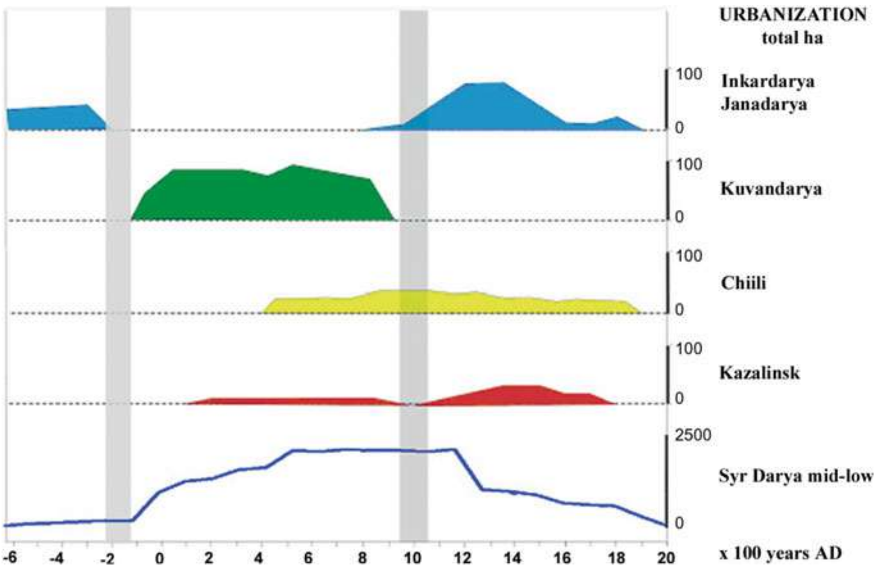

Fig. 5.12 Phases of urbanization along different distributaries of the Syr Darya delta. Two discontinuities in the urban development are detected at II BC and X AD (grey bands), both accompanied by drying delta distributaries and peaking upstream urban development (*source* Sala 2012)

along the Telikol paleo-distributary and its diverging branches. Synchronous with the urban development of the Chiili oasis is the progressive abandonment between the VIII and X AD of the agro-urban structures of the lower Syr Darya delta,[27] apparently as result of critical upstream water subtraction along the mid-Syr Darya course (Figs. 5.11 and 5.12).

[27]This process of urban contraction represents the last phase of the longstanding Jety-Asar culture established in the II century BC along the Kuvandarya delta distributary.

Referring to *historical accounts*, the existence of a very large lake called Gorguz in what seems corresponding to the Daryalyk plain is quoted in the "*Kitab Nuzhat al-Mushtaq*" ('Book of pleasant journeys') of the medieval Muslim geographer Muhammad Al-Idrisi (1100–1165 AD): "*the Gorguz lake...bigger than the Aral Sea.…similar to an ocean*".[28] Even the words of the Timurid ruler Babur quoted in Sects. 2.3.2 and 5.2 could refer to the Telikol diversion (Babur 1530, 45).

The presence of a lake (or of a system of lakes) named Telikol in correspondence of the Daryalyk plain and Ashikol depression still figures in several maps of the XVIII–XIX centuries (Schraembl 1792; Pansner 1816; Von Humbold 1843).

Among the modern specialists supporting the establishment of a large lake in that region during medieval times are counted the English orientalist Miller (1926) and the Soviet ethnographer Vaynberg (1999). B. Vaynberg, who during the 40ies and 50ies was member of the Tolstov's multidisciplinary expeditions involved in the ethno-archaeological study of the ancient civilizations of the Amu Darya and Syr Darya deltas, says: "*To the east of Kzyl-Orda there is an extensive takyr plain (Daryalyk-takyr) where, apparently, in antiquity and perhaps in the Middle Ages, there was a lake into which flowed the Sarysu and Chu rivers and part of the Syr Darya runoff. It is possible that this was the same lake marked on ancient and medieval Chinese maps and mentioned by medieval Muslim travelers (Bichurin 1851, tome III, annexes; Agadzhanov 1969, p. 65 and further). The Inkardarya and the ancient Janadarya courses, which have origin at the south of this region, did not flow into this lake, but undoubtedly into the Daryalyk-takyr "poured" a number of right bank paleo-distributaries clearly discernible in the Chiili region and dated by archaeological material from the early Iron Age to the Middle Ages*." (Vaynberg 1999, pp. 52–57).

The Telikol diversion and the flooding of the Daryalyk-Ashikol evaporation basin could have subtracted, for few centuries around the turn of the I millennium, a large part (17.6 km^3) of the residual river stock of the Syr Darya (21.1 km^3), in agreement with the evaluated total annual river inflow into the Aral Sea of 49 km^3 (3.5 km^3 from the Syr Darya and 46.5 km^3 from the Amu Darya).

The "*Telikol hypothesis*" is certainly debatable but does raise a new significant factor in the complex puzzle of the Aral Sea water levels: diversions of river course along the middle-low Syr Darya. In particular, it introduces a diversion event that during X–XII AD put in correspondence the evaluation of the anthropogenic water withdrawal of 36.54 km^3 as calculated in Sect. 4.4 with the Aral Sea terminal river inflow of 49 km^3 and water level at +49 m a.s.l. inferred by paleo-environmental analyses (Sect. 2.2 and note 16).

[28]Such quotation has been resumed by two subsequent Muslim geographers, Ibn Kaldun (1332–1406) and Ibn Iyas (1448–1522). Ibn Kaldun is adding that the lake is fed from the north by "*several streams originating from the Mrgar mountains*" (Ulytau mountains?) (Agadjanov 1969, 70).

5.6 Conclusions

As conclusion it must to be admitted that, in modeling the interaction of the driving factors of the hydrological parameters of an internally draining basin located in an arid zone, the main difficulty encountered is that here rivers are flowing in wide flat floodplains with discharges decreasing significantly downstream with high annual and centennial anomalies, so that the "*…modeling of flow regimes requires data on the spatial and temporal distribution of* (natural and anthropogenic) *transmission losses…due to infiltration to channel store and/or floodplain soils, evapotranspiration, and ponding in terminal storages, such as ephemeral pools, channels and other wetlands…*" (Costelloe et al. 2003).

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Chapter 6
Reconsidering Archaeological and Environmental Proxies for Long Term Human-Environment Interactions in the Valley of Kashmir

Michael Spate

Abstract As response to climate change becomes an ever present issue, considerations of human-environment interactions in the past have moved beyond deterministic notions of climatically driven cycles of social expansion and collapse to more complex examinations of anthropogenic effects upon environments, as well as the transformative effects environmental change has upon human societies. The entanglement between these processes may be explored through a number of theoretical frameworks, including Niche Construction Theory (NCT) and other notions of human resilience. The Valley of Kashmir in the northernmost region of South Asia presents an opportunity for examining a number of these processes. This paper aims to synthesise past archaeological and Holocene palaeoclimate data, as well as review past interpretations of human responses to climate factors in Kashmir. Arguments are raised for new theoretical and methodological approaches to understanding human-environment interactions in the valley, based on recent studies from Kashmir and adjacent regions. These approaches aim to address gaps in understanding arising from poorly resolved environmental records or uncritical integration of archaeological and palaeoclimate data. Some early conclusions may be drawn as to ways in which differentiated land use patterns across the valley and adjacent mountain zones would have allowed for long term patterns of adjustment and reorganisation as a response to climate pressures. New preliminary data that has the potential for exploring some of these processes in the valley is also presented.

Keywords Kashmir · Neolithic · Kushan · Climate change · Holocene
Niche construction theory (NCT)

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6.1 Introduction

Situated at the intersection of the Tibetan Plateau, the Indian Subcontinent and Central Asia, the valley of Kashmir has long been considered a temperate, fertile basin between the often unpredictable monsoon driven environments to the south and desert-steppe-mountain regions to the north and east. Due to political disturbances within Kashmir since the 1980s, little archaeological or palaeoenvironmental fieldwork was undertaken for several decades. In recent years, some limited systematic archaeological survey and excavation has taken place (Yatoo 2005, 2012; Mani 2000), leading to publication of new palaeobotanical and archaeological data (Spate et al. 2017; Pokharia et al. 2017). Broader discussions of prehistoric crop dispersals (Stevens et al. 2016; D'Alpoim-Guedes et al. 2014) have situated Kashmir as a node within regional system of agricultural exchange predating the development of the historic Silk Roads. Renewed interest in the Silk Road regions of China, Central and South Asia more generally have placed cultural and economic change into contexts of human-environment interaction, providing new frameworks against which we can consider social and environmental change in Kashmir.

Drawing on a reappraisal of past archaeological and environmental data as well as preliminary analysis of new fieldwork, the following discussion will examine these long term cultural and environmental processes in the valley. Chronological focus will be on the pre-, proto- and early historic periods in the valley, beginning with the Neolithic ca. 3000 BCE, through to the Karkota Dynastic period ending ca. 900 CE. This study begins with a review of the geography of the Kashmir Valley, as well as currently available archaeological and Holocene climate data (Sect. 2). Past interpretive frameworks for human responses to environmental change are discussed in Sect. 3, followed by an examination of recent interpretive palaeoecological frameworks in adjacent regions of South and Central Asia and considerations of how they may be applied to Kashmir. A concluding discussion raises potential new avenues for research in the valley.

6.2 Valley of Kashmir

6.2.1 Geographic and Climatic Context

The valley of Kashmir is an intermontane basin in the Western Himalayas, the northernmost region of the Indian Subcontinent. Stretching roughly 140 km north-south and 40 km across its widest point, the valley is flanked on the eastern side by the Greater Himalaya and on the west by the Pir Panjal ranges. The valley floor generally sits between 1600 and 1800 m above sea level (ASL), with the peaks of the Pir Panjal rising to around 4500 m ASL and the Greater Himalaya maintaining a crestline of around 5000 m ASL.

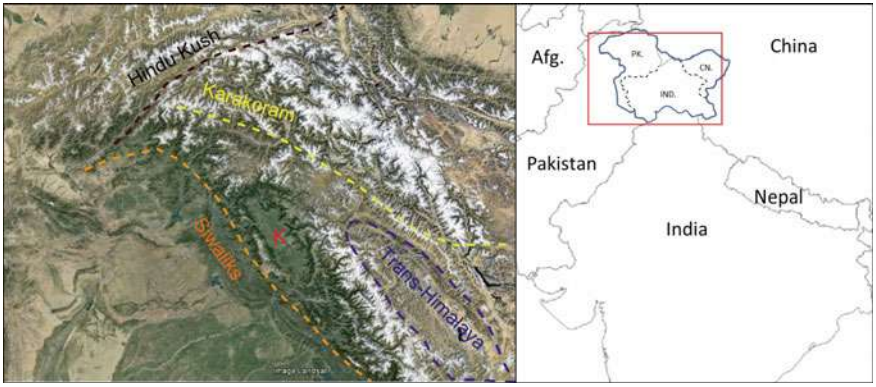

Fig. 6.1 Left—Kashmir valley (K) and surrounding mountain and foothill zones (Landsat, Google Earth). Right—Historic borders of greater Kashmir region and modern military lines of control

To the north and east of Kashmir are the Trans-Himalaya and Karakoram ranges, leading to high altitude steppic-deserts of Ladakh and the Tibetan Plateau (Husain 2008). South of the valley are the Himalayan Siwalik foothills, transitioning to the monsoonal environment of the Punjab forelands. This topography situates the Kashmir valley as a transitional environmental niche between the Indian subcontinent to the south and the mountainous and arid zones of Central Asia and Tibet (Fig. 6.1).

The Kashmir basin was formerly a massive lake, impounded by Pir Panjal orogeny at around 4 million years ago. Ongoing upthrust at around 200 thousand years ago (KYA) drove the water body against the Himalayan flank and began the lifting of lacustrine sediments, known locally as *Karewas*, on the western side of the valley. The relict landforms of this first phase of Karewa building on the Pir Panjal are grouped as the Lower Karewa formation (Agrawal 1992: 47). From 200 to 85 KYA, aridity driven desiccation and further tectonic activity pushed the lake into the north eastern corner of the valley, leading to the emergence of the younger Upper Karewa sediments. Initiation of loess deposition on the Lower Karewa sediments of Pir Panjal flank began around 300 KYA and on the Upper Karewas from their first emergence ca. 200 KYA (Agrawal 1992: 45). Faulting at the Baramulla gorge in the northwest of the valley at around 85 KYA led to the draining of the lake and the formation of the Jhelum River, as well the final emergence of Upper Karewa sediments on the Himalayan flank (Dar et al. 2014). The lacustrine sediments of the Lower and Upper Karewa and subsequent loessic sequences provide a long term climate archive for the Plio-Pleistocene in Kashmir (Agrawal 1992).

Due to the orographic effect of the Pir Panjal, the Indian Summer Monsoon is effectively blocked in Kashmir leading to a localised humid continental climate (Köppen Dfb), with most precipitation in the form of cold winter rain and snow (Husain 2008: 51). Precipitation is primarily driven by Westerly Disturbances, known locally as *Alamgir*, between December and April (Kaul 2014: 157). Excessive winter precipitation may be detrimental for Rabi (winter) crops such as wheat and barley, though good spring snow melt is crucial for irrigated Kharif (summer) rice agriculture (Husain 2008: 137–139). This bi-seasonal cultivation takes place across the valley in various ecological and topographic niches, with rice typically on the valley floor, smaller fields of wheat and barley on the flanks, and in modern times maize being the dominant middle-high altitude crop of Gujjar nomadic pastoralists.

The distinction between the valley floor, middle and high altitude zones are key for examining variability in economic and cultural adaptations in Kashmir both in the present day and in the past. The valley floor is an alluvial landscape comprised of old and new alluvium, also categorised as river terrace and floodplain soils (Sidhu and Surya 2014: 7). These soils are rich in potassium, phosphorus, calcium and magnesium, and accumulation of nitrogen occurs in significant quantities allowing for high agricultural potential (Qazi 2005: 30). At the margins of the alluvial landscape are flat topped Upper Karewa terraces, known locally as *wudur*, standing up to 60 m in height (Husain 2008: 27). Archaeological survey (Yatoo 2012; Bandey 2009) has indicated that Neolithic villages in Kashmir tended to cluster on *wudur*, likely as a means of mitigating flood risk. This alluvial landscape and associated tablelands form a zone for intensive cultivation and settlement, extending into the mountain foothills to an altitude of around 2200 m ASL (Kaul 2014: 56).

Between 2500 and 3500 m ASL are meadows known locally as *marg* or *pathri* (Singh 1963), situated within mountain forest belts at middle altitudes, as well as above the timberline. Bhatt (1978) divides these into a high altitude type ca. 3000–3500 m ASL, based on Hirpur clay formations and a lower type based on a silty substratum between 2400 and 3000 m ASL. Agrawal (1992) describes the lower meadow landscapes as being built on the infilling of glacially ground basins and lakes, ideal for environmental coring. Both types of meadow are grazed by flocks of goats and sheep as part of the annual migratory cycle of Gujjar-Bakharwal transhumant groups in the region today (Casimir and Rao 1985).

The ecological diversity in the Kashmir Valley may allow us to conceive of the valley as generally comprised of two ecotopes, being the valley floor and the montane zone. Within these zones are a number of smaller transitional areas (Fig. 6.2), particularly between the forest and meadow communities in the montane zone. More broadly, we may consider the entire valley as a transitional ecotone, situated between the high altitude desert of the Ladakh region, the desert and steppe regions of Central Asia and the sub-tropical regions of the Siwaliks and Punjab to the south, at the interface of Summer Monsoon and Westerly dominated climate zones. The interrelations between various ecotopes and social and economic organisation are argued as primary drivers of cultural and technological exchange in Bronze and Iron Age Central and South Asia (Frachetti 2012; Spengler et al. 2013; Stevens et al. 2016).

6.2.2 Archaeological and Historical Context

Early cultural development in Kashmir has primarily been understood through excavations of five pre and proto historic sites, whilst early historic (Kushan and Karkota)

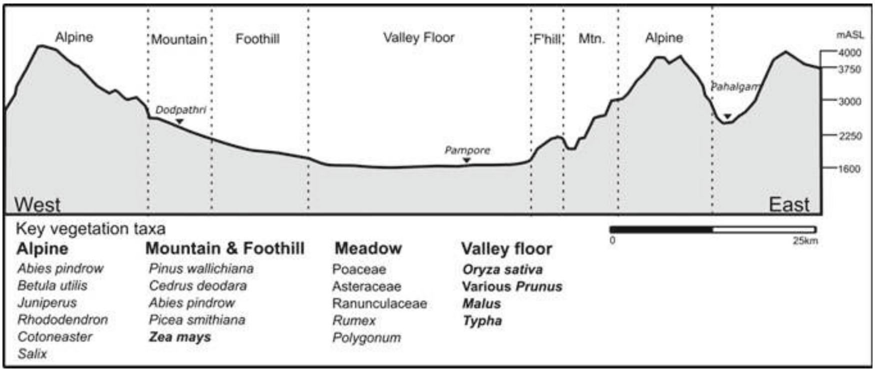

Fig. 6.2 Transverse section across Kashmir valley depicting topographic variation and zonal differentiation. Mid altitude pastures Dodpathri and Pahalgam marked as is Pampore city on the valley floor. Major modern vegetation taxa from each zone is listed, economically important cultivars in bold

periods were also documented in Kashmiri and Chinese historical accounts. A general chronology of cultural changes is presented in Table 6.1.

Excavations at the sites of Burzahom, Gufkral and Kanispura (Fig. 6.3) in the east, south and northwest of the valley have allowed for the development of an archaeological sequence beginning with an Aceramic phase, followed by Early, Late and Megalithic Neolithic periods (Possehl 2002; Sharma 2013; Mani 2000). Though only a small number of absolute dates have been returned from Burzahom and Kanispura (Agrawal and Kharakwal 2002; Pokharia et al. 2017), a fuller sequence from Gufkral is available (Sharma 2013) and a stratified sequence of dates from a surveyed Late Neolithic pit at Qasim Bagh have recently been published (Spate et al. 2017). From these sources, a tentative internal chronology of Neolithic development in the

Table 6.1 General chronology of cultural phases and excavated sites in Kashmir (Agrawal 1992; Bandey 2009; Shali 2001; Spate et al. 2017; Yatoo 2012)

Period	Date range	Sites
Karkota	600–900 CE	Semthan
Hunnic	300–600 CE	Kanispura, Harwan
Kushan	1–300 CE	Kanispura, Semthan, Harwan
Indo-Greek	200 BCE–1CE	Semthan
NBPW	700–200 BCE	Semthan
Megalithic	1500–700 BCE	Burzahom, Gufkral, Semthan
Late Neolithic	2000–1500 BCE	Burzahom, Gufkral, Qasim Bagh
Early Neolithic	2500–2000 BCE	Burzahom, Gufkral, Kanispura
Aceramic Neolithic	3000–2500 BCE	Kanispura, Gufkral

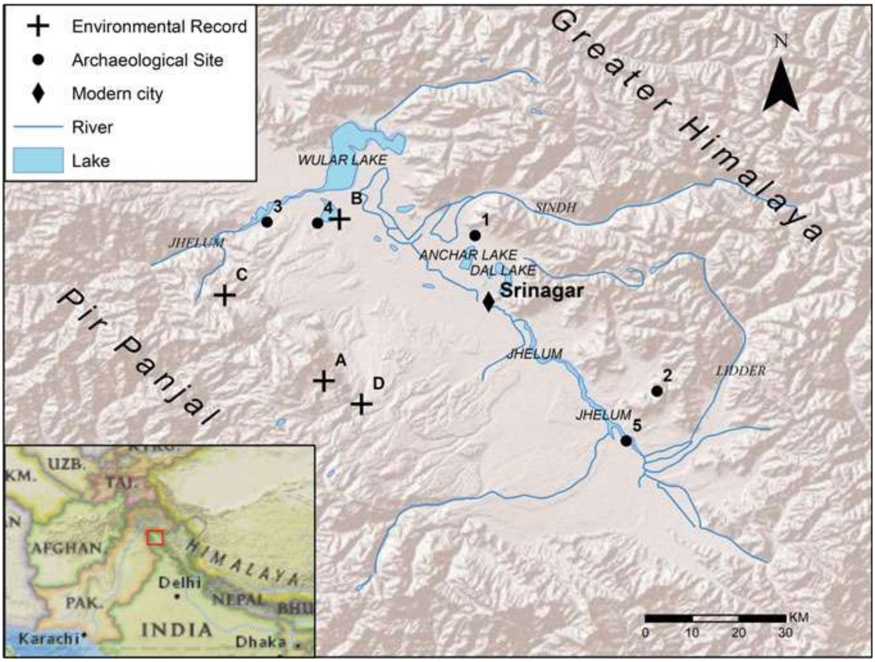

Fig. 6.3 Archaeological sites and environmental cores discussed in text. Sites: 1. Burzahom & Harwan; 2. Gufkral; 3. Kanispura; 4. Qasim Bagh; 5. Semthan. Cores: A. Toshmaidan; B. Hygam; C. Butapathri; D. Pari-Has (Basemap source: ESRI)

valley may be conceived as: Aceramic Neolithic 3000–2700 BCE; Early Neolithic 2700–2000 BCE; Late Neolithic 2000–1500 BCE; Megalithic 1500–700 BCE.

Change in material culture through the Neolithic is relatively conservative, beginning with a ground stone lithic industry during the Aceramic (Pant et al. 1982), the use of which continues throughout the cultural sequence. During the Late Neolithic polished stone harvesters are introduced comparable to types from the Yangshao Neolithic of China, leading to speculation of cultural connections with North Asia (Possehl 2002). The ceramic sequence begins with coarse ware cooking pots during the Early Neolithic, with later introductions of fine and burnished wares. During the Megalithic, a gritty red ware is introduced (Yatoo 2012). Structural remains consist of subterranean rectangular dwellings with a timber superstructure in early periods, followed by rammed earth platform buildings during later phases (Sharma 2013). Throughout the Neolithic, large conical pits up to 3 m deep were dug, the use of which is subject to ongoing debate (Conningham and Sutherland 1997; Young 2003; Bandey 2009).

Analysis of botanical (Lone et al. 1993; Spate et al. 2017; Pokharia et al. 2017) and faunal (Sharma 2013) remains seems to indicate the early economy during the Neolithic was based upon hunting and cultivation of winter barley and wheat. A later shift towards consumption of domestic animals and the introduction of rice and millet may be interpreted as a shift towards bi-seasonal cropping, and the development of a herding economy.

Later cultural phases are represented at the site of Semthan in the southeast of the valley. Little excavation data has been formally published and most information is gleaned from annual reports (Thapar 1980; Mitra 1983) and a systematic botanical study (Lone et al. 1993). The sequence begins with a phase comparable to the Megalithic (ca. 1500–700 BCE) at Burzahom and Gufkral (Semthan Phase I), whilst subsequent phases represent the first changes in material culture linking Kashmir to the rise of Iron Age urbanism on the Indian Subcontinent. Phase II (ca. 700–200 BCE) is analogous to the Northern Black Polished Ware (NBPW) culture of South Asia, whilst Phase III (ca. 200 BC–1CE) represents an Indo-Greek period. The Kushan period is represented by Phase IV (1–300 CE), whilst Phase V (600–900 CE) is considered contemporary with the "prolific temple building" period of the Hindu Karkota Dynasty (Mitra 1983: 23). The Kushan period is also evident in temple and settlement remains at Kanispur (Mani 2000; Pokharia et al. 2017) and temple structures at Harwan in Srinagar (Kak 1933). Post-Kushan period remains (ca. 300–600 CE) at Kanispura and Harwan have been interpreted as evidence of incursion by Central Asian Hunnic nomads (Shali 2001).

Botanical macro remains from Semthan indicate a shift towards summer rice and millet agriculture during all phases, and also sees the introduction of several South Asian summer pulses such as *Vigna mungo*, *Vigna radiata*, and *Vigna acontifolia* (Lone et al. 1993: 209–212). Lone et al. (1993) have argued that despite this broadening of the agricultural package, the thinness of the archaeological deposits of the NBPW and Indo-Greek phases, coupled with a declining diversity index of wood charcoal at the site indicates some form of population collapse during this period.

It is unclear whether the Kushan period represents a population recovery following collapse as interpreted by Agrawal and Lone et al., or rather represents the first major archaeological evidence for social reorganisation and intensified urban settlement in Kashmir. Excavation data from the pre and proto historic periods suggest evidence for both economic diversity and horizontal social complexity, whilst the Kushan period may be the first instance of development of vertical complexity and state building in the valley. These institutional changes would shift the opportunities and constraints for responses to climate or demographic pressure in the valley, processes that would have continued through the Karkota period. Bamzai (1994) has also argued that the Karkota period was a time of major institutional realignment, with an expansion of bureaucracy, intensification of public works including major irrigation systems and centralisation of social responses to environmental calamity. This period also saw a political re-orientation towards China against the backdrop of the decline and fall of the Sassanian and Gupta Empires in Greater Iran and India.

6.2.3 Holocene Palaeoclimate

The earliest paleoclimate studies in Kashmir tended to focus on glacial cycles and Pleistocene vegetation changes in Lower Karewa sediments (De Terre and Paterson 1939). Holocene climate reconstruction was first undertaken by Singh (1963), producing a post-glacial vegetation sequence from a high altitude peat bog at Toshmaidan in northwest Kashmir. Singh identifies 8 pollen zones and 9 stratigraphic sections, which were dated through later re-excavation and sampling of bedding planes (Singh and Agrawal 1976). These dates have been recalibrated and presented in Table 6.2 alongside Singh's original phasing.

Singh (1963: 103) uses broad leaf/coniferous (B/C) ratios as an index of post-glacial warming and cooling, finding correlation between the advance of broad leaved and thermophilic non arboreal taxa, most notably in Stages b, d and e. Despite the return of *Pinus* dominance in Stage c, Singh interprets Stages a-e as a post-glacial amelioration with a climatic optimum during Stage e. Dating of this stage remains problematic due to poor correlation between the initial pollen study and later resampling to date the column (Singh and Agrawal 1976). Vishnu-Mittre (1966; Vishnu-Mittre and Sharma 1966) has argued the three warm phases of Toshmaidan stages b, d and e correlate with other past thermophilic vegetation stages in an undated sequence at Haigam on the valley floor, positing a succession of post glacial warming and cooling directly comparable with the European Blytt–Sernander pre-Boreal to sub-Atlantic phases.

Two high altitude pollen records from peat bogs at Butapathri-I and Butapathri-II (3000 m ASl) attempted to refine the chronology of the Toshmaidan sequence (Dodia 1983). The first record is argued to be evidence advance of broad leaf species over conifers from around 18,000–15,000 BP, indicating an early period of climatic amelioration following the last glacial maximum (Agrawal 1988). This broad leaf advance is also synchronous with strong formation of paleosols throughout the valley (Kusumgar et al. 1986). A warm wet phase at 18 Kya is indicated by $\delta^{13}C$ ratios from Paleosol 1 at Burzahom, where a ratio of -25.3% indicates strong dominance of warm wet favouring C3 plants, which contrasts clearly with C4 dominance in the organic fraction of earlier buried paleosols (Krishnamurthy et al. 1982). The record at Butapathri-II gives a sequence dating back to ca. 12 K BP (Dodia 1983). Both records seem to indicate the onset of thermophilic *Juglans*, *Carpinus*, and *Corylus* broad leaved taxa at around 5000 BP, again roughly synchronous with the start of the Neolithic period. Reconstructing a well resolved chronology from these records presents some difficulty due to bulk organic dates being taken from samples up to 50 cm in length, and these records may best serve generally refining the cool-dry/warm-wet phases in the valley.

Later Holocene climatic records have been reconstructed through pollen sequences from lower altitude lakes at Anchar and Horkasar (Dodia 1983; Agrawal et al. 1989), dating to 4000 BP and 1000 BP respectively (Agrawal et al. 1989). Anchar is characterised by the dominance of grasses interpreted as cereals in the NAP curve, with *Pinus*/broad leaf fluctuations in the arboreal pollens. An anti-

Table 6.2 Toshmaidan pollen stages (Singh 1963) and date ranges (Singh and Agrawal 1976). Dates recalibrated in OxCal 4.2

Stage	Depth (cm)	Arboreal pollen (%)	Non arboreal pollen (%)	Phase	Notes	Stratigraphy	Dates cal. BP
h	25–5	80–50	50–20	Blue Pine—Alpine Fir	Sudden rise of Alpine Fir; almost total disappearance of *Quercus*, *Ulmus*, *Juglans* and other broad leaf varieties	Fibrous and Humified peat	–
g	80–25	40–50	50–40	Blue Pine	Coniferous dominance; retreat of *Artemisia* and grasses; maximal fern values	Humified peat	3364–2493
f	140–80	20–80	80–20	Transitional (cooling)	Rapid advance of blue pine at cost of *Ulmus, Quercus*; reversal of Stage d	Humified peat	–
e	245–140	20–40	80–60	Broad leaved	Dominance of *Quercus* and *Ulmus*; thermophilous advance	Fine organic mud	–
d	280–245	25–40	75–60	Transitional (warming)	*Pinus* declining in favour of *Quercus*; rising *Artemisia*	Fine organic mud	15,199–11,824; 12,654–10,598; 11,804–10,280
c	372–280	10–50	90–50	Blue Pine	Drop in *Quercus* in favour of *Pinus*; return of *Ephedra*; correlation between broadleaved and NAP advance	Fine organic mud; clay mud	20,602–16,660; 18,398–15,507
b	388–372	10–30	90–70	Blue Pine-Oak	Rapid drop in *Pinus,* advance in *Quercus;* near disappearance *Ephedra*, Poaceae established	Blue-grey clay	20,606–15,467
a	405–388	5–30	95–70	Blue Pine-Cedar	*Pinus Wallachia* dominant; establishment of meadows, forest advance	Blue-grey clay	18,934–14,239

correlation between anthropogenic plants and aquatics suggests the reclamation of farming land at lake margins on the valley floor. A similar relation anti-correlation is found at 800 BP in the Horkasar core, which Agrawal et al. (1989) believe to be evidence for the beginning of intensive rice paddy cultivation. Fluctuations in anthropogenic crops against a background climate index based on B/C ratios may allow for an understanding of ecological responses to climate change, however complete data sets from these records remain unpublished.

Agrawal (1988: 339) notes the early post glacial warming in Kashmir may be correlated with pollen records from Nepal and Japan, and suggests the possibility of a latitudinal climatic belt. As Agrawal (1988: 340) also describes an inverse correlation between Kashmiri and lowland North Indian records, the orographic effects of the Pir Panjal and Tibetan plateau on the paleoclimate of Kashmir may be a dominant factor in influencing local and regional conditions. The regionally out of synch climate proposed by Agrawal seems to be supported by comparison of the Kashmir records with pollen, isotopic and geochemical records from the Siwalik foothills to the south (Trivedi and Chauhan 2009; Das et al. 2010) and the Trans-Himalayan and Ladakh regions to the northeast (Rawat et al. 2015; Leipe et al. 2014; Demske et al. 2009). A comparison of shifts in climate between Kashmir and adjacent regions (Table 6.3) reflects more frequent onsets of optimal conditions and transitional periods in the valley than the protracted cold dry desert conditions of the Trans-Himalaya or fluctuations in monsoonal periods of the Siwaliks.

The apparently regionally asynchronous climate shifts in Kashmir have allowed for some scholars to conceptualise cultural change in the valley as driven by fluctuations between warm-wet and cool-dry cycles, treating the valley as a climatically optimal ecological refuge between the steppe-desert and monsoonal systems of surrounding areas (Agrawal 1988, 1992; Shali 2001). In these schemes, the Neolithic, Kushan and Karkota periods map neatly onto warm wet periods (Table 6.3), interspersed with periods of cultural or societal degradation. Whilst these may be useful interpretations in a broad sense, they are complicated by the poorly resolved chronology of climatic records and gaps in knowledge of the economy, ecology and social organisation during large parts of these cultural phases. Taking into regard the variability of environmental zones within the valley and what is known from archaeological and palaeoclimatic records, we are presented with the opportunity to produce an integrated model for understanding long term human-environment interaction in Kashmir.

6.3 Human-Environment Interaction in Kashmir

6.3.1 Previous Studies

Early examinations of the interrelation between climate change and human activity in Kashmir were raised by De Terre and Paterson (1939: 233–235), critiquing the provenance of artefacts previously believed to be Palaeolithic and arguing that human habitation of the valley most likely became possible as a response to warmer conditions of the Holocene. In this interpretation, late Palaeolithic hunters colonised the valley in the pursuit of new game, before taking up agriculture. Despite raising these question, much of their work was dedicated to glacial cycles and climate change operating at time scales longer than human occupation of the valley.

Subsequent studies drew upon the interpretation of anthropogenic markers in pollen records. Singh (1963) ascribes some changes in the Toshmaidan record to deforestation during the migration of Aryans and Indo-Greeks, grazing by Central Asian pastoralists and large scale works during the Mughal period, however the impacts and timing of these are not clearly articulated. Vishnu-Mittre (1966) has argued that the pollen record from Toshmaidan provides little to no evidence for human impact on the environment, in contrast with the Hygam record with some indicators of agricultural intensification, based on fluctuations in the pollen curves of cereal grasses and *Plantago lanceolata*. Vishnu-Mittre and Sharma (1966: 206) describe the Hygam records as having four anthropogenic phases: the commencement of agriculture; low level cultivation; intensification of agriculture; and decline. Notably, the decline corresponds with the end of Hygam pollen Stage e, marked by an increase in coniferous species interpreted as evidence for regional cooling. Vishnu-Mittre and Sharma argue that agricultural intensification corresponds with

Table 6.3 Comparative chronology of Kashmir climate and cultural phases with regional climate shifts (Kashmir records: Singh 1963; Dodia 1983; Agrawal 1992. Siwaliks: Trivedi and Chauhan 2009; Das et al. 2010. Trans-Himalaya: Rawat et al. 2015; Leipe et al. 2014; Demske et al. 2009)

Cultural Periods	YBP	Kashmir	Siwaliks	Trans-Himalaya
Historic	500	Cool Dry	Cool Dry - Ameliorating	Cool Dry - Ameliorating
	1000	Warm Broad Leaf dominance		
Karkota	1500	Transitional - Cooling		
Kushan	2000	Warm Broad Leaf dominance		Cold Dry
NBPW/Indo-Greek	2500	Cool Dry	Cool Dry	
Megalithic	3000			
	3500	Transitional - Cooling		
Late Neolithic	4000			Transitional - Cooling
Early Neolithic	4500	Holocene Optimal		
Aceramic Neolithic	5000			
	5500		Warm Broad Leaf dominance	Holocene Optimal
	6000			
	6500		Cool Dry	
	7000	Cool Dry		Transitional - Warming
	7500			
	8000			8.2k Cold Event
	8500		Warm Broad Leaf dominance	
	9000	Transitional - Cooling		
	9500			Cool Dry
	10000			
	10500	Warm Broad Leaf dominance		
	11000			
	11500		Records unavailable	Warm Wet
	12000	Transitional - Warming		
	12500			

the Holocene optimum during the Neolithic period and subsequent contractions are again evidence of a climate driven societal collapse. These interpretation are problematised by the lack of absolute dates from the Hygam record.

The Kashmir Palaeoclimate Project (KPCP) was initiated in the early 1980s before being interrupted by rising militancy in the valley. In addition to documenting the first securely dated Upper Palaeolithic in the valley at around 18 kya (Pant et al. 1982), the project revised produced new chronological, palynological, isotopic and geological data. A synthesis of these studies (Agrawal 1992) argued for expansions of settlements and population expansion in the valley during warm wet periods of the Upper Palaeolithic, Neolithic, Kushan and Karkota periods, as evidenced by the spread of Neolithic villages, and later, monumental constructions throughout the valley during climatic ameliorations. Agrawal (1992: 271) argues that settlement expansion and population growth during these periods led to Malthusian pressures precipitating societal collapse when average temperatures declined by one to two degrees during periods of cooling.

Drawing on historical accounts, and KPCP and archaeological datasets, Shali (2001) interpreted culture change in Kashmir as a unilinear sequence of cultural development, following Agrawal's (1992) scheme of acceleration during optimal conditions and slowing during cold dry periods. Shali integrates some discussion of economic changes during these periods, attributing the expansion of agriculture and animal husbandry to ongoing increases in social complexity allowing for the division of labour and the importation of new crop species as part of regional trade intensification. Shali (2001: 134) has also argued for regional climate change as a driver of migrating Central Asian tribes, forcing them into closer contact with Kashmir due to the more favourable climate of the valley. These demographic influxes are argued to have contributed either to fragility of social structures during climatic deteriorations (Shali 2001: 129), or accelerated technological and cultural change and synthesis during optimal conditions (Shali 2001: 182).

The interpretive frameworks of the studies above are closely tied to notions of environmentally driven societal collapses that have been subject to reappraisal in recent archaeological literature (McAnany and Yoffee 2009; Faulseit 2015). Common to collapse oriented studies are varying degrees of human-induced stresses on environments, or global and regional climate change as the primary forcing factors of historical transformation (Middleton 2012). Yatoo (2012) has argued that interpretations such as this arise partly as the result of site-centric archaeological studies in Kashmir and ad hoc correlation with often poorly resolved climate data, evident in such assumptions as the presence of monumental construction during the Kushan and Karkota periods as periods of wealth and stability interspersed with periods of climate driven hardship. Scott (2017) has argued that archaic states, rather than populations as a whole, are particularly susceptible to climate change, and that the absence of large archaeological monuments during periods previously interpreted to be phases of "collapse" may simply be evidence for the breakdown of coercive forces able to centralise labour for such large scale constructions. Yatoo's (2012) landscape oriented studies in northwest Kashmir may present early evidence for social reorganisation, and dispersed and adaptive patterns of land use in the valley, though further archaeological testing and excavation is required to better understand these changes.

Resilience to acute or protracted climate change in South Asia has been examined through shifts in cropping pattern that allowed Indus Valley populations to cope with environmental diversity and stresses in prehistoric northern South Asia (Petrie et al. 2017). Changes in water management, crop selection and settlement pattern have opened new debate onto the ways that Harappan populations responded to climate episodes such as the 4.2 k event, shifting discussions from one of collapse following the Mature Harappan period to reconsidering the post-urban Late Harappan as an adaptive settlement strategy rather than necessarily a period of collapse. Young (2003) has modelled long term economic and social adaptation across multiple environments in the valleys and lowlands of northwest Pakistan. Drawing on botanical and faunal remains as well as environmental, archaeological and ethnographic evidence for shifting patterns of seasonal pastoral mobility, sedentism and cultivation, Young argues for complex and shifting relationships between Bronze and Iron Age agro-pastoralists, their environment and adjacent regions of China, Kashmir and Central Asia (Young 2003). These multi-proxy studies may provide the best avenue to build more robust new models of past human-environment relationships in Kashmir.

6.3.2 *Kashmir as Ecological Niche*

Based on the geography and climate of Kashmir described in Sect. 2, we may consider the valley to be an orographically circumscribed entity comprised of smaller ecological zones. Though the valley has long been culturally and ecologically enmeshed with adjacent regions, the enclosing topography allows for well-defined spatial constraints for testing hypotheses relating to human-environment interactions. We may consider Kashmir as a fertile and temperate niche, attractive for various forms of settlement, cultivation and resource exploitation (Agrawal 1992; Shali 2001; Bandey 2009). Whilst these naturally occurring conditions may have been a factor in initial settlement of the valley, anthropogenically induced environmental stresses and opportunities in the valley were likely major drivers of social change.

Niche Construction Theory (NCT) originates in evolutionary biology, emphasising the ability of organisms to partially direct their own, and other species evolutionary pathways through the modification of the dwelling niches in which they exist (Laland and O'Brien 2010). Laland and O'Brien (2010) have argued that due to the capacity *Homo sapiens* have for intergenerational cultural and technological transfer, human niche construction is unique in its potency for directing the evolution of human and other species. Examples of this may include the ways that dietary patterns relating to hunting and gathering, agriculture or pastoralism may have impacted both human genetic evolution in terms of the capacity to process starch or lactose, and the evolution of cultivated crops or domestic animals. As opposed to dichotomous relationships of co-evolutionary frameworks such as host-parasite, predator-prey, herbivore-plant, Laland and O'Brien (2010: 311–312) stress that NCT may be conceived of as a broader network of indirect evolutionary linkages that may be recognisable archaeologically.

Responding to debates pushing for a global Anthropocene beginning in the 20th Century, archaeologically focused scholars argue that human niche construction has impacted environments and species distribution globally since the Late Pleistocene (Boivin et al. 2016). Of four key phases of human niche construction identified by Boivin et al. (2016), two are particularly useful for examining human-environment relations in the Kashmir Valley, the first being the spread of agriculture and pastoralism, during which a number of domesticated plants and animals, alongside other commensal species, dispersed across the globe. The second phase is the subsequent development of urbanism and elaboration of trade networks during which intensified patterns of land usage, cultural exchange and overexploitation of resources began to take place. Ellis et al. (2017) list several archaeologically and geologically visible proxies of niche construction by agrarian societies, including anthrosols and degraded soils, deforestation and permanent fields, all of which may be detected in Kashmir.

In addition to detecting landscape modification by cultivators, Spengler (2014) has argued for NCT as an informative framework for understanding practices of Central Asian pastoral groups during the Bronze (ca. 2500–500 BC) and Iron Ages (500 BC–AD 500). Contra to past views that nomadic or transhumant pastoralists simply inhabited ecological niches, Spengler argues for long term processes of intentional landscape modification as a cultural and economic strategy, visible through environmental markers for deforestation and suppression of woody taxa in favour of herbaceous colonists associated with grazing, most commonly *Chenopodium* species. Miehe et al. (2009) have also argued that this phenomenon is visible in changes in the pollen spectrum in Tibet, where pollen and micro charcoal indicators for mid-Holocene deforestation and grazing fluctuate independently of isotopic and geochemical records displaying no evidence of pasture management, tying into wider debates on the ways that economic adaptation may have allowed humans to colonise the Tibetan Plateau. These case studies provide a method for detecting pastoralist niche construction in Kashmir.

6.3.3 Conceptualising Long Term Human-Environment Interaction in Kashmir

The framework proposed in this paper aims to draw on multiple lines of archaeological and environmental data to model both human responses to environmental or climatic changes in the valley, and human modification of the valley itself. Based upon differentiated geographical and topographical zones within Kashmir, long term human ecology may be characterised through shifting patterns of settlement, economic and cultural organisation across the alluvial valley floor (1600–1800 m ASL), Karewa tablelands and foothill zone (1800–2200 m ASL), mountain (2200–3000 m

Table 6.4 Framework for modelling local and regional scale human activities in Kashmir valley, including potential archaeological and environmental proxy evidence. Local scale dynamics are bridged across topographic zones by regionally controlling social, political and climatic factors

Topgraphic Zone	Environmental factors	Economic/technical adaptation	Anthropogenic factors	Adaptive mechanisms	Proxy evidence
Alluvial	Mineral input Flooding	Agriculture	Soil degradation Flooding	Cropping patter/multi-cropping Settlement pattern	Palaeobotanical Geochemical Structural remains
Foothill	Flooding	Village/town Agriculture Horticulture	Soil degradation Flooding Population pressure	Settlement pattern Irrigation	Site size/density Structural remains Palaeobotanical
Mountain	Seasonality Plant species diversity	Pastoralism Hunting/foraging Supplementary agriculture	Overgrazing Diversity decline	Grazing pattern Deforestation Mobility pattern	Pollen Microcharcoal Faunal Palaeobotanical
Alpine	Seasonality Plant species diversity	Pastoralism	Overgrazing Diversity decline	Grazing pattern Mobility pattern	Pollen

Local scale dynamics

Regional dynamics - climate change, social complexity, interaction and trade, etc.

ASL) and alpine (3000–4000 m ASL) zones. Though certain activities in each of these zones may be geographically constrained, they do not operated as discrete units and are integrated into a dynamic, valley wide network (Table 6.4). Certain social or environmental factors may influence these activities at local scales (Table 6.4, x-axis), whilst also being subject to shifting climatic, cultural or political dynamics at regional or extra-regional scales (Table 6.4, y-axis). Regional factors may include broad climate shifts as described by Singh (1963) and Agrawal (1992), the interaction of Kashmir with prehistoric networks of pastoral and agricultural exchange (Stevens et al. 2016), or cultural integration with prehistoric cultural complexes (Yatoo and Bandey 2014) and later systems of imperial control (Shah 2013).

Modelling local scale dynamics across the valley requires consideration of the appropriateness of specific proxy evidence and the ways these datasets may be interpreted to separate regional scale changes from local human-environment interactions. Such interpretation may be reasonably uncomplicated in the cases such as long term studies of relatively stable archaeological features, though may become more problematic when trying to resolve small scale human activities in long term environmental archives.

6.3.3.1 Settlement Pattern

The first systematic field survey of settlement pattern in relation to ongoing social process and environmental change in Kashmir was undertaken by Yatoo (2012) in the Baramulla District in the northwest of the valley. Yatoo's work aims to integrate long term settlement stability and change with other shifts in resource utilisation and cultural interactions. Despite the fact that the study examined only surface features, settlements seemed to vary topographically through time, and multi-period sites were in the minority of those recorded (Yatoo 2012: 197). Yatoo's data shows that during the Neolithic period, settlements typically clustered on *Karewa* table tops above the Jhelum floodplain, around or above 1600 m ASL. All surveyed Neolithic sites were within a single size category of 7500–9000 m^2. In subsequent protohistoric and historic periods, there is a greater diversity of altitudinal distribution and settlement density. Yatoo attributes these changes to broadening resource utilisation, including paddy cultivation within the floodplain and grazing in mountain zones, as well as responses to climatic shifts, such as fluctuation in river and lake levels on the valley floor.

Conningham and Sutherland (1997) and Young (2003) have also raised questions of seasonal settlement pattern during the early Neolithic periods. Subterranean conical structures during this period were traditionally believed to be winter habitation pits (Bandey 2009). Reassessing these structures in the Kashmir and Swat Valleys, Conningham and Sutherland argue for food processing or other non-habitational uses of the pits, the nature of winter dwellings in the valleys. This has been explained through the possibility of seasonal pastoralism and wholesale abandonment of settlements in the valley during winter (Conningham and Sutherland 1997: 32), perhaps as part of a seasonal pastoral migration. Seasonal mobility may be one explanation for variation in settlement patterns that goes beyond growth and contraction settlement and climate cycles, as it may allow for some flexibility in response to climate pressures, from short term to long term scales. Despite the appeal of this model, there is yet little other evidence for wholesale movements of populations out of the valley, and from the Neolithic onwards the seasonal growth cycles of certain crops within archaeobotanical assemblages suggests a tendency to year long occupation in the valley.

6.3.3.2 Agricultural Adaptations

The Early Neolithic botanical assemblage from four phases at Kanispura provides the first insights into agriculture in the valley. The oldest plant remains at the site are dated relative to c. 2700 BC, with wheat and barley grains from a later phase directly dated c. 2200 BCE (Pokharia et al. 2017). The overall assemblage is dominated by barley (*Hordeum* vulgare) with smaller amounts of emmer wheat *(Triticum dicoccum*), compact wheat (*T.* cf. *aestivum*) and a large proportion of lentil (*Lens culinaris*). The composition of this assemblage is comparable to contemporary sites situated to the west of Kashmir, including Sheri Khan Tarakai (Thomas and Cartwright 2010), Mehrgarh (Costantini 1981) as well as at southern Central Asian sites including Jeitun (Harris 2010) and Anau (Miller 1999). Costantini (2008) describes these early periods of farming at Mehrgarh as developing prior to specialisation of agriculture and selective cultivation of crops. This protracted transition to agriculture in South Asia occurs through shifting relationships between cultivation, sedentism and pastoralism (Murphy and Fuller 2016). Though there is not yet any recorded evidence for early sedentism or cultivation at during the Aceramic phase at Kanispur, the presence of stable settlement structures and agricultural crops at the slightly later dated Gufkral Aceramic (Sharma 2013) raises possibility for their discovery in the future.

The Aceramic period at Gufkral is also characterised by cultivation dominated by barley, followed by smaller proportions of wheat, lentil and pea (Sharma 2013: 103). During the Early Neolithic wheat becomes the dominant crop, and rice introduced during the Late Neolithic, becoming the primary crop by the Megalithic. These changes in consumption patterns are comparable to the Neolithic botanical assemblages from Burzahom, from the Early Neolithic onwards, though rice never comes to dominate the assemblage as at Gufkral (Lone et al. 1993). These developments have been interpreted as a shift from single season to bi-seasonal cultivation, with the emergence of rice as the dominant crop linked to more favourable summer growing conditions in Kashmir (Lone et al. 1993: 202–203). However, the diversity of botanical assemblages across sites in the valley seems to suggest at least some form of localised selection of crops. This may be reinforced through examination of stratified botanical remains from a conical pit at Qasim Bagh (Spate et al. 2017), where wheats dominated throughout the sequence dated ca. 2000–1400, with smaller proportions of broomcorn millet (*Panicum miliaceum*) and lentil. Barley and rice are entirely absent from the assemblage.

Rice dominates the Megalithic and NBPW phases at Semthan, before a shift to primarily barley and wheat during the Indo-Greek and Kushan periods (Lone et al. 1993). Barley and wheat together make up the largest proportion of crops during the Kushan period at Kanispur at nearly double the quantity of summer rice and millets (Pokharia et al. 2017). The returning dominance of winter wheat/barley may be ascribed to their higher calorific returns (Bates et al. 2017), as well as their suitability to cooler-dry conditions following the Megalithic period. Due to a lack of excavation data, it is unclear whether there was a form of population collapse, though fragmentary evidence suggests some form of "Iron Age" social reorganisation took place in Kashmir and regionally following 1000 BC (Yatoo 2012: 287–289). Climate or population factors aside, these reorganisations may have led to shifting of patterns of labour, better suited to flexible forms of agro-pastoralism incorporating wheat and barley, rather than the more centralised cultivation of rice on the valley floor.

Archaeobotanical remains from pre and early historic sites in Kashmir give insight into long term patterns of human adaptation to the ecology of the valley. The early barley and emmer wheat dominated phases at Kanispur and Gufkral may be evidence of the initial importation into the valley of aridity tolerant forms of cultivation more suited to the hilly northern regions of South Asia. Shifts towards wheat and rice cultivation may be driven by social or cultural factors as well as exploitation of the more fertile Jhelum alluvial soils and water availability in the valley. Proportional representation of botanical remains may be influenced by taphonomic and other predeposition factors, however the spatial and chronological variation of these remains across the valley allows some understanding of economic shifts as part of long term human-environment interaction in Kashmir.

6.3.3.3 Evidence for Pastoralism

Mortality patterns and species composition in faunal assemblages from Gufkral indicate an economy based on hunting of wild animals during the Aceramic Neolithic period, with domestic sheep and goats representing only 5% of the total assemblage (Sharma 2013). By the Early Neolithic, domestic caprids represent 26% of the animal economy, with domestic cattle making up a further 18%. These proportions increasing to 45 and 20% during the Late Neolithic. No faunal data has been published from either Burzahom or Kanispur, though preliminary reports indicate a significant hunting element at Burzahom during the Early Neolithic (Allchin and Allchin 1982: 112). Changes in these assemblages suggest an increasingly important pastoral component to the economy of Kashmir, though this development has been little examined other than Singh's (1963) attribution of some past deforestation on the flanks of the valley to Central Asian pastoralist groups.

With the exception of Singh's comments, there has been little consideration of the past impacts of transhumant grazing in Kashmir. Recent studies in the mountainous zones of Central Asia have situated pastoral groups as drivers of prehistoric crop exchange (Stevens et al. 2016; Spengler 2015), as well as pastoralist ecological practices and routes as laying the basis of the historic Silk Road networks between China, Central and South Asia (Frachetti et al. 2017). Stevens et al. (2016) have considered Kashmir as an important node in the spread of Chinese technologies and domesticates including stone fruits, millets and ground edged harvesters into northern South Asia, though the timing and mechanisms for this exchange are not yet articulated. The recent discovery of broomcorn millets at Qasim Bagh (Spate et al. 2017) seems to indicate that these exchanges likely took place through contact with pastoralist networks of exchange throughout Central and South Asia in the second millennium BCE. As well as their importance in developing these exchange networks, long term and flexible land use patterns by pastoral groups in Central Asia maybe important tools for understanding patterns of human resilience and environmental adaptation in the region (Spengler et al. 2013; Frachetti 2012). Due to the limited survey and excavation that has taken place in Kashmir, particularly at middle altitudes, detecting the presence of past patterns of pastoralism may be best approached through environmental records. Following the NCT concept for pastoralist modification of the landscape proposed by Spengler (2014), we may consider applicable markers for pastoralist modification of, and adaptation to, the Kashmir landscape in the past.

Though there has been no major research into past pastoral environmental impacts in Kashmir, modern ethnographic (Casimir and Rao 1985) and ecological (Mir et al. 2015; Ahmad et al. 2013; Dad and Khan 2010) studies have documented the impact of grazing of various intensities on vegetation communities distributed spatially and altitudinally across Kashmir. Through participant observation of seasonally migrating Bakharwal nomads, Casimir and Rao (1985) observe the cutting of corridors through mature *Pinus* forests on the northern slopes on the Pir Panjal at the southern pass into Kashmir (2500 m ASL) and exploitation of *Poa* and *Chrysopogon* grasses, as well as of white clover (*Trifolium repens*) and intensive gathering of various *Poly-*

gonum, *Chenopodium* and *Cerastium* for both human and animal consumption. The suppression of *Pinus* stands assists in the propagation of these herbaceous taxa and may be considered one form of ecological niche construction by pastoralist groups. Propagation of *T. repens* and *Plantago* species are also associated with pastoral activity at the high altitude (3400 m ASL) meadow at Chandanvari (Casimir and Rao 1985: Table 3).

In pasturelands adjacent to the valley floor, near the modern city of Anantnag, Ahmad et al. (2013) analysed species composition at 12 sites subject to varying intensities of grazing. At ungrazed sites, the grass *Bothriochloa pertusa* dominated the species composition, while at moderate and heavily grazed sites, *Cynodon dactylon* was the dominant grass species. As grazing intensity increased, the Imporance Value Index (IVI) of these two grasses increase and a strong association between the two species was found at sites subject to overgrazing. At moderately grazed sites, *Medicago lupilina* is closely related to *C. dactylon*. Strong IVI values were also reported for *Trifolium repens* in relation to grazing, with evidence for colonisation by *Plantago laceolata* and *P. majora* at heavily grazed sites.

Mir et al. (2015) also recorded a strong correlation and dominance between *B. pertusa* and *C. dactylon* at three alpine pasture sites around Sonmarg in the east of Kashmir. These grasses along with *Poa annua*, *Stipa siberica* and *Sambucus whightiana* dominate IVI both before and after grazing at all three sites. Substantial to total declines in IVI of *Rumex nepalensis* and *Rumex dentata* after grazing at two of the sites may indicate the palatability of these taxa as forage plants. Similar taxa were associated with grazing at several high altitude sites studied by Dad and Khan (2010). Dad and Khan also note the colonisation of abandoned grazing campsites by nitrophilious *Rumex nepalensis*. All studies recorded a marked reduction in overall herbaceous diversity correlated with grazing intensity.

The viability of these taxa for reconstructing past pastoral practises is complicated by a number of factors. Declining *Pinus* or other arboreal forest pollen may be a proxy indicator of some form of land clearing, particularly if these changes can be separated from climatic effects. Micro-charcoal influxes may also be an informative indicator of forest clearing. Long range deposition of coniferous pollens may also have a masking effect on localised changes in forest communities. The primary taxa associated with grazing intensification in the above studies are all grasses whose pollens may not be separable from other species and may not be representative of grazing induced changes in the landscape. Despite these problems, wholesale advance of grass species as the expense of forest taxa may be a general indicator of pastoralist activities within the mountainous zones of Kashmir below the timber line. Of non-arboreal or grassland taxa, *Trifolium* and *Medicago* species associated with grazing are insect pollinated and not likely to be represented in environmental archives. Fluctuations in palatable *Polygonum, Chenopodium* species that may be propagated by pastoral actions may be good indicators of past grazing. More suitable may be wind pollinated *Rumex* species as these are closely related to grazing intensity in the above studies and are also early colonisers of grazed and disturbed land. Ruderal *Plantago* species may also be good indicators of gazing induced dis-

Table 6.5 Potential pollen proxies for past grazing in Kashmir

Forest taxa	Grasses	Herbaceous—palatable	Herbaceous—ruderal
Pinus wallachiana *Cedrus deodara* *Abies pindrow* Fern understory	*Bothriochloa pertusa* *Cynodon dactylon* *Poa annua*	*Polygonum* sp. *Chenopodium* sp. *Rumex nepalensis* *Rumex dentata*	*Rumex nepalensis* *Plantago lanceolata* *Plantago majora*

turbances. Table 6.5 summarises potential marker species for pastoralist activity in Kashmir.

6.4 Conclusions

6.4.1 Discussion

The above archaeological and environmental data have highlighted the potential for multi-proxy studies in understanding long term human-environment interaction and resilience in Kashmir. Current limitations to building on this framework include difficulties in undertaking new archaeological fieldwork, and the lack of finely resolved chronologies at singular sites and across the valley more generally. The lack of a well resolved sequence at the environmental cores from middle and high altitude grazing sites at Toshmaidan (Singh 1963) and Butapathri (Dodia 1983) complicates the detection of pastoral strategies in the past.

Despite the shortcomings of these records, early examination of settlement, archaeobotanical and environmental data indicates that past populations in Kashmir not only responded to climate changes beyond cycles of population expansion and collapse but undertook varying strategies to modify both social behaviour and the environment to allow for resilient responses to climatic deteriorations. Fluctuations in climate conditions may have been responded to by shifting patterns of summer/winter cultivation and differentiated usage of alluvial or foothill zones as adaptations to higher summer runoff or increased winter precipitation. We may see evidence of these shifts in the changing archaeobotanical assemblages of the Neolithic and Kushan periods (Pokharia et al. 2017; Spate et al. 2017; Lone et al. 1993).

Changes in agricultural land use may have also led to shifting patterns of settlement as well as an expansion of pastoralist exploitation of middle and high altitude pastures. Data from Yatoo's (2012) survey indicates a colonisation of mountain zones during the Kushan period, though this may have taken place earlier without leaving marked archaeological signatures. This pastoralist ecology may have allowed for engagement with other transhumant groups from around the mid-second millennium BC and intensified following the emergence of the historic Silk Roads (Frachetti et al. 2017). Connections with neighbouring Silk Road polities during the Kushan and Karkota periods, along with the centralisation of power under dynastic rule in the valley may have presented trade, technological and political means to mitigate the effects of climate change in the valley.

In contrast to previous notions of climate driven cycles of social expansion and collapse in Kashmir, we may take steps to examine long term patterns of resilience across differentiated landscapes and altitudinal zones in Kashmir. Detecting these responses and adaptations at local and regional scales presents the opportunity for new problem oriented and hypothesis testing fieldwork to take place in Kashmir, employing spatially and temporally suitable environmental and archaeological proxies and datasets.

6.4.2 *Future Prospects*—Pari-Has

In May 2017 a series of preliminary environmental soundings were taken at several sites across Pir Panjal flank of Kashmir. This sampling aims to detect anthropogenic change in the landscape at middle and higher altitudes, with a focus on grazing impacts. Much of this work focused on the Dodpathri area of Budgam district, a meadow zone within the montane forests on the east flank of the valley. Altitude in the area ranges from around 2500–2800 m ASL and is situated below the passes to the higher pastures at Toshmaidan.

Pari-Has (Site D, Fig. 6.3) is a peat deposit situated upon a series of grazing terraces, within a wooded *Abies-Pinus* belt (Fig. 6.4). Two samples were taken up to a depth of 2 m using push cores. The first core, PH01, was only sampled to a depth of 1.2 m, but this sample was favoured for further study due to possible contamination of the second sample. A sequence of peat-clay-peat was logged (Fig. 6.5), and three AMS dates from bulk organic material were returned from the base of the sample as well as below and above the peat-clay transitions (Table 6.6). The base of the sequence dates between 2330 and 2150 BP whilst peat formation is arrested around 1900 BP, resuming around 750 BP (Fig. 6.5). It is unclear whether the formation of clay bedding is a result of cool dry conditions, or wetter conditions transforming the peat bog to a small lake. The chronology of the formation and deposition of the peat-clay sequence seems to run contra to the general scheme of cold dry conditions in Kashmir for several centuries before 2000 BP, followed by a climatic amelioration of around 500 years (Agrawal 1992).

Low magnetic susceptibility (K) throughout the sample (Fig. 6.5) suggests the steady deposition of diamagnetic materials (Evans and Heller 2003). Previous mag-

Table 6.6 AMS dates from core PH01. Calibrations in Oxcal 4.2

Lab	Lab code	Sample code	Depth (mm)	RC age	Cal. BP (2-σ)
DirectAMS	D-AMS023859	PH01-A1	490	832 ± 26	787–692
DirectAMS	D-AMS023860	PH01-C1	760	1948 ± 49	2002–1741
DirectAMS	D-AMS023861	PH01-C2	1150	2223 ± 28	2321–2153

Fig. 6.4 Peat swamp at Pari-Has. View to northeast, showing slope up to grazing terrace

netic studies in Kashmir (Kusumgar et al. 1985) have used increased magnetic susceptibility of sediments as proxies for higher weathering and runoff of magnetite rich parent materials and thus wetter conditions, though this is generally reflected in mass magnetic susceptibility (χ) values higher than those of the Pari-Has record. Phadtare (2000) has correlated similar positive χ values comparable to Pari Has with warm wet conditions in a peat bog record from the Trans-Himalayas.

The sedimentary evidence suggests localised conditions within the mountain pasture belt around Dodpathri, beginning around the same time as the rise of the Kushan period in Kashmir. A single Kushan settlement has been reported around 5 km from the study site, and has been interpreted as part of a general movement by Kushan rulers to colonise and control mountain pastures and passes between Kashmir, the Kushan heartland of northern Pakistan and Silk Road trade routes into Tibet, China and Central Asia (Shah 2013). Aside from macro-botanical remains from the sites on the valley floor, little is known of the Kushan economy in Kashmir. The Pari-Has core has the potential for examining Kushan landscape management, pastoral and possible cultivation practices in mountain zones on the valley flanks. Prospects for further work include analysis of charcoal influx through the sediment column and large count numbers of herbaceous pollen grains, with a focus on indicator type

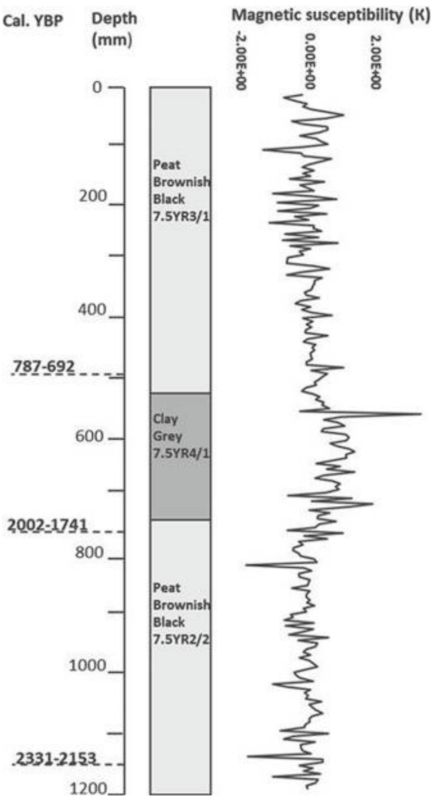

Fig. 6.5 Stratigraphic section(left) and volume magnetic susceptibility (K-dimensionless in SI) (right) of core PH01

pollens discussed above. More closely controlled data relating to land and environmental management practices will allow for long term understanding of human resilience in Kashmir against the background of wider climate and social changes. Characterising the valley as an especially rich ecological niche will also help better link the valley with long scale cultural and political processes in adjacent centres of Central, East and South Asia.

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Part III
Natural Disasters and Impacts in the Past Societies

Chapter 7
Living with Earthquakes along the Silk Road

Miklós Kázmér

Abstract Earthquakes are among the most horrible events of nature due to unexpected occurrence, for which no spiritual means are available for protection. The only way of preserving life and property is to prepare for the inevitable: applying earthquake-resistant construction methods. Zones of damaging earthquakes along the Silk Road are reviewed for seismic hazard and to understand the ways local civilizations coped with it during the past two thousand years. China and its wide sphere of cultural influence certainly had earthquake-resistant architectural practice, as the high number of ancient buildings, especially high pagodas, prove. A brief review of anti-seismic design and construction methods (applied both for wooden and masonry buildings) is given, in the context of earthquake-prone zones of Northern China. Muslim architects in Western China and Central Asia used brick and mortar to construct earthquake-resistant structural systems. Ancient Greek architects in Anatolia and the Aegean applied steel clamps embedded in lead casing to hold together columns and masonry walls during frequent earthquakes. Romans invented concrete and built all sizes of buildings as a single, non-flexible unit. Masonry, surrounding and decorating the concrete core of the wall, did not bear load. Concrete resisted minor shaking, yielding only to forces higher than fracture limits. Roman building traditions survived the Dark Ages, and 12th century Crusader castles erected in earthquake-prone Syria survive until today in reasonably good condition. Usage of earthquake-resistant technology depends on the perception of earthquake risks and on available financial resources. Earthquake-resistant construction practice is significantly more expensive than regular construction. Frequent earthquakes maintain safe construction practices, like the timber-laced masonry tradition in the Eastern Mediterranean throughout 500 years of political and technological development.

Keywords Seismicity · Anti-seismic · Construction method · Masonry · Timber Adobe · China · Central Asia · Turkey · Syria · Greece · Italy

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7.1 Introduction

While seismicity of any area on earth can nowadays be easily measured by instrumental seismology, the quantity, quality, and distribution of the seismograph stations has been more or less sufficient for the purpose during the last 50 years only. Recurrence period of damaging earthquakes is often longer than this, even longer than individual and social memory (Force 2008). To gain information about seismic events one needs to study historical sources (Guidoboni 1993; Guidoboni and Ebel 2009), archaeological evidence (Stiros and Jones 1996), and geological evidence (McCalpin 1996).

Archaeoseismology, the archaeological study of earthquakes is extremely useful for scientists assessing seismic hazards (Sintubin 2013). It is a treasure trove of information about ancient societies. Perception of earthquakes, the risk a society can and will tolerate, the longevity and means of their social memory (Kázmér et al. 2010), expertise of builders to construct buildings which can resist ground shaking, and technology transfer associated with these activities are relevant questions for historical and social sciences.

Another worthwhile direction of research is the role of external forcing factors on human evolution. Recent studies almost invariably focused on climate change and climate-influenced change of vegetation (Maslin and Christensen 2010), while mostly neglecting the effects of seismic and volcanic catastrophes (King and Bailey 2010). An interesting idea of Force and McFadgen (2010) states that there are thirteen Neolithic cultures which later developed into major civilizations (Roman, Etruscan, Corinthian, Mycenaen, Minoan, Tyre, Jerusalem, Niniveh, Ur-Uruk, Mesopotamian, Persian, Mohenjodaro, Aryan India, Memphis in Egypt, and Chinese). One can readily add the Aztec, Maya and Inca cultures along the seismic western margin of the Americas. Putting these on a map of earthquakes it is striking to observe that all of them evolved in close proximity to faults and mountain ranges of high earthquake activity (Jackson 2006). In this study another set of sites is added, arranged along tectonically active zones along the northern margin of the Eurasian mountain range: the belt of settlements and cultures collectively called the Silk Road (Lieu and Mikkelsen 2017).

There is long but somewhat meagre tradition of studying seismic hazard, risk, and resilience of societies along the Silk Road. Earthquakes are parts of nature and life, and people have developed a connection with land throughout millennia (e.g. in Iran: Ibrion et al. 2014; however, the 2003 Bam earthquake arrived to a community not believing it can happen: Parsizadeh et al. 2015). Knowledge of seismicity and the methods used by local people to resist and survive destruction inflicted by natural calamities in general (Janku 2010) and by earthquakes in particular (Jusseret 2014; Rideaud and Helly 2017) are valuable contributions to the understanding how human society works.

Environmental history of the Silk Road has been studied intensively (see papers in the present volume), but earthquake hazard and risk, even when known to exist (Xu et al. 2010), were not systematically considered (Li et al. 2015). An exception is

Fig. 7.1 Modern land routes (*red*) of the Silk Road economic belt and sea routes (*blue*) of the Maritime Silk Road of the 21st Century (Li et al. 2015). Both networks are patterned according to the traditional merchant routes of Antiquity and the Middle Ages

the activity of the team of Korjenkov (later spelled as Korzhenkov) in Central Asia, mostly Kyrgyzstan (Korjenkov et al. 2003, 2006a, b, 2009; Korzhenkov et al. 2016).

While there is a rich literature in China on archaeoseismology of individual buildings (Zhou 2007), on regional studies (Lin et al. 2005; Hong et al. 2014), and of conceptual questions (Hu 1991; Zhang et al. 2001; Shen and Liu 2008) these often lack the necessary detail to support their conclusions. While the ideas put forward are interesting, it is necessary to make a systematic survey of earthquake-damaged buildings and other constructions to improve the seismic hazard assessment of the country. Here an overview is provided of some seismic problems along the overland Silk Road and how these were overcame by various societies during the last two millennia (Fig. 7.1).

Forlin and Gerrard (2017) reviewed the ways how communities affected by earthquakes behave after the event: the spiritual, constructional, and financial steps taken to restore the community and its property. Here we discuss the preventive measures taken by populations living along the Silk Road, irrespective whether these have been applied consciously or unconsciously, based on tradition only.

7.2 Seismicity Along the Silk Road

There is a great earthquake and mountain belt that runs from China to Italy. Throughout this region the topography is largely created by fault movement in earthquakes. These faults move as a result of the ongoing collision between the Eurasian plate to the north and the African, Arabian and Indian plates to the south. Settlements are concentrated along the range fronts (Jackson 2006).

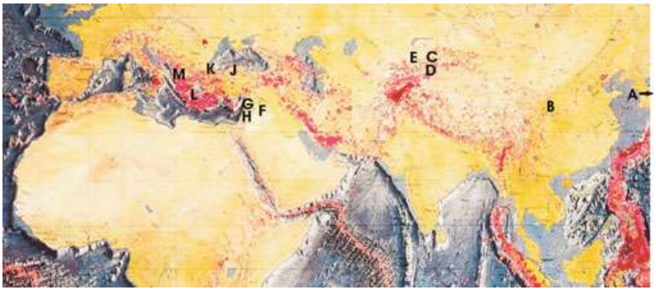

Fig. 7.2 Locations of anti-seismic construction practice discussed in the text along the Silk Road. 3D topographic map overprinted by sites of earthquakes (of the magnitude 4.5–7.5 range), which occurred between 1960 and 1980 (red dots) (Espinosa et al. 1981). **A** Wakamatsu, Japan. **B** Tianshui, Gansu, China. **C** Kamenka fortress, Issyk-kul, Kyrgyzstan. **D** Tossor, Issyk-kul, Kyrgyzstan. **E** Burana, Kyrgyzstan. **F** Palmyra, Syria. **G** Al-Marqab, Baniyas, Syria. **H** Safita, Syria. **J** Safranbolu, Turkey. **K** Istanbul, Turkey. **L** Athens, Greece. **M** Elbasan, Albania

The Silk Road, a classical artery of travel, trade and conquest, ran along the southern, mountainous margin Eurasia. It started in the ancient Chinese capital of Xi'an in the east, allowing the transfer of people, goods and ideas into the Middle East, especially to Persia, Baghdad and Anatolia. Connections reached as far as the Greek and Roman world in the Mediterranean. Probably it is not by chance that this caravan route followed the occurrence of springs, rivers, and settlements arranged along the foot of tectonically active mountains. Although certainly being a route of convenience, people and pack animals needed water, food and rest during their travel, and markets to exchange goods. These were provided by mountain-foot springs, by agriculture developed on alluvial fans, and the settlements inhabited by farmers, craftsmen and traders (Jackson 2006).

While most of the Silk Road runs in the temperate and subtropical desert zone, there is ample mountain topography to create orographic rain, and to provide year-round streamflow and perennial springs.

The Indian subcontinent and the Asian continent has been in collision obeying plate tectonic forces for tens of millions of years (Tapponnier and Molnar 1979). This deformation created the Himalayas, the range closest to India, and all the mountain ranges north of it as far as the Altay. As India is still forcing its way into the 'soft belly' of Asia, the mountains within are currently being uplifted and displaced in various ways. This active tectonics presents itself repeatedly in the form of catastrophic earthquakes (Fig. 7.2).

So the mountains are both beneficial to their inhabitants: providing rainfall, storing water, and at the same time fatally dangerous: producing earthquakes and other natural calamities. It is a well-calculated decision of societies to live there or abandon these places. It seems that humans prefer to take risks, and—considering the benefits—do not mind to live in areas regularly destroyed by catastrophic earthquakes. In this paper methods are examined on how people counter seismic destruction of their buildings, and the evidence on people's understanding and misunderstanding of these life-threatening natural processes.

7.3 Archeoseismology and Other Seismologies

The way we recognize and understand earthquakes is in tremendous change nowadays. There are digital instruments worldwide to receive seismic signals globally, and internet-connected computers automatically calculate the place, depth, and magnitude of earthquakes. This has been going on for not more than twenty years. Before that individual seismometers have been recording earthquakes for up to a hundred years. This is enough to understand the major seismic patterns of the earth, but not enough to be prepared for major earthquakes, especially in areas where these occur rarely.

The bigger an earthquake, the more rarely it occurs again at the same place. This recurrence period is often longer than the period covered by data of seismographs. To understand seismicity of the pre-instrumental period one must refer to historical documents: it is a scientific field called historical seismology (Guidoboni and Ebel 2009). A few centuries, rarely millennia can be more or less covered by these data. Where historical records are missing, there might be evidence preserved in ancient monuments. The way these were damaged by earthquakes is studied by archaeoseismology (Stiros and Jones 1996). Earthquakes recurring beyond these millennial intervals are studied by paleoseismology, theoretically into millions of years of Earth history (McCalpin 1996).

Seismicity of the past has been studied in detail on both ends of the Silk Road. Japanese historical earthquake catalogues have been reviewed by Ishibashi (2004). In China there are multiple catalogues available (Academia Sinica 1956; Li 1960; for a modern treatment of philological depth see Walter 2016). There are two recent catalogues in the Mediterranean region (Ambraseys 2009; Guidoboni and Comastri 2005). Between them there is the area covered by the catalogue of Ambraseys and Melville (1982) on Persian earthquakes, and historical catalogue of Kondorskaya and Shebalin (1982) of earthquakes in the former Soviet Union. The latter covers much of the Central Asian sector of the Silk Road.

7.4 Construction Materials in Earthquake-Resistant Techniques

Materials used in permanent and semi-permanent construction varies according to purpose, availability, financial resources, cultural and climatic influences. Adobe, brick, wood, stone, concrete, and metal reinforcements are discussed below. Our knowledge of past construction practices are limited by preservation: adobe is the worst, wood is second, while monumental stone masonry and Roman concrete has the best potential to be preserved for future generations and for the inquisitive eyes of the researcher. Finances determine permanence of buildings, therefore rural construction has the least chance to survive, urban dwellings stand in the middle, and secular and religious monumental constructions are the best to resist destruction of passing millennia.

In respect of anti-seismic construction practices monumental buildings provide the best examples. These are built from the best material, even if it had to be transported from faraway locations at high expenses. The best architects and builders were hired so that the building would last for eternity. Usually high cultures were able to build these at the height of their power.

These cultures—flourishing at opposite ends of the Eurasian continent—used a variety of construction techniques, hampering comparison of the earthquake-resistant construction practices. China did not use the marble columns of Greece and Rome, neither masonry arches invented by the Romans. Instead, a combination of wood and brick masonry was often used in ways not found in the Mediterranean. Italy extensively used metal anchors to hold together buildings already damaged by earthquakes (Forlin and Gerrard 2017); this method was not seen towards the east.

7.4.1 Yurt

Timber-framed felt tents (Turkish *yurt*, Mongolian *ger*) have been the preferred housing of nomadic shepherds of Asia, probably for millennia (Fig. 7.3). Being lightweight, it can be dismantled, transported and re-erected by two persons in a matter of hours. It provides excellent indoor temperature and ventilation in summer, and tolerable protection against winter frost. Protects the people and their property inside from rainfall, snowfall, and from strong winds. It is still in use today both in rural and in urban environment. A rarely considered property of the yurt is being totally earthquake-resistant. One of the largest intracontinental earthquakes, the 1957 Gobi-Altay earthquake ($M = 8.3$) ruptured the crust over a length of 260 km, causing elevation differences over 7 m. However, despite the enormous energy released, no casualty was reported after the event (Kurushin et al. 1997). Although the affected area is considered uninhabited, it is far from that. Permanent villages and farm-like semi-permanent settlements, both consisting of yurts, are scattered widely. Neither vertical nor horizontal ground displacements caused by passing seismic waves did any reported harm to yurts.

Fig. 7.3 Mongolian yurt (ger) in the Gobi, Mandalgovi, Mongolia. Photo: Mark Fischer. Creative Commons licence. https://en.wikipedia.org/wiki/File:Mongolian_Ger.jpg. Accessed January 30, 2018

7.4.2 Rammed Earth, Adobe

Rammed earth is an ancient construction technique. Clay, silt and sand are compacted and rammed into removable formwork (Figs. 7.4, 7.5, 7.6 and 7.7). The resultant wall and single-floor buildings constructed this way have good vertical load-bearing capacity (Jaquin 2008). In case of frequent horizontal forces caused by earthquakes it is reinforced by *hatil*-style wooden boards (see under *Wood-reinforced masonry* below) (Ortega et al. 2014). It is excellent heat insulator both in winter and in summer. Another advantage is that it can be built and restored cheaply. Rammed earth is a frequently used construction material in vernacular architecture. Monumental and military architecture uses rammed earth and adobe brick buildings in Central Asia (e.g. Chuy, Kyrgyzstan: Korjenkov et al. 2012; also in Bam, Iran: Zahrai and Heidarzadeh 2007).

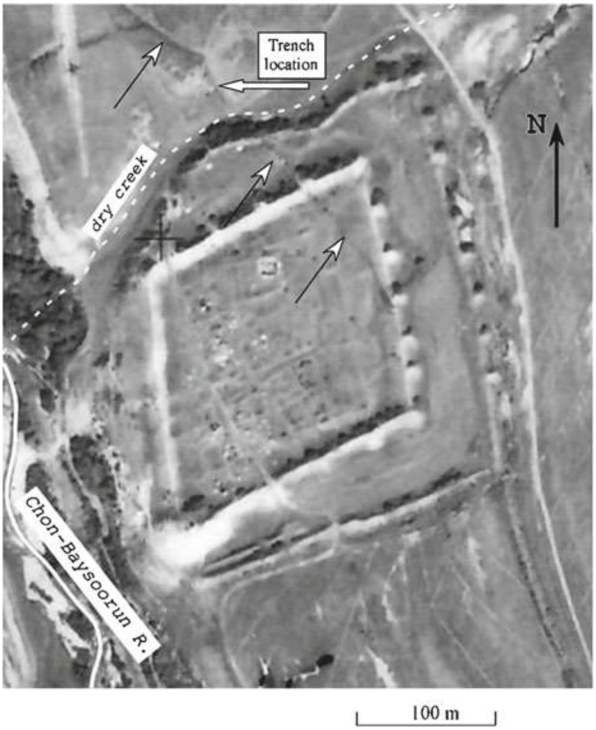

Fig. 7.4 Aerial image of the earthworks of Medieval Kamenka fortress north of Issyk Kul, Kyrgyzstan. The rhomb-shaped fortress, surrounded by towers, is cross-cut by an active fault (marked with arrows), which caused 4 m left-lateral displacement during the M 8.2 Kemin earthquake in 1911. Rammed earth walls survived with minor damage (Korjenkov et al. 2006a, Povolotskaya et al. 2006)

Fig. 7.5 Northwestern wall of Medieval Kamenka fortress. In the front: trenched cross-section of rammed earth wall. Background: 4 m displacement caused by a the left-lateral fault activated in the 1911 earthquake [Photo M. Kázmér, #1178 (Serial numbers of photographs refer to the Archaeoseismology Database (ADB), currently being built at Eötvös University, Budapest (Moro and Kázmér 2018)]

Fig. 7.6 Rammed earth wall of Tossor fortress (Lake Issyk Kul, Kyrgyzstan) as seen in excavation trench cross-cutting the buried wall. Layers are marked by horizontal scratches made by the excavating archaeologist. Three ruptures dissect the wall. Trench is 2.5 m deep (Photo M. Kázmér, #1246). For details see Korzhenkov et al. (2016)

7.4.3 Wood

Wood is the ultimate earthquake-resistant construction material (Fig. 7.8). Its flexibility allows to accept moderate horizontal load. The relatively cheap construction allows quick reconstruction in case of damage. In earthquake-prone Japan most of the traditional buildings, from the monumental to the vernacular, are made of wood. Therefore practically there is no way to do archaeoseismological studies, because evidence—even if only a few decades old—has not been preserved (Barnes 2010). If seismic destruction happens, it is always immediately repaired, at least during the past 1500 years.

Fig. 7.7 Rammed earth is still used in construction today: a roadside retaining wall was built by pressing sandy clay between two wooden planks on-site (Photo M. Kázmér, #1249)

Fig. 7.8 Thick vertical wooden columns and horizontal beams form a solid, three-dimensional framework, suitable to support the heavy, tiled roof. Forecourt of a Buddhist temple in Wakamatsu prefecture, Japan (Photo M. Kázmér, #0700)

7.4.4 Wood-Reinforced Masonry

Hımış and *hatil* method of wood reinforcement of brick and stone masonry houses, especially in Greece, Turkey and in the Pakistani and Indian Himalayas are repeatedly discussed (Porphyrios 1971; Gülkan and Langenbach 2004; Langenbach 2007) emphasizing the beneficial effects of flexible wood columns, beams, and crossbars embedded in an otherwise brittle masonry structure (Figs. 7.9, 7.10, 7.11 and 7.12).

In general, all timber-framework houses are based on the same structural principle: the wooden structural system bears mainly the horizontal loads while either the masonry or timber columns support the gravity loads (Dutu et al. 2012). The variety of framework geometries applied are practically unlimited. However, the simplest buildings, like a vernacular house in the city of Elbasan in Albania (Fig. 7.10), having only horizontal boards embedded in masonry (*hatil* construction) increases the resistance of the buildings to horizontal loads, i.e. lateral shaking by seismic waves. Niyazov (2012) provided a concise report on how both adobe and masonry vernacular buildings are routinely reinforced with wooden beams im Tajikistan. The European (Mediterranean) historical practice was reviewed by Dutu et al. (2012).

Fig. 7.9 Timber frame with masonry infill in a residential building in the Buddhist monastery at Tianshui, Gansu, China. This structure is extremely resistant to earthquakes: well-jointed columns and beams maintain structural integrity, although masonry infill might get loose under strong seismic shaking (Photo M. Kázmér, #3068)

Fig. 7.10 Horizontal timber embedded in load-bearing wall masonry (hatıl construction). Wooden boards, when tied around the facade-side wall junctions aid in reducing the occurance of corner wedge failures. These horizontal boards accept lateral loads during seismic shaking (Dogangün et al. 2006). Elbasan, Albania (Photo M. Kázmér, #8769)

7.4.5 Brick Bands

Byzantine monumental buildings built from the 5th to the 15th century are easily recognized by a conspicuous banding of horizontal red brick layers, repeatedly emplaced within an otherwise fully stone masonry wall (Figs. 7.13, 7.14 and 7.15). These brick layers were laid across the width of the 5 m wide Theodosian walls of Constantinople (Istanbul) (Ahunbay and Ahunbay 2000). While the exact engineering role of this banded construction is not well understood, it is considered as *hatil*, i.e. a monumental analogue of the horizontal wooden boards (Homan 2004). An interesting experience of the 1999 earthquake was that recently restored walls, where the brick banding was used for decorative purposes only, collapsed, while adjacent ancient walls did not (Langenbach 2007).

Fig. 7.11 Timber-laced masonry house in Safranbolu, Turkey (*hımış* construction). The ground floor is unreinforced masonry, followed by two floors of intricate timber structure. Note oblique timbers at corners, providing support against lateral shaking. Photo Uğur Başak. *Source* https://commons.wikimedia.org/wiki/File:Safranbolu_traditional_house_1.jpg. Creative Commons license. Accessed September 23, 2017

Fig. 7.12 Timber-framed house in Athens, Greece. This modernized house displays vertical columns, horizontal beams and X-shaped crossbars (Photo M. Kázmér, #1399)

7.4.6 Metal Clamps, Bolts, Anchors and Chains

Iron ingots hold together carefully hewn masonry of a seawall in Hangzhou Bay dated to the Ming and Qing dynasties (Wang et al. 2012). Whether this technology, well-known in Greek architecture of Antiquity, was widely applied in China is a matter of further research. The use of cast iron—of as yet unknown metallurgical characteristics—would certainly raise eyebrows of any modern engineer. The Greeks never used it; they used steel instead, surrounded by lead to protect rusting and to dampen the eventual collision of metal and the embedding stone during earthquake (Stiros 1995, 1996). Metal clamps and dowels were used in construction of the Parthenon in Athens, Greece (Fig. 7.16) and in the Baal temple of Palmyra, Syria (Figs. 7.17 and 7.18). Elastic steel provided strength, while plastic lead casing absorbed minor shifts of blocks without fracturing rigid stone.

Fig. 7.13 Alternating layers of brick and stone masonry. Early 5th century Theodosian wall, Istanbul, Turkey. There are seven courses of brick bands laid at intervals, running through the entire thickness of the wall (see Fig. 7.14) (Ahunbay and Ahunbay 2000). The brick layers are considered to be antiseismic constructions (Photo M. Kázmér, #0279)

Fig. 7.14 The brick layer traverses the full width of the 5 m thick stone wall. Early 5th century Theodosian wall, Istanbul, Turkey (Photo M. Kázmér, #0283)

There is a widely used method in Italy to reinforce a building moderately damaged by earthquake. Opposite walls are clamped together tightly by smith's iron rods (anchors), often ending in decoratively shaped crossbars (Forlin and Gerrard 2017) (Fig. 7.19).

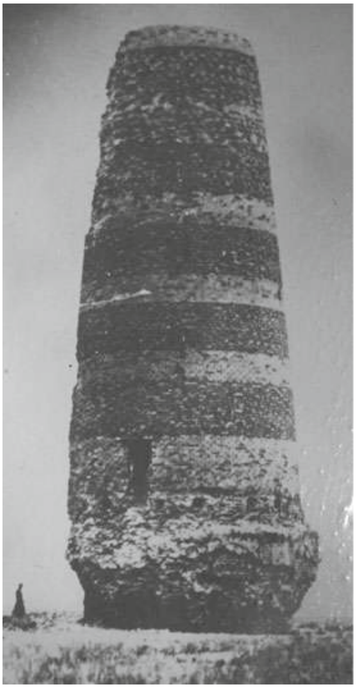

Fig. 7.15 Burana minaret (10–11th century; Kyrgyzstan), before restoration. It was probably damaged by late Medieval earthquake, removing more than half of the originally 46 m high tower, leaving only a 18 m high portion standing (Korjenkov et al. 2006a, b). Note alternating layers of different bricks: this construction practice is similar to Persian-Byzantine brick-stone masonry (Photo of local postcard, #1084)

Fig. 7.16 Lead-covered steel clamp connecting adjacent blocks of stone masonry. 5th century B.C., Erechtheion, Athens, Greece (Photo M. Kázmér, #1171)

7.4.7 Interlocking Masonry

A spectacular element of Islamic architecture is the widespread use of interlocking masonry in arches. The example shown is an ‘arch’ constructed of interlocking masonry arches (Fig. 7.20), functioning as lintel. During seismic excitation alternating in-plane extension and compression allows elements of arch masonry to drop, ultimately leading to collapse. Interlocking masonry prevents vertical displacement of arch stones. Doubts can be raised whether the technology is a strictly Islamic development, although it is most widely used there. In the ruined city of 6th cen-

Fig. 7.17 Steel clamps, enclosed by lead were inserted between adjacent masonry blocks. Subsequently lead was 'recycled' from the building by chiselling a wide opening to the clamp and melting the lead. 1st century A.D. Baal temple, Palmyra, Syria (Photo M. Kázmér, #4245)

Fig. 7.18 Columns were set up with steel dowels inserted. Space around dowels was filled by molten lead, introduced via the narrow canals leading to each dowel hole. 1st century A.D. Baal temple, Palmyra, Syria (Photo M. Kázmér, #4255)

Fig. 7.19 Iron rods traversing the building terminate in these crossbars. These hold together a house moderately damaged by earthquake in Treviso, Italy (Photo M. Kázmér, #1902)

tury Zenobia (Halabiyya, Syria)—rebuilt at that time by the Byzantine emperor Justinian—there are lintels composed of interlocking masonry (Fig. 7.21). However, Crusader castles of 11–13th century along the Mediterranean coastal region do not use this technique, despite being in close contact with Islamic culture.

Fig. 7.20 Elements of interlocking masonry support adjacent blocks from fall during wall-parallel vibration. Ottoman building in Al-Marqab citadel, Baniyas, Syria (Photo M. Kázmér, #1416)

Fig. 7.21 Flat arch (encircled) functioning as lintel composed of interlocking masonry. Praetorium at 6th century Halabiyya (ancient Zenobia, Euphrates, Syria) (Photo B. Tombor)

7.4.8 Roman Concrete

Most walls of al-Marqab citadel in coastal Syria, both Crusader and Muslim, are one of two types: either stone masonry or *opus caementitium*, i.e., "Roman concrete" (Lamprecht 2001) or "ancient concrete" (Ferretti and Bažant 2006). Stone masonry is characterized by dressed stones, hewn rectangular and of standard size, with or without mortar, always without metal anchors. Arches, domes, thick walls routinely have been constructed this way.

Roman concrete or *ancient concrete* is a mixture of sand, lime, and stone rubble. It is very similar to modern concrete in appearance. Invented by the Romans, the technique survived well into the Middle Ages. *Opus caementitium* is often combined with traditional masonry, where an outer, visible layer of variously dressed blocks was erected with mortar. This external, regular masonry work served during

Fig. 7.22 Roman concrete fills the space between two leaves of hewn masonry. 11th century Safita castle, Syria (Photo B. Major, #DSC_9559)

Fig. 7.23 Remnants of the main hall of 11th century Safita castle, Syria, displaying Roman concrete (*opus caementitium*) structure (Photo B. Major, #Safita (36))

construction as a mold for casting the core. Poured material served for the inner, invisible parts of the wall (Figs. 7.22 and 7.23) (Ferretti and Bažant 2006; Mistler et al. 2006). Masonry both served aesthetic demands and provided a hard, protective layer to counter weather effects and enemy attacks. This layer often served as framework during concrete pouring only, having no supporting function when concrete hardened. Walls and vaults of variable thickness, from a few decimetres up to 5 m thickness, were constructed this way (Kázmér and Major 2010). Buildings constructed of Roman concrete are extremely resistant to natural calamities: the Pantheon of Rome, having a dome of 60 m diameter, was cast as monolithic building. It has been standing practically intact for the past two millennia.

7.5 Discussion

7.5.1 Social Memory of Calamities

As we learned from Jackson (2006) “it is the fault that provides the water, but the fault may kill you when it moves”. The relatively minor agricultural and trading settlements developed along the Silk Road in the past millennia are vulnerable to earthquake destruction. However, even if human fatalities can reach sizeable proportion of the inhabitants (Jackson 2006), these often come infrequently, beyond the length of individual and social memory. There is very little research on the longevity of social memory; we can assess with confidence that it probably lasts at least for three generations (from grandparents to grandchildren). Longer memory can be assured if and where religious practice or taboo is associated. Repeat times of earthquakes on individual faults are likely to be measured in hundreds or thousands of years and they are most unlikely to recur on a timescale relevant for human memory (Jackson 2006).

One is ready to consider a natural calamity (in our case the earthquake) as root cause of devastation and loss. As it has been recognized in social sciences some time ago, a catastrophe is a trigger mechanism only, which releases a disaster that was waiting to occur, due to deep-rooted social causes (Degg and Homan 2005). A similarly high-magnitude earthquake which causes neither loss of life, nor material damage in Mongolia (the Gobi-Altay M_w8.1 earthquake in 1957), can cause fatalities well into the hundreds of thousands in China (the Tangshan M7.5 earthquake in 1977), not only because population density is so much higher in the latter, but because of inappropriate construction methods.

7.5.2 Anti-seismic Construction Practices

Timber structures and timber-reinforced masonry and adobe structures have been in use all along the Silk Road from China to the Mediterranean for millennia (Semplici and Tampone no date). Whether their use is the result of parallel innovation or spread of good practices either east or west, is a matter of research in progress. Detailed study on fitting of beams and columns, for example, might help to recognize independent or dependent development of life-saving construction practices.

Monumental buildings are the best for the study of anti-seismic construction methods. These, especially the religious buildings were created for eternity. The best material was used, even if transported from faraway location. The best workmanship was applied. From site selection to construction and to subsequent maintenance probably the best conditions existed.

Some construction methods are characteristic for certain civilizations only. E.g. marble and sandstone columns are typical for Greek and Roman monumental architecture. These columns, especially if made of multiple drums, are kind of seismoscopes, i.e. simple earthquake-sensing devices, being easily deformed by earthquakes. As China did not use these stone columns, an important archaeoseismological evidence is inherently missing there.

7.5.3 Earthquake-Resistant Construction Without Apparent Need

While Palmyra (Tadmor, Syria) is not particularly active seismically (Sbeinati et al. 2005), the use of lead-enclosed metal dowels and clamps in the 2000 years old Nabatean Baal temple shows high knowledge of anti-seismic construction methods. We are aware of three Greeks, one of them an architect, who worked on the construction (Stoneman 1994). This construction method probably was developed in Greece, which is the seismically most active part of the Alpine-Himalayan mountain belt (Tsapanos 2008). It is possible that architects of the era carried their experiences from the homeland to faraway territories, transferring essential knowledge of earthquake resistant construction, and routinely applied it to the monumental architecture they created.

7.5.4 Traditional Good Practices and Modern Construction

One of the construction materials discussed invites an important remark. Wood-reinforced masonry is at least as good as modern steel-frame and reinforced concrete (RC) buildings, and the chance of survival for their inhabitants is often higher, as engineering studies of modern earthquakes show. The reason is not necessarily that RC is inferior; it can be designed and produced to be earthquake-resistant. The problem is the uneducated, unregulated and uncontrolled construction industry in the rapidly growing developing countries overlapping major seismic zones worldwide. In this situation traditional construction practices of vernacular architecture are better, more reliable than the RC construction in need of sorely lacking construction skills (Langenbach 2015).

The importance of engineers' understanding and appreciation of vernacular construction practices cannot be overestimated (Dixit et al. 2004). Portugal, since the tragic 1755 Lisbon earthquake, has been in the forefront of developing earthquake-resistant construction practices, contributing to the awareness of the local seismic culture (Correia et al. 2014). There was even an European centre for studying traditional anti-seismic practices based on archaeological approach (Helly 1995). Application of good practices learned from local seismic cultures would significantly reduce vulnerabilty of communities living in earthquake-prone areas (Karababa and Guthrie 2007).

Although experts agree that wooden framework buildings resist earthquakes very well, the presence of ancient timber-framework buildings does not indicate an earthquake-prone area. Where wood is available, and local tradition and builders are at hand, this construction method is widely applied (see the German and Austrian *Fachwerk* construction) (Bostenaru Dan 2014).

Systematic use or disuse of known earthquake-resistant techniques in any society depends on the perception of earthquake risk and on available financial resources. Earthquake-resistant construction practice is significantly more expensive than regular construction. Perception is influenced mostly by short individual and longer social memory. If earthquake recurrence time is longer than the preservation of social memory, if damaging quakes fade into the past, societies commit the same construction mistakes again and again. Longevity of the memory is possibly about one to three generations' lifetime, i.e. less than 100 years. Events occurring less frequently can be readily forgotten, and the risk of recurrence considered as negligible, not worth the costs of safe construction practices. Frequent earthquakes maintain safe construction practices, like the timber-laced masonry tradition in the Eastern Mediterranean throughout 500 years of political and technological development.

7.6 Conclusions

Archaeoseismology, the archaeological study of past earthquakes, is a treasure trove of information about the behaviour of ancient societies. Earthquakes are part of nature and life along the overland Silk Road between China and the Mediterranean; peoples developed various methods to cope with the risk. Making buildings able to resist the shaking of the ground and knowing ways of quick reconstruction after destruction depend on available material and knowledge of good construction practices.

Materials used in permanent and semi-permanent construction vary according to purpose, availability, financial resources, cultural and climatic influences. Mostly adobe, brick, wood, stone, ancient concrete, and metal reinforcements were applied for earthquake-resistant construction. *Rammed earth* houses can be built and restored quickly and cheaply. *Wood* is the ultimate earthquake-resistant construction material: it can resist seismic shaking and allows quick reconstruction in case of damage. *Wood-reinforced masonry* provides flexible support to masonry buildings. *Brick layers* laid within stone masonry walls provide additional flexibility during shaking. *Metal* dowels, clamps, bolts, anchors and chains provide minor but essential support of structures in case of moderate earthquakes. *Interlocking masonry* prevents vertical displacement of arch stones. *Roman concrete*, rubble cemented by lime and additives is another excellent construction material for anti-seismic purposes. Our knowledge of past construction practices are limited by preservation: adobe is the worst material for long-term survival, wood is second, while monumental stone masonry and Roman concrete has the best potential to be preserved for millennia.

Architects of the era carried their experience from the homeland to faraway territories, transferring essential knowledge of earthquake resistant construction. They routinely applied anti-seismic techniques even far away from seismically active faults. Application of good practices learned from local seismic cultures would significantly reduce vulnerability of communities living in earthquake-prone areas. Knowledge of seismicity and the local methods used to resist and survive destruction are valuable contributions to understand how society works.

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Chapter 8
Natural Disasters in the History of the Eastern Turk Empire

Rustam Talgatovich Ganiev and Vladimir Vladimirovich Kukarskih

Abstract This article analyzes the effect of climate extremes on the historical processes that took place (AD 536, 581, 601, 626 and 679) in the Eastern Turk Empire (AD 534–745) in Inner Asia. Climate extremes are sharp, strong and sometimes protracted periods of cooling and drought caused by volcanic eruptions that in this case resulted in a negative effect on the economy of a nomadic society and were often accompanied by famine and illness. In fact, many of these natural catastrophes coincided with the Black Death pandemics among the Eastern Turks and the Chinese living in the north of China. The Turk Empire can be split into several chronological periods during which significant events that led to changes in the course of history of the nomadic state took place: AD 534–545—the rise of the Turk Empire; AD 581–583—the division of the Turk Empire into the Western and the Eastern Empires; AD 601–603—the rise of Qimin Qaghan; AD 627–630—the Eastern Turks are conquered by China; AD 679–687—the second rise of the Eastern Turk Empire. The research shows that there is clearly-discernable interplay between important historical events and climate extremes in the history of the Turk Empire. This interplay has led us to the conclusion that the climatic factor did have an impact on the historical processes that took place in the eastern part of Inner Asia, especially on the territories with a nomadic economy.

Keywords Turks (Tujue) · The Eastern Turk Empire · China · Climatic change Dendrochronology · Ice-core

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8.1 Introduction

The middle of the 6th century saw the rise of a new nomadic Turk Empire on the territory of what today is Mongolia and Southern Siberia. In a period of 20 years (AD 551–573), as a result of active military campaigns, the Turks (Tujue) spread their influence onto a vast territory of Inner Asia that ranged from the Caspian Sea to Liaodong Bay. As a result, a vast number of non-Turkic peoples found themselves included into their empire. The Turks played a significant role in the cultural interaction of the West and the East. They furthered the development of trade along the Great Silk Road and established trade relations with the leading empires of the time (Sasanian Empire, Byzantium and China). In AD 581, the Turk Empire broke up into two parts—the Western one and the Eastern one. We are going to dwell mainly on the Eastern Turk Empire. Its northern borders spread out to Lake Baikal, the southern to North China (the Great Wall), the western to Eastern Kazakhstan, including Tuva and the Altai, the eastern to the Greater Khingan Range (Fig. 8.1).

Researchers divide the history of the Turk Empire into several periods (Sinor 1990b; Barfield 1992; Gumilev 1967; Klyashtorny 1964; Beckwith 2009). The first (AD 534–630) is characterized by the appearance of the Turks on the Chinese border and the beginning of intensive Turkic-Chinese trade relations accompanied by a gradual strengthening and broadening of the spheres of influence of the nomadic state. In the second period (AD 630–679) the independent state of the Turks was non-existent anymore. The main reason for the defeat of the Turks is considered to be the military campaign undertaken by Emperor Taizong in AD 630 which was later followed by his active policy in strengthening China in AD 630–649. The consequence of this was that the Turks were no longer a serious military or political threat until the year

Fig. 8.1 Map of the Eastern Turk Empire

AD 679 when several uprisings occurred. The third and last period (AD 679–745) is characterized by the rise of the Eastern Turk Empire, which managed to restore itself by undertaking several massive rebellions against the Chinese army in AD 679–685.

The Turk Empire continued to be China's main rival up to AD 745, that is, until the time when the Uyghur Empire conquered both of them (AD 745–840) (Mackerras 2000; Kamalov 2001). Therefore, the history of the Turk Empire consists of several chronological stages during which periods important historical events took place: AD 534–545—the strengthening and appearance of the Turks on the international arena; AD 581–583—the division of the Turk Empire into its Western and Eastern parts; AD 601–603—the weakening of the Western Turks and the strengthening the Eastern Turks under the leadership of Qimin Qaghan; AD 627–630—the maximum weakening and subordination of the Turks to China; AD 679–685—the rebirth and consequent strengthening of the Turk Empire.

Sinologists and turkologists have been trying to find reasons why all these events took place mainly by analyzing the regularity of development of socio-economic, military and political laws of the nomadic society and of China in Inner Asia (Kradin 2014; Beckwith 2009). However, historians have practically never taken into consideration the effect produced by natural and climatic factors in the region under study. The aim of this research is to show the importance of climatic cataclysms that occurred in Inner Asia during the period under consideration and the effect they had on the key historical events in the Turk Empire.

8.2 Methods

Changes in climate and their effect on human society is one of the most pressing problems for the world today and for science in particular (Fei et al. 2004; Zhang et al. 2007, 2010; Büntgen et al. 2011; Zhang et al. 2011; Ludlow et al. 2013; Hsiang et al. 2013; Wei et al. 2015). Global warming and human susceptibility to it cannot be taken lightly (Trenberth 2012).

In the recent period quite a number of works (Pederson et al. 2014; Büntgen et al. 2016; Di Cosmo et al. 2017; Putnam et al. 2016; Drobyshev 2014) have been devoted to the problem of the influence of changes in climate on the culture of whole nations, those living in Inner Asia being among them. A number of researchers hold to the opinion that climate changes could have led to grave consequences for the nomadic peoples if they were accompanied by unfavorable socio-political and economic factors. In other words, climate extremes may have a negative influence only if they coincide with unfavorable socio-economic, political and demographic changes within the nomadic society (Di Cosmo et al. 2017). This work is devoted to the influence of climate dynamics on the history of the Eastern Turk Empire. Our research shows that in several cases changes in climate could, in fact, have exerted a crucial influence on the political and economic life of the Turks.

Medieval economy operated in a traditional way and was to a greater degree than now dependent on climatic factors. One of the regions that were highly exposed to natural cataclysms in the early Middle Ages was that of Inner Asia and the nomads who lived there.

Though nomadic societies were highly mobile, large-scale changes in ecological factors (mainly climatic) must have, no doubt, told on the livestock that was the basis of nomadic culture (Sinor 1990a, b). This makes it possible for us to say that long-term temperature fluctuations and climate extremes in particular did have a global effect. Evidence of this can be found in the registered yearly tree-ring structures in all parts of the Northern Hemisphere.

It is also known that in the period of climate extremes the nomads practiced a mutually agreed-upon consecutive grazing of cattle or changed their regional location by moving along the steppes. However, in quite a number of cases, the Turks could not do this for the reason that the relations with their neighbors were not friendly at all, there being a fierce competitive struggle between the rival tribes for the bordering territories.

Our research is based on tree-ring data (D'Arrigo et al. 2001; Hantemirov et al. 2011; Myglan et al. 2012; Briffa et al. 2013) which makes it possible to determine climate extremes to a higher degree of accuracy than the more general chronological results ice-core study gives (Clausen et al. 1997; Cole-Dai et al. 2000; Jiang et al. 2012; Plummer et al. 2012; Jouzel 2013; Abbott et al. 2014). With the help of documentary sources, we shall compare the political and socio-economic evidence of events that took place in the Turk Empire with the material received from contemporary climatological research.

Unfortunately, climate reconstructions for the period under examination are too short-term and inadequate as far as their quality is concerned (https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets). Global atmospheric circulations, mainly the NOA (North Atlantic Oscillation) and the AO (Arctic Oscillation) make it possible for us to refer to distant paleo-climatological sources to help understand the processes that took place on the territory of the Turk Empire. Similar teleconnections were described earlier in other works (Büntgen et al. 2016), that is why we have analyzed oscillatory reconstructions for the Northern Hemisphere taken from other regions. Most of the information on the history of the Turk Empire is based on Chinese dynastic chronicles—Zhoushu, Beiqishu, Suishu, Jiutangshu and Xintangshu (Bichurin 1828, 1950; Liu 1958; Cen 1958; Ershisi shi 2012).

8.3 The Influence of Climate Extremes on the History of the Eastern Turk Empire in AD 536–685

8.3.1 Climate Extremes of AD 536–545

Turkic tribes are first mentioned in Chinese chronicles of AD 534 (Liu 1958), which describe the appearance of the Turks on the border with China as buyers of Chinese goods, but not as typical barbarians whose aim is to raid, as is often depicted in Chinese sources.

The Turks are next mentioned in the sources of AD 542. Only 8 years had passed between AD 534 and 542, but modern climatologists tell us that these 8 years were the ones with the greatest climatic changes in the history of the medieval world. A sharp fall in the mean temperature took place in the Northern Hemisphere, one of the worst in the last 2000 years (Keys 2000).

Here is what the famous Byzantine historian, Procopius of Caesaria, wrote about the events of AD 536–537: “One of the greatest wonders took place that year: the whole year the sun shone like the moon, without rays, as if it was going to lose its power. It did not shine clearly and brightly as before. Ever since then, there were wars among people, pestilence and other calamities that brought death with them” (Procopius 1998).

In AD 536–537, similar phenomena were noted in other regions: Ireland, China, Chile, Europe and Asia (Barash 1989). The Anglo-Saxon Chronicle in Britain also says: “AD 538. This year the sun was eclipsed, fourteen days before the calends of March, from before morning until nine. A.D. 540. This year the sun was eclipsed on the twelfth day before the calends of July; and the stars showed themselves full nigh half an hour over nine” (Garmonsway 1972).

Today, the climatic anomalies of AD 536–545 have brought together a great number of scientists who are studying this problem. Participants of The Greenland Ice Sheet Project (GISP) have studied samples of ice core from Greenland and the Antarctic (Jouzel 2013). They have discovered that ice samples of AD 536, 538, 539, 541 and 543 from Greenland all have a very high content of sulfates (Baillie 2008; Abbott et al. 2014), which may point to their high content in the atmosphere at that time and to the low temperatures of their formation (Larsen et al. 2008).

Dendrochronological data also indicate that the years AD 536, 537, 543 and 545 were the ones with the coldest extremes (D’Arrigo et al. 2001; Hantemirov et al. 2011; Myglan et al. 2012).

Volcanologists study samples of lava and traces of past explosive volcanic eruptions. They analyze the chemical composition of mineral ores and the activity of volcanoes. Several volcanologists adhere to the opinion that the reason for such a temperature drop in AD 536–545 could have been the eruption of Krakatau on the Philippines or Tavurvur in Papua New Guinea (Keys 2000; Southon et al. 2013; Churakova-Sidorova et al. 2014).

Other scientists think that the reason for the anomaly could have been a comet or an asteroid that hit the Earth (Rigby et al. 2004), but here arises the question of where exactly it had happened. Dr. Dallas Abbott says that the Gulf of Carpentaria in the north of Australia could have been one of the locations (Abbott et al. 2007).

Currently Dr. Dallas Abbott is working on a hypothesis that volcanic and cosmic reasons had caused the climate extremes of AD 536–545 (Abbott et al. 2014). Dr. Abbott thinks that it was the dramatic events of AD 536–545 that produced an overall cooling effect on the planet (in the Northern Hemisphere). Researchers have found traces of volcanic activity in Greenland ice cores, but a single eruption in AD 536 would not have caused such an extreme change in climate. Dr. Dallas Abbott believes that there might have been a volcanic eruption along with a comet, but the main factor was, most probably, a comet strike. As proof of this, samples of Greenland ice have shown contents of alien particles with Ni-rich material and Fe oxide-rich spherules, both of which are the characteristic signs of cosmic objects (Abbott et al. 2014).

The overall effects of cooling led to the great disasters that took place in the Middle Ages. Moreover, a pandemic called the Plague of Justinian (Stavrakakis 2015) struck at the very same time. It is the first historically known pandemic of the Black Death and it is remembered in history as the plague of the Byzantine Emperor Justinian I. More than 100 million people perished as a result. The Plague of Justinian originated in Egypt in AD 540–541. Then it was brought by Mediterranean trade routes to Constantinople, from there to all of Byzantium, then to the countries of North Africa, Europe, Central and South Asia and Arabia. However, the latest genetic studies show that the Plague of Justinian did not come from Africa—it came from Inner Asia (Wagner et al. 2014; Schmid et al. 2015). Rodents, such as marmots, gophers, rats and mice are the natural reservoirs of the plague, and consequently myriads of fleas, which live on rodents, are the carriers of the disease.

It is not accidental that after AD 534 Chinese sources do not mention any contacts with the Turks until AD 545. One of the possible reasons for this may be the decline in economic production and the decrease of population both in China and in the Turk Empire. In addition to that, in the years AD 534–535, a civil war broke out in China, the result of which was the division of the Northern Wei Dynasty into the Eastern Wei Dynasty and the Western Wei Dynasty. Moreover, in the years AD 536–537, North China was hit by a famine that killed 80% of its population (Bichurin 1828; Durand 1960).

Unfortunately, written sources say nothing of the plagues that affected the Turks in that period, but taking into account the plague pandemic in the east of North China and in the west of Byzantium, the Turks, who were located along the trading routes of the Great Silk Road, must have also suffered from the disease. As is known, prior to AD 630, that is before they began to have active relations with China, the Turks did not bury their dead, they cremated them. This might be the reason why, in the period from 543 to 551, the Turks were able not only to withstand all of nature's trials, but emerge from them with minimal losses. The fact that the density of population at the start of the formation of the powerful and huge Turk Empire was not too great could serve as an additional factor that helped them to survive. To note, the density of population in North China at the time was considerable.

Let's look at the main events of that period.

In AD 534–545, there were four strongholds in the region: the Eastern Wei Dynasty, the Western Wei Dynasty, the Rouran Empire, and the recently formed Turk Empire that had conquered the Rouran Empire, but remained in the shade, though it had already made itself known to the Chinese in AD 534 as a new and independent political force (Liu 1958).

Both dynasties (the Western Wei and the Eastern Wei) rivaled with each other to establish friendly contacts with the Rouran Empire by way of a marriage union. The struggle went on against the background of climatic anomalies and, as a result, there was economic decline, so it can be well supposed that the Chinese had lost their former strength. The Rouran took advantage of the situation in China, but did not take into account the internal situation in its own Empire. The Western Wei Dynasty turned to the Turks for help. Thus, in AD 545, a new center of political and military power appeared in the region, one in which the Turks began to play the leading role (Liu 1958).

A new stage in the rise of the Turks was their victory over the Tiele tribe in AD 546. The Tiele were a threat to the dominance of the Rouran and the Turks took upon themselves the task of protecting them. The final mistake that the Rouran Empire made was their refusal to agree to a matrimonial union with the Turks, thus making relations between them hostile. After that, it took the Turks seven years to overcome the climate extremes of AD 536–545, though later, in AD 552, they came to occupy the place of suzerain in the region.

This shows that the climatic extremes of AD 534–545 were the catalyst that aggravated the internal and external political struggle between the Chinese dynasties, a factor which led to a more serious situation than the one the nomads in the steppes were in. The internal political strife in China in AD 534–535 and the anomalies of AD 536–545 that aggravated China's situation were the main reasons that led to changes in the military and political affairs in the region. China lost its strength when, in tough competition with the Tiele and the Rouran, the Turk Empire gained power. The Turks were more successful due to the timely mobilization of their internal forces and the excellent personal skills of their leaders.

8.3.2 Climate Extremes of AD 581–583

The united Turk Empire was not long in existence. After the death of the Turkic leader Taspar (Tobo) Qaghan in AD 581, internal strife began to ferment within the ruling circles of the Empire which in the end led to its collapse. In addition to that, in AD 581, China, being already split prior to that, joined forces under the Sui Dynasty (AD 581–618). The reforms that took place in China led to the fast growth of the economic and military strength of the Empire. Chinese sources inform us that China's rise was accompanied by a most devastating famine in the steppes (Bichurin 1950).

The Suishu chronicle writes: "Each winter they have thunder there, and the flames of the lightning hit the Earth. The Tujue's life depends on grass and water. All throughout the previous year there was no rain, no snow, their rivers have dried up and locusts have appeared; plants and trees have been totally destroyed by fire; half the population has died of hunger and disease. The place where they used to live before has become wasteland not fit for living. So they turned their steps to the south of the desert to try and brave it out … They suffered from famine, and couldn't find food for themselves, so they grinded bones to make flour out of them—and that's what they ate. Moreover, an epidemic broke out, and many of them died (Liu 1958).

Unfortunately, Chinese sources do not contain more detailed information about the events of that period. But it can be understood that the climatic anomaly and its effects on the common people of the Turk Empire, who were deprived of their means of existence as a result of massive livestock loss in AD 581–583, brought the Turk

Empire to a sudden social and political crisis and internal warfare, the result being that the Turk Empire finally split into the Eastern Empire and the Western Empire.

Natural anomalies of AD 581–583 have been confirmed by ice-core finds in the Antarctic and in Greenland and also by tree-ring data from North America and Southern Siberia (Clausen et al. 1997; Cole-Dai et al. 2000; Salzer and Hughes 2007; Gao et al. 2008; Jiang et al. 2012; Myglan et al. 2012; Plummer et al. 2012; Sigl et al. 2013, 2015). The studies of climatic extremes range from the years AD 564 to 581. The clearer evidence comes from ice cores of the Southern Hemisphere, which makes it possible to confirm that the volcano was located somewhere in that part of the planet. However, we shall be able to get a fuller picture of natural extremes of AD 581–583 only after additional research.

8.3.3 Climatic Extremes of AD 599–601

After the collapse of the Turk Empire (AD 581–583), the Western and the Eastern Turks were in a state of constant warfare with each other. The Sui Dynasty was originally a neutral party in the conflict, but soon the Chinese set up and supported a new political center in the southern part of the Eastern Turk Empire with Qimin Qaghan as their new leader. The new Turk Empire, supported by the Sui Dynasty, undertook a confrontation with the Eastern and the Western Turks, both of them uniting against it in the warfare that followed. However, in AD 603, Qimin Qaghan defeated them and united the whole territory of the Eastern Turk Empire under his command. It is obvious that climate extremes played a significant role in the glorious victory and tremendous success of the young Qaghan. In AD 598–599, sources report about natural climatic events that were mistakenly taken for two large military campaigns of Emperor Wen of the Sui dynasty against the Eastern Turks (Tulan Qaghan) "frequent disasters occur over their camps; a red rainbow in the night, its light illuminating hundreds of miles all around; three days … there was a bloody rain, the falling stars with a crash landing on the tents. Every night Tulan Qaghan was in fear, and imagined that it was the Sui army approaching!". In AD 601, the sources also report an interesting natural phenomenon that turned out to be a major volcanic eruption. A Chinese military commander reported to the Emperor: "When at night I went up onto the fortress tower, I saw a red mist 30 miles north of the desert; it looked like rain, it was hanging low over the land covering it. After that, I found a war guide book where it says that such a phenomenon is called "bloody rain", which means that the country is doomed! If we want to destroy the barbarians, now is the time!" (Liu 1958).

8.3.4 Climatic Extremes of AD 627–630

The next period of sharp unseasonal and protracted cooling that affected the Eastern Turks were the years AD 627–630.

The years AD 627–630 were marked by natural cataclysms on the territory of the Empire. Chinese sources give the following descriptions: "Every year they had heavy snowfalls and snow lay thick on the ground. The cold and the famine brought with it a great loss of sheep, horses and men" (Liu 1958).

The Chinese chronicle Xintangshu says: "In spite of it being summer, the Tujue are having unseasonal frosts; five suns have risen at the same time, three moons shone as well; a red mist covered their pastures" (Liu 1958). This is what the Jiutangshu chronicle says about the situation of the Turks in AD 630: "The Tujue's life depends only on sheep and horses. Now their animals are sick and lean and their people look starved. Besides, when they prepare their food in the tents it turns into blood. This is a dangerous foreboding!" (Liu 1958).

Scientists say that the large-scale cooling on the territory of Eurasia in AD 627–630, evidence of which can be seen on tree-rings in Yamal, in North America and in the north of Central and Eastern Siberia, was caused by large explosive volcanic eruptions (Stothers 1999) and the parhelion. Fog and red sunsets described in the sources are well-known indicators of such eruptions. We know from European chronicles that, starting from October AD 626, for about 8 or 9 months, a dry mist covered a vast territory including Ireland and the eastern Mediterranean (Ludlow et al. 2013). Unseasonal night frosts at the end of summer occurred in China (the Tang Empire) in AD 627, which destroyed the harvest in several provinces. Similar events occurred in China in AD 628–629 (Fei et al. 2007).

Economic hardships led to a destabilization of the political situation within the Empire. In AD 627, the conquered tribes rebelled against the Turks and deposed the henchman of the Turkic leader on their territory. Within the Empire, relations between the Ruler and his subjects also became strained. Sources say that the relations between the Qaghan and his closest assistant were severed, the result being that the high official deserted to join the forces of the Chinese Emperor Taizong.

The economic situation put the Turks on the brink of survival and bared all the internal contradictions within their community, the same thing happening in the Eastern Turk Empire.

Sources say: "Xielikehan mobilized soldiers every year and invaded Chinese territory so often that his people could not put up with these campaigns any longer. There was famine year after year. Taxes and payments were heavy, so more and more tribes left him" (Liu 1958). Thus, an internal conflict began to grow within Turkic society; discontent grew, nobody trusted Xielikehan anymore, nor supported the policy he pursued.

The situation in the Empire became worse and many tribes, as the Chinese chroniclers say, began to rely only upon themselves and refused to be under the command of Xielikehan. Even the high officials closest to Xielikehan defected to Taizong. In AD 630, the Emperor's army attacked Xielikehan. As a result, the latter fled to the north of the desert whereas his closest courtiers, the ones who held high posts in the Empire, left him and joined the Tang Dynasty (Liu 1958).

Therefore, the defeat of Xielikehan's army in AD 630 by Chinese forces was a logical solution to the situation that had formed within the Turkic community with the climate extreme of AD 626 being the key to victory and not at all the skillful leadership of the Chinese Emperor Taizong of the Tang Dynasty, as many researchers might think.

Chinese researchers who studied the volcanic eruption of AD 626 hold a similar opinion. They believe that the cooling affected all the territory of Inner Asia, as well as the northern provinces of China, but the territory that suffered the most was the Eastern Turk Empire, whose nomadic economy could not withstand the sharp and protracted cooling (Fei et al. 2007; Di Cosmo et al. 2017). In conditions of an economic catastrophe which had put the Turks on the brink of survival, all internal conflicts came to the fore and the powers-that-be could not cope with the situation.

8.3.5 Climatic Extremes of AD 679–685

Several decades later, in the years AD 679–685, as a result of a number of rebellions, the Eastern Turk Empire restored its independence and managed to retain it till AD 745. However, the conditions that developed in AD 679–685, as they are described in Chinese sources, also point to a complicated natural and climatic situation in the region.

The Xintangshu chronicle describes a curious event witnessed by Chinese officials on the northern border of China. In the spring of AD 680 large flocks of desert pigeons fell dead from the sky (Liu 1958).

What could have been the reason for such an unusual natural phenomenon described in the Chinese sources? It is well-known that birds are indicators of the state the environment is in. The reason for this could have been both the global changes in the environment and the high content of volcanic dust in the layers of the atmosphere deposited there after a large explosive volcanic eruption.

In addition to that, in the years AD 681–682, Chinese sources repeatedly mention cases of famine among the Eastern Turks. "Famine, snow, drought, locusts, disease, numerous dead bodies lying all around, people turning into cannibals, several years of crop failure and starvation" (Bichurin 1828).

In AD 685, the Chinese official Ts'ui Zhi-zhi in his report to the Chinese Emperor described the situation the nomads were in thus: "The Tujue … devour each other; they wander around, starved, and don't know where to go".

"Their numbers had already exceeded several tens of thousands of people. They were covered with a rash and had tumors, they were famished and did not resemble human beings at all; countless numbers of people died on the way. Prior to that, the Nine Tribes (Toquz Oghuz) (those who inhabited the area to the north of the Great Chinese Wall) experienced a great drought that lasted for 3 years: all the pastures are reddish with practically no grass growing on them, thus causing massive loss of livestock. Those who came here are those who survived and were able to cross the desert, but on the way here they lost their sheep and horses due to lack of food and water. They had to hunt for field rats and eat the roots of grass; they killed each other to get provision. I asked different people about it and all told me the same story. By the way, one of their old men told me that from the time the Nine Tribes (Toquz

Oghuz) had come into existence, they had never experienced such a famine…" (Liu 1958).

There is also mention of "The Great Famine" in China in AD 687 (Bichurin 1828). Thus, Chinese chronicles state that many nomads were on the brink of death because of the heavy and protracted famine and disease in AD 682–687, though climate extremes were already mentioned in AD 680–681.

In AD 685, the Anglo-Saxon Chronicle in Britain also mentions climatic anomalies and their consequences: "A.D. 685. This year in Britain there was a bloody rain, and milk and butter were turned into blood" (Garmonsway 1972) and in AD 680 the Mozarabic chronicle also writes "that Spain was laid waste in that year" (Wolf 1999).

The period between AD 677 and AD 687 was also exceptionally arid in Central Europe. West Germany went through a drought in AD 679, 680 and 681. As a result, there was crop failure and a severe famine, the year AD 681 being the worst (Barash 1989). Thus, a vast geography (China, Spain, Germany and Britain) of climatic deviations may well mean that there could have been a global catastrophe on the planet at that time.

Anomalous climatic events of AD 680–685 are also confirmed by tree-ring data from North America, Europe, the Yamal and by ice-core results from the Antarctic and Greenland (Salzer and Hughes 2007; Gao et al. 2008; Plummer et al. 2012; Sigl et al. 2013, 2015; McKee et al. 2015).

Let's analyze the historical events of that period.

Regardless of the failures, in AD 682, the buck was taken up by the new leader of the Turks named Ashinagudulu who got together what was left of the Turks and created a 5000-strong army of mounted warriors. His first victory over the Chinese army took place in AD 682. In the years AD 683–685, under the leadership of Ashinagudulu, the Turks sacked quite a number of provinces and cities, killed a great number of local Chinese officials, and occupied the territory of a weakened tribe of nomads to the north of China. The said territory was practically a wasteland by that time. By AD 685, the Turks had the strongest army in the region. Nobody could withstand their attacks, even China, though it did undertake several unsuccessful attempts to defeat them.

Here we can trace a similarity with the events of AD 536–545. The Turks, as other nomads in the region, experienced all the hardships of life in the conditions of climatic cataclysms of AD 680–685. However, due to the predatory policy pursued by the northern provinces of China in AD 682–685, the Turks, not without losses of course, managed to overcome the heavy crisis, whereas the other nomadic tribes of Inner Asia were hit by the frost and died of starvation and disease, because they did not have any external source of food supply. As a result, the Turks turned out to be the strongest of all the other nomads in the region. Due to the successful military operations of Ashinagudulu in AD 682–685, China lost its military supremacy and the Turks had no need of China's protection anymore, so they became independent.

8.4 Conclusion

The material presented here demonstrates that there is a definite interplay between the historical events and the climate extremes on the territory of Inner Asia, and that these events coincide with other climate anomalies in Europe and China.

It has been proved that such coincidences come parallel with the key events in the Turk Empire and with those in Northern China in the following years: AD 535–545—the rise of the Turk Empire; AD 581–583—the division of the Turk Empire into the Western and the Eastern Empires; AD 599–603—the strengthening of the Eastern Turks under the leadership of Qimin Qaghan; AD 627–630—the collapse of the Turk Empire; in AD 679–685—the second rise of the Turk Empire (Table 8.1).

Most climatologists believe that the reason for such phenomena is a large explosive volcanic eruption. It is quite possible that the center of the explosive volcanic eruption in AD 626 was in the Northern Hemisphere, and in AD 536, 581, 679 in the Southern Hemisphere, whereas in AD 536 and in AD 679, the eruption was supposedly caused by the Tavurvur volcano (Gao et al. 2008; McKee et al. 2015; Sigl et al. 2015).

In most cases, the climate extremes that are marked by tree-rings on fossils suggest that the global changes in the climate took place on a world-wide scale. The extremely sharp and protracted cooling on the territory to the east of Inner Asia affected this region more because it had a nomadic economy.

As is said in this thesis, it was the protracted droughts that led to the consequences that followed the natural catastrophes of this kind on the territory of the Turk Empire and in Northern China (AD 536, 581, 679). A case of an early and very long winter with heavy snowfalls was also recorded in AD 627–630, right after the eruption of a volcano in AD 626.

The most difficult times for the Turks were the years AD 627–630, when the Empire practically stopped existing due to massive loss of livestock and famine.

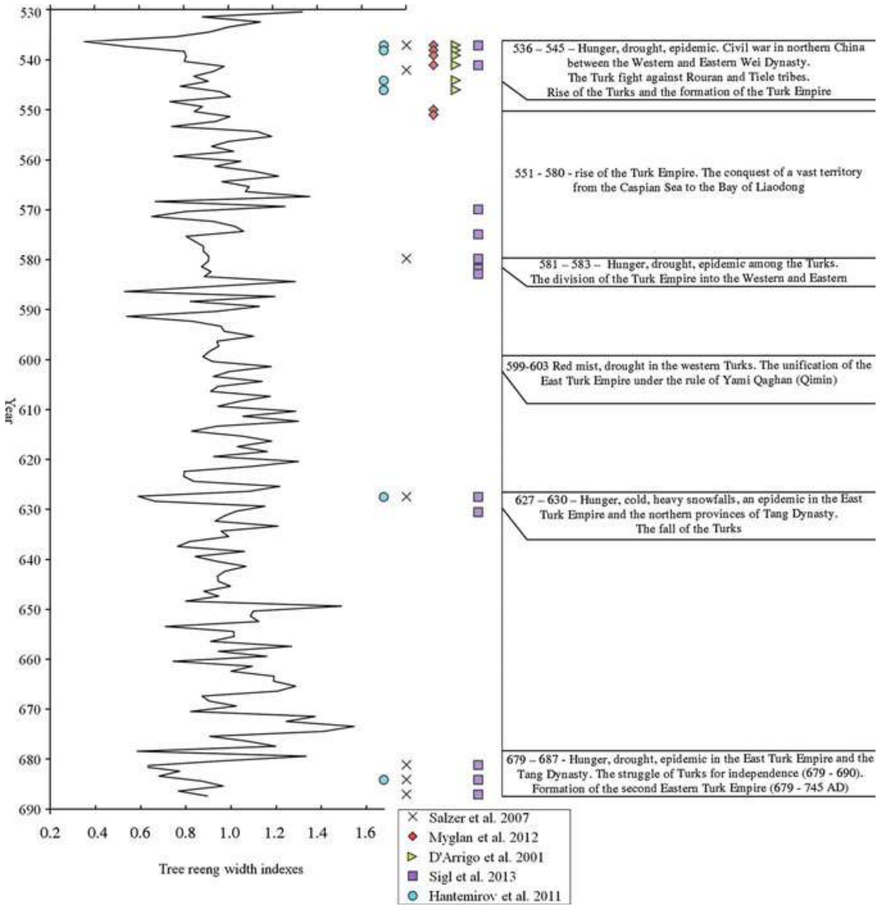
The droughts of AD 536, 581 and 679 turned out to be a serious trial for everyone in the region. Grazing vegetation dried up, forests and steppes blazed in fires.

However, Chinese sources tell us that during the droughts the Turks were in a better position than the Chinese. It happened at the time when the Turks took over the initiative from China to strengthen (in AD 545) and restore (in AD 682) their state. However, the drought led to serious consequences in China: the change of dynasties (AD 581) and the An Lushan Rebellion in AD 754.

In order to give a correct evaluation of the influence of the climatic extremes and its effects such as droughts, protracted cold and snowy winters on the territory to the east of Inner Asia, we must also take into account all the aspects of the political and socio-economic life in the region, so as to be able to give a correct evaluation of its influence on the Turkic and the Chinese population. The peculiar dynamics of the historical processes in that region were determined both by the climatic factors and by the complicated political situations.

Climate extremes were a prerequisite for changes in the military and political sphere in the region. They served as a background against which various socio-economic and political events developed. However, they were not only a threat to the

Table 8.1 Interplay of the historical facts and paleo-climatological data. As referential chronology we have used the most sensitive one for the given territory—Altai—LASI—ITRDB RUSS246 (Büntgen et al. 2016; Esper et al. 2016)



Standardized chronology—LASI (Büntgen et al. 2016)—on the left-hand side
Anomalies in the structure of yearly rings—in the center
Historical events in the Turk Empire taken from Chinese written sources—on the right-hand side

existence of the Turk Empire—they also provided certain advantages. Who was to use these advantages and how they were to be applied depended solely on the parties of the conflict and the circumstances they found themselves in. For example, in the case of the Turks—as with many other nomads of steppe Eurasia, a lot depended on the personality of the leader and his military skills.

Though much discussion is going on at present among researchers concerning the problem of the influence of climate changes on nomadic society, we hold to the opinion that the historical events that took place in the Turk Empire in AD

534–551 and in AD 679–687 developed in a line parallel to the unfavorable changes in climate which may be considered as an additional factor that led to changes in the regional situation. Historical sources show that in the year AD 534 the Turks had already become stronger—a fact that happened prior to the climate extremes, but the discontent of the Turks with Emperor Gaozong's (AD 650–683) policy grew during the whole period of his reign and it is this that led to the rebellion of AD 679. Nevertheless, the sharp changes in the economic and political situation in the Turk Empire in AD 581–583, in AD 599–603 and in AD 627–630 totally coincide with the extreme changes in climate in these periods, a fact that may be looked upon as indirect proof of the interplay of historical processes in the region with climate dynamics.

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Chapter 9
Dry and Humid Periods Reconstructed from Tree Rings in the Former Territory of Sogdiana (Central Asia) and Their Socio-economic Consequences over the Last Millennium

Magdalena Opała-Owczarek and Piotr Owczarek

Abstract One of the richest societies along the Silk Road developed in Sogdiana, located in present-day Tajikistan, Uzbekistan, and Kyrgyzstan. This urban civilisation reached its greatest prosperity during the golden age of the Silk Road (sixth to ninth century CE). Rapid political and economic changes, accelerated by climatic variations, were observed during last millennium in this region. The newly developed tree-ring-based reconstruction of precipitation for the past millennium revealed a series of dry and wet stages. During the Medieval Climate Anomaly (MCA), two dry periods occurred (900–1000 and 1200–1250), interrupted by a phase of wetter conditions. Distinct dry periods occurred around 1510–1650, 1750–1850, and 1920–1970, respectively. The juniper tree-ring record of moisture changes revealed that major dry and pluvial episodes were consistent with those indicated by hydroclimatic proxy data from adjacent areas. These climate fluctuations have had long- and short term consequences for human history in the territory of former Sogdiana.

Keywords Arid Central Asia · Silk road · Precipitation reconstruction
Dendroclimatology · Social growth and decline

9.1 Introduction

Recently, there has been growing interest in the relationship between climate change and its socio-economic consequences throughout human history. Abrupt climate

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changes not only affect the dynamics of natural systems like glacial and geomorphological processes (Solomina et al. 2016) or the distribution of vegetation zones (Klemm et al. 2016), but may also have long-lasting consequences for societies by causing a rapid transformation of the prevailing hydrological regime (Boroffka et al. 2006; Sorrel et al. 2007). Possible impacts of climate on human life, migration, agricultural production, and the growth and decline of societies have been extensively studied in recent years (Hodell et al. 1995; deMenocal 2001; Weiss and Bradley 2001; Sidle et al. 2004; Buckley et al. 2010; Büntgen et al. 2011; Giosan et al. 2013; Latorre et al. 2016).

The consequences of climate fluctuations are particularly evident in arid and semiarid areas, where ecosystem responses are very rapid. In the long history of the Silk Road, rich ancient societies developed in arid Central Asia under the influence of favourable conditions in the natural environment, where access to water and fertile soil were the most important factors (Owczarek et al. 2018). One of the richest societies along the Silk Road developed in Sogdiana, located in present-day Tajikistan, Uzbekistan, and Kyrgyzstan. This urban civilisation reached its greatest prosperity during the golden age of the Silk Road (sixth to ninth century CE) (Schafer 1963; Litvinsky et al. 1996; de La Vaissière 2002; Marshak 2003; Owczarek et al. 2018). Archaeological excavations indicate that this territory, crossed by several main branches of the Silk Road, was a melting pot where Sogdian merchants met others from a wide range of areas, from China to Byzantium (Marshak 2003). Sogdiana, one of the most advanced areas and the leader of all Transoxania, collapsed in eighth to ninth century (Grenet and de la Vaissière 2002; Marshak 2003). However, Sogdiana's civilizational, economic and social achievements have been visible for many centuries after its decline.

Despite its great significance, this territory, located between the Pamir Mountains and the large mid-latitude desert systems, is relatively little known in terms of climate and socio-economic changes (Opała-Owczarek et al. 2018; Owczarek et al. 2018), in contrast to research showing links between climate and the rise and fall of empires such as the Mongolian (Pederson et al. 2014; Putnam et al. 2016) and Chinese (Fan 2015; Wei et al. 2015; Yin et al. 2016; Li et al. 2017). Recently, Yadava et al. (2016) reconstructed drought periods and historic social upheavals and invasions of India.

The purpose of this paper is to analyse dry and wet periods over the last millennium in the former territory of ancient Sogdiana on the basis of tree-ring data, with a particular focus on the relationship between changes in precipitation and economic growth and decline.

9.2 Description of the Study Area

9.2.1 Regional Settings

Ancient Sogdiana was located in the upper part of the Aral Sea basin between two large Central Asian rivers, the Amu Darya (Oxus) in the south and the Syr Darya

Fig. 9.1 Location of the ancient Sogdiana on the background of political (ca. sixth century AD) and key physiographic units in Central Asia (modified after Abazov 2008)

(Jaxartes) in the north. It stretched from the Pamir Mountains in the east to the Kyzylkum and Karakum deserts in the west (Abazov 2008) (Fig. 9.1). The axis of this territory is marked by the longitudinal Zeravshan River Valley, along which the most important towns of Sogdiana, namely Panjikent, Samarkand, and Bukhara, were situated (Owczarek et al. 2018) (Fig. 9.1). Today this area forms parts of Tajikistan, eastern Uzbekistan, and south-western Kyrgyzstan. The area is characterised by extremely diverse relief. The eastern part includes the partly glaciated Pamir Mountains, where the average height of the main ridges reaches ca 6000 m a.s.l. (max. Ismail Somoni Peak, 7495 m a.s.l.). The Pamir-Alay Mountains, which form the transition zone between the Pamir and Tien-Shan Mountains, cover the central and north-eastern part of the former territory of Sogdiana. They consist of three longitudinal mountain ridges: Gissar, Zeravshan, and Turkestan, which reach a maximum height of 5600 m a.s.l. (Rahmonov et al. 2017a, b). These mountainous regions are characterised by a high level of seismicity, connected with their location in the vicinity of the Pamir Frontal Thrust system (Schurr et al. 2014; Owczarek et al. 2017). The western and south-western parts of the former Sogdiana territory include lowlands within the Central Asian mid-latitude desert system (Kyzylkum, Karakum) and tectonically conditioned mid-mountain basins (Afghan-Tajik Depression) (Fig. 9.1).

The tree-ring sampling sites are located in the central part of the Zeravshan Ridge in the Pamir-Alay Mountains (Fig. 9.1). This area is drained by the Urech-Kshtut river system, which constitutes the left tributary of the Zeravshan River. The samples were taken from two sites located in the Urech Valley at elevations between 2200–2900 m a.s.l (Fig. 9.2a). The upper part of the valley includes a high-mountain glacier basin; surrounded from the south by Chimtarga Peak (5489 m a.s.l) (Fig. 9.2b). Below the basin, the Urech River flows through a deep U-shaped valley with alternating wide

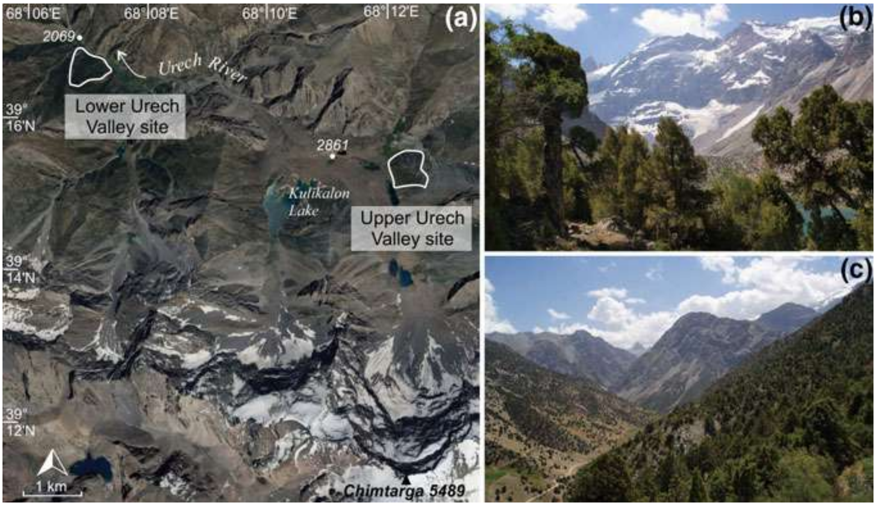

Fig. 9.2 **a** Location of the tree-ring sampling sites within the highest part of the Zeravshan Range in the Pamir-Alay Mountains (on the basis of 2018 DigitalGlobe, 16 June 2017, Google Earth), **b** general view of the Upper Urech Valley site, on the background Chimtarga Peak (5489 m a.s.l.); **c** general view of the Lower Urech Valley site

and narrow zones (Fig. 9.2c). The most important plant community here is composed of *Juniperus semiglobosa* and *Juniperus seravschanica*, which form an open forest up to an elevation of 3400 m a.s.l. (Rahmonov et al. 2017a, b).

9.2.2 Climate of the Study Area

The landlocked location of the study area and its great distance from oceanic sources of moisture makes its climate extremely continental, with hot, dry summers and cold winters. Climate conditions are characterised by extreme local contrasts dependent on altitude and landforms. Air temperatures tend to depend strongly on altitude. The mean annual temperature drops from 13.5 °C at 726 m a.s.l. in Samarkand to 10.5 °C at 1680–1700 m a.s.l. at the mouth of the Urech River, then to 0 °C at 3200 m a.s.l. near the upper line of juniper forests, and finally to −1.8° C at the Anzob Pass (3373 m a.s.l.) (Fig. 9.3). At the highest peak, Chimtarga, the mean annual temperature is estimated at about −15 °C (Rahmonov et al. 2017b).

Mean annual precipitation for the discussed area ranges from 400 to 500 mm on peaks and slopes at altitudes about 3000–3400 m a.s.l. (434 mm at Anzob Pass) to 250–350 mm in the Pamir-Alay foreland (353 mm at Samarkand). Most precipitation occurs in spring (about 60 mm per month in March, April, and May), while the summer months (JJA) receive either minimal quantities or none at all (Fig. 9.3).

Air temperatures in most areas of Tajikistan and Uzbekistan are increasing (0.3–0.5 °C in the period 1940–2000, with the warmest decades in the 1930s, 1980s and 1990s); however, changes in atmospheric precipitation are uneven due to the

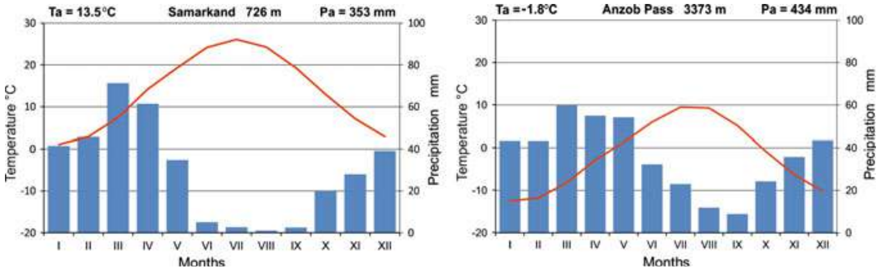

Fig. 9.3 Monthly mean temperature and mean precipitation for Samarkand and Anzob Pass meteorological stations during the period 1936–2003 on the basis of data from CATPD (Williams and Konovalov 2008)

geographic and climatic diversity of the territory (Makhmadaliev et al. 2008; Chub and Ososkova 2009; Kayumov 2010). In Uzbekistan, observed changes in the hydrological cycle include a decrease in precipitation in the west and an increase in the east of the country as well as around irrigated lands along main river valleys due to increased evaporation (Lioubimtseva and Henebry 2009; Chub and Ososkova 2009). The eastern part of the studied area, covering the territory of Tajikistan, experiences more humid conditions. In general, periods of humid weather alternate with periods of dry weather. According to available instrumental climate data the driest decade for all altitudinal zones was from 1941 to 1950. A trend towards increasing amounts of precipitation is especially visible in the second half of the twentieth century. After 1990, the rainiest period was in 1998–99; the following years 2000–01 were the driest, with drought predominating nearly throughout the territory.

9.3 Materials and Methods

9.3.1 Tree Ring Sampling and Development of Chronologies

In 2014 and 2015, we collected 110 cores using increment borers (5.15 mm in diameter). To minimise non-climatic effects on tree growth, only uninjured, healthy trees were sampled. Tree cores from junipers were collected from two sampling plots (Fig. 9.2a). The Upper Urech Valley site (UUV) is situated in a high mountain basin, partly filled by one of the Kulikalon Lakes, at an altitude of 2800–2900 m a.s.l. (Fig. 9.2b). The second site, the Lower Urech Valley site (LUV), is located at an elevation of 2200–2300 m a.s.l. on a valley slope (Fig. 9.2c).

According to standard dendrochronological techniques (Speer 2010), the sampled tree-ring cores were dried naturally and sanded to a high polish using progressively finer grades of sandpaper until the cellular structures of the rings were visible under a binocular. Ring widths were measured to the nearest 0.001 mm using the WinDENDRO system (WinDENDRO 2006). Next, we used the COFECHA program (Holmes 1983) to check our dating by comparing ring-width measurements between all series from the two sites. Before calibrating the tree-ring data with climate data, the biological age trend inherent in the raw data series had to be removed. We used the ARSTAN program (Cook 1985) to detrend individual series with a negative exponential curve to preserve climate-related variations at both high and low frequencies. The chronology was calculated as the residuals between the raw measurements and fitted trend curves, resulting in a dimensionless index series. The detrended single series were then combined into a standard chronology, using a biweight robust mean to minimise the influence of biases in tree-ring indices (Cook and Kairiukstis 1990). The reliability of the tree-ring records was evaluated using the so-called expressed population signal (EPS) (Wigley et al. 1984). To assess replication through time at every site, we used the commonly acceptable cut-off value of 0.85 (85% of common chronology signal retained) and an adequate sample size (series $\geq$3).

9.3.2 Climatological Data and Dendroclimatic Methods

The longest series of meteorological data for the studied region is available from the Samarkand meteorological station in Uzbekistan (station code 38696, 67.00° E, 39.70° N, 726 m a.s.l.). Meteorological station data were obtained from Central Asia Temperature and Precipitation Data (CATPD), 1879–2003 (Williams and Konovalov 2008). Monthly temperature means and precipitation sums for the period 1936–2015 were used in our calculations. These were also compared to monthly $0.5° \times 0.5°$ gridded climate variables obtained from the Climatic Research Unit (CRU TS 3.21, Mitchell and Jones 2005). For calculation, we used data averaged for the mountainous region 39–40° N and 68–69° E, the mountain foreland region 37–38° N and 67–68° E, and the average of the grids 38–41° N and 67–70° E, which equally represent the climates of the mountainous part and low elevations of the study area. A comparison between the precipitation levels noted in various meteorological records available for the region is shown in Fig. 9.4.

The relationship between juniper ring width variations and climate was determined by calculating a response function and conducting a correlation analysis between the site-level chronologies, mean monthly temperature, and total monthly precipitation over the so-called 'dendroclimatological year'. As the growth of a tree can be affected by the climatic conditions of the current as well as those of the previous growing season, climate response analysis was performed from monthly data from the previous July to the current September. For calculations we used the DendroClim2002 program (Biondi and Waikul 2004), which provides estimates of bootstrapped confidence intervals for evaluating the significance of correlation coefficients. Following the successful verification and calibration procedure, the climate reconstruction was performed using the transfer function described by Cook and Kairiukstis (1990).

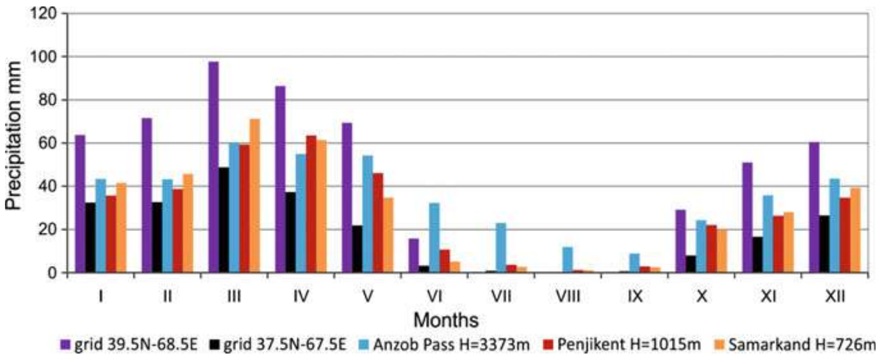

Fig. 9.4 A comparison between the precipitation levels noted in various meteorological records available for the central part of former Sogdiana territory (present-day north-western Tajikistan, eastern Uzbekistan) on the basis of CATPD dataset (Williams and Konovalov 2008) and Climate Research Unit (CRU) TS 2.1 gridded dataset (Mitchell and Jones 2005)

9.4 Results and Discussion

9.4.1 Characteristics of Tree-Ring Chronology and Its Response to Climate

The constructed local site chronologies showed a significant inter-site correlation of 0.49, which indicates a common climatic signal. The chronology from the lower site (LUV) covers the last 220 years (1795–2014, with EPS > 0.85 from AD 1877); the time span of the chronology from the upper site (UUV) was much longer, covering the last 1215 years (801–2015, with EPS > 0.85 from AD 1092). Difference between the length of these two chronologies is connected with timber harvesting in the vicinity of settlements, that lasts already for many centuries.

Climate response analysis showed that local chronologies are positively correlated with monthly precipitation, while the influence of temperature is minor or insignificant. In general, both chronologies are positively correlated with the monthly precipitation from the previous July to the current September recorded at the meteorological station in Samarkand. The highest significant correlations were found between tree-ring widths from the lower location and spring precipitation (March–May, $r = 0.60$; April–May, $r = 0.58$). As shown in Fig. 9.5, the correlation coefficient values for the upper location, though slightly lower, indicate a similar growth response to climatic variability. Significant correlations were found with mean monthly precipitation in spring months (April–May) and precipitation in the dendroclimatological year (pJune–September). The correlations between the gridded precipitation data were consistent to some extent with the correlations observed with weather station data (Fig. 9.5).

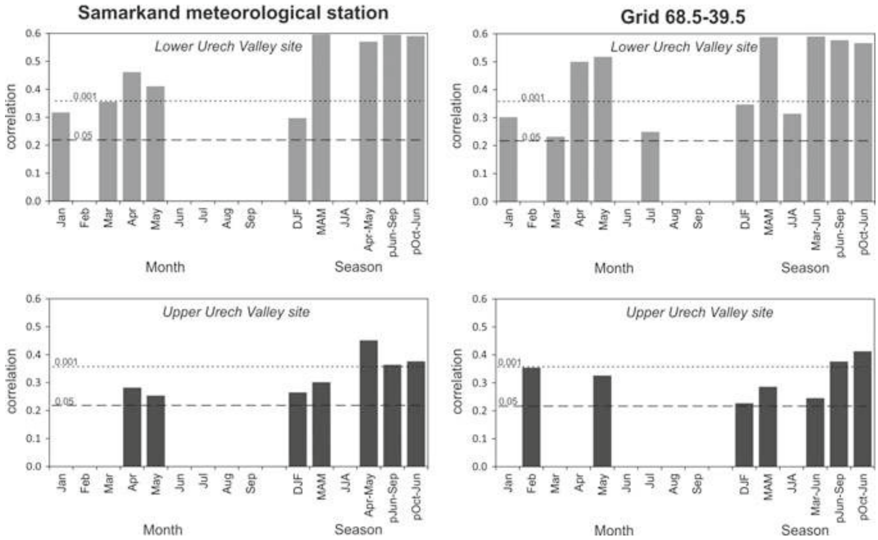

Fig. 9.5 Correlation between juniper tree-ring width chronologies from lower and upper Urech Valley study sites and precipitation data from Samarkand (726 m) and gridded dataset (68.5–39.5)

In earlier studies it was also noted that pluvial conditions during the winter months are very important for the growth of trees from southern slopes near timberline locations in the Pamir-Alay (Opała et al. 2017; Opała-Owczarek and Niedźwiedź 2018). Moreover, Seim et al. (2016) stated that junipers growing on the southern slopes in Uzbek part of the Pamir-Alay and Tien-Shan are mainly dependent on spring and annual precipitation. Differences in seasonal response are connected with local conditions (altitude, topography, location within the mountain massif). Moisture supply in the early growing season (from liquid precipitation or snowmelt) is the most important climate variable affecting the growth of junipers. As summer precipitation in the studied region is scarce, drought stress is expected to be one of the main growth limiting factors for these trees.

The significant climate-growth correlations enabled us to reconstruct April–May precipitation anomalies from the tree-ring-width chronology of junipers. The high-elevation chronology was used to calculate the reconstruction, as it allows to cover the longer time span. The moving correlation analysis indicated that the climate-growth relationship is stable only in the second part of the instrumental data period (Fig. 9.6a). Such result is usually associated with the low quality of the instrumental data in the early period of observations, but it may be not a single factor. Other possible causes are e.g. dust storms in arid Central Asia, which were especially frequent during the 1950–60s, when vast areas of natural desert pastures were dramatically transformed by agriculture and human pressure. This led to increase in the frequency of dust storms outbreaks (Indoitu et al. 2012). Therefore, we used shortened period 1966–2014 for calibration with proxy data (Fig. 9.6b).

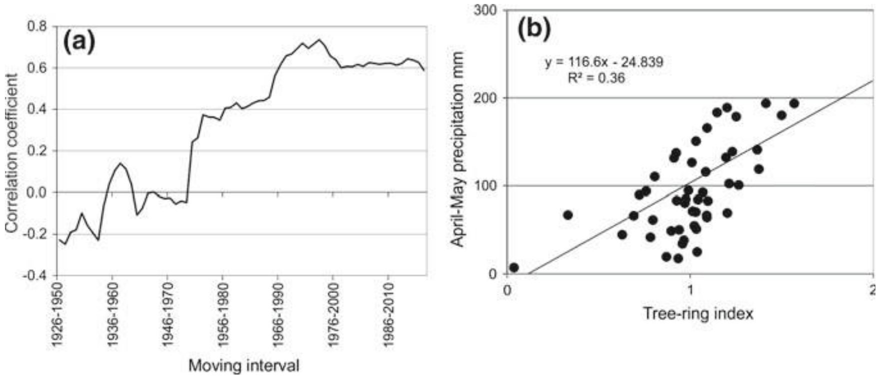

Fig. 9.6 **a** Moving correlation function between April–May precipitation and the tree-ring width index from the upper site chronology considering an interval lengths of 25 years; **b** the relation between these variables over the period 1966–2014

The regression model accounts for 36% of the variance in the instrumental spring precipitation (April–May totals) over the calibration period from 1966–2014. The results of ca 30–40% of explained variance in the dendroclimatic reconstruction is widely acceptable (e.g. Chen et al. 2015; Gou et al. 2015; Shah et al. 2018). We are aware that the dendroclimatic method of climate reconstruction is associated with a certain degree of uncertainty. However, standard methodology have been used to assess whether the model has the ability to reconstruct the climate. The cross calibration-verification tests for two split periods revealed that the model passes the standard tests of reconstruction reliability (a positive reduction of error (RE) and coefficient of efficiency (CE)). Because our calibration-verification sub-periods are relatively short (1966–1990, 1990–2014), additional verification of spring precipitation reconstruction model was made using a grid dataset (Table 9.1). Finally, a linear regression model was developed to reconstruct April–May precipitation variations back to 800 CE. The reconstruction of spring precipitation variability over the last 1200 years presented in Fig. 9.7 revealed variations on an inter-annual to decadal and centennial scale.

9.4.2 Moisture Changes in the Last Millennium

The reconstructed climate history of the former territory of Sogdiana for the past millennium revealed a series of dry and wet stages. Referring to the time frame of the Medieval Climate Anomaly (900–1300 CE) and the Little Ice Age (1570–1900 CE) described by Lamb (1965) and Matthews and Briffa (2005) some regional differences can be observed. In the studied western Pamir-Alay region during the Medieval Climate Anomaly (MCA) two dry periods occurred, with a shift to wetter conditions

Table 9.1 Calibration and verification statistics for split (1966–1990, 1990–2014) and entire period (1990–2014) for the spring precipitation reconstruction model based on tree rings

Type of data	Samarkand station data				Samarkand station data	Grid data[a]
Time period	Calibration (1990–2014)	Verification (1966–1990)	Calibration (1966–1990)	Verification (1990–2014)	Calibration (1966–2014)	Verification (1966–2014)
r	0.65	0.62	0.62	0.64	0.60	0.56
R^2	0.41	0.38	0.38	0.41	0.36	0.32
RE		0.41		0.42		0.21
CE		0.38		0.40		0.18
ST+/−		19/6		21/4		34/14

Explanations: r—correlation coefficient; R2—explained variance; RE reduction of error; CE coefficient of efficiency; ST sign test

[a]For independent verification data for grid (38–41° N and 67–70° E) was used

between them. The Little Ice Age (LIA) in this area was characterised by wetter conditions interrupted by a dry period with conditions closer to the average (Fig. 9.7).

According to new Pamir-Alay tree-ring data, dry periods prevailed in the following time spans: 900–1000, 1200–1250, 1510–1650, 1750–1850, and 1920–1970 (Fig. 9.7b). The first long period of arid climate conditions present in the tree-ring-based precipitation reconstruction started as early as 900 and lasted to ca 1000 CE. This drought is consistent with data from the Guliya ice cap (Thompson et al. 1995; Yao et al. 1996) and Badain Jaran Desert (Ma and Edmunds 2006), and is also in line with the modelled changes in rainfall anomalies of the ECHAM5 simulation of the arid Central Asia domain (Fallah et al. 2016). At the turn of the tenth and eleventh centuries, a shift to wetter conditions occurred. This period of two hundred years is characterised by a high level of variability with a clear predominance of above-average precipitation. Increased rainfall in Central Asia in this period is evidenced by low-resolution records, such as speleothem carbon isotope data, ostracod assemblages from lake sediments, and pollen concentration data (Chen et al. 2010).

At the beginning of the thirteenth century, a rapid transition to dry conditions is observed. This period lasted only fifty years, but probably constituted the most severe drought in the entire analysed period. Low precipitation before ca 1250 was confirmed by many other natural proxies from arid Central Asia, e.g. Uluu Too Cave (Wolff et al. 2017). After a period of considerable higher precipitation from 1300 to 1400, a homogeneous period of nearly 200 years, with values close to the long-term average, prevailed during the fifteenth century, becoming progressively drier during the sixteenth century. The occurrence of low levels of precipitation and very dry conditions during this time is confirmed by historical reports from Afghanistan (Beveridge 1921, after Yadava et al. 2016). A rapid transition between dry and wet climate conditions took place around 1650. The two most significant pluvial periods in the Pamir-Alay tree-ring reconstruction, around the eleventh and twelfth and from the mid-seventeenth to mid-eighteenth centuries, are in accord with data on Pamir-Alay glacier fluctuations (Solomina et al. 2016). The evidence for a glacier advance

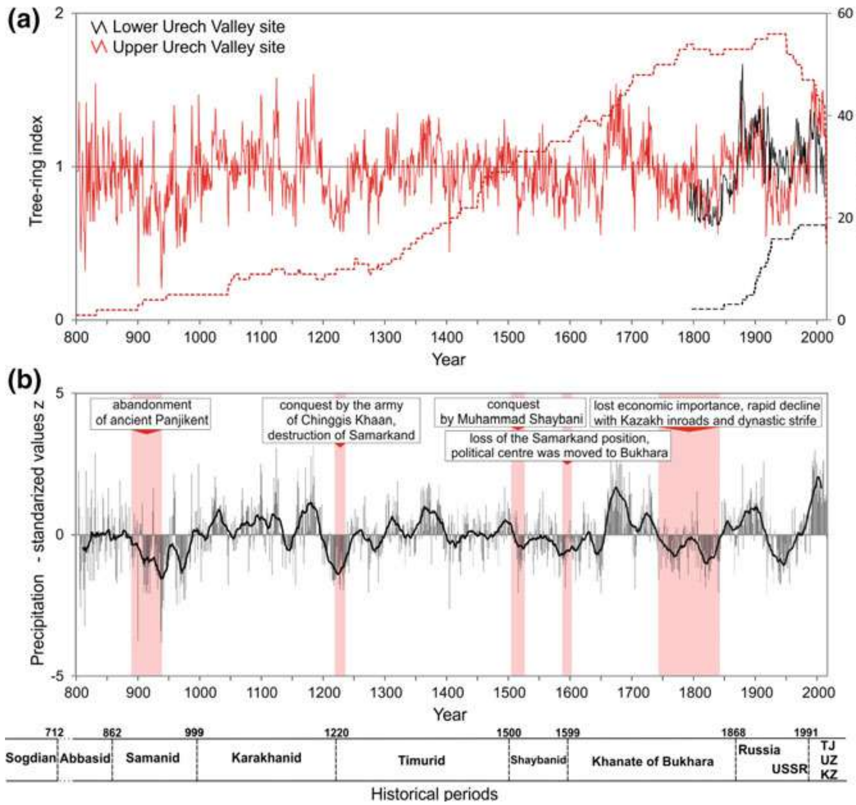

Fig. 9.7 **a** Tree-ring width chronology of *Juniperus seravshanica* from the lower Urech Valley (1795–2014) and *Juniperus semiglobosa* from the upper Urech Valley (801–2015). The solid and dashed lines represent the tree-ring index and sample depth, respectively. **b** Tree-ring-based reconstruction of precipitation variability during the past 1200 years with important historical periods for the former territory of Sogdiana. The vertical red bands denote dry periods, which correlate with rapid political and economic changes

shortly after 985 ± 115 CE was found via radiocarbon dating of shallow soil horizon below a fresh till at the Abramova Glacier (Zech et al. 2000). The youngest advance took place at the end of the seventeenth century (ca 1690 CE) as dated by a ^{14}C age determined from a trunk of *Juniperus turkestanica* broken by an advance of the Raigorodskogo Glacier (Narama 2002). In the light of glaciological evidence, these two advances were of similar magnitude, although the former was slightly larger.

The Pamir-Alay tree-ring reconstruction shows that LIA precipitation maximum (1650–1740) was followed by a long dry period, 1750–1840 (Fig. 9.7b). The first dry sub-period, 1756–1768, known as the Strange Parallel Drought, is well documented in different parts of Asia. Of the four well-documented historical droughts indicated in the Monsoon Asia Drought Atlas (MADA, Cook et al. 2010), it was the only mega-drought to occur in the studied area. At the end of the LIA, a pronounced wet period took place around 1850–1910, followed by advances of the Raigorodskogo Glacier dated to 1908–1934 (Narama 2002).

The twentieth century was characterised by two opposing precipitation regimes. A pronounced drought was observed between ca 1920 and 1970. A significant change in precipitation variability is evident during the second half of the twentieth century. The recent wetting trend in Central Asia was captured by many moisture-sensitive tree-ring series, e.g. from north-western India (Yadav et al. 2017), northern Pakistan (Treydte et al. 2006) and Kyrgyzstan (Chen et al. 2015; Zhang et al. 2015), as opposed to the case of Mongolia or of Nepal, where contemporary drought is evident (Pederson et al. 2014; Panthi et al. 2017).

9.4.3 Socio-economic Changes During the Past Millennium

The oasis of Samarkand in the Middle Zeravshan Valley was the most important political and economic centre at the turn of the first and second millennium of the common era. Samarkand was the capital of ancient Sogdiana, which collapsed in the eighth century; nevertheless, it maintained its importance in the following centuries. During this time, the area was in the possession of various tribes and dynasties (Fig. 9.7). Political changes, both negative and positive, in the former territory of the kingdom of Sogdiana, as reflected in the history of Samarkand, were often associated with climate changes, i.e. the occurrence of alternate dry and humid periods (Owczarek et al. 2018).

Following the Arab conquest at the beginning of the eighth century, most of the former Sogdiana area fell into the orbit of Islamic influence (Grenet and de la Vaissière 2002; Marshak 2003; Ghafurov 2011). The period ca 800–900 was characterised by relatively warmer and wetter climate conditions. This is confirmed not only by tree-ring data but also by other proxy data from the Aral Sea basin and the surrounding areas (Sorrel et al. 2006, 2007; Boomer et al. 2009). During this time Samarkand and its surroundings became part of the Samanid Empire. This period of prosperity was experienced not only in this area but along the entire Silk Road as well. Public buildings and mosques were enlarged and the water supply ensured by means of ancient aqueducts, conduits, and irrigation canals (Ivanitskij and Inevatkina 1999; Malatesta et al. 2012). Samarkand's oases, with their famous peach gardens, experienced a golden age at the end of the Tang Dynasty (Schafer 1963). Despite the tenth-century drought, the economy of Samarkand remained unaffected. This cannot be said of the nearby town of Panjikent, one of the most important cities in ancient Sogdiana and along the Silk Road (Fig. 9.8) (Belenitskij et al. 1973). Although the Arab conquest in 722 did not cause its definitive collapse, Panjikent gradually lost its significance in comparison to Samarkand and Bukhara (Marshak 2003). A period of drought in the tenth century was one of the influences leading to the abandonment of ancient Panjikent and the town's displacement to the lower terrace of the Zeravshan River, where water was more accessible (Fig. 9.8) (Owczarek et al. 2018). The arid conditions during this time have also been clearly documented by

Fig. 9.8 **a** General view of the ruins of ancient Panjikent, partly destroyed during Arab conquest in AD 722 and completely abandoned in the 9th/10th century, **b** archaeological excavation within the area of ancient Panjikent (photographs were taken in July 2015 by the authors)

means of pollen analysis of sediments from the northern shore of the Aral Sea (Sorrel et al. 2007) and other palaeoclimatic records from arid Central Asia (Yang et al. 2009). In the eleventh and twelfth centuries, in stable moisture climate conditions, the former Sogdiana area became part of the Karakhanid Khanate. This period was marked by continued development for Samarkand as a new administrative centre. Several buildings were erected, including a new palace in the citadel, a madrasa, and caravansaries (Davidovich 1998). The Bibi-Khanym Mosque was enlarged and, to a great extent, rebuilt (Grenet and Rapin 1993; Paul 1993).

The tree-ring data from the first half of the thirteenth century documented strong arid conditions (Fig. 9.7). This dry period was also marked by the increasing salinity of the Aral Sea (Sorrel et al. 2006), a high level of carbonate content in lake sediments (Chen et al. 2006), and falls in the levels of lakes in arid Central Asia (Boroffka et al. 2006; Narama et al. 2010), and diminishing ice accumulation in Central Asian glaciers (Yang et al. 2009). This period was marked by drastic political and economic changes in the area of former Sogdiana. In 1220, Samarkand was seized by the army of Chinggis Khaan and destroyed (Grenet and Rapin 1993). The huge losses sustained by the working population and the decreasing availability of water in connection with the dry climate conditions were the main factors contributing to the decline of Samarkand, as maintenance of the water supply required more skills and labour than were available (de Hartog 2006). The increasing humidity in the fourteenth century coincided with the rebuilding of Samarkand and re-establishment of its significance. In 1371, Timur established the city as his capital and renewed the irrigation system in the Zeravshan River valley, which was used extensively for agriculture (Manz 1989). Traces of a high water level and flooding in this period, indicating a moister climate, were found in sediment from canals carrying water from the Zeravshan River to the oases of Samarkand (Malatesta et al. 2012). The next arid interval, recorded ca 1500–1600, was marked again by violent political changes in the former Sogdiana (Fig. 9.7).

In 1500, Timurid Samarkand was conquered by Muhammad Shaybani (Grenet 2002; Mukminova and Mukhtarov 2003). The gradual decline in the importance of the Silk Road in the sixteenth century coincided with the prevailing arid conditions and the loss of Samarkand position. The political centre of the former territory of Sogdiana moved to Bukhara, which became the capital of the Khanate (Mukminova and Mukhtarov 2003). Sixteenth-century aridification was confirmed by an increase in salinity and changes of lake levels of the Aral Sea (Sorrel et al. 2006; Boomer et al. 2009; Boroffka et al. 2006). The rapid increase in humidity in the second part of the seventeenth century was marked by flood sediments in the irrigation canals in the Samarkand oasis (Malatesta et al. 2012). During the period 1750–1850, a return to arid conditions was documented. The former territory of Sogdiana lost its economic importance along with the collapse of trade on the Silk Road. A rapid decline occurred in the second part of the eighteenth century, with the inroads made by the Kazakhs and dynastic strife (Fig. 9.7). The Samarkand oasis was depopulated and the madrasas were converted by nomads into winter stables (Grenet 2002). The wet period in the second part of the nineteenth century coincided with Russian expansion. In 1868, Samarkand was conquered by the Russians and the remainder of the area of the former Sogdiana became an informal Russian protectorate (Fourniau and Poujolvc 2005). The last aridification interval occurred in the middle of the twentieth century. This was a period of rapid socio-economic changes in the Soviet republics of Central Asia. Arid conditions exerted a negative influence on increased human activity and unsustainable farming.

9.5 Conclusions

Our dendroclimatic reconstruction of changes in spring precipitation, which covers important climatic periods of the last millennium, including the drier Medieval Climate Anomaly, the wetter Little Ice Age, and modern times, revealed a series of dry and wet stages. Despite our tree-ring data were collected from relatively limited area, the newly developed proxy record of moisture changes revealed that major dry and wet episodes over the past millennium were consistent with those indicated by other hydroclimatic proxy data (such as speleothems, pollen data, glacier retreats or ice accumulation, lake sediments or changes in lake levels) from adjacent areas.

In general, during dry periods, negative socio-economic changes were observed. Our palaeoclimatic data show drought during the tenth century, influencing the abandonment of ancient Panjikent. The next dramatic decrease in precipitation took place in the first half of the thirteenth century. This period was marked by drastic political and economic changes in the former territory of Sogdiana, as Samarkand was destroyed by the army of Chinggis Khaan and additionally suffered from decreasing water availability, leading to a decline in its importance. Severe drought conditions also occurred in the sixteenth century, contributing to a deterioration in living conditions which coincided with the decline of the importance of the Silk Road and, finally, the loss of Samarkand position. On the other hand, wetter climatic conditions led to improvements in living conditions, followed by expansion and development, as was particularly evident in the eleventh, twelfth, fourteenth, and seventeenth centuries. A socio-economic perspective of wet conditions in the historic past reveals the great vulnerability of societies in arid Central Asia to climate change. However, one should keep in mind that climate may trigger problems in a society, but does not necessarily automatically lead to collapse of cultures.

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Chapter 10
A Drought Reconstruction from the Low-Elevation Juniper Forest of Northwestern Kyrgyzstan since CE 1565

Feng Chen, Shulong Yu, Qing He, Bakytbek Ermenbaev and Rysbek Satylkanov

Abstract Naryn River provides large amounts of water resource for Central Asian countries. Thus, the severity and frequency of drought variation relate to runoff has important influences on social and economic development of this region. In this study, the new tree-ring width chronologies of juniper trees from the low-elevation site of the western Tien Shan are used to reconstruct drought variation for northwestern Kyrgyzstan and place the short instrumental period (1950–2013) of Standardised Precipitation-Evapotranspiration Index (SPEI) in a long-term context. The SPEI reconstruction successfully reflects the dry and wet periods over the past 451 years, and captures a recent wetting trend that generally agrees with the drought reconstructions for the spruce-dominated area. However, some differences between the tree-ring records from spruce-dominated and juniper-dominated areas reflect regional climate differences. The comparison between drought events in the SPEI reconstruction and historical event of Central Asia reveals drought variations have had profound influences on some historical archives over the past several centuries. This study provides the first long-term SPEI reconstruction and drought evaluation from the low-altitude area of Central Asia, contributing to climate change issues in Central Asia.

Keywords Northwestern Kyrgyzstan · Tree rings · SPEI · Drought reconstruction Central asia · Historical archives

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10.1 Introduction

Tree-ring width series have been applied to reconstruct regional- to large-scale drought/precipitation variation over the pre-instrumental period in the drylands of the world (e.g. Cook et al. 2004; Gray et al. 2007; Neukom et al. 2010; Touchan et al. 2011; Fang et al. 2010; Yang et al. 2014; Gou et al. 2015; Chen et al. 2015a). Most of drought/precipitation reconstructions or related index value (e.g. runoff) from Central Asia are inferred from the Xinjiang province in China (Yuan et al. 2007; Zhang et al. 2013; Chen et al. 2014, 2015b), where drought events are common and the socio-economic development is limited by scarce water resources. Despite the large impact of droughts on the socio-economic welfare of numerous Central Asian countries, relatively little is known about the drought frequencies in these regions. Henceforth, the development of reliable, highly resolved moisture sensitive tree-ring chronologies certainly contributes to a more accurate assess of the recent climate change in this region.

During the last three years, the situation have been changed greatly, and many new moisture-sensitive tree-ring chronologies have been constructed (Chen et al. 2013, 2016; Zhang et al. 2015; Seim et al. 2016a, b; Opała et al. 2017). Among these studies, spruce trees have provided the primary information source about past drought/precipitation variations of Central Asia (Chen et al. 2013, 2015a, b; Zhang et al. 2013, 2015, 2016). Although previous dendroclimatic studies revealed that the tree-ring width variations of juniper trees in Central Asia can record drought events, only a few studies carried out to develop precipitation/drought reconstructions from juniper tree-ring records (Esper et al. 2001; Chen et al. 2016; Seim et al. 2016a).

Here, we present a 451-year annual drought reconstruction for the low-elevation juniper forest region near the Toktogul Reservoir in the western Tien Shan of north-western Kyrgyzstan. The reconstruction is based on a tree-ring width chronology developed from long-living turkestan juniper (*Juniperus turkistanica* Kom.). We used this drought reconstruction to examine interannual to decadal moisture variations during the pre-instrumental period. Additionally, our reconstruction was compared to neighbouring drought reconstructions in order to unravel the spatio-temporal moisture variability in Central Asia. Finally, using the drought records, we explore linkages between drought variation and the historical events of Central Asia over the past five centuries.

10.2 Data and Methods

10.2.1 Study Area

The sampling area (41° 34′N, 72° 32′E, 795–820 m a.s.l.) is situated within a 40 km radius of the Toktogul dam near the Naryn River within the western Tien Shan range (Fig. 10.1). Turkestan juniper trees typically grow in an open canopy woodland

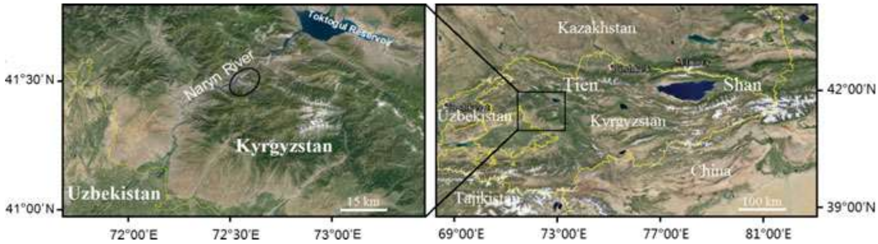

Fig. 10.1 Location of the sampling site (ellipse), the study area (square), and Naryn River

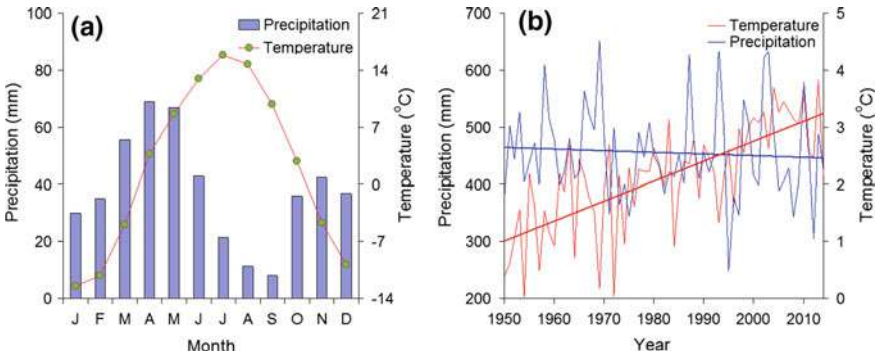

Fig. 10.2 **a** Climograph of mean monthly temperature and total monthly precipitation for our study area (1950–2014). **b** Annual average temperature and total precipitation for our study area (1950–2014)

induced by the semiarid continental climate conditions in the region. Many Turkestan juniper trees are growing on stone cliffs of the Naryn River valley, in elevations between 800 and 950 m a.s.l. Based on monthly CRU (Climatic Research Unit, Harris et al. 2014) climate data, the climate of the Naryn River valley is characterized by cool summers and cold winters (Fig. 10.2a), with average January temperatures of −12.5 °C and average July temperatures of approximately 15.8 °C. Average annual total precipitation is 455 mm, and approximately 44% of precipitation falls as snow from previous December to current March. Just 18% of annual total precipitation falls during the summer and early autumn (June–September). Annual mean temperatures showed a significant upward trend (Fig. 10.2b).

10.2.2 Tree-Ring Width Chronology Development

To develop the drought reconstruction for this area, samples were collected during the autumn 2013 and 2015. 45 juniper trees were cored from stone cliffs along the Naryn River valley with increment borers. Two cores of opposite sites were collected per tree, in order to cope with growth asymmetries. After mounted and sanded, the annual widths of cores were measured with a TA Unislide Measurement System (Velmex Inc., Bloomfield, New York) at 0.001 mm precision. The quality of cross-dating was examined with the computer soft COFECHA (Holmes 1983). After trends not related to climate change removed with the negative exponential curve, the detrended tree-ring series were used to develop the standard (STD) and residual (RES) chronologies with the computer software ARSTAN (Cook 1985). Due to the sample size decreases in the early period of the chronology, the expressed population signal (EPS > 0.85) was used to truncate the tree-ring width chronology due to a weaker coherence of the individual tree-ring width series (Wigley et al. 1984).

10.2.3 Statistical Analysis

Due to the lack of continuous observation data in this region, monthly CRU (Climatic Research Unit) average temperature, total precipitation (1950–2014, Harris et al. 2014) and Standardised Precipitation-Evapotranspiration Index (SPEI, Vicente-Serrano et al. 2010) gridded data (averaged over 41° 30′–43°N, 72–73°E) for 1950–2013 were used in this study. Based on these data we used Pearson's correlation to unravel the climate sensitivity of our juniperus tree-ring width chronology. For that purpose, we consider the climate elements of the previous ('p') and current ('c') grwoing season (from previous July to current September).

Once the predictand with highest explanatory power was selected, the linear regression model was developed and applied for the reconstruction. SPEI data from 1951–1981 were used for verification and from 1982–2010 for calibration. Verification statistics included the sign test (ST), coefficient of efficiency and the reduction of error (RE) (Cook and Kairiukstis 1990). In this study, the wet and dry periods were determined if the 20-year low-pass values were lower or higher than the mean value from 1565 to 2015 continuously for more than 10 years. To demonstrate the geographical representation of our drought reconstruction, we computed correlations of our drought reconstruction with the SPEI dataset by the KNMI climate explorer (http://climexp.knmi.nl) for the common period (1951–2013). Toktogul Reservoir (41° 30′N, 72° 22′E, 700 m a.s.l.), located in the Jalal-Abad Province of Kyrgyzstan, is the largest of the reservoirs on the path of the Naryn River. It was created in 1976 after construction work lasting 14 years on a dam to flood the Kementub Valley. To establish links of our drought reconstruction with water resource availability and the related historical processes in Central Asia, correlations of our SPEI reconstruction with the streamflow series of Naryn River from the hydrological station of Toktogul Reservoir were conducted during the period 1951–1995. In addition, we used a superposed epoch analysis (SEA, Haurwitz and Brier 1981) to determine the resilience of juniper growth under extreme dry climate conditions.

10.3 Results

10.3.1 Tree-Ring Width Chronology Response to Climate and SPEI Reconstruction

The running EPS value is higher than 0.85 from 1565, indicating a significant coherence among the individual tree-ring width time series during CE 1565–2015 (Fig. 10.3). Thus, we use the chronologies spanning the period 1565–2015 to develop the SPEI reconstructions. The correlation analysis indicated the standard chronology were positively correlated with monthly total rainfall in previous July, October and December, and current February–April, July–August at the 95% confidence level. The standard chronology was significantly linked with monthly mean temperature in previous July–August, December–February, and current May, July at the 95% confidence level (Fig. 10.4). Higher positive correlations were found between the standard chronology and SPEI. Similar significant correlations were found between the residual chronology and climate factors. After screened the relationship between seasonally averaged climate factor and the tree-ring chronologies, the standard chronology and mean P_{July}-C_{May} SPEI consistently showed the highest correlation ($r = 0.64$, $p < 0.01$, n = 63). Meanwhile, high correlation ($r = 0.70$, $p < 0.01$, n = 63) between the residual chronology and mean $P_{October}$-$C_{September}$ SPEI was also revealed.

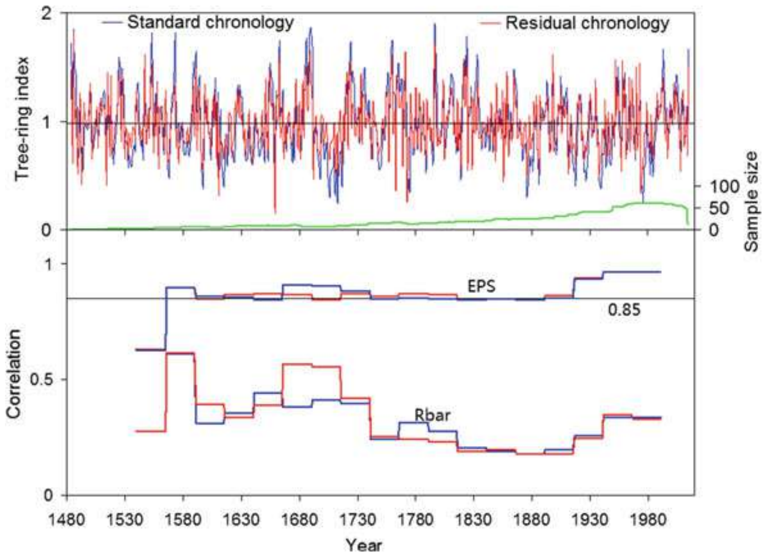

Fig. 10.3 The standard and residual chronologies (1484–2015), EPS and Rbar statistics

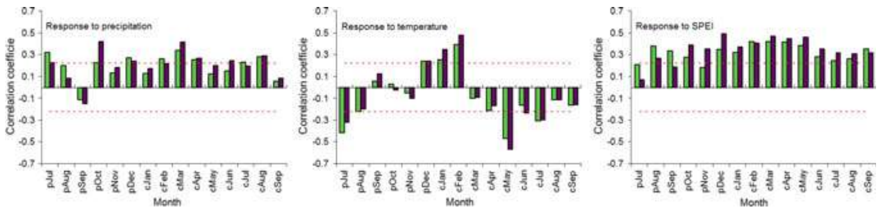

Fig. 10.4 Correlations of the chronologies with the monthly total precipitation, average temperature and SPEI during the common period (1950–2014 and 1950–2013). The dotted lines represent significant variables ($p < 0.05$)

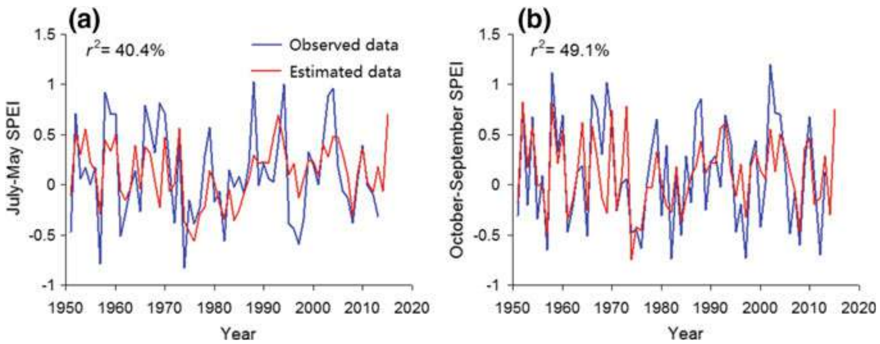

Fig. 10.5 **a** Comparison of the observed and reconstructed P_{July}-C_{May} SPEI for northwestern Kyrgyzstan from 1951 to 2015. **b** Comparison of the observed and reconstructed $P_{October}$-$C_{September}$ SPEI for northwestern Kyrgyzstan from 1951 to 2015

Using the standard and residual chronologies as predictor, the linear regression models ($Y = 0.89STD$-0.786 and $Y = 1.069RES$-0.963) were designed to develop the mean July–May and $P_{October}$-$C_{September}$ SPEI reconstructions. Figure 10.5 shows that the SPEI reconstructions simulate the actual SPEI series very well. The two SPEI reconstructions could explain 40.4 and 49.1% of the instrumental SPEI variance over the calibration period from 1951 to 2013, respectively. Results of the split calibration-verification test showed that the values of RE and coefficient of efficiency were positive), indicating the validity of our SPEI reconstructions (Table 10.1). The results of sign test were both significant at the 0.05 level. These results revealed that the two reconstruction models are suitable for the SPEI reconstruction. Based on the standard and residual chronologies, we developed the two SPEI reconstructions back to 1565. The reconstructions exhibited considerable fluctuations on annual and decadal scale. We used the standard version of the SPEI reconstruction in the following analysis, which retains low and high-frequency signals.

Table 10.1 Verification and calibration statistics for the drought reconstruction models of northwestern Kyrgyzstan

	Calibration (1982–2013) RES/STD	Verification (1951–1981) RES/STD	Calibration (1951–1981) RES/STD	Verification (1982–2013) RES/STD
r	0.74/0.59	0.71/0.68	0.71/0.68	0.74/0.59
r^2	0.55/0.35	0.50/0.46	0.50/0.46	0.55/0.35
RE		0.47/0.45		0.50/0.34
Coefficient of efficiency		0.45/0.43		0.49/0.31
Sign test		$(24^+/7^-)/(25^+/6^-)$		$(25^+/7^-)/(24^+/8^-)$
Sign test of the first difference		$(25^+/5^-)/(23^+/7^-)$		$(24^+/7^-)/(25^+/6^-)$

10.3.2 The Drought Characteristics of Northwestern Kyrgyzstan

The SEPI reconstruction provided the long-term background to evaluate regional drought variations over the past 451 years (Fig. 10.6). The SPEI reconstruction showed that dry periods prevailed in the 1577–1586, 1598–1625, 1632–1651, 1669–1678, 1695–1719, 1743–1753, 1772–1792, 1838–1851, 1870–1888, 1911–1950 and 1971–1987. In contrast, the intervals the 1567–1576, 1587–1597, 1652–1668, 1679–1694, 1720–1742, 1754–1771, 1793–1837, 1819–1837, 1852–1869, 1889–1910, 1951–1970 and 1988–2015 were relatively wet. The 10 most extreme dry/wet years and 10 wettest/driest decades in northwestern Kyrgyzstan were summarized in Table 10.2. Spatial correlation analyses indicated that actual and reconstructed SPEI linked significantly with the gridded SPEI and exhibit similar patterns during the period 1951–2013, albeit the signal strength of the latter is relatively low (Fig. 10.7). Figure 10.8 shows the SEA results based on the list of 10 most extreme dry years, and reveals a statistically significant ($p < 0.01$) reduction in SPEI is indicated happening in the same year as extreme events, and the extreme dry events may be persisted for 5-years.

10.4 Discussion

10.4.1 Comparisons with Other Drought Reconstructions

The developed SPEI reconstructions shows strong annual and decadal coherency to neighbouring moisture sensitive chronologies. A January–May Palmer Drought Severity Index (PDSI) reconstruction has been developed from the spruce-dominated

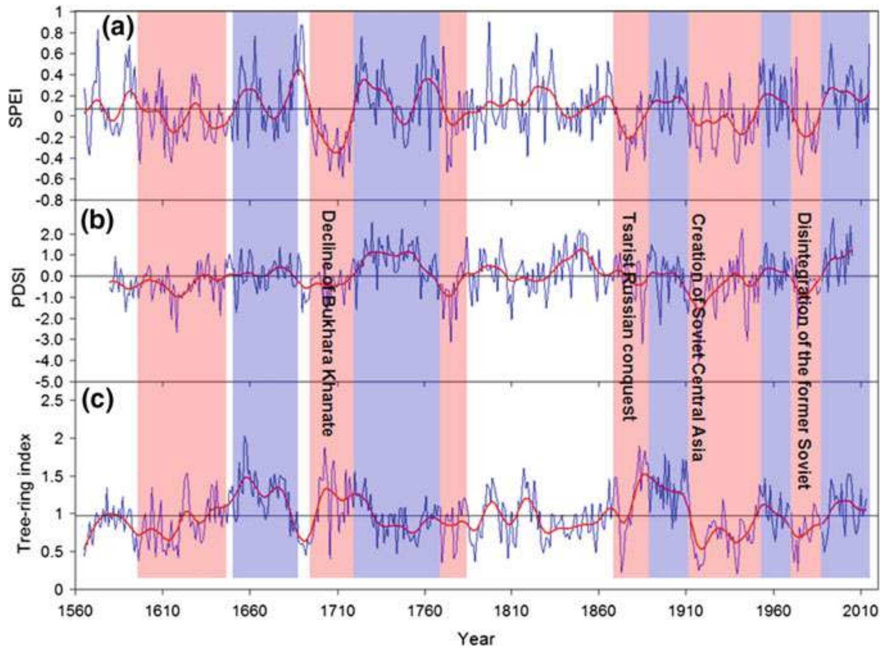

Fig. 10.6 Comparison between the reconstructed SPEI and the tree-ring records from vicinity. **a** Authors' reconstructed SPEI (previous July to current May) in this text; **b** January–May PDSI reconstruction for the spruce-dominated area of eastern Tien Shan by Chen et al. (2013); **c** A moisture-sensitive tree-ring width series of juniper trees from northern Tajikistan (Chen et al. 2016); Dry (wet) periods are emphasized in red (blue), respectively. To emphasize low-frequency variations, all series were smoothed with a 20-year low-pass filter

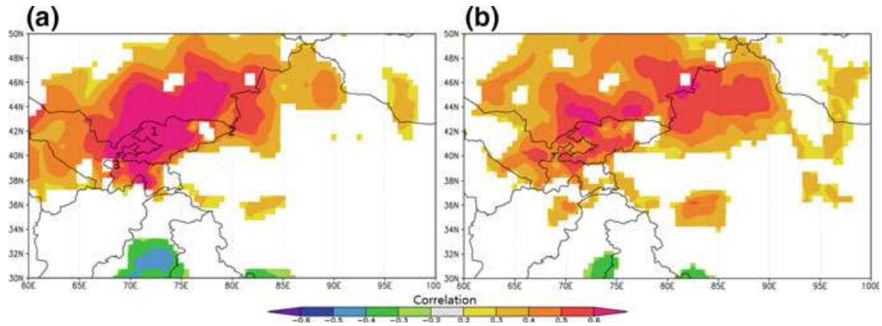

Fig. 10.7 Spatial correlation fields of instrumental **a** and reconstructed **b** mean P_{July}-C_{May} SPEI for northwestern Kyrgyzstan with regional gridded P_{July}-C_{May} SPEI for the period 1951–2013. The numbers 1, 2 and 3 denote the tree-ring sites of northwestern (This study) and eastern (Chen et al. 2013) Kyrgyzstan, and northern Tajikistan (Chen et al. 2016)

Table 10.2 Rankings of the dry/wet years and periods for northwestern Kyrgyzstan

10 most extreme years				10 wettest and driest decades			
Year	Driest	Year	Wettest	Year	Driest	Year	Wettest
1713	−0.58	1797	0.91	1710	−0.27	1720	0.36
1976	−0.56	1690	0.87	1700	−0.23	1680	0.32
1773	−0.53	1689	0.87	1870	−0.18	1760	0.32
1706	−0.53	1573	0.83	1940	−0.15	1820	0.29
1876	−0.53	1824	0.80	1610	−0.14	1990	0.25
1711	−0.51	1686	0.78	1910	−0.10	1730	0.23
1775	−0.48	1663	0.77	1970	−0.08	1950	0.22
1975	−0.46	1760	0.77	1640	−0.07	2000	0.22
1597	−0.45	1724	0.76	1980	−0.07	1830	0.21
1939	−0.45	1691	0.71	1770	−0.07	1660	0.20

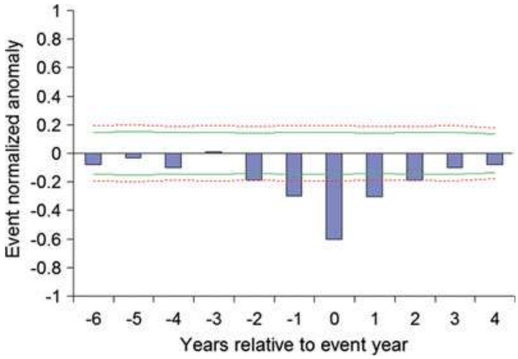

Fig. 10.8 Results of superposed epoch analysis (SEA) testing the impact of extreme dry years. The bold and dotted lines indicate the 95 and 99% significance level, respectively

area of eastern Tien Shan, eastern Kyrgyzstan and China (Chen et al. 2013), and provided a chance to validate our drought reconstruction. Correlation between Chen et al. (2013) and this study, computed over the period 1580–2005 are 0.22 ($p < 0.001$), and increase to 0.41 ($p < 0.001$) after 20-year smoothing, respectively. Our SPEI reconstruction shows high similarities with the drought series in eastern Tien Shan (Chen et al. 2013) (Fig. 10.7). The comparison reveal that regional dry conditions during 1598–1646, 1695–1719, 1774–1785, 1870–1888, 1911–1950 and 1971–1987, and wet conditions during 1651–1690, 1720–1773, 1889–1910, 1951–1970 and 1988–2005 found in eastern and western Tien Shan, Kyrgyzstan. Some extremely dry events of the spruce-dominated area (e.g. 1774–1775, 1885–1886, 1917–1919, 1974–1976) also found in the western Tien Shan.

Further west, the study showed that tree-ring widths of juniper trees of northern Tajikistan were also sensitive to P_{August}-C_{July} drought variations (Chen et al. 2016). The period 1850 to 2005 appears to coincide with similar dry/wet periods in Tien Shan. In particular, juniper and spruce series both show a upward trend at the period 1987–2015, suggesting a consistent wetting trend in Central Asia. However, some divergences existing in the tree-ring records from spruce-dominated and juniper-dominated areas during 1565–1850 that is supposed to be associated to small scale climate variations.

10.4.2 Current and Historical Drought Perspectives

The wetting trend since 1980s has raised the concerns about water resource variation and possible future climate change of Central Asia (Shi et al. 2007). Understandably, this consistently wetting trend, especially in lowland areas, is of advantage to social and economic development and ecology of Central Asia. Nevertheless, the drought risk reduction strategies are still prominent topics for Central Asian countries. The comprehensive drought information from the SPEI reconstruction reveals the natural drought variations of northwestern Kyrgyzstan over the past centuries. For example, the 1970s drought likely included the driest years of the last 451 years, but the drought periods (e.g., 1710s and 1870s) in the pre-instrumental period were probably drier than any in the instrumental SPEI record (Table 10.2). Similar to recent wet period with wet years (e.g., 1993 and 2015), many wet periods and years found in the 451-year chronology, but there are few wet periods lasted more than 40 years in the past 451 years. Therefore, the recent wet period and how to deal with the possible dry period are need to further study.

In history, irrigated agriculture which relies on water resources was always the basic social economical engine in Central Asia (McKinney 2004; Clarke et al. 2005). Since Naryn River is an important water resource for the Fergana Basin, which is the most densely populated area in Central Asia, fluctuations in drought and streamflow can have serious geopolitical consequences (White et al. 2014; Duishonakunov et al. 2014). Correlations of our SPEI reconstruction with annual and highest monthly streamflow series of Naryn River, calculated over the 1951–1995 common period are 0.60 and 0.64 ($p < 0.01$), respectively (Fig. 10.9). This significant positive correlation supports the linkage of regional drought variation with streamflow and agricultural production. Meanwhile, many severe drought events lasted a long time (Fig. 10.8) and have had more profound impacts on the peoples of central Asia over the past several centuries. From the historical perspective, some drought periods in northwestern Kyrgyzstan correspond well with the historical events of Central Asia. During the prolonged drought period 1695–1719, the national strength of Bukhara Khanate was weaken consistently, and led to the division of the khanate (Roudik 2007). The 1876–1878 drought events and the dry period 1870–1888 from our SPEI reconstruction matches the turbulent period 1865–1877. During this period, the Tsarist Russian conquest of Central Asia was completed (Soucek 2000; Kharin 2002; Kilavuz 2007), and the bad climate weaken the resistance of the Feudal khanates, which were mainly agricultural and accelerated the conquest process, and many local inhabitants left the Fergana Basin for China, and leaded to the war in Xinjiang (Kim 2004). The 1917–1918 drought events from our SPEI reconstruction correspond to the dry decade 1910s which some official documents of local government report low pre-

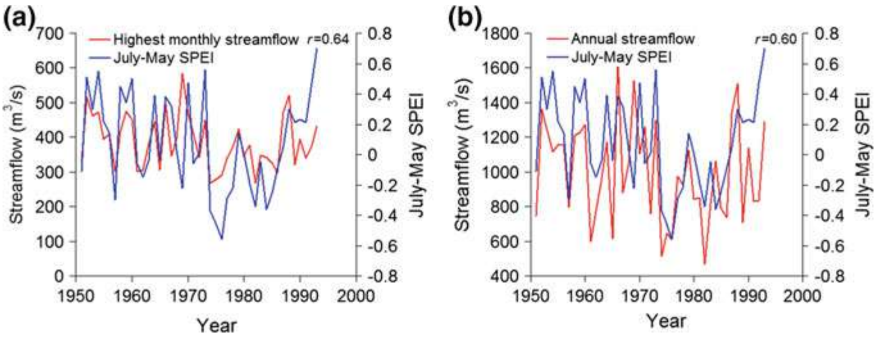

Fig. 10.9 **a** Comparison of the highest monthly streamflow and reconstructed P_{July}-C_{May} SPEI for northwestern Kyrgyzstan from 1951 to 1995. **b** Comparison of annual streamflow and reconstructed P_{July}-C_{May} SPEI for t northwestern Kyrgyzstan from 1951 to 1995

cipitation and bad agricultural yields (Allworth 1994; Esper et al. 2001; Chen et al. 2013). The feudal khanates at the lower reaches eventually perished, and began to sovietize Central Asia. Before the disintegration of the former Soviet Union, the study region experienced a dry period since 1970s (Lamb 2002).

10.5 Conclusions

We developed the standard and residual chronologies from the low-elevation juniper forest of northwestern Kyrgyzstan, where previously drought reconstruction were missing. Standard and residual chronologies are both sensitive to regional drought variation. Based on standard chronology, a SPEI reconstruction was developed over the past 451 years. Spatial correlation fields revealed that our SPEI reconstruction can represent regional moisture variability over northwestern Kyrgyzstan. Comparison with the drought reconstruction from the spruce-dominated area of eastern Tien Shan shows high coherency. The SPEI reconstruction also shows a strong positive response to streamflow variation of Naryn River, and reveals that some significant drought events are linked with regime change and catastrophic historical during the past 451 year. The spatiotemporal divergence of drought variation between spruce-dominated and juniper-dominated areas was also found, and may reflect the impacts of regional climate features.

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Part IV
Climatic Factors in the Transitions of Social Systems

Chapter 11
Social Impacts of Climate Change in Historical China

Xiuqi Fang, Yun Su, Zhudeng Wei and Jun Yin

Abstract The social impact of past climate change is one of the key areas of study relating to global climate change, particularly its ability to provide valuable lessons for dealing with ongoing challenges of global climate change. Drawing on the abundant historical literature, many recent studies have examined the social impacts of climate change in China during the past 2000 years. This paper reviews the main progress of these studies in three parts. First, a concept model based on the food security in relation to global climate change has been constructed, which can then be used to interpret impact-response processes of climate change in the history of China. Second, we derive a methodology for quantifying the impact of historical climate change, drawing on a series of 4 key social and economic sequences at a 10-year resolution. These have been reconstructed based on the semantic differential method over the past 2000 years in China. Third, using a variety of statistical analyses, we update the understanding of climate impacts throughout the history of China. The overall impacts of climate were negative in the cold periods and positive in the warm periods, at decadal to centennial scales during Chinese history. However, the impacts seemed a mixed blessing both in the cold or warm periods. The social-economic development and population growth in warm periods would intensify the natural resource shortage and disequilibria in the human-environment system, especially when encountering abrupt climate changes. Adaptation to adverse climate change could not only help people to avoid hardship whilst maximizing profits, but also expanded the capabilities for the continual development of Chinese civilization.

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Keywords Historical period · Climate change · Social impact
Process mechanism · China

11.1 Introduction

As the most active element in the natural environment, climate change has had wide and profound impacts on human society at multiple temporal and spatial scales, although it might not a determinative driving force. A growing number of cases from all around the world have proved that climate change played an important role in the rise and fall of regional civilizations, especially during the period before industrial revolution (deMenocal 2001; Haug et al. 2003; Zhang et al. 2007; Büntgen et al. 2011; Butzer 2012; Buckley et al. 2014).

The lessons learned from the past are valuable for current human populations to improve our understanding of the impact of ongoing climate change, and social adaptation to the challenge of future global change appropriately (IHOPE 2010). Studies on the impacts of past climate change worldwide can be summarized as follows. First, climate change could lead to both positive or negative social changes, from production systems to social systems, such as harvest fluctuation, population variation and migration, economic fluctuation, social harmony and crisis, and dynastic transition, at multiple temporal and spatial scales (Büntgen et al. 2011; Tol et al. 2010; Pederson et al. 2014; Zhang et al. 2007; Lee et al. 2008). Second, the way of climate change impacting society could be summarized through 5 general patterns (Fang et al. 2017), including periodic changes (Zhang et al. 2005; Lee et al. 2008), pulse (Pederson et al. 2014), adaptive transition (Willcox et al. 2009; Chen et al. 2015), collapse (Weiss et al. 2001; Haug et al. 2003; Douglas et al. 2015), migration and replacement (Büntgen et al. 2011, 2016; Kuper et al. 2006; Timmermann et al. 2016). Third, there is a set of studies focusing on the impact mechanism of climate change. A few attempts have been made under an idealized theoretical framework, for example the concept of social resilience for interpreting historical collapse as summarized from case studies (Butzer 2012), or a set of causal linkages relating climate change to large-scale human crises in preindustrial Europe (1500–1800) based on statistical analysis (Zhang et al. 2011). However, most of the above conclusions have been derived from direct comparisons of historical climate change events and related social phenomena occurring during the same period. A more detailed understanding of the processes and mechanisms of climate change impacts remain to be researched quantitatively.

China is a country that has great potential for the research of impacts of past climate change. As an agriculture-oriented society under the Asia monsoon climate regime, the history of China has been strongly impacted by climate change. Although historical China varied its borders from dynasty to dynasty, its core social-economic closely aligned with the major agricultural area throughout history. This geographic and temporal overlap allows for continuous comparison across the Chinese core areas. There are abundant historical records spanning thousands of years that relate the impacts of and adaption to climate change in China. These records provide opportunity for studying the process and mechanism of the social impacts of past climate change and human adaptation. Using the information from these historical literatures, a number of studies have examined the interaction mechanisms and processes of social impacts of historical climate change in China. This paper summarizes the main findings relating to the impacts of climate change in China during the past 2000 years.

11.2 Concept Model: Impact-Response Processes of Climate Change Under the Framework of Food Security

Agriculture was the foundation for ancient China, as such food security was not only the material foundation for human survival, but also the base for maintaining the economic development and the stabilization of social system. There is a general consensus that climate change has had a strong impact on historical agricultural production in China (Ge 2011; Ge et al. 2014; Zhang et al. 2005, 2006).

To further understand the impact of climate change, recent studies use concepts of vulnerability and food security in relation to Global Changes(GECFS) (Ericksen 2008) to illustrate the impacts of, and responses to (impact-response processes) historical climate change in China. Corresponding to the concepts of food access, food availability and food utilization, the food security of historical China can be simplified to three levels of security—food production, food supply and food consumption. In this system, the impact of climate change is most pronounced upon grain harvest in the food production subsystem. These impacts are then transferred further up to the subsystems of economy, population and society (Fig. 11.1). However, due to the complexity of human society, the impact-response processes of climate and social change could not be attributed to a simple causality. The initial impact could be amplified or suppressed in feedbacks, which processed within or between subsystems of human society (such as cultivated land area, population, policy, and the surrounding neighbors, etc.) (Fang et al. 2015). Both the spontaneous behaviors of the people and the policies and operations of governments played very important roles in all steps of adjusting the responses to the impacts of climate change. But each adjustment had its limitation under the given historical condition. The impact of climate change could be positive or negative. To a certain degree, even the negative impacts could be converted into new opportunity for development if right countermeasures were taken.

(1) Food production security, is the fundamental aspect in ensuring an overall food security. The relationship between any given population and the productivity of its land-use systems is dynamic and responsive not only to demographic forcing but also to the social and economic processes regulating resource demand, land availability, technology adoption and availability, environmental variation, and

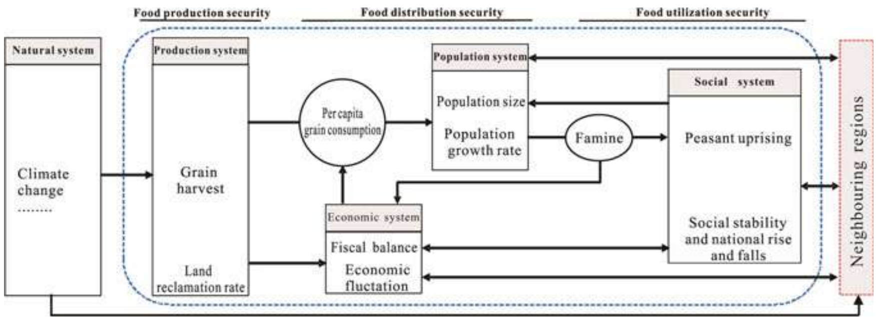

Fig. 11.1 A conceptual model of climate change impact-response in the history of China based on food security (after Fang et al. 2014a, 2015)

the potential for intensive use of land to degrade its potential productivity over time (Ellis et al. 2013). As one of the factors affecting the balance of food productivity and population, impact of climate change is more sensitive during the phases of productivity crises. Changes in per capita grain production could possibly reflect the sensitivity of the food production subsystem to climate change. The security of food production in response to climate change in the historical period was initially based on the per unit yield. Annual yields were influenced by both the sensitivity of the crops to climate conditions, and the human capacity to ensure the stability of production and to resist agricultural disasters. Both regional cultivated land area and population were important factors in food production security, shifting the balance of per capita food production.

(2) Food supply security, refers to means for either individuals or the wider society to acquire enough food to meet food security standards. Factors in this include the volume of production yield, or the capacity for regulating food supplies by the society. Climate change impacted on the food supply security by changing regional food production and supply capacity in the historical period. When individual food supply security was not satisfied, consumers would at first try to survive themselves by using their own food stocks, or in more severe cases, to draw on natural and foraged foods. The adaptive response to declining food supply in market was generally to raise the price of foods in order to attract more food into the market, as well as to restrict consumer demand. In wider society, insecure food supply could possibly lead to conflicts among different social classes, the public and the government. To avoid conflicts, the government had to use its economic capacity and administrative power to regulate the food supply and ease social contradictions. The main measures included reducing tax or delaying tax collection, controlling food prices by supplying state reserved grain to markets, dispatching food from other regions, and migrating people to other regions, etc.

(3) Food consumption security also involves both individuals and wider society. It refers to the way in which demand of food maintained security of individual

livelihood and social-economic development. If insecurity in the food supply of individuals threatened the security of individual's food consumption, it would become a threat to survival, potentially resulting in a large number of famine victims. The famines could develop into refugee flows, trigger social unrest, and even cause social instability or collapse. Under such situations, the measurements for regulating food consumption security taken by the governments generally included the following aspects: to relieve refugees in order to avoid enlarging the size of refugee populations; to encourage spontaneous or organized migration to reduce population pressure in the region affected by climate change; to maintain public security and social stability, and to avoid the feudal dynasty being endangered by enlarged unrests.

Under this framework of food security, the impact and response mechanisms of climate on society in historical China began with the direct impact of climate on the harvest, and then were transmitted in two basic routes. One was harvest—famine victims—social instability for individual food security; the other was harvest—economy—social stability for social food security (Fang et al. 2014a). Along the individual food security transmission chain, the impacts were regulated by social food security, which was mainly through the regulation of economy to population and social system.

11.3 Methodology: Quantifying Historical Social and Economic Series Based on Semantic Differential Over the Past 2000 Years in China

Reconstructing social-economic series with the same temporal resolution, duration, and continuity as climate series is a precondition for studying the processes and mechanisms of the impacts of climate change in history. The key quantifiable variables should be able to represent the subsystems of agriculture, population, economy, society, etc. The most difficult issue for the quantification is a lack of standardized social-economic statistical data in historical China. Other data, such as population, farmland area, price and etc. are discontinuous throughout the past few thousand years, except for the relatively continuous data of crop harvest in the Qing Dynasty.

On the other hand, China has abundant, continuous and high-resolution historical literature over the past 2000 years to record or describe the social-economic conditions. The Chinese words are rich in meaning. The semantic differential of these words is definite, and the meaning of the word is generally stable during the history. Therefore the historical records could be used to reconstruct graded climatic series (Zheng et al. 2006) and socio-economic series based on Semantic Differential. The two key methods for the reconstruction are gradation of literal description and normalization of time resolution, respectively (Fig. 11.2) (Fang et al. 2014b).

The core of the Semantic Differential method is to convert the qualitative description of the social-economic conditions during different historical periods into quanti-

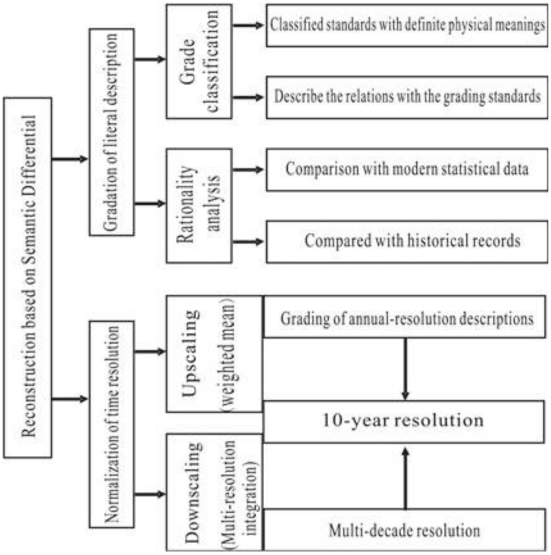

Fig. 11.2 Methodology for quantifying historical social and economic series based on Semantic Differential (Fang et al. 2014b)

tative grades. In this method, the properties of the objects are distinguished by bipolar adjectives (relativity and antonym), which are quantified by the adverbs of different degrees, such as extreme, very, somewhat, normal, etc. To construct the grading scale by Semantic Differential, it is important to pay attention to whether the meanings of the vocabularies are easily distinguished, and to consider the physical meanings of the standard vocabularies corresponding to each level as much as possible. There are generally 4 steps that the literal descriptions are quantified to grades, although the implementation for quantifying the literal descriptions to grades is varied based on individual properties of the records. These steps are as follows: (1) collecting the direct and indirect literal records on social and economic description; (2) confirming the standard of classified quantification against reconstruction indexes; (3) ranking the grades of social-economic condition reflected in the historical documents, on the basis of the classified quantification standard; (4) analyzing the rationality of classified results (Fang et al. 2014b).

Following is an example of the gradation of historical harvest (Su et al. 2014; Fang et al. 2014b). It is based on 2755 items of original descriptions regarding agricultural yields garnered from the 25 chronicles on the dynastic histories of China named *Twenty-Four Histories* and *Qing History Draft,*[1] covering the period from Western Han Dynasty (206 BC–AD 24) to the Qing Dynasty (AD 1645–1911). Detailed descriptions on the steps and the uncertainties of the reconstruction are described in Su et al. (2014) and Yin et al. (2015).

The bipolar adjectives, such as "bumper" and "poor" in the records of harvest in historical China were used to distinguish the good or bad variation on the annual grain

[1]《二十四史》和《清史稿》.

production relative to average grain yield (normal or common year). The superposition of adverbs of degree, such as "very bumper/poor", "near bumper/poor", were used to further distinguish the level of the harvest.

The key words describing crop harvest corresponded well to the quantified ten-point harvest system (10 points represent 100% of per capita harvest was met; with each 1 point reduction corresponding with a 10% diminishing of harvest) in historical China. This provides proof that such descriptions of harvest have clearly physical meanings to be used to identify annual crop harvest grades that could be selected as reference, and that standard words represent the different harvest grades. Referring to the standard words, the annual grain yield was divided into six levels from 1 to 6 corresponding to the key words of "Very poor harvest", "Poor harvest", "Slightly poor harvest", "Normal harvest", "Near bumper" and "Bumper", respectively, based on the semantic differential. By matching the descriptions on bumper or poor grain yields from historical documents to the key words, the annual harvest grade series is reconstructed, which is used to reconstruct a harvest index series for unifying the time resolution later.

Several principles are given for the gradation of annual harvest records. (1) Records with their time-scale matching or higher than the resolution of the reconstructed series are used initially. (2) Records covering the whole country or the core agricultural area of the country are prioritized as the main data source; then records covering local or marginal regions are used as auxiliary records, on the condition of correcting their spatial representation to the national scale. (3) Direct evidence from the historical record are used first, following by the indirect evidence. When disagreement between records occurs, the position supported by the majority of records is adopted. (4) In periods without any record spanning only 1 or 2 years, these are regarded as average years according to the basic principle that history usually recorded unusual events rather than common events; if the no-record years are up to or more than 3 to 4 consecutive years, they are graded in reference to the major historical events of the period.

Time-scale normalization is mainly used to solve the problems that time resolutions of original grade series are unequal or the series is discontinuous, by up-scaling or down-scaling the series. 10 years have been used as the basic time unit for up-scaling the annual resolution data or down-scaling the lower than decadal resolution data (Fang et al. 2014b).

The 10-year resolution harvest grade series of China in past 2000 years is an example of time up-scaling (Fig. 11.3). The historical harvest records were recorded in annual resolution, but they were discontinued in some years. To reconstruct a grade series of harvest in 10 years resolution, an up-scaling method was needed to convert annual resolution series into decadal resolution series. In our research, the annual harvest grade series had been converted to a decadal harvest index by calculating decadal average of the annual harvest grade with unequal weights. Then a harvest grade series at 10 years resolution has been reconstructed by dividing the decadal harvest index value into 5 grades.

The 10-year resolution macroeconomy grade series of China in past 2000 years is an example of time down-scaling (Wei et al. 2015a; Fang et al. 2014b). The series was

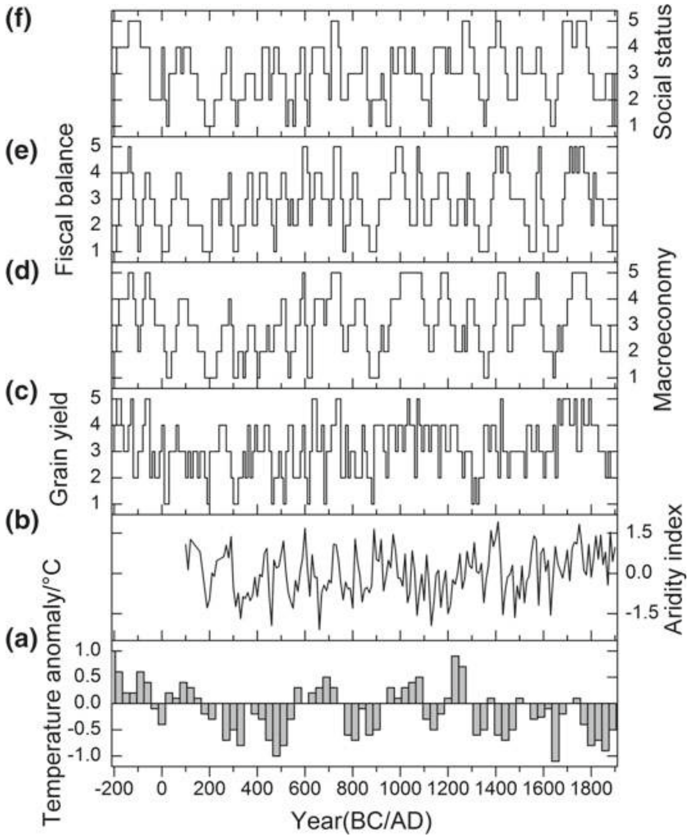

Fig. 11.3 Climate Change and socio-economic grade series during the past 2000 years in China. **a** Winter-half-year temperature anomaly with 30-year resolution during 210 BC-1910 AD in Eastern China (Ge 2011); **b** wet-dry index of Eastern China during 101-1910 AD (Zheng et al. 2006); **c**–**f** 10-year resolution grade series of the grain harvest (Yin et al. 2015), macroeconomy (Wei et al. 2015a), fiscal balance (Wei et al. 2014), social vicissitudes (Yin et al. 2016a), respectively, in the past 2000 years in China, and the grade 1–5 represents the state from bad to good, respectively

reconstructed on the basis of 1091 records regarding the economic history of China, extracted from 25 books written by leading Chinese scholars and published in the last thirty years. The time resolution of the historical records on the macroeconomy of China varied from annual scale to the empire-scale (usually 20–30 years) resolution or even dynasty-scale (centennial scale) resolution. The 10-year resolution macroeconomy grade series of China was reconstructed through the following steps. First, to identify the grade or changing trend from one grade to other one, according to each historical record; then by integrating all data in different resolutions from annual to centennial to divide relative low temporal resolution data into 10 years resolution step by step, using the differences of start/end year and temporal resolution among the records; and lastly re-sampling the grade data decade by decade.

Using the gradation methodology of semantic differential, 4 historical social-economic graded series of China in 10 years resolution over the past 2000 years, including harvest (Su et al. 2014; Yin et al. 2015), economy (Wei et al. 2015a, b), finance (Wei et al. 2014) and social vicissitudes (Yin et al. 2016a, b), have been quantitatively reconstructed (Fig. 11.3). In addition, other series of famine index, peasant uprising frequency, and frequency of wars waged between nomadic and farming groups of China in 10 years resolution over the past 2000 years were also reconstructed (Teng et al. 2014; Fang et al. 2015; Su et al. 2016). Detailed descriptions on the specific steps and the uncertainties for each reconstructed series are in the cited references.

The duration of the series mentioned above was from 210 BC to AD 1910 that covered the Western Han Dynasty (206 BC–AD 24) to the Qing Dynasty (AD 1645–1911) of China. All the series could represent the social systemic changes in China as a whole over the past 2000 years, because they have a similar spatial coverage and are mainly based on the historical records coming from the eastern part of China, which has long been the major agricultural area as well as the core social-economic area throughout the dynastic history of China. Using these series, and the winter half-year temperature series (Ge 2011) and wet-dry series (Zheng et al. 2006) in eastern China, which also covered the key farming region over the

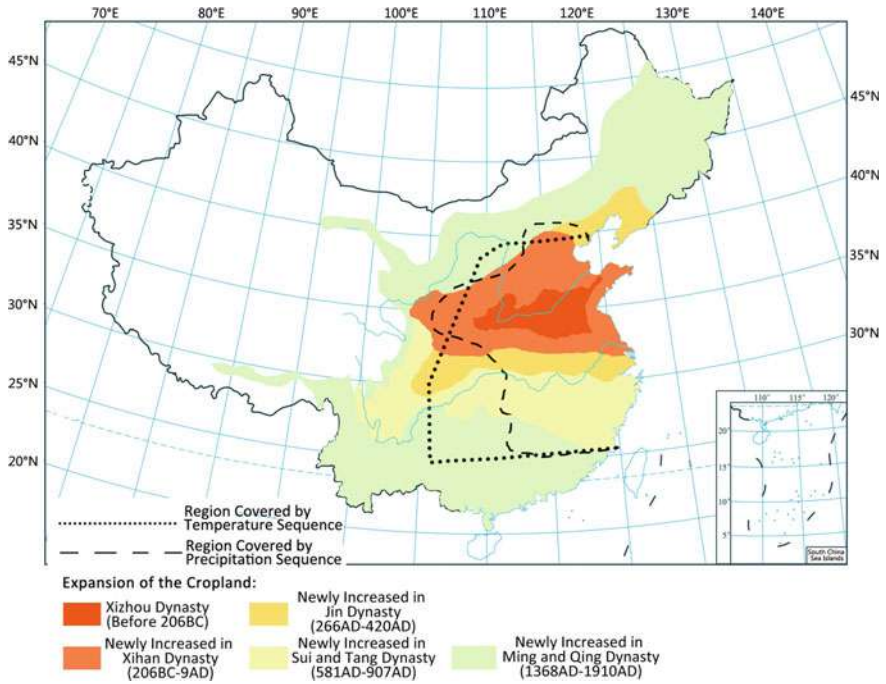

Fig. 11.4 Historical expansion of the major agricultural area in the history of China and the region covered by the temperature series and the wet-dry series over the past 2000 years (Yin et al. 2015)

past 2000 years (Fig. 11.4), the impacts of historical climate change on society of China could be quantitatively analyzed.

11.4 Scientific Understanding: The Macroscopic Rhythm of Climate and Social-Economic Changes

By analyzing the relationship between climate change and social-economic changes in China over the past 2000 years, the scientific understanding of general characteristics of the impacts of historical climate change on social-economy in China are summarized in the following.

First, as many scholars have surmised (Hsu 1998; Lee et al. 2008; Zhang et al. 2005, 2006; Ge 2011; Ge et al. 2014; Pei et al. 2014), the general characteristics of the impacts of historical climate change were negative in the cold periods and positive in the warm periods. On the centennial scale, the flourishing of economic and social health, population increase and territorial expansion generally occurred in the warm periods, with an inversion occurring during cold periods (Yin et al. 2015, 2016b; Wei et al. 2014,2015a, b). Among the 34 dynastic prosperity periods in the empirical China, 18 occurred in warm or relative warm periods, 26 of them occurred when the climate changed from cold to warm. On the other hand, 11 of the14 dynastic transitions periods occurred in cold or relative cold periods (Yin et al. 2016b). The primary driver of the above processes are regarded to be warm conditions generally benefitting agricultural development. The better harvest could provide the material foundation to accelerate social-economic development. The main impact of cold periods are to increase vulnerability of human systems, causing a capacity decrease in social-economic system, limiting ability to respond to climate change or social-economic crisis.

Second, further to simple correlation of negative conditions in the cold periods and positive in the warm periods, both the impacts of warm and cold climate seemed a mixed blessing from a view of social development. The social-economic development and population growth in warm periods increased the pressures on the natural environment via resource utilization. For the agriculture-based society of empirical China, such a high pressure could lead to natural resource shortage and disequilibria in the human-environment system, and trigger social crisis when abrupt climate change (such as cooling and precipitation decrease) occurred. Among the 9 high social risk periods indicated by the social-economic series over the past 2000 years in China, 8 were partially or wholly contemporary with the transition periods of climate from warm to cold (Ge et al. 2015; Yin et al. 2016b). During these periods, extreme climate events or disasters were likely to trigger social crises, some of which even became the trigger for social turbulence and dynastic collapse or replacement. The collapse of the Ming dynasty was a typical case. On one hand, climate change turned to cold and dry at the late 16th century to early 17th century that caused the crop yields decrease directly, resulting in a chronic food crisis in North China, destroying the military farm system, and thus exacerbated fiscal deterioration. On the other hand, peasantry uprising in Shaanxi and Shanxi provinces were triggered by the severe droughts which lasted more than 10 years (1627–1643 AD) in northern China (named “Chongzhen Drought”), the worst drought event in North China over the past 500 years. The drought had also replenished the peasantry troops, and severely disrupted the food supply for the government troops. The Ming Dynasty eventually collapsed in a peasant uprising (Zheng et al. 2014; Xiao et al. 2015).

Finally, successful adaptation could not only help populations to mitigate harms while also to expanding productivity, but also enhancing the capabilities for the continual development of Chinese civilization. The Chinese people could choose suitable countermeasures according to the temporal and regional differences in order to adapt to the impacts of climate change. For example, the warm climate of the “Medieval Warm Period” increased heat resources in most areas of China. To adapt to the warm climate, the people expanded the crop planting boundary northward in the 10th–13th century, especially in the agriculture-pasture transitional zone in northern China and the transitional area between the warm temperate zone and subtropical zone. During the Medieval Warm Period, the Song dynasty (960–1279 AD) had to adapt to the regional differentiation of precipitation regimes, with conditions dry in the south and wet in the north of eastern China. As a response, rice planting areas were expanded to the Yellow River basin of northern China, while Champa rice plantation with a shorter growing season and a rice-wheat succession cropping system was developed in the Yangtze River basin of southern China. The rice-wheat succession cropping system, which was finally established in the South Song dynasty (1127–1279 AD) and has been used to the present day, is regarded as an important revolution of cropping system in Chinese agricultural history that had a profound contribution to sustaining food security and socioeconomic development in China (Ge et al. 2015). Another example of adaptation was by the Qing Dynasty during the Little Ice Age (Fang et al. 2013; Xiao et al. 2015). With the exception of its earliest periods, the Qing Dynasty was characterized by tense human-environment relationships for the rapid population growth. Against this background, the Qing Dynasty responded and adapted to the impacts of climate change in many ways, including the introduction and expansion of some higher yield crops (such as corn, tuber crop), adjustment of the cropping system to fit the changed climate (such as adopting double cropping rice in the Yangtze river basin during a period of climate warming in the early 18th century) (Atwell 2002; Ge 2011) and some other agricultural measures. In addition, social changes such as encouraging migration to marginal regions for reclamation took place. Taking a long time scale perspective, the migration and reclamation appears to be driven by not only by population pressure and some political factors, but was also strongly impacted by climate change, especially extreme climate events. On the short time scale, migrations were often the result of flood and drought disasters. For example, in the mid to late 17th century, tens of thousands to hundreds of thousands of people migrated spontaneously or were migrated by government to the areas beyond the Great Wall, after almost every extreme drought or flood event occurred in North China (Ye et al. 2012). Up to the 19th century, the capacity of Qing Dynasty in coping with disasters was weakened significantly by fiscal crisis. The quarantine policy which isolated Hans and Manchus or Mongols with the Great Wall and the Willow Palisade was conditionally removed and eventually abolished by the Qing Dynasty. As a result, migration to Northeast China where was a vast territory with a sparse population became the main way of dealing with the impacts of adverse climate and extreme climate disasters for the people in North China. These migrations not only reduced social risk in North China, but also promoted the development of Northeast China (Fang et al. 2013; Xiao et al. 2013, 2015).

11.5 Conclusions and Prospects

Based on long-term and continuous historical literature, this paper summarizes the main impacts of climate change during the past 2000 years in China.

First, a concept model based on Food Security is given for studying the impact-response processes of climate change in the history of China. The food security-based concept model proposed in the present study is not only applicable to the ancient China, but also to traditional societies relying greatly on agriculture or food production in other areas.

Second, a methodology based on Semantic Differential has been developed for reconstructing and grading social and economic series over the past 2000 years in China, permitting the impacts of historical climate change on Chinese society to be quantitatively analyzed.

Third, it has renewed scientific understanding of the impacts of climate change in the history of China, with the impacts generally being negative in the cold periods and positive in the warm periods but also mixed blessing, and a successful adaptation to climate change should be considered according to temporal and regional differences. It is different from the traditional Malthusian population theory that positive checks (i.e. hunger, disease, and war, et al.) on population would appear since population growth rate usually exceeded production growth rate (Malthus 1826). Climate change would lead to the relative overpopulation by shrinking natural resource and thus suffered society from Malthusian trap, but on the other hand, human adaptations could help the people to survive and to create new opportunities even under the bad climate conditions. This cognition of responses to climate change in history could provide valuable lessons for dealing with ongoing challenges of climate change.

Although the summary and review in this paper is mainly based on research in recent years, the main conclusions align with the consensus of other scholars. Due to limitations of this article length, we are not able to provide a more detailed data analysis, which are available in the cited references.

Because the impacts of historical climate change were highly related to the specific situations of climate and socio-economic development, many gaps in research on climate-human relationship in Chinese history remain. For instance, it may be productive to investigate the synergetic features between climate change and socio-economic fluctuations based on those reconstructed time series; it would be helpful to track the pathways of the transmission of the impacts from climate change to ecological changes, agricultural production, population, economic fluctuation, and political or cultural development for better understanding how active elements of human agency (i.e. population, economy and policy, etc.) moderated the impact-response chain from a macro-history perspective; finally it is important to untangle the influence of climate change from other factors on historical events.

Future studies on historical climate impacts should be focus on spatial and temporal diversification, comprehensive regional analysis and comparison. Therefore it is necessary to carry out more case studies with specific spatial-temporal scales, from a micro-history perspective. As a result, multidisciplinary integration will be a great help in promoting research on the impact of historical climate change.

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Chapter 12
Climate Change and the Rise of the Central Asian Silk Roads

Daniel J. Hill

Abstract The final centuries BCE (Before Common Era) saw the main focus of trade between the Far East and Europe switch from the so called Northern Route across the Asian steppes to the classical silk roads. The cities across central Asia flourished and grew in size and importance. While clearly there were political, economic and cultural drivers for these changes, there may also have been a role for changes in climate in this relatively arid region of Asia. Analysis of a new ensemble of snapshot global climate model simulations, run every 250 years over the last 6000 years, allows us to assess the long term climatological changes seen across the central Asian arid region through which the classical Silk Roads run. While the climate is comparatively stable through the Holocene, the fluctuations seen in these simulations match significant cultural developments in the region. From 1500 BCE the deterioration of climate from a transient precipitation peak, along with technological development and the immigration of Aryan nomads, drove a shift towards urbanization and probably irrigation, culminating in the founding of the major cities of Bukhara and Samarkand around 700–500 BCE. Between 1000 and 250 BCE the modelled precipitation in the central Asian arid region undergoes a transition towards wetter climates. The changes in the Western Disturbances, which is the key weather system for central Asian precipitation, provides 10% more precipitation and the increased hydrological resources may provide the climatological foundation for the golden era of Silk Road trade.

Keywords Silk roads · Climate change · Climate model · 6000 years Precipitation

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12.1 Introduction

Climate has changed throughout the course of the human civilization (Mayewski et al. 2004). The last 6000 years has seen significant climatic and precipitation changes, which have been well documented from both proxy records and modelling studies (Braconnot et al. 2004; Harrison et al. 2014). However, the relationship between these broad-scale, long-term changes in climate and the local environmental impacts is little understood, despite the major disruptions to ancient civilizations across Asia and Africa these have been implicated in (Butzer 2012). Across the world major civilizations have responded to climate change, from Africa (Welc and Marks 2014), Europe (Büntgen et al. 2011; Drake 2012), Asia (Staubwasser et al. 2003; Dong et al. 2012), the New World (Kennett et al. 2012) and maybe even the colonization of the Pacific Islands (Anderson et al. 2006). As well as driving civilization collapse, climate change could affect societal structures, polities and trade routes, particularly in the Silk Road region, where a complex network of trading routes cross the central Asian dry region.

Central Asia has been continuously inhabited for thousands of years and was home to thriving late Bronze Age cultures, including the Oxus Civilization (Lamberg-Karlovsky 2013) and Sapalli culture (Kaniuth 2007). The city of Samarkand was founded around 600 BCE (Grenet 2002) and this may be associated with drying of central Asia and the initiation of irrigation of the Samarkand Oasis (Malatesta et al. 2012). Although there is evidence for settlement in the region of Bokhara from 3000 BCE, the city itself was founded around 500 BCE as part of the Achaemenid Empire or first Persian Empire (Lo Muzio 2009). Trade along the classical Silk Road accelerated greatly with the rise of the Han Dynasty in China in the second century BCE and continued, with only minor interruption during the rise and fall of empires, for almost 2000 years until the collapse of the Safavid Empire in the 1720s (Faroqhi 1994).

Trade in precious materials, such as lapis lazuli, between the great civilizations of the Bronze Age, shows evidence of 4th millennium BCE trade, at least in sections of the classical Silk Roads (Herrmann 1968). However, the main exchange of goods, technologies and culture across Eurasia seems to have accompanied the move to mobile pastoralism in the vast Eurasian steppe region (Christian 2000). Central Asia hosted a unique Bronze Age culture, the Oxus Civilization, with established contacts with surrounding cultures in Mesopotamia and the Indus Valley (Lamberg-Karlovsky 2013) between roughly 2200 and 1700 BCE. Although the demise of central Asian Bronze Age cultures has not been extensively investigated, two hypotheses have been put forward for the collapse of the Oxus Civilization. Firstly, reduced hydrological resources and the demise of the agricultural canal system (Salvatori 2008), suggests a climatological driver for collapse. Whilst the second hypothesis, the increasing influence and hostile advance of pastoral nomads (Cattani 2008), suggests more cultural forces at work. Despite the interconnected nature of Bronze Age Eurasia, it was only after Chinese expansion in the second century BCE that a continuous connection was established across Asia from China to the Mediterranean (McNeill

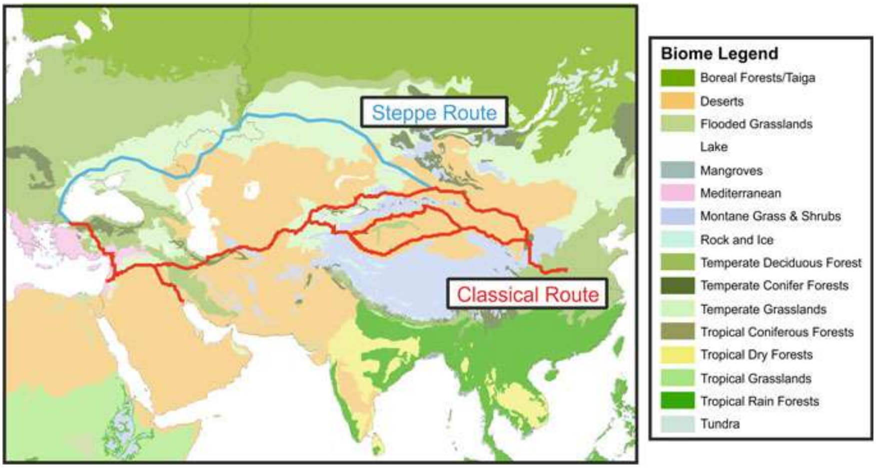

Fig. 12.1 Map of Central Asia, showing the biomes (Olson et al. 2001) and the older trade route of the Northern or Steppe Route (blue) and Classical Silk Roads (red)

1998). This seems to have shifted the main route of trade across Eurasia from the steppe to central Asian trade routes (Fig. 12.1), which in the late nineteenth century would become known as the Silk Roads (Christian 2000). This paper will investigate the evolution of climate of central Asia over the last 6000 years, using a climate model and investigate its impact on the changing trade, cultural and settlement patterns along the Silk Roads of Central Asia.

12.2 Methods

12.2.1 Climate Model

The HadCM3 version of the UK Met Office's Unified Model (Gordon et al. 2000), used in this study, is a fully coupled ocean-atmosphere General Circulation Model (GCM). It incorporates an atmospheric model with a resolution of $3.75° \times 2.5°$ with 19 levels in a hybrid vertical coordinate and an ocean model of $1.25° \times 1.25°$ with 20 levels (Cox 1984). Among the improvements in this version of the model are the simulation of convection (Gregory et al. 1997), orographic drag (Milton and Wilson 1996), the gravity wave drag scheme (Gregory et al. 1998) and the mixed phase cloud parameterizations (Gregory and Morris 1996). The land surface scheme incorporates the TRIFFID Dynamic Global Vegetation Model (Cox 2001), which is run coupled to the HadCM3 climate model.

GCMs have a long history of simulating global climate and have shown great skill in simulating modern day climate and palaeoclimatic change (Braconnot et al.

2012; McMahon et al. 2015). Asian climate is dominated by the monsoonal regimes originating in the tropical Indian and Pacific Oceans. HadCM3 has been shown to perform skilfully in reproducing these monsoons and climate across Asia (Inness and Slingo 2003; Turner et al. 2005). The HadCM3 model has also been shown to be able to produce realistic representations of the Western Disturbance weather systems that dominate rainfall totals in central Asia and simulate changes in weather patterns in line with other similar GCM models (Ridley et al. 2013). As is a common feature of modelled precipitation, different GCMs predict different sensitivity of regional rainfall to increased greenhouse gas forcing, but the increases seen in future warming scenarios from HadCM3 are at least in line with the observational record (Dash et al. 2009).

12.2.2 Methodology

This study uses an ensemble of HadCM3 simulations covering the last 6000 years. This consists of 25 snapshot simulations, with boundary conditions appropriate to every 250 years between 6000 years B.P. and 250 years ago, with a final simulation using the full standard pre-industrial boundary conditions. Each of the simulations was initialized from an existing pre-industrial simulation and run for 250 years to allow the model to respond to the altered greenhouse gas and orbital forcing. Climatological means were taken from the last 50 years of the simulations.

12.2.3 Boundary Conditions

These simulations incorporate greenhouse gases and orbital forcing changes over the last 6000 years (Fig. 12.2), but otherwise the model boundary conditions are kept the same as standard HadCM3 pre-industrial simulations. Greenhouse gases are taken from ice core measurements, carbon dioxide (Monnin et al. 2004) and nitrogen dioxide (Flückiger et al. 2002) exclusively from the EPICA (European Project for Ice Coring in Antarctica) Dome C Antarctic ice core. Methane is taken to be the mean of the EPICA and GRIP (Greenland Ice Core Project) ice cores (Blunier et al. 1995; Flückiger et al. 2002), as it is not well mixed in the atmosphere. Orbital parameters are calculated from the orbital solutions of Laskar et al. (2004).

12.3 Modelling Results

The central Asian region has undergone significant changes in precipitation over the last 6000 years. This is reflected in this ensemble of HadCM3 simulations, where an 18% increase in mean annual precipitation is seen across a broad swathe of the central

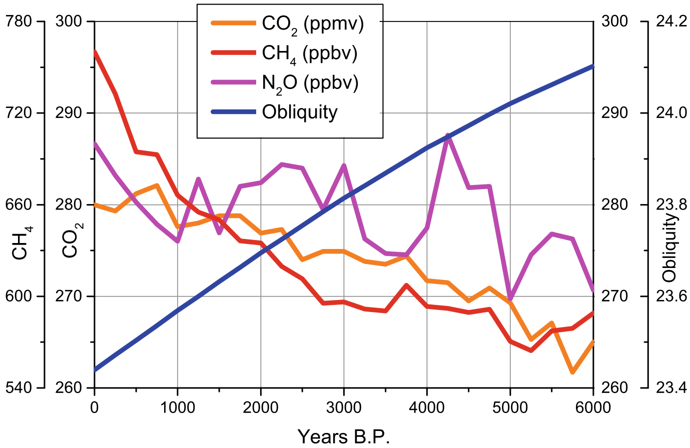

Fig. 12.2 Parameters used in each of the snapshot simulations in the ensemble for the last 6000 years. Atmospheric carbon dioxide (Monnin et al. 2004), methane (Blunier et al. 1995; Flückiger et al. 2002) and nitrogen dioxide (Flückiger et al. 2002) concentrations and obliquity component of the full orbital solution (Laskar et al. 2004) for each simulation representing a snapshot every 250 years of the last 6000. All other parameters are kept the same as the standard pre-industrial simulation

Asian region (Fig. 12.3). These simulated dry mid-Holocene climates are punctuated by short-lived periods that are significantly wetter, although still dryer than the pre-industrial simulation. The latest of these occurs at approximately 1500 BCE and its demise may be contemporaneous with climate drying in Mycenaean Greece and Hittite Anatolia associated with the Late Bronze Age Collapse (Kaniewski et al. 2013), but quickly (in approximately 500 years) returns to typical early Holocene values.

As well as precipitation change over the Holocene, other parameters have also changed, such as temperature. However, the change in precipitation in this region seems to dominate the water availability, as measured by simulated precipitation-evaporation (Fig. 12.4). The ensemble seems to show a clear transition from the dryer climates of the middle Holocene to wetter climates of the late Holocene between 1000 and 250 BCE (Fig. 12.3). In common with the drying following the 1500 BCE event, the simulated increase in precipitation is strongest in the central Asian region, particularly in the area covered by the main classical Silk Road cities, from Merv to Kashgar (Fig. 12.5).

In the steppe region of Asia, through which East-West trade originally occurred on the Northern Route, no significant trend in Holocene precipitation is simulated (e.g. Fig. 12.5). Water resources are more plentiful in this region throughout the Holocene, but this means there has been neither the drive to urbanization and centralization of aridifying conditions or a significant increase in hydrological resources to create an elite class of wealthy individuals.

The response in the central Asian arid regions is in contrast to much of the ancient world, where civilizations were built in the great river valleys of the monsoonal

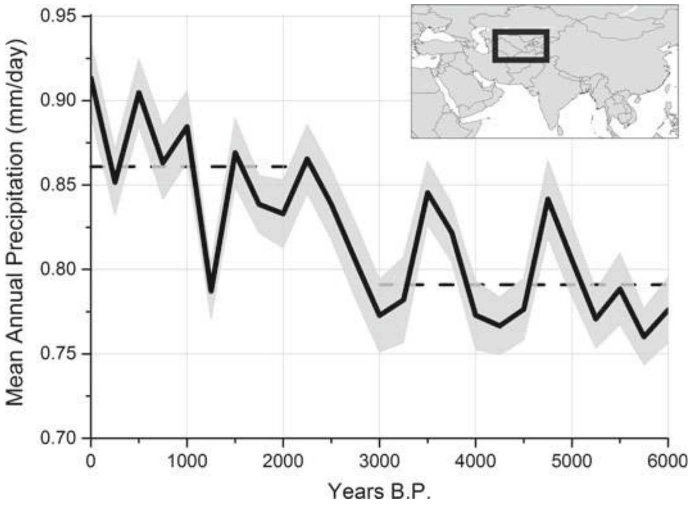

Fig. 12.3 Average mean annual precipitation over the central Asian region (35°–45°N, 56.25°–75°E) for each of the simulations for the last 6000 years. Shading shows the standard error for the average, with the area over which precipitation is averaged shown in the inset map. Dashed horizontal lines show the mean of the simulations up to 3000 years B.P. and after 2250 years B.P

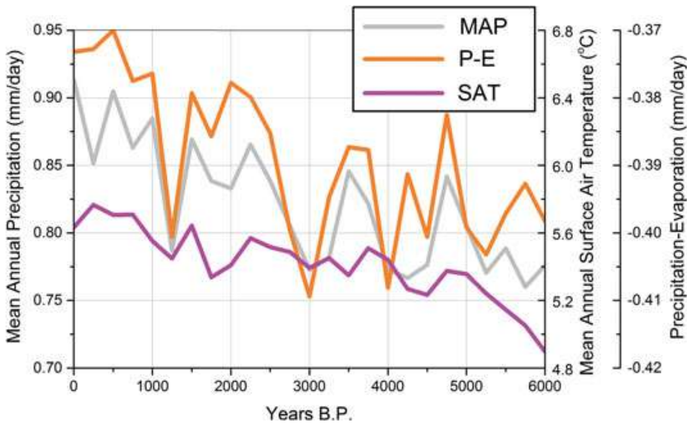

Fig. 12.4 Average mean annual precipitation (MAP; grey), precipitation minus evaporation (P-E; orange) and surface air temperature (SAT; magenta) over the central Asian region (35°–45°N, 56.25°–75°E) for each of the simulations for the last 6000 years

regions (Macklin and Lewin 2015) and hence were susceptible to the reduction in monsoons through the Holocene. Central Asian increases in rainfall are not linked to the monsoonal rains, but rather are produced by changes in the winter Western Disturbance weather systems, which provide the bulk of the annual rainfall in the region (Syed et al. 2006). Previous suggestions of the driving mechanisms of

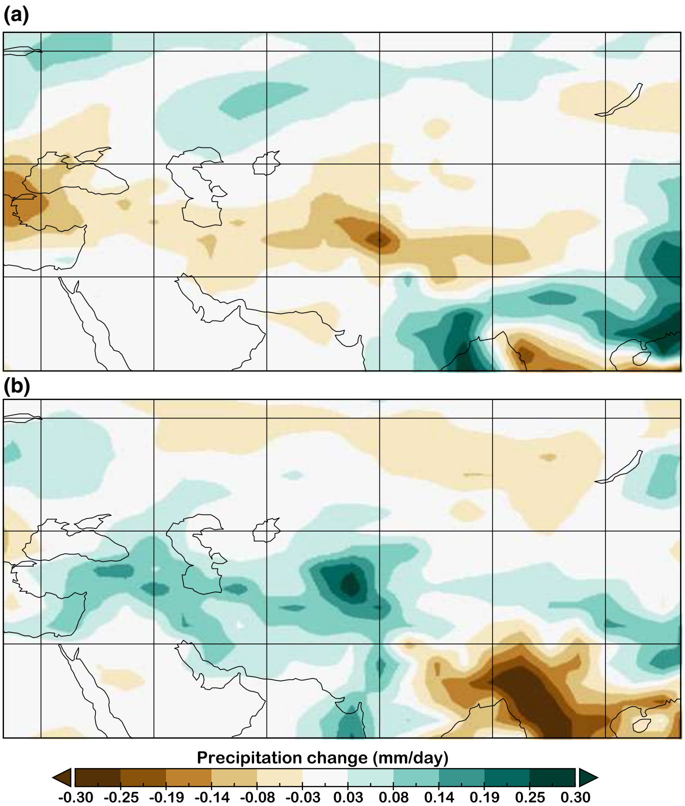

Fig. 12.5 Spatial patterns of modelled precipitation changes between 1500 and 1250 BCE (**a**) and the transition that occurs between 1000 and 250 BCE (**b**). Precipitation changes in central Asia are focussed on the area of interest (Fig. 12.2), although the link to other areas varies over time. For example, the pattern of change in Indian monsoon region and the Eastern Mediterranean is different between **a** and **b**

variations in Western Disturbances, based on observational datasets, include changes in Icelandic Low related to NAO (North Atlantic Oscillation) or the Siberian High related to ENSO (El Niño Southern Oscillation).

Although there are times when changes in these pressure systems correlate with central Asian precipitation, particularly the Icelandic Low over the last millennium, for much of the last 6000 years the changes are decoupled. HadCM3 has previously been shown not to represent the teleconnections between ENSO and the monsoon systems (Turner et al. 2005), which may explain some of this decoupling. However, these simulations show changes in central Asian precipitation are related most closely to the contrast in Himalayan and Mediterranean pressure (Fig. 12.6). As these regions respectively represent the locations where the Western Disturbances initiate and ultimately disburse, the forcing mechanisms from these mean pressure features are clear.

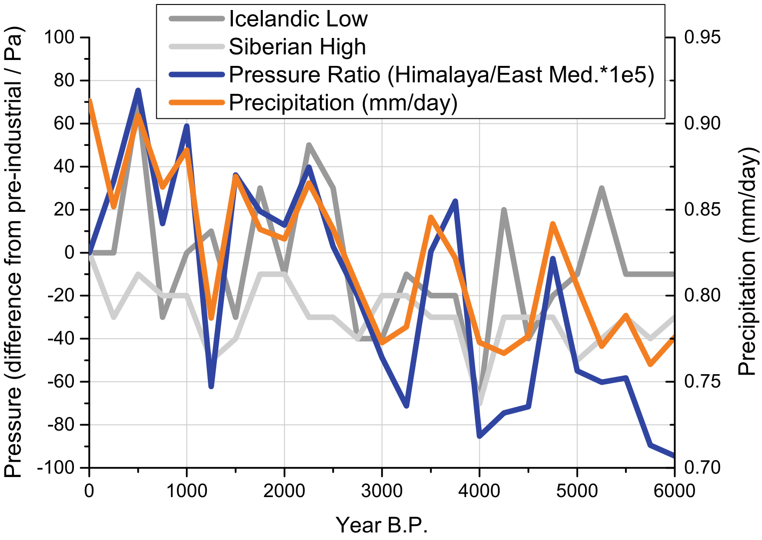

Fig. 12.6 Comparison of variations in central Asian dry region precipitation and selected pressure variables over the last 6000 years. Shown are the differences in the strength of the Icelandic Low, the Siberian High and pressure ratio of the Himalayan Low and the East Mediterranean High (H/M*1e5). The Icelandic Low system is related to North Atlantic Oscillation (NAO) and the Siberian High has been suggested to mediate the impact of El Niño Southern Oscillation (ENSO) on central Asian precipitation (Syed et al. 2006)

12.4 Discussion

The best Holocene palaeoenvironmental records of continental precipitation tend to come from large lakes and speleothems. As such there are few palaeoenvironmental records that track the precipitation in the central Asian arid regions (Chen et al. 2008), particularly in the region where changes are seen in these simulations (Fig. 12.5). However, a recently published speleothem record from Fergana Basin, shows a similar transition in precipitation inferred from oxygen isotopes (Wolff et al. 2017). As well as showing the shift at approximately the same time as the model, the general dynamics of precipitation in the region closely resemble that seen in the model, although the temporal resolution of the simulations does not allow for us to closely compare these with the data. Furthermore, the record from Lake Issyk-Kul in Kyrgyzstan, which is close to the eastern end of the Silk Roads, shows a significant change in sediment composition at around 3000 years B.P. This change is associated with a shift towards wetter taxa in the pollen record (Rasmussen et al. 2001). These changes are not reproduced in other records from the margin or outside of the region in which precipitation changes were simulated, including the Aral Sea (Ferronskii et al. 2003; Huang et al. 2011), Lake Karakul, Tajikistan (Mischke et al. 2010), Lake Balikun (An et al. 2011), Wulunga Lake (Jiang et al. 2007), Lop Nur (Mischke et al.

2017), Lake Karakuli (Aichner et al. 2015), China or the Chinese Loess plateaux (Zhang et al. 2013).

There seem to be significant changes in precipitation in central Asia over the Holocene, which are linked to changes in the Western Disturbances, driven by variations in the Himalayan Low—East Mediterranean High pressure contrast. Although significant changes in precipitation and P-E are simulated within this modelling framework, increased resolution in the atmosphere model, could greatly improve the signal and spatial definition of the climatic changes. Moving to transient simulation of Holocene climate would give better temporal coverage, rather than relying on equilibrium climate response to snapshot climate forcing. This study has shown the changes in regional climate associated with the largest forcing of Holocene climate change, namely greenhouse gases and orbital forcing, but could be further extended by incorporating changes in volcanic forcing (Kobashi et al. 2017), solar variability (Steinhilber et al. 2012) and Himalayan glacial coverage (Solomina 2015).

Although there remain many questions as to how ancient cultures responded to climate changes, it appears that there are concurrent changes in Holocene climate and cultural developments in the region (Fig. 12.7). The period in which Late Bronze Age (LBA) cultures declined and the initial drive towards urbanisation are associated with climate deterioration from a short period of high precipitation around 1500 BCE. While the current imprecise timings of the loss of the Bronze Age cultures and the climate changes mean that causal relationships cannot be tested, the fact that significant changes in precipitation are simulated during this interval (Fig. 12.7) adds weight to the suggestion that climate may be involved (Salvatori 2008). The major cities of Samarkand and Bukhara were founded in this period, while some of the other classical Silk Road cities were founded in the final centuries BCE. A drying climate may have forced the founding of cities and initiation of large scale irrigation (Malatesta et al. 2012), however, the increased hydrological resources may have ultimately allowed these cities to flourish and provide the backbone of the Silk Road trade routes.

Although central Asia is particularly susceptible to changes in the extent that the Western Disturbance weather systems penetrate into Asia, changes in other parameters of these systems could have significant implications for other climate-human interactions across the Levant, Mesopotamia and into the Indian Subcontinent (Syed et al. 2006). Different regions and weather systems respond in different ways to the changes in Holocene forcings. Each civilization has its own technological development and ways of utilizing hydrological resources and thus to really understand the connection between societal adaptation and changing climate requires collaboration between palaeoclimate scientists and archaeologists.

12.5 Conclusions

Novel climate model simulations of the last 6000 years show significant shifts in central Asian precipitation. Of particularly note is the transition to wetter climates

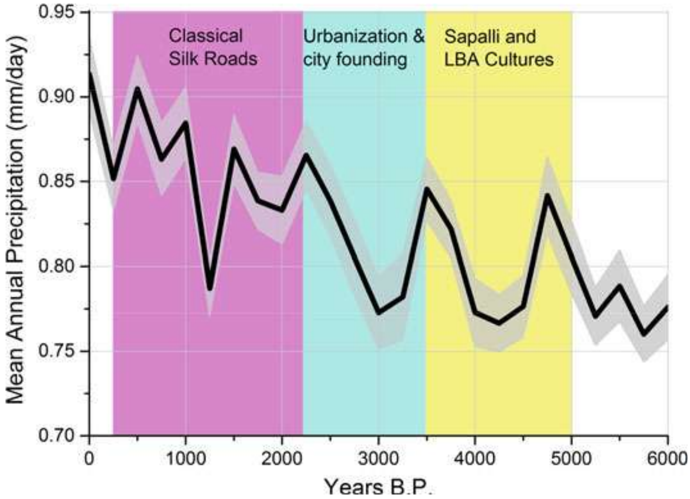

Fig. 12.7 Comparison of average annual mean precipitation over the central Asian dry region (35°–45°N, 56.25°–75°E) for each of the simulations for the last 6000 years (Fig. 12.2) and cultural development of the central Asian region. Times of the classical Silk Roads correspond to increased hydrological resources, while period of urbanization began as climate deteriorated from a temporary high, before a time of increasing precipitation

that is simulated to occur between 1000 and 250 BCE. This coincides with the founding of the great cities of central Asia and the rise of the classical Silk Road trade routes through the region. While much more work is required to understand the impacts of this climate changes and the cultural responses to these, this study provides a provocation to explore these relationships in greater detail.

Acknowledgements These climate modelling simulations were undertaken on the ARC (Advanced Research Computing) facilities, part of the High Performance Computing at the University of Leeds, UK.

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Chapter 13
The Coming of the Barbarians: Can Climate Explain the Saljūqs' Advance?

Yehoshua Frenkel

Abstract The present study reviews recent interpretations of Central Asia's and Northern Iran's environmental and political history during the first half of the eleventh century. Namely, to cast light on the deficiencies in recent interpretations of Turkic *Volkswanderung*, and to advocate searching for political-social agents that would explain the Eurasian Steppe's history. In opposite to climatological reading of those years regional history, it aims at advancing a call for a more nuanced paradigm of the coming of the Saljūqs.

Keywords Ghaznavids · Saljūqs · Bulliet · Ellenblum · Historiography · Memory Environmental history

In this study, I will focus on the assumed influence of nature on human history. I will not touch upon questions concerning interaction between human modes of production and the climate, which is a common topic in modern environmental studies. Ecological policy and environmental ethics will also not be touched upon here.

For the purposes of the current contribution, I will define environmental history as the study of the effect of climate on society. Or, to use a more precise classification: the study of the consequences that freezing weather has on a certain region. I am using weather and not climate because the sources do not provide climate data. Weather is what we sense outside on any particular day. Climate is the average of that weather.

A second introductory comment concerns the term "Silk Road" (*Seidenstrasse* in German) used by the organizers of this conference and in the popular literature. The term is a conventional construct. It is not used in the geographical literature that was composed for the Abbasid Caliphate administration, nor by Muslim voyagers who travelled across the Eurasian Steppe. Their accounts highlight the ethnic, environmental and cultural differences that separated the Central Islamic lands (i.e. Iran and the Fertile Crescent) from Central Asia. These literary sources are archives of societies. They narrate not only on environment, fauna and flora, but also on religious

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knowledge and political events. Moreover, we do not have a clue to the geographical terminology used by the nomads who roamed in the Steppe in the 11th century.

13.1 Introduction

Reports on natural hazards that have shaped mankind's history, and the place that these catastrophes occupy in societies' memories, are quite old. The biblical account of the flood and Noah's saving of his family and fauna in his ark is a well-known example of disasters that serve as a means to explain major changes in people and their societies.

Hegel opens his analysis of climate and ethnography with the statement that nature should neither be rated too high nor too low (Hegel 1914). The great philosopher's remarks are not novel: their roots can be recognised in ancient geography. Similar interpretations of human nature and its geography of origin can be detected in Arabic-Islamic intellectual traditions. Ibn Khaldūn's theory of race qualities immediately springs to mind (Hall 2011; el-Hamel 2013). He advances the hypothesis that physical and intellectual abilities and talents result from the climatological environment of the ethnic communities with which he was familiar. And we can add other names of Arab scholars from the Middle Islamic period (1055–1517), who advocated this vision of mankind. Certainly, contemporary scholars have moved away from these deterministic and racist visions of human societies.

Yet many modern scholars still search for an ecological interpretation as the key solution to human history. These present-days geographers and historians investigate the history of climate and nomadism in Central Asia.[1] At the early years on the 20th century Ellsworth Huntington (1907) advanced the paradigm of "The Pulses of Asia", arguing that "pulsations of climate had served as a driving force history of Eurasia, impelling nomadic invaders to overrun the civilized nations that surround them".

13.2 Ecological Frontiers

The border of the Eurasian Steppe was ethnic and ecological. The Caliphate imported from this vast territory a variety of goods. Muslim and other merchants traversed it in their travels to remote sedentary and nomadic civilizations, returning across the Steppe to the heartlands of the Islamic Caliphate they carried with them exotic merchandises. The data that excavations and artefacts provide supports the line that the narrative sources tell. These texts present a picture of cross-border trans-civilization movements and influence. Moreover, archaeological findings fit well the pre-Saljūqid Arabic and Persian historiography of Eurasia (Frenkel 2015).

[1] For historian's rejection of climatological paradigm and the re-emergence of environmental history see Chappell (1970) and Brentjes (1986).

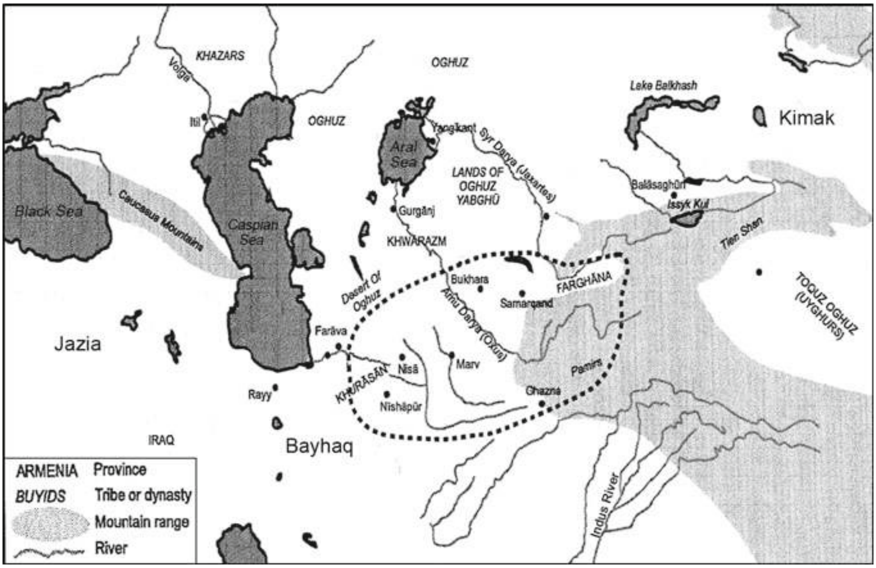

Fig. 13.1 The Eurasian steppe and Islamic Central Asia in the second half of the 10th Century. Adopted and re-edited from Peacock (2010:22)

An early example in support of this claim is the itinerary of Tamīm b. Baḥr, who travelled to the Uyghurs in the Abbasid period (c. 821). He recounts travelling a day and a night as hard and as fast as he could. He journeyed twenty days in steppes with springs and grass but neither villages nor towns. After that, he travelled twenty days among villages lying closely together among cultivated tracts.[2] Most of the population were Turks. Their king was related to China by marriage. The picture of the Kimak that he paints is similar (Fig. 13.1). They live in vast deserts, steppes and plains abounding in grass and wells where there are pastures (Minorsky 1948).

Ibn Faqīh al-Hamadhānī (c. 903) tells that in the lands of the Turks there are many excellent sables and foxes (*fennec*), ideal for making excellent furs. And that the Turks are the most skilled bowmen on Earth. The pseudo-travel writing by Abū Dulaf describes the Ghuz dress, which is made from furs. The recruitment of Eurasian slave-soldiers by the Abbasid caliph is well researched and there is no need to dwell upon this phenomenon here (Kennedy 2011).

13.3 Sources

Before continuing with the tale of the advance of the Saljūqs and their Turkoman hordes, however, allow me to dwell briefly on the sources at our disposal in the study

[2]Note the ecstatic equilibrium. Yet the topic of style is beyond the limits of the present study.

of Eurasian and Iranian histories. Most of the narrative sources which we are using to construct the story of the coming of the Turks were written in Arabic; yet some were composed in Syriac, Armenian and Persian. The claim that no Arab chronicler is a contemporary of the coming of the Saljūqs will not surprise students of medieval Western and Central Asia. The state of Persian sources differs only slightly.

Abū ʿAbd Allāh Muḥammad b. Salāma b. Jaʿfar al-Quḍāʿī (d. 454/1062) ends his condensed chronology of Iraq in the year 1022 and moves on to tell the story of Egypt (till 432/1040). ʿUmar b. Muḥammad al-Nasafī (461–537/1069–1142) wrote the history of Samarqand's scholars during their high days under the Great Saljūqs.

The two main Arabic histories of the early Saljūq Sultanate were composed in the late twelfth or early thirteenth century. Jamāl al-Dīn Abū al-Faraj Ibn al-Jawzī (510–597/1117–1201) was an active player in twelfth-century political and intellectual Baghdad and an observer of the declining Saljūq sultanate in Iran and Iraq (McAuliffe 1988). ʿIzz al-Dīn ʿAlī b. Abī al-Karm Ibn al-Athīr al-Jazīrī (555–630/1160–1233) was a contemporary of Saladin. His voluminous universal history begins with the Creation and runs to 628/1231. In the sections on Eurasia, Iran and the Turks he uses earlier works that have not reached us. Inspired to write by his sense of living at the turn of the ages, Matthew of Edessa (Matt'eos Urhayets'i, ca. 1070-ca. 1136), employed biblical verses to convey his perception of the Turks, (MacEvitt 2007) who he saw as agents of Satan (Czeglédy 1973).

Telling the story of the eleventh-century (1030–1071) Michael the Syrian (Mīchāʾil Raba; fl. c. 1166–1199) depends on earlier sources. In interpreting those years his point of departure is the Sacred Scriptures. Based on the words of the prophets he provides his audiences with biblical interpretations of the events that his predecessors experienced. The deep demographic change that was caused by the advance of the Turks is revealed by him as a fulfilment of ancient prophesies. No word on climate catastrophe.

The *mafriyana* (maphrian, the deputy of the Syriac Church) Gregarious Yoḥanan Bar ʿIbraya [Bar Hebraeus] (fl. c. 1226–1286) continued in his world-history, which he composed in Syriac and in a shorter Arabic version, the chronicle of Michael the Syrian (Mīchāʾil Raba; Todt 1988; Morony 2000; Widell 2007). Despite using a lost early Saljuqid source (the Book of King) his narrative is mainly political and dynastic and not adds a record of ecological history.

Turning to the Persian sources the history of the source material tells a similar story. With the exception of the contemporary chronicle by Abū al-Faḍl Muḥammad b. Ḥusayn al-Bayhaqi (c. 470/996–1077), no Persian source tells the story of the advancing Saljūq in real time. Remarks on weather in these chronicles are limited.

The Ghaznavid historian Ģardīzī (wrote after 1041 AD), a valuable source for the history of the eleventh-century eastern Iranian world and Central Asia, reports concisely on events in Khorasan and Transoxiana, as well as on the people of the Eurasian Steppe (Czeglédy 1973). Gardīzī narrates that the sultan responded favourably to the nomads' request, which was mentioned previously, and issued a royal command permitting the Turkic groups to cross the Oxus and Mughrab Rivers (416/1025–26). The Turkmen moved to the desert (*yābān*) near the cities of Sarakhs, Faravah and Bavard (Abivard; Le Strange 1905; Fig. 13.1). Two years later, as is stated by Gardīzī, the people of these cities came to the Ghaznavid court and complained about damages (*fasād*) caused by the Turkmen (Gardīzī 1928).

The picture of the past that the chroniclers have painted includes portrayals of weather hazards and deadly epidemics (in 1010, 1031, 1040; Christensen 1993; Rassi 2017) combined with descriptions of soldiers' looting (Ibn Funduq al-Bayhaqī 1968).[3] Yet, the information that the above-mentioned sources supply is far from an accurate accumulation of meteorological data. At most, these sources inform their reading audiences on farming and food shortage.

These sources, whether in Arabic or in Persian, do not report on the effects the fluctuating weather had on the nomadic tribes who roamed the Eurasian Steppe in the last quarter of the tenth and first half of the eleventh century. Indeed, I was not able to trace in the narrative sources from these long years any sort of meteorological information about the Steppe. The chronicles report only on weather events. This no doubt will be visible in the conclusions I deduce.

Nowhere in these narrative sources is climate blamed for the military-break down of a straining empire that failed to defend its territory against invading nomads. Famine should affect both parties, even if not equally. Moreover, nowhere is it said that the environmental conditions in Central Asia differed from the climate in Iran during those days. I will return to these points below.

Indeed, irregularities in climate are recorded in past and modern periods Moreover, as a whole, settlements in this region demonstrated resilience and recovery, despite famine, plague and massive deaths of humans and animals. The recovery from climatological disasters is quick. Data from the Chronicle of Michael the Syrian (tran. Chabot 1905) suggest that climatic and agricultural disasters were very common in northern Syria and the Jazira in antiquity (Fig. 13.1). Hence, we should ask: do these irregularities cause a permanent change? (Paul 2016).

In addition, the data furnished by these sources illuminates their vision of their time and place. They used mainly political and anthropological reasoning. Al-Quḍāʿī, a contemporaneous historian, already mentioned above, summarizes the political situation in Baghdad and the neighbouring lands during early days of the Abbasid caliph al-Qādir (991–1031):

> during this period (c. 1022) the political situation resembled the conditions [in Iran] in the days of the Diadochi kings (*mulūk al-ṭawāʾif*) who ruled in the days that followed the execution of Darius [the third; 330 BC] by Alexander the Great, a period of disorder that continued till the days of Ardashir the son of Babak (Papag) [208-241 AD] (*al-Quḍāʿī*).

13.4 The Coming of the Saljūqs

Following these condensed introductory remarks, we can turn now to an interpretation of the coming of the steppe barbarian in the eleventh century. The collapse of Samanid

[3]The source of the account is presumably the author's grandfather; the number of one thousand fighting horses, in addition to 200 elephants, seems unrealistic.

rule removed a buffer separating the Eurasian Steppe and the Iranian Plateau. The Saljūq house succeeded in mobilizing Eurasian pastoral-nomads and led them into the Central Islamic lands. These two developments, one that took place deep in the Eurasian Steppe and the other that materialized on the gates of the Caliphate's Central Asia frontiers, seem to be the key explanations to the political transformation that happened in Iran and Iraq in the mid eleventh century. They elucidate the massive penetration of pastoralist nomads into the territory of a highly developed urban civilization, which subsequently experienced several decades of crises and political disorders.

According to the authorized Ghaznavid version of Turkmen history and the crossing of the Oxus by the Saljūqs, a group of their tribal commanders and chiefs came over the border. They complained about their sufferings at the hands of Turkistan's governors and asked the sultan Maḥmūd's permission to cross the Syr Darya (Jaxartes) River. Gardīzī (d. c. 444/1053),[4] who presumably was in the service of the Ghaznavids at that time, inserts in his chronicle what he implies was the Turks' oral appeal to the sultan:

> We number 4,000 families.[5] If the lord was to issue a royal patent and allow us to cross the River [Oxus] and settle in Khurasan, he would be relieved from worrying about us and them, for there would be plenty of space for us in his realm, since we are steppe (*dasht*) people and have extensive herds of sheep. Moreover, we would provide additional manpower for his army.

The author, who devotedly guards the reputation of the Ghaznavid monarch, depicts Maḥmūd as a generous patron. According to his description of events, a conversation then took place between the sultan (*amīr*) Maḥmūd and the governor of Ṭūs (Mashhad). The historian stages the governor as the critical voice who objects to the coming of the Turks and who warns the sultan that he is committing a crucial mistake. In line with this version of history, the sultan regrets his initial agreement. Gardīzī adds his personal conclusion: "this grave error (*ghayyat*; read *ghiyyāt*) still has no satisfactory remedy." These words seem to reflect the developments on the ground, and indeed, as it was "predicted." Ṣadr al-Dīn al-Ḥusaynī, who composed the official Saljūq historiography (Husaynī 1933)[6] and does not depart fundamentally from this line, says:

> The sultan died (in 422/1031), having by that time regretted his allowing the Turks (*atrāk*), the followers of the sons of Saljūq, to settle in his realm.

Reports on the advance of the Saljūq brothers towards the Iranian Plateau, together with accounts of skirmishes, contain also records of shortage and famine (Bosworth 1963). It is said, to provide one example, that lack of fodder forced the Ghaznavid

[4]For a similar employment of negotiations between nomadic Turks and sedentary rulers see below.

[5]The number 4000 (*chehār hazār suwār maʿrūf*) elite horsemen is a set number in Gardīzī's account of the Turkmen.

[6]A native of Khurasan, he echoes the views of the Saljūq dynasty branch that ruled over the Iranian Plateau. This would explain the salient role he grants to Chaghrī Beg Dāwʾūd. Cf. the different account by Ibn al-Athīr 2003).

army to depart Khorasan and to regroup in the province of Jurjān. On the same pages, we read that for several years plowing and harvesting was not chronicled in the province of Bayhaq (Fig. 13.1). At this historical junction a Saljūq army, led by Čaghrī Beg Dāwūd (d. 452/1050), attacked and routed Subashī, the commander of the Ghaznavid expedition force (428/1037). Reinforcements from Ghazna arrived and camped in the rural region near Bayhaq. It was winter, and the expedition force cut down the Pistachio trees, using the wood to warm themselves. They also uprooted the trees and sent the wood to Ghazna (Fig. 13.1). At the battlefield the Saljūqs won the day. Following their victory over the Ghaznavid army, the Saljūqs seized Marw (in 428/1037; Ibn Funduq al-Bayhaqī 1968).[7]

While the official Ghaznavid historiography paints the nomadic *Turkemān* as intruders and as a potential threat to the stability and prosperity of the sedentary civilization, the Saljūqs' narrative, on the other hand, offers a different interpretation of events (Luther 2001; Morton 2004). Historians who served the ruling Great Saljūqs portray the first generation of the family as a loyal force in the service of sultan Yamīn al-Dawla Maḥmūd. Deeply terrified by the advance of Turkic nomad clans, the Ghaznavid sultan forced the enormous Qiniq tribe, which was led by the chief (*muqaddam*; *amīr*) Mīkāʾīl b. Saljūq, to cross the Oxus River and thus creating a buffer zone that would separate between the sedentary population and the nomads (Husaynī 1933). Acting in accordance with a common nomad practice, Mīkāʾīl approached Abū Sahl, the civil governor of Khurasan, and offered him gifts: "three horses, ten Bactrian camels and three hundred sheep." After Mīkāʾīl's death, the Turkic tribes agreed that his son Abū Ṭālib Ṭughril (Toghril) Beg Muḥammad would replace him and would be their chief.

At this juncture in the narrative the sources do weave in an environmental thread. Taking advantage of harsh climatic conditions in Iran, the three Saljūq brothers were ready to face the sultan Masʿūd, the new Ghaznavid ruler. While the weighty Ghaznavid army had been paralyzed by the climate, the Saljūqs could find shelter in neighbouring provinces. The dwellers of the Iranian cities applied to the Ghaznavid sultan and asked him to intervene and rescue them. Facing a formidable threat, the nomad Turkmen reacted by sending a message to the Ghaznavids: "We are [your] slaves (*bandkān*) and we are obedient."[8] The next months witnessed heavy fighting. Under the heavy military pressure, the Turkmen leaders agreed to renew the concord that their chieftain had undertaken in the past.

Al-Ravandī narrates that Čaghrī Beg and Ṭughril Beg, the two leading Saljūq brothers, their uncle Mūsá b. Saljūq nicknamed Yabghū-Kalın,[9] their cousins, chiefs and the army commander assembled and concluded a pact agreeing to unite and provide mutual assistance (*yak-digar*). "I heard", says the historian, that:

> Ṭughril gave an arrow (*tir* used for casting lots; Turan 1955) to his brother [Chaghri] and told him to break it. He [Chaghri] could not reject the request, heeded [the command] and broke the arrow. In this manner [Ṭughril handed] two [additional arrows and Chaghri] broke them

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[7]The report does not contain the weather account.

[8]Cf. the similar wording "We are slaves and obedient to [the Sultan's] commands" (Gardīzī 1928).

[9]The future al-Malik al-ʿĀdil of Herat (1043–56).

> jointly. Then he handed three [arrows] and [Chaghri] broke them with considerable difficulty (*dush-khwar*). When the number [of the arrows] reached four it became impossible for him [Chaghri] to split the arrows. Ṭughril said: "This is exactly a parallel (*mithl*) [or *mathal*, likeness or metaphor] to our manner (*hamcunān*). When we are apart every peon will be determined to break us. Yet if we are united, no man will defeat us. If disagreement comes between us we shall not conquer the world (*jihān gushadan*; John of Ephesus 1860; Dickens 2004)[10] and our rivals will be stronger, and kingship will slip from our hand. A verse: If two brothers help and protect the back of each other the stony hard mountain is in their fist (Ravandi 1921).

13.5 Climatological Determinism?

The suggestion that migration and political changes in Western Asia resulted from ecological upheavals can be traced in old scientific works. On the eve of World War One, Carl H. Becker (d. 1933) argued:

> The sudden surging of the Arabs was only apparently sudden… It was the last great Semitic migration connected with the economic decline of Arabia with the decline of political power, the care of public waterworks, on which the prosperity of the land more or less depended, also suffered (Becker 1913).[11]

During recent years several scholars have addressed questions regarding climate changes, large scale migration and political changes in central (Eurasia) and western Asia (the Levant; Issar and Zohar 2007; Raphael 2013). Salient here are the publications by Richard Bulliet and Ronnie Ellenblum. The second section of the present contribution provides a condensed report on the works of these two highly acclaimed historians. They were not the first historians that advanced the argument that in addition to the human factors we should consider ecological reasoning (Brentjes 1986). Conflicts over grasslands, weather fluctuations and migration constitute common components in pastoral-nomads' communities. And their leverage on Eurasian society, including violent struggles on resources, is a common historical reasoning (Peacock 2010:44–45).

Richard Bulliet claims that in the fifth/eleventh century the Iranian Plateau suffered severe contraction. "The engine that drove the agricultural decline and trigged the initial Turkish migration was a pronounced chilling of the Iranian climate that persisted for more than a century". Reiterating this argument, he says:

> "Iran experienced a significant cold spell in the first half of the fourth/tenth century, followed by prolonged climatic cooling in the fifth/eleventh and early sixth/twelfth centuries… [A] certain impact of this cold (the Big Chill) involves the folk migration into north-eastern Iran of the Oghuz Turks" (Bulliet 2009; Mikhail 2016).

[10] The idea of world-domination is echoed in the account of Michel the Syrian. However, it could be a late invention. Michel quotes John of Ephesus (c. 507–586) who narrates an apocalyptic story. The king of the Turks says to Zemarchus, the Byzantine ambassador, that their tradition is that when they see an ambassador from the Romans enter their lands, all kingdoms will be dissolved and the whole world will come to an end.

[11] Becker served as a Prussia's minister of culture.

Yet Bulliet is cautious and carefully states that weather stories in the chronicles do not constitute a trend. To make his point he turns to dendrochronology. An analysis of tree-ring thicknesses provides him with supportive evidence of the Big Chill in 313/926 and 398/1007. Decades prior to the Saljūqs. Following an in-depth geographical investigation, Bulliet deduces that the Turkmens who were camel herders moved from the Eurasian Steppe southwards, contrary to other Eurasian nomads, who were horse breeders and moved westwards. Yet this observation can be challenged. The Persian source that describes the Turkmens as *sārbānān* (camel herders) also mentions ten thousand Turkish horsemen (*siwār*) who crossed over to Khorasan (Bayhaqī 2002).

Ronnie Ellenblum follows Bulliet's historical interpretation. Inspecting a vast range of narrative sources, he first criticizes historians who have used political explanations to elucidate the penetration of the Steppes' barbarians into the Central Islamic Lands in the eleventh century. Next, he turns to the ecological reasons behind the Turks' W*anderung*. He interprets late sources, a point clarified above, as supportive evidence of his thesis that lingering hunger caused many Ōghuz Turks who still dwelt in the Trans-Oxonian regions to migrate south (in the 1030s; Ellenblum 2012).

13.6 A Revisionist Approach

It would be accurate to maintain that it is not rare to come across wide brash lines painting a historical picture that lacks sufficient details to discern a landscape of the past. Hence, I do not contest the interpretation that Central Asia and the Iranian Plateau experienced natural hazards during the years studied here. Reports of natural or catastrophic events, such as a devastating earthquake (in 444/1051)[12] or a drought that caused hunger, pop up even in a quick look at the narrative sources. The increasing number of raids (*ghārāt*) are said to have prevented the people of Bayhaq for seven years from slaughtering lambs outside the walls of the city's fort (*qaṣba*). The local population did not consume lamb during those seven years. The supply of eggs, cereals and fruit was also limited. Although during Friday prayer the name of the Saljūq sultan Ṭughril Beg was called (Ibn Funduq al-Bayhaqī).[13]

Again, I am arguing that the sources do not provide decisive evidence to support a meteorological interpretation as the prime explanation of the massive human movement across the Steppes/Iranian frontier during the eleventh century. The impression created by these accounts, briefly mentioned above, is that nomadic pressure and lawlessness combined with the governors' strong hand are the prime cause of disability and social unrest (Gardīzī 1928). The chroniclers do not point their fingers towards an environmental origin of the advance of the Saljūq Turks. It might be the case that cold winters or long dry summers inflicted heavy pressures on the Eurasian

[12] The story of the people who fled the town and spent 40 days and nights in the desert is a literary construct.

[13] The number 7 is supposedly a literary device.

nomads, yet the narrative sources do not refer to this as a source of destabilization and *Volkswanderung*.

Those scholars that advance the climatological thesis should be asked, given the living conditions in eleventh century Iran and Iraq, the countries that came immediately under direct Saljūq government, why are there no records of massive urban migration of populations that hoped to escape harsh climatic conditions? Moreover, why the weather-related thesis is not the leading hypothesis with regard to the migration westward of the Pecheneg or the Mongol? In great similarity with the coming of the Saljūqs and their Turkmans' followers also these Eurasian peoples wandered in the Steppe and penetrated new lands ruled by powerful empires. Yet, the common interpretation of their history combines social, ideological and political explanations with climatological accounts (Lamb 2011), and is not limited to precipitations, temperatures and pasturage (Jenkins 1974). Furthermore, "The occurrence of a climatic change can never be a sufficient explanation for a migration that ensued. Societies always possess a range of other ways of coping with any challenges" (Mayer 2000).

To advance the thesis that bad winters drove the Turkomans across the Oxus River to Khurasan and the Iranian Plateau we cannot rely on literary narrative sources. The chronology of the historiography examined here leads me to argue that the climatological thesis is based on texts that preserve the collective memory and popular interpretation of past events and not on solid *longue durée* recorders written in real time.

Generalization should be based on painstaking gathering of minute facts. Describing massive social, cultural and political changes, modern historical studies quite often refer to climate fluctuations; or at least use environmental arguments as a partial component in explaining phenomena such as vast migration, collapse of old regimes, etc. But at their disposal there are enough details to support an ecological thesis. In our case there are not.

Moreover, climatic conditions cannot be considered the sole causal factor in respect of economic prosperity or decline, nor for political upheavals or nomadic incursions. The Byzantine historian Iohannis Skylitzes (c. 1040–1101), for example, narrates the following episode:

> When the neighbouring peoples, Turks, Serbs, Croats and the rest of them, learnt of [the Bulgars' king] Symon's death they immediately made plans to campaign against the Bulgars. The Bulgar nation was suffering a severe famine and a plague of locusts which was ravaging and depleting both the population and the crops, so the Bulgars were very fearful of an incursion by these other people (Skylitzes 2010).

Ibn Funduq al-Bayhaqī reports that in 432/1040-1 the Saljūqs, led by Ṭughrïl Beg, "arrived at the borders of Khwarazm with a large army and countless *khargāh*s, camels, horses and sheep" (Bayhaqī 2002). So, if weather was harsh how could these herds survive freezing temperatures and hunger?

Much quoted is the saying by Maḥmūd Kashgarī: "*başsız börk bolms tatsız türk bolmas* (without a head there is no hat; without sedentary there can be no nomad '[There is no Turk [i.e. nomad] without a Tad(jik) [non-Turkish sedentary])" (Kāshghari 1982) is another textual reference that supports my position. It casts light on the symbiotic ethnic reality in Central Asia. No one claims that harsh winters tested the resilience of the sedentary population of Transoxiana, who reacted by evacuating their villages and towns and accompanied the Oghuz Turks to Iran (Fig. 13.1).

13.7 Conclusion

The chronicles and biographies that were scrutinized in this research call a more nuanced vision of the historical reality in Transoxiana and the Iranian Plateau. The sources that we have at our disposal preserve the mid-twelfth and early thirteenth-century collective historical memory of urban classes governed by non-local armies, mostly by Turks, and who were surrounded by wandering Turkman tribes. These sources illuminate a long and deep political crisis, characterized by lack of order and stability. Chilly seasons and dwindling grasslands constituted significant components in the complex environment that surrounded the Turkic pastoral nomads.

Yet, in the interpretation of the historical developments at Islam's Central Asia frontiers additional constituents should be considered. To ascribe the Turkic tribes' migration from the Steppes to the Iranian Plateau at a period when this land supposedly witnessed natural hazards limits the historical explanation to climatological determinism. Given this, we should look to socio-political explanations to clarify the penetration of the Saljūqs and their Eurasian hordes.

Hence, we need archives of nature, namely analysed data of changing climatological conditions in the medieval Eurasian Steppe, which will illuminate the lacuna not covered by the archives of society, written in Persian and Arabic. This deduction can be compared to arguments advanced by scholars who have inspected the history of Byzantine during the tenth-eleventh centuries (Preiser-Kapeller 2015).

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Chapter 14
Climate Change and the Rise and Fall of the Oxus Civilization in Southern Central Asia

Élise Luneau

Abstract During the Final Bronze Age (around 3750/3700 BP), the proto-urban sedentary cultural entity in southern Central Asia—known as the Oxus civilization or Bactria-Margiana Archaeological Complex—underwent major social transformations in different field aspects leading to a deep cultural change in the middle of the 4th millennium BP. Among the different reasons suggested to explain these sociocultural changes, the hypothesis of global climate change in Central Asia at the beginning of the 4th millennium BP has been emphasized by different scholars. In this paper, I will examine current paleo-environmental data in relation with the climate evolution during the Mid- and Late Holocene. A critical assessment of the hypothesis of climatic change in Central Asia at the beginning of the 4th millennium BP allows to stimulate the discussion anew. I argue that the present data do not support a drastic climate change during the first half of the 4th millennium BP as a responsible factor for the fall of the Oxus civilization, although local environmental modifications should also not be underestimated and further investigated in a more integrated perspective of co-evolution of the ecological environment and the human societies.

Keywords Central Asia · Bronze age · Oxus civilization/BMAC
Climate variation · Sociocultural evolution · Collapse

14.1 Introduction

The issue concerning the variability of the climatic system, its impact on sociocultural changes and human action on climate is currently strongly debated in view of the present-day situation of climate disruption. This topic causes controversy, which often derives from determinism—environmental or anthropic—and/or

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denials, although the co-evolution and co-adaptation of people and environment has recently been proposed (Dearing 2006; Holdaway et al. 2013; Kirch 2005; Morales et al. 2009).

Numerous scholars put forward the idea that environmental modifications can be the vector of change, or at least can act to develop and amplify internal tensions within society. Thereby, climatic causes are frequently assumed in the case of disappearance of past societies and cultural entities, revealing both the resilience and the vulnerability of complex societies to climate change (Dalfes et al. 1997; deMenocal 2001), such as for instance, the Akkad Empire (Cullen et al. 2000; Kuzucuoğlu and Marro 2007; Weiss 2017; Weiss and Courty 1993), the Indus civilization (Giosana et al. 2012), the Maya civilization (Haug et al. 2003) or the Tiwanaku civilization (Binford et al. 1997). This is also true in case of the Oxus civilization, which occupied southern Central Asia and north-eastern Iran during the Bronze Age (Fig. 14.1) between the second half of the 5th and the middle of the 4th millennium BP.[1] Some scholars have tried to explain this fall by considering "*a disturbance of the equilibrium in the eco-social system induced by the growing aridity of the climate and by the resultant decline in agroclimatic potential*" (Dolukhanov 1981: 383). Climate variation then is a crucial question for understanding the interplay of the environmental and anthropic factors in the evolution of the Oxus civilization.

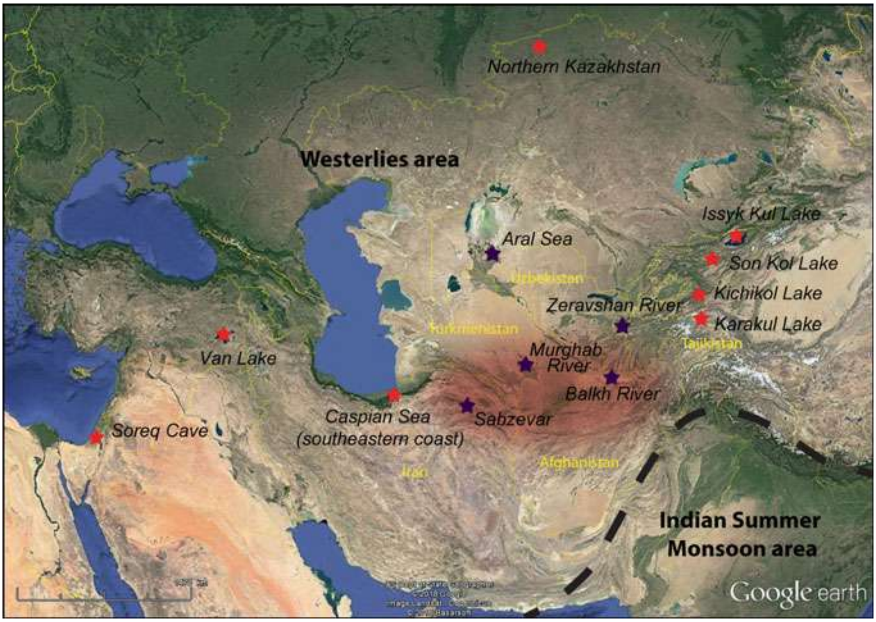

Fig. 14.1 Location of the Oxus civilization and of the mentioned palaeoclimatic records (in red) and geomorphological/geoarchaeological studies (in blue)

[1]The datations BP (Before Present) use the year 1950 as a reference point for "the present".

The relation between climatic, environmental and societal change is not direct (Wilkinson 2003), and the impact of climate variation on human actions is far from clarified (d'Alpoim Guedes et al. 2016). The crossing of the disciplines and approaches—environmental studies with anthropology—enlightens the reciprocal interaction between Human and Environment, and offers to encompass the natural processes as well as to highlight the constant adaptations of societies and environments. Climatic change is a complex, multifaceted and multiscalar phenomenon, and, besides the extent of climatic change, the reaction of human societies is essential in order to elucidate the interaction between climate change and social evolution (Butzer 2012).

This article proposes a cross-over study of archaeological evidence and current palaeo-climatic data for a critical review of the hypothesis of climate variation as sufficient to cause the sociocultural evolution of the southern Central Asian proto-urban culture at the end of the Bronze Age. It also examines the variability of the climate cause-effect chain and of consequences of environmental changes.

14.2 Short Note on the Geography of Southern Central Asia and Northern Iran

The territory of the Oxus civilization covers southern central Asia and north-eastern Iran, approximately between the Aral Sea drainage basin and the Dasht-e Kavir desert on the Iranian plateau, mainly between the latitude 35° and 40° north (Fig. 14.1).

As one of the driest areas in the world, southern Central Asia is undergoing the influence of different climatic systems at different space and time scales, but presently dominated by prevailing winds from the West, so-called 'westerlies' (Cheng et al. 2012, 2016; Heinecke et al. 2016; Lauterbach et al. 2014; Wang et al. 2010). It belongs to the desert climatic zones, with a semi-arid to arid climate, characterized by low rainfall from the end of fall to mid spring and by a maximum exposure to the sun and high temperatures the rest of the year (Mannig et al. 2013). 90% of this area receives less than 400 mm of precipitation per year (De Pauw 2007; Fig. 14.2).

This fragile ecosystem is very sensitive to changes and depends greatly upon water resources (Gessner et al. 2013). The availability of water (more than the temperatures) has always been of crucial significance for the evolution of human settlement patterns, explaining the uneven population distribution and the relocation of sites throughout time.

The high mountain system, such as the Pamir and Tian Shan which extend towards the West into the Mountains Alai or Turkestan slit along by long and narrow valleys, as well as medium mountains such as the Kopet Dagh range delineating Turkmenistan and Iran, are of major importance in Central Asia, especially as headwaters of numerous rivers (for instance, Amu-Darya, Syr-Darya and their tributaries). The mountain ranges present a stepped relief with different ecotopes (highlands, foothills, alluvial terraces and valley floors) allowing a diversity of economic strategies. The alpine zone or the high plains—such as the Khorasan landscape in northern Iran—are mostly covered by steppe-like vegetation. The foothills watered by small mountain rivers are covered by montane and sub-alpine vegetation (pasture lands and forests). Below,

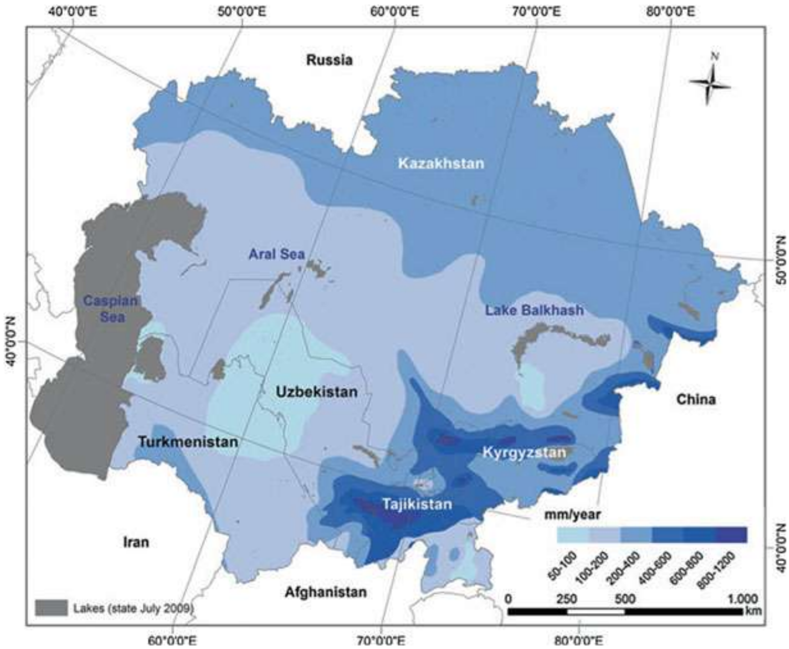

Fig. 14.2 Distribution of the precipitations over Central Asia (after Mueller et al. 2014: 17, Fig. 7)

terraces and river plains are constituted by a thick layer of fertile sediments deposited by the wind (loess) allowing cultivation.

Besides, most of this area are deserts (Karakum and Kyzylkum mainly located in present Turkmenistan and Uzbekistan), covered by Irano-Turanian steppe vegetation with a high variation determined by the climate (Djamali et al. 2012). Water resources are supplied by diverse courses spreading across alluvial fans: for example, the Murghab River in central Turkmenistan and the Balkh River in northern Afghanistan flanked by relatively dense, natural vegetation called *tugai* consisting of riparian forest or woodland associated with fluvial and food plain areas (Aishan et al. 2015). Seasonal floods contribute to the cultivation of lands, but agriculture mostly relies on irrigation practices in these areas.

In short, the landscape of the southern part of Central Asia consists of very varied and fragile ecological zones. This environmental variability emphasizes the importance of considering specific localized ecological conditions, which do affect our understanding of the global environmental systems (mechanisms and effects of the evolution) and do impact the sustainability of the resources exploitation and the lifestyles in the different areas of Central Asia.

14.3 The Oxus Civilization or Bactria-Margiana Archaeological Complex (BMAC)

Despite the aridity, southern Central Asia has a long history of sedentism based on agropastoral economy since the Neolithic, necessarily determined by water management. Most of the population lived along the banks of rivers or in the mountain foothills, which were better suited for agricultural use, while the climatic conditions in the mountainous areas were adequate for livestock breeding and dry agriculture. In the Bronze Age, the Oxus civilization developed between ca. 4250–3350 BP (Kohl 2007; Francfort 2009; Lamberg-Karlovsky 2012; Lyonnet and Dubova in press). The rise of the Oxus civilization is still unclear, and this ensemble is better known and defined as the mature phase (ca. 4250–3750 BP), where a specific material culture presents a large homogeneity over a vast territory in current northern Iran, south-eastern and central Turkmenistan, northern Afghanistan, southern Uzbekistan and southern Tajikistan (Fig. 14.1).

The Oxus civilization played a significant role in the system of exchange in Middle Asia—sometimes called Middle Asian Interaction Sphere (Kohl 2007; Possehl 2007)—for raw material (gold, lapis lazuli, turquoise, alabaster, tin, etc.) and finished items. Specific objects related to this culture have also been recorded in neighboring areas (Zeravshan valley, Ferghana valley, Indo-Pakistani area, Gorgan plain, Arabian peninsula, etc.). At that time, along with the long distance trade, the cultural entity experienced increasing proto-urban development, social stratification, task specialization, territorial expansion and homogenization. Populations lived in mudbricks or adobe houses in settlements of varying sizes. Monumental architecture, specific burial practices as well as prestige and luxury goods reflect a hierarchized society, possibly organized as proto-state. Numerous aspects linked to the exploitation of natural resources need further research, but the populations practiced agropastoralism in a complex socioeconomic pattern with a rich and diversified agricultural production along with the husbandry of diverse animals. The productions in ceramic, metal and stone reveal an extraordinary handicraft related to the skills gained by specialist craftsmen and the iconographic wealth exposing a singular symbolic system, connected with the Middle East but also locally rooted. Large questions are still open on the language(s) spoken by the populations—indo-iranian, proto-tokarian, elamite or unknown—as well as on the religion associated with this culture without writing.

14.4 The Fall? Overview of the End of the Oxus Civilization

From c. 3750/3650 BP onwards, the Oxus civilization progressively underwent major sociocultural transformations (Table 14.1); the last cultural features related to it disappeared around 3400/3350 BP with the manifestation of new significant changes, identified as the beginning of the Early Iron Age (Luneau 2014, in press). This long period of change has often been perceived as the collapse of the previous urban system.

Table 14.1 Summary of the major transformations in different sociocultural areas of the Oxus civilization during the Final Bronze Age (ca. 3750-3350 BP)

	Transformations/evolutions
Settlement pattern	• Abandonment and reduction in size of sites • But territorial expansion?
Material culture	• Changes in the quantity of items and in the morphology • Higher variability in the morphology of the ceramic complex • Appearance of miniature metallic items • Higher portion of material related to the northern central Asian traditions • Less cultural homogeneization
Sociopolitical organization	• Disappearance of the monumental architecture • Disappearance of the previous social status markers
Exchanges and Trade	• Slackening of the interregional exchanges, with a possible change of direction of the trade • Higher contacts with the mobile populations related to the "Andronovo" community
Ideology and beliefs	• Diversification of the burial practices • Disappearance of the figurative expressions, especially mythological
Subsistence economy	• Possible evolution of the subsistence economy towards a more pastoral and more mobile economy

Despite the lack of study on this period viewed as unattractive and the numerous gaps in the state of research, the available data provide nevertheless a solid basis for questioning the evolutionary process of the southern central Asian society during the first half of the 4th millennium BP. These mutations are indeed complex and diverse, such as innovations or changes alongside the oldest traditions, and permanencies also coexisted with the previous period (Luneau 2014, 2015). The settlement pattern shifted towards a reduction in the size of sites. The abandonment of sites is also noticeable, but this occurred parallel with the appearance of new sites and a possible territorial expansion. Changes are also obvious in the material culture, in the quantity of items discovered at the sites as well in their morphology. The ceramic production was affected by a higher variability. Technological processes seem globally similar with a trend to less investment of time and skills in the production. Metallurgy was also affected by sociocultural changes, mainly concerning the size rather than the shape of the items and the greater presence of artefacts related to the "steppe Bronze Age" cultures, as well as by the technological progression of the bronze metallurgy. A less cultural homogeneity over the whole territory of the Oxus civilization is also noticeable. Modifications are likewise clearly visible in the sociopolitical organization with the disappearance of social status markers, in connection with the slackening of the long-distance exchange networks. Trade appears to have been more active among the mobile populations referred to as belonging to the "Andronovo Cultural Community" than with the Middle Eastern cultures, as was previously the case. This situation can be particularly explained by the greater presence and influence of mobile populations in southern Central Asia (Cattani 2008; Cerasetti 2012; Frachetti and Rouse 2012; Luneau 2017; P'jankova 1994; Vinogradova and Kuz'mina 1996). The diversification of burial practices, correlated to the disappearance of the figurative, especially mythological, expressions likely indicates a major shift in the ideological and symbolic beliefs. The socioeconomic profile, as far as we know, seemed not to strongly change throughout the duration of the Oxus civilization. Irrigation was maintained, and the plants exploited vary little, excepting for the possible rise of the use of millet (see below). Herding also might have increased in relation to an increased exploitation of the highlands.

All in all, the long evolution, which occurred over 300 years at least, rather appears as a (transitional) phase of a slow sociocultural reconfiguration at the roots to a less urban, less concentrated, possibly less hierarchical society in the second half of the 4th millennium BP (Early Iron Age).

14.5 The Environmental Hypothesis as Responsible for the Changes of the Oxus Civilization

Among the different explanations for these changes, the impact of climate has been frequently proposed, although opinions differ on climate changes in southern central Asia.

Numerous scholars (Dolukhanov 1981, 1988; Gentelle 2001; Koshelenko et al. 1994; Ljapin 1990; Mousavi 2008; Vinogradov and Mamedov 1974) assert that the climatic conditions were more humid during the Mid-Holocene,[2] between 8950 and 3950 BP. A drastic drying of the climate then happened, around 3950/3750 BP, inducing important environmental changes and impacting human societies.

This phenomenon also emerged as an explanation for the fluctuations of the hydraulic system in the Murghab alluvial fan in central Turkmenistan, where the geomorphological dynamic may have determined the location of ancient settlements. The retraction of the alluvial fan with the desertification of the north-eastern distal part of the channel networks over time has been observed (Cremaschi 1998). This would have resulted from the progressive decrease of the Murghab River, on one hand, and the constant sand movement carried by the northern winds in the Karakum desert, on another hand.

In consequence, the aridification process would have been modified the courses of the rivers, depleted the water supply and reduced the agricultural land potential. It would have involved a demographical pressure, causing a reduction in population density, thus leading to depopulation and a shift in settlement patterns. The hypothesis was consolidated by the first results on the periodization of different Bronze Age sites, which has now been proven to be incorrect. At that time, the chronological overview suggested the existence of non-contemporaneous independent groups of sites called 'oases', whose successive occupation followed the retraction of the alluvial fan to the South, downstream-upstream, with the desiccation of channels (Masimov 1981; Sarianidi 1981, 1990: 64). The distribution of the sites since the early phases of

[2]The Holocene is defined as the current geological period, which began approximately 11,700 years BP. It is commonly divided into three sub-periods (Walker et al. 2012): the Early Holocene (11,700–8200 BP), the Mid-Holocene (8200–4200 BP) and the Late Holocene (4200 BP–present).
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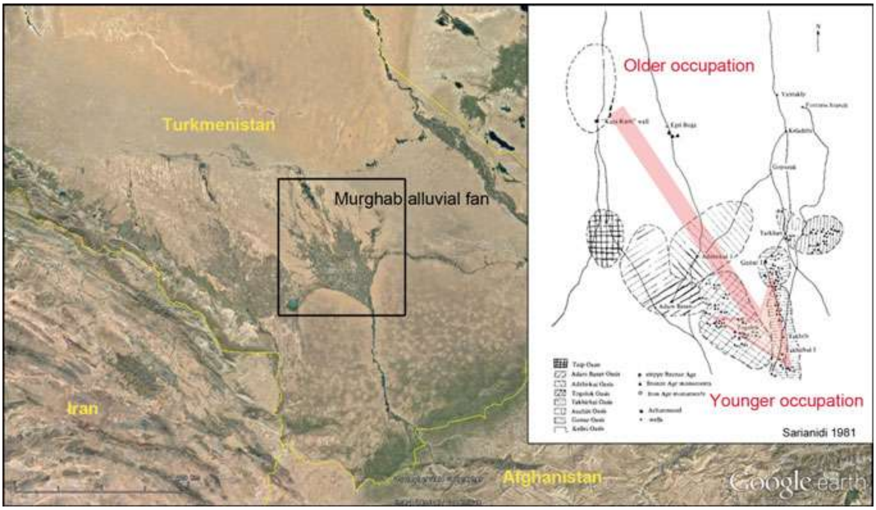

Fig. 14.3 Location of the Murghab alluvian fan and schematic map of distribution of the archaeological sites

the Bronze Age in the North until the Iron Age in the South (Fig. 14.3; Kohl 1984, Fig. 16a) has given proof of the impact of the environmental change, since settlements would have moved in relation to water availability.

This hypothesis also provided an explanation for the arrival of the "Andronovo" populations from the North, who occupied lands largely abandoned by the local populations due to the decrease in irrigation and the advancing desert (Cattani et al. 2008; Cerasetti 2012). All in all, a drying climate variation at the beginning of the 4th millennium BP could have been responsible for the "collapse" of the urban system of the Oxus civilization.

By contrast, other scholars (Cremaschi 1998; Gerasimov 1978; Khlopina 1972; Lewis 1966; Lisitsyna 1978, 1981) disagree on major environmental modifications at the turn of the 5th and the 4th millennium BP. They assert that environmental dynamics linked to water supplies were not limited to the question of climate and waterfalls, but were the combination of several factors, such as geomorphological and geological events (Gerasimov 1978; Fouache et al. 2012).

Nevertheless, these previous assumptions are still based on few solid studies, not only concerning climate evolution and the specific ecological system of southern Central Asia, but also the duration of the settlements as well as water management in prehistory. All these issues require more long-term field investigation.

14.6 The Palaeoclimate Data

Yet, the compilation of current data available on environmental changes already contributes towards better tackling the issue of the evolution of the environment and its impact on human groups in southern Central Asia during the Bronze Age.

Palaeoclimate studies in Eurasia are increasing in number in recent years. The synthesis of palaeoclimate records in Arid Central Asia from the Caspian Sea borders to Mongolia (Chen et al. 2008) reveals global tendencies, with a dry climate in the early Holocene (until ca. 8000 BP), followed by maximum-moisture conditions in the Mid-Holocene (ca. 8000–4000 BP), before decreasing moisture in the Late Holocene (4000 BP to the present day). Another synthesis of data from Central Asia (Wang et al. 2010) points at the differential evolution of the regions influenced or not by the two Asian Summer Monsoon sub-systems. In the Indian Summer Monsoon area, an increase of moisture levels and temperatures has been identified at around 10,000 until 8000 BP (Holocene Optimum), followed by drier and colder conditions until the Late Holocene. In the area outside of the present monsoon boundary, this decrease appears around 7500 BP—although interrupted by a wet period between 5000 and 2000 BP, whereas it appears by 6500 BP in the Indian Summer Monsoon area. However, the studies do not discuss potential abrupt changes during the different phases of the Holocene.

In that regard, another examination of records on world distribution (Mayewski et al. 2004) concludes several climate-change events during the Holocene, with rapid shifts marked by low latitude drought in 6000–5000, 4200–3800 and 3500–2500 BP, among others. Although no records correspond to Central Asia, a global aridification seemed to occur around 4200/3750 BP, known as the 4.2 ka BP aridification event. This "*megadrought brought a 30–50 percent reduction in precipitation and cooling across the Mediterranean, west to east, and across West Asia, Central Asia, Africa and the western hemisphere, as expressed in marine, lake, speleothem, glacial core, and tree-ring records*" (Weiss 2017: 13).

In central Asia, Palaeoclimate studies particularly investigated the relationships between the atmospheric circulation and high-mountain environments through alpine and subalpine lake records (Beer et al. 2007; Heinecke et al. 2016; Lauterbach et al. 2014; Mischke et al. 2010; Ricketts et al. 2001). These studies infer the decrease of the influence of the Monsoon and the dominance of the Westerlies, bringing arid conditions during the second half of the Mid-Holocene to the present. At the lake Issyk Kul in Kyrghystan, Ricketts et al. (2001) identified a change in the climatic condition of the basin around 6900 BP (transition from a fresh-water open-basin, well-mixed system to a closed-basin, more saline and relatively poorly mixed system) related to increasing aridity and atmospheric changes, diagnosed as the strengthening of the Siberian High, or the weakening of the Southwest Asian Low (Indian monsoon). The development of the Lake Karakul in Tajikistan marked by a reduction of the lake levels from 6600 BP suggests a similar aridification of the climate (Heinecke et al. 2016). Later, from 4200 to 3500 BP, a high water level resulting from an intake from the melting of glaciers, snow fields and frozen grounds indicates warm climatic conditions, whereas subsequently (3500–1600 BP), a rapid cooling and a lower water level has been reconstructed (Mischke et al. 2010). In parallel, studies of palaeolimnology has reconstructed a cooling, a decrease of the water level and a glacier advance connected with precipitation surplus between 4200 and 3000 BP (Taft et al. 2014). Multi-proxy analyses at the lake Son Kol in Kyrgyzstan (Lauterbach et al. 2014) also confirm relatively wet climate conditions during the Mid-Holocene (between ca. 6000 and 5000 BP), followed by a drying between 4950 and 3900 BP, a return to more humid conditions around ca. 3900 BP, and then a moderate drying trend until present times. Alternatively, the study of vegetation and lacustrine development at the sub-alpine lake Kichikol in Kyrgyzstan (Beer et al. 2007) reveals a progressive increase in humidity with two stages of rise of the water table at ca. 5000 BP and 4000 BP, which has also been interpreted as the weakening of the Central Asian High and Indian monsoon systems and the increase of westerly moisture transport from the Mediterranean region. Around 4000 BP, contradictory events have been identified: the increase of water level (suggesting more rainfall or a high meltwater inflow), and the marked decrease in pollen of *Juniperus*. The authors suggest the diminution of Juniperus forests, previously dense, may be related to other causes such as local effects of climatic changes. Later, from 4000 to 90 BP, climatic conditions are described as rather stable.

Outside mountains area, the study related to the sea-level of the Caspian Sea at the southeastern coast in Iran (Kakroodi et al. 2012) indicates a rapid rise of the water level between around 5000 and 2300 BP, which does not call for a climatic aridification. Lastly, peripheral data from Kazakhstan at the southern border of western Siberia (Kremenetski 1997; Kremenetski et al. 1997) show a drier continental climate in the area between around 4500 and 3600 BP, with certain stability in the period.

In short, beside the absence of clear abrupt dry episode at the beginning of the 4th millennium BP, the recent studies demonstrate the spatial variability and complexity of the climate system in Central Asia,[3] as well as the sensitivity of the environment and the diversity of natural responses to climate change locally.

According to palynological studies made in the Aral Sea (Sorrel et al. 2007) and the similarities between records from central Asia and from the Near East (Cheng et al. 2012), central Asian climate can be viewed as integrated in the eastern Mediterranean system (Fouache et al. 2012, 2016). Palaeoclimatic data from this area may thus be also broadly meaningful of the conditions in Central Asia. They indicate a progressive increase in aridity in the second half of the 5th millennium BP (Courty and Weiss 1997; Kuzucuoğlu 2007). Two periods of dryness have been recorded (4200–4100 BP and 4050–3850 BP) separated by a half century more humid. This drying phase seemed to stop around 3850 BP to be followed by a period of low humidity and relatively stable between 3850 and 2950 BP. The study of the speleothems of the

[3]Mischke et al. (2010: 10) point at "*significant spatial differences in Holocene climate history between specific regions […], and a complex Holocene climate heterogeneity within specific regions […]. However, the number of Holocene climate records is still low in many regions of Central Asia and not sufficient to allow discussion and comparison of regional patterns of climate history*".

Soreq cave in Israel (Bar-Matthews and Ayalon 2011; Bar-Matthews et al. 1997) also indicates that, from 7000 BP onwards the general climatic conditions became closer to the present conditions with several dry events, one of which fits between 4200 and 4050 BP. The analysis of the soils of the Van Lake, Turkey (Lemcke and Sturm 1997) illustrates a climatic change towards a more continental climate (decrease of the water level and of the humidity) between 4190 and 3040 BP.

Farther to the East also the synthesis of palaeoclimatic studies carried out in the Indian subcontinent (Madella and Fuller 2005)—with the aim to explain the "collapse" of the Indus civilization—concludes an aridification during the last centuries of the 5th millennium BP in the area of the Indus valley.

To sum up, even though Central Asian records are still patchy (Fig. 14.1) and more local and detailed palaeoclimatic studies from southern central Asia are lacking, the current data tend to demonstrate a globally wetter climate during the Mid-Holocene with several rapid changes. Considering the period of duration of the Oxus civilization (ca. 4250–3350 BP), a climatic aridity in the late 5th millennium BP is attested in different areas of the world, while the following first half of the 4th millennium BP would have been a period of relative climatic stability.

14.7 Geomorphological Studies

Recent geomorphological studies from southern Central Asia also largely contribute to the understanding of the Human-Environment interaction. They have been mostly carried out in the ecological niches of low or high river plains (Fig. 14.1). In the Murghab alluvial fan presently in the Karakum desert (central Turkmenistan), the work done by M. Cremaschi (1998) on different palaeochannels assumes very different climatic conditions than the present day, with a more important water supply until the 4th millennium BP. Accordingly, the Murghab would have been a fertile alluvial plain and the hydrological system near Bronze Age sites (Gonur Depe and Takhirbaj) were active until the end of the Bronze Age, i.e. the middle of the 4th millennium BP. Thus, these data suggest that there were no major changes in water sources during the period discussed here. Other fluvial geomorphological studies have been made in Afghanistan and Uzbekistan (Fouache et al. 2012, 2016). The examination of the palaeochannels of the Balkh River and the river Zerafshan reveals the strong dynamic of the hydrographical system with an extreme mobility of channels, a large range of movements and a great number of changes. This constant dynamic is created by classic avulsion processes, due to neotectonic deformations and the intensity of the flow. In parallel, the displacement of human settlements over the past 10,000 years has been recorded according to these changes. In northern Afghanistan, the persistency of occupation northwest of the plain (Dashly area) has been observed from the Bronze Age to Achaemenid times, suggesting a constant water availability. By contrast, in Iran (Fouache et al. 2013), around the site of Sabzevar (Khorasan), another evolution in the location of sites according to the water sources has been observed. Initially located along a river course or at the end of a natural channel during the Chalcolithic and early Bronze Age periods, sites progressively moved according to water availability, which suggests that water was less abundant. This evolution seems to occur during the chronological range between 4450 and 3850 BP. Lastly, around the Aral Sea, significant changes in moisture conditions have been reconstructed through the study of the water level from the archaeological data (Boroffka 2010; Boroffka et al. 2006). The authors reveal a shift in the course of the Amu-Darya River and the rise of water in the Sea around 3950 BP without substantial change in the next centuries.

In short, these environmental analyses carried out in Central Asia and northern Iran mostly record a permanency in occupation patterns and water availability, or coincide with those climatic data which identify a climate variation at the end of the 5th millennium BP.

14.8 Discussion

14.8.1 A Present Lack of Correlation Between the Environmental Data and the Sociocultural Evolution

All in all, the present palaeoenvironmental data, resulted from palaeoclimatic (Fig. 14.4) and geomorphological studies, do not allow us to correlate the progressive disappearance of the Oxus civilization during the first half of the 4th millennium BP with a climatic event.

These facts, however, do not mean that environmental dynamics did not contribute to the final evolution of the Oxus civilization. The study of climate history still requires special attention and clarification.[4] Climatic changes can be long-term phenomena, which may not be immediately noticeable. Consequences from more local changes must be evidenced as well (Wilkinson 2003). Climate phenomena may be limited to specific, sometimes small, areas. Environmental effects of climatic changes can vary according to the degree of sensitivity of the geographical area and to the different hydrogeological contexts. The same event may not have the same impact according to the microscales. Numerous issues need to be further investigated, such as the reaction of the different geographical features to climate change or conversely the impact of changes in the ecological milieu on local/global climate (Dallmeyer and Claussen 2011; Heinecke et al. 2016).

Besides, the natural factors, in particular tectonic movements and cataclysms such as earthquakes, sea quakes, storms, etc., may also have played a significant role in local disturbances (Fouache 2013). Although this area records a high level of seismicity, until now very limited studies are involved in highlighting such disruptions

[4]"*The previous climate, as the most important agent influencing the alteration of all other parts of an environment, is the subject of many scientific disciplines, although the outcomes are, despite tremendous efforts, still somewhat unsatisfactory. The main reasons for this are: the complexity of the climate system as such, the regionality of the climate, the short history of its direct instrumental measurement, the evaluation of the climatic parameters in relative terms (e.g. wetter, drier), the varying sensitivities of the proxies, and the difficulties of their more precise dating*" (Dreslerová 2012: 43).

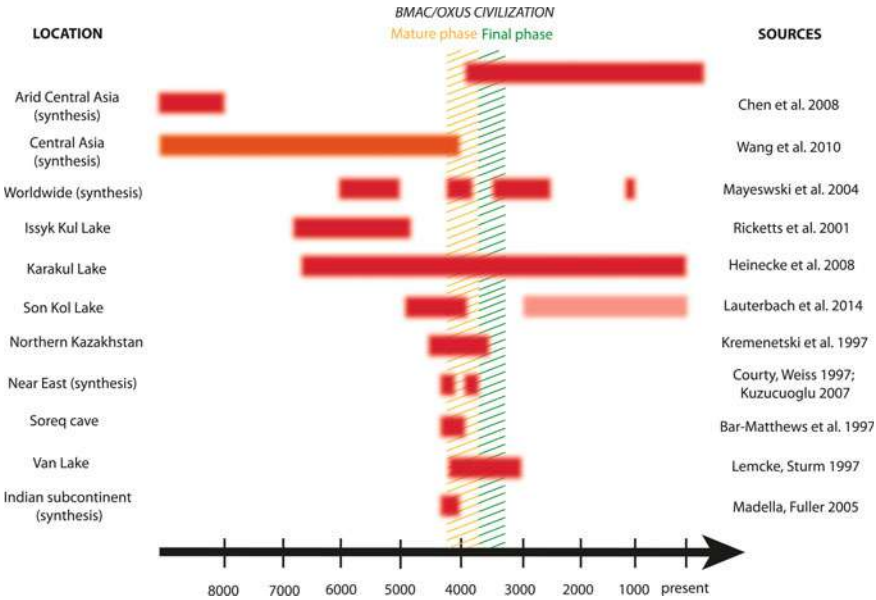

Fig. 14.4 Schematic graph of the records mentioning drier periods during the Mid- and Late Holocene in Central Asia and Middle East

(Berberian and Yeats 2001; Hollingsworth et al. 2010). However, if seismic activity may potentially explained some abandonment of settlements, local destructions are likely not sufficient to trigger a long-lasting sociocultural evolution, such as the transformation of the Oxus civilization which mirrors a plurality of changes.

14.8.2 Resilience and Adaptations of the Populations to Climate Variation

The impact of environmental changes differs according to the subsistence economy, the organisation of urban/rural relation, the settlement pattern and the size and type of archaeological sites, which are highly variable and for which correlations are still not clearly identified. Indeed, climatic change does not always imply a crisis situation. Cases of the independence of prehistoric societies when confronted with climatic conditions are known (Magny et al. 2008; Müller 2015). The difficulty of the study is to correlate the climate scale with the human scale too. Climate changes are not brutal phenomena, but rather an evolution, which suggests possibilities of adaptation to the events (Gregoricka 2016; McAnany and Yoffee 2009; Miller et al. 2011; Petrie et al. 2017). Populations often possess the capacity to adapt to changes, which depends upon the production system, the social organization and the interests of the different social groups (Rosen 2007: 148–149; Sala 2014). "*Social and technological* *resilience versus resistance to change can be critical factors in the ability of societies to adapt to new environmental conditions. Resilience may vary between segments of society leading to greater resistance to change among those members of society leading to greater resistance to change among those members of society who benefit from current conditions*" (Rosen 2007: 173).

Broadly speaking, resilience to climatic modifications can take several forms (Binford et al. 1997; Rosen 1997, 2007; Sala 2014; Weniger 2012): (1) the move and/or the dispersion of the population towards areas less affected by climatic modifications (new ecological areas); (2) an economic adaptation by a change in the economic strategy or by a technological adaptation to increase the production and/or the efficiency of storage to minimize the risks of shortages. Climatic change can also be a factor of technological innovations in order to compensate difficulties and to maintain a certain threshold of vital yields for the whole population, such as the adaptation of irrigation techniques or actions on cultivated plants (transformations of the plants known, new distribution of the different cultivated plants, etc.). Yet, during the Final Bronze Age in southern Central Asia, both phenomena occurred.

The movements of Bronze Age populations from North to South in the Murghab area according to the retraction of the alluvial fan have been suggested (Hiebert 1994; Sarianidi 1981, 1990). First, climatic and archaeological data must correspond in order to confirm such displacement was due to climatic reasons. Second, it should be acknowledged that, according to the proposed periodization, the populations would have already moved since the beginning of the Bronze Age occupation in this area, attested in the north-western area around Kelleli (Masimov 1981), dated at least to the Namazga IV period (ca. 4950–4450 BP). Especially considering the possible consequences of the 4.2 ka BP event, there is a priori no reason to suppose the inefficiency of the "displacement strategy" during the first half of the 4th millennium BP, unless other factors occurred at the same time.

In any case, the one-time occupation of the sites in the Murghab has been definitely rejected (Luneau 2014; Salvatori 1998, 2008). The long chronological range of different sites, such as Gonur Depe (Jungner 2007) or Adzhi Kui (Rossi-Osmida 2007), whose occupation may have started at the end of the 6th/beginning of the 5th millennium BP until the Final Bronze Age, is now well attested. The settlement pattern in the Murghab alluvial fan appears more complex than previously supposed, with a wider distribution of multi-period sites during the whole Bronze Age and a better geographical stability of sites. The data suggest that "*the settlement system of Margiana during the Bronze Age had not been generated or conditioned by an environmental situation […], but by spatial rules connected to human group dynamics and by the structural complexity of the political and administrative forms of the territory*" (Salvatori 2008: 62). The effect of water availability for the duration of Bronze Age sites in the Murghab alluvial fan, and the systematic displacement of sites (according to the water availability) during the Bronze Age must still be demonstrated too, according to a detailed chronology in many areas. It is unlikely that a site persisted without a water supply in the vicinity, unless a larger more sophisticated irrigation network was expanded, and this does not seem to be the case according to the current data.

Another example of the dispersion of Final Bronze Age populations is the increase in sites dated to this period only in the foothills in Tajikistan (Vinogradova 2004), where the environmental conditions do not necessarily require supplementary water intake. In Iran as well, Bronze Age populations adapted to the decrease in water resources by changing location (Fouache et al. 2013).

This adaptation to new ecological conditions also demonstrates the capacity of socioeconomic transformation of society. A reorganization of the ratios agriculture and herding in a subsistence economy in favour of an increase of herding with "*a supplementary exploitation of marginal areas by a lighter agro-pastoralism of steppe type, but without reducing nor the productive capacity, nor the demography of the sites related to the Oxus tradition*"[5] (Francfort and Lecomte 2002: 646) has also been suggested. In southern Uzbekistan, for instance, the evolution observed at the end of the Bronze Age has been interpreted as an "*adaptation to an environment in which the sole irrigated agriculture is not the most suitable mode of exploitation*"[6] (Stride 2004: 280). The intensification of pastoralism would represent a real economic alternative required by the installation of populations in the foothills areas and the exploitation of diverse ecological areas which can be viewed as a flexible strategy. Along the Kopet Dagh range as well, P.M. Dolukhanov (1981) interpreted the deposits of silts between different layers at several sites as the result of repeated mud flows implied by the deforestation of the mountain slopes or by the increase of herding in the foothills.

Considering the improvement of farming practices, the current state of research on irrigation evokes the high dependency of Bronze Age populations upon the proximity of an active channel. Actual irrigated systems are still not proven in the different areas of the Oxus civilization. But in some regions, like in northern Afghanistan, ever since the Bronze Age populations succeeded in developing sophisticated techniques of control and regulation of water, demonstrating direct actions on the environment. For instance, even though this is yet to be proven for the Bronze Age, in the Balkh area the former riverbeds abandoned during the successive defluviations were used as irrigation canals, indicating high technological skills of the ancient population to control the hydraulic flow (Fouache et al. 2012). Likewise, the study of the spatial relationship of sites to water in the Murghab alluvial fan between the Late Bronze Age and the Early Iron Age (Rouse and Cerasetti 2015) indicates an increase of the average distance for the Early Iron Age sites in comparison to the Late/Final Bronze Age sites, which might be related to the use of more advanced hydraulic technology in the second half of the 4th millennium BP.

[5]Original quotation: "*une mise en exploitation complémentaire des zones marginales par un agro-pastoralisme plus léger de type steppique, mais sans que ne soient en rien diminuées ni la capacité productive ni la démographie des sites de la tradition de l'Oxus*".

[6]Original quotation: "*adaptation à un environnement dans lequel l'agriculture irriguée seule n'est pas le mode d'exploitation le mieux adapté*".

Further, the possible intensification[7] of the cultivation of millet in the area during the 4th millennium BP has been discussed, in particular regarding the connection with mobile populations and the exchanges over large distances in Eurasia (Miller et al. 2016; Spengler 2015). This plant is viewed as better adapted to dryness, and it may have been cultivated more with respect to an aridification. However, millet cultivation could also be linked to other reasons: the wish to increase the yields, an adaptation to the ecological environment of some specific sites, especially in the foothills, an adaptation of the agricultural practices to a possible decrease in irrigation, or a cultural choice influenced by other population groups, such as mobile populations coming from the North.[8] In other areas, like in the Indus Civilization, millet could have been part of a strategy for the exploitation of new ecological areas, and it would have reduced the dependency on the winter cultures and ensured food supplements (Meadow 1993). These agricultural changes could have contributed to the decline of the urban Harappan civilization, according to some scholars (Madella and Fuller 2005). In the case of the Oxus civilization, it is possible, too, that changes of the agricultural strategies on a local scale towards a more diversified and extensive agriculture may have contributed to social changes, implying a possible restructuration of the urban social system.

14.8.3 Convergence of Multiple Causes

These reflexions also go towards new perspectives of research that consider the sociocultural transformations of the Oxus civilization around 3750 BP. The hypothesis of a single cause, especially climatic, is likely not the most appropriate. The synchronism between long and one-time events, climatic and sociocultural, always seems difficult to state and hazardous (Roberts et al. 2011). Sociocultural evolutions are expected to be more complex than simplistic hypotheses; they can result from multiple causes by the combination of different events, which are not necessarily solely environmental (Butzer 2012; Butzer and Endfield 2012; Knapp and Manning 2016). It should be reminded that changes at the end of the Bronze Age in southern central Asia did not only affect the settlement pattern and the subsistence economy, but also the ideology, the funeral strategy and the relations with neighbouring societies. Populations of the Oxus civilization at that time were faced with important transformations related to interregional exchanges (Luneau 2016) and cohabitation with mobile populations in the territory of the Oxus civilization (Cerasetti 2012;

[7]In archaeological literature the presence of millet is mentioned at several sites chronologically dated prior to the Final Bronze Age in southern Central Asia, such as Shortughaï from the Period I, Level II (Francfort et al. 1989: 175–185), which is currently dated to the end of the 5th millennium BP (Francfort 2016) or, possibly at Sapallitepe dated to the beginning of the 4th millennium BP (Askarov 1973: 133), and becoming more frequent in the latest levels dated to the Final Bronze Age, especially in campsites of mobile populations (3650–3450 BP).

[8]Archaeobotanical studies recently put forward the role of mobile pastoralists in the dispersion of crops, particularly millet (Spengler et al. 2014).

Kuz'mina 2007; Luneau 2014, 2017; Rouse and Cerasetti 2018; Vinogradova and Kuz'mina 1996). The understanding of the convergence of these events is a wider topic of research.

14.9 Conclusion

The palaeoclimatic data available with reference to the Mid- to Late Holocene in Central Asia indicate so far a general wetter climate than the preceding Early Holocene with different events of rapid climate changes. In particular, the well-attested 4.2 ka BP aridification event may have been also effective in Central Asia, which suggests that the early period of the Oxus civilization was faced with an aridity, whereas the last phase (ca. 3750–3350 BP) could have been a period of relative climatic stability. The absence of a clear coincidence between specific climatic events and the "collapse" of the Oxus civilization can be inferred, as far as now.

On the contrary, the palaeoclimatic data raise questions about the consequences of an aridification at the beginning of the Oxus civilization. How and to what degree? Was the rise of the Oxus civilization linked to water management (water availability, improvement of irrigation techniques, etc.)? The climate aridity in the area at the end of the 5th millennium BP asserts the ability of the populations to maintain a high agricultural and economic potential for the development of the society and particularly challenge on the nature and degree of dependence of the subsistence system on irrigated cultivation. The relationship between irrigation and the state as well as the model of hydraulic societies as asserted by K.A. Wittfogel (1957) have been rightly criticized (see Francfort et al. 1989; Stride et al. 2009 for instance) because of the existence of complex societies without large-scale irrigation or conversely, the practice of large-scale irrigations by small independent communities. Further research on the link between water management and the development of the Oxus Civilization will be particularly relevant.

Indeed, the Human-Environment relationship in the past, as in the present, is a complex process, which can have highly various impacts on both human society and ecology in regard to the local situation. Environmental changes and events may not be a factor of human innovation and cultural evolution (Roberts et al. 2016), just as they may also create significant vulnerability and disruptions in human actions (Manning et al. 2017).

Hence, the challenge relies upon the identification of the impacts of climate variations on local natural resources, flora and fauna and of the societies that depended upon this environment. "*A key focus for understanding the impact of climate on humans is now to create a record that reflects local climate at high temporal and spatial resolution across an entire landscape*" (d'Alpoim Guedes et al. 2016: 3). Multi-scalar research is needed for increasing more precise archaeological records on social shifts and on the Holocene climate variability in Central Asia, according to regional and micro-regional analyses and related to a robust and detailed chronology (Butzer 2012; Dearing 2006; Sala 2014). The temporal uncertainty does not allow us currently to provide an adequate temporal and spatial climatic reconstruction of the climate and constitutes a primary target for future research. The review of environmental studies on Central Asian prehistory also reveals that the fluvial dynamics, which can have different explanations, should not be the only field in study to consider the human socio-spatial evolution. Different fields in research (geography, geology, anthropology, ecology, isotopes, etc.) must be exploited in order to make statements about the Holocene climate variability in Central Asia and the local impact on the environment and on human communities (settlement pattern and sociocultural transformations, coevolution of the fauna and the flora in specific environments, etc.). Simultaneously, anthropic factors are crucial for sociocultural mutations (whatever the environmental conditions). The capacity of anthropogenic changes (deforestation, desertification, salinization, woodland management, etc.) and of adaptation of human groups, according to phenomena that are currently underestimated (such as flexible economic exploitation of different ecosystems, actions on plants and animals, etc.) is still a large field to explore in the human-environment dynamics in prehistoric Central Asia. It is necessary to take the complexity of human interactions with the ecosystem into account, as suggested by the niche construction approach (Spengler 2014). The simulation of the interactions between social and natural forces through modelling (Butzer and Endfield 2012; Sala 2014) also provides now a major support for the understanding of the long-term socio-natural systems in Eurasia.

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Chapter 15
Climatic and Environmental Limiting Factors in the Mongol Empire's Westward Expansion: Exploring Causes for the Mongol Withdrawal from Hungary in 1242

Stephen Pow

Abstract From its formation in the early years of the thirteenth century, the Mongol Empire expanded rapidly along the steppe belt and trade routes comprising the Silk Road, forming partnerships with merchants and encouraging commerce, while also subjugating the resident nomadic and sedentary societies. In 1241–1242, the Mongols invaded and occupied Hungary for a year before mysteriously withdrawing eastward into the steppes. Many theories have been offered for this event and why Hungary's border ended up marking the westernmost terminus of the Mongol Empire, including most recently Büntgen and Di Cosmo's "environmental hypothesis" that short-term climatic fluctuation and environmental factors played a decisive role. This paper employs a comparative historical methodology to discuss three broad topics: the suitability of the Kingdom of Hungary for long-term occupation by the Mongols; the role that the climatic events of 1242 played in the famine that ravaged the kingdom after the withdrawal; and the role that environmental factors could have played in Mongol military setbacks and problems during the invasion. By doing so, this paper also aims to address additional points newly raised by Büntgen and Di Cosmo in a reply they made to an earlier article which questioned the enviromental hypothesis.

Keywords Mongol Empire · Mongol invasion of Hungary
Mongol invasion of Europe · Climate history · Steppe history
Kingdom of Hungary

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15.1 Introduction

15.1.1 Background

The Mongol invasion of Europe in 1241–1242, centered on Hungary, appears to have been part of a major operation aimed at the permanent occupation and conquest of territories. We cannot dismiss easily the "conquest" aspect of this massive westward drive and temporary occupation of Hungary when we consider a wide range of primary sources which emphasize that such an intention existed, before and after the invasion, including texts written in thirteenth-century Mongol imperial courts (De Rachewiltz 2015, 194; Boyle 1971, 108; Jahn 1977, 53). Moreover, other regions invaded during the Mongols' larger overall campaign (1236–1244) were incorporated into their Empire. These include the Bulgar state on the Volga, the Russian principalities, and the Cuman-Kipchak tribes based on the steppe belt north of the Caspian and Black Sea. As those conquests were taking place, another smaller Mongol force was pushing westward, albeit on the southern side of the Caucasus, bringing into submission states such as Cilician Armenia, and even invading Syria by 1244 (Jackson 2005, 74–75). Thus, it is evident that the larger campaign which terminated in western Hungary and Croatia—also ruled by the king of Hungary in the thirteenth century—was one that resulted in permanent conquests and the expansion of the Mongol Empire. Yet, Hungary escaped the fate of its neighbors to the east specifically because the Mongol occupiers completely and suddenly pulled out of Europe. This is surprising for several reasons. The first is that textual accounts of the invasion of Hungary, whether from a European or Asian perspective, agree that it was a highly destructive invasion; some add it resulted in huge amounts of plunder for the withdrawing invaders (Bak and Rady 2010, 221; Boyle 1958, 271). Furthermore, the Mongols were victorious in the decisive Battle of Muhi in April 1241, which largely destroyed the Hungarian royal army, hindering the kingdom from offering further unified resistance. Recent archaeological findings, such as coin-hoards and rural settlement sites with traces of destruction, which can be positively dated to the invasion period (Fig. 15.1), bear witness to widespread destruction, particularly on the Great Hungarian Plain (Vargha 2015; Laszlovszky 2012; Laszlovszky et al. 2016). The invasion and occupation of Hungary reads like a litany of Mongol successes at the expense of the local populations and their leaders, which makes the Mongol decision to abruptly withdraw thousands of kilometers eastward in 1242 all the more mysterious to scholars. The Mongol Empire expanded over much of the Asian continent, subduing China, Korea, the Abbasid Caliphate, and the peoples of Inner Asia. Yet, no persuasive reason for the withdrawal from Hungary is actually found in the source material, and the reasons for it are an ongoing topic of research and speculation.

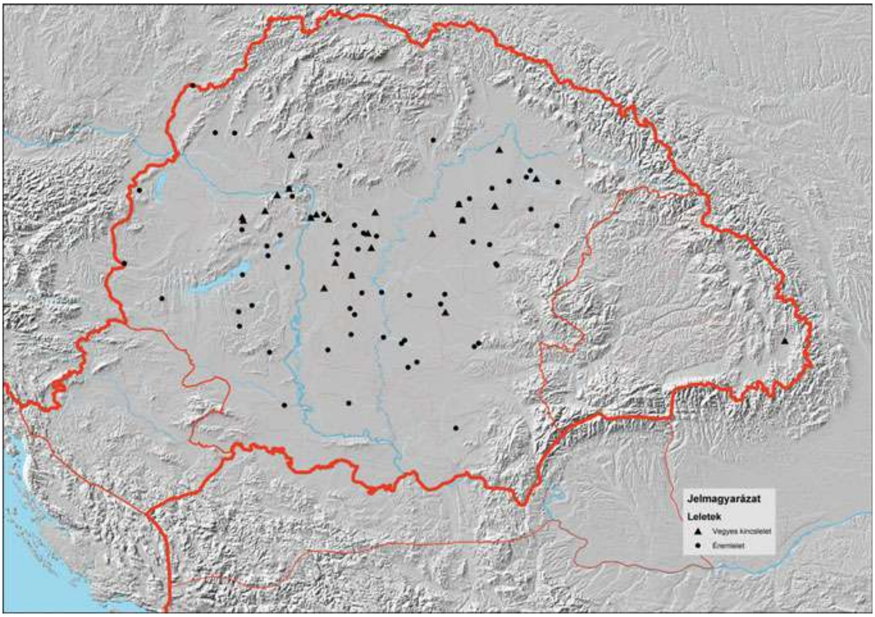

Fig. 15.1 Distribution of hoards found in Hungary connected to the invasion: triangle = mixed coin and jewelry hoard; circle = coin hoard. Image courtesy of the Hungarian National Museum

15.1.2 State of the Art and Research Questions

Regarding this invasion and withdrawal, many theories have been offered over the last century though none has reached a consensus. A "single satisfying explanation" has not emerged in the literature, Greg S. Rogers noted over two decades ago (Rogers 1996). His article was a seminal piece as it attempted to organize and categorize theories for the Mongol withdrawal in 1242, noting both the evidence for and against the various theories. He broadly defined four types of explanation for the withdrawal, which he termed: the "political" theory, the "geographical" theory, the "military weakness" theory, and the "gradual conquest" theory. The political theory, which still tends to be largely favored in literature, rests mainly on the testimony of John of Plano Carpini who visited Mongolia as a papal emissary a few years after the withdrawal. He reported that the Mongols were essentially forced by custom to take part in the election of a new khan in Mongolia, following the death of Ögödei Khan in December 1241. Yet, this seems unlikely because the Mongol leader Batu and his forces did not actually return to Mongolia (Thackston 1999, 354). He instead based his moving court on the Volga River and established the Golden Horde without ever returning for the new khan's election. The geographical theory, first suggested by Denis Sinor several decades ago, offered an alternative—the Mongols met with insufficient pasturage on the Hungarian Plain to conduct their campaigns (Sinor 1972). Joseph Fletcher disagreed with the underlying premise that the Mongols would only try to permanently occupy locations that were geographically suitable

(Fletcher 1986), while other scholars, like Vernadsky, had argued previously that Hungary was an ideal location at the end of the steppe belt to serve as a base for operations against Europe (Rogers 1996). The military weakness theory, holding that the Mongols were too weakened to continue their conquest, has some support in primary sources but could be criticized in light of the fact that the Mongols conquered so many other great powers like the Jin Dynasty. Besides, nationalistic feeling could drive scholars to support it. Lastly, the theory of the "gradual conquest" held that conquest in 1242 might not have been the intention. This explanation has proven harder to criticize, possibly because the Mongols were good at keeping intentions and plans secret, even from the eager gaze of later historians. But a major problem with it is that our best textual source on the Mongol invasion, that of a churchman, Rogerius, who was taken prisoner during the occupation, points out that the Mongols set up a highly effective administration in Hungary during their occupation. Rogerius was even taking part in the administrators' regular meetings (Bak and Rady 2010, 209). Creating a local government seems a rather surprising act to be undertaken by a raiding party during a punitive expedition.

As noted, while none of the past explanations for the Mongol withdrawal has been wholly persuasive, theories posited more recently continue at least basically along the same tracks outlined in the article of Rogers. Peter Jackson, taking a broader view of the entire progress of Mongol-European relations from the early thirteenth century to the beginning of the fifteenth century, introduced an alarmingly complex picture of their interactions, which hardly ended in 1242 (Jackson 2005). Hungarian scholarship, as well, has not remained silent on the issue of the Mongol occupation, later invasions, and the significance and intentions behind Mongol activities directed at the Kingdom of Hungary (Nagy 2003). The work of Jenő Szűcs, for instance, explored the short-term and long-term impacts of the Mongol attacks, noting that many developments once thought to represent direct responses to the Mongols had precedents; the Mongol attacks acted more as catalysts for modernizing developments while the startling recovery of the Kingdom of Hungary suggests the destruction inflicted during the first invasion of the Mongols was far from total (Szűcs 1993). I offered my own theory, the only monograph-length study on this topic, several years ago; taking a comparative approach with other Mongol conquests in diverse regions over the thirteenth century, and the long-term character of Hungary's interaction with Mongols in the aftermath of the withdrawal, I concluded that it was likely strategic problems, or future military problems perceived by the Mongol leaders, which prompted the withdrawal (Pow 2012). While this does not subscribe exactly to the "military weakness" theory as the evidence does not suggest the Mongols ever lost their capability to effectively wage war in Europe before or after 1242—I rather contend the Mongol leadership felt it was too costly or risky to advance or stay put—it still might best be placed under that rubric.

Recently, Büntgen and Di Cosmo proposed a novel combination of paleoclimatic data with documentary evidence to reach an explanation. The results of their findings formed the basis of their "environmental hypothesis" which ascribes the Mongol withdrawal in 1242 to "a general syndrome in which the effectiveness of nomadic armies was constrained by a short-term, regional-scale climate fluctuation." With dendroclimatological evidence, they were able to reconstruct a weather situation in

Hungary, which saw above-average temperatures from 1238–1241 followed by a sudden fluctuation to unusually cold and rainy conditions in early 1242. Owing in part to landscape and soil conditions, "marshy terrain across the Hungarian plain most likely reduced pastureland and decreased mobility" for the Mongols, bringing about their withdrawal (Büntgen and Di Cosmo 2016).

The 2016 article attracted a great deal of international media attention soon after its publication, with the findings being discussed in ordinary news stories and popular scientific websites, often announcing the resolution of a centuries-old historical mystery. Nicola Di Cosmo clarified that the climate may have been one of several factors at play; climate being the major driver behind the Mongol withdrawal did not preclude other factors playing a role. Nonetheless, he compared the weather's role in Batu's campaign in Hungary with the Russian winter's effect on Napoleon's disastrous campaign in 1812, asserting that to ignore it is "like saying the winter in Russia had no effect on Napoleon's army" (Gearin 2016).

Scholars in Hungary from a variety of disciplines, including archaeology and landscape ecology, raised questions regarding the environmental hypothesis, stemming from paleoclimatic, archaeological, and historical evidence of the invasion, and we collaborated on a response (Pinke et al. 2017b). Büntgen and Di Cosmo's investigation of the relationship between reconstructed weather patterns and documentary evidence was justified; climate exerted important effects on steppe-based societies and polities. Yet, the evidence could have led to an opposite conclusion than that reached by the authors—namely, that there is little evidence that climate was a major factor in the Mongol decision to withdraw. Our paper focused on specific aspects of their arguments that are relevant for the larger questions we are looking at, regarding Mongol involvement in the Eastern Europe region. We argued that above-average rainfalls should have been beneficial for pasturage. Besides textual evidence, coin hoards suggest the greatest Mongol impact was in the low-lying Great Hungarian Plain—where such evidence should be limited if flooding had seriously impeded Mongol mobility during their occupation (Nagy 2015; Székely 2014; Laszlovszky et al. 2016). The historical documents from the time seem virtually silent on climate issues specifically working against the Mongols. When faced with the range of data, our article concluded that the Mongol withdrawal in 1242 likely was not primarily the result of environmental and climatic drivers. Simultaneously to the publication of our work, Büntgen and Di Cosmo published a further brief reply, offering responses to five main arguments we made, while reiterating the importance of focusing on the very specific set of data and circumstances pertaining to 1242 when assessing the withdrawal (Büntgen and Di Cosmo 2017).

15.2 Methodology

15.2.1 A Comparative Historical Approach

Rather than being a simple response, point by point, to the reply of Büntgen and Di Cosmo, the intention here is to move to somewhat broader issues related to the historiography of the Mongol invasion of Hungary, which have been highlighted in these latest stages of the ongoing debate on the causes of the withdrawal. This does not represent a collaborative effort with specialists of various fields, but rather an individual attempt to show what the particular problems with climatic explanations are when a historian applies a broad comparative approach to the source material (Pow 2012). One of the advantages for a researcher of the Mongol Empire is the huge range of sources, diffuse in both the sense of genre and the geographical and social contexts from which they emerged.

My approach then to addressing any issue pertaining to the Mongol Empire, and in this case the role of climatic and environmental problems in the withdrawal of 1242, is not to squander the opportunity for a wide-ranging comparison of evidence, particularly textual evidence. If the report of a Chinese emissary (Olbricht and Pinks 1980, 53), the account of a Persian governor in the service of the Mongols (Boyle 1958, 92), and a Hungarian clergyman (Bak and Rady 2010, 213) match closely in their description of the use of massed groups of local prisoners to besiege towns, for example, we should see historicity in these accounts rather than finding another explanation for the parallels. Repeatedly, historians of this period can employ comparative approaches; we can see discussions of the same events from authors in societies that had extremely limited contact with one another. Their common interface was with Mongol rulers or invaders. Often accounts from the period can be confused or cursory, but the ability to view the same events from a variety of angles is something that should be the envy of historians dealing with any other medieval topic. For a particularly relevant example, we should consider the Battle of Muhi between the Mongols and the Hungarians, in which we have a Chinese account based on Mongolian sources (the only such detailed medieval account of a battle in Europe), Persian, Hungarian, German accounts, etc. (Laszlovszky et al. 2016; Pow and Liao 2018).

In their reply article, Büntgen and Di Cosmo emphasize the importance of using "absolutely dated and spatially explicit natural archives and historical sources, when linking climate variability with human history" (Büntgen and Di Cosmo 2017). They then offer replies on five points we made: (1) We cited a letter in which Béla IV reported to the pope that his kingdom was ideally suited to the Mongols raising their herds, but the authors responded that this would be only under normal conditions, quite unlike those in 1242; (2) We pointed out that precipitation was beneficial for agricultural production in Hungary based on twentieth-century records, but the authors suggested that applies to ordinary steppe conditions but not thirteenth-century Hungary in which rising water levels would have reduced land suitable for occupation and agriculture; (3) We suggested the famine was largely manmade, but the authors held that (long-term) cold and wet conditions were found to contribute to famine in the fourteenth century; (4) We pointed out that destruction was concentrated mostly on the Great Hungarian Plain, but the authors held that weather accounted for western Hungary escaping largely intact since it was invaded only in 1242; (5) We showed an Early Modern depiction of Székesfehérvár to show that it was ordinarily surrounded by marshes, but the authors stated this was anachronistic and furthermore supported the view that marshes would have hindered the Mongols (Büntgen and Di Cosmo 2017).

As is evident from the back-and-forth, the authors found our approach reliant on anachronistic data and failing to contextualize within the narrow framework of spring 1242 in the Carpathian Basin with its short-term climate situation. Here, I want to restate that an advantage Mongol historiography offers by allowing comparison of so many accounts is that we can use the broader context to make better sense of short-term events at the local level. In the following discussions, I would like to highlight three broad topics. The first is the question of Hungary's suitability for Mongol occupation, which ultimately draws into focus point (1) of Büntgen and Di Cosmo's reply. The second discussion is focused on the famine experienced during the invasion and its aftermath, which raises issues pertaining to points (2) and (3). Finally, I discuss the topic of Mongol military capacity and the issue of resistance, fortifications etc., which highlights points (4) and (5) made by the authors in their reply.

15.3 Discussions

15.3.1 The Question of Hungary's "Suitability" Within the Mongol Empire: Before and After the Withdrawal of 1242

There are two realities of Hungary's conditions, which would have made its long-term incorporation into the Mongol Empire during the thirteenth century unsurprising. The first is that the Carpathian Basin, the region in which the Kingdom of Hungary was established, is widely recognized as the westernmost extension of the long Eurasian steppe belt, stretching like a highway all the way from Mongolia in the east. Indeed, the steppe did see the rapid movement and migration of nomadic or semi-nomadic peoples along this highway, and Hungary's history before the Mongol invasion attests to no shortage of peoples such as the Huns, Avars, Pechenegs, and eventually the Magyars themselves who arrived in the ninth century and established their state in the Carpathian Basin (Pinke et al. 2017b). As such, many groups of steppic origins had viewed the area as a suitable base to migrate, raise their herds, and wage wars of conquest or simple plundering on surrounding states. Thus, we might expect that the Mongols in the thirteenth century would have viewed it in a similar way.

The second reality of medieval Hungary's conditions was that it lay on important trade routes, along which widespread international trade was carried out. Hungary had remained in the Middle Ages, after the arrival of the Magyars and the establishment of their kingdom, very much a country at the intersection of Turkic nomads, Byzantium, and the Latin West; not surprisingly, it had a highly heterogeneous population (Berend 2001, 23). The kingdom hosted significant Jewish and Muslim populations whose merchants carried on a lively international trade between Europe and Asia in the leadup to the Mongol invasion. Recent archaeological research has revealed that a series of former Roman earthwork fortifications known as the Devil's Dykes (*Ördög árok* or *Csörsz árka*) began to function as a north-south trade route with Muslim communities in the period of the Arpad Dynasty (1000–1301). This is evinced, for instance, by the even spacing of towns, which suggests major mercantile activity. Products such as salt would have moved along this route from Transylvania to the waterways of the Balkans and Byzantium (Pinke et al. 2017a). When we consider its active trade and political connections with Turkic nomads, Russian principalities, and Byzantium, along with its close links with the Middle East—Muslim accounts describe Hungarian Muslim clerics who went to study in Aleppo, for instance (Berend 2001, 238–239)—we can see that Hungary was very much tied into a larger Eurasian network. Friar Julian for instance ultimately reached Magna Hungaria on the Volga by moving with merchants along eastern trade networks stretching from Hungary (Göckenjan and Sweeney 1985, 75–77). From the tenth century, it was part of this trade network and its direction of emphasis was both eastward toward Kiev, a major center of international trade, and southward toward Constantinople; if not located on the routes that characterized the Silk Road per se, Hungary was at least an important extension of periphery networks in the period leading up to the Mongol invasion, though at that point Hungary's trade focus was shifting westward (Szende 2011, 168–169). These networks continued to function as major trade routes across East-Central Europe during Hungary's post-invasion period of recovery and prosperity in the fourteenth and fifteenth centuries (Fig. 15.2).

This is meaningful because the Mongol Empire, since its inception in 1206, had expanded not simply along the steppe belt, but also along the trade routes that traditionally, or perhaps out of modern fashion, are called the Silk Road. These routes shaped the empire's functions, becoming arteries of communication vital for the central government in Mongolia to exercise control over disparate regions as the empire grew. As such, we might view the Silk Road, along with the Eurasian steppe belt, as social and environmental conditions which made the Mongol nomads' unprecedented conquests possible. Chinggis Khan and his descendants had an established pattern of forming close partnerships with merchants who functioned in their empire as go-betweens and even spies (Allsen 1989).[1] Merchants were some of the great beneficiaries from the conquests in the thirteenth century; we might think of Marco Polo's own storied career as a merchant simultaneously operating as an agent of the Mongol administration. When the Mongols reached Europe in the early 1240s, it seems that Hungary, sitting at the nexus of trade routes between multiple regions (Szilágyi 2012, 77–95), would have fit well within the larger framework of their empire.

Whether the Mongols were, as many scholars believe, really driven by a mandate set by Chinggis Khan for world conquest (Jackson 2006), or were simply motivated by opportunism to seize areas suitable for the conditions of their nomadic lifestyle and which offered wealth they could accumulate from commerce along trade routes

[1]As Thomas Allsen notes, the Turkic term for merchants in the Mongol Empire, *ortoγ*, means "partner." Chinggis Khan had a very positive attitude to both commerce and merchants in his empire. He was using them as messengers, go-betweens, and spies, in his very first moves toward imperial expansion beyond the steppes of Mongolia. An increasing appetite for luxury items coming from the empire's frontiers only further intensified the role of merchants within it, along with the Mongol government's efforts to foster trade.

Fig. 15.2 Kraków and Buda in the road network of medieval Europe, in: On Common Path. Budapest and Kraków in the Middle Ages. Ed. Judit Benda, Virág Kiss, Grazyna Lihonczak-Nurek, Károly Magyar. Budapest: BTM, 2016, pp. 31–37. Image courtesy of András Vadas

(Berend 2001, 35), the occupation of Hungary would appear to be the next logical step in their expansion after they arrived on its borders. If we see trade routes comprising the so-called Silk Road and the Eurasian steppe belt as limiting factors to the Mongol Empire's expansion, Hungary still seems like it was suitable for a long-term occupation. That is what makes the Mongols' evacuation of the country in 1242, and their apparent lack of efforts to quickly return there,[2] such a mystery.

If we consider that Hungary was suited for Mongol conquest and thus was occupied, there are a couple of observations related to general problems with the Büntgen and Di Cosmo's premise. First, it is difficult to imagine that such a short-term fluctuation in climate as that in early 1242 could convince a highly successful and campaign-hardened army to retreat. To subscribe to the "environmental hypothesis," one must be of the belief that a few short months of unseasonable precipitation and lower than average temperatures were the deciding factor in driving off an army of Mongols that had successfully conquered, or was to conquer, the territory from the eastern edges of Asia to Hungary. It is hard to believe that the warriors capable of conquering the steppes and forests from Mongolia to Hungary would have found the latter's climate and mud an insurmountable obstacle. That relates to a second point. The Mongols, and the other Inner Asian tribal groups they subjugated, emerged from rugged regions prone to climatic extremes far worse than what might be expected in the European continental climate of Hungary. Simply taken at face value, it is difficult to accept—to paraphrase Fletcher when he criticized Sinor's geographical theory—that people who had emerged from (and adapted a lifestyle to) such conditions, and who waged victorious wars of conquest in the forest zone of Russia, the rice paddies of Song China, and the deserts of the entire Middle East, decided to retreat from the Great Plain of Hungary because an unusually wet and cold early spring in 1242 proved too much for them (Fletcher 1986). Several historians have argued that ecological factors did come into play in some Mongol withdrawals—for instance, they withdrew from Syria in 1244 and two contemporary Near Eastern authors mentioned that the Mongols' horses' hooves were damaged by the summer heat (Jackson 2005, 74). John Masson Smith Jr. thoroughly analyzed several unsuccessful Mongol campaigns in Syria and noted that logistical factors, such as the limited supplies of pasturage and water, could have greatly constricted Mongol military operations (Smith 1984). So, there is evidence that ecological factors really did hamper the effectiveness of Mongol campaigns, but these failures seem related to long-term, ordinary conditions of regions, like the deserts of Syria. Moreover, the Mongols seem to have ultimately adapted to conditions and subjugated many powerful adversaries, such as the Song Chinese or the Abbasid Caliphate, in geographical regions that were hardly suited to steppe modes of living and fighting. It is a trend that we acknowledge their high adaptability in cases where they conquered, but in cases where they did not ultimately succeed, the conclusion is often that this was predominantly because the Mongols could not adapt to local ecological conditions.

Turning to Béla IV's letter to the pope, discussed in point (1) of Büntgen and Di Cosmo's reply and written a few years after the invasion, the king certainly was not of the mind that the Mongols deemed his country unsuitable for occupation. He thought that the Mongols were going to return, and he was hearing reports of it from his spies and contacts to the east. Moreover, he was emphatic about the danger of the

[2]They did, however, invade Hungary in force again in 1285, an important detail which is neglected in the environmental hypothesis.

Mongols occupying the country, in his words, "because they can settle their families and animals—in which they abound—marvelously well here, better than elsewhere" (Rosenwein 2013, 421). The authors in their reply stated that the Hungarian king was referring to normal conditions, rather than the short-term climate fluctuation of 1242. A problem is that is not what the source records. Béla did not offer any nuance to the circumstances in which the Mongols could settle.

Denis Sinor's own earlier geographic theory for the Mongol withdrawal highlights a danger related to any environmental explanation. The author is forced to overlook textual evidence that challenges a theory or amend it to make it work when faced with new data. In the original iteration of his theory Sinor recorded that the Great Hungarian Plain had an area of 100,000 km^2, each horse needed 120 acres per year (based on American horse breeding statistics), each Mongol soldier needed 3 horses, and therefore Hungary could have accommodated at most 68,640 Mongol troops (Sinor 1972). A few decades later, his calculation read as follows: The Great Hungarian Plain had 42,000 km^2 of pasturage, each horse needed 25 acres per year, and therefore Hungary could support only 83,027 Mongol troops because each soldier needed 5 horses (Sinor 1999). It seems like what had priority in Sinor's view was the theory and the data could be shifted around at will simply to keep the maximum number of Mongols low.

Büntgen and Di Cosmo offer something more convincing since their theory is based on a reliable paleoclimatic model, rather than a mysteriously evolving calculation, but sometimes they follow Sinor's track by making reaching inferences to connect statements in the textual primary sources to what had been observed from the reconstructed year-by-year weather conditions. An especially noticeable example of this tendency is when the authors refer to Mongol activities and decisions during the summer and fall of 1241 while they were occupying Hungary. They ordered servants to provide shelter and fodder for their horses, did not burn crops, and kept peasants alive with the command to take in the harvest. Even when the authors accede that the documentary sources are silent on any weather-related issues during that phase of the invasion, they note, "These preparations are somehow indicative of an early onset of the fall/winter in 1241" (Büntgen and Di Cosmo 2016). Statements like this leave one with the feeling that the documentary evidence is being forced to construct a narrative that emerged initially from paleoclimatic data.

Subscribing to any geographic or climatic theory requires the researcher to overlook what happened in the long-term aftermath of 1242. The Mongols regularly threatened Hungary's monarch with ultimatums to submit to their rule, and even offered him military alliances, in the years following their departure (Göckenjan 1991, 61). Büntgen and Di Cosmo did not draw really any attention to this ongoing pattern of Mongol-Hungarian interactions in formulating their hypothesis for the withdrawal. Furthermore, the Mongols did eventually launch a large-scale invasion of Hungary in 1285. Again, the motivations of the Mongols and the scale of that invasion are uncertain and subject to debate. Nonetheless, we may conclude that it was a much larger undertaking than the scant secondary literature on it would suggest. While English-language literature has not yet offered major studies on the so-called Second Mongol Invasion in 1285, two major Hungarian studies have explored these important, if largely overlooked, events (Székely 1988; Szőcs 2010). These works offer important perspectives from which to approach the question of what Mongol intentions were for Hungary in light of their return. Moreover, the source material does indicate the Mongols suffered in 1285 from epidemics, serious weather issues, and ultimately famine in their disorganized retreat from Hungary. That the paltry sources for the 1285 campaign so persistently mention these issues, but the larger body of sources on 1242 are utterly silent on any such difficulties suggests that the Mongol forces did not experience such problems in the earlier campaign.

Hungary's landscape and geography lent itself to nomadic incursions and occupations. This makes the fact that Hungary retained its autonomy more remarkable than the Kingdom of Bohemia's survival, for instance, or that of the principalities of Poland. As for Hungary's other regional neighbors, such as Serbia, the Kingdom of Bulgaria, and areas of present-day Romania, they actually *were* subjugated by the Mongols to varying degrees and for different periods during the course of the thirteenth century (Vásáry 2005, 69–94).[3] Though Büntgen and Di Cosmo do acknowledge that shortly after evacuating Hungary, the Mongols invaded and subjugated Bulgaria, they do not really mention the larger trend of Mongol conquest and interference in the Balkans throughout the remainder of the thirteenth century. In fact, they state, "Our paper shows that a possible reason why the Mongols who occupied Russia under Batu and his successors did not make further attempts to expand westward may have depended on the realization that local conditions would not have supported a prolonged occupation" (Büntgen and Di Cosmo 2016).

15.3.2 The Issue of the 1242–1243 Famine in Hungary and Its Causes

The famine that affected the Kingdom of Hungary during and after the Mongol invasion is a frequently discussed topic among Hungarian researchers of the Middle Ages. Andrea Kiss, for instance, has looked at the topic and while she argued that the Mongol invasion was "very much responsible for the hunger," she also speculated that the unusual cold of the winter of 1241–1242, coupled with abundant snow and ice, may have played a contributing role in the situation (Kiss 2000). As such, this could support Büntgen and Di Cosmo's hypothesis. On the other hand, József Laszlovszky has pointed out in a publication touching on economic history that the ecological situation of medieval Hungary was such that famine occurred very rarely—which would suggest the famine in the 1240s was brought on by a truly exceptional set of circumstances, i.e. severe disruption caused by the invasion (Laszlovszky et al. 2018). In any case, it should be noted that this famine has been already heavily studied by generations of Hungarian scholars. The most recent conclusions by Andrea Kiss are that during major and long-lasting climatic changes and many years of extreme

[3] Vásáry's work offers a long and detailed summary of the continual Mongol conquests and interference in the Balkans throughout the second half of the thirteenth century.

weather, famine occurred but very rarely in the whole country. Famines and food shortage crises in Hungary were usually related to particular regions. There were very few exceptional cases when such situations affected the whole kingdom (e.g. the mid-1310s, 1362, or 1364). But even in these periods different social groups were affected in different ways and there were areas which were lightly or negligibly affected. It is also important to underline that the crisis periods were the same as those faced in contemporary Western or Central European contexts—that is, people in other regions of Europe were experiencing the same famine (Kiss et al. 2016).

While the causes of the famine in 1242 remain an ongoing topic of debate, the issue has much significance for the question of the withdrawal, since much of the textual evidence being used to support a climatic explanation relates to famine. A major component of Büntgen and Di Cosmo's theory is their attempt to relate the famine to a food crisis that the Mongol occupiers were experiencing. They argue that the Mongol decision to feed their prisoners with less desirable parts of sheep, as recorded by their captive Rogerius, indicates that the Mongols themselves could foresee the great famine that was to overtake Hungary. Deciding to feed prisoners only parts of sheep, rather than the whole sheep they were receiving beforehand, could be motivated by a variety of factors, including a lost sense of the value or importance of the prisoners. Indeed, Rogerius heard from informants that the same prisoners would be subjected to a wholesale massacre (Bak and Rady 2010, 221). Moreover, Rogerius, who escaped captivity around that time, mentioned that this change in the rations allotted to prisoners happened only after the Mongols began withdrawing from eastern Hungary into Cumania (Wallachia and/or Moldavia). So, it seems rather problematic to try to link the Mongol decision to feed prisoners less generously with a recognition that famine was going to strike Hungary.

Famine did severely afflict the local Hungarian population, but textual sources make it clear why this happened, and climate was not the primary driver. A contemporary churchman stated that it happened because the peasants were forced during the invasion to abandon their crop fields for two growing seasons (Karbic et al. 2006, 303). Naturally, if the farmers were unable to cultivate crops because they could not stay on their fields owing to the disruption and danger of the invasion, a serious famine was going to set in. Others had harvested some crops but only to supply them to the Mongols in 1241 (Bak and Rady 2010, 211).

What happened in Hungary in 1242 was hardly an isolated incident. Shortly after the withdrawal, a Dominican emissary was sent into the Mongol Empire to meet them with letters from the pope. He passed through many regions that had been affected recently by invasions and eventually met with the Mongols in Armenia. In his report, detailing Mongol methods of waging war, he stated, "In every country which the Tartars destroy, famine always follows" (Richard 1965, 44). What his report would suggest is that Mongol invasions consistently triggered famine in all the affected areas, far beyond Hungary, and we can easily infer that this happened because it was a larger strategy of the Mongols. The famines they triggered were intentional—a sort of weapon to crush resistance. When we consider that testimony, it is very hard to entertain the notion that the starvation which affected Hungary's people in 1242 was the result of a short-term fluctuation in climate. Kirakos of Gandzak, an Armenian churchman taken prisoner, noted that the Mongols invaded in the summer when the harvest had not been reaped or gathered in the granaries. They came with their livestock and ate and trampled everything, so that when they left Armenia in the winter the people had nothing to eat and died of starvation. However, Kirakos noted, that winter was "not severely cold, as at other times but as mild as one could wish" (Bedrosian 1986, 224). Here we see a close parallel to what happened in Hungary in terms of famine, albeit without the cold weather.

If we need further proof, Juvaini describes instigating famine as a regular feature of steppe warfare against sedentary societies. Describing the actions of Küchlüg, a Naiman chieftain who fled from Chinggis Khan to the Qara Qitai and was attempting to subjugate the famous Silk Road city of Kashgar, Juvaini noted, "Küchlüg, at every harvest time, would send his troops to devour their crops and consume them with fire. When for three or four years they had been prevented from gathering in their corn, and a great dearth had made its appearance, and the populace were distressed with famine; they then submitted to his command" (Boyle 1958, 65). This type of warfare was being practiced from the very beginning of the empire, even by refugees fleeing from Chinggis Khan. Changchun, a Chinese Daoist monk, passed through the former Khwarazm Empire shortly after its conquest and described a society so broken down by famine and brigandage that the Mongol governor of Samarkand refused to reside in the palace of the former shah (Waley 1931, 93). In their campaigns against Korea, the Mongols inflicted famine on the population to pressure the king to submit. The king in turn complained to the Mongol leadership in terms that sound rather familiar: "…several times you sent army leaders to censure [the people]. The people have no land to cultivate and in farming there was no time to harvest. Considering this land [had only] flowering grass, what could be produced? Thinking that we had no way of offering up tribute and to present it would be difficult, my fear was extreme" (Schultz and Kang 2014, 307). The Mongols inflicted such severe starvation on the population that finally they started killing their own government-appointed leaders or inciting Mongols to attack certain fortresses. Ultimately the military governor of Korea was overthrown and assassinated, not long after he refused to open a granary. In the end, the king finally sent his son to the Mongol court to submit in 1259 by which time the Mongols had seized the entire harvest, epidemics were breaking out, and starvation was rampant (Schultz and Kang 2014, 369–377).

A comparative look at texts from different times and regions should lead us to the conclusion that the famine that unfolded was intentionally brought about by the invaders. As for the Mongols' animals and their pasturage needs, the carrying capacity of the Great Hungarian Plain allowed for millions of animals, even during the Little Ice Age of the Early Modern era (Pinke et al. 2017b), so it is difficult to imagine that even a large Mongol army would have faced a crisis with pasturage owing to short-term climate fluctuations. Büntgen and Di Cosmo did not always clearly distinguish if the food crisis was one afflicting the animals of the Mongol occupiers or simply one affecting the agrarian-based populace of Hungary. These are two very different things. Furthermore, it seems the authors supplied documentary evidence of a victual crisis facing the latter group as evidence that the former group was experiencing something similar. It is problematic to link the accounts of widespread starvation of Hungary's sedentary, agrarian population to the issue of pasturage being limited by short-term climate fluctuation of early 1242. The obvious problem with such a viewpoint is that it is well known that the Mongols relied primarily on their herds of animals for food. So, the disruption of grain harvests would not have had the same effect on the Mongol occupiers as it had on the local peasantry. Büntgen and Di Cosmo, however, argued that not only did cold wet conditions in 1242 affect cultivated crop production, but they limited pasturage in the Great Plain, placing stresses on the Mongols to feed their animals. The sources from a Hungarian context, and far beyond, leave us no doubt that the famine was mostly a manmade and intentionally triggered phenomenon.

15.3.3 Local Resistance and the Possibility of Diminished Military Capacity as a Result of Climate in 1242

There are primary source accounts of military problems that the Mongols experienced in 1242, and it is an important question to what degree these were caused by a wet and cold climate and its effect on soil, fortifications, pasturage etc. In point (4) of their reply, Büntgen and Di Cosmo suggested a sort of dichotomy between the military successes experienced by the Mongols in 1241, and the setbacks they are recorded to have suffered, ostensibly because of climate, in 1242 (Büntgen and Di Cosmo 2017). Nonetheless, their description of 1241 as a year flush with successes might be a bit of an oversimplification because the Mongols appear to have been prevented from crossing the Danube and pursuing the Hungarian king, Béla IV. In fact, the king stated in his letter to the pope that his forces held off the Mongols from advancing for ten months after the disaster at Muhi (Rosenwein 2013, 421). Furthermore, the biography of Sübe'etei, the famous general who oversaw the invasion of Hungary, which is found in the *Yuan Shi*, states that the Mongol princes wanted to flee the country during or shortly after the battle of Muhi in April 1241 (Pow and Liao 2018). They were only prevented from doing so by Sübe'etei shaming them. All of this suggests that the level of resistance they were experiencing may have had a demoralizing effect on the Mongol commanders already a year before they in fact withdrew their forces.

Büntgen and Di Cosmo suggest that the difficulties the Mongols experienced taking fortresses in 1242 had much to do with the swampy conditions they encountered, owing to the unique climate situation experienced at that time. This tends to reductionism since it ignores some topographical differences (between the hilly west and flat east of Hungary for instance), and the archaeological issues related to fortifications. In fact, an earlier study by Erik Fügedi demonstrated that the important factors in the survival of fortresses during the invasion had to do with building materials to a large degree; stone castles fared much better than wood and earthworks. However, another key element, perhaps more important than building materials, was the strategic situation of the fortress on a hilltop or island (Fügedi 1986, 45–48, 57–59). Those based on hilltops (Pannonhalma, Esztergom's citadel, Klis fortress in Croatia), or islands (Tihany, Trogir, Wroclaw) stand out for their successful resistance against concerted Mongol attacks. Particularly in Croatia where Béla IV had taken refuge, Mongol sieges mentioned in the sources usually ended abortively (Karbic et al. 2006, 299–301). If conditions in the flatlands and plains were indeed swampy from heavy precipitation, it is difficult to imagine that the outcome of Mongol sieges of hilltops or offshore islands like Trogir were seriously altered by the short-term climate fluctuation in the winter and spring of 1241–1242. The Mongols probably experienced more or less ordinary conditions in those sieges, so the cause of unsuccessful outcomes should probably be attached to the strong strategic position and natural or manmade defenses of these places rather than to weather. In response to Büntgen and Di Cosmo's criticism in point (5) of their reply—that a sixteenth-century depiction of Székesfevehérvár is anachronistic—I contend that the image was chosen to highlight the fact that many fortresses and towns were highly defensible in *ordinary conditions*. The eastern flatlands and plains, however, that should have been protected by swampy conditions in early 1242, according to Büntgen and Di Cosmo's hypothesis, are the very areas that show the greatest signs of devastation and destruction at the hands of the invaders (Laszlovszky 2012). Moreover, new archaeological investigations in those same areas of the Great Hungarian Plain reveal a number of large improvised settlements fortified by ditches and earthworks, where people from the surrounding area came for defense. In all cases, they show signs of being overrun and destroyed which suggests such improvised fortifications in the open plain were simply not effective at resisting the Mongols (Laszlovszky et al. 2018). The findings closely parallel the account of Rogerius of the situation that unfolded at places like Pereg, where people from seventy villages gathered and held out against Mongol onslaughts for a week before being overrun (Bak and Rady 2010, 213).

Previously, I looked at Mongol sieges of fortresses and urban centers in Russia, China,[4] Korea, India, Persian, the Caucasus, etc. A wide geographical and chronological framework was useful because it demonstrated that well-situated fortresses and those built of stone tended to perform well against Mongol assaults in different geographical regions (Pow 2012, 79–121). Thus, in making sense of failed Mongol assaults on fortresses, a comparative approach is useful, especially when we consider that descriptions of Mongol tactics for taking fortresses show distinct patterns, regardless of the geographical origin and societal context of the authors.

Returning to the issue of Hungary in 1242, we have documentary evidence that the unusually cool winter conditions worked to the advantage of the Mongols in a decisive way on at least one occasion. The unseasonable cold froze the Danube, an unusual occurrence, which enabled the Mongols to at last cross over and continue their conquests in western Hungary. This important event also enabled them to resume their pursuit of Béla IV who had been safely based in Croatia for roughly a year after the defeat at Muhi. So, we are faced with statements in the sources that the evinced short-term climate situation worked against the Hungarians and to the strategic benefit of

[4]They did conquer China, but it took many decades and only was accomplished with the aid of many Chinese defectors and supporters. Furthermore, they had great difficulty with strategically situated Song fortresses (Pow 2012).

the Mongols. Using the same data with which Büntgen and Di Cosmo worked, other authors could hypothetically have reached a totally different interpretation, arguing instead that short-term climate trends worked to facilitate the Mongol occupation of Hungary. Therefore, I continue to contend, as I did earlier (Pow 2012, 73), that local resistance and a growing perception of a threatening and unresolvable military situation made the Mongol leadership decide to pull back in early 1242. As it was, however, they first moved into Bulgaria and apparently subjugated it on their way out. While strategic issues were a primary driver in my view, we must certainly be facing a very complex set of circumstances and multi-causal drivers which prompted the withdrawal, which is precisely why a single satisfying explanation has eluded researchers.

15.4 Conclusions

In this paper, beyond simply rehashing some issues with Büntgen and Di Cosmo's "environmental hypothesis," I hope to have offered something novel in my discussions of broader topics. First, I have attempted to demonstrate the *suitability* of the Kingdom of Hungary for incorporation into the Mongol Empire in the thirteenth century. By forming a segment of the same steppe belt from which the Mongols first arose and crossing a series of international trade networks of the medieval period, its appeal to the Mongols as a potential subject state must have been obvious to their leadership. In light of this, problems with Denis Sinor's geographical theory and previously undiscussed issues with Büntgen and Di Cosmo's hypothesis were raised. For instance, the viewpoint that a few months of unseasonable cold and above average precipitation convinced experienced Mongol leaders that the Carpathian Basin was unsuitable for a long-term occupation ignores the larger context of their successful and often overlooked conquests in the Balkans in subsequent years. This unfortunate tendency to isolate Hungary and the major invasion it suffered from the larger set of ongoing Mongol activity in southeastern Europe afterwards is probably detrimental to our fuller understanding of why they invaded in the first place, what they hoped to accomplish, and of course the question of the withdrawal itself. Second, I have demonstrated with a wide range of textual material that the Mongols used famine as a weapon against people they were trying to subjugate everywhere. When we combine that evidence with recent findings on medieval Hungary's reaction to long-term climate change, it seems that the famine of 1242 was largely manmade. Thus, the use of textual accounts of famine to support a climate-centered explanation for the withdrawal is untenable. Finally, this paper discussed the problem that strategically situated fortresses represented for the Mongols in any geographical context and in any climate, which is why strategic sites were selected in the first place, and why the castles that held out against the Mongols often had perennially strong natural defenses. The results of the discussions in this paper illustrate that a comparative analysis of a broad range of data, particularly textual material, is an effective methodological approach toward understanding even very specific events that occurred in the Mongol Empire's history.

Büntgen and Di Cosmo's argument for the 1242 withdrawal posits that the wet conditions in the winter and spring made the formerly favorable situation of the Mongols suddenly problematic because soil wetness delayed the onset of vegetation, while the muddy terrain interfered with their military capability. So, the authors argue, the withdrawal in the spring took place in conditions of "(i) reduced mobility and military effectiveness; (ii) reduced fodder for the horses; and (iii) reduced victuals for the army." We can group points (ii) and (iii) together, and state that the authors hold that the wet weather had precipitated a crisis for the Mongols to feed themselves and their animals. Point (i) holds that Mongol military operations, such as sieges, were seriously impeded by this same weather situation (Büntgen and Di Cosmo 2016). But when we look at these two distinct arguments in turn, we can see the authors used some documentary evidence to support their hypothesis unpersuasively. Moreover, there is other available documentary evidence, not employed by the authors, which contradicts their viewpoint. The silence in Latin texts on any weather-related phenomena driving off the Mongols is curious, were it the case, since this would allow authors of a clerical background to assert that God had interfered with nature to spare Christendom. Rather, nature aided the Mongols at key points.

Though I have outlined some criticisms of their theory, the authors' project certainly has been beneficial for scholarship. They used climate science to reconstruct the weather in Hungary during the invasion and in the lead-up to it. This reconstruction sheds light on the conditions in the Kingdom of Hungary before the invasion and can be explored in light of political and social conditions documented in the sources. Their work provides a confirmation of the accounts of an unusually cold winter in 1241–1242 found in several sources, and their visual mapping of the withdrawal routes is more in line with what the primary sources describe than one could find previously in monographs or maps depicting the campaign. Furthermore, Büntgen and Di Cosmo's work was a necessary and useful attempt to explore the possible connections between climate and the Mongol withdrawal using the scientific methods now available. For some readers, the takeaway from Büntgen and Di Cosmo's collaborative paper is that it was a necessary and useful exercise to explore the effects of the climate on the Mongol invasion of Hungary. What that exploration ultimately suggests, however, is that we should continue to seek additional causes, rather than emphasizing short-term climate fluctuation, for the withdrawal in 1242. As a final observation, in their reply, Büntgen and Di Cosmo advised to avoid following deterministic and reductionist approaches to these issues (Büntgen and Di Cosmo 2017), a point on which I fully agree. That is why I also aim at an approach that offers a multicausal, complex interpretation of the events of the Mongol invasion and withdrawal, in which climate could have played a meaningful role.

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Part V
Social Adaptation and Resilience to Environmental Stresses

Chapter 16
Resilience of the Human-Water System at the Southern Silk Road: A Case Study of the Northern Catchment of Erhai Lake, China (1382–1912)

Anning Xu, Liang Emlyn Yang, Weibing Yang and Aubrey L. Hillman

Abstract This study focuses on the northern catchment of Erhai Lake that lies in the heart of the ancient Southern Silk Road (the Tea-Horse Roads) in southwest China. The hydrologic environment of this region is complex and evolved under significant human impacts, especially after large populations migrated after 1382 under the policy of military tillage. This led to increased pressures on the human-water relationship of this region but also stimulated social resilience to water stresses. This paper investigates the manner in which local people addressed the conflicts of utilizing limited water for people, livestock and irrigation until 1912. The approaches of statistical analysis, spatial analysis and correlation analysis were adopted, and historical data on floods, water conservation projects, plants, and disease were collected to support a detailed examination of the evolution of the human-water relationship in the study area. The results indicate that: (1) the evolution of the hydrologic environment, including the river system and the hydro-chemical environment, had a close correspondence with human activities; (2) local people constructed various water conservation and engineering facilities and changed their farming structures to cope with water stresses, which partly contributed to the break out and spread of Schistosomiasis japonica; (3) the resilience of the human-water relationship became weaker as the management of water projects diminished; (4) the sustainable development of the human-water relationship could be maintained through regular water management and environmental governance. These findings emphasize the influences of social policy and human activities on the resilience of the catchment and improve our understanding of resilience theory.

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Agriculture production · Resilience theory · Schistosomiasis japonica
Erhai lake · The Tea-Horse Road · Southwest china

16.1 Introduction

Water, as a basic element of the environment, has a close relationship with humans. The human-water relationship occupies an extremely important position in the development of society. In its long history, China has been a country frequently and seriously affected by natural disasters such as floods and droughts (Liu and Yang 2012; Ji et al. 2015). Water governance strategies aimed at combating these disasters are linked with political, social and economic developments in Chinese history. There have been many famous water management projects that made a contribution to successful water governance. For example, Dam Dujiangyan and Canal Lingqu were built 2000 years ago and are still in use today (Wang et al. 2017). At the same time, the Chinese people have experienced several changes in understanding and utilizing water, including fear, worship, control, and conservation (Wang 2009a, b). In these human-water relationships, humans had made great achievements, created various cultures and religions focused on water, developed water related habits, and created rich water-related theories (Yuan 2014; Zhang and Wang 2014).

Here, the hydrologic environment refers to the formation, distribution and transformation of both water quantity and quality in the natural environment (Wu and Zhang 2009). The hydrologic environment plays an essential role for humans to survive and for society to develop. However, it has also been seriously disrupted by human activities (Harper and Snowden 2017) from the past to present. In the future, the human-water relationship will experience increased tension due to many challenges such as population growth, increased urbanization, higher standards of living, and climate change (Ding et al. 2014a, b). Faced with these challenges, modern society has begun to rethink its water use activities and social development strategies, and reexamine the human-water relationship to emphasize the sustainable utilization of water resources and the harmony between humans and water (Liu et al. 2012; UN-WWAP 2015). Understanding the evolution of this human-water-relationship during the historical period is therefore of significance for its current and future management planning.

This paper aims to understand the resilience and evolution of historical human-water relationships in the northern catchment of the Erhai Lake in southwest China. The focus is on key changes that reflect water impacts and social responses during the Ming and Qing Dynasties (1382–1912 A.D.), in which a combination of qualitative and quantitative approaches are adopted. It is expected that the findings from this study can help understanding local human-water relationships in the past and their implications for future water governance at basin scale.

16.1.1 Relationships Between Human and Water in the Long Historical Period

The concept of the human-water relationship has been a topic of research for many years (Turner II et al. 1990; Simmons et al. 2007). Recently it has become clear that the increase of population and the intensification of human activities are leading to increased tension between humans and water resources, which calls for macro control to maintain a harmonious relationship (Lautze et al. 2005; Ding et al. 2014a, b).

Ji (1981) emphasized that the development of water conservation projects brought about a high level of agricultural production and prosperity to ancient China (before 1860 AD). By analyzing the developmental processes and geographical distribution of ancient water conservation projects, Ji put forward the concept of a "basic economic zone". A basic economic region with superior agricultural production and water conditions was the main support of a centralized feudal Chinese dynasty, which relied closely on water. The main inland economic areas were usually the "basic economic zone" which the central dynasty relied on, including the lower Yellow River plain and the Yangtze River basin. Meanwhile, remote border areas were regions in which the control of central feudal power was relatively weak, and the economic development was limited compared to the main inland economic areas. These regions include the mountainous Yunnan area, during the Ming and Qing Dynasties.

Research has been done on the relationships between humans and water during historical periods, with a large amount of focus on the Chinese heartland, of which the middle and lower Yellow River is an important basic economic zone. Tan (2000) suggested that soil erosion is directly related to vegetation coverage on the Loess Plateau and that the vegetation is dominated by the agricultural production of the people living there. Due to the varying types of land use in these areas during the historical period, the amount of sediment entering the Yellow River has changed significantly. After the Eastern Han Dynasty (25–220 A.D.), the development of animal husbandry in the Loess Plateau, especially in the Shanxi-Shaanxi Gorge and the upper zone of Jing River, Wei River and Luo River, greatly reduced the amount of sediment transported downstream and resulted in long-term stability of the Yellow River (Tan 2000).

Another basic economic area is south of the Yangtze River, which has also been researched extensively. Wang (2013) believed that water conservation technology had a great impact on the water environment, which was reflected in social development levels and resulted in the emergence of new water conservation units. Further research has revealed the effects of culture and disease on the hydrologic environment. Wang (2015) found that as water space was divided into smaller sections, there were less poems that mentioned "girls picking lotus" while more mentioned "girls picking water chestnut".

According to the division of main inland economic areas and remote border areas by Ji (1981), many studies focused on the former but relatively less on the later, and with no comparison of the two. In the late imperial periods of the Ming and Qing Dynasties, both the main inland economic areas and the remote border regions experienced huge pressures with a surge in population. The land use mechanism in basic economic zones crumbled under the weight of huge populations (Li 2006). With the rapid expansion over the border regions of China by Han culture during the Ming and Qing Dynasties, a significant influence was exerted on existing local societies and cultures, though how this influenced the basic land use and associated water management remains unclear. Basins within the mountains of these southwest border areas are significant regions of grain production, making them critical regions of study.

One such example is the Erhai catchment. Recent years have seen an increasing number of studies on the Erhai water environment, especially with regards to water quality problems during historical periods (Crook et al. 2008). Physical geographic studies have been focused on the water quality of Erhai Lake, but over a relatively short-time span. Dearing et al. (2008) undertook a series of studies on this area and examined the mechanisms of sustainability in this area. Though fascinating, these studies are somewhat less systematic in their historical perspective, as historical changes cannot merely be explained through data whilst neglecting the specific adjustments or processes of society.

Yang (2007) studied floods in the Erhai Basin by summarizing the character, causes, and solutions relating to flooding in ancient times. Even though research has been done on this subject, the historical materials used were incomplete, and the reliability of these analyses depends highly on the integrity of the data. For example, the records of floods in The Veritable Records of the Qing (清实录) are far more abundant than sources used in previous research. Consequently, the attempt by Yang (2007) to rebuild the historical database and to reconstruct the sequence of floods in time and space is very informative, but the theories and effects of river harnessing are still unclear.

Due to the limitations of existing studies, a detailed and rigorous study of the Erhai Basin is necessary. This research on the human-water interrelationship in historical times would yield useful findings to help manage the water problems that still bother local people now. This study would further broaden vision and enhance the understanding of the importance of solutions to hydrologic challenges for both the present and future.

16.1.2 Resilience Theory in Human-Water Relationships

Resilience originates from the Latin word ‘resilio’ (re = back, silio = to leap) From the concept of mechanics, resilience is the ability of a material to deform and store potential energy without breaking or becoming completely deformed (Pelleg 2012, 27). Since the 1970s, the term resilience has been extended to encompass the ability of a system to restore itself and to return to its initial state. The development of Resilience Theory over the last few decades has undergone three phases since Holling put it forth in the 1970s (Holling 1973): Engineering Resilience, Ecological Resilience and Socio-ecological Resilience.

Specifically with regards to coastal complex systems, Klein et al. (1998) divides resilience into three parts: (1) natural resilience, (2) ecological resilience and (3) socioeconomic resilience. This suggests that there is no initial or equilibrium state in coastal systems, and that coastal resilience maintains the ability to self-organize in a constantly changing hydrological and geomorphological environment. This ability is derived from the dynamic processes of natural, ecological and socioeconomic conditions, and is limited by the maintenance of functions. Berkes (1998) further identified four aspects of resilience research: (1) learning to coexist with changes and uncertainties; (2) fostering diversity for renewal; (3) integrating different categories of knowledge; (4) creating opportunities for self-organization, restoration, and construction of a socio-ecological system.

According to Resilience Theory as described by Holling (2001), the adaptive cycle as a fundamental unit of dynamic change comprises a forward and backward loop in four phases: exploitation, conservation, release and reorganization, which may provide the potential foundation to assess human-water system changes. Adger et al. (2005) further put forward that restoring resilience is the ability of a system to absorb periodic disturbances, such as hurricanes or floods, while maintaining its basic structure, process and functions. Adger et al. believe that the diversity of means of livelihood, societal knowledge, and local emergency agencies can all be important resources to buffer extreme natural disasters and to recover from them. Accordingly, some ecologists believe that the resilience of an ecosystem will change if disturbed, and cannot be fully restored to the state before interference (Sun et al. 2007). Therefore, it is the aim of resilience researchers to find ways to enhance the system's resilience by studying it, in order to avoid an undesirable state even if it might be stable.

With particular focus on the Erhai Basin, Dearing (2008) adopted Resilience Theory to compile a relatively complete temporal series of environmental evolution and human activity over the past three millennia, with analysis of historical data and sediment sequences from the basin. The results indicated that the resilience and sustainability of the modern agricultural land system of the Erhai area depends on reducing the use of high altitude and steep slopes for grazing and cultivation. Unfortunately, this research had a coarse temporal resolution and didn't make full use of available historical materials, leaving a need for further analysis.

Through the literature review above, we identified two shortcomings of existing research on the human-water system resilience: for one, the historical evolution of the human-water relationship in the Erhai catchment has not been studied systematically; second, the human-water relationship in history is far more complex than just an "adaptive cycle" and there are still many unknown interactions. Previous research has been mainly introductory in both interpretation and analysis. The lack of specific historic details has led to a deficiency in scientific rigor. For example, what role did anthropogenic disruption play in flooding process or as a triggering factor? These are essential problems that are necessary to be addressed in order to reveal the change in the hydrological environment from a historical perspective. The aim of this article lies in analyzing the evolution of the human-water relationship in the Erhai catchment and improving resilience theory when applied to research on human-water relationships.

16.1.3 The Research Objectives and Materials

This paper introduces several innovations to address existing problems of past research and addresses several new problems arising from this study. The study takes the northern catchment of the Erhai Lake as a case study area that is of significance in terms of historical geography, water environment, anthropology, social development and other aspects along the well-known Southern Silk Road, also called the Tea-Horse Road (details in Sect. 2). This research assumes ongoing change in the hydrologic environment of the case study area and aims to reveal the evolution of the water system and determine which factors dominated, on the one hand, the change of the hydrologic environment, on the other hand, human activity and its influence. The goal of this study is to reveal the interactive dynamic of the human-water relationship in the study area and to understand its resilience.

Specifically, this study utilizes historical profiles, including documentary, gazetteer, local chronicles and epigraphic records, and archaeological records of human activity. Integration of these various data resources is supported by further analysis including comparison, statistical modelling, and classification. Overall, the study contributes understandings of the following issues:

– What were the essential characteristics and changes of the water environment in the northern catchment of Erhai Lake during the Ming and Qing Dynasties (1382–1912)?
– What were the interaction effects of the human-water system in this basin?
– How did the resilient state of human-water systems evolve in this basin and how could it be promoted?

16.2 The Southern Silk Road and the Erhai Basin

16.2.1 Introduction of the Southern Silk Road (the Tea-Horse Road)

The Silk Road is a modern concept for an ancient network of trade routes that for centuries facilitated and intensified processes of cultural interaction and goods exchange between West China and its neighbors (Yang et al. 2017). It generally includes the Northern Silk Road (also called oasis Silk Road and desert Silk Road), Maritime Silk Road and the Southern Silk Road. Though the former two are more generally well-known, the Southwest Silk Road was the earliest one to come into being. The Southern Silk Road is often known as the "Ancient Tea and Horse Road" (茶马古道), also called "Road between Shu and Shendu (Ancient India)" (蜀-身毒道) (Fig. 16.1). It was partly formed during the Qin Dynasty (BC221–BC207) when the first Emperor Qin Shihuang conquered the region of Yunnan, about 200 years before the development of the traditional Northern Silk Road via Central Asia. It

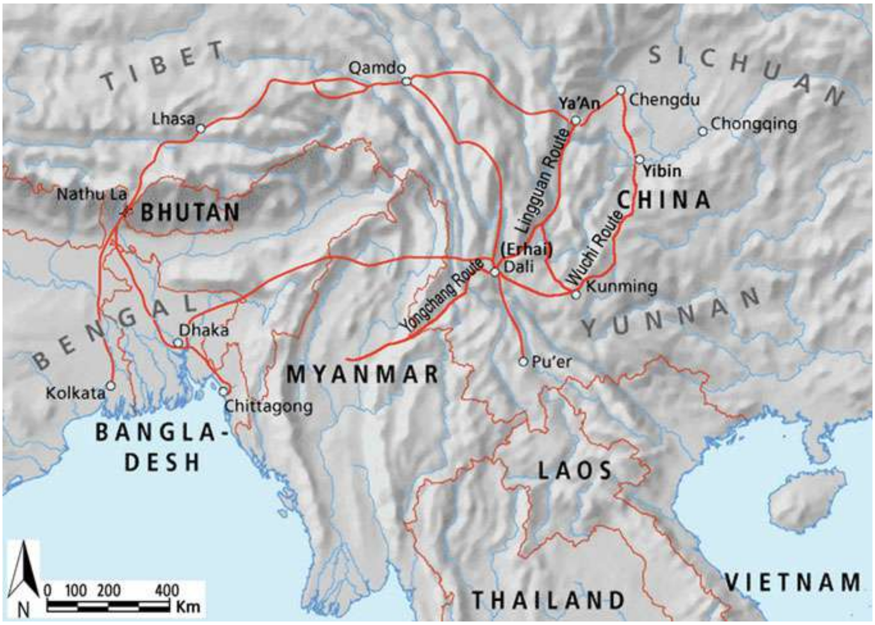

Fig. 16.1 A brief illustration of the ancient Tea-Horse Roads network (Southern Silk Road). Edited by Liang Emlyn Yang based on a figure from the "WikiPedia Tea Horse Road"

was active around 2200 years BP, with Dali becoming a regional center in the Erhai Lake basin in the Tea Horse Road networks (Xu et al. 1987).

The Tea-Horse Road was not only an important road network for early regional and international trade, but also the channel of interactions among ethnic groups and political, economic and cultural exchanges. The formation and development of this road promoted the development of commerce, the handicraft industry, mining and metallurgy, and the salt industry in the southwest mountain area in ancient times. During the last two decades, research on the Tea-Horse Road has been characterized by complexity and diversity, and has resulted in many achievements in historical geography, archaeology, anthropology, economic history, the history of transportation, tourism and other aspects; however, there has not been detailed research on specific sectors (Lan 2008). As a typical basin area in the center of the Tea-Horse Road network, the research on the Erhai catchment is therefore of great significance.

The Tea-Horse Road network consists of three major routes: Lingguan Route (灵关道), Wuchi Route (五尺道), and Yongchang Route (永昌道), with an entire length of more than 5000 km (Fig. 16.1). This network of routes links many major cities such as Yibin (宜宾), Kunming (昆明), Chuxiong (楚雄), Dali (大理), Yangbi (漾濞), Baoshan (保山), Tengchong (腾冲), Yongping (永平), Qamdo (昌都) and Lhasa (拉萨). It further connects southwest China to central China (Xi'An) in the East and to Myanmar and India in the south and west.

For the past two thousand years, people of different ethnic groups including the Zang (藏), Yi (彝), Naxi (纳西), Lisu (傈僳), Hani (哈尼), Jinuo (基诺), Qiang (羌), Pumi (普米), Bai (白), Nu (怒), Jingpo (景颇), A'chang (阿昌) connected with each other economically and culturally through the Tea-Horse Road. Along the development of the routes network, horse caravans (马帮) played a significant role in transporting goods, such as tea, salt, cotton, gemstones, and opium.

Dali became a regional center of the Erhai Basin largely due to economic activity along the Tea-Horse Road, sustaining a large immigrant population, as well as other complex social factors. Before the Ming Dynasty (1368–1644 AD), the population in Dali and the Erhai Badin was limited and the social economical system was less developed. The evolution of the hydrologic environment in the northern catchment of Erhai Lake was also slow. Beginning with the large number of Han Chinese migrating into the area at the start of the Ming Dynasty, the local economy was gradually developed. At the same time, these developments led to disturbance of the natural environment, with rapid and obvious changes to the hydrologic environment in the form of frequent floods and droughts. Because of this, the Miju River (弥苴河) was called "the Small Yellow River".[1]

16.2.2 Erhai Lake at the Tea-Horse Road

The Erhai Basin is located in the central part of the Tea-Horse Road connecting Sichuan, Yunnan and Myanmar (Fig. 16.1). Erhai (25°36′–25°58′N, 100°05′–100°18′E) is China's seventh largest lake with a surface area of 250 km^2 at the present time. It lies in an intermontane basin between the Tibet-Yunnan fold belt and the Yangtze para-platform (Zhang et al. 2000) (Fig. 16.2). It is about 1974 m a.s.l. (above sea level) with a combined lake and catchment area of ~2500 km^2. The lake basin is geologically dominated by Palaeozoic metamorphics (gneiss/granite and marble) on the west side and Mesozoic basic volcanic and sedimentary rocks on the east side (Lin 1982). The catchment of Erhai Lake is composed of four parts (Fig. 16.2) with the majority of discharge coming from the north, supplying more than 59% of the 5.18×10^8 m^3 inflow annually.[2]

The north catchment is composed of the basins of Mici River, Fengyu River, and Miju River (A and B in Fig. 16.2) with continuous hills and deep river valleys. The river drops substantially from 2050 to 1987 m a.s.l. and empties into Erhai Lake with a rapidly aggrading delta at the Miju River mouth.

The basins A and B (Fig. 16.2) together are often called the Miju River basin, which is divided into upstream and downstream regions by the Putuo Gorge (蒲陀

[1]"The small Yellow River" is a quote from the local chronicles of Eryuan County (1996), which means it was similar than the Yellow River with big floods, high sediment concentrations, and over ground riverbed.

[2]This data is quoted from Erhai Management Chronicles (2007), edited by Erhai Protection Administration of Dali.

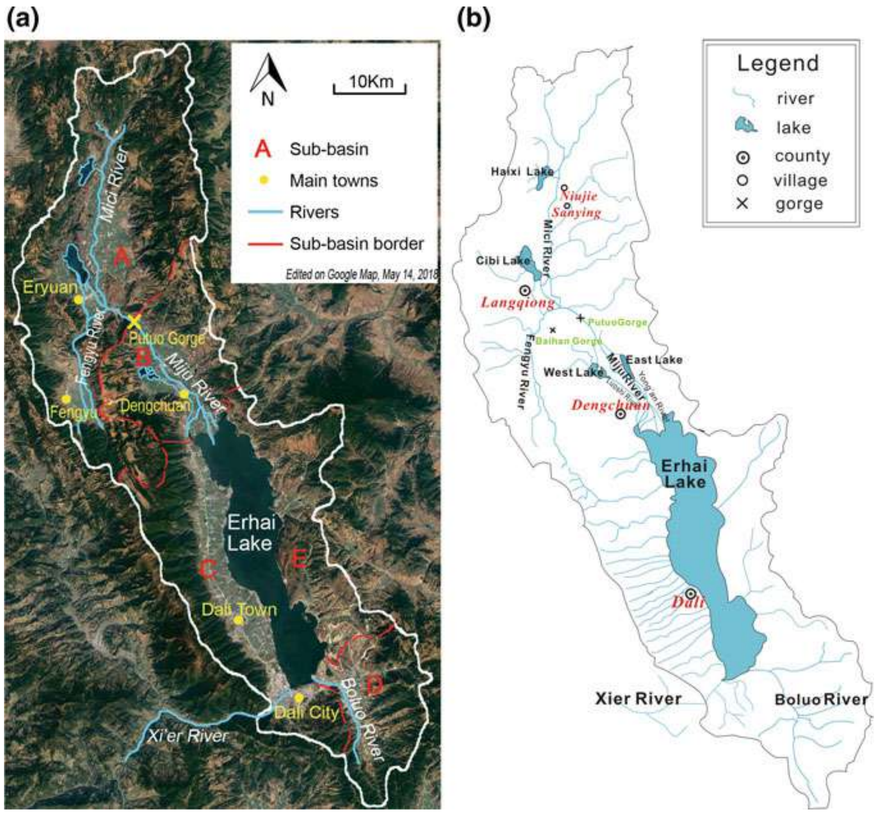

Fig. 16.2 Brief illustration of the topography (left) and river system (right) of the catchment of Erhai Lake

崆). The upstream (A) consists of two major branches, the Mici River (43.4 km) and Fengyu River (36 km). Cibi Lake (茈碧湖) and Haixihai Lake (海西海) merge at the beginning of the Putuo Gorge in an area called Sanjiang Port (三江口) and empty into downstream through the Putuo Gorge (Fig. 16.2, right). There are two smaller lakes (West Lake and East Lake) and three channels flowing in parallel at the downstream area (Fig. 16.2, right), which look similar to the Chinese word "chuan" (川). The main channel is the Miju River, while the other two have local names, the east is called Yong'an River (永安江) and the west called Luoshi River (罗时江). The three river channels flow into Erhai Lake separately, but they are often together called the Miju River basin.

The total length of the main stream system in the north catchment (the areas A and B in the left pattern of Fig. 16.2) is 71.08 km, with a catchment area of 1259.43 km^2. The heavily embanked and elevated Miju River provides irrigation water for intensive agriculture on the floodplain. The sub-basin A (Mici River and Fengyu River) is surrounded by mountains with one only outlet at the Putuo Gorge. The elevation is much higher at the villages of Niujie (牛街) and Sanying (三营) at the north of Mici River, while it is lower in the Fengyu River basin in the south, between 2060 and 2200 m a.s.l.. Both of them join with the Cibi Lake outlet (2055–2100 m a.s.l.) and flow via the Putuo Gorge to the mainstream Miju River. As the downstream region, the elevation of sub-basin B sits between 1965 and 1987 m a.s.l.. The population is dense and the fields are better fertilized in this sub-basin, which makes up more than 70% of the whole county's population and at the same time demands a larger amount of water for drinking and irrigation.

16.2.3 Social Economic Characteristics of the Erhai Lake Basin

Agricultural production is the dominant economic activity in the Erhai Lake basin, and the land use is mainly comprised of woodland, grassland and farmland, which respectively accounted for around 33.5, 35 and 24.1% of land coverage around the year 2000 (Yang 2004).

In the 15th year of Hongwu in the Ming Dynasty (1382), the Army General, Mu Ying (沐英), was ordered to conquer Yunnan Province. He brought in 200 thousand garrison troops and peasants (mainly people of Han ethnicity) to reclaim land and grow food grain in the areas surrounding Dali and Erhai.[3] The sudden influx of large numbers of people made a great contribution to the economic development of the area, but also brought considerable land pressure and people began to move up to the mountainous areas.

For example, a village named after a leader, Dawa (大娃), was filled with immigrants from Jiangsu and Jiangxi Province and settled close to the transportation line and the center of the north catchment (Fig. 16.3). The native people of Bai ethnicity who lived there since the Nanzhao (南诏) and Dali (大理) Periods (748–1254) had to move to the surrounding higher hilly regions (Yang and Li 1996). In order to attain self-sufficiency in grain production with the natural growth of the population, the military population and their families made efforts to expand cultivation areas by reclaiming land from wasteland, slopes, and desolate marshes. Han villagers settled densely at both sides of the Miju River where there was an abundance of water (Liu 2013), which eventually developed into the present town Dengchuan (Fig. 16.3).

[3]Record of the Ming Dynasty《明实录》.

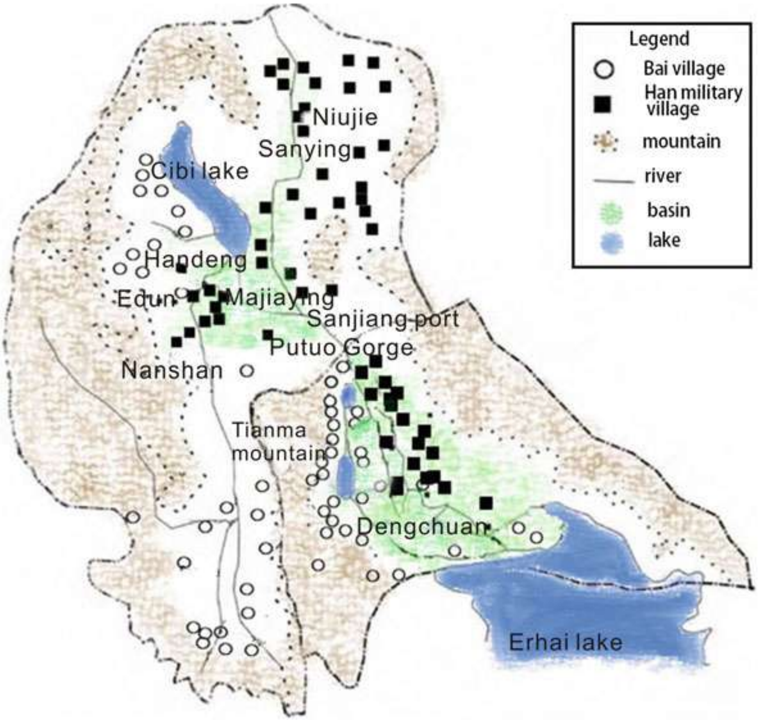

Fig. 16.3 The distribution of villages in north catchment of Erhai Lake in the Ming and Qing Dynasties. Re-edited by Anning Xu based on Liu (2013)

16.3 Human-Water System in the Northern Catchment of the Erhai Lake

16.3.1 The Water Problem in the Northern Catchment of Erhai Lake

As mentioned above, the hydrologic challenges in the northern catchment of Erhai Lake are mainly concentrated at the Miju River (sub-basin B in Fig. 16.2). The Miju River is called "the Small Yellow River" for its high sediment load and pronounced fluctuations in seasonal precipitation. The surface runoff supplied through precipitation varies largely with the seasons, and is the main reason for floods in the summer or autumn and droughts in springs. Additionally, this runoff contributes to the deterioration of water quality (Wu et al. 2012). With continuous hills and deep river valleys, the topography of the northern catchment changes greatly, leading to substantial elevation drops along the river from 2050 to 1987 m a.s.l. Consequently, the river empties into Erhai Lake at high velocity (ECC 1996). Under these circumstances, the standing time of the water is short and rainfall is not stored for long periods; therefore scarcity of rainfall may easily lead to droughts.

The population is dense and fields have been fertilized in this region since the large migration in 1382, resulting in high water demand for drinking and irrigation all the year round. Therefore, tension exists between the huge demand and the short supply of water for most of the time. In addition, population pressures have caused the increased cultivation of unstable mountain surface soils on the slopes of the upstream areas, which was detailed in the gazetteer.[4] The result has been a massive increase in sedimentation of the river. Additionally, the dykes in the downstream rose to a level above the farmland. When heavy rains occur and break the banks, this often results in floods.

Several scholars have done detailed research on the floods and droughts of the northern catchment of Erhai Lake (Yang 2007), but the materials used were not comprehensive. By collecting historical materials in the Ming Dynasty and the Qing Dynasty (1382–1912), the present study built a database of floods (Table 16.1) and droughts (Table 16.2). Particular attention was paid to a few key sites in the research area, including Langqiong (浪穹) and Dengchuan (邓川) as basic local administrative regions of the Qing Dynasty.

Floods were so frequent in the north catchment that the records of floods are very common in historical archives. Torrential floods exerted a tremendous influence, the most serious one being in 1905 (the 31st year of Guangxu in the Qing Dynasty). According to the record, the flooded field area was up to 321 qing (顷) in Dengchuan, whilst the entire paddy field area was only 400 qing, leading to over 80% of the paddy fields failing, a particularly rare situation in southwest China. Additionally, the bursting of banks leading to floods was also quite common. In 1691, the Miju River burst its banks and the chief of the prefecture, Liang Dalu, led the local people to plug the leaks. It seemed like a normal event in the record, with the area submerged by flood sediments being over 79 qing(顷); this means that a quarter of the paddy field failed to grow rice. Additionally, the estuary was often blocked by sediments, resulting in poor drainage and overflowing lake conditions. For example, in 1694 (the 33rd year of Kangxi in the Qing dynasty), there was a flood from the Baihan Gorge (Fig. 16.3), which resulted in sand blocking the river and flooding of the fields and houses.

The climate of the northern catchment is mainly affected by the southwest summer monsoon. Weak summer monsoons lead to a scarcity of precipitation and subsequently droughts. In early 20th century, droughts in Dengchuan lasted for years due to a lack of precipitation. Additionally, delays in the timing of rainfall may also cause droughts. In the May of 1747, the rice seedlings could not be planted because of the late arrival of rainfall in Dengchuan. In years when the strength of the monsoon is highly variable, seasonal change may induce both droughts and floods within the same year. In 1859, it barely rained in the summer in Dengchuan, leading to drought. However, it rained too much in the autumn, which caused floods. Overall, the frequency of droughts was much lower than that of floods.

[4]Eryuan County Committee (ECC) (1996). Local Chronicles of Eryuan County.

Table 16.1 Selected records of floods in the northern catchment of Erhai Lake during the Ming and Qing Dynasty

Time (B.C.)	Location	Original record in Chinese documents	Material resources in Chinese
1501, August	浪穹 Langqiong	八月"浪穹淫雨,山崩水溢冲圮,居民溺死百余人,公署文案尽漂没" Flood in August of the lunar calendar, over hundred people were drowned	天启《滇志》卷三十一"灾祥" Yunnan Province Gazetteers in Tianqi Years
1663, July and August	East Lake, Dengchuan	邓川七八月间红石泛滥,倒灌东湖,淹没田庐。Flood in July & August of the lunar calendar, inundated the field and houses	咸丰《邓川州志》[a] (Xianfeng) Dengchuan Gazetters
1691	Dengchuan	"弥苴河决,知州梁公大禄塞之。" Miju River burst its banks; The prefecture chief Liang Dalu lead the local people to plug the leaks	咸丰《邓川州志》 (Xianfeng) Dengchuan Gazetters
1693	Baihan Gorge of Langqiong	白汉涧水发,沙石填河,湖水横流,冲田宅无算。Flood from Baihan Gorge and sand block the river	《浪穹县志略》 The Langqiong County Gazetteers
1694	浪穹,邓川 Langqiong, Dengchuan	洱源"白汉涧水发,沙石坝河湖水横流,冲田宅无算。" Flood from Baihan Gorge, sand block the river and flooded the field and houses	《浪穹县志略》 The Langqiong County Gazetteers
1732	浪穹 Langqiong	浪穹县羽河等处。筑堤四十余丈。但补苴一时。急宜委勘加修。Build dam of Yu river in Langqiong for the flood	清世宗实录 The Record of Shizong Emperor in Qing Dynasty
1749	邓川 Dengchuan	除云南邓川州、水冲沙压民屯田地额赋米、二十二石有奇。银、二十五两有奇。 Exempted from taxation of affected people in floods	《清高宗实录》 The Record of Gaozong Emperor in Qing Dynasty

(continued)

Table 16.1 (continued)

Time (B.C.)	Location	Original record in Chinese documents	Material resources in Chinese
1760	Fengyu River	夏秋之间,每淤塞倒漾,淹浸田庐。The water submerged the field and houses in summer and autumn	清世宗实录 The Record of Shizong Emperor in Qing Dynasty
1782, February	邓川 Dengchuan	弥苴河…河高湖低。遇夏秋潦发,青不涧、九龙涧等处之水,会冲入河。河水宣泄不及,回流入湖,附近粮田俱被淹没。The field were flooded in summer and autumn along the Miju River	清高宗实录 The Record of Gaozong Emperor in Qing Dynasty
1801	Miju River at she Gorge, Ning Lake	浪穹之宁东、宁南、宁北各村田亩,均被冲淹。The field on east, south and north of Ning Lake were flooded in Langqiong	咸丰《邓川州志》卷五"灾祥志" (Xianfeng)The Dengchuan Gazetters
1806, Jume	Langqiong	奏报查明浪穹县被水田亩情形,请分别赈抚事。Report and find out the situation of fields were submerged	《军机处全宗》 Record of Military Aircraft Department
1808	浪穹 Langqiong	嘉庆十三年灾益甚,南北城垣尽圮,请赈,除田赋五百余石。The flood were so serious that request help	道光《浪穹县志 》(Daoguang) The Langqiong County Gazetteers
1859, July	Dengchuan	邓川淫雨经旬,淹没禾苗无算。 The field were flooded countless after rain for months in Dengchuan	新纂云南通志 The New Yunnan Province Gazetteers
1906, March	邓川 Dengchuan	豁免云南邓川州属上年被水地方银米。 The tax of Denghcuan were exempted because of the flood	清德宗实录 The Record of Dezong Emperor in Qing Dynasty

[a]Hou Yunqing, (Xianfeng) Dengchuan Gazetters, reprint by Chengwen Press, 1976
[b]Qing (顷) is a unit of area that equals to 6.67 ha

Table 16.2 Selected records of droughts in the northern catchment of Erhai Lake

Time (B.C.)	Locations	Original record in Chinese documents	Material resources
1606	浪穹 Langqiong	是岁洱源旱甚,南水浸沟,不能注下。Heavy drought in Eryuan	康熙浪穹县志 (Kangxi)The Langqiong County Gazetteers
1665	洱源Langqiong	大旱heavy drought	洱源县志 The Eryuan County Gazetteers
1692, spring to summer	洱源 Langqiong	康熙三十一年,自春月不雨至夏五月不雨,民益惶惶。It has no rain from spring to summer	康熙大理府志 (Kangxi)the Dali Prefecture Gazetteers
1747, from May	洱源、邓川 Dengchuan	雨泽愆期,秧苗不能全栽。The Rice seedling cannot plant because of the late of the rain	张允随奏稿 The memorial to the throne from Zhang Yunsui
1792, summer	邓川Dengchuan	壬子 (1792年)之夏,邓 (川)境乏雨 it was lack of rain in summer of Dengchuan	咸丰邓川州志 (Xianfeng)The Dengchuan Gazetteers
1817, autumn	浪穹Langqiong	夏雨雪,秋大旱,民复饥。It was drought in autumn	道光浪穹县志 (Daoguang) The Langqiong County Gazetteers
1837, summer	邓川Dengchuan	邓川夏旱。Drought in summer of Dengchuan	咸丰邓川州志 (Xianfeng)The Dengchuan Gazetteers
1859, summer	邓川Dengchuan	邓川夏旱,秋淫雨。Drought in summer but flood in autumn of Dengchuan	云南通志 Yunnan Province Gazetteers
1893, summer	邓川Dengchuan	邓川夏大旱。Drought in summer of Dengchuan	柿坪记述 Description of Shiping
1905	邓川Dengchuan	邓川等州“大旱连年,赤地千里”。Drought for years in Dengchuan	云南通志荒政草稿 Yunnan Province Gazetteers

Floods occurred 41 times upstream (sub-basin A in the left pattern of Fig. 16.2) and 58 times downstream (sub-stream B) of the Miju River basin during the Ming and Qing Dynasties (1382–1912), as summarized from available records. When dividing the collected flood events into different periods according to Yang (2007), there were 20 downstream floods before the channel diversion of the Fengyu River during the period 1659–1760 as the first phase, while only 9 floods occurred upstream during the same time frame. In the second phase (~1760–1860), a period of one hundred years after the twenty-fifth year of Qianlong in the Qing Dynasty (1760), the frequency of upstream and downstream floods were similar—20 and 21 times respectively. This finding differs from the previous opinion of Yang (2007), that the floods in Langqiong were more frequent than in Dengchuan. During the third phase

(1851–1912), the number of upstream floods was 12 while the number of downstream floods was 17, showing that the floods in Dengchuan were actually more frequent than in Langqiong. These results are roughly consistent with previous findings, except for the second phase. Although the outbreaks of drought were less frequent than floods, the occurrence of droughts downstream were more often than that in the upstream area; therefore, we conclude that the droughts in Dengchuan were more serious than in Langqiong.

As floods in this area are far more serious than droughts, the following sections will focus on the causes of and local responses to the floods.

16.3.1.1 Climate Impacts

The northern catchment of Erhai Lake has a typical humid monsoon climate that is often found in the north subtropical Yunnan Plateau where there is a clear distinction between dry winters and wet summers. The average annual rainfall is 742.4 mm and 90% falls from May to October. Runoff into Erhai is mostly made up of this rainfall. Relative humidity averages around 66% with an average annual temperature of 15.1 °C and an annual sunshine duration of 2354 h. In addition, the microscale climate within the basin varies with topography and altitude.[5]

Huang et al. (2014) found that the main synoptic systems giving rise to heavy rainfall in the Erhai Basin were shear line, Bay of Bengal storms, a low vortex, a convergence zone of two high-pressure south branching troughs, and a westbound low-pressure typhoon. These meteorological features often facilitate rain storms. Combined with previous research on the summer monsoon and the rainy season in the Yunnan Province during the Qing Dynasty (Yang et al. 2006), analysis indicates that there were obvious inter-annual and inter-decadal fluctuations of the starting date of rainy seasons in Yunnan, as well as long-term fluctuations on the decadal and centennial scale. The monsoon arrived earlier in the beginning of the 18th century, later in the 19th century and earlier again in the 20th century (Huang et al. 2014). The variability of the summer monsoon therefore leads to great changes in precipitation and thus brings floods and droughts.

16.3.1.2 Topographic Factors

Some scholars believe that the location of burst banks and collapses are not random (Yang 2007). The location of such events shifted downstream, which was closely related to the evolution of sedimentation in downstream areas. According to historical records, burst river banks were not the only reason for the severe flooding in Dengchuan. There were 7 burst banks in 61 years (1851–1911), with 21 recorded floods, indicating that burst banks were not an inevitable cause of the floods.

[5]Eryuan County Committee (ECC) (1996). Local Chronicles of Eryuan County.

As stated in The Record of Gaozong in the Qing Dynasty: "Whenever it rains too much in summer, a lot of water accumulates in the low-lying land", it reveals that the occurrence of excessive rainfall was the main cause of flooding in Dengchuan, which corresponds to a phase of *exploitation (rapid growth)* in resilience theory. For example, "in the third year of Kangxi in the Qing Dynasty (1663) there was a flooding outbreak and the water invaded into East Lake and submerged farmland and villages in July and August" (Eryuan County Water Conservancy and Electric Power Bureau 1995). In the seventeenth year of Qianlong in the Qing (1752) "[Dengchuan] standing grains were flooded in rural areas" (Yunnan hydrology and Water Resources Bureau 1997). In the ninth year of Xianfeng in the Qing Dyansty (1857), "after rains for months, the grains were flooded countless times in Dengchuan by the time of July in autumn" (Zhou and Zhao 2007). Excessive rain often led to floods since the basin is large and flat while its outlet is too small to accommodate the inflow from the surrounding mountains (Fig. 16.4). If the riverbanks were strong enough and the river was sufficiently deep and wide, floods may not have occurred. However, technology was limited in the Ming and Qing dynasties and cannot compare to modern reinforced concrete engineering measures,[6] so dams were often unable to withstand the floods.

Compounding the problem is that the natural channel of the Miju River is quite shallow; the river bed was even higher than the adjacent ground in times of heavy

Fig. 16.4 The flat landscape of Dengchuan Basin surrounded by mountains (taken by Weibing Yang in 2012)

[6]The reinforced concrete engineering measures was first invented by Aspdih in 1824; and China built the first cement plant in Shanghai at the late 19th centuries.

sediment flow. The breaching of the dyke can therefore hardly be avoided as the channel cannot accommodate even slightly excessive runoff. Dengchuan used to be an area of "swamp and shallow lake beach" before the time when the riverbanks of the Miju River were built by Deng Danzhao (邓赕诏) in the year 649 and before Luo's brothers excavation of the Luoshi River in the year 785.[7]

The dykes were built to prevent the river from brimming over, but the channel was relatively fixed by these dykes after being constantly repaired and renovated for hundreds of years (the *conservation phase* of resilience theory). When it rained excessively and there was inadequate drainage, "the water would backflow into the lake and the grain nearby would all be submerged" (the record of Gaozong Emperor in Qing Dynasty) (the *release phase* of resilience theory). Excessive sediment deposition exacerbated the already serious problem of flooding.

16.3.1.3 Characteristics of the Water System at the Cibi Lake

The Cibi lake basin is naturally shallow and has a low capacity to adjust to water levels in both cases of drought and flood. This has been documented in many historical materials. In 1762 (the 27th year of Qianlong in the Qing Dynasty), the governor of Yunnan Province, Liu Zao (刘藻), wrote the reason and response to the flood in the memorials to the emperors[8]:

> The water from Cibi Lake (also called Ning Lake), Feng Yu River and Mici River in Langqiong County joins with other inflows at the point of Sanjiang Port, and drains downstream in Dengchuan through Putuo Gorge with sands and sediment. When it comes to summer and fall, the river would be blocked and water overflowed, flooding lands and villages. The crib and pile were arranged from the east bank at the Old Dam located at the north end of the gorge, in order to block sand and stones from rushing into the river. But both the dam body and dam crest are only five feet high and thick, which is difficult to withstand the flood challenge. The dam should be built in the size of twelve feet in height and ten feet thick, while the foot of the dam should be thicker than three feet. In addition to the old earth dam of 903.5 zhangt(丈), a new dam was added spanning 5768.5 zhang(丈) in all. As for the west riverbank where the Creek of Baihan Gorge flow into river, the sands should be excavated to build the dam.

The floods of Eryuan were mainly caused by the water rising in Cibi Lake. As early as in 1692, it was recorded in the local chronicles that once in water of the Baihan Gorge (Fig. 16.3) rose, sand filled the river, resulting in the floods and the submergence of countless fields and houses (Zhou 1976). In 1765, as the water rose and flowed out of Cibi Lake, the northern, southern and eastern walls of the city Eryuan were washed away by the water. In 1801 (the Sixth Year of Jiaqing (嘉庆) in the Qing Dynasty), "The Ning Lake is so shallow in Langqiong County (Eryuan) that there is dredging of mud from the lake bed every year, so whenever it rains

[7]Local records of river and lakes in Eryuan County (1994). P91.

[8]Memorials to the Qianlong Emperor of Qing Dynasty. Reprint by Palace Museum in Taipei Press in 1982.

heavily, the eastern, northern, southern villages would be flooded".[9] In June of 1805, "villages and fields near the lake were flooded, where water cannot drain out."[10] This kind of flood situation was so frequently seen in local chronicles that we conclude that the fundamental cause of the flood lies in its shallow lake basin, which restricts water storage capacity.

16.3.1.4 Sediment Deposition

The accretion of lake sediment reduced lake water storage and also deposited silt resulting in river blockage, which led to dam bursts and floods. It has been mentioned above that because the basin of Cibi Lake is relative shallow, small increases in precipitation could raise the water level and lead to floods. In 1760 (the twenty-fifth year of Qianlong in the Qing Dynasty), the Fengyu River was diverted into Cibi Lake. Although the floods subsided gradually in the short term, sediment brought by the Feng Yu River was deposited in the lake, reducing the basal depth of Cibi Lake, leading to reduced water storage, increasing the risk of flooding. Floods at upstream areas brought serious problems to the silted up riverbed in Sanjiang Port and Putuo Gorge, restricting the stream flows. Thus, whenever the Sanjiang Port area was blocked, the local government would put efforts to dredge it, so that the water blockage was addressed immediately.

Yang (2007) attributed the major cause of floods in the north catchment (sub-basin A in Fig. 16.2) to the development of the sensitive area of the Fengyu River catchment. He believed that the floods of the Fengyu River and Cibi Lake were previously infrequent and that floods only occurred when the Sanjiang Port was silted up by sediment from the Baihan Gorge after the 25th year of Qianlong (1760). A comprehensive analysis of data in this study (in Table 16.1) also shows that the frequency of floods increased from 1760 to 1850 (the end year of Daoguang in Qing Dynasty), supporting Yang's view. It is also found that floods subsided again after the years of Xianfeng (1861). We could detect a full resilience loop during the process above, but cannot not attribute the *reorganization* process to natural functions, but rather to governing activities. The deposition of sediment in rivers and lakes increased the risk of flooding and exacerbated the risk of dyke break. By dredging the sediment, the drainage was improved, the moisture storage capacity was increased and the floods were alleviated to a certain degree, which can be identified as *reorganization*.

An infilling of lake floor leads to a decrease of lake water storage, and, of course, reduces the regulating function of the lake. In dry seasons, drought can be easily triggered if precipitation is insufficient. For instance, "*In the 31th year of Kangxi in Qing (1692), it barely rained from spring to summer [in Eryuan] and aroused the*

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[9]The Dengchuan Gazetteers during the Xianfeng periods of Qing Dynasty.

[10]Historical materials of floods and droughts in Yunnan Province.

public panic”.[11] Without adequate water reserves in rivers and lakes, people were unable to irrigate farmland.

16.3.2 Human Impacts on the Human-Water System

To address flooding issues, the local people made great efforts to construct water projects, which had remarkable but inconsistent effects. The increased need for maintenance led to the restructuring of parts of the system of government and the lives of the local people. Specific principles, ideas and characteristics of flood control and river planning and harnessing in Dengchuan are presented according to data, experiences and lessons recorded in various archives.

16.3.2.1 Watercourse and Dams

Due to the frequent and serious flood impacts along the Miju River, especially in the lower reaches where the channel is shallow and riverbed accumulated over ground, local people have developed various measures to address the problem. Most significant solutions were water conservation projects (Table 16.3). In 1732 (the 10th year of Yongzheng in the Qing Dynasty), the governor of YunGui and Guangxi, E’Ertai (鄂尔泰), reported to the Emperor Yongzheng and proposed six suggestions for water conservancy projects in the Erhai Lake catchment. His report “*Suggestions on the Construction of Water Conservancy*” included a specific proposal on “*embankment and dredging engineering of the Fengyu River in Langqiong County*”. The Ministry of Works immediately replied “*it is appropriate to build an embankment of 40 feet for the Fengyu and other rivers in Langqiong County quickly*”.[12] However, the dykes were only a temporary measure and the effect was not as expected.

In addition to reinforcing dykes and excavating sediments in the river, local people tried to open up new channels. For example, in 1782 (the 47th year of Qianlong in Qing Dynasty), the Governor of Yunnan Province, Liu Bingtian (刘秉恬), presented a memorandum to the Emperor regarding the flood problems in the Miju River basin at Dengchuan County.[13] The problem was that the riverbed was high while the East Lake was low, and that when it rained in the summer, a flash flood in the upper reaches could expand into a more general river flood. If the water could not drain out effectively, it would flow back to the lake and flood the surrounding fields. The local officers and inhabitants advocated donations to build a dam at the end of East Lake and construct a new channel to drain out the water directly into the Erhai Lake. A few years after the new causeway was built and a stone watergate was established

[11](Kangxi) Local chronicles of Dali prefecture.

[12]Memorial to the Emperor by E’Ertai.

[13]The Record of Gaozong Emperor in Qing Dynasty.

Table 16.3 Some collections of the water management projects during Qing Dynasty (1644–1912)

No.	渠 Channel	堤 Dam	河道疏浚 river dredging	闸 Sluice
1	西堤十四渠 Fourteen channels to the west	弥苴佉江堤 Mijuqv River dam	三江口 Sanjiang Port	上东西二闸 two sluice at upstream on east and west
2	东堤六渠 Six channels to the east	罗时江堤 Luoshi River dam	白汉涧 Baihan Gorge	下西闸 sluice at downstream on west
3	驿东乾沟渠 Yindong Gangou Channel	圆井堤 Yuanjing dam	凤羽河 Fengyu River	
4	南怒地江渠 Nan Nudijiang Channel	上七里公堤 Up Qiligong dam	瀰茨河 Mici River	
5	溪登渠 Xideng Channel	下七里公堤 Down Qiligong dam	真珠涧 Zhenzhu Gorge	
6	东源沟 Dongyuan Channel	旧东闸堤 Old Dongzha dam	南涧 Nan Gorge	
7	山根渠 Shangen Channel	卧虹堤 Wohong dam	北涧 Bei Gorge	
8	红山渠 Hongshan Channel	普陀河堤 Putuo River dam	永济河 Yongji River	
9	安民沟 Anmin Channel		罗凤溪 Luofeng Stream	
10	山关渠 Shanguan Channel		九龙泉 Jiulong Spring	
11	三江渠 Sanjiang Channel		金龟山涧 Jingguishan Gorge	
12	大波渠 Dabo Channel		沂水河 Yishui River	

to constrain the river, more than 11,000 acres of previously flooded farmland were dried out and could be cultivated again.

Drought in the lower reaches was much more severe than the upper reaches of the river because the river was straight and the riverbed was high so that water could hardly be stored for long time use. Water rushed into Erhai Lake quickly after flow out of the Putuo Gorge, even though there was sufficient precipitation. When there were extreme precipitation events, either droughts or waterlogging would occur, which would affect both the production of agriculture and people’s lives and property. Therefore, the construction of the artificial canals played a significant role in regulating water storage during periods of uneven water conditions.

In order to keep the river calm over the long-term, the people of Langqiong County developed the “Maintenance Regulations for the Sanjiang Canal” in the 26th year of Qianlong (1761) and received funds from salt-tax income. Thus, financial resources of 20 Liang (两)[14] were available annually for minor maintenance and 120 Liang for major repairs and silt removal every three years. As shown partly in Table 16.3, local people excavated over 30 channels, built 8 dams, dredged 12 river sections and opened more than 2 sluices during the Ming and Qing Dynasties (1644–1912). There is an old saying that “Dengchuan is small, while the canals are countless like stars”, which is a direct reflection of this situation. The implementation of these hydraulic facilities had a significant effect on water management and benefited the life, property and safety of surrounding people. However, once political interest waned and the funding stopped, serious river blockages occurred again. Details of the maintenance regulations can be referred to in Dearing et al. (2008).

16.3.2.2 Water Diversion

The floods of the Fengyu River were especially serious since sands were gradually accumulating due to the relatively flat terrain. The old downstream area of Fengyu River turned into a field of sediment around 1762 (the 27th year of Qianlong in

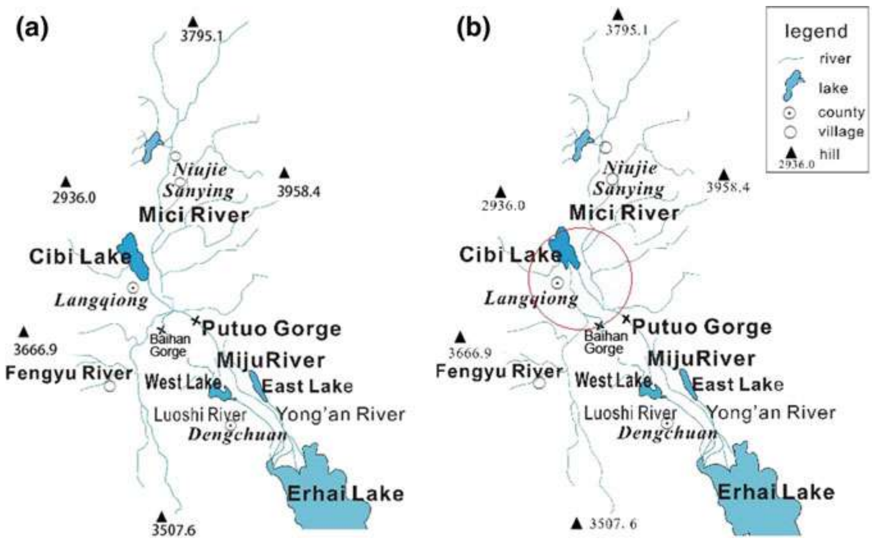

Fig. 16.5 A comparison of two maps showing significant changes (area in the blue circle) of the river system in 1368 (**a**) and 1820 (**b**)

[14]A concrete measurement unit of weight in ancient China, that 1 Liang is 31.25 g.

Qing Dynasty) when local people reached a consensus to divert water, as it was more efficient to excavate new artificial canals rather than clean up the silted stream sections. The outlet of Fengyu River was diverted northwards to the Cibi Lake and the floods at the old outlet area subsided (Fig. 16.5). From local people's point of view, if the riverbank of Fengyu River were thick and high enough, there would be no flooding of the river or stresses relating to annual maintenance. These maintenances included repairing the dam regularly, dredging sediment, and guiding the water into the lake. However, the effect was not as expected due to the natural constraints of the river terrain and limited engineering capacities. As a result, the river still broke its banks and flooded vast areas when the water rushed down from upstream every autumn.

Another technique to harness the river was to maintain the overflow channels created by flooding. For example, local people allowed a diversion channel out of Baihan Gorge, which guided the northern ravine flow down from the mountain to the mainstream of Fengyu River. Although this reduced the flood damage around the original riverbanks, it increased sediment delivery to the Fengyu River.

16.3.2.3 Separation of Sand from Water

In response to the difficulties mentioned above, a new idea was to separate the sand and water to control soil erosion at the source and prevent sediment influx to the river. The representative governors of this new river-training approach were Lin Zhonglin (林中麟) and Chen Wei (陈炜) who used to be the chancellors of Langqiong County. As early as in 1753 (the 18th year of Qianlong in Qing Dynasty), Chancellor Lin advocated for building a dry dam of stone at the mouth of Baihan Gorge, which had the effect of separating sands and water, and mitigated flooding within a few years. However, during three days of heavy rain in June 1808, the dry dam collapsed into the due to years of disrepair. Under these circumstances, the new chancellor Chen took over. He realized that the old systems didn't discharge water with enough energy, and consequently the flow was too slow to move sand. He decided to reconstruct the dry dam one hundred feet high and two feet wide and also lengthened it from the foot of the mountain to the southwest. They made use of the uncultivated lands to settle the sands from river dredging. A drought bank was also built around the dam for about a hundred Zhang (丈[15]), and hundreds of willows with strong root-nets were planted behind to strengthen the bank. Water was released at the end of the bank while mud and sand were deposited inside the dam to prevent river siltation.

It is no wonder that the local people all praised "the construction plan [which] was very good for controlling the river, which was no longer harmful for many years thereafter".[16] However, with sediment accumulation over time, the risk of dyke breaching increased, indicating that the need for the establishment of maintenance regulations. The changes correspond to the *release phase* in the resilience theory introduced by

[15] A traditional measurement unit of length in China, 1 Zhang (丈) equals to 3.33 m.

[16] (Daoguang) The Langqiong County Gazetteers".

Holling (2001) that a process loses its former tight organization. It is particularly worth mentioning that this approach was so effective that it was continuously used and maintained for centuries until the present. Due to the building of a recent sand factory in 1980s to intercept sediment upstream at Baihan Gorge, the sediment load and suspended sediment entering the estuary has decreased in both wet and dry seasons. Since then, the permanent goal of mitigating river floods has been certainly attained, and the frequency of flooding has been properly controlled.

16.4 Impacts of the Water Environment Changes

16.4.1 Impacts on Waterways

The evolution of the hydrological system is a basic aspect of the water environment change in the north catchment of Erhai Lake. It includes two factors: one is the movement and change of the river channel and the other is the contraction of the water surface area, both of which changed dramatically during the Ming and Qing Dynasties.

River changes were mainly concentrated in the upstream reaches of the Mici River and Fengyu River. In the seventeenth century, both the Mici and Feng Yu Rivers flowed around the county town of Eryuan, and did not run into Cibi Lake. The Mici River flowed along the east coast of the lake, while the Fengyu River flowed south of the town along the foothills. The Mici and Fengyu Rivers entered the confluence at Sanjiang Port and flowed into the Dengchuan basin through the Putuo Gorge (Fig. 16.5, left). In 1760 (the 25th year of Qianlong in Qing Dynasty), the embankment of Fengyu River broke at Nanshan village, resulting in diversion of the river toward Majiaying; consequently, a new river channel had to be built. Since then, the Fengyu River has flowed northeast, passing by Majiaying, Langqiong County Town, then into Cibi Lake at E'dun village. In addition, numerous artificial canals were excavated for irrigation, as shown in Table 16.3, which greatly changed the appearance of Miju River system.

The other aspect of the river system change is the contraction and expansion of water surface area of Cibi Lake, demonstrating that great changes have taken place many times (Deng et al. 1995). Through analysis of raw historical data and previous studies, this study has also found that there were four phases in this process over the past three hundred years.

- The first phase is during the early Hongwu years of the Ming Dynasty (1382–1398) when the Cibi Lake was relatively large with an area of almost 20 km^2. This was evidenced in "The Travels Journal of Xu Xiake" (徐霞客游记).
- The second phase is during the Hongwu years of the Ming Dynasty (1398) to the Kangxi years of the Qing Dynasty (1654–1722). During this period, the lake's inflow stagnated and the water level gradually decreased. The surface of Cibi Lake

was about 14.2 km^2 and remained stable at about 2055.20 m a.s.l.[17] At that time, the terms “outer sea” were locally used to represent the large and shallow south part while “inner sea” was commonly known for the small and deep north part.[18]

- The third phase began in the Jiaqing years of the Qing Dynasty (1760–1820). The transition into the third phase was mainly caused by continuous flooding. The frequent floods from 1803 to 1808 caused the lake surface to rise. The silt in the lower reaches blocked the river and impeded drainage, which also resulted in the continued expansion of the lake area and increased floods, causing disasters in an extensive area for decades. These high lake levels persisted for a long period of time, until the 1870s at least, and the area of the lake may even have been much larger than the area when Xu Xiake visited in the first stage (Deng et al. 1995; Geng 2015).
- In the fourth phase during the Guangxu years of the Qing Dynasty (1871–1908), the water in the southeast region of Cibi Lake retreated again and the area was just less than 8 km^2 until the middle of 20th century (Deng et al. 1995).

The diversion, storage and siltation situations in different sections of the Miju River system reflected changes of the hydrological and hydro-chemical environments in the past. These changes further influenced other aspects of local environment and society, including the changes in land use pattern and the spread of waterborne diseases.

16.4.2 Impacts on Land Use

The Dengchuan basin in the northern catchment of Erhai Lake is one of the basic economic regions of the Yunnan province, with the average altitude at around 1900 m a.s.l. The runoff area recently contributes to 44% of the total area and 70% of the population in Eryuan County. Crop differentiation in this area shows vertical zonality across the varied topography. As mentioned above, soil erosion has become a serious issue and the vegetation in the mountains has declined over the past six centuries due to increases in human populations and intensified agricultural activities. Areas of natural mountainous vegetation declined to 54% in the middle of the 1950s and lower to 28.6% by the end of the 20th century (Eryuan County Committee 1996). According to the research by Dearing et al. (2008), terrace technology has allowed for the continuous development of this region over the long-term, even under severe water stressed conditions.

Mitigating flood waters and opening up vegetative lands into farmland is not a modern creation. As early as the Tang Dynasty (around the year 785), the Luo brothers donated fields and money to construct a channel along the west foothills, changing the outlet of the West Lake from the Miju River to the Erhai Lake.[19] For over

[17] River and lake chronicles in Eryuan County,1995.

[18] River and lake chronicles in Eryuan County,1995.

[19] (Xianfeng) The Gazetters of Dengchuan.

1200 years the local inhabitants have benefitted from these changes, and accordingly named the river as Luoshi River.

According to previous research on the farming by garrison troops in the Ming Dynasty (Wang 2009a, b), the land they reclaimed was mainly abandoned, rather than in already cultivated lands. The land configuration of three rivers with two lakes (the East and West Lakes) in Dengchuan basin enables the basin to maintain an abundant source of water in the long-term. Liu (2013) found that the indigenous groups who had settled there earlier were mainly living in the piedmont area with higher terrain around the basin, while the garrison troops of the Han People concentrated mainly in the low-lying areas of the central basin. Although the low area of the basin is wide and flat with fertile soil, it was not an ideal area for cultivation because of frequent flood disasters at both sides of the Miju River. Since the Ming Dynasty, the settlement of garrison troops in the center of the Dengchuan basin has brought hydraulic engineering technologies to control floods, drain water and reclaim farmlands near the East and West Lakes.

In 1781 (the 46th year of Qianlong in the Qing Dynasty), an engineering approach was put forward by Gao Shanggui (高上桂), a successful candidate in the highest imperial examinations who was born in Dengchuan. Gao received support from the chief of Dengchuan prefecture and opened up a new channel known as the Yong'an River (Fig. 16.2, right), that diverted the East Lake directly to the Erhai Lake (instead of drainage into the Miju River). This artificial channel (Yong'an River) helped dry out more than 11,200 acres fields for crop planting.[20] The whole basin thereafter became a rich land of breeding fish and rice on the plateau, and Gao's contribution was rewarded by the Qianlong Emperor.

The low-lying Dengchuan basin is still an important region today, with its 160,629 acres of cultivated land, of which 98,815 acres are paddy fields, accounting for the vast majority of Eryuan County.[21] In the historical period, the land here has undergone anthropogenic transformation that greatly changed the local water and soil features. The migration of large populations in the Ming Dynasty led to tense water conflicts. The local people had to reclaim parts of lake coasts and river beaches for farmland. They also excavated some river channels to not only reduce flooding but also to drain lake water for farming the margins. This had many consequences including the transformation of crop planting structures, as aquatic farming and aquaculture in the newly exposed shallow swamp areas were developed. In the 1980s, there were 2870 acres of aquatic crops, 2340 acres of lake margins and marsh ponds for fishing, and 3790 acres of shallow water for rice and fish farming.[22]

[20] (Xianfeng) The Gazetters of Dengchuan.

[21] Eryuan County Committee (ECC) (1996). Local Chronicles of Eryuan County.

[22] See Footnote 21.

16.4.3 Impacts on Waterborne Disease Schistosomiasis Japonica

The Miju River Basin has experienced several epidemics of Schistosomiasis japonica in its history. Outbreaks of this waterborne disease did not happen frequently, but its impacts are broad and deadly. Schistosomiasis japonica is usually associated with sewage-contamination or inadequately treated water. As existing studies have indicated, the water-environmental condition, climatic characteristics and associated biological conditions in the Miju River basin provide a beneficial habitat for *Oncomelania hupensis* (Yang 2004), a particular type of snail hosting Schistosoma japonicum. The density, quantity and spatial distribution of *Oncomelania hupensis* corresponds closely with that of Schistosoma japonicum.

The five conditions necessary for the spread of schistosomiasis are host populations, feces with eggs, snails, water contamination by feces and human contact with contaminated water (Ma et al. 2011). The entry of a large number of immigrants led to a changes in the water chemistry through increased influxes of human and livestock wastes, and thus provided ideal conditions for *Schistosomiasis*. Provision of safe water and sanitation is critical to reduce the outbreak of Schistosomiasis japonica, cholera and other waterborne diseases.

The breeding environment, and consequently the largest area of habitat for the snail is a shallow water zone with slow flow, while other common habitats are grasslands and ponds. The proportion of snails in ponds is decreasing while the proportion of snails in grasslands is on the rise. A possible reason for this trend may be that the grassland proportion of land area in the basin is the largest. The epidemic of schistosomiasis in Eryuan County is closely related to floods in the historical period (Hu 2014). In the process of fighting against floods and droughts, such as the construction of water management projects, harnessing river courses, the construction of bur-rock and the excavation of canals and ditches, the change in the hydrologic environment led to a change in schistosomiasis prevalence.

The excavation of water ditches helped to reduce flood hazards and alleviate pressure on the main channel, yet at the same time, water velocity slowed. The water in ditches was stored for irrigation and improved for water availability in dry seasons or years. On the other hand, the ditch provided suitable habitat for the oncomelania snails. A large number of channels were excavated in a crisscross pattern throughout the whole basin, again increasing the habitat area for oncomelania.

In the chorography of Eryuan County (1996), the epidemic history of schistosomiasis is as recorded:

> In the Tongzhi years of the Qing Dynasty (1862–1874), in Eryuan County, there were “timpanists” and “Shau Kei swelling”, “hematochezia” and “dry shake disease” among the doctors of traditional Chinese medicine and the general public, which showed similar symptoms to advanced schistosomiasis ascites. At the beginning of the 1960s, an old farmer from the third battalion of the Yongsheng commune brigade, named Dai Qiyou (66 years old), said that his father saw a patient of “Shau Kei expansion” whose stomach was badly swollen like a Xiaoqi (a basket for washing rice) at the age of 20 when he moved into the Sanying basin,

Table 16.4 Records on the schistosomiasis situation in Eryuan County during the period 1953–1979 (*sources* from the Annals of Eryuan County Schistosomiasis Control)

Villages with recorded schistosomiasis	Situation of schistosomiasis in records
Niujie commune	According to a Chinese memory who are more than 70 year old, his grandfather died of schistosomiasis and one of his daughter is suffering this disease now
Xidian village of Niujie commune	There are 500 mu of land in the Xidian basin, which are full of wild grass which no one is cultivating [due to the disease]
Yichang village of Sanying commune	More than 60 years ago, there were over 70 households and 370 lives, … while there were only 18 households and 66 lives till the mid of 20th. The villager named Cun Bingnan had married three wives but 10 of his family members died of schistosomiasis. Yang Ruxiang's family had 17 persons, while 16 of them died of schistosomiasis
Xunzhuang village of Niujie commune	There used to be over 160 households and more than 300 lives, but there were only 33 households and 120 lives left until the mid of 20th. An old man named Zheng said 14 of his 16 family members died of schistosomiasis
Yousuo commune	Ruan Yuting was only 30 years old, when due to the torture of schistosomiasis he killed himself
Yunxi village of Jiangwei commune	There were over 70 households, but only 20 households left until 1952
Wenyi village of Jiangwei commune	The survey in 1950 reported an 11-year-old girl with potbellied, which is a typical patient of advanced schistosomiasis… the girl married at the age of 18, but finally got pregnant at the age of 30 and the baby was stillborn due to schistosomiasis

Annals of Eryuan County Schistosomiasis Control (1953–1979). A preliminary survey on the prevalence of schistosomiasis in the coastal areas of Erhai, Yunnan. Eryuan County of advanced schistosomiasis control materials—Niujie Xiang

> which had already existed among the local farmers in legend. His father died of "Shau Kei expansion" in the end.

Hu (2014) found that the distribution of schistosomiasis in Eryuan County was mainly along the Mici River system in the upstream areas, including the villages of Niujie and Sanying, rather than in downstream where the floods were more severe. Overall, she concluded that the epidemics of schistosomiasis were negatively associated with the frequency of floods (Table 16.4).

As the link between flood and schistosomiasis, *Oncomelania hupensis* is the intermediate host of Schistosoma japonicum. However, the distribution of the snail can be affected by the hydrodynamic conditions of the river. Schistosomiasis is distributed mainly along the main river channel and the center of the basin in low-lying flat terrain where the water has a slow velocity. The population is dense and feces and other waste is dropped into the water, causing water pollution and eutrophication. The blocking of the Miju River upstream resulted in poor drainage, gradual sediment deposition, and slow flow, all of which formed an environment suitable for snail breeding and the outbreak of schistosomiasis in the basin. In contrast, locations where the river course was dredged and the sediment was frequently cleaned up, the occurrence of Schistosomiasis japonica was infrequent because the snail could not survive and thus the transmission of the disease was more difficult.

16.5 Resilience Theory of the Human-Water Relationship

The existence of different development stages could be represented by distinct and relative steady states of adaptive cycle, as indicated in the resilience theory of Holling (2001). From 1482 to 1912, we can identify stages where floods were relatively serious, then diminished in severity by various water control measures. This can certainly be explained as following an evolutionary cycle of the human-water relationship, including exploitation (increasing floods), conservation (control measures), release (slack management) and re-organization (redevelopment of agriculture), but without a clear division of the four phases.

Due to the difference of topography and development degrees in sub-regions of the north catchment of the Erhai Lake, the four stage of resilience theory are not synchronous. As for the Baihan Gorge stream, the evolution was somewhat extreme. The water system of the stream collapsed when the dam burst into the stream and blocked the channel. The stream diverted toward west and flow into Fengyu River, a channel which was maintained thereafter. In this case, the former Baihan Gorge stream changed completely and could not evolve into the *re-organization* stage as stated in adaptive cycle of the resilience theory.

In the case of the Fengyu River, resilience theory can be applied appropriately to the sediment deposition and river diversion. The water velocity dropped quickly when the river flowed to Eryuan County and thus sediment accumulated gradually in the riverbed. The continuous deposition of silt resulted in a dam collapse, and people diverted the river directly into Cibi Lake in the 25th year of Qianlong in the Qing Dynasty (1760). After the excavation of this newly diverted channel, the floods of Fengyu River gradually subsided. Though the diverted channel sediments no longer entered the Sanjiang Port, they continued to silt up in the new channels and in the Cibi Lake. However, after a period of accumulation the siltation affected the water storage capacity of the Cibi Lake, especially during rainy seasons, leading to regular overflowing of the lake. Thus, we argue that the evolution of Fengyu River and its water environment was consistent with the four stages of the adaptive cycle in the resilience theory.

The situation of Miju River was far more divergent from the description of change in resilience theory. The natural Miju River flowed randomly with changing channels (no main stream) before the Ming Dynasty (1368–1744). Following the settlement of military migrants, the random channels were controlled and riverbanks were constructed gradually. Over time, local people opened up many sluices and branch channels in order to both irrigate farmlands and separate floodwater. A dense river network was formed in Dengchuan basin, thus the flow accessibility and water controlling capacity was greatly improved. We can identify the stages of *exploitation* (naturally frequent floods) and *conservation* (channel constructions) in the water governance history of Miju River, though these didn't develop into the *release* stage (slack management) and *re-organization* stage with the continuous maintenance measures.

For the upstream Mici River, the water environment with deep and broad river channels that rarely lead to floods, gave rise to a rich environment for human activity. However, the stable river environment benefited the breeding of Oncomelania Snails that induce schistosomiasis. As described above, local people along the Mici River suffered serious Schistosomiasis japonica outbreaks for over six centuries due to the lack of knowledge regarding the links between river environment and the disease. The disease was better controlled only when research provided allowed for targeted countermeasures from the 1960s. The process over six centuries corresponds well to the stages of *exploitation* (naturally increasing disease conditions), *release* (disease outbreaks) and *conservation* (knowledge and counter measures), but the relationship between human disease and water environment probably won't evolve into the *re-organization* or subsequent *release* stages due to the development of local knowledge regarding prevention of infection.

From the case analysis of these sub-basins, we argue that the adaptive cycles of resilience theory may not be general or universal regarding human-water relationships in the studied area. Especially in a socio-ecosystem where humans can grasp the systemic principles and develop appropriate management capacities by learning and practicing, resilience of the system can be continuously improved in a positive trend.

16.6 Summaries and Outlooks

16.6.1 Summaries on the Human-Water Relationships in the Study Area

It is undeniable that the water environment in the northern basin of Erhai either deteriorated or improved as a response to human activities. Large numbers immigrants greatly changed the hydrologic environment, not only through the construction and excavation of dams, banks and canals, but also through hydro-chemical pathways. Human activities and water management measures changed the drainage system and land use structure, and also changed the hydro-chemical environment to some extent, resulting in the outbreak and spread of typical waterborne disease.

The results of this research indicate that the evolution of the hydrologic environment, including the river system and the hydro-chemical environment had a close interaction with human activities during the last six centuries. Local people constructed various water engineering and conservation projects, and also changed their farming structures to cope with water stresses, which partly contributed to the outbreak and spread of Schistosomiasis japonica. In addition, the study reveals that resilience of the human-water interrelationship weakened under lax or mismanagement of water engineering projects. The sustainable development of the human-water relationship in the Erhai Lake basin could be maintained by regular water management and environmental governance, which is of high relevance for decision making on water management in the present day.

16.6.2 Human Impacts on Evolution of Resilience of Human-Water System

Through the discussions above, it can be found that the hydrologic environment in the northern catchment of Erhai Lake fits in generally with parts of the adaptive cycle in resilience theory described by Holling (2001). After a large number of immigrants moved in, the water environment was subject to a period of rapid development. Meanwhile, the development of the region also brought about a sharp deterioration of the environment and associated water disasters, which was called a serious ecological crisis in the Ming and Qing Dynasties (Zhou 2015). However, with a large number of water management projects, favorable environmental conditions were gradually restored and maintained. In some cases, these projects diminished and coping measures proved to be ineffective, leading to a new loop of the deterioration of the human-water system.

There are certainly some inconsistencies identified in our study. According to resilience theory (Holling 2001), the adaptive cycle as a fundamental unit of a dynamic process is comprised of a forward and backward loop with four phases, however, we cannot identify complete cycles in the sub-basin cases of Erhai Lake. A lack of consideration of social processes and man-made adjustment may lead to deviations. The evolution process of the human-water system did not necessarily follow this cycle of four phases, and if so, they could likely also occur at the same time rather than being distinct or defined separately.

In our Erhai Lake case study, these four phases were largely effected by human activities and could be modulated to a certain degree with front-loops or even back-loops. In other words, without human activities, such as water conservation works, the adaptive cycle of resilience may not finish a complete circle but instead Remain in an undesirable situation. Therefore, the evolution of resilience theory may need to be further articulated by considering the factors of human activities when it is applied to a long-term human-environment evolution process. Humans are not often ineffectual in response to the degradation of the natural environment particularly if we develop a set of effective measures and follow an appropriate management framework.

16.6.3 Outlooks

There are many aspects related to hydrologic challenges that are worth looking into deeper, including the limitations of administrative maintenance and the adjustment by local people in their cooperation during the construction of river projects. The mechanism of river engineering projects and expertise in the Erhai Lake basin has lasted for 530 years, from 1382 when the military migrants settled into 1912 when the Republic of China was established, which formed a mature institutionalization of maintenance. In this period, the human-water relationship has undergone several cycles, while river training and water management measures have mitigated the magnitude of negative impacts. However, the construction and management of engineering projects deteriorate in correspondence with lax governance and management for some sub-periods. Thus, it is necessary to raise awareness among both decision makers and local inhabitants that a resilient and sustainable human-water relationship requires continuous concern and effort.

In addition, folk religion has been deeply influenced by hydrologic challenges in the Erhai basin. Such influences in this region has resulted in a specific "water culture" where the Dragon King became one of three deities worshipped by the local people. These folk religious beliefs have been important through history and are closely related to the daily life and national consciousness of the local Bai people. It would be interesting and meaningful to investigate this cultural perspective of human-water relationships in the tradition of the Bai people. Such research could be informative to the broader concerns on human-environment interactions under present global changes and local governance, and to broader areas in the mountainous regions China and South Asia.

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Chapter 17
The Age and Origin of Karez Systems of Silk Road Oases around Turpan, Xinjiang, P.R. of China

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Abstract Age and origin of ancient famous Karez water systems in the oases of the Turpan Basin are open questions in geoarchaeological and historical research. Four hypotheses exist: (a) invention during Han dynasty more than 2000 years ago, (b) transfer of technology from Persian Qanat's more than 3000 years ago, (c) independent invention of local Uyghur people in the 15th century, and (d) late invention during the Chinese Qing dynasty (19th century). Our study dates, for the first time, 8 Karez systems by ^{14}C from plants buried during the formation of Karez mounds, and interviews in order to record oral tradition. We found that the oldest investigated Karez systems originated in the Uyghurian Huihe dynasty (790–1755 AD), which coincides with the oral tradition. A second phase may have occurred during late Huihe/Qing dynasty (after 1755 AD), which may explain why information and the Uygurian term „Kan er jing" went down in historic Chinese records. In conclusion, hypothesis (d) that oldest Karez systems were built during Qing dynasty has to be rejected because they are at least 600 years old. Instead, during the 3rd Chinese expansion in the 19th century AD the Karez system expanded and got maintenance. A review of regional palaeoclimatic proxies suggests that the origin and the maintenance of the Karez systems took place rather in more humid periods than in more arid ones. However, more research is needed on other Karez systems to test the pending hypotheses of a much older age.

Keywords Karez origin · ^{14}C dating · Oral history · Silk roads
Climatic fluctuations · Turpan Basin

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17.1 Introduction

The Karez systems of Turpan (Xinjiang province, NW China) are one of the most extensive agglomerations of ancient subterranean tunnel-wells in the world (English 1968), and demonstrate an impressive version of ancient water harvesting technology. In Iran, these systems are known as Qanat (which is an Arabic term, English 1968) or Kariz (which is a Persian term), and in northern Africa as Fuqara. Similar systems are known from Mexico from Spanish times (galerias; Kortum 2004). All in all, such systems are known from more than 34 countries in the world (see Fattahi 2015 and references therein). Many local terms exist in different regions of the world (for a full list, see Salih 2006 and for a discussion of the history see Briant 2001). Located typically in arid environments, with annual rainfall between 100–300 mm (Lightfoot 1997), this sustainable technology gives access to buried water resources by conveying groundwater by gravity to the surface, feeding large oases during the past and documenting the technological potential of our ancestors ~2500–3000 yrs. BP, when the first Qanat systems have been invented probably in the surroundings of Tehran or somewhere in Persia (Kobori 1973; Lightfoot 1997). Some ancient capitals were based on Qanat irrigation, e.g. Palmyra (Kobori 1973).

However, the exact dating of the origin of these systems is difficult. Fattahi et al. (2011) dated Miam Qanat in NE Iran by Optical Stimulated Luminescence (OSL), but due to a minimal number of samples the age estimation remains doubtful. If the first dating is correct, the oldest known Karez dates further back to 3600–4300 yrs. BP. Also Bailiff et al. (2015) did OSL on Qanat systems in Aragon, Spain, constructed in the 15th century.

It is still under debate how and when the technology was transferred further to the Mahgreb in the west and along the Silk Roads to Afghanistan, Kazakhstan (Remini et al. 2014) and to the Turpan oases in the east. The latter is "still a big theme to be resolved" (Kobori 1973). Additionally it remains unclear if there was a single center of innovation or if the systems were developed independently at different places instead (Fattahi 2015).

Chinese scholars assume that the technology was developed independently in mainland China and was brought to Turpan during the first period of Chinese control over the area during the Han dynasty (220 BC–206 AD), which is why Karez rank among the three "Great Ancient Chinese Works". This hypothesis predicates on the description of irrigation in the Turpan oases in Chinese literature. However, in 984 AD the Chinese ambassador Wang Yande travelled to Turpan but he gave no hint to the existence of Karez during this time (Trombert 2008). The author of the Chinese compendium Nongzheng quanshu (农政全书, 1639 AD), Xu Guangqi, a water expert, also did not mention the Karez system, hence why Trombert (2008) assumes that they were absent during this time.

Furthermore, neither the term Karez or the chinese Kan er jing nor a description of specific gravity-fed underground channels can be found before the Qing dynasty. According to a critical study and interpretation of Chinese historical sources, Trombert (2008) dates the Karez of Turpan to the early 19th century. This is close to

Huntington (1907), who assumed a Persian origin and dated the invention to Turpan to ~1780 AD. In Chinese history, the Karez are referred to as “The underground great wall” as part of the three great construction projects in ancient China (along with the Great Wall and the Beijing-Hangzhou Grand Canal; Abudu et al. 2011).

Therefore, due to ambiguous historical sources, a precise and representative numeric dating of the Karez systems is needed, in order to identify the period of first construction and the subsequent dynamics of Karez use in the Turpan Basin. Four hypotheses exist (Trombert 2008):

(a) The Karez came to Turpan by technology transfer along the Silk Roads, which enabled exchange at least since the Han dynasty;
(b) The Han brought the technology from mainland China 3000 yrs. ago;
(c) The first Karez have been built during Uyghur reign;
(d) Karez did not exist in the Turpan Basin before Tang dynasty (640–790 AD), most likely they are not older than 200 years.

The aim of the study at hand is to date a set of Karez systems in the Turpan Basin by the use of radiocarbon dating, which is, for distinct times, more accurate than OSL and which was not done before on Qanat/Karez. We use a sampling strategy adapted to the Karez building and maintenance technique, and, by way of comparison, information given by local farmers (oral tradition). Our study is the first step to test some of the hypotheses listed above. After more intense research, questions about the trigger of Karez invention can be asked, e.g. if the systems had strategic functions to support the control points along this part of the Silk Roads or if climatic fluctuations forced the people to harvest additional water.

17.2 Study Area

The study area is located in the hyperarid Turpan Depression, with the Aiding saline lake (or Aydingkol, 42° 39′ N/89° 16′ E) in its center (Bubenzer et al. 2016), the third lowest continental point on earth (154 below sea level). The city of Turpan is situated about 20 km northwest of the lake (Wang and Wu 2003; Fig. 17.1). The Turpan Basin has a complex polycyclic sedimentary history since the Late Permian, in which more than 7000 m of clastic sediments are accumulated (Shao et al. 1999). Because the northern part of the basin was uplifted in the Late Jurassic, the Bodga Shan as part of the Tianshan Mountains provides the main sediment source since the Early Cretaceous. From the Middle Triassic to the early Tertiary, subsidence took place (Shao et al. 1999). With regard to the Karez systems, the thick fanglomerates of the Piedmont between Bogda Shan and Aiding Lake provide the main aquifers (Fig. 17.2). Due to the complex tectonic picture, surface water and groundwater on its way into the basin follow multiple paths (Halik et al. 2009). The mean annual precipitation in Turpan is 16.6 mm, whereas the Bogda Shan (5455 m a.s.l., Bertrand 2010) receives between 150 and 600 mm of rainfall (Chen et al. 2013). The Bogda Shan is the “water tower” for the region. There, spring to early summer rainfalls

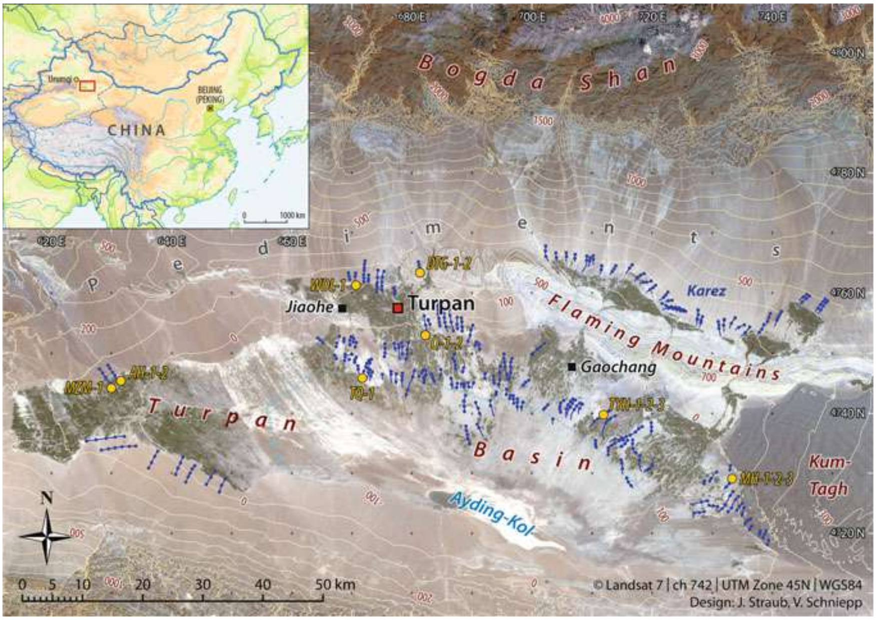

Fig. 17.1 Map of the Turpan oases with Karez distribution (based on Stein 1933). Karez systems which were studied during fieldwork in 2013 are labeled

brought by the westerlies predominate (Domrös et al. 1992; Yang et al. 2004; Fricke et al. 2009). During the summer season, some wet air masses from the polar front can reach the Tianshan from the north and produce, supported by local convective processes, rainfall (Domrös & Peng 1988). The northern slopes of Bogda Shan receive 80 mm of winter precipitation (Böhner 2006) due to channeling of northern winds in the Dsungar Basin (Rhodes et al. 1996). The average temperature is 34.1 °C in July, maximum summer temperatures can reach 50 °C (Li & Yin 1993), minimum temperatures are around −16 °C (Chen et al. 2013), with average winter temperatures of −8.7 °C (Ding 2002). High temperatures in summer can last for more than 120 days. The annual average potential evaporation is 2845 mm (Halik et al. 2009).

The specific environmental setting offers all the features required for successful water harvesting: Firstly, mountains in the hinterland, which are high enough for glaciation and snow accumulation during winter times. Secondly, a piedmont foreland with large alluvial fans and pediments, where the melt water infiltrates into layered fanglomerates of variable permeability (a comparable situation is described by Thomas & Kidd (2017) in Afghanistan). There, the groundwater table can be reached by digging mother wells as the origin of a Karez system. In the footzone of the Bodga Shan, the aquifers are located between 150–100 m below the surface. Close to the neotectonic chain of the Flaming Mountains, the groundwater table can be found in 20–30 m depth (Lein & Shen 2006). After passing the Flaming

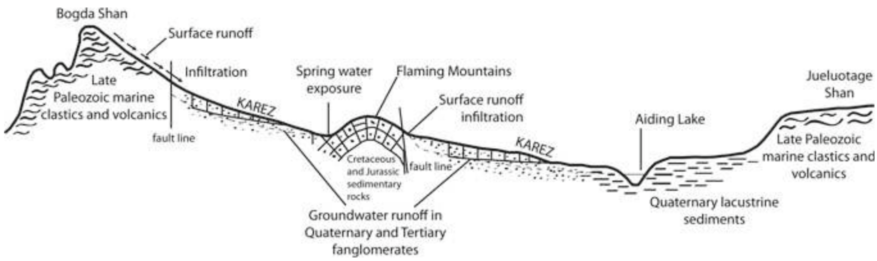

Fig. 17.2 The multiple conversions of surface water and ground water in Turpan Basin (after Lein & Shen 2006 and Halik et al. 2009 with modifications). The fanglomerates of the Piedmont between Bodga Shan and Aiding Lake act as an aquifer for the Karez systems

Mountains, groundwater feeds also the Karez systems south of the mountain chain (Fig. 17.2).

The surface water from Bogda Shan runs down to the basin until it reaches the barrier of the Flaming Mountains (Kizil tagh). There, only three main gorges give the surface runoff way to the center of Turpan Basin: In the east, Toyuk gorge supports the eastern part with water. In the middle, Shengjinkou gorge feeds the oases of Gaochang, whereas in the west the Turpan gorge with the Davandir River and its bifurcation supported Jiaohe ancient city during the past and recently the city of Turpan. Groundwater flow along faults supports few artesic springs in the basin. To the south, the lower Chöl-tagh ("desert hill") chain do not offer water discharge to the Turpan Basin due to its lower heights and the lack of rainfall and glaciers (Stein 1933). Surface water resources therefore can only support a limited number of people, which is why an expansion of agriculture has been possible only by the building of Karez systems. In the Turpan Basin, the Karez systems are distributed asymmetrically. In the north and east, the irrigated oases are very close to Aiding Lake, whereas to the west there is a larger distance. Stein (1933) ascribed this to a higher salinity to the west, which coincides with the flat topography of the western basin, where large areas become impregnated with salt by evaporation.

17.2.1 Human Occupation of the Turpan Basin

The Turpan oasis has been populated for a long time. During the 3rd century BC, the Yuezhe bred horses in the northeastern Turpan Depression in a steppe environment and had a trading relationship with China (Liu 2010). It has to be assumed that for a long time human settlements were supported just by surface and spring water. At least since the 5th century AD, besides agriculture (mainly barley and millet), people practised viticulture (Trombert 2008). With irrigation, two annual harvests are possible (Stein 1933).

To support the ancient city of Jiaohe ("between the rivers") with water, people dug wells probably before the first century BC. During the reoccupation by the Han in 61 AD, numerous wells existed (Bertrand 2010). The majority of wells was dug between the 5th century and the end of Tang dynasty (Li 1999). During the Han and Tang dynasties, trade flourished along the Silk Roads (Liu 2010).

In order to use the Turpan oases as a hub for the Silk Roads, more water was needed. Higher water availability may have been experienced during a more humid past or achieved due to the building of Karez systems. The development of the Turpan oases was controlled by the two capitals: (1) Jiaohe (Fig. 17.1), located on a 30 m high isolated plateau in the middle of the Davandir River. This city was dependent on tapping groundwater from deep wells (Li 1999). Its decline was probably related to decreasing runoff in the Davandir River and a lowering of the groundwater table. (2) Gaochang, where the situation is somewhat different, as the city is supported on the one hand also by surface water, and on the other hand by Karez systems. Jiaohe and Gaochang existed at least since the beginning of the Han dynasty and lasted until the 15th/16th century. During the independent Gaochang Kindom (500–640 AD), an open air channel system was built around Gaochang (Bertrand 2010 and references therein). If the abandonment of these important cities was triggered by changing runoff of the rivers, palaeoclimatic information is required (see below).

17.2.2 The Karez Systems of the Turpan Basin

In contrast to the general description of the Qanat systems that tap water in alluvial deposits (Cressey 1958), there is a greater variety in the Turpan Basin with regard to petrography, topography and hydrogeology (Laureano 2012). The Karez systems have different sources. Firstly, they tap the groundwater flow of large alluvial fans, secondly aquifers on the thick piedmont fanglomerates and thirdly the water from shallow groundwater resources, which are located along faults within the basin close to the Flaming Mountains. The latter sources offer the best water with lowest salinity (Chen et al. 2013).

With regard to their distribution, the Karez systems of Turpan are extraordinary. They had a length of more than 5000 km in total until the 18th century (English 1968). In the 1950s, 1300 Karez systems with a length of 4000 km were in use (Sun et al. 2009). Due to the favorable hydrological conditions, the quality of its water is high and meets today´s requirements of China sanitary standard for drinking water without treatment (Abudu et al. 2011). Therefore, high quality crops can be produced compared to the use of local groundwater (Cenesta 2003 in Abudu et al. 2011). As the Karez supply year-round water, during winter times the fields are watered to leach out the salts, which were accumulated in the summer season (Abudu et al. 2011).

In recent decades, the sustainable system of gravity-driven utilization of water in the Turpan Basin has been threatened by groundwater drawdown due to the widespread use of less labor-intensive deep-well pumps. Between 1996 and 2006, pumping led to a lowering of the groundwater table in the village of Hope (south of

Turpan district) from 20 to 33 m below the surface (Lein & Shen 2006). As more and more Karez systems run dry, Lein & Shen (2006) expected a collapse of the last systems between 2015 and 2025. The number of systems declined from 1084 in the year 1949 to 446 in the year 2000 (Turpan District Water Conservancy Bureau 2001, in Lein & Shen 2006). By 2009, the number had declined to 400 (Sun et al. 2009), which is a fall by 63% since 1949, whereas the number of deep wells increased from 500 in 1988 to more than 5000 in 2003 (Abudu et al. 2011). Water discharge out of the Karez systems in the year 2003 was about 170 million m^3, enough to support 8800 ha of farmland. However, in 1950 the discharge amounted to 700 million m^3, with 24.000 ha of farmland (Sun et al. 2009). Therefore, it is highly recommended to restore and protect the Karez systems, as a sustainable way of water harvesting, in arid lands worldwide because it enlarges the resilience of agricultural systems during years of extreme droughts and lacking surface water.

17.2.3 Environmental Conditions During the Quaternary

They have been controlled by climatic fluctuations. Thus, water availability changed markedly during the past. For example, Aiding Lake covered an area of about 3.000 km^2 during the last glaciation, and still covered 152 km^2 during the rainy season in 1949 (Gao & Wu 2004; Yu et al. 2001). The colder conditions of the Pleistocene enhanced westerlies and moisture support to this region, whereas during the Holocene, drought increased markedly due to a northward position of the westerlies and higher evaporation, coupled with an enhancement of the Asian summer monsoon system (An et al. 2012). Climatic fluctuations also occurred during the Holocene due to the anti-phase relationship between monsoons and westerlies (Bubenzer et al. 2016). Ran & Feng (2013) state the Holocene moisture optimum for Xinjiang was from 4–0 ka, due to increasing sea surface temperatures (SST) and evaporation in the North Atlantic region, coupled with intensified westerlies which brought moisture far inland into central Asia. In addition, weaker summer monsoons due to weaker summer insolation decreased the propagation of dry air masses from the south. The Tian Shan is an important climatic divide and separates an arid-steppe climate in the north from an arid-desert climate in the south, including the Turpan Depression. With regard to the late Holocene climate of the Turpan basin detailed information is lacking. Furthermore, it is difficult to extrapolate palaeoclimatic information from abroad geoarchives, as the mountain chains in this region lead to a strong climatic diversity due to synoptic effects (Wolff et al. 2016). The western part of Central Asia from Kabul to Bishkek receives winter rainfall, whereas in the eastern part, e.g. the Tian Shan and the Tarim Basin, summer rainfall prevails (Sorg et al. 2012).

However, in the Tsungar Basin, located north of the Bogda Shan, sediments in Lake Manas indicate two late Holocene lacustrine episodes between 3.5–2.5 and (with a weaker wet pulse) 2.0–1.0 ka cal BP (Rhodes et al. 1996). From the Guliya ice core (western Kunlun Shan), Shi et al. (1999) reconstructed a rapid decrease in temperatures and precipitation at the end of the warm and humid Han dynasty

250–280 AD, lasting until 970 AD. The medieval warm period between 970–1200 AD was moderate and dry. From 1220 AD onwards, temperatures and precipitation increased until around 1510 AD. During the Little Ice Age (LIA), the variability of climate increased, with strong cold-warm fluctuations. The years 1520–1530 AD were very cold and wet, the 1600s were temperate, although the second half of this century was colder. The 1700s were warmer and wet, the period 1800–1910 AD colder again (Shi et al. 1999). Liu et al. (2010) reconstructed moisture changes during the last millennium by silty-clayey sediments in the hyperarid Tarim Basin and further paleoclimate archives of the region. They concluded that the region was less arid during the LIA from 1490 to 1890 AD, in sync with an increase of westerly moisture support to the region, whereas until 1490 and after 1890 AD the region received less moisture. Around 1560 and 1625 AD, two clay layers indicate the peaks of humidity. An increase in humidity is also indicated by an increase in ice accumulation from the Guliya ice core (Yao et al. 1996) between 1550–1830 AD. Until the 5th century, the oases at the southern margin of the Taklamakan, Nixa, Miran and to the east Loulan, located at the margin of the former Lop-Nor, were part of the flourishing kingdom of Kroania (Bertrand 2010). Loulan was abandoned due to shrinking Tarim drainage. At the northern fringe of the Tarim Basin, the oases of Caohu, Tarim, Luntai and Yuli were also abandoned due to drought (Berque 2005). During the 18th century, a massive expansion of Karez systems occurred in the Turpan Basin. Bertrand (2010) suggests this was an adaption to climatic change.

17.3 Materials and Methods

For the study at hand, 8 Karez systems along the northern rim of the Turpan Basin were investigated (see Fig. 17.1). They were selected after extensive interviews and the study of archaeological reports, which indicate they constitute the oldest systems still in use.

Karez systems were constructed by digging short vertical shafts into the loose fanglomerates or alluvial fans in the foreland of dryland mountains. In general, these piedmont surfaces are distinctly inclined. At first, the constructors explore for groundwater proximal to the mountains by digging a so-called "mother well". After success, the Karez shafts are dug, beginning at the final (English 1968). Proceeding upslope, further shafts are built and connected by a gently sloped underground channel, draining the water to the outlet in the oasis (see Fig. 17.2) ("telemai", which is an Uyghur term, Lein & Shen 2006). The length of the Karez in the Turpan basin varies from three to 50 km (Sun et al. 2009). The distance between the shafts is about 20-30 m close to the outlet and increases to 30–70 m to the mother well in the oasis. There, some shafts are more than 100 m deep (Lein & Shen 2006). It takes up to eight years to build a Karez system (Sun et al. 2008). In comparison, the Qanats in Iran have mean lengths of about 4.2 km (Kortum 2004), with a maximum of 120 km (Zarach Qanat, Molle et al. 2004), and vertical shafts of up to 150 m deep (English 1968). Most likely, the shortest Karez systems, and the shafts close to the basin, are

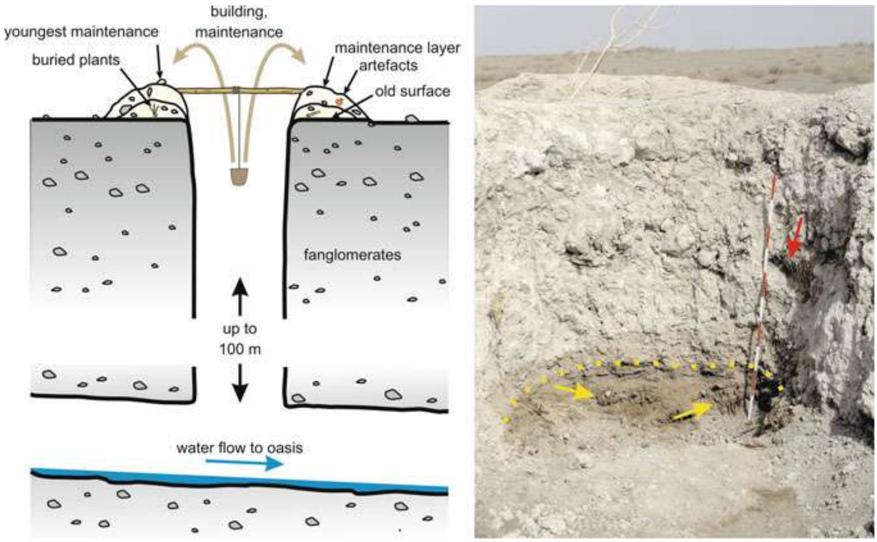

Fig. 17.3 Schematic structure of Karez mounds (left), Karez profile MH-3 (right) with buried plants (yellow arrows) close to the old surface (dotted line) and position of plant fragments at the base of a maintenance layer (red arrow). In the background, sparse vegetation is visible despite the hyperarid conditions. Such vegetation existed and was buried also during the time of construction of the Karez systems

also the oldest ones. In Turpan modern Karez had to be dug deeper and the Karez tunnels become longer due to the drawdown of groundwater, which started in the 1950's, subsequent to the expansion of cultivated land by 30% during one decade (Lein & Shen 2006).

During construction, spoil is piled up around the shaft, which builds a protection against sheetflood inflow and eolian input. In Persia, such rings are called "Karvar" (Troll 1963 and references therein). As the fanglomerates consist of deposits from loose clasts to silt and clay, the systems need permanent maintenance. Therefore, the spoil heaps grow successively, forming a "man-made" geoarchive. In order to enable a dating of the Karez systems by the radiocarbon method, we used the fact that the original piedmont surfaces were covered by sparse vegetation. These plants were covered by the spoil heaps during construction (Fig. 17.3). An alternative way of dating the dump is possible by the luminescence method (OSL). However, we rejected this method due to most likely insufficient bleaching of the material during the very short time span of deposition, as is also reported by Fattahi (2015).

Applying radiocarbon dating technology, we got the time of death of the plants and hereby the age of the construction. As Karez mounds grow over centuries by repeated maintenance, the mounds show different layers and some living plants have been incorporated into the mound during maintenance cycles. These layers were also dated. The organic samples were treated with HCl before burning. Carbon was measured at the MICADAS-AMS device at Klaus-Tschira-Laboratory Mannheim, Germany. The ages are given in cal years AD (1 σ), calibrated with INTCAL2013 (Reimer et al. 2013) and SwissCal 1.0 (L. Wacker, ETH Zürich) and normalized to $\delta^{13}C = -25$.

17.4 Results

Local people report that some Karez systems have been working since at least the 15th century AD. Based on such oral information/tradition, 16 test pits were selected, which revealed the typical stratigraphy of spoil heaps (comp. Fattahi 2015; for a detailed description see appendix). A heterogeneous mixture of spoil covers the original, vegetated surface. Grain sizes may vary from coarse gravels to sand and silt. The new surfaces were probably vegetated again. After a maintenance of the system the next sediment layer was deposited. Thus, several periods of spoil heap growth can be distinguished.

Table 17.1 presents the results of radiocarbon dating. Interestingly, three results correlate well, the others less so with information provided by oral tradition. We found that the oldest investigated Karez systems originated in the early 15th century, and that there was a period of maintenance and construction of new systems during the last 300 yrs. More detailed age determination is not possible for the latter period due to the limitations of the radiocarbon method (^{14}C plateau) (e.g. Bronk Ramsey 2006).

Numeric datings and oral tradition correlate well for 3 of 10 Karez, 2 of 10 were older and 5 of 10 younger than expected from oral tradition. Tongqi Karez was said having been of service around 1450 AD, which was confirmed by our ^{14}C results (1421–1437 AD, 1 σ). In addition, construction material found at Dataogou Karez (DTG-1) date to nearly the same age (1410–1426). Mahao 2 Karez was installed at least 1550 AD according to the oral history, but dated older (1416–1435 AD and 1497–1631 AD, respectively). Mierzhamou Karez is older (1532–1643 AD) than oral tradition (1732 AD). Dataogou Karez (1650–1950 AD), Mahao 1 Karez (1700–1954 AD, by oral tradition thought to be 1550 AD), and Ahong Karez (1654–1795 AD, most likely 1751, as oral tradition suggests) date to the expansion period. A Hulu fruit incorporated in the sediments dates a maintenance phase of Mahao 3 Karez to 1678–1951 AD. Tuyuhu Karez dated to 1681–1937 and 1698–1953, respectively, in contrast to oral tradition (1588 AD).

The results show that a number of Karez mounds have to be studied to find the oldest systems. Some Karez mounds may be younger in an old system due to common collapse of older ones and the subsequent construction of a bypass, or the digging of a younger mother well after groundwater drawdown. Therefore, we suggest sampling at least 3 mounds in a Karez system and a careful selection of the sites.

Table 17.1 Radiocarbon age (cal AD, 1σ) and oral tradition of studied Karez systems

Karez name	Sample description	Age range cal AD (building phase)	Age range cal AD (maintenance phase)	Oral tradition
Dataogou DTG-1, maintenance layer	plant remnants		1694–1952	
Dataogou DTG-1, building rubbish	straw (construction)	1410–1426		
Datagou DTG-2 from 1st building phase	plant remnants	1650–1950		
Tongqi TQ-1, old surface	plant remnants	1421–1437		1450 out of service
Mahao MH-1 above/from surface	plant remnants	1700–1954		1550
Mahao MH-2, old surface	plant remnants	1416–1435		1550
Mahao MH-3, old surface	plant remnants	1497–1631		1550
Mahao MH-3, maintenance layer	hulu fruit		1678–1951	
Mierzhamou MZM-1, from 1st building phase	plant remnants	1524–1643		1732
Mierzhamou MZM-1, maintenance layer	wood		1651–1950	
Ahong AH-1, old surface	plant remnants	1654–1795		1751
Ahong AH-2, old surface	plant remnants	1681–1952		
Qiong Q-1, old surface	plant remnants	modern		
Qiong Q-2, old surface	plant remnants	1683–1952		
Tuyuhu TYH-1, old surface	plant remnants	1681–1937		1588
Tuyuhu TYH-2, old surface	plant needles	1698–1953	1682–1953	1588
Tuyuhu TYH-2, maintenance layer	plant remnants	1682–1952		1588
Tuyuhu TYH-3, old surface	plant remnants	1691–1923		1588
Wudaolin WDL-1, 1st building phase	plant remnants	1686–1952		
Wudaolin WDL-1, maintenance layer	plant remnants	1893–1905		

17.5 Discussion

Our results show that the oldest investigated Karez systems in the Turpan Basin were constructed during the Uyghur reign and reactivated during the Qing dynasty. At this time, we have no evidence of older Karez systems. During the Tang dynasty (640–790 AD), a large irrigation system, fed by the seasonal runoff of the Xinxing Gorge, was arranged around the city of Gaochang (Fig. 17.1). Some Chinese scholars assign the innovation of Karez from Afghanistan to the period 640–790 AD, the second period of Chinese reign in this region, but Trombert (2008) judges that clearly aboveground channels existed. They were described in detail in several documents, but there is no hint to Karez systems. The Tang period was more humid with increased surface runoff, which might have been sufficient to support the Turpan oases. Similarly, Stein (1933, 238) concludes climatic fluctuations prompted the construction of Karez, as *"…the economic importance of Turpan was quite as great, if not greater, during ancient and medieval times, when we must assume that its oases depended wholly on irrigation from surface drainage"*. Despite the medieval age of the Karez systems, the occurrence of large settlements points to higher water availability at that time (Huntington 1907), most likely from surface runoff or increased spring discharge.

In the 15th/16th century, the abandonment of Jiaohe (Fig. 17.1) and Gaochang, both supported by a certain degree by surface water, may be the result of increased drought. Our study shows that age determinations of Karez systems merely based on historical records, can be misleading. The Qing expansion to the Turpan area started in 1755 AD, and the oases have been converted to military agricultural settlements (Trombert 2008). Hening, the Chinese governor, reports one single Karez system, but Qi Yunshi, a Chinese traveler, only reported surface irrigation. Therefore, Trombert (2008) concluded that just a few Karez systems existed during this time.

Overall, due to our oldest radiocarbon datings to the Huihe period, the Karez systems of Turpan have obviously an age of at least 600 years. Therefore, hypothesis d) of Trombert (2008) that still working Karez were built during Qing dynasty for the first time, has to be rejected. Instead, during the 3rd Chinese expansion in the 19th cent. AD, the Karez system expanded and underwent maintenance. The fact that the Chinese transcribed the Uygur word Karez/Kariz to ka'er (Trombert 2008) points to an adaption of both the technique and the terminus.

Although our results so far date the origin of the studied Karez system to Uyghur times, an innovation of systems during the first (Han dynasty, 206 BC–220 AD) or the second (Tang dynasty, 640–790 AD) expansion period is conceivable. From the Taklamakan, early connections to mainland China, India, Pakistan and central Asian steppe regions are known, e.g. from Kunlun Shan and Tian Shan (Debaine-Francfort et al. 2010), which allowed technology transfer along the "Proto Silk Roads".

It is hard to decide if climate triggered Karez activity in the Turpan Basin. Fattahi (2015) hypothesized that people in Iran have been forced to dig channels deeper during more arid periods due to groundwater drawdown, which led to an increase of the spoil heaps. Thus, in addition to the normal maintenance activities, spoil layers shall give the chance to date periods of drought. In contrast, we hypothesize that a lowering of the groundwater table would lead to an extension of the Karez gallery further to the mountains, where the groundwater can be reached easily by digging a new mother well. Alternatively, a growth of the spoil heaps may also be triggered by a more humid period, when desiccated Karez could be reactivated (and cleaned) due to a higher groundwater level. In comparison to the regional climate proxies and with regard to our dating results we conclude more humid rather than arid conditions occurred during the construction and maintenance of the investigated Karez systems. At the Kesang Cave, located at the northern margin of the central Tian Shan colder conditions were indicated (see D in Fig. 17.4). The Tarim Basin showed generally wetter conditions (B in Fig. 17.4), which possibly triggered (re)activation of the systems due to increasing groundwater resources. If this holds true, a southerly trajectory of the westerlies and their intensification led to increased moisture transport to the Turpan Basin. As this hypotheses has yet to be tested by further palaeoclimatic information, we suggest the use of independent proxies in order to estimate changes in precipitation and to keep in mind changes in natural resources as a possible trigger of Karez system construction in the Turpan Basin.

17.6 Conclusions

The study at hand demonstrates that the presented approach of sampling and dating buried plant remains at the shafts of Karez systems, combined with interviews in order to record indigenous knowledge, is successfully applicable for determining their origin and subsequent maintenance periods. Our results show that the oldest investigated Karez systems in the Turpan Basin were firstly constructed during the Uyghur reign in the early 15th century and reactivated during the Qing dynasty after around 1750 AD. According to the local population, the last new Karez systems, which constitute a sustainable way of water harvesting, were built in the early 1990s. Today, around 400 Karez systems are still in use. However, they are highly endangered due to groundwater lowering after drilling of modern deep wells.

Although the number of Karez systems studied by our Sino-German group is not enough for a clear result, the sampled systems and ages may point to a spatial limitation of early Karez innovation to the eastern part of the basin. There is an open question if the Karez innovation or expansion was due to political and military reasons or due to changes in water availability. From our results and the regional palaeoclimatic context, the periods of innovation and maintenance seem to fit well to short humid periods in eastern Central Asia at the Guliya ice core (Shi et al. 1999) and colder conditions at Kesang cave (Cai et al. 2017). Therefore, climatic factors may have triggered the boom periods along the Silk Roads and supported trade along the pathway crossing the Turpan Basin. We hypothesize that rapid demand of water and food during flourishing times of the Silk Roads trade forced the people to activate additional water resources by constructing Karez systems.

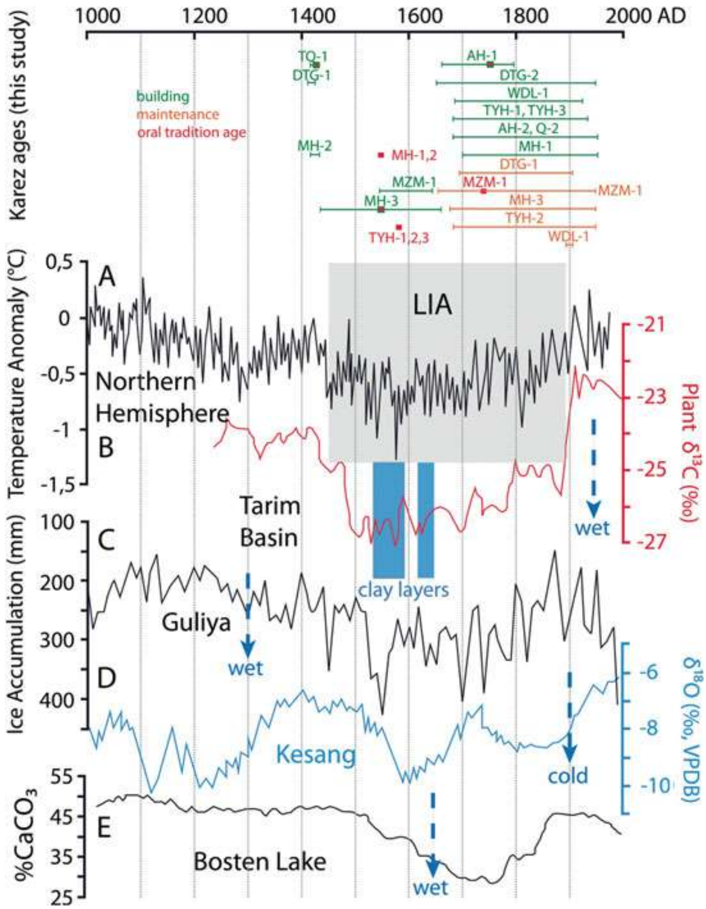

Fig. 17.4 Karez ages compared to climate proxies. **a** The Northern Hemisphere temperature record (after Liu et al. 2010, based on Moberg et al. 2005); **b** Carbon isotope variations of plant leaves/remains preserved in the Tarim Basin in aeolian sediments over time (running average values) and indication of two layers of silty clay deposits in a sequence at the end of the Tarim River, N 39° 47’ , E 88° 23’ (after Liu et al. 2010); **c** Ice accumulation from Guliya ice core (western Kunlun Shan, Yao et al. 1996); **d** Oxygen isotope record ($\delta^{18}O$) from the Kesang Cave stalagmite (Tekesi Country, Xinjiang Autonomous Region of China, N 42° 52’ , E 81° 45’ ,~2070 m a.s.l.) (after Cai et al. 2017), higher negative values indicate lower temperatures; **e** Carbonate percentage record from Bosten Lake, ca. N 87° 15’ , E 42°05’ (after Liu et al. 2010, based on Chen et al. 2006), high carbonate contents correlate to lower lake levels and more arid climate. The dating of Karez expansion may coincide with the transition to colder conditions at Kesang Cave (C), which gives hints at probably more humid conditions during these periods

Assuming the applicability of the same climatic mechanisms, we may postulate that the oases of the Turpan Basin along this section of the Silk Roads received enough surface water during Han and Tang dynasty, which enabled an exchange along the Silk Roads, but also made the activation of additional water resources by Karez systems unnecessary. Finally, we may assume that knowledge about this Persian technique also existed during Han dynasty in the Turpan Basin.

17.7 Outlook

The selection of Karez systems, studied by our group, focused on still working systems. Therefore, the question about the oldest Karez systems cannot be answered finally. In order to get a more precise dating of later maintenance periods, which may be a result of cultural dynamics along the Silk Roads and/or hydro-climatic changes, more research is needed. For example, ^{210}Pb-dating is suggested for identifying maintenance period younger than 200 years. Cross-dating with ^{14}C will decrease the possible age range. The next steps of the research will focus on old abandoned systems, identified by remote sensing and geomorphological methods in combination with archaeological work and interviews. Following this approach, we may finally answer the question about the origin of the Karez systems in the Turpan Basin, which are of great importance for the Chinese history, and were set on the tentative list to receive the UNESCO World Heritage status. This will help to protect these traditional and sustainable systems, which also represent great technical and social achievements, for future generations.

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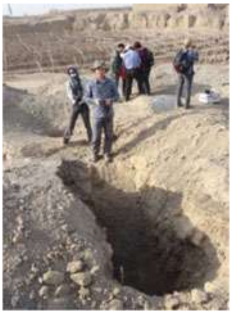
Appendix

Recent description of the studied Karez (cp. XUARBCH 2011):

Karez Name	Location
Tongqi Karez (TQ) 	Tongqi Karez is located in Zhuangzi village, 0.4 km west of the Aidinghu village.
Qiong Karez (Q) 	Qiong Karez is located in Huoyilakanerzi village. This Karez is layed out in south-north direction, with a total length of 3660 m and 92 shafts. According to oral tradition, this system was installed in 1200. Its historical maximum discharge was in 1955.
Wudaolin Karez (WDL) 	Wudaolin Karez is also known as Datou Karez, located in Shanghu village and 2 km southeast of the village committee.
Mahao Karez (MH) 	Mahao Karez is also known as Shakale Karez, located 1 km northeast of Tuotekanerzi village. Mahao Karez is arranged in east-west direction, with a total length of 2540 m and 155 shafts. The average depth is about 20 m. The historical maximum discharge was in 1980. According to the record of Karez, Mahao Karez has a history of about 450 years. The flow of water has plummeted since 1998.

(continued)

(continued)

Karez Name	Location
Tuyuhu Karez (TYH) 	Tuyuhu Karez is also known as Kawa Karez, located 2 km northwest of Zerifukanerzi village. Tuyuhu Karez is laid out in south-north direction, with a total length of 3900 m and 247 shafts. According to oral tradition, this system was installed in 1588, and dried up in 1642. After reactivation, its historical maximum discharge emerged in 1965. It dried up again in 1995.
Mierzhamu Karez (MZM) 	Mierzhamu Karez is located 0.7 km east of Guolebuyi village in Toksun county. Mierzhamu Karez is arranged in northwest-southeast direction, with a total length of 2653 m and 112 shafts. This Karez is still in use. According to oral tradition this Karez was installed in 1732, and dried up in 1985. The historical maximum flow was in 2000.
Ahong Karez (AH) 	Ahong Karez is located in Guolebuyi village. This Karez is layed out in northwest-southeast direction, with a total length of 4595 m and 123 shafts. Ahong Karez was installed in 1752.
Dataogou Karez (DTG) 	Dataogou Karez is located at the northern fringe of Turpan municipality with an estimated total length of ~1500 m and ~50 shafts.

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Chapter 18
Water Supply and Ancient Society in the Lake Balkhash Basin: Runoff Variability along the Historical Silk Road

Irina P. Panyushkina, Mark G. Macklin, Willem H. J. Toonen and David M. Meko

Abstract Expansion of agricultural practices from the Fertile Crescent to China during the mid and late Holocene are believed to have shaped the early network of Silk Road routes and possibly regulated the dynamics of trade and exchange in the urban oases along the Silk Road throughout its existence. While the impacts of climate change on the Silk Road are more or less documented for the medieval period, they remain poorly understood for early history of the Silk Road, especially in Central Asia. We analyze hydroclimatic proxies derived from fluvial stratigraphy, geochronology, and tree-ring records that acted on various time scales in the Lake Balkhash Basin to learn how changes in water supply could have influenced the early farmers in the Semirechye region of southern Kazakhstan. Our approach aims to identify short-term and long-term variability of regional runoff and to compare the hydrological data with cultural dynamics coupled with the archaeological settlement pattern and agricultural production. The reconstructed runoff variability underscore the contribution of winter precipitation driven by the interaction between the Arctic oscillation and the Siberian High-Pressure System, to Central Asian river discharge. We show that Saka people of the Iron Age employed extensive ravine agriculture on the alluvial fans of the Tian Shan piedmont, where floodwater farming peaked between 400 BC and 200 BC. The early Silk Road farmers on the alluvial fans favored periods of reduced flood flows, river stability and glacier retreat in the Tian

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Shan Mountains. Moreover, they were able to apply simple flow control structures to lead water across the fan surface. It is very unlikely that changes in water supply ever significantly constricted agricultural expansion in this region.

Keywords Central asia · Ili river · Water resources · Silk road archaeology
Saka agriculture · Dendrochronology · Fluvial geomorphology · Siberian high

18.1 Introduction

Human-environmental interactions are extremely complex, and can be obscured not only by the dynamic complexity of the climate system but also by the diversity in societal response and human adaptation to changing landscape (Adger et al. 2013). Societal response to climate change greatly varies and relies in part on a particular level of cultural sophistication and economic development that can seldom be measured. The role of climate change on the landscape and water resources throughout the prehistory of Central Asia has been researched with multi-disciplinary approaches for a long time. Yet the progress in unveiling physical mechanisms linking socio-economical change to the environment and climate change has been limited (Koryakova and Epimakhov 2007; Kuzmina 2007; Giosan et al. 2012; Macklin and Lewin 2015). Along the historical Silk Road the timeframe of ancient trade and technological exchange between the west and the east is reaching back in time from the medieval period to the Bronze Age (4500 years ago) (Frank and Thompson 2005; Frachetti et al. 2017). However it is not evident how the landscape itself could have facilitated the early development and sustainability of historical Silk Road networks.

It is reasonable to suspect that understanding water resource availability would lead to a comprehensive model explaining surplus accumulation and population growth at particular nodes of the ancient trading networks in the arid lands of Central Asia. Here we describe an approach that synthesize hydroclimatic variability modeled with fluvial geomorphology and dendrochronology to understand the fluctuations of water supply for agriculture in agropastoralist communities of Bronze Age and Iron Age occupying the Tian Shan piedmonts. We hypothesize that fertile alluvial fans could have engaged the ancient population in a pursuit of agriculture while the mobile pastoral economy of the time encouraged exchange with neighboring people.

In this chapter we outline two case studies in the Lake Balkhash Basin exploring variations of local and regional hydrology of the past. The first case study addresses long-term variability of runoff to link Holocene river dynamics, climate change and floodwater farming on the Talgar alluvial fan of Tian Shan piedmont (Macklin et al. 2015). The second deals with modeling short-term river discharge from tree rings and explores the atmospheric circulation drivers in the runoff fluctuations (Panyushkina et al. 2018). The technical details on methods and datasets used in this chapter could be found in aforementioned publications. Although, the second case study considers the last few centuries only, it identifies the key climatic drivers of hydrological variability that most likely regulated the fluctuation of regional water resources in the ancient times. We note that the scarcity of archeological data and hydro-proxies greatly limits our understanding of the impacts of water supply on the ancient agricultural communities. This work is currently most comprehensive assemblage of measured and absolutely dated information approximating the changes of hydrological regime in the region. To familiarize the readers with the historical background of this Central Asian region we describe briefly the geography and ancient society of Lake Balkhash Basin. The discussion is mainly focused on social impacts of runoff fluctuations and adaptations of farming populations to hydrological changes.

18.2 Ancient Society of the Lake Balkhash Basin

18.2.1 Historical Region of Semirechye in the Lake Balkhash Basin

The study is located in the Semirechye (Land of Seven Rivers) of Central Asia also called Zhitasu by Kazakhs that geographically corresponds to the Lake Balkhash Basin (Fig. 18.1). This closed basin in Inner Eurasia is comparable in area (413,000 km^2) to the neighboring Aral-Caspian and Tarim basins. Most regional rivers have headwaters in China and Kyrgyzstan, and flow from south to north through Kazakhstan. Annual runoff of the Lake Balkhash Basin is 0.26–0.36 km^3/y (Mamatkanov et al. 2006; Kuzmichenok 2009).

Glacier and snow meltwater with high flows between May and September, and the highest peaks in July and August dominate the hydrological regime of the watershed (Fig. 18.2). While the glacier share of runoff is estimated to range from ca. 10 to 40%, there is large uncertainty in estimation of glacial area and glacier volume of the hundred small glaciers in the basin (Sorg et al. 2012; Farinotti et al. 2015).

The Ili River (length 1439 km, catchment area 140,000 km^2), formed by the confluence of the Tekes and Kunges rivers in Xinjiang, China, is the largest river in the basin (Fig. 18.1 insert). The main tributaries of the Ili River that drain the Zailiyskiy Alatau Range, and the Tian Shan Mountains in Kazakhstan, are the Charyn, Keskelen, Talgar, Turgen and Chilik Rivers. The delta of the Ili River runs through the Sary Aka and Taukum Deserts, and forms vast areas of wetlands, sand dunes, and marshes before reaching the southeastern shoreline of Lake Balkhash. The tributary catchments contain nearly one hundred small glaciers, whose areas range from 4 to 26% of the area of the watershed, and which contribute from 17% (Keskelen River) to 56% (Talgar River) of the summer runoff (Vilesov and Uvarov 2001). The total area of these small glaciers is presently ca. 253 km^2 (Konovalov and Pimankina 2016). The average discharge of the Ili is about 480 m^3/s per year. The highest discharge peak is in July ca. 770 m^3/s and the lowest flow in January is ca. 230 m^3/s (Fig. 18.2). The tributaries have multi-faceted alluvial fans (Fig. 18.1), 15–25 km wide and up to 20 km long, with multiple lobes decreasing in elevation from west to east (Akiyanova 1998).

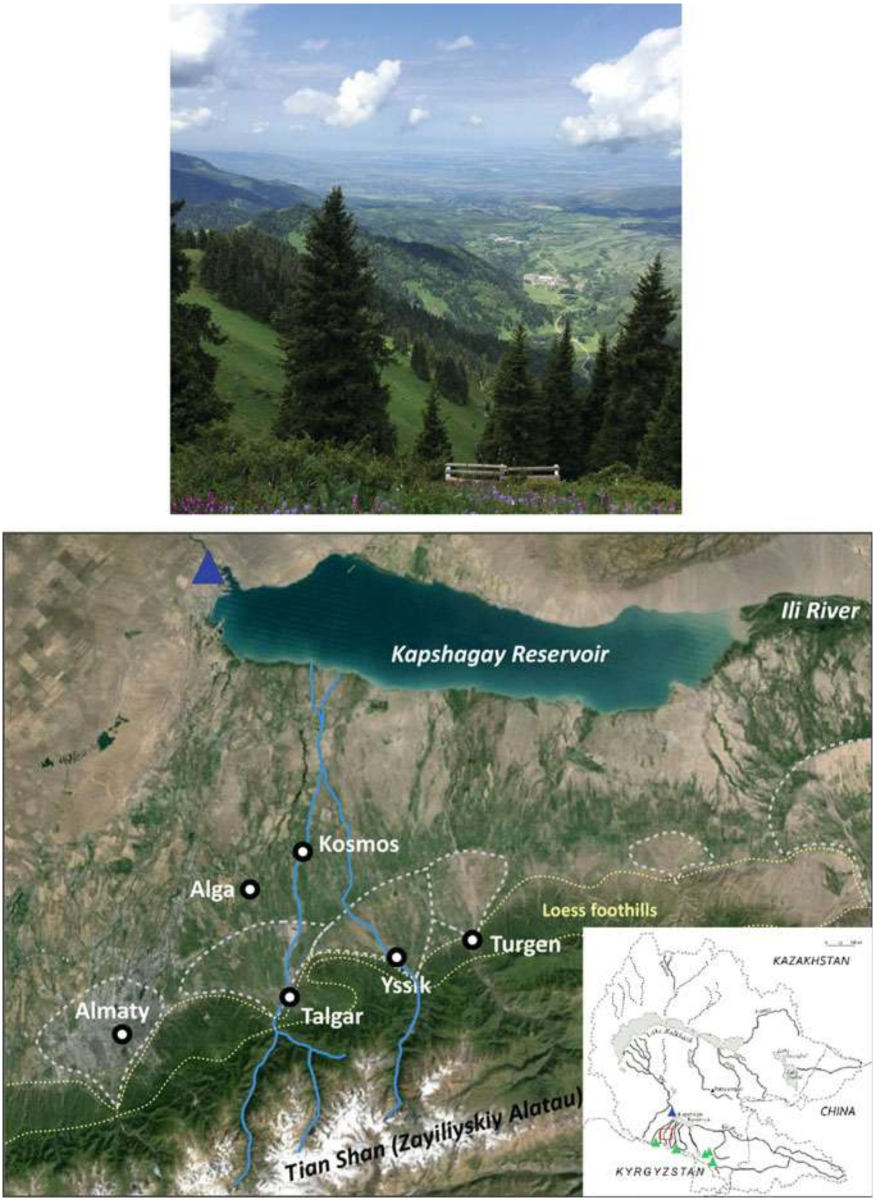

Fig. 18.1 Rolling foothill landscape on the northern slopes of the Tian Shan Mountains in southern Kazakhstan. Photo on the right is the Talgar alluvial fan viewed from the upper valley covered with spruce forest. Below is catchment of the Talgar-Yssyk Rivers (Scale: 5 km in 1 cm) and its position in the Lake Balkhash Basin (right insert). *Blue lines* are Talgar and Yssyk Rivers. *Circles* show locations of geomorphological ground survey and sediment sampling. *White dashed line* delineates alluvial fans at the foothills of Trans-Ili Range (former Zailiyskiy Alatau). The Kapchagay Reservoir and power station (*blue triangle*) built in 1969 are located on the Ili River. *Green triangles* of the insert map mark the tree-ring sites sampled for modeling the Ili River discharge. *Red rectangle* marks the Talgar-Yssyk catchment

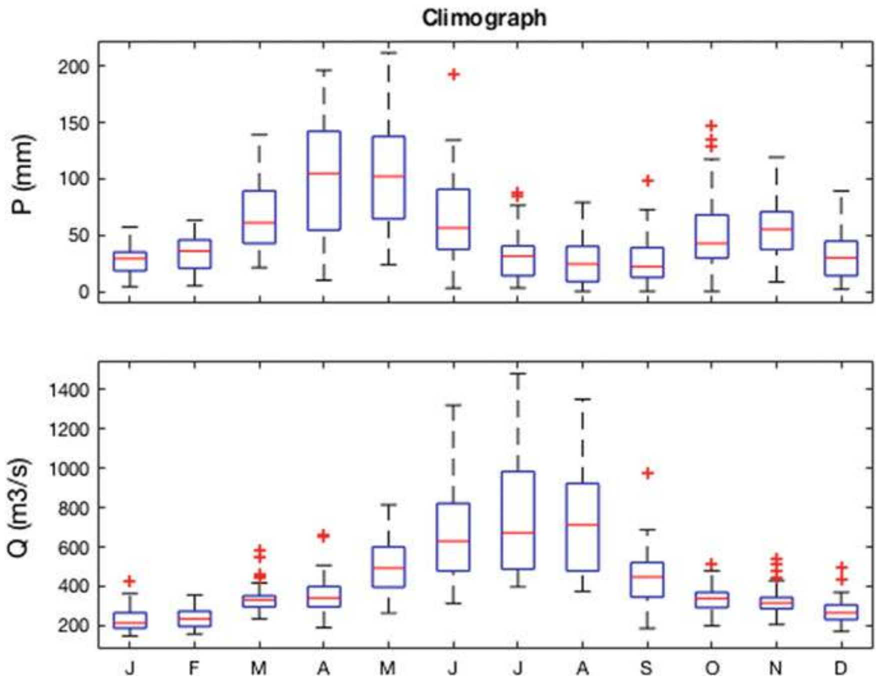

Fig. 18.2 Annual regime of precipitation and river flow in the study area. Top plot is monthly precipitation for the instrumental interval 1936–2014 at weather station Almaty (43° 23′ N, 76° 93′ E, 895 m asl) located in the Malaya Almatinka River Valley adjacent to the Talgar River catchment. The station represents precipitation variation in the Lake Balkhash Basin (Zhou et al. 2017). Bottom plot is monthly hydrograph of Ili River discharge as recorded at the U. Kapchagay gauge (44° 13′ N, 76° 98′ E, 428 m asl) for the instrumental period 1936–1985 (Fig. 18.1). Precipitation and discharge in individual months are displayed as box plots with a horizontal line at the median, a box over the interquartile range, and plus signs at values more than 1.5 times the interquartile range above or below the box. If there are no such outliers, the bracket marks the data extremes

Analysis of instrumental data covering the last 70 years indicates that runoff in this region has not changed significantly or has declined only slightly (1–2%) over the period 1940–2005 while regional temperature has a warming trend (Aizen et al. 1996; Konovalov and Pimankina 2016). The measured contribution of glacier melt has been decreasing, while snowmelt significantly increased over 1940–1991 (Konovalov and Pimankina 2016). Glacier mass-balance modeling estimates an 18–27% decrease in the glacier area across the Tian Shan since 1961 (Farinotti et al. 2015). Precipitation over the larger region of Central Asian drainages is decreasing (Lammers et al. 2001; Bothe et al. 2012). Ili River runoff has been permanently altered since 1970 by construction of the Kapchagay Dam and Reservoir (Fig. 18.1). The dam was completed in 1969 and the reservoir filled over the next 20 years.

18.2.2 Socio-Cultural History of Semirechye During the Late Holocene

The Bronze Age World System on the Eurasian steppe is often characterized as the precursor for the Silk Road (Christian 1994; Frank and Thompson 2005; Frachetti et al. 2017). The Bronze Age (BA) of the Semirechye was represented by a small population of Andronovo people (2500–1400 BC) in the upland valleys and foothills of the Dzhungarskiy Alatau and Zailiyskiy Alatau Ranges. The Andronovo people were primarily pastoralists, who negotiated trade in surplus livestock and metal goods along mountain corridors (Frachetti 2012). Later, during the Iron Age (800 BC–AD 200, IA), the foothill alluvial fans supported mixed farming and herding, but not yet mobile pastoralism (Akishev 1969; Chang et al. 2003). Archaeological data suggest multiple scenarios for the shift in economic strategies from transhumant pastoralism to settled agro-pastoralism that took place at the transition from the Late BA to IA (Chang et al. 2003; Frachetti 2012; Spengler et al. 2013; Chang 2018): (1) upland mountain valleys served refuges for mobile pastoralism that persisted despite a climate change to cooler and drier conditions in the first millennium BC; (2) groups of sedentary agro-pastoralists moved into fertile lowland regions and combined both mobile pastoralism and small-scale agriculture during the IA; and (3) throughout both BA and IA periods, the population facilitated upland transhumant pastoralism and lowland agro-pastoralism. The most recent archaeological framework in the Semirechye favors a diversified and highly intensified economy (scenario #3) that emerged by the Late BA, and during which the agricultural pursuits on the alluvial fans led to exchange of surplus grain throughout Central Asia (Spengler et al. 2017).

Historical evolution of the IA in the Semirechye climaxes into military confederacies of the Saka (Asian Scythians) and later Wusun, which had highly complex production from farming and herding to metalworking, and intensive trade with the neighboring agrarian kingdoms of Bactria and Parthia (DiCosmo 1999). Further adaptation of Late IA population to the warming medieval times served as the economic backbone for the social development of hierarchically arranged principalities in the region by c. AD 600 (Baipakov 2008).

The medieval history of the Semirechye involved several Turkic Khaganates[1] primary occupied the Ili River basin and the Tian Shan foothills. At this time the culture and economy of urban oases reached their peak, being imbedded into the Silk Road networks. Farming and irrigation played an important role in the economic development of the region (Groshev 1985; Oberhänsli et al. 2007; Baipakov 2008). The last Khaganate, called the Kara Khanid (10th–11th century), introduced Islam, which blended organically into the well-developed urban environments of the Semirechye.

The conquest of the Kara Khanid by the Mongol Empire (after AD 1206) destroyed the urban centers, reduced the population and dramatically changed the social order in the region. The regional economy fell into stagnation, and agricultural production

[1]Khaganate, alternatively spelled as Khanate, is a political entity of Central Asian tribes ruled by Khagan or Khan. This is an equivalent to tribal chiefdom, principality or kingdom.

halted while the mobility of pastoralists increased. Along with the crash in technological growth and cultural diffusion, the Silk Road network fragmented (Christian 1998). The Kazakh Khanate (AD 1465–1731) unified nomadic people ruled by multiple tribal alliances branched out from the Jochi Khan (the eldest son of Genghis Khan) clan. There are no historical data documenting the agricultural production in the Semirechye during this time. Winter camps of herders occupied the low reaches of rivers draining the area south of Balkhash Lake where freshwater springs were abundant (Krasnov 1887; Baipakov 2008). The fertile alluvial fans of the Tian Shan foothills served as the transit corridor between the lowland winter camps and summer camps in the upland meadows. The modern era started with Russian colonization of the Semirechye (Eastern Turkistan) after 1867. With colonization came revived farming and gardening practices, development of new irrigation lands, and westernization (including sedentarization) of the nomadic population.

18.3 Long-Term Variability of Runoff in the Semirechye Derived from Fluvial Geomorphology and Its Relation to Ancient Farming

The case study by Macklin et al. (2015) demonstrated how changes in water supply could have impacted early farmers that occupied the Talgar alluvial fan in the Ili River Basin. Environmental proxies of runoff in Central Asia are limited and their temporal resolution is irregular, so instead, a long-term and absolutely dated fluvial chronology of a small catchment was used to investigate centennial and multi-centennial variability of water supply and its impact on the society. The long-term variability of runoff was approximated on the Talgar River catchment where a Kazakh-American archaeological team lead by Prof. Claudia Chang (Sweet Briar College, VA) conducted archaeological excavations and surveys over the past 25 years focusing on sedentary settlements (Chang 2018). Linking fluvial terracing to long-term changes in water and sediment supply, a chronology of Holocene major aggradation and incision episodes was established. These were dated with radiocarbon (^{14}C) and Optically Stimulated Luminescence (OSL). The chronology was compared with other regional hydroclimatic records, and the river dynamics are linked to climate change. This allowed evaluating the impact of runoff variability on water supply for floodwater farming.

18.3.1 Settings of Fluvial Geomorphology Study on the Talgar Alluvial Fan

The Talgar River (length c. 120 km, drainage area c. 440 km^2) is located in the Ili River catchment and drains the Trans-Ili (former Zayliysky Alatau) Range (Fig. 18.1). Topographic maps prior the construction of the Kapchagai reservoir (1969) show the Talgar River splitting into a series of distributary channels that drained into an enclosed wetland, not connecting directly with the Ili river except possibly during floods. Annual precipitation at the apex of the fan is 755 mm with spring (major) and autumn (minor) peaks, rising to 900 mm (Aubekerov and Gorbunov 1999) at the higher elevation of the Mount Talgar (5020 m asl), the highest point in the Talgar catchment.

Field data on river terrace sedimentology, stratigraphy and geochronology were collected along a 35-km transect stretching from the apex of the Talgar fan downstream to the Talgar River confluence with the Yssyk River (Figs. 18.1 and 18.3). Geomorphological mapping was carried out using satellite imagery (Shuttle Radar Topography Mission: SRTM), topographic maps, and ground survey. OSL and ^{14}C dating of fluvial units was undertaken at three 1-km long reaches: 1) apex of the fan centered on the medieval town of Talkhar (43°16′ N, 77°13′ E), 2) Kosmos (43°30′ N, 77°15′ E) and 3) Talgar-Yssyk confluence (43°35′ N, 77°17′ E) (Fig. 18.1). The ages reported herein use (1) calibrated ^{14}C years before present (AD 1950), which we denote as 'cal AD' and 'cal BC', and (2) annum unit with error or age range denoted with "ka" (thousands years ago) for OSL dates. In some cases, cross-referencing OSL and ^{14}C dates with archaeological and historical periods results in denoting the calendar time with AD or BC datum.

18.3.2 River Terraces, Stratigraphy and Geochronology in the Talgar Catchment

At the upper Talgar River valley, four terraces are found at c. 13.5 m (T1), 9.5 m (T2), 4 m (T3), and 2.5 m (T4) above the current river-bed (Fig. 18.4). The medieval town of Talgar (alternative spelling Talkhar), occupied from 9th to the 13th centuries AD, is located on the surface of T1 (Fig. 18.4). The buried soil contains 9–13th century AD ceramics as well as abundant bones and charcoal associated with the Kara Khanids (Figs. 18.3c and 18.5). The age of this soil is about cal AD 890–1040, which is consistent with the historical dating of Talgar. These deposits above that soil relate to a major period of flooding and channel aggradation that buried the medieval settlement around cal AD 1680–1940 (Macklin et al. 2015).

Downstream reach Kosmos is located 30 km from the fan apex (Fig. 18.1), where the valley width is about 300 m (Fig. 18.3d). The present river runs in a 100 m wide meander channel belt, has a high-sinuosity channel and is confined within river terraces of Holocene age 2–7 m (Fig. 18.4). Four major terraces are evident at c. 7 m (T1), 6 m (T2), 3 m (T3), and 2 m (T4) m above the present river level and can be traced fragmentally for 15 km northwards towards the Kapchagay Reservoir and 10 km upstream. A well-developed soil was formed in the IA between 2880 and 2490 cal BC and c. 2440 (±450) BC (Fig. 18.4f). A second palaeosol is dated to cal AD 1460–1640. Confluence with the Yssyk River (Figs. 18.1 and 18.4) reckons three terraces (T1—11 m, T2—8 m, and T3—3.5 m), while the Yssyk River has only two major terraces (Y1—11 m and Y2—5 m). The ages of the buried soil at the Talgar-Yssyk confluence is dated to cal. AD 1320–1450 at T3 and from cal AD 1300–1400 to 1450–1630 at Y2 (Fig. 18.4).

Fig. 18.3 Collection of field data on river terrace: **a** Typical box-shaped valley on the alluvial fan surface, with fine-grained deposits on the valley floor (**a′**). **b** Exposure of Terrace 1 in the fan apex reach. **c** Terrace 3 in the fan apex reach with a buried soil, ceramics, hearth, and flood units at the top of the section. **d** The Talgar River valley in the Kosmos reach. **e** Section of Terrace 1 in the Kosmos reach showing glaciofluvial deposits, cross-bedded fluvial sands, flat-bedded fluvial sands, and fluvially redeposited calcified aeolian silts. **f** Section of Terrace 2 Kosmos reach showing Holocene channel-fill deposits, and a well-developed paleosoil capped by fine-grained fluvial sediments containing reworked loess. **g** Section of Terrace 4 in the Kosmos reach showing 19th century AD coarse grained flood units. **h** Incision in the alluvial fan surface caused by recent flow diversion of the Tseganka tributary

Morpho-stratigraphic relationships between Talgar fan and valley terraces, and dating estimates (Table 1, Macklin et al. 2015) provide the reconstruction of a chronology of river aggradation and down-cutting for the last c. 20,000 years

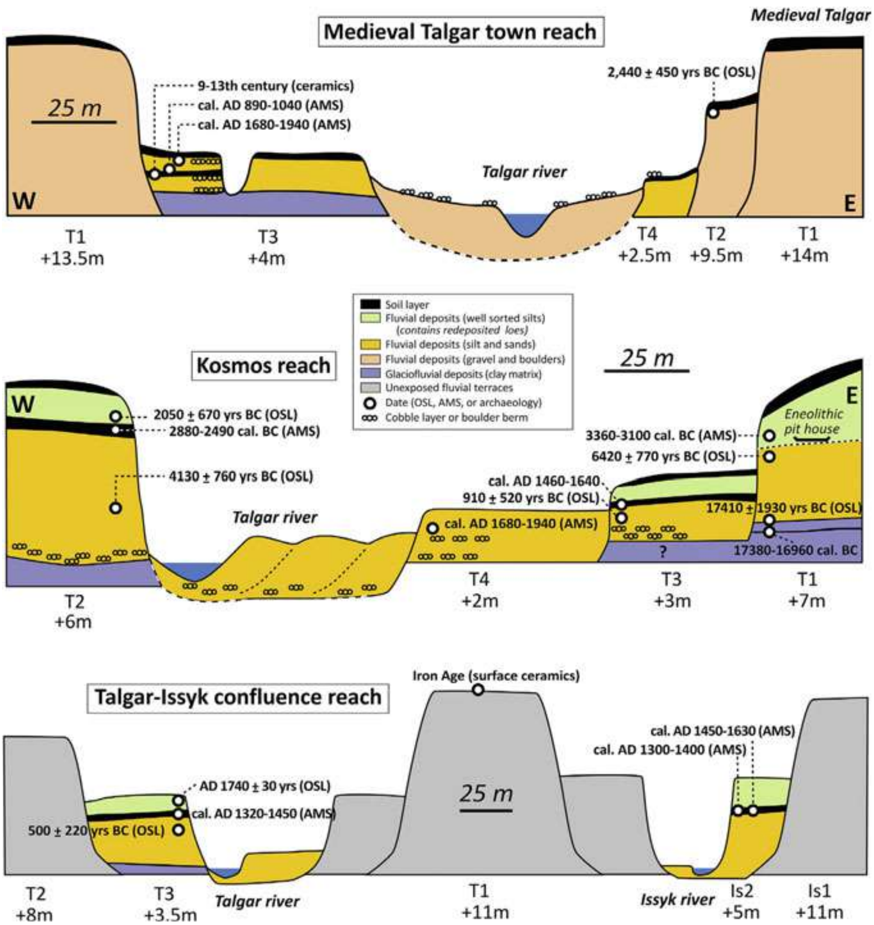

Fig. 18.4 Sketch of river terrace stratigraphy, sedimentology and geochronology of Talgar-Yssyk catchment (tributary of Ili River) reconstructed for the last c. 20,000 years (reproduced from Macklin et al. 2015). *S*tratigraphic cross-profiles of the apex reach near medieval Talgar town, the Kosmos and Talgar -Issyk confluence reaches show the terrace sequences (T1…T4), terrace height and key dates. Direction of profiles is from the west (W) to the east (E)

(Fig. 18.4). The most recent T1 with evidence of human occupation records channel aggradation from c. 17,400 to 17,000 cal BC until c. 6420 BC (±770) BC, followed by a 3000 year long hiatus and then renewed overbank sedimentation after 3360–3100 cal BC (BA).

T3 is contemporaneous to Y2 in the Yssyk Valley. River entrenchment in the Talgar catchment (and formation of T2) began c. 2880–2490 cal BC with valley floor filling re-commencing sometime before c. 910 (±520) BC (Kosmos reach, Fig. 18.4) and continuing until c. 500 (±220) BC (Talgar-Yssyk confluence reach, Fig. 18.4). A well-developed buried soil within T3 and Y2 is dated to cal AD 890–1040 in the

Fig. 18.5 Photo of the most recent terraces at upstream reach near the medieval town of Talgar (left) and downstream reach Kosmos (right). The buried soil dated to cal AD 890–1040 related to the terrace T3 contains 9–13th century AD ceramics as well as abundant bones and charcoal (right). The top deposits relate to a major period of flooding and channel aggradation that buried the medieval soil and the riparian trees during the Little Ice Age. In situ tree stump dated cal AD 1680–1940 is imbedded in the terrace T4 (left)

medieval Talgar town reach, cal AD 1460–1640 in the Kosmos reach, and cal AD 1320–1450 (T3) and cal AD 1300–1400 to 1450–1630 (Y2) in the Talgar and Yssyk confluence reach. These dates indicate a prolonged, 400–700-year-long episode of valley floor stability roughly between the late 9th and early 17th century AD with little overbank sedimentation in the Talgar and Yssyk rivers. A phase of channel sedimentation is evident at c. AD 720 (± 260) within the Tseganka distributary of the Talgar fan (Fig. 18.3h), but is not recorded downstream in the Talgar river valley.

Valley floor sedimentation began again sometime during the late 17th century AD (T3 medieval Tagar town reach) with dated fluvial deposits at c. AD 1740 (± 30), and continued into the 19th and possibly early 20th century. The date of cal AD 1680–1940 on the buried tree stump within T4 (Kosmos reach, Fig. 18.5) provides a *terminus post quem* for the last significant episode of channel aggradation in the Talgar valley.

18.3.3 Talgar River Response to Holocene Hydroclimatic Variability in the Lake Balkhash Basin

To explore the relationship between river dynamics in the Talgar catchment and climate change in the Holocene, the phases of river aggradation and incision are correlated with: (1) periods of glacier dynamics in the Tian Shan Mountains (Savoskul and Solomina 1996; Sorg et al. 2012; Takeuchi et al. 2014); (2) water level records in the Aral Sea (Krivonogov et al. 2010, 2014) and Lake Balkhash (Endo et al. 2012; Sala et al. 2015; Chiba et al. 2016); (3) regional episodes of soil development (Sun

2002; Solomina and Alverson 2004; Blättermann et al. 2012); and (4) strength of the Siberian High Pressure System (SH) (Meeker and Mayewski 2002; Mayewski et al. 2004). Although there are quite a wide range of proxy climate records available for the Lake Balkhash Basin, only water levels in the Aral Sea and glacier advances in the Tian Shan span the entire Holocene and have centennial-scale time resolution.

We compare the river dynamics with a multi-millennium record of the SH index inferred by K^+ fluctuations in the GISP2 ice core that represent long-term variability of seasonal atmospheric circulation in Asia (Meeker and Mayewski 2002; Mayewski et al. 2004). The primary source of moisture for runoff in the region is cold season precipitation and spring storms embedded in the mid-latitude westerlies, with some contributions from the higher latitudes (Lydolf 1977). The annual and seasonal distribution of runoff in Central Asia is impacted by modulations of the prevailing hemispheric circulation lead by climate change (Cohen et al. 2001; Jeong et al. 2011). In winter, Central Asia is under the influence of the SH, a cold-season anticyclone over Mongolia that forms in response to radiative cooling of the air above snow-covered Eurasia in October and remains until April (Lydolf 1977). During a strong SH the region west of and outside the SH source area (Mongolia) experiences high cyclonic activity, and fall and spring storms deliver excess precipitation. The variability of SH intensity and its teleconnections have been linked to large changes in patterns of snow in the fall, heavy snowfall events, severe cold-surge outbreaks and frequency of spring storms over Inner Eurasia (Panagiotopoulos et al. 2005; Jeong et al. 2011). Short-term variability of the SH index has been reconstructed with Eurasian tree-ring records for the last 400 years (D'Arrigo et al. 2005). This SH record links to recent climatic fluctuations and will be applied to the runoff variation in next section.

Figure 18.6 summarizes the response of Talgar runoff to climate change during the Holocene. Early Holocene river aggradation up to c. 6420 (± 770) BC coincides with a high-stand in Lake Balkhash (Endo et al. 2012; Sala et al. 2015) and renewed glaciation in the Tian Shan mountains between c. 12,500 and 8000 (Takeuchi et al. 2014). The first major phase of Holocene channel entrenchment in Talgar River (c. 6420–4130 BC) likely onsets shortly after 6420 (± 770) BC and has counterparts in falling water levels of Lake Balkhash, including an abrupt drop at 6200 cal BC (Sala et al. 2015), and significant glacier shrinkage at 6000 cal BC with very low rates of ice accumulation until 4220–3970 cal BC (Takeuchi et al. 2014). A major regression in the Aral Sea is also recorded between 5050–4650 cal BC (Krivonogov et al. 2014). Early-middle Holocene river incision in the Talgar valley appears to be a response to a warming climate and higher temperatures under a weaker SH between c. 6000 and 4000 cal BC (Fig. 18.6).

Renewed channel and floodplain aggradation occurred in the Talgar valley between 4130 (± 760) and 2880–2490 cal BC coinciding with cooler conditions and glacier expansion in the Tian Shan (Takeuchi et al. 2014), a period of strong SH (Mayewski et al. 2004), and high water levels in the Aral Sea (Krivonogov et al. 2014) and Lake Balkhash (Endo et al. 2012; Sala et al. 2015; Chiba et al. 2016).

The second and most prominent phase of Holocene river down-cutting occurred in the Talgar catchment shortly after 2880–2490 cal BC and before 910 (± 520) BC. Similar to the early-middle Holocene entrenchment phase, it coincided with a

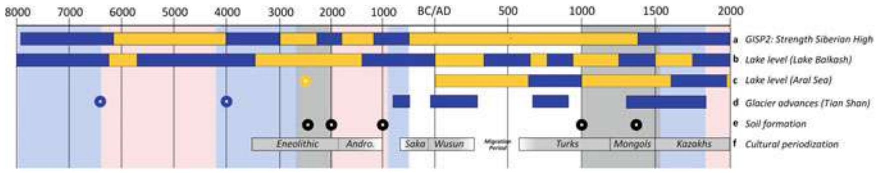

Fig. 18.6 Correlation of Holocene Talgar river entrenchment (*pink*), aggradation (*blue*) and soil formation (*grey*) with regional hydroclimatic proxies: **a** long-term variability of Siberian High (Mayewski et al. 2004), **b** fluctuation of Lake Balkhash and **c** Aral Sea levels (Krivonogov et al. 2010, 2014; Endo et al. 2012; Sala et al. 2015; Chiba et al. 2016), **d** Tian Shan glacial advances (Savoskul and Solomina 1996; Aubekerov and Gorbunov 1999), **e** soil formation in Central Asia (Sun 2002; Solomina and Alverson 2004; Blättermann et al. 2012), and **f** cultural periodization (Andro. = Andronovo community complex of BA). Dated periods of floodwater farming on the Talgar fan in the Iron Age and medieval periods are shown *in black*. Phases are depicted with *bars* and shorter known episodes with a *dot*. *Yellow* and *blue* denote, respectively, strong and weak Siberian High, or low and high water levels in the lakes, or warm and cold intervals (**d**)

shift to a drier and probably warmer (weaker SH) climate. This is recorded by a pronounced dry interval between c. 3000 and 1950 cal BC in Lake Son Kol, Central Kyrgyzstan (Lauterbach et al. 2014), a regression in the Aral Sea between c. 2250 and 1250 cal BC (Krivonogov et al. 2014) and a major period of local and regional soil development (Sun 2002; Solomina and Alverson 2004; Blättermann et al. 2012).

New river aggradation took place in the Talgar valley between 910 (±520) and 500 (±220) BC with valley floor refilling sometime earlier. This aggradation phase coincides with a strong SH, glacier advances in the Tian Shan Mountains and high water levels in the Aral Sea (Fig. 18.6). With the exception of a sedimentation episode in the Tseganka distributary on the Talgar fan at c. AD 720 (±260), which coincided with brief high-stands of the Aral Sea cal AD 500–600 and cal AD 850–950 as well as glacier re-advance in the Tian Shan, the period between c. 500 BC and c. AD 1740 was one of reduced geomorphic activity in the Talgar catchment. It coincided with a weakening of the SH between the second half of the 1st millennium BC and the end of the 14th century AD, as well as with major regressions in the Aral Sea between 150 cal BC–cal AD 600–650 and again between cal AD 850–950 and 1600–1700 (Krivonogov et al. 2010, 2014). Extensive floodplain soil development between cal AD 1300–1640 indicates significantly reduced flooding and relatively dry conditions. It also coincides with a major regression of the Aral Sea documented in the late medieval period (Yang et al. 2014; Krivonogov et al. 2010, 2014). The last phase of river aggradation in the Talgar catchment is dated to c. AD 1740 (±30), and may have continued until the early 20th century. It matches high-water levels in the Aral Sea until a drop to modern levels since AD 1960 and a stronger SH.

Overall, Holocene river dynamics in the Talgar catchment have been controlled by fluctuations in regional hydroclimate and by glaciation in the Tian Shan Mountains. Phases of Late Pleistocene and Holocene channel aggradation and floodplain sedimentation in the Talgar River at c. 17,400–6420, 4130–2880 and 910–500 cal BC, and between the mid-18th and early 20th centuries correspond with periods of cooler and wetter climate as reflected by high-water levels in the Aral Sea and Lake Balkhash, glacier advances in the Tian Shan and a stronger SH (Fig. 18.6). River entrenchment between these dates, and soil development between c. 2880 and 2490 cal BC and cal AD 1300–1640, correlate with low-water levels in the Aral Sea and Lake Balkhash, and glacier retreat associated with a warmer and drier climate.

18.3.4 Influence of Holocene Hydrological Regimes on Floodwater Farming in the Semirechye

The earliest Late Eneolithic/Early BA site in the Talgar valley is a pit house dated to c. 3360–3100 cal BC within T1 in the Kosmos reach (Fig. 18.4). Occupation coincides with river aggradation and cooler conditions, as recorded by a strong SH and high water-levels in the Aral Sea (Fig. 18.6). On the basis of a single house no wider archaeological inferences can be drawn other than that similar age settlements may be concealed below alluvium elsewhere at the fan. The preservation of this house, and its position on an upstanding floodplain surface reflect a period of relatively rapid but low energy sedimentation.

Dated mid BA or Andronovo sites are recorded in the upland headwaters of the Talgar (Panyushkina et al. 2010), but no sites of this age have so far been identified on the Talgar fan (Fig. 18.1). The Andronovo period c. 1800–1550 cal BC was a time of channel incision and occurred under regionally dry and warm climatic conditions as shown by a major regression in the Aral Sea and a weaker SH (Fig. 18.6).

IA settlement and floodwater farming on the Talgar fan and along the Talgar River are ^{14}C dated at three settlements to between 760 cal BC and cal AD 10 with nearly 62% of the dates on archaeological charcoal falling in the period of 400–200 cal BC (Chang 2008). This period of intense floodwater farming, the most significant before the modern period, immediately follows a major phase of aggradation along the Talgar River at c. 910–500 BC that coincides precisely with a strong SH, glacier advances in the Tian Shan Mountains and high water levels of the Aral Sea (Fig. 18.6).

This period of late extensive IA settlement and floodwater farming occurs during a period of stable channel bed levels in the Talgar River, a weakening SH at 500 cal BC and a major regression in the Aral Sea at c. 150 cal BC (Fig. 18.6). The apogee of IA agriculture on the Talgar fan is also bracketed between two major glacier advances in the Tian Shan Mountains that ended at c. 500 cal BC and began again around 50 cal BC. Taken together these records indicate a period of warm climate in the late IA with reduced river flow from c. 150 cal BC as evidenced by a fall of the Aral Sea water level. Nevertheless, given the elevation of the Tian Shan Mountains, late spring and early summer glacier and snow melt floods, would have still produced adequate water for irrigation on the Talgar fan, as can be seen today with glacier shrinkage under a warming climate.

18.4 Short-Term Variability of Runoff from Tree Rings

The linkage between short-term climatic variability, mainly forced by the SH, and Central Asian runoff can be explored at high precision with annually resolved tree-ring proxy of river flow in recent past. The decadal and annual variability reflects the scale of runoff fluctuation that might have affected past farming communities, in addition to long-term variability as reflected in river dynamics, by changes in water supply from one year to another. Networks of tree-ring records for the Semirechye have been developed in the Tian Shan Mountains since the early 1970s, but record lengths are limited to the last 600 years (Borscheva 1988; Panyushkina et al. 2010; Chen et al. 2016). Below we focus on a recent study of tree-ring reconstruction of Ili River discharge for the interval 1779–2015 (Panyushkina et al. 2018), and use it to address the potential impact of short-term variability of runoff on water supply on economic development in the region on the time scale of last few centuries - with a discussion of potential impacts of similar variability on prehistoric people.

18.4.1 Climatic Signals in Annual Variation of Spruce Tree-Ring Widths

Picea schrenkiana (Fisch. and C.A. Mey.), or Schrenk's spruce, is a widely distributed conifer specie in the mountain forests of Central Asia, which tree rings form a suitable climatic proxy for the hydroclimatic modeling in the Lake Balkhash Basin. The tree-ring studies suggest that spruce growth in the Tian Shan Mountains is limited by both temperature and precipitation (Borscheva 1988; Wang et al. 2005; Solomina and Maksimova 2010). Trees growing under moisture stress at low and high elevations, and under temperature stress at the upper tree-line are found within the elevation range 1700–2750 m asl. Cold-season temperature and summer drought generally limit the growth of winter-dormant conifers. Radial growth rate is high in March–May and declines in summer following the July-August dry period (Wang et al. 2005). A warm spring and early snowmelt favor an early onset of the growth season and a high rate of tree-ring growth (Kozhevnikova 1982; Wang et al. 2005). High precipitation in the previous fall and winter recharges soil moisture, which along with snowmelt can help trees cope with summer drought, but deep snowpack can also negatively impact growth by shortening the growing season (Kozhevnikova 1982; Borscheva 1988).

The moisture signal in annual rings of Schrenk's spruce has been discussed in relation with previous fall-winter precipitation, and has been successfully used in reconstruction of precipitation, Palmer Drought Severity Index (PDSI), water balance and streamflow (Yuan et al. 2007; Solomina and Maksimova 2010; Konovalov and Maksimova 2012; Chen et al. 2015, 2016; Zhang et al. 2017a, b). In recent years, a tree-ring team lead by Dr. Feng Chen has produced an array of tree-ring reconstructions from the Lake Balkhash watershed describing in detail the spatial-temporal pattern of moisture variability of the last 200–300 years (Chen et al. 2017a; Zhang et al. 2017b).

Air temperature over the last few centuries has surged upward, in agreement with the transition from the Little Ice Age to the modern warming. Warming has been noticeably faster in winter and spring than in summer. Reconstructed decadal variability of moisture can differ greatly between the tree-ring studies depending on the season of reconstruction and location. For example, precipitation reconstructed for the previous July to current April shows low variance for extended periods of time since 1560 and identifies decadal droughts centered at 1660s, 1710s, 1770s, 1900s, and 1980s (Chen et al. 2017a, b). Reconstructed January-May PDSI highlights nine multi-decadal droughts since 1580 (Cheng et al. 2014). Reconstructed July-June precipitation since 1474 points out eight different intervals of multidecadal drought with on average a frequency of one-two dry periods per century (Zhang et al. 2013). Even though the growing number of tree-ring studies leads to better synchrony of the modeled hydrological patterns across Central Asia in general an interpretation of water supply impact on past agricultural production taken place at a small catchment would be critically dependent on specific runoff reconstruction closely related to the locality of archaeological data.

18.4.2 High-Frequency Variability of Ili River Discharge Derived from Tree Rings

Figure 18.7 shows the tree-ring reconstruction of Ili River annual discharge for the last 235 years published by Panyushkina et al. (2018). This publication presents the details of spruce tree-ring chronologies and the reconstructing model. Here we discuss only the decadal and interannual variability of tree-ring reconstructed discharge of the Ili River for the recent centuries. The record has relatively frequent periods of low flow lasting 25–30 years, and shorter periods of high flow lasting 10–15 years. Flow was low in 1825–1850, 1865–1885, 1916–1938 and 1975–2000; flow was generally high in 1793–1809, 1850–1857, 1886–1909, 1952–1962 and 2001–2013 (Fig. 18.7). Thirteen runoff events outside the $\pm 2\sigma$ interval around the mean (316–594 m^3/s) are found in reconstructed record. Individual years of extremely low flow are 1871, 1879, 1846, 1788, 1829 and 1933; years of extremely high flow are 1799, 1851, 2005, 1856, 1808, 1960 and 1816. The driest year is 1871, with a discharge (239 m^3/s) only half the historical average (460 m^3/s). The wettest year is 1799, with a discharge of 728 m^3/s (+58% of historical average).

The spatial correlation field of gridded self-calibrated Palmer Drought Severity Index (scPDSI) with reconstructed Ili River discharge suggests that dry and wet hydrological conditions are similar across the entire Lake Balkhash Basin and Lake Issyk Kul Basin (Fig. 18.8). Great similarity of runoff anomalies and trends in these two adjacent basins has also been demonstrated with meteorological and hydrological data (Aizen et al. 1997). Decadal variability of reconstructed Ili discharge agrees

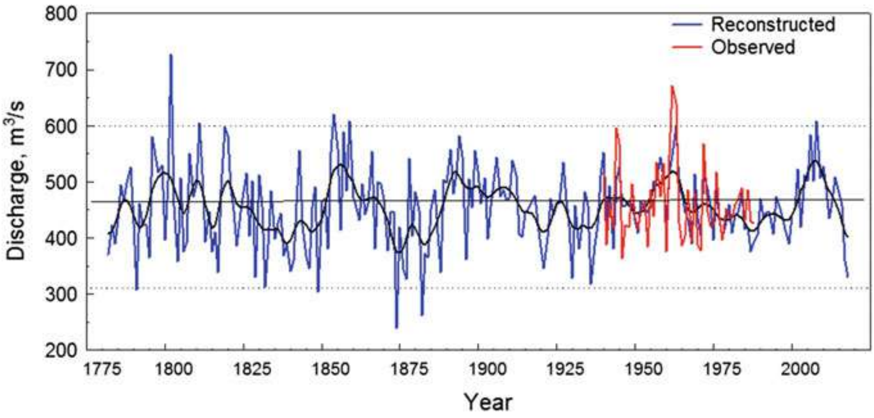

Fig. 18.7 Short-term variability of Ili River flow. Tree-ring reconstruction of the Ili River discharge for October-September water year shown in *blue* is from 1779 to 2015 (reproduced from Panyushkina et al. 2018). *Red line* is instrumental discharge at the U. Kapchagay gauge (Fig. 18.1). *Black line* emphasizes the decadal variations estimated with 10-year Tukey filter. *Horizontal grey line* is at 460 m^3/s calibration-period mean (1937–1985). *Grey dashed lines* at +2σ (594 m^3/s) and -2σ (316 m^3/s) delineate discharge extremes for the last 235 years

fairly well with tree-ring reconstructed discharge for the Aksu, Kurshab, and Black Irtysh Rivers, and with the water balance of the Lake Balkhash, Lake Issik Kul and Tarim Basins (Fang et al. 2010; Konovalov and Maksimova 2012; Chen et al. 2015, 2017b; Zhang et al. 2016). PDSI and precipitation reconstructions from spruce tree rings in southern Kazakhstan and the broader Pamyr-Tian Shan region are consistently coherent on the decadal scale (Li et al. 2006; Fang et al. 2010; Zhang et al. 2017a, 2017b).

Spectral analysis of the runoff reconstruction reveals a significant ($\alpha = 0.05$) peak at 42.7 years, and other peaks near 11.6, 8.0, 5.7, and 2.9 years (Fig. 18.9). The spectral peaks show some agreement with reported frequency bands in significant modes of variability of atmospheric circulation indices, such as the SH index, East Asian Winter Monsoon (EAWM), and El Nino-Southern Oscillation (ENSO) (Wu and Wang 2002; Jhun and Lee 2004; D'Arrigo et al. 2005). The 42.7-year rhythm is also evident in the smoothed time plot (Fig. 18.9), which shows a prominent low-frequency fluctuation with most recent peaks in the 1950s and early 2000s. Wavelet analysis shows this low-frequency feature most prominent in the late-1800s, and indeed the time plot shows a major low near 1870 flanked by major peaks near 1850 and 1895 (Fig. 18.9). Variance is relatively low over 1975–2000, a period when flow stabilizes considerably below the historical average. This reduced-variance interval is a prominent feature not only of Ili River discharge but also of other reconstructed and instrumental runoff records for internal drainages in Inner Eurasia (Aizen et al. 1997; Yuan et al. 2007; Zhang et al. 2016; Chen et al. 2016, 2017b; Chen and Yu 2017). Interestingly, flow recovers after that segment and is marked by high-amplitude

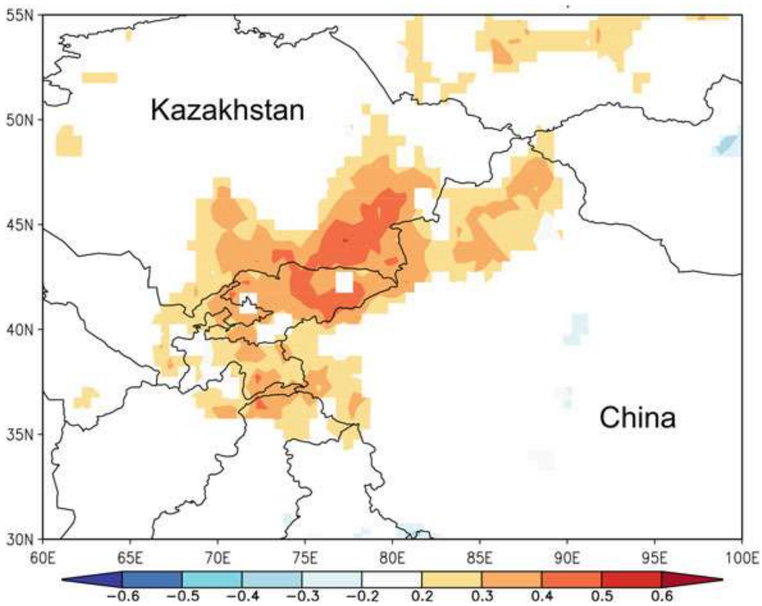

Fig. 18.8 Geographical coverage of runoff represented by the Ili River discharge. Map shows pattern of spatial correlation between reconstructed October-September discharge of the Ili River and gridded October-September scPDSI field (CRU 3.24) for interval 1901–2014 (p_{field} <0.5). *Rectangle* marks the location of tree-ring sites in Semirechye (reproduced from Panyushkina et al. 2018)

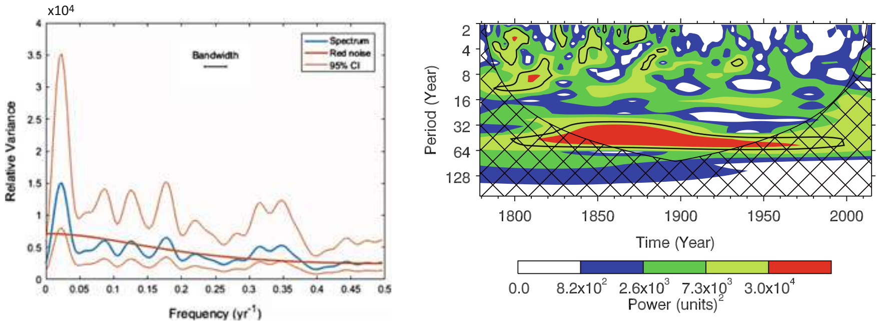

Fig. 18.9 Runoff periodicity in the Lake Balkhash Basin inferred from tree rings (reproduced from Panyushkina et al. 2018). Left plot is smoothed-periodogram spectrum of reconstructed October-September discharge of the Ili River, 1779–2015. Significant spectral peak relative to red noise is at 42.7 years. Cl- confidence level. Right plot is the wavelet power spectrum (Morlet 6.0/6) of the reconstructed series. *Contour levels* are chosen so that 75, 50, 25, and 5% of the wavelet power is above each level, respectively. The *cross-hatched region* is the cone of influence, where zero padding has reduced the variance. *Black contour* is the 10% significance level, using a red-noise (autoregressive lag1) background spectrum

swings, in which the smoothed curve reaches a peak in the early 2000s and a low at the end of the record more extreme than any since the late 1800s (Fig. 18.7).

18.4.3 Linking Ili River Discharge to Climate Change

The physical mechanisms behind runoff changes in Central Asia are not yet well understood. Temperature appears less important as a forcing factor than previously thought (Lammers et al. 2001). Changes in Central Asian instrumental runoff have been reported to be consistent with the decline of snowpack since 1940 (Aizen et al. 1997). Greater snowpack over broader Eurasia results in positive anomalies of instrumental runoff for the largest Siberian Rivers with headwaters in Central Asia (Shiklomanov et al. 2013). The Ili River discharge reconstruction underscores the importance of winter precipitation above summer drought.

Surface pressure over the Ili River basin is positively correlated with surface pressure over the broader geographical region of the seasonally strong SH during the October-February season of snow accumulation (Panyushkina et al. 2018). Anomalous strength and positioning of the SH likely moderates snow delivery to the Ili Basin through steering of storms and winter moisture delivery. Spring moisture as well is important to the river flow (Fig. 18.2), and its conveyance would also be influenced by anomalies in westerly flow (Cohen et al. 2014). This suggests that the SH should contribute to the interannual variability of runoff. A test of this hypothesis with cross-wavelet analysis of tree-ring reconstructed river discharge and SH index (D'Arrigo et al. 2005) fails however, to indicate consistent coherency through time at any band of wavelengths (Panyushkina et al. 2018). Significant coherency is found only at high frequencies (e.g., periods less than 4 years) and then only for some isolated times in the 19th and 20th centuries. Furthermore, where coherency is significant, the phase is opposite; meaning high flow is linked to weak SH. In-phase coherence does appear only near wavelength 30–40 for one episode around the late 1900s.

The link between SH intensity and interannual runoff variability in the Lake Balkhash Basin appears to be complex and may be entangled with Arctic forcing of north-south linkages of atmospheric circulation features in Inner Eurasia (Cohen et al. 2001, 2014). A reconstruction of the latitudinal position of the North Atlantic jet in August from the European tree-ring network explained an exceptional number of extreme weather events like floods and heatwaves in the mid latitudes over the recent decades (Trouet et al. 2018). The finding of an increase in variability of meridional sways of the polar jet could be similarly important for the region considered in this study. Since Arctic thermodynamic amplification can reinforce regional geopotential height patterns, we assume that the late 20th century Arctic warming impacts the hydroclimatic extremes and interannual climatic variability in the study region.

December extremes in the Arctic Oscillation (AO) have been more variable in the past decade than at any other time since the mid-20th century (Overland and Wang 2016; Francis et al. 2017). Generally, large positive values of the AO indicate

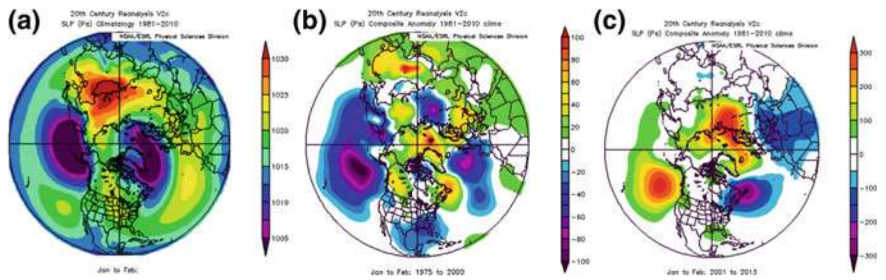

Fig. 18.10 Composite maps of the 20th Century Reanalysis data of January-February surface pressure for **a** normal condition for interval 1981–2010, **b** anomaly low-flow interval of 1975–2000, and **c** anomaly high-flow interval of 2001–2013 reconstructed Ili River discharge (reproduced from Panyushkina et al. 2018)

zonal flow and large negative values suggest increased meridional circulation that brings cold air advection into the mid latitude inland (Thompson and Wallace 1998). Comparison of reconstructed runoff variations with 500 hPa geopotential height and surface pressure anomalies over Eurasia, and with primary teleconnection modes of Eurasia upper air circulation indicates that the natural runoff variability (extremes, decadal trends and spectral properties) are linked to the interaction of Arctic air circulation with the SH intensity and negative phase of North Atlantic Oscillation (NAO). The Ili River discharge correlates negatively with the spring Polar/Eurasian Pattern index (−0.32, $p < 0.05$) and with winter AO (−0.34, $p < 0.05$). Our estimated associations are consistent with a weaker circumpolar vortex during the increased flows. The development of the strong SH has been associated with an enhanced East Asian winter monsoon (Jhun and Lee 2004; Panagiotopoulos et al. 2005), which suggests an even more complex relationship of runoff to the atmospheric teleconnections during the warming trends.

In some intervals, the teleconnections of SH surge the impact on the runoff. The annual discharge correlates significantly and negatively with December-February SH index for 1950–2014 (−0.32, $p<0.05$), and the correlation is driven by few extreme years. The SH is normally centered over Mongolia, to the east of the study area (Fig. 18.10a). A shorter period of generally low recent flows (1975–2000) coincided with a weakening of the SH and a shift of the high pressure southward to the Tibet Plateau. (Figure 18.10b). A subsequent decadal period of generally high Ili River discharge (2001–2013) coincided with increased SH intensity and a shift in the position of the winter surface high toward Western Siberia (Fig. 18.10c).

Clearly, these recent and short time associations are consistent with a positive correlation between the runoff and strength of the SH. In recent decades, therefore, different mechanisms of SH influence on Ili River flow may operate at high frequencies less then 1 year. The resolution of the reconstruction does not allow examination of summer and winter discharge independently or finer periodicity. A side of this ambiguity, snow cover has profound implications for runoff variability in the Lake Balkhash Basin, which is directed by the interaction of SH and AO.

18.4.4 Social Impact of Short-term Runoff Fluctuations in Semirechye During Recent Times

The tree-ring reconstructed discharge of the Ili River represents runoff variability over Semirechye and more broadly over the internal drainages of the Pamyr-Tian Shan Mountain system, which includes bordering southern Kazakhstan, Kirgyzstan, eastern Uzbekistan and China (Fig. 18.8). The historical conquest of Semirechye by the Russian Empire took place between 1847 and 1864. Our data on flow extremes and anomalies suggests that hydrological conditions are unlikely to have a major role in the response of Kazakh population to the military campaign. The Russian troops had been building forts and gradually advancing from the southeastern part of Lake Balkhash Basin westward, finding very minor resistance from the Kazakh nomadic herders in this part of Central Asia. Siberian Cossacks and farmers from the Tomsk Governorate were the first colonists who started agricultural production in the Semirechye. However, the arrival of new settlers coincides with the 1886–1909 wet interval (Fig. 18.7), the farming population significantly increased the area of apple and apricot orchids, gardens, grape estates and wheat fields through irrigation with aryks. By 1909, Verniy (Almaty) uyezd (administrative district of the Russian Empire comparable to the Soviet raion or U.S. county) comprised 23 towns with a population of 277,569 people (Lukhtanov 2014). Russian and Uyghur immigrants arriving from China involved in agricultural production made up 40% of the total population. This illustrates successful adaptation of agriculturalists coming from both wetter and dryer environments (north and south) to farming on the Semirechye alluvial fans in relatively short interval.

During the Soviet period (1918–1990) the government heavily subsidized water allocation and irrigation in the region. Key studies based on instrumental data indicate that runoff in this region has remained unchanged or has declined only slightly (1–2%) over the period 1940–2005 (Aizen et al. 1996; Konovalov and Pimankina 2016). Both low variance of natural discharge during that time and Soviet water management directed by five-year plans of highly politicized economic development that were ineffective (Propastin 2012) but could have muted the social impact of climate stress on the water supply and agriculture production. The situation has changed radically since the Soviet Union collapsed in 1991. Newly independent republics of Central Asia have abolished the high number of USSR water management institutions and abandoned funding, and domestic disputes on the water supply have turned into international conflicts. In modern time, water supply shortfalls in conjunction with rapid economic development and population growth have become a tangible problem for Central Asian countries situated across the internal drainage systems (Bernauer and Siegfried 2008). Weak environmental policies and political tensions over water withdrawals increasingly impact Asian geopolitics and create new international conflict zones (Abdolvand et al. 2015).

Water allocation on the Syr Darya River is the most serious issue in the region. A total of 75% of Syr Darya runoff originates in Kyrgyzstan (Naryn River), then flows through arid and riparian Uzbekistan, Tajikistan and Kazakhstan. Uzbekistan is the major hydrocarbon and irrigation user that formerly controlled the electric power production on the Syr Darya. Around 90% of the Syr Darya annual flow is regulated by reservoirs that are used for irrigated agriculture (Bernauer and Siegfried 2008). The fragile balance was broken when Kyrgyzstan changed the operation mode of the Toktogul reservoir from irrigation to electric power production, and started construction of new power stations. Thus, Uzbekistan and Kazakhstan located downstream, face the most severe water security risks whereas upstream Kyrgyzstan is in almost total physical control of the catchment's runoff.

The Ili River catchment has been the second hotspot of water conflicts in the region since 1999 (Propastin 2012). The mean annual runoff of Balkhash Lake Basin is about 27.8 km^3, 41% (or 11.7 km^3) of which originates in China. Unparalleled economic boom and development in Xinjiang Province, China, challenges the international balance in water allocation and creates uncertainty in the water supply of Kazakhstan. The irrigation area of the Ili River catchment in Kazakhstan (346,000 ha for the Akdala area in the Ili River Delta in 2000) is continually declining, while the Chinese government develops 15 water reservoirs on the Ili River's upstream tributaries (Tekes, Kashe and Kunes) to extend the irrigated area by 450,000 ha. This will increase the annual water consumption of Ili water by Xinjiang Province by 5 km^3/y. Under various scenarios, the forecasted discharge of the Ili River could be reduced from 15 km^3/y to 6-10 km^3/y (Propastin 2012). This would impair the water supply for the Akdala irrigated land and for the largest power station in the region at the Kapchagay reservoir, which has already experienced severe water shortages in the recent decade similar to those of the low flow interval since 2003 (Figs. 18.1 and 18.7). The tree-ring reconstructed discharge shows the changes in spatial–temporal domains of runoff variability before the last 60–70 years of instrumental observations, and provides a historical background of natural runoff variability for modeling the socioeconomic response to water stress. The sharp decline of the Ili River flow after 2003 is comparable to the onset of pronounced drought 1865–1885 (Fig. 18.7), however the social implications of water supply impact on the society are not alike. In modern times, a prolonged climatically-driven period of drought greatly enhanced the water stress in the region as a larger volume of water has been allocated in China due to high rate of economic and population growth, and putting more stress on the remaining flow in the Ili River basin.

18.5 Linking Runoff Variations and Agriculture Along the Historic Silk Road in the Semirechye

The geomorphological reconstruction provides evidence for how the IA population (Saka) used the water of the Talgar River for farming. With limited evidence for early farming in the Bronze and Iron Ages but more detail for the Late IA we can conclude that floodwater farming on the Talgar fan reached its height in the Late IA (400 BC to AD 1); high population density attested from more than 70 settlement sites and

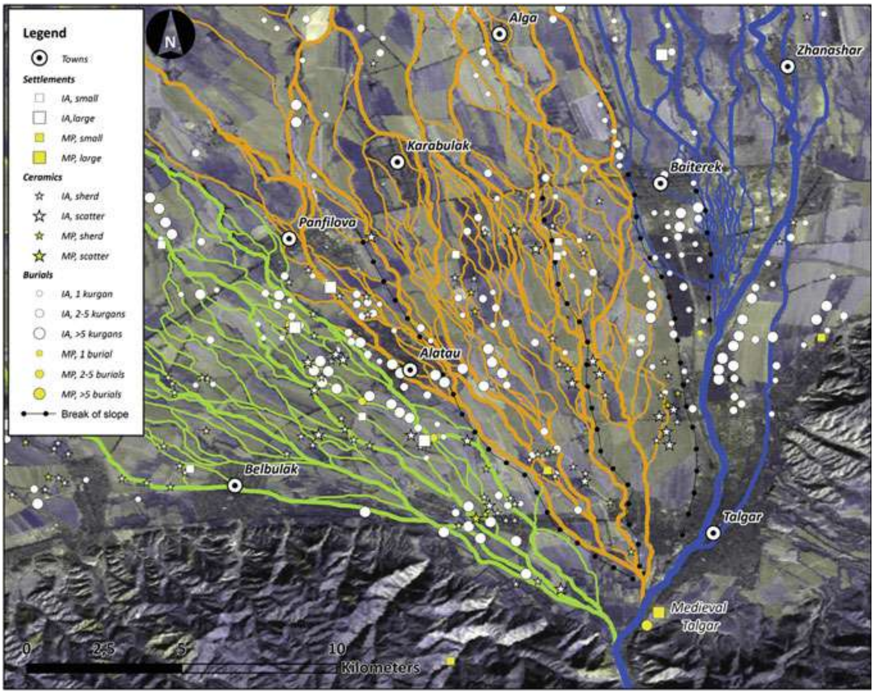

Fig. 18.11 Distribution of archaeological sites on the Talgar alluvial fan (reproduced from Macklin et al. 2015). The positions of archeological sites are compiled from a GIS database assembled by C. Chang and colleagues as part of the Kazakh-American Talgar Archaeological Project. The GIS database categorizes different types of archaeological sites (settlements, cemeteries, and ceramic scatters) using age and morphology of surveyed artifacts, which are plotted on the SRTM satellite imagery (Chang 2018). IA sites are indicated in *white* and medieval sites (MP) in *yellow*. Settlement size was inferred from surface finds (small) and excavations (large). Distributaries of the Talgar River are shown using different colors: Taldy Bulak (*green*), Tseganka (*orange*), and the main Talgar River (*blue*). Breaks of slope separating alluvial fan facets are marked by *black dashes and dots* (after Akiyanova 1998)

700 burial mounds (Fig. 18.11). It is unlikely that the Talgar fan is a single isolated episode of agriculture in the Semirechye, yet supportive archaeological research is largely missing from other parts of Semirechye.

18.5.1 Ancient Agriculture in the Semirechye

The Semirechye is the southeast margin of the Eurasian steppe that extends along the northern piedmont of the Tian Shan Mountains where the northern routes of the ancient Silk Road came together before crossing the Tian Shan Mountains and entering northwest China. The foothills, alluvial fans and rivers of the Tian Shan constitute near ideal environments for floodwater farming (Lewis 1966), with spring-summer floods generated by melting glaciers and snow providing a reliable source of water for irrigation. Floodwater farming is still practiced today in southern Kazakhstan and there is good evidence that in the medieval and prehistoric periods it was an important locus for irrigation agriculture (Groshev 1985; Itina and Yablonskiy 1997).

Eurasian archaeology holds a long-standing debate concerning the development of farming systems in the Eurasian steppes. Traditionally Central Asia, including the Semirechye region, is referred as a pastoral realm during the BA-IA with a shift ca. 800 BC toward a highly mobile pastoralism, followed by medieval nomadism (Christian 1994; Kuzmina 2007; Spengler et al. 2017). As early as 1990s the debates on the mobility development in Eurasia have been pointing to climate change. Christian (1998) describes a mixed farming-herding strategy during the BA (c. 2500–1100 cal BC) under warm and wet conditions with a shift to a horse riding pastoral economy in the Early IA (c. 800 cal BC) coinciding with a cold and dry climate, and deforestation.

However, recently a large body of archaeological evidence from environmentally specialized studies challenges the traditional nomad-centered system in the ancient economy model of Central Asia (Chang 2012; Macklin et al. 2015; Spengler 2015; Frachetti et al. 2017). Achaeobotanical studies at the Talgar alluvial fan strongly suggest that the IA farmers cultivated free-threshing wheat and hulled barley (long-season grain crops), broomcorn, foxtail millet, grapes and apples (Rosen et al. 2000, Spengler et al. 2017). Spengler et al. (2014) demonstrate that a similar assemblage of crops was grown across Central Asia from the Tian Shan to Himalaya during the second millennium BC (BA), and argue (Spengler et al. 2017) that hulled-large-grained forms replaced by the first millennium BC the compact-naked forms of barley dominated in the BA. This revolutionizes our understanding of the spread of ancient farming in Central Asia, and breaks the traditional dogma on the Central Asian economy during the BA-IA. It is clear that in Central Asia regional agriculture and sedentary communities existed since the Late BA.

18.5.2 Agricultural Water Management on the Talgar Alluvial Fan During the Iron Age

Figure 18.11 shows the density of archaeological sites across the Talgar alluvial fan (Macklin et al. 2015). The most-studied Iron Age settlements on the Talgar fan lies along the Taldy Bulak and Tseganka distributary stream networks (green lines) located in the middle reaches of these systems, 5–10 km downstream of the fan apex (Figs. 18.1 and 18.11). Largest settlements, burial sites, and concentrations of surface finds, are preferentially located along a series of distributaries, many of which must have been engineered in order to enable water diversion onto adjacent terraces.

It appears that the key to floodwater farming during the Late IA, similar to modern irrigation, was the control and management of water flow from the Tseganka and

Taldy Bulak channel systems. For the current Taldy Bulak, stream water is still diverted by a simple stretch dam and lateral outlet at the apex of the alluvial fan. The force of flow from the main river 'pushes' water into a low-gradient distributary channel, which allows bringing the flow up onto the higher terrace at downstream locations. IA farmers could also have very well used this simple technique. Notably, the levels of the Talgar River bed during the Early IA were c. 2 m higher than now, such decreasing the difference in gradient between action river channel and engineered distributary. The study of fine alluvial sediments infilling the floor of the Tseganka channel (Macklin et al. 2015 and Fig. 18.3a′) show that flow was not high enough to naturally maintain these distributaries as perennial or seasonal channels. Hence, water supply was depending on engineered channel networks and sufficient discharge to make the upstream bifurcation function.

The bifurcation node of the Taldy Bulak system is roughly 1 km upstream and 5 m above the level where the Tseganka channel leaves the present day Talgar River. IA farmers must therefore have constructed flow control structures to lead water across the fan surface. Careful management of these systems would have been required to ensure that water flow down the Tseganka and Taldy Bulak channels was not too large to cause channel incision, making it difficult and eventually impossible to direct flow into smaller irrigation canals that would have fed fields on the higher fan surface. Indeed, in the Soviet period this is exactly what happened through the inadvertent leakage of flow from concrete irrigation canals. Figure 18.3h shows an example of the Tseganka channel, which locally incised 6 m into fine-grained loess-derived sediments after artificial redirection of flow. Large floods in these distributary systems have always been a significant hazard to floodwater farming because of the highly erodible nature of their channel banks and regional substrate.

18.5.3 Hydrology of the Tian Shan Piedmont and Water Supply for Ancient Farming

In Semirechye, and probably in Tarim Basin, the southern Tian Shan and Pamir piedmont, high river flow and the maximum *potential* for water resources to support floodwater farming in both prehistoric and historical times have been associated with cold and wet conditions and glacier expansion (Sect. 5.1). However, the development of extensive Late IA settlement and rapid growth of population in the Talgar area, supported at least in part by floodwater farming, occurred during a phase of relatively warm and dry climate associated with a period of channel stability. This would suggest that hydroclimate and hydrology, at least locally, were not a constraint to the establishment of IA farming on the Talgar fan, nor were they the only factors in its demise. The key to the success of the Late IA (and medieval) agriculturists appears instead to have been a period of moderate main channel river flows confined within a Late Pleistocene age alluvial fan that as a consequence of having small, partially entrenched distributary channels was naturally configured to facilitate floodwater farming.

We, therefore, do not need to evoke hydroclimate change as the proximate cause for this relatively short-lived (c. 400 years) period of Late IA floodwater farming in the Talgar region. Instead we should develop explanatory models that emphasize the skill of these IA societies in choosing and exploiting particular river environments and hydromorphic regimes that facilitated successful and long-lived farming practices (Macklin and Lewin 2015).

Nevertheless, considering the large Ili, Syr Darya, and Amu Darya dryland rivers downstream of, and fed by, the Tian Shan and Pamir piedmont, conjecture might suggest that wet Holocene neoglacial periods with higher river flow would have been more conducive to floodplain irrigation agriculturists. This may explain the great expansion of irrigation in the region during the first half of the 1st millennium BC as originally noted by Lewis (1966) nearly 50 years ago. New research on Holocene river dynamics, underpinned by robust geochronologies is urgently required on Central Asia's main rivers—the Syr Darya, and Amu Darya—in order to evaluate long-term society-river environment interactions.

18.6 Conclusions

We demonstrated a novel approach integrating fluvial geomorphology and tree-ring studies to explore the relationship between natural variability of runoff and its impact on ancient society. The approach links diverse spatial scales (small river catchments and regional watersheds) and temporal scales (centennial, decadal and inter-annual) of proxies for hydrological variability to explore the relationship between economy and settlement pattern of ancient societies, and climate change. The relative contribution of each method is skewed in this study because the tree-ring records do not overlap the emphasis of archaeological data. Nevertheless, the tree-rings provide valuable insight into a potential mechanism linking variability of recent and past runoff in Central Asia to large-scale atmospheric circulation. The interaction between a warming or cooling Arctic and intensity of the Siberian High surface-pressure system could be a key to unlock that mechanism. The tree-ring reconstructed hydrological extremes provide new information on the length and frequency of droughts and wet episodes in the endorheic basins of Central Asia that may be applied to help decipher strong socioeconomic impacts identified in the post-history of Silk Road.

The new proposed model for use of water by the IA farmers brings into the light many scattered archaeological shreds of evidence related to plant cultivation on the alluvial fans of Pamir-Tian Shan piedmont. We did not anticipate synthesizing these shreds of evidence, yet the reconstruction of river dynamics in the Tian Shan piedmont prompts us to challenge the dogmatic concept of Central Asian nomads prevalent in Inner Eurasian archaeology till now. Previously unknown correspondence of agricultural expansion c. 400–200 BC with a period of reduced flood flows, river stability and glacier retreat in the Tian Shan Mountains explains the strategy of Late IA agriculturists for exploitation of moderate flows within an alluvial fan environment to facilitate transfer of water through a series of partially entrenched distributary channels. Holocene climate change was therefore not a proximate cause for the development and demise of this relatively short-lived (c. 400 years) period of IA farming.

River dynamics in the Tian Shan piedmont are, however, strongly coupled with regional hydroclimatic fluctuations, and they have likely acted locally as 'push' and 'pull' factors for riparian agriculturists in both upstream and downstream directions. Future geoarchaeological research in the region needs to expand downstream from the Tian Shan piedmont into the Ili, Syr Darya, and Amu Darya rivers, as it is likely that these exotic and dryland systems will have human-river environmental dependencies comparable to those of ancient river civilizations in Mesopotamia and the Indus Valley (Giosan et al. 2012; Macklin and Lewin 2015).

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Chapter 19
Demographic Changes, Trade Routes, and the Formation of Anthropogenic Landscapes in the Middle Volga Region in the Past 2500 Years

Leonid A. Vyazov, Ekaterina G. Ershova, Elena V. Ponomarenko, Konrad Gajewski, Mikhail S. Blinnikov and Ayrat G. Sitdikov

Abstract The development of landscapes of the central part of the Middle-Volga region in the last 2500 years was a discontinuous process of the explosive growth of population and land utilization alternating with stages of depopulation and desolation. The periods of depopulation and transitions of cultures occurred at similar times to climate changes. Some cultures were associated with distinct climatic episodes, such as the association of the Dark Ages Cold Period with Hun, post Hun, Heraldic, and Khasarian times, and the Medival Warm Period with the time of Volga Bulgaria. A combination of archaeological and paleoecological analyses allowed us to reconstruct a sequence of landscape and land use changes in relation to the historical development of the region. The first millennium CE was a time of major changes in population, agricultural technologies, social structure, and settlement patterns in the forest-steppe zone. The MiddleVolga region underwent a transition from a non-populated, mainly-forested landscape of first centuries CE to a highly deforested agricultural landscape of the Volga Bulgarian state by the 11th century CE. Within several centuries, the landscape was transformed by shifting cultivation, wood and ore extraction, and the formation and expansion of pastures and road networks. The process of deforestation in the region was facilitated by the relatively warm climates of the Medieval Warm Period.

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Little ice age · Medieval warm period · Dark ages cold period
Roman warm period

19.1 Introduction

In this paper, we provide an overview of the human-environment interactions in the Middle Volga region of Russia during the past 2500 years. Few results of the archaeological research in the region have been published in English, and we therefore present a first summary of the historical and archeological data that have been accumulated over the past century. An important part of this work is a map-based analysis of population dynamics that is linked with a discussion of the trade and landscape development in the region. As the vegetation history and ecosystem dynamics of Middle Volga are poorly understood, we present new paleoecological data obtained from soil profiles and show how these record land use changes over the time period. Finally, we synthesize human and environmental history of the area, and show the potential for future work.

19.1.1 Study Area

The Middle Volga (*Srednee Povolzhye*) is an informal region centered on the middle portion of the Volga River Basin near the confluence of the Volga and Kama rivers (Fig. 19.1). In a narrow sense, it includes four regions of the Russian Federation: Republic of Tatarstan, Penza, Ulyanovsk, and Samara. In some classifications, Mari El Republic, Chuvash Republic, and Saratov Region are also included.

The Middle Volga forms a part of the Middle Russian Province of the East European (Russian) Plain between latitudes of 53° and 56°N and longitudes of 45° and 52°E. Elevations range from 150 m above sea level in the east to 250 m above sea level west of the Volga River. The Volga River bisects the region flowing mainly from west to east in the northern part and north to south in the southern part, with the city of Kazan located north of the sharp bend. For about 650 km the Volga River, along with the Kama River in its lower reaches, forms part of the massive Kuybyshev reservoir (built in 1957) with an area of 5900 km^2.

The bedrock geology is predominately Paleozoic, Mesozoic and Cenozoic rocks covering the ancient crystalline pre-Cambrian Russian Platform below. Much of the upland area east of the Volga River is underlain by Upper Permian sedimentary rocks, with river valleys and lowlands south of the Kama River underlain by Pliocene rocks. West and south of the Volga River is mostly Jurassic and Cretaceous bedrock.

The most recent, late *Valdai* glaciation (*ca*. 21–18 ka; 1000 years before present) did not reach the region, with the main terminal moraines stretching across the Nizhni

Novgorod and Perm regions far to the west and north. Thus, most of the Quaternary landforms are not glacial, and wind-blown loess deposits are fairly common.

The climate of the region is temperate continental Dfb type (Alisov 1956) with long and cold winters (−14 °C mean January temperature) and warm summers (19 °C mean July temperature). The vegetative season lasts between 120 and 150 days. Typical total annual precipitation values are 400 mm in the south and 600 mm in the north, more-or-less evenly distributed over the course of the year. Snow cover lasts between 5 and 5.5 months.

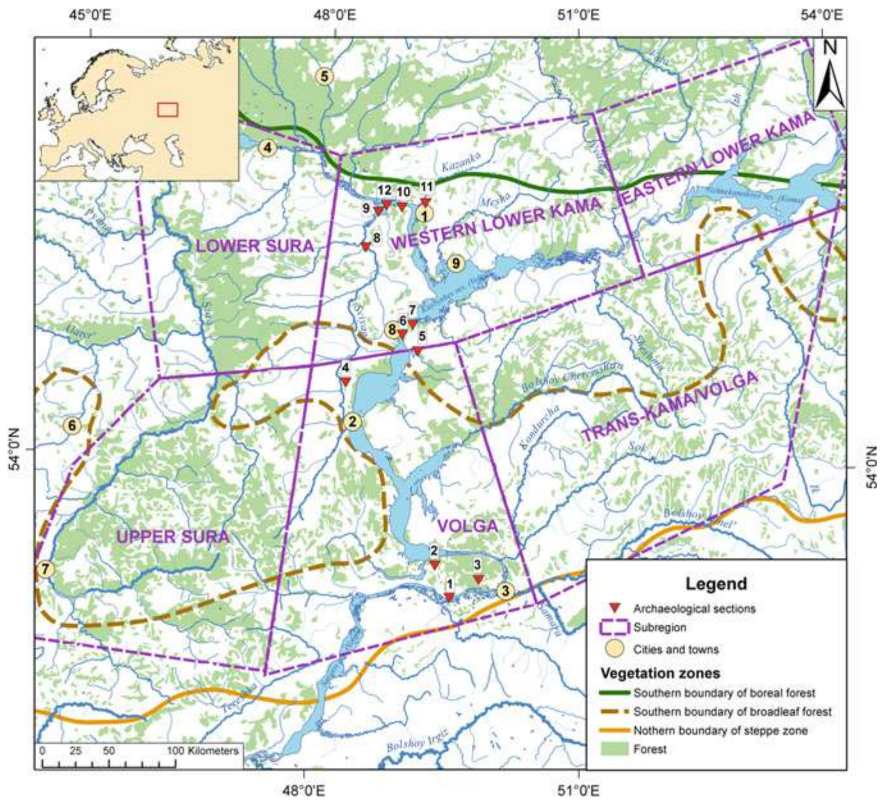

Fig. 19.1 Map of the study area showing the subregions, modern vegetation and major rivers. Sites discussed are noted by numbers, and abbreviations are used in subsequent figures. Red triangles depict study sites/soil sections: **1**—Lbische hillfort (Lb); **2**—Zhiguliovskiy gully (Zg); **3**—Shelekhmet' (Osh-Pando-Ner' 1 and 2 sites) (She); **4**—Komarovka ensemble (Ke); **5**—Tankeevka fortified settlement (Ta); **6**—Urnyak hab. site (Ur); **7**—Bolgar (MI—Maly Jerusalimskiy gully, BI—Bolshoy Jerusalimskiy gully, Bo—medieval city of Bolgar, excavation blocks 178, 179, 189, 199); **8**—Burunduki hab. site (Bu); **9**—Mizinovo hab. site (Ms); **10**—Morkvashi site (Mo); **11**—Kazanka, smaller hillfort (Ka); **12**—Makar'yeskiy hillfort (MaH). Orange circles depict modern cities and towns: **1**—Kazan; **2**—Ulyanovsk; **3**—Samara; **4**—Cheboksary; **5**—Yoshkar-Ola; **6**—Saransk; **7**—Penza; **8**—Tetyushi; **9**—Laishev

The Volga-Kama river system is an ancient waterway with deep, well-developed valleys featuring multiple (commonly three to four) terraces of late Pleistocene to mid-Holocene age. The lower terraces are now mainly covered by the reservoir. A thick mantle of alluvial deposits covers the banks, and in the uplands, loess deposits commonly form steep river bluffs along the valley sides.

The region spans the transition from southern taiga to steppe (Fig. 19.1). A continuous forest is present only in the northern part of the study area. In the central and southern part of the region, the forest is preserved only on sandy soils not suitable for modern agriculture and in areas distant from water sources.

North of the Volga River, spruce (*Picea abies*) is found, while south of the Kama River it occurs only in plantations. The southern limit of its natural distribution today closely tracks the +20 °C July isotherm. Pine-dominated forests are widespread and found as far south as southern Tatarstan. They tend to grow on sandy soils and are pyrogenic in origin. Old-growth pine forests, sometimes with a proportion of oak, are found in Ulyanovsk Region on the right bank of the Volga River and north of the Samara Luka region on the left bank. There are also many scattered pine plantations, mostly <60 years of age.

Mixed forests with spruce, fir, oak, lime, and elm are found in the extreme north of the area The most common deciduous trees in the primary forests are oak (*Quercus robur*), small-leaf lime (*Tilia cordata*), maple (*Acer platanoides*), ash (*Fraxinus*) and two species of elm (*Ulmus*). Scotch pine (*Pinus sylvestris*), aspen (*Populus*) and two species of birch (*Betula*) grow in the secondary forests. Local forest communities occur on the floodplains (willows and alders) and in the steppe ravines (prunes, wild cherry). Oak forests and oak-lime forests are the two most important and presumably ancient forest types in the region. Some oak forests are found on highlands, while others may occur along the rivers on high terraces. Oak is temperature-limited towards the east, where lime replaces it as the dominant broadleaf tree.

The steppe in the region is mainly of the meadow variety with a diverse and common forb community consisting of species from the Rosaceae, Caryophyllaceae, Fabaceae and Asteraceae families and with needlegrass (*Stipa* spp.) and bunchgrass fescue (*Festuca valesiaca, F. pseudovina*). Steppes are found locally in small fragments in southernmost Tatarstan and in parts of the Samara and Ulyanovsk regions, although little steppe survives, as much has been transformed into farmlands. While over 50% of the region is under cultivation today, the remainder is fallow or pastureland (25%), forest (20%), water and settlements.

In the southern taiga, game is plentiful (brown bear, roe and common deer, moose, wild boar, beaver, capercaillie) and wolf and lynx can still be found. In the steppe, red fox and badger are important, and there are many rodent and shrew species as well. Both the Volga and the Kama river valleys are important migratory corridors for birds. Many of these animals played a major role in the diet of early agriculturalists in the region.

In the past 30 years, much farmland was abandoned and progressively reclaimed by forest. Birch, maple, and elm are the dominant tree species growing on former farmlands and pastures, and pine is a common pioneer species of the previously overgrazed slopes. The recolonization by tree and shrub vegetation is especially noticeable in floodplain meadows that were traditionally in high demand for haying.

19.1.2 Human History of the Area: The Sources of Information

19.1.2.1 Written Sources

The first written descriptions of Middle Volga landscapes and environment appeared in the 9th to 10th centuries CE. The most important original description of Middle Volga that was written by an eye-witness and survived until our time was “Risala”, or “The Journey to the Country of Bulgarians” by Ibn Fadlan, a secretary of the Bagdad Embassy (Journey of Ibn-Fadlan 2016).

19.1.2.2 Archaeological Records

Archaeological research in the Middle Volga region began over 100 years ago. In the initial stage from the end of 19th century to the beginning of 20th century, the most significant archaeological sites of the region were found and the basic typology of archaeological materials was developed. The first maps of archaeological sites were created, and some interesting sites, mainly burials, were excavated. From mid-20th century onward, research focused on the development of the chronological and ethnocultural interpretation of findings. Archaeological cultures were determined as complexes of typologically similar sites and artifacts found within a specific area over a certain time period.

A more intensive program of archaeological research between 1950 and 1980 CE produced a large body of data which allowed for the reconstruction of the cultural dynamics in the region. Attempts were made to reconstruct the ethnicity and subsistence of the archaeological cultures. In recent decades, the development of new methods of paleoecological analysis has opened opportunities for the reconstruction of human-environment-subsistence interactions.

19.1.3 Environmental History of the Area

Most palynological data for the forest-steppe zone of European Russia have been obtained from bogs and archaeological sites (Serebryannaya 1976; Klimanov and Serebryannaya 1986; Spiridonova 1991), however the age of the layers was either unknown or derived from archaeological seriation. In the entire Middle Volga region, only one systematic palynological study was done in a peat bog, however, it was not radiocarbon dated and was based on small pollen counts (Blagoveshenskaya 2009). Radiocarbon-dated palynological spectra were obtained for peat bogs only in the western portion of the forest-steppe zone to the west of the Middle Volga, in the upper Don, Orel, and Kursk regions (Novenko and Olchev 2015; Novenko and Volkova 2015; Novenko et al. 2009, 2011, 2015, 2016). These studies revealed the following environmental phases:

1. *7000–4800 cal year BP*: Forest-steppe was the dominant vegetation in the region. The pollen spectra contained 10–55% arboreal pollen (AP), represented mainly by *Pinus* with a proportion of *Quercus* and *Tilia*. Xerophytic/steppe taxa (e.g., *Ephedra*) were present. A short-term cooling and increase in moisture were reconstructed for the time period between 6750 and 6500 cal year BP. The first evidence of pastures was found in pollen of Neolithic layers and Bronze Age layers contained evidence for both grazing/pastures and crop production.
2. *4800–1700 cal year BP*: Between 4800 and 3700 cal year BP, the forest margin moved southwards, *Picea* became an ubiquitous component of the pollen spectra and broadleaf taxa increased in abundance. An increase in AP between 3700 and 1700 cal year BP was attributed to climate cooling. Despite this general trend, some sites experienced fire-triggered deforestation during this period.
3. Between *1700 and 1300 cal year BP* and from *900 to 700 cal year BP*: Fire-triggered deforestation was recorded in the area, presumably due to land clearance for agriculture. During the periods between 1300 and 950 and 600–500 cal year BP, elevated AP indicates an increase in forested area.

The area north-west of Samara Luka (Fig. 19.1) was almost entirely forested (pollen was mainly *Quercus*) in the mid-Holocene, between 6000 and 4500 cal year BP (Blagoveshenskaya 2009). In the early Subboreal, ~4500–3200 cal year BP, *Betula* and *Alnus* pollen became more abundant, while oak pollen declined. The proportion of arboreal pollen decreased towards the end of the period. The Subatlantic, ~2500–700 cal year BP, was marked by an increase in *Pinus* pollen. This time period was associated with the transition to the Iron Age and spread of agriculturalism in the region. Finally, pollen spectra attributed to the last 2500 years have low proportions of AP, characteristic of the forest-steppe transition zone.

19.2 Methods

19.2.1 Archaeology

The archaeological data were analyzed at several scales. At the macro-level we analyzed the degree of the development of the territory based on the locations of archaeological sites of Middle Volga published in regional archaeological maps (Archaeological Map of Tatarstan 1981–1990; Burov 1977; History of Samara Volga Region 2000; Archaeological Map of the Chuvash Republic 2013–2015). Sites were ordinated into cultural areas (groups of the archaeological cultures), archaeological cultures and cultural types, and the chronological frame was based on recent publications. In most cases the ages of archaeological sites were determined by relative archaeological dating, although some sites were radiocarbon dated. Site topography and location in relation to the distance from water sources was determined. Maps of the distribution of sites for the various time periods were obtained from the database of the Khalikov Institute of Archaeology of the Tatarstan Academy of Sciences (Kazan, Russia) and plotted in ArcGIS. To analyze the degree of development of the territory, the "kernel density" tool in ArcGIS was applied. Subsistence strategies were described according to published data as well as our recent work.

19.2.2 Paleoclimate Inferences

Paleoclimate reconstructions of the past 2500 years were obtained from the National Centers for Environmental Information (USA) Paleoclimatology Database (www.ncdc.noaa.gov/paleo). There were no data available from the immediate area, so regional-scale temperature reconstructions of Europe and Asia from the recent PAGES2k global climate synthesis of the past 2000 years were obtained (PAGES2k Consortium 2013). Three longer summer temperature reconstructions based on tree-rings were available from Europe and Russia (Esper et al. 2012; Büntgen et al. 2016) and also plotted in C2 (Juggins 2007).

19.2.3 Paleoenvironments

19.2.3.1 Sites

Our reconstruction of the ecosystem dynamics for the last 2500 years was based on an analysis of 20 sites in the Middle Volga region (Fig. 19.1). Instead of analyzing a continuous chronological sequence of layers in one site, we analyzed synchronous layers from many different sites and then ordinated the results into a chronological sequence. Pollen spectra for each time period were derived from several sites located in different geomorphological positions. We assume that such an approach would reflect both the temporal dynamics of vegetation and spatial variations in the vegetation cover indicative of the local land use structure.

The following deposits were analyzed:

1. Colluvial deposits and immature soils on slopes and in gullies and located in the vicinity of archaeological sites (archaeological ensembles of the Hun, Post-Hun and Khazar periods in Ulyanovsk and Samara Regions).
2. Immature soils and surficial layers of mature soils buried under anthropogenic deposits. Examples are soils buried under earthen fortifications (fortified settlements of the Early Iron Age in the north-western part of Tatarstan) or immature soils that formed on construction debris and buried under the materials that were dug out and redeposited during the next construction stage of the medieval city of Bolgar.

3. Tree uprooting structures dividing occupational layers of subsequent periods (Hun/post-Hun/Khazar/pre-Mongolian).

In most cases, several layers of different ages were analyzed in each site, varying from two layers in upland sites to 15 in gullies. Occupational layers of habitation sites were generally avoided, as these could be strongly affected by the input of pollen from anthropogenic materials. Layers were synchronized with archaeological cultures based on the presence of diagnostic archaeological artifacts, using radiocarbon dating of charcoal from the layers, or both.

19.2.3.2 Soil Pollen Analysis

Samples were processed by acidification with 10% HCl, boiling in 10% KOH, and centrifuging with heavy liquid (sodium polytungstate) (DeVernal et al. 2010). Counting was done on a light microscope with a magnification of 400–1000x, and 250–300 grains were identified per sample. The percentages of pollen taxa were calculated on the basis of total pollen, and the percentage of spores was based on the total number of pollen and spores. A principal components analysis of the more common pollen taxa (mean > 1% or maximum value > 5%) was performed on the correlation matrix to summarize the pollen assemblages.

19.2.3.3 Dating of Layers

The age of selected layers was determined by AMS radiocarbon dating of charcoal. The layers associated with human occupation commonly contain charcoal, moreover, the presence of charcoal is often considered as evidence of human occupation. Archaeological dates were obtained for layers that had a clear cultural affiliation. Not every layer was radiocarbon dated; for some layers in colluvial sequences an approximate age was estimated using the age of a basal layer and calculated accumulation rates. Some undated layers were placed in a chronological order according to their stratigraphic position between radiocarbon-dated layers.

19.3 Results

19.3.1 Outline of the Cultural Dynamics of the Middle Volga Region

The cultural and economic history of the region can be summarized into eleven periods prior to the modern times (Fig. 19.2).

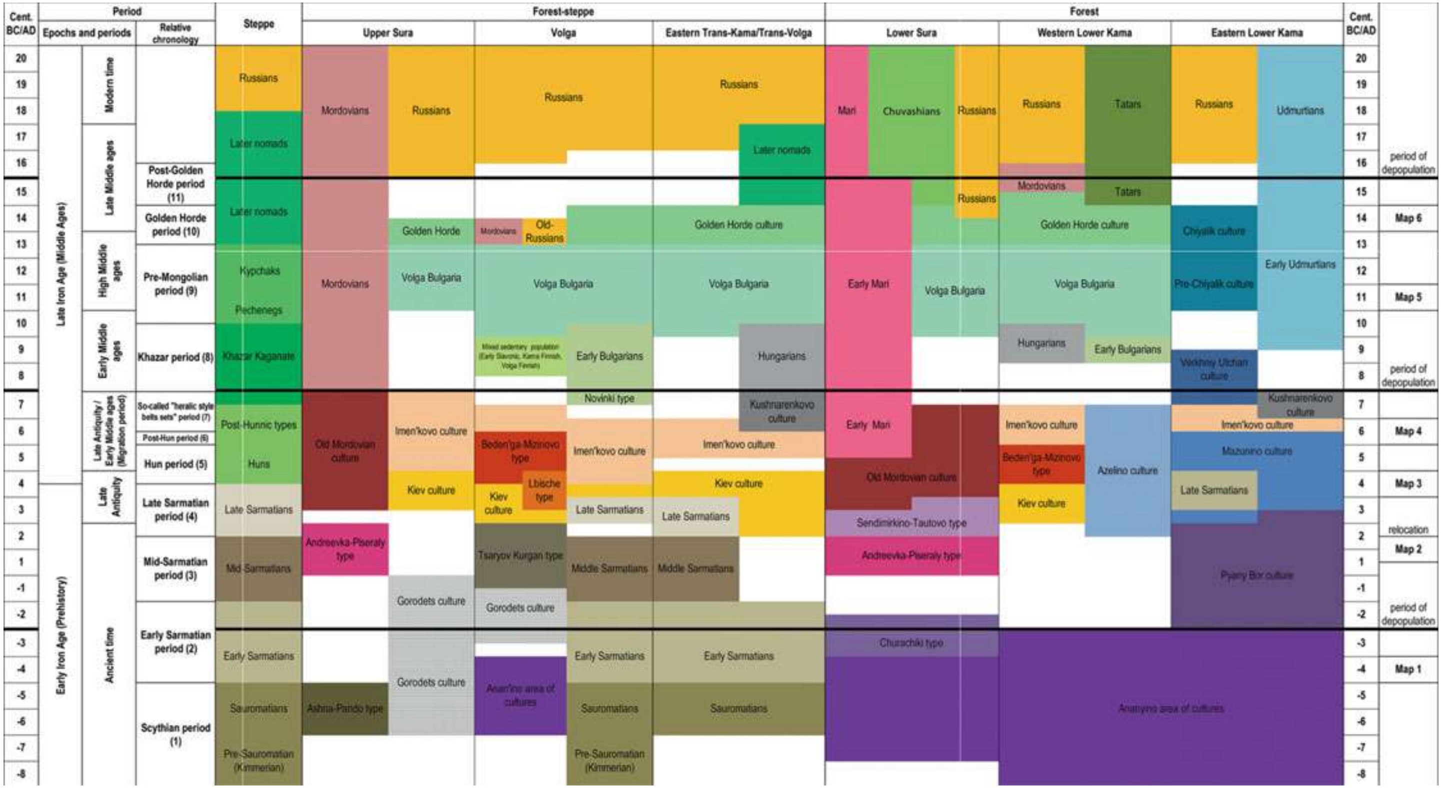

Fig. 19.2 Summary of the cultural history of the Middle Volga region. Colors match those in Fig. 19.3. Probable ethnic interpretation: Brown—Iranian-speaking people; Purple—Pre-Finno-Ugric people; Red—Volga Finnish-speaking people; Blue—Kama Finnish-speaking people; Grey—Ugric-speaking people; Yellow—Slavonic-speaking people; Green—Turkic-speaking people

19.3.1.1 Scythian Period, 8th–4th Century BCE

From the 8th to 4th century BCE, the banks of the Volga and Kama rivers were inhabited by several groups of people belonging to the cultures of the *Ananyino* area (Fig. 19.3, Map 1). There are at least 200 sites of the *Ananyino* cultures in the region, located within the forested areas. The *Ananyino* peoples lived in well-protected bluff forts surrounded by open settlements situated several kilometers apart, on both high and low banks of the largest rivers (Orudzhov 2017). Their subsistence is poorly known but they were undoubtedly pastoralists who used the surrounding forests for hog grazing. There is no clear evidence of agriculturalism (Petrenko 2009; Kuz'minykh and Chizhevsky 2009).

From the 8th to 4th century BCE, the steppes were populated by nomadic *Sauromatian* people. The northern boundary of the nomadic territories followed a line from Ulyanovsk to the middle reaches of the Bolshoi Cheremshan River and from there to the town of Ufa (Myshkin and Skarbovenko 2000). During the next stage, there was a prolonged depopulation of the Middle Volga region.

19.3.1.2 Early-Sarmatian Period, 4th–2nd Century BCE

The late stage of the cultures of the *Ananyino area* is dated to the 4th to 2nd century BCE (Chizhevsky 2017), synchronous with the *Early Sarmatian* culture of the steppe zone of Eastern Europe. At this stage, *Ananyino* sites were more numerous on the middle Kama River and in the forest-steppe of the Volga region. The disappearance of the cultures of the *Ananyino* area was followed by a decrease in population and a gradual cultural differentiation of the Middle Volga region. Some groups of people probably lived only at the northern periphery, while the central part was depopulated, except for solitary settlements and hillforts of *Gorodets* culture in the Volga River valley (Matveeva 2000a).

The *Sauromatian* culture in Volga-Urals steppe was replaced by the *Prokhorovka* culture of the 4th–2nd century BCE. The *Early Sarmatian* culture spread northward of the Kama River (Chizhevsky 2017) through both cultural contacts and also a physical movement of nomadic peoples.

19.3.1.3 Mid-Sarmatian Period, 1st Century BCE—2nd Century CE

Repopulation of the region began in the first centuries CE when two groups of people moved into the broadleaf forest zone (Fig. 19.3, Map 2). In the north-west, sites of *Andreevka-Piseraly* type appeared (Myasnikov 2013) that played a major role in the formation of Middle Volga Finnish ethnicity, beginning with the *Old-Mordovian* culture. *Andreevka-Piseraly* archaeological sites are distinctive burials of foreign military groups as well as fortified and non-fortified habitation sites. The habitation sites usually have thin occupational layers poor in artifacts, indicating brief occupations. The land-use system and subsistence have not been studied.

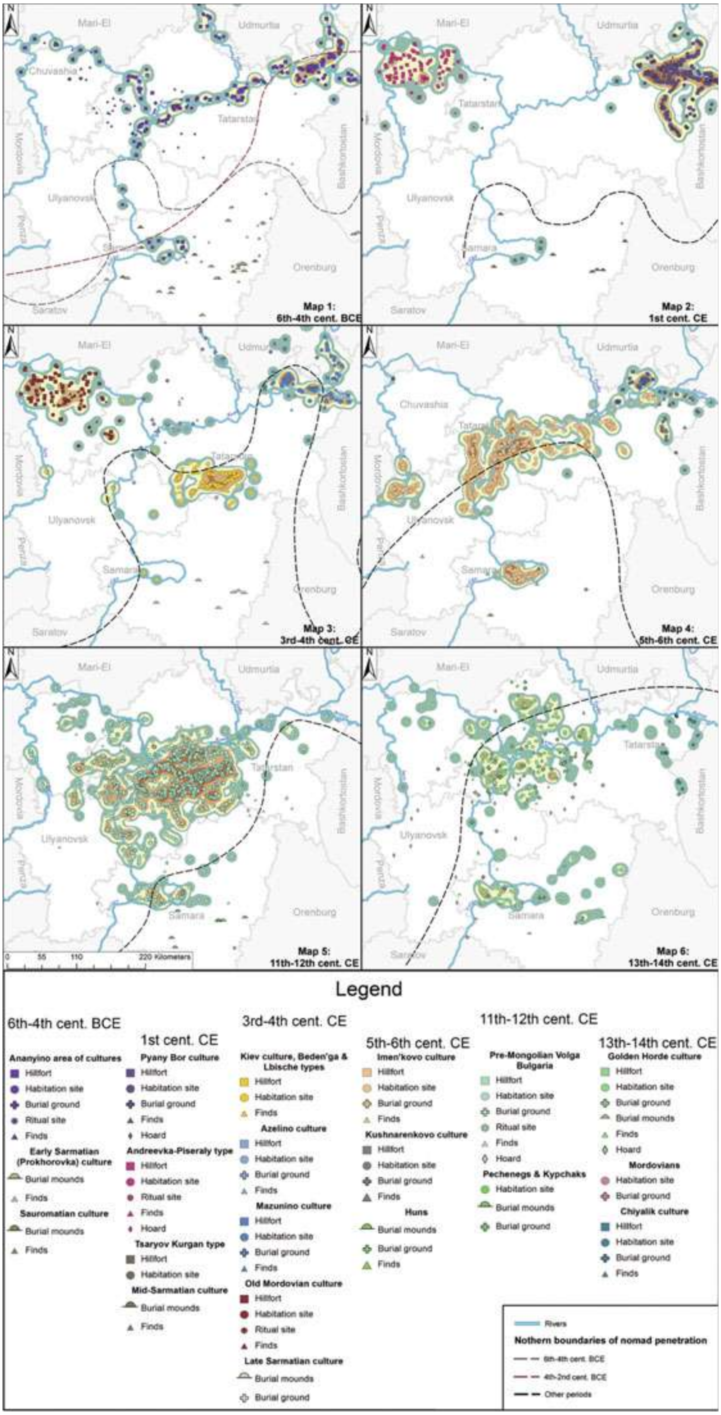

Fig. 19.3 Maps of the distribution of archaeological sites, classified by culture and site type. Colors on the maps match those used in Fig. 19.2

The *Pyany Bor* culture expanded into territories north of the Kama and east of the Volga rivers between the 2nd century BCE (shortly before the Mid-Sarmation period) and 2nd century CE (Ageev 1992). *Pyany Bor* sites were most dense in the lower reaches of Belaya River and adjacent areas of the lower Kama River, where more than 300 habitation and 40 burial sites have been found (Fig. 19.3, Map 2). The subsistence system is interpreted based on site locations. *Pyany Bor* sites were located on high terraces of rivers with wide floodplains, or occasionally in the floodplains, which may indicate the importance of fishing. Subsistence was presumably based on swidden cultivation and complemented by hunting and pastoralism, focused on horse and cattle livestock (Bugrov et al. 2011).

In the southern and southwestern parts of the region, a few groups of migrants from the southwest (probably from the Don River area), had appeared by this time. The sites of these small sedentary groups, called *Tsaryov Kurgan* type, are located on high hills in the forest-steppe (Stashenkov 2003; Volkova 2017). Only short-term, solitary archaeological sites have been found, with few artefacts in their occupational layers. Therefore, the Middle Volga region remained largely depopulated until the 3rd century CE. The marginal groups of people inhabiting small areas along rivers had non-specialized multi-faceted subsistence and their impact on the environment at this time period could not have been extensive.

Finally, nomadic groups of the *Middle-Sarmatian* culture were advancing northwards in the steppes, on the left bank of Volga River, penetrating up to the mouth of the Bolshoy Cheremshan River. Middle-Sarmatian artefacts were also found in several habitation sites in the Samara Luka region (Fig. 19.1) and to the south (Myshkin and Skarbovenko 2000; Matveeva 2003). The movement of nomadic groups into the forest-steppe region was more pronounced in the Early Sarmatian time, from 4th to 2nd century BCE, as the number of the archaeological sites attributed to nomads of the Middle-Sarmatian time was noticeably smaller (Myshkin and Skarbovenko 2000). It is not yet clear whether the absence of archaeological sites (and population) in the Middle Volga region at the turn of the eras was caused by hostilities among various groups or some other, perhaps environmental factors. However, the depopulation of the area set the stage for intensive exploration of the landscape by newcomers immediately prior to and during the Migration Period.

19.3.1.4 Late-Sarmatian Period, Middle of the 2nd to the End of the 4th Century CE

After a long period of depopulation, a new wave of migration to the Middle Volga region began at the end of 2nd to the beginning of the 3rd century CE. Both the local population that lived at the periphery of the region and new migrants from remote areas were part of this process (Fig. 19.3, Map 3). In the Sura River basin, new cultural traditions were developed by descendants of the *Andreevka-Piseraly* people. They left sites of the *Simdimirkino-Tautovo* type in the southern part of Chuvashia, and can be considered as the earliest population of the *Old-Mordovian* culture (Myasnikov 2013). Numerous, but small and poorly fortified hillforts and settlements in the 1st to 2nd quarters of the first millennium CE were located along small streams or ravines

(Fig. 19.3, Map 2). Tools associated with farming or cattle breeding are unknown, and the economic system is poorly understood.

At the same time, the western part of the Lower Kama region was inhabited by a small but widespread population of the *Azelino* culture (Gening 1963), who were the descendants of the *Pyany Bor* cultural tradition (Fig. 19.3, Map 3). The location of the *Azelino* sites along the large rivers indicates that they migrated from east to west/southwest, eventually crossing the Volga and Kama rivers. Not more than 50 archaeological sites of *Azelino* Culture are concentrated within the territory of the Volga-Vyatka interfluve. Most are burial grounds; habitation sites have not been sufficiently surveyed (Leschinskaya 2014). Among the findings that characterize the subsistence of the population are many specialized hunting arrowheads, knives for apiculture, skeletons of riding horses (imported from the steppe zone), and skeletons of dogs found in burials. *Azelino* population subsistence was largely focused on forest resources.

A new group of nomads, termed Late Sarmatians, spread into the steppe zone of Eastern Europe in the 2nd to 4th centuries CE. This population also occupied the left bank of the Volga River; burial grounds were found in the Trans-Volga and Trans-Kama regions (Myshkin and Skarbovenko 2000).

Another population appeared in the forest-steppe zone. One of the groups is the most eastern type of the *Kiev* culture of the second quarter of the first millennium CE. The oldest sites of this culture appeared in the Trans-Volga area as early as the beginning of the 3rd century CE (Stashenkov 2005). At the same time or slightly later, they also appeared in the valleys of the Sura (Vyazov et al. 2016) and Volga rivers (Vyazov and Semykin 2016). About 140 unfortified sites attributed to this cultural group are located on the low banks and first terraces of small rivers. The settlements were generally several hectares in size, forming long chains of sites spaced 1–2 km apart. Osteological remains indicate that they relied on animal husbandry with a relatively important role of small cattle breeding and with a much smaller proportion of meat provided by hunting (Stashenkov 2005). The role of agriculture has not been sufficiently studied, but they did not have soil tillage implements suitable for ploughing. It is possible that settlements of this population were very short-lived.

A distinct cultural complex of so-called *Lbische* type appeared in 3rd to 4th century CE in the Samara Luka as a result of migration of sedentary groups from the south and southwest (Stashenkov 2010a). The *Lbische* people led an isolated life in two large, well-protected hillforts. The absence of wild animal bones in these sites (Petrenko 2011) indicates that they used only domestic cattle as the source of meat. Both the *Kiev* and *Lbische* people used small iron sickles that first appeared in the middle Dnieper region among forest-steppe Scythian-influenced cultures and ultimately spread throughout the East-European forest-steppe. The new population of the forest-steppe zone interacted with the Late Sarmatians, whose burials where found in *Kiev* and *Lbische* sites (Stashenkov 2005; Matveeva 2000b).

The penetration of the new groups of people into the region did not lead to the disappearance of other cultural traditions. Sites of the *Azelino* culture became even more numerous and wide-spread, appearing on both banks of the Volga River and in Trans-Kama area (Bugrov 1998). In the eastern part of the lower reaches of the

Kama, a new culture of *Mazunino* (Ostanina 1997) developed from the *Pyany Bor* culture in the 3rd century CE. The subsistence of the *Mazunino* population followed *Pyany Bor* traditions of multi-faceted forest utilization with a major role for hunting and gathering. Over 420 *Mazunino* sites are known and this is a significant increase in comparison to their predecessors. New types of tools, including sickles and narrow-blade iron axes, appeared in their tool set. The distribution of sickles may reflect the migrations of *Kiev* and *Lbische* people, whereas the appearance of narrow-bladed axes resulted from cultural contacts with the population of the Oka basin. *Mazunino* sites were commonly hillforts ("palisaded homesteads") of under one hectare in size and located in small river valleys, unlike the *Pyany Bor* sites associated with wide floodplains (Ostanina 1997). A scattering of pottery shards, common around the hillforts, is usually interpreted as the occupational layers of settlements but can also be associated with agricultural activities. However, evidence for farming is scarce and based on solitary finds of charred cereals. Grinding stones are interpreted as tools for processing crops, which would indicate that the population either produced or traded small amounts of cereals. Osteological remains suggest that hunting played a major role in their subsistence and apiculture knives emphasize the importance of the forests in the economy.

A similar economic system was formed at the opposite edge of the region, in the Sura Basin. Two versions of *Old Mordovian* culture appeared in the 3rd century CE (Grishakov 2017), located in lower (Myasnikov 2013) and upper reaches of the Sura River (Grishakov 2000). They are considered to be predecessors of the medieval Mordovian population. Therefore, in the 3rd to 4th centuries CE, the landscapes of the Middle Volga region were populated and transformed by groups of migrants from the southwest. The exploration and utilization of the landscape began initially in the forest-steppe, clustered along river valleys. The areas in the vicinity of rivers were dotted by dozens of short-lived settlements located within one to three km from each other.

19.3.1.5 Hunnic Period, from the End of the 4th to the End of the 5th Century CE

The Hunnic invasion triggered a period of significant cultural transformation. In the late 4th to early 5th centuries CE the entire Eastern European culture was reshaped as cultural relations were destroyed and the vectors of contacts and interactions changed. The Middle Volga region also underwent significant cultural change.

The archaeological remains that are attributed to Huns and related nomads in the steppe zone are solitary burials and findings of (ritual?) bronze cauldrons (Zasetskaya 1994). The northern boundary of their distribution runs along a line from the source of Sura River to the middle reaches of the Bolshoy Cheremshan River and further to the east (Polivanov 1890; Stashenkov 2007; Bogachev 2000). Several groups of well-armed people moved across the Kama River from the southwest (Gening 1976). The changes triggered by the Hun invasion of the steppes occurred also in the forest-steppe zone and in the southern parts of the forest zone, where the Hunnic time was the period of the greatest cultural diversity.

In addition to the existing *Kiev* and *Lbische* population, two more groups of people appeared in the forest-steppe at this time. Short-lived villages and fortified settlements of the *Beden'ga-Mizinovo* type are found on the west bank of the Volga and in the Sviyaga River valley. The material culture of this type could originate from the *Old Mordovian* and *Kiev* culture with some admixture of traits characteristic of Oka Basin Finnish groups. Iron ore mining was an important part of the economy, predominantly surface deposits in the Volga-Sviyaga interfluves (Vyazov and Semykin 2016).

The second and more numerous group of sites are from the early stage of the *Imen'kovo* culture (Stashenkov 2010b), which appeared along the Volga River and in the middle reaches of the Sura River at the beginning of the Hunnic times (Fig. 19.3, Map 4). The source area for this migration is still unknown (Matveeva 2004). In the early stages, sites of this culture were represented solely by unfortified settlements of one to two hectares confined to the terraces and banks of oxbow lakes (Vyazov 2007). The abundance of fish bones in the sites indicated that fishing was an important part of the *Imen'kovo* subsistence. Hunting in the forests was apparently as important as raising livestock, as reflected by a high proportion of wild species bones (Petrenko 2011). The large thickness of the occupational layers, which include an abundant and diverse set of household items, and the diversity of archaeological features (e.g., various pits) unequivocally point to the long-term functioning of the *Imen'kovo* habitation sites. The high density of dwellings suggests large numbers of inhabitants in the settlements. Numerous finds of sickles and dolomitic millstones used for the manual grinding of cereals in the earliest sites of this culture attest to the importance of agriculture (Matveeva 2004). The *Imen'kovo* people were agriculturalists who developed an economic system more efficient than that of any other cultural groups of Hunnic times in the region.

The *Imen'kovo* people are believed to be the first truly sedentary inhabitants of the region (Matveeva 2004). The high-efficiency land use system played an important role in the rapid expansion of the *Imen'kovo* population throughout the Middle Volga in the 5th century, which occurred alongside the disappearance of other cultures or their displacement from the region.

19.3.1.6 Post-Hunnic Period, End of the 5th to the Middle of the 6th Century CE

The boundary between the Hunnnic and post-Hunnic periods in the Middle Volga region is tentative due to the lack of radiocarbon-dated burials and stratified habitation sites. According to our recent radiocarbon datings, it could be set somewhere between the middle of the 5th and the beginning of the 6th centuries CE. The general trends of the regional development that started by the end of the Hunnic time continued during the later period.

By the end of the Hunnic period, the *Imen'kovo* population was the largest in the region and one of the largest cultural entities of Eastern Europe. By the beginning of the 6th century, the *Imen'kovo* population occupied the entire forest-steppe zone of the region, while other cultural entities were either forced out of this territory or assimilated. The *Imen'kovo* culture reached its maximum extent in the post-Hunnic times, with over 500 sites, including about 100 hillforts. These are located in the Sura region, in the Sviyaga Valley as well as on the both banks of the Volga and Lower Kama rivers.

During the 5th century, unfortified settlements on the low river terraces ceased to exist and the *Imen'kovo* population expanded to the high banks of rivers and gullied areas of the upper river terraces. The settlements became spatially structured, with numerous small settlements ("suburbs") clustered around a much larger settlement or a well-protected hillfort (Vyazov 2007) (Fig. 19.3, Map 4).

The change in settlement structure was accompanied by a change in the tool set. The most important example is the appearance of small iron ploughshares, which are more numerous in the sites of *Imen'kovo* culture than in other cultural formations of Eastern Europe of this time (Vyazov 2008). Larger and more effective sickles and numerous finds of millstones attest to large scale grain production. Finally, narrow-bladed axes with socketed heads are frequently found (Vyazov 2012).

The *Imen'kovo* population caused a significant alteration of the landscapes of the Middle Volga region by the second half of the 5th century. Along with land clearance for habitation sites and agriculture, activities related to mining and processing of iron could have played an important role in changing the landscape.

The agricultural tool set of the *Imen'kovo* culture is only found in the Middle Volga region, although some components appear in the cultures of the surrounding areas. For example, millstones were found in *Mazunino* sites, and a short scythe of the late *Imen'kovo* type was found in one of the late *Azelino* burials. However, the small number of these findings indicates that the other cultures only borrowed some tools from *Imen'kovo*, but this was not linked with significant changes in their subsistence.

Nomadic artifacts of post-Hunnic times are limited to areas south and east of the *Imen'kovo* territory, in Trans-Volga on the border between the forest-steppe and steppe zones. The single burial (Bogachev 2000) and some accidental finds associated with elite groups of nomads were discovered in the Ulyanovsk part of the Middle Volga region, dated either to the first half or mid-6th century CE (Zasetskaya et al. 2007). Apparently, the steppe population of this time was not numerous.

19.3.1.7 "Heraldic Type Belt Sets" Period, Middle of the 6th to the End of the 7th Century CE

In the middle of the 6th century, a new migration wave reached the steppe region. It was forced by aggressive Turkic campaigns, which led to the establishment of the Turkic Khaganate. After the Turkic military elite fashion, a new style of belt sets decoration, with belt plates shaped as a heraldic shield, spread over the steppe zone of Eurasia. While the Turkic Khaganate itself did not strongly influence the cultural processes in Eastern Europe, this fashion became popular in the steppe and forest-steppe, from Byzantium to the Altai Mountains, and gave its name to the time period. In the Middle Volga region, this period was a time of asynchronous decline of the *Imen'kovo* culture followed by depopulation of the region.

The reasons behind this process are not fully understood. The latest of the *Imen'kovo* sites are dated to the first half of the 7th century in most regions east of the Volga. On the right bank of Volga River and on the banks of the Sura River, *Imen'kovo* sites survived until the middle of the 7th century and perhaps until the beginning of the 8th century (Vyazov et al. 2016). Another very late group of the *Imen'kovo* population appeared in the eastern part of the Lower Kama region (Gening 1977; Ostanina 2002).

Several groups of newcomers replaced the *Imen'kovo* population. In the eastern part of Trans-Volga, a new population of the *Kushnarenkovo* culture (Kazakov 1981), spread in the second half of the 6th century (Fig. 19.3, Map 4). For the first decades, the *Kushnarenkovo* people lived in contact with the *Imen'kovo* population from the southern bank of the Kama River to the Samara Luka region, as shown by finds of *Kushnarenkovo* potsherds in *Imen'kovo* dwellings. After the collapse of the *Imen'kovo* culture, the *Kushnarenkovo* people remained in the Middle Volga region south of the Kama River. The subsistence system of this population is unknown. The presence of very thin occupational layers of the *Kushnarenkovo* habitation sites is consistent with a relatively mobile, semi-nomadic lifestyle. Descendants of the *Kushnarenkovo* population are considered to be ancestors of the Hungarians.

To the west of the *Kushnarenkovo* cultural area, on the left bank of the Volga, several very rich burials of the nomadic aristocracy were found. A set of finds called the "Burakovo hoard" and another discovery in the vicinity of Ulyanovsk (Mukhametshina 1999; Gismatulin 2006) include golden belt attachments dated to the middle of the 7th century CE, probably originating from a destroyed burial. Another group of nomads appeared at the same time or a little later on the right bank of Volga, as indicated by the Shilovka burial mounds (Bagautdinov et al. 1998).

19.3.1.8 Khazar Period, from the End of the 7th to the Middle of the 10th Century CE

The collapse of the *Imen'kovo* culture was followed by a depopulation of the Middle Volga region in the second half of the 7th century CE. Occupational sites are recorded only in the periphery of the region. To the west, there was a group of sedentary populations in the Sura River valley, including sites of the *Early Mordovian* culture and the latest settlements of the *Imen'kovo* culture. To the east, the *Verkhniy Utchan* and *Kushnarenkovo* cultures occupied the eastern part of the Lower Kama region.

By the end of the 7th century, a recolonization of the Middle Volga began. This process continued until at least the second quarter of the 10th century. This period is called the Early Bulgarian time, and corresponds to the Khazar time in the archeology of Eastern Europe. It can be divided into several stages.

The first stage (~690–750 CE) was initiated by nomads of Turkic (Khazarian and Bulgarian) origin (so called *Novinki* type): their burial mounds appeared along the Volga, in Samara Luka, and near Ulyanovsk (Matveeva 1998; Bagautdinov et al.

1998). Small groups of sedentary people, practicing different burial rites and probably of different origin, also appeared in the Volga valley, occupying areas near the nomads as revealed in the Zhiguli archaeological complex in the Samara Luka area (Ponomarenko et al. 2015).

The second stage (~750–850 CE) was influenced by the defeat of the Khazar Khaganate by Arab forces in 737 CE. In 740–750 CE the area of the *Saltov* culture became the source of a new wave of migration to the Middle Volga region (Kazakov 1992). The burial grounds of the 8th to 9th centuries were distributed along both banks of the Volga River valley.

At the end of the 8th century, a new group of people appeared in Trans-Volga. Descendants of the *Kushnarenkovo* culture, recognized as early Hungarians, moved through the Middle Volga along their migration to the Danube (Kazakov 1992). Their largest burial ground, dated from the end of the 8th to the first half of the 9th century, was located far to the north of Samara River.

The number of occupation sites increased and the cultural traits of the sedentary population of the region became more diverse in the 8th century CE. The newcomers moved from the Don basin (Slavonic and Turkic-speaking populations of the *Saltov* Culture) to west of the Sura river (inhabitated by Mordovians) and Middle Kama region (populated by people of the *Nevolino* culture). The occupation sites of the first two stages, from the end of the 7th to the middle of the 9th centuries, have comparatively thin occupational layers poor with finds (Stashenkov 2010c), consistent with temporary camps. Most of the occupation sites were situated on high terraces of the Volga and on the banks of second-order ravines, within 10 km from the river. Many sites were associated with iron ore extraction and iron smelting (Vyazov and Semykin 2016). The newcomers of the *Saltov* culture were agriculturalists who used ards with iron ploughshares as a plowing tool (Khuzin 2011).

The third stage of migrations to the Middle Volga during the time period from 850 to 910 CE was associated with the decision of the Khazarian rulers to convert to Judaism (Khuzin 2011). As a result, the 9th century was a period of mixing of different cultural groups in the Middle Volga region. The most numerous were migrants with *Saltov* cultural traditions (mainly of Turkic origins) and Finnish newcomers from the Middle Kama. Archaeological sites include burial grounds and settlements along the Volga and also in the Trans-Volga region, around the future city of Bilyar. Both groups were comparatively numerous, for example, the Tankeevka burial ground contained more than 5000 graves (Khalikova and Kazakov 1977). The territories to the north of Kama remained unpopulated. The total number of sites increased, at least some were used as year-round settlements and some were fortified (Semykin and Matveeva 2010).

The end of the 9th to the beginning of the 10th centuries was the beginning of the Volga Trade Route, connecting the Caspian Sea and Middle East with the Baltic Sea and with the Middle and Upper Kama region, rich with furs. The beginning of the intensive trade is indicated by numerous dirhams and weights found in archaeological sites within the Kama floodplain. Several dirhams from the beginning of the 10th century were also found in the Maly Yerusalimskiy gully site, which is thought to be the earliest Bulgarian medieval settlement in the city of Bolgar itself (Khuzin 2011). A Viking presence is also recorded in several sites (Izmaylov 2006).

The peripheral areas remained comparatively poorly populated during the entire Khazarian Period. In the Upper Sura region, only a dozen Early Mordovian sites have been found in a small forested rugged lowland (Belorybkin 2003). The Lower Sura was inhabited by a small group of Early Mari people (Archaeological map of Chuvashia 2013–2015) and the eastern part of the Middle Volga region remained almost totally depopulated except for the *Verkniy Utchan* group of about 30 sites of the 6th to the 9th centuries (Goldina and Chernykh 2011).

Thus, the repopulation of the region in the 7th through the 10th centuries advanced from south to north, with areas along the Volga the first to be developed. The locations of the burial grounds and settlements of the 8th through 9th centuries coincide with the route of the Ibn-Fadlan voyage of 920 CE (Journey of Ibn-Fadlan 2016). In the 9th and early 10th centuries, the banks of the Volga were cleared of forest to satisfy the needs of pastures and communication routes. The peripheral areas remained populated during the entire time period, although the marginal groups of peoples did not play a significant role in the process of repopulation.

19.3.1.9 Pre-Mongolian Period, Middle of the 10th to the Middle of the 13th Century CE

No later than the second quarter of the 10th century, the number of habitation sites in the Middle Volga region began to grow explosively, reaching at least several hundred by the beginning of the 11th century (Fakhrutdinov 1975) and exceeding 1500 by the 12th century. About 15% of the sites were fortified. Economic development took place on the banks of both the major rivers as well as in the 3rd to 4th order tributaries (Fig. 19.3, Map 5). For the first time, the watershed areas were cleared of forest and used for agriculture. The most populated areas were the valley of the Volga River and the part of Trans-Volga territory south of the Kama River, while Cis-Kama remained poorly developed. A separate group of 30 sites of *Pre-Mongolian Volga Bulgarian* culture appeared in the southern part of the Upper Sura region, and may be connected with activity on the trade route from Bolgar to Kiev (Belorybkin 2003).

Large fortified towns, including Bilyar, Bolgar, and Suvar, occupied areas up to several hundred hectares and were surrounded by dozens of satellite settlements, typical for medieval urban agglomerations (Khuzin 2006). The economy of Pre-Mongolian Volga Bulgaria was based primarily on crop production using ploughs equipped with wide plowshares and coulters. This highly-efficient type of plough (*saban*) was capable of cutting and overturning the upper layer of loamy soils. A large number of millstones for hand rotary mills were found in the Volga-Bulgarian sites, indicating high yields and large quantities of cereals. Finds of iron shovel blades point to the development of horticulture and vegetable gardening (Khalikov 2006).

Osteological data from Pre-Mongolian settlements reflect significant changes in the structure of meat consumption, and possibly in the composition of the herds (Petrenko 2006). There was a noticeable increase in the proportion of small cattle, implying an increase in the size of open pasture available for goat and sheep grazing. Hunting and especially fishing still played a role in providing the population with protein.

There is extensive data related to the craftsmanship and industries of the Volga Bulgaria economy, which included products made of ferrous and non-ferrous metals, bones, glass, and pottery. The spatial distribution of artifacts reflects the development of highly specialized production of artisan goods in urban centers and its marketing to the countryside. This is evidenced by pottery and blacksmith workshops, craftsman's brands on pottery, and in the high quality of the products. This process certainly had to be accompanied by the development of communication routes and the spread of both local and long-distance trade.

In summary, Pre-Mongolian Volga Bulgaria was a society with a highly developed and multi-faceted economy. The rapid agricultural development of the region, reflected by an explosive increase in the number of settlements, provided the population with food. Towns played an important role in the economy, being centers of craftsmanship and trade. The wide distribution of urban artisan products in the rural areas and the large number of imported products in rural areas are typical for a highly developed territory with extensive communication networks.

19.3.1.10 Golden Horde Period, from the Second Half of 13th Century to the 1440s

The Mongolian invasion of 1236 CE brought major changes to the cultural and demographic map of the region. Many settlements were demolished, and the majority of large urban settlements never recovered. The catastrophic results of the Mongolian invasion were recorded as fire layers with numerous human remains. The Golden Horde Period in Middle Volga is divided into an the early period (second half of the 13th century to the first half of the 14th century) when they reached the apogee of political and economic power, followed by a period of civil wars and gradual decline from the middle of the 14th century to the 1440s CE.

The Mongolian invasion resulted in the formation of a new political and governmental system in Eastern Europe. The Middle Volga area was a part of the northwestern province of the Mongolian Empire called the Ulus of Jochi. Following the invasion, the majority of the settlements in the forest-steppe and the upper reaches of the Sura simply disappeared (Belorybkin 2003). In Trans-Volga, the number of sites greatly decreased, with sites almost disappearing in the basin of the Bolshoi Cheremshan (Archaeological map of Tatarstan 1990, vol. 6). In Samara Luka, the invasion caused a change in the spatial distribution of settlements (Kochkina 2016) and the arrival of first wave of Mordovian and Russian colonists, probably as a result of the Golden Horde state relocation policy (Stashenkov 2016). The Volga, from Bolgar to the Usa River was desolated (Burov 1977) while the population of the northern part of the former Volga Bulgarian state was less severely affected or else recovered more successfully. Several agglomerations of settlements appeared on the banks of Volga and Kama rivers (Rudenko 2016), the most significant being about

50 settlements centered on the city of Bolgar, which became the capital of the Ulus of Jochi from the 1240s to1260s (Izmaylov 2009a). The first coins of the Jochides were minted here and its status is attested by the monumental stone architecture of that period (Rudenko 2016). Thus, in 13th through 14th centuries, the areas along the Volga and Kama rivers were densely populated. In the early Golden Horde period the population shifted northwards, exploring the western part of the lower Kama area and including the areas north of the Kama River. The total number of the habitation sites of the Golden Horde period in the region is about 400 (Fakhrutdinov 1975).

The economy of the Golden Horde towns was based on crafts and trades. Although the agriculture of this period has not been extensively studied, an increase in the size of settlements and the adoption of more advanced tillage implements may indicate an increase in productivity (Mardanshina 2008). The local population preferred to get their meat supply buying livestock from steppe nomads rather than breeding them locally (Yavorskaya and Antipina 2016).

The settlements of this period became strongly clustered and agglomerated. During the second half of the 13th to the first half of the 14th centuries, towns and cities flourished along the Volga River valley, from the Caspian Sea to the mouth of the Kama River. The largest cities, such as Kazan, Bolgar, and Muranka site on the Volga River and Juketau on the Kama River were associated with the Volga trade route. The number of urban centers decreased, but their size grew and it is possible that each center marked a separate principality within the Ulus of Jochi. These changes in the spatial structure of settlements could have engendered a large heterogeneity in landscape utilization. The suburbs that provided the citizens with agricultural production were used more intensely than in the Pre-Mongolian period, while the remote areas could have been either under-utilized or abandoned (Fig. 19.3, Map 6).

At the beginning of the second half of the 14th century, the Golden Horde entered a long crisis that ended with the disintegration and collapse of the empire a century later. The crisis could have been caused by ecological, economic or political factors, or perhaps by the Black Death pandemics. The pandemics of 1346 and 1364 CE caused a potentially long-lasting decrease in the urban population. The maximal decrease in a population affected by the plague is reached approximately 140 years after the pandemics (Shamiloglu 2009), so this could account for the depopulation of the region at the end of the 15th to the beginning of the 16th centuries.

There is indirect evidence for a climatic cause for the destabilization. In the second half of 14th century, winter settlements and burial grounds of nomadic peoples appeared on the southern bank of Kama River. At the same time, nomadic burials appeared in necropolises of sedentary populations, both in cities and villages, as far north as the northern bank of the Kama River (Rudenko 2013). In the second half of the 15th century, artifacts belonging to Nogai nomads appeared in Bilyar (Sitdikov 2016). The northward movement of nomads along with the historical descriptions of droughts (Izmaylov 2009b) attest to climatic changes in the region.

In the 1360s CE, civil war broke in the Ulus of Jochi, providing opportunities for invaders from Russian lands. Evidence of military intrusions includes numerous money hoards, with 70% of the hoards of the Golden Horde Period in Tatarstan dated to the second half of the 14th century (Sitdikov 2016). Some studies documented massacres of the local population (Kochkina 2012).

The late Golden Horde Period was associated with major changes in the spatial distribution and ethnicity of the population of Middle Volga. During the crisis, the population shifted further northward, to the right bank of the Kama River and abandoned the traditional trade centers. Following the depopulation of Trans-Kama and Trans-Volga, the territory north of Kama River became the most densely populated. The centre of economic life shifted from Bolgar to the areas of Kazan and Arsk fortresses that became the heart of the Kazan Khanate.

19.3.1.11 Post Golden Horde Period

The period of the Kazan Khanate from the 1430s to the 1550s is the least-researched period in Middle Volga. Most of the available data, both archaeological and historical, come from the northern part of the region. The most densely populated areas were located north of Volga and Kama and include Cheremis (the medieval name of the Mari people), Chuvash, and Tatars. The southern boundary of their distribution followed the Kama River to its mouth in the west (Sitdikov 2016), with no permanent population south of this line. In Trans-Volga and Trans-Kama, a small sedentary population was concentrated around Bolgar and Bilyar, the largest urban agglomerations now transformed into religious centers. In the 1530s, the Kazan Khans gave the Trans-Volga lands to rulers of Nogai Horde.

The southern part of the region was populated in the late 15th to 16th centuries by nomads of the Nogai Horde. Their summer migration routes covered the entire territory from the Samara River to the Kama River. The Nogai arrived in Middle Volga in the spring, following the left bank of the Volga River. The migration routes of nomads on the right bank of the Volga is unknown, but it is plausible that they used the same routes as the Bulgarians during their migration to Middle Volga. The close proximity of Nogai precluded the development of agriculture in the region and no evidence of permanent settlements of this period has been found, although written sources mention fisheries in Samara Luka starting from the 1520s (Dubman 2012).

In the second half of the 16th century, Kazan was conquered by the army of Muscovy, and the Kazan Khanate became a part of the Muscovy State Territory. The new government begun the construction of forts Svyazhsk (1551), Cheboksary (1555), Laishev (1557), Tetyushi (1578), Samara and Ufa (1586) at major fords of the Kama and Volga Rivers. The forts became the military and administrative centers of the region that protected the newly annexed lands from Nogai, and from the 1570 onwards, from the Cossaks. As a result, a sedentary population gradually established in the territories south of Kama River.

19.3.1.12 Summary

During the last 2500 years, the development of the Middle Volga region was spatially and chronologically heterogeneous. The first episode of depopulation occurred in the last centuries BCE, and was marked by the disappearance of *Ananyino* sites in the forest zone and a decrease in the Sarmatian population of the steppe zone. The second depopulation took place in 7th to 8th centuries, following the cessation of *Imen'kovo* occupation, and the third occurred during the time of the Kazan Khanate.

On the other hand, the subsistence and lifestyle of people living at the periphery of the Middle Volga region, in the forests along Sura River north of Kama River, and especially in the lower reaches of the Belaya River was more conservative, sustainable, and continuous. The anthropogenic transformation of forest landscapes was slower and more gradual than in the forest-steppe zone; large urban agglomerations did not appear until Late-Medieval time, and the population never increased as greatly as in the forest-steppe and steppe zones. It appears that the population utilizing multifaceted forest resources since the *Ananyino* times was more resilient to various unfavorable circumstances, resulting in a more continuous presence of peoples in the periphery of the region during the times of depopulation and abandonment.

19.3.2 Trade Networks in the Middle Volga Region

Trade as an exchange of goods for money or its equivalent appeared in Middle Volga only in the Middle Ages. However, the importance of the earlier, non-monetary forms of exchange of goods and ideas was crucial to the development of local societies. The main vectors of the cultural and trade connections were already defined by the beginning of the 1st millennium CE (Fig. 19.4).

Until the 7th century BCE, most cultural novelties came into the region from the Caucasus and Scythian territories. Later, trade connections shifted eastwards, predominantly to the territories of the nomadic Sauromatian, and later the Sarmatian populations (Kuz'minykh and Chizhevsky 2009). In the 5th to the 3rd centuries BCE, trade goods were imported to Middle Volga from the east. The source areas of the long-distance trade in the time of the *Ananyino* group of cultures were the regions of the Achaemenids Empire: the Eastern Mediterranean, Egypt, Iranian Plateau, and countries of the Persian Gulf (Ivanov 1997).

With the formation of the northern branch of the Great Silk Route (GSR) in the 1st century CE, the territories of Middle Volga and Cis-Kama functioned as one of the corridors that connected North-Eastern Europe and the countries participating in transcontinental trade along the GSR. From this time onwards, imports into the forest zone of Eastern Europe through nomadic intermediaries noticeably increased. The sources of imports changed as well; among the trade goods were artifacts from the Far East as well as Roman artifacts and coins. Imported goods circulated in the north-western and north-eastern periphery of the region among the peoples of the *Pyany Bor* culture and in contemporaneous sites of *Andreevka-Pyseraly* type. The

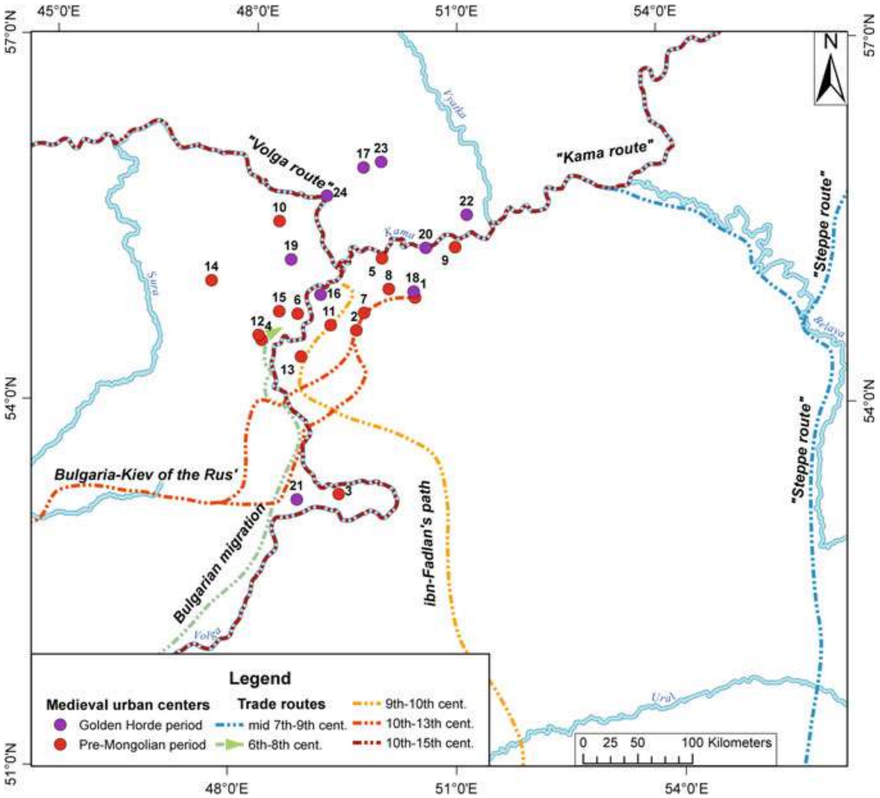

Fig. 19.4 Map showing major trading routes on Middle Volga. Urban centers (italicized are names of archaeological sites): **1**—Bilyar; **2**—Suvar; **3**—*Muromskiy Gorodok* site; **4**—*Staroye Aleykino* site; **5**—*Gorodok* site; **6**—*Bogdashkino* site; **7**—*Krasnyj Kluch* site; **8**—*Romodan* site; **9**—*Malaya Polyanka* site; **10**—*Gorodische* site; **11**—*Kokryat'* site; **12**—*Krasnoye Syundyukovo* site; **13**—*Yurmanki* site; **14**—*Tigashevo* site; **15**—Khulash; **16**—Bolgar; **17**—*Iske-Kazan* site; **18**—*Balynguz* site; **19**—Shongut; **20**—Juketau; **21**—*Muranka* site; **22**—Kirmen; **23**—Arsk; **24**—Kazan

two groups interacted, as indicated by the finds of *Pyany Bor* artifacts in *Andreevka-Pyseraly* sites and vice versa. The imported goods were largely related to clothing, suggesting that they resulted from migration processes rather than the trade itself.

Based on the distribution of the imported artifacts in sites of the 1st to 2nd centuries CE, the interaction between populations of the steppe and forest zones was most active outside of the Middle Volga region, in the interfluves of the Oka and Sura rivers in the west and along Belaya River in the east. The Sarmatians retained their role of the main mediator between the forest and steppe populations during the second quarter of the 1st millennium CE, and Late Sarmatian artifacts were widely used by the populations of *Azelino* and *Mazunino* cultures.

The appearance of peoples of the *Kiev* culture in the Middle Volga in the 3rd to 4th centuries CE marks the formation of a new intercultural communication that connected Middle Volga with the Don region, the left bank of Dnieper River, and possibly even with regions further west. This route approximately follows the modern southern boundary of the forest-steppe zone. Important agricultural innovations, coins from the Bosporus and Rome, and metal ingots used by local people for jewelry making were transported to Middle Volga along this route.

The trade networks underwent major changes in Hunnic times, when the amount of imports greatly decreased. The decrease in southern imports was possibly caused by a decline in the steppe population of the Volga-Ural region due to their involvement in the Hunnic military efforts. At that time, the forest-steppe route that connected Middle Volga region with the Don and Dnieper basins disappeared.

In the 6th century CE, the population of *Imen'kovo* established some connections with the Cis-Caucasus and Northern Caucasus regions. Sassanid drachmas are found in three sites, one in Samara Luka and two on the northern bank of Kama River. The context indicates that they were used as raw material for metal working. It is unclear whether the coins were transported along terrestrial or water routes, but the routes were definitely tied to the Volga River, as indicated by other finds of Byzantine and Sassanid coins of the 6th century CE. The erection of fortresses of *Imen'kovo* culture occurred within the narrow time period from the end of the 5th to the 6th century CE. Their location on high banks of large rivers and the form of their structures suggest that their main function was protection from riverside. The finds of camel bones in several *Imen'kovo* fortresses are suggested to be consistent with terrestrial trade routes.

In the middle of the 7th century CE, the Belaya River valley became the main trade route connecting the steppes with the densely populated areas along the Kama. Sassanid and Byzantine coins and toreutic objects accumulated in Khwarezm, Central Asia, after Arabian conquests were distributed in large numbers along this route. Historical descriptions indicate another route along the western bank of the Volga River that was used for movement by various groups of peoples.

Not later than by 9th century, a caravan trade route from Khwarezm to the Middle Volga was established. This route connected the Ustyurt Plateau with the left bank of the Volga River near present-day Samara, and continued north along the left bank of the Volga and up its interfluves with the Kama River, forming a large loop to the west. The distribution of archaeological sites of this time is associated with this route, and most places where the route crossed Volga tributaries contain Early Bulgarian burial grounds. In the early 10th century, Samanid dirhams were brought from Middle Volga to Northern Europe by this route. The establishment of the trade route that connected Middle Volga with Khwarezm, bypassing the Lower Volga region and the Khazarian Khanate, provided the Bulgarian rulers with independence from the Khazarian Khanate. The formation of a new political union in Middle Volga shifted Volga-Kaspian trade routes. Prior to the 10th century CE, most goods travelled from the Upper Volga to the Oka, then to the Don, and finally to the Lower Volga rivers. In the 10th century, the main trade route shifted to the Middle Volga region, as reflected in the finds of Scandinavian objects in archaeological sites of the end of 9th through the 10th centuries on the Middle Volga (Valeev 2010).

The development of towns and urban craftsmanship in the Middle Volga led to the export of artisan objects from Volga Bulgaria to the Russian Principalities (Rus') along the Volga waterway. The growing trade resulted in the establishment of a new terrestrial trade route that connected the towns of Volga Bulgaria with Rus'. The trade networks established in the 10th through 11th centuries continued until the Mongolian invasion of the 13th century, with the most extensive trade activity along the Volga route between the 10th century and the first half of the 12th century (Motsya and Khalikov 1997). Most Western and Northern European imports reached the territory of Volga Bulgaria during this period while considerable quantitates of Bulgarian goods were also transported north along Volga River (Valeev 2010).

Beginning in the second half of the 11th century, a series of military conflicts occurred between Russian and Bulgarian dukes (in 1088, 1107 and 1120 CE), marking the increasing Russian influence in the north-western periphery of Bulgarian lands. After 1160 CE, the growing power of the Vladimir-Suzdal' principality led to a new series of conflicts between 1164 and 1220 CE (Izmaylov 2006). The Rus'-Bulgarian confrontation coincided with the decline of the Volga trade transit as Bulgarian imports could not pass the borders of the Vladimir-Suzdal' principality (Poluboyarinova 2006).

These conflicts were probably one of the factors that led to the development of a new terrestrial trade route that connected Volga Bulgaria with the southern part of Rus' in the 12th to the 13th centuries. The historical descriptions of this Middle Volga route are supported by archaeological finds of Old-Russian artifacts along the route (Motsya and Khalikov 1997), although the exact location of this route is disputed (Belorybkin 2003; Viskalin 1992; Gismatulin 2014). It is possible that several parallel routes were in operation at the same time. A new group of archaeological sites with a material culture closely resembling that of Pre-Mongolian Volga-Bulgaria first appeared in the upper reaches of the Sura River in the 10th century, and flourished in the 12th to 13th century, probably in association with this new trade route (Belorybkin 2003).

Despite the decreasing trade with Northern and Western Europe, the Volga route retained its importance as the major transit of furs to the Islamic countries. The source areas of fur were lands along mid- to upper reaches of the Kama River (Belavin 200). The main trading partner of Volga Bulgaria on the Lower Volga was the city of Suksin, which acted as mediator in the trade between the Middle Volga population, Iran and the Trans-Caucasus (Vasil'yev 2015). Trade activities along the Kama were accompanied by expansion of Volga Bulgaria (Belavin 2000).

The Mongolian conquest radically changed the system of East-European trade communications, due to the disappearance of major trade centers and the desolation of entire regions. However, during the reign of the Golden Horde the vast area of the empire was governed by strong leaders who maintained routes in strict order and considered trade as the basis of state wealth. Importantly, the Middle Volga region was chosen as the centre of the Ulus of Jochi, with the first capital of the Golden Horde khans in Bolgar.

Golden Horde trade peaked in the second half of the 13th to the first half of the 14th centuries. The largest cities, craft centers and urban agglomerations were located along the Volga River, which was the main trade route, and by the 13th century, Bolgar had become the main transit city on the route (Yemanov 1995). Archaeological evidence of intensive trade includes numerous finds of imported goods and coins. The beginning of 14th century is marked by the growth of cities along the lower reaches of Volga River, reflecting a shift of the trade centers to this region (Nedashkovsky 2009). Trade declined following the crises, pandemics, and civil war that began in the 1360s. Numerous coin hoards were buried during these times of change.

The attempts of the Tokhtamysh government to stabilize the situation in the 1380s CE were unsuccessful, and the invasion by Tamerlan in 1395–1396 CE further deepened the economic crisis. After a series of military conflicts with the dukes of Muskovy in the second quarter of 15th century, the role of the regional trade center was relegated to Kazan. From this time on, the economy of the region was gradually incorporated into the sphere of the strengthening Muscovy State that became the major trade partner of Kazan.

In summary, the dynamics of trade networks on the Middle Volga depended on political influences, the density of population, and degree of territorial development along the trade routes.

19.3.3 Climate History of the Past Two Millennia

Over the past few thousand years, there has been a long-term cooling in northern hemisphere continental regions, later interrupted by the recent warming, which goes by the general term "neoglaciation". This cooling is seen in the majority of paleoclimate records (PAGES2k Consortium 2013), although it tends to be underestimated if only tree-ring records are included (Esper et al. 2012). Superimposed on this neoglacial cooling are shorter-term variations in temperature that can last several hundred years, with transitions of up to several hundred years between them. Because these periods are superimposed on the long-term cooling trend, the variability tends to increase over time (Gajewski 1987; Viau et al. 2006).

Shorter-term variations seem to be frequently forced by volcanic activity (Büntgen et al. 2016; Sigl et al. 2015; Stoffel et al. 2015) or solar variability, but overall, the causes are not entirely understood. Several studies note that intense volcanic eruptions can cause reduced temperatures globally that last for a few years (Büntgen et al. 2016; Sigl et al. 2015; Stoffel et al. 2015). Determining the impacts of these on human activities is dependent on a very precise chronology.

The climate of the past two millennia can be divided into five general periods of alternating cool and warm climates (e.g., PAGES2k Consortium 2013; Büntgen et al. 2016; Helama et al. 2017b). These were not uniformly cold or warm and furthermore temperature is only one component of the climate. However, long-term changes in temperature are associated with changes in the atmospheric general circulation, so a protracted period of warm or cool temperatures would be associated with changes in

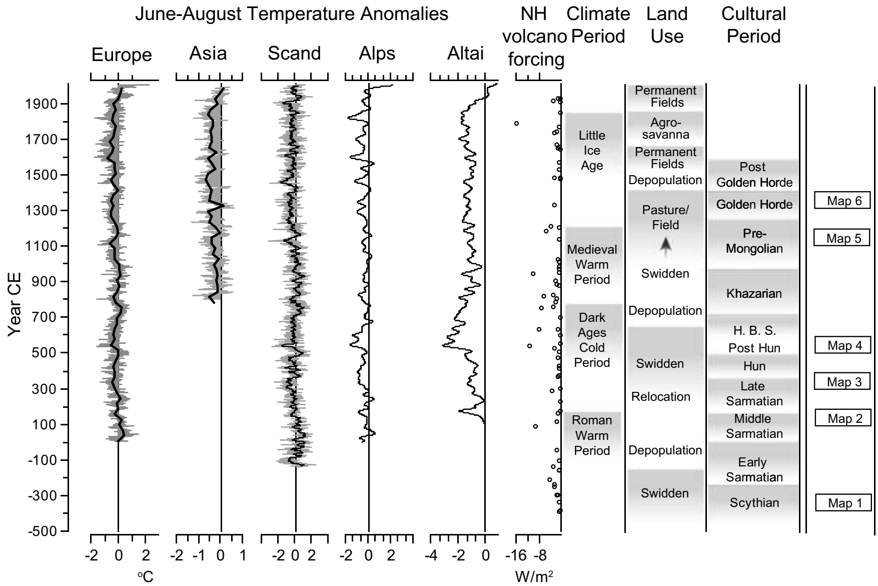

Fig. 19.5 Several paleoclimate reconstructions relevant to the Middle Volga region. Sources for the series are: (a) Europe and (b) Asia standardized June-July-August temperatures from PAGES2k Consortium (2013). Grey is annual values and black lines are 30-year means. (c) JJA temperatures anomalies (with respect to AD 1951-1980) from tree ring densities from Scandinavia (Esper et al. 2012). Grey line indicates annual values and black line is an 11-year running mean. JJA temperature anomalies based on normalized tree-ring width series from (d) Alps and (e) Altai mountains (Büntgen et al. 2016); shown are the 40-year spline fits to the data. (f) Northern Hemisphere volcanic eruptions (Sigl et al. 2015); units are estimated forcing in Wm^{-2}. Summary of the (g) climate, (h) land use and (i) cultural periods as discussed in the text. H.B.S is Heraldic Belt Set. The time of the maps in Fig. 19.3 is shown in (j)

pressure patterns, thereby affecting precipitation and other climate variables as well. The periods are not distinct and the transition between these periods can be of short or long duration (Fig. 19.5).

1. *Roman Warm Period* (1–300 CE) (Ljungqvist 2010; Esper et al. 2012; McCormick et al. 2012). Esper et al. (2012) consider this period to be warmer than present in Scandinavia, as it was superimposed on a long-term cooling. The extent and intensity of this period are not as well-known as subsequent periods.
2. *Dark Ages Cold Period* (410–775 CE) (Helama et al. 2017b). The Dark Ages Cold Period was associated with the migration period by Helama et al. (2017b). It was generally cool and frequently relatively wet. The typical span of this period in various records is 370 years, with coldest temperatures around 625 CE. Büntgen et al. (2016) consider the period between 536–660 CE as an extensive, volcanically-caused cold period, although Helama et al. (2017a) question its extent. Many studies have shown societal impacts of the climate at this time (Büntgen et al. 2016).

3. *Medieval Warm Period* (850–1200 CE) (PAGES2k Consortium 2013). This period is generally considered warm, although with considerable variability, especially between regions. As with the subsequent Little Ice Age, peak periods of warm or cool temperatures tend to vary spatially.
4. *Little Ice Age* (1450–1850 CE) (PAGES2k Consortium 2013) This is probably the best defined and consistently-seen climate episode. There are several times of more-or-less cool conditions, for example, the 1600s-1850 CE are general cold.
5. *Modern Period* (1850 CE -present). The modern period is characterized by the human-caused global warming.

19.3.4 Land Use and Vegetation History of the Region

19.3.4.1 Pollen Record

The vegetation dynamics in the region during the last 2500 years can be divided into two major periods: a predominantly forested landscape prior to 12th century CE and a mosaic of open habitats and patches of forests, composed mainly of early successional and light-demanding taxa (pine and birch) from 12th century CE onwards (Fig. 19.5). The boundary between the two lies at the end of the Pre-Mongolian Period. Although the proportion of taxa associated with open habitats increased during the Medieval Warm Period, the threshold change occurred ca 200 years later (Fig. 19.6). Major transitions in the vegetation cover coincided with changes in both the population density and settlements pattern, allowing for an assumption that these changes were correlated. Therefore, more subtle changes of the pollen spectra within each of the two time periods can be interpreted as result of changes in the land-use structure.

19.3.4.2 Principal Component Analysis

A principal components analysis of the pollen data summarizes the pollen assemblages and permits the division of the data into zones (Fig. 19.7). The pollen taxa form four distinct groups of variables with highly correlated groups of taxa that can be interpreted as associations caused by different land use types. Types 1 and 4 are well-defined, while differences between the types 2 and 3 are less distinct, consistent with the interconnectedness of these land-use types.

- Type 1 (*swidden*) includes tree pollen such as *Betula*, *Tilia*, and shrubs such as *Alnus* and *Corylus.* These taxa were more abundant in older sections. Although *Pinus*, a species commonly associated with fires is absent, the presence of shrubs and Onagraceae pollen (*Chamerion*, fireweed) indicates the presence of fires during this time, associated with swidden agriculture. This combination is consistent with the managed burning of the forest in the form of slash-and-burn cultivation.
- Type 2 (*pasture*) includes non-arboreal pollen (NAP) of meadow taxa indicative of pastures and abandoned farmlands, such as Poaceae, Brassicaceae, and Asteraceae. These spectra become more abundant in the recent past and indicate the presence of pastures.

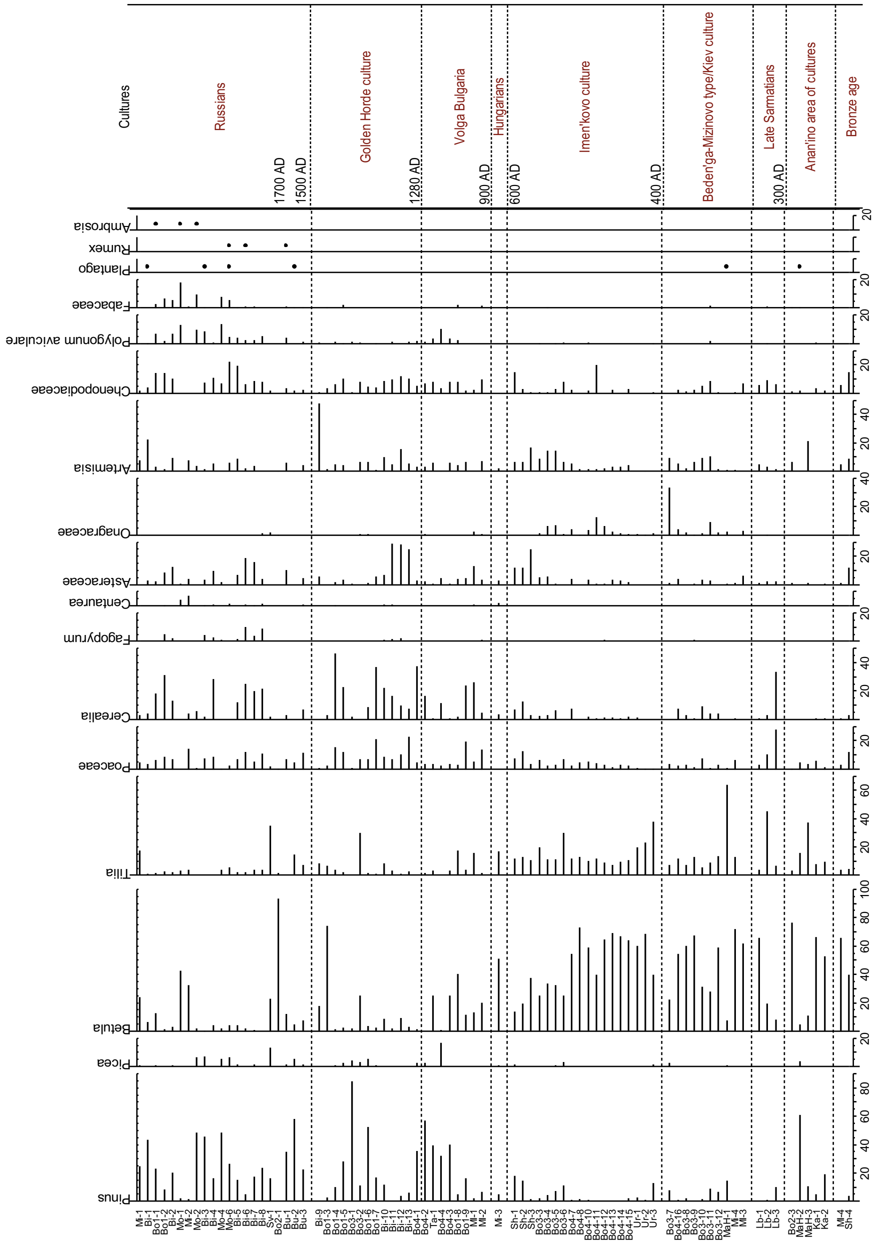

Fig. 19.6 Pollen assemblages from soil profiles of the study region. Sample codes on the left refer to site locations in Fig. 19.1

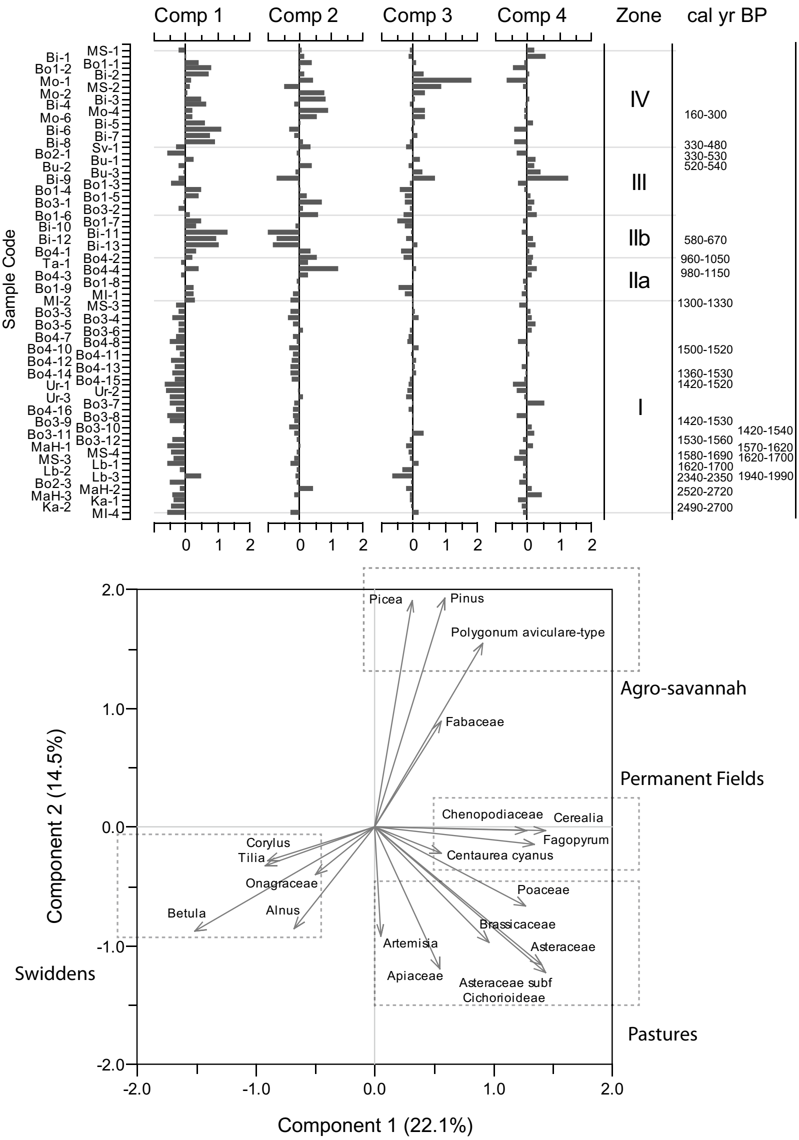

Fig. 19.7 Principal components analysis of the pollen data in Fig. 19.6. Zones are based on major transitions in the component scores. The first component explains 22.1% of the variance, the second 14.5%, the third 10.2% and the fourth 7.9%. Correlated groups of taxa and their interpretation (see text) are indicated by dotted rectangles

- Type 3 (*permanent fields*) includes cultivars and their weeds, some of which can grow in both functioning and abandoned farmlands. Pollen includes Cerealia and *Fagopyrum* (taxa characteristic of permanent fields), and Chenopodiaceae (weeds).

These were important in the recent past and also during the time of zone IIb (Fig. 19.7).
- Type 4 (*agro-savannah*) includes taxa associated with soil compaction and roads (*Polygonum aviuculare*) as well as coniferous trees (*Picea* and *Pinus*) along with Fabaceae. This group is highly loaded on the second component, and is most abundant in the more recent assemblages. The dominance of coniferous taxa is typical of landscapes with extensive herbivory, such as the long-term utilization of forest pastures and selective extraction of deciduous trees for firewood. Arboreal pollen (AP) was dominated by the pollen of pine that could, however, be transported from hundreds of kilometers away. The open landscape with patches of grazed/selectively logged forest was similar to type 3, but presumably had a greater proportion of forested patches.

Apparently, the combination of taxa does not mean that these plants grew in the same habitats, it reflects their co-existence in the landscape. For example, road networks (*Polygonum aviculare*), pastures/meadows (Fabaceae), and secondary coniferous forests (*Pinus, Picea*) appear simultaneously and their appearance is not independent (they are correlated).

19.4 Discussion

The development of the landscapes of the central part of the Middle Volga region in the last 2500 years was a discontinuous process of the explosive growth of population and land utilization alternating with stages of depopulation and desolation. Periods of depopulation or major changes in settlement locations seem to occur at similar times as climate changes (Fig. 19.5). Some cultures were associated with distinct climatic episodes, such as association of the Dark Ages Cold Period with the Hun, Post Hun, Heraldic, and Khazarian times, and the Medieval Warm Period with the time of Volga Bulgaria.

Depopulations of the area were associated with the transitions between cultures and also with transitions between the climate regimes. However, this does not explain the complexity of interactions between the peoples and the environment. The subsistence and land use strategies changed through time, and the landscape changed accordingly. The settlements and land use were concentrated along rivers until 10th century and from this time onward, watersheds were included in the pattern of agricultural utilization.

The land use signatures are reflected in palynological spectra as specific combinations of plant taxa associated with the times of occupation by the population of certain archaeological cultures (Fig. 19.7). The boundaries between palynological zones generally coincide with the chronological boundaries between archaeological cultures (Fig. 19.5). The major archaeological time periods have distinct palynological signatures, suggesting that changes in land use can be associated with the various cultures. Moreover, major changes in vegetation occurred rapidly, within one to three centuries, so it may be possible to use the forest cover composition as a chronological tool in archaeological studies. Furthermore, not only combinations of taxa, but also some indicator taxa have a clear chronological affiliation. For example, *Onagraceae* pollen are prominent only between 1700 and 1300 cal year BP (*Beden'ga-Mizinovo* type and *Imen'kovo* culture) and *Picea* pollen appeared in the pollen spectra at levels exceeding 1% only towards the end of the Pre-Mongolian time, in the 1200s. *Fagopyrum* is predominantly associated with the most recent 500-year period.

Swidden pollen spectra are associated with the occupation of the area by the people of the *Beden'ga–Mizinovo* type, the *Imen'kovo* culture and by the early Bulgarians. Episodes of land clearance using swidden techniques apparently also occurred in the beginning of the Russian colonization. A combination of taxa similar to the swidden group was recorded for the *Ananyino* occupations, but Onagraceae and Cerealia (marker components of slash-and-burn cultivation) were absent; more sites need to be analyzed for definitive conclusions.

During the Pre-Mongolian Period, the combinations of pollen taxa/land use types changed from swidden to pasture and further to agro-savannah in less than 300 years. Swidden techniques were applied to clear the forested landscape in the beginning of colonization and, shortly thereafter, permanent fields and pastures were established on the cleared lands.

Pasture land use was prominent during the Golden Horde time, ~580–670 cal year BP, alternating with fields and farmlands. During the pasture phase, the diversity of the local vegetation cover was maximal, with the percentage of arboreal pollen fluctuating from near-zero to almost 100% at various times and locations.

Agro-savannah is associated with the period of the Russian colonization. However, fields, pastures, farmland and agro-savannah pollen spectra alternated during the last 500 years, reflecting changes in the intensity of the anthropogenic impact. The percentage of arboreal pollen indicating forest cover was higher in the beginning of the Russian colonization, in the 1500s to the 1700s, and in the recent decades following the collapse of the Soviet Union and communal farming. Several peaks of birch pollen within the last 500 years marked the short-term abandonment of agricultural lands during times of social instabilities.

The formation of the anthropogenic landscape occurred in the Pre-Mongolian Volga Bulgaria time, during the 11th through the mid-13th centuries. The beginning of this period coincided with the Medieval Warm Period that perhaps facilitated the process of deforestation in the region. At this time, an agricultural landscape of a nearly modern appearance was shaped, with stable/well-defined boundaries between fields and forests, permanent fields, and road networks.

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Part VI
Social-Culture in Connection with the Environment

Chapter 20
Routes Beyond Gandhara: Buddhist Rock Carvings in the Context of the Early Silk Roads

Marike van Aerde

Abstract This chapter presents the first results and interpretations of a selected dataset of rock carvings from the Karakorum mountains. The research is focused on early Buddhist carvings and their spread and role within networks of the early Silk Roads in Central Asia from the 2nd–1st century BCE. The rock carvings and their archaeological context are studied to gain insight into routes from Gandhara through the Karakorum range. The first part presents the general aims and relevance. The second and third parts describe the analysis and interpretation of the Karakorum dataset, followed by the main points of discussion and conclusions to incite future investigations.

Keywords Silk Roads · Buddhism · Rock carvings · Karakorum · Gandhara Dynamic networks

20.1 Introduction

> Concepts that have proven useful in ordering things easily achieve such authority over us that we forget their origins and accept them as unalterable givens. The path of scientific progress is often made impassable by such errors.
>
> —Albert Einstein[1]

As early as 1916, Albert Einstein remarked on a pressing epistemological issue still faced by scholars and scientists today: the methodological necessity to create categorised concepts in order to study reality, paired with our subsequent tendency

[1] A. Einstein (1916), *Physikalische Zeitschrift* 17, 101: 'Begriffe, welche sich bei der Ordnung der Dinge als nützlich erwiesen haben, erlangen über uns leicht eine solche Autorität, dass wir ihres irdischen Ursprungs vergessen und sie als unabänderliche Gegebenheiten hinnehmen. Der Weg des wissenschaftlichen Fortschritts wird durch solche Irrtümer oft für längere Zeit ungangbar gemacht'.

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to come to regard those predetermined categories as truths. The initial 19th/20th-century campaigns of Gandharan archaeology (modern-day Afghanistan to northern India and Pakistan, cf. Foucher 1905; Cunningham 1871; Marshall 1975) were often marked by this tendency, as evident from John Marshall's own words upon starting his campaign at the site of Taxila: 'At that time I was a young man, fresh from archaeological excavations in Greece and filled with enthusiasm for anything Greek, and in that far-off corner of the Punjab it seemed as if I had lighted of a sudden on a bit of Greece itself' (Marshall 1975, xv). In particular, connections were sought between Buddhist material culture and the Hellenistic presence. The earliest-known anthropomorphic depictions of the Buddha originate from the Gandhara region, and these statues were particularly noted for their 'Greek' or 'Hellenistic' style. These initial campaigns focused on the 'Greek' style of Buddhist sculptures and reliefs, generally with the intent to demonstrate that the arrival of Hellenistic settlers in Gandhara, especially in the form of the Indo-Greek kingdoms (one of the first founders was Menander I in 130–131 BCE), became a 'superior filter' for the local Buddhist culture (Bussagli 1984, 161–165). This approach resulted in the stylistic category and ethic-cultural container of 'Greco-Buddhist art', which was usually subdivided by means of multiple sub-categories, e.g., 'proto-Hellenic Buddhist art' or 'barbaric Afghan style', in order to keep fitting the diversity of finds from Gandharan sites into this preconceived Greco-Buddhist container (Marshall 1975 II, 520–521).

Since the mid-20th century, new archaeological, historical and epigraphical investigation have added important new insights into the complexity of both Gandharan and early Buddhist archaeology, especially pertaining specific sites and contexts within the Gandhara region and the remarkable diversity of intercultural material culture encountered there (Faccenna 1980; Bussagli 1996; Behrendt 2007; Boardman 2015; Facenna and Taddei 1993; Verardi and Filigenzi 2003; Mairs 2014). In order to continue this trend, it is imperative to keep challenging the more traditional culture-container categorisations that once marked this field. The present chapter endeavours to do this by focusing on the relatively neglected dataset of early Buddhist rock carvings from the Karakorum mountain range between Gandhara and the Tarim Basin (Xinjiang, China). These carvings appear to (literally) take early Buddhist iconography and architectural styles, many of which specifically known from Gandhara, beyond that region. In doing so, the analysis works towards new archaeological evidence for specific mountain routes as part of the Silk Roads networks from the 2nd–1st century BCE onwards. By focusing on Buddhist carvings specifically, the role of Buddhism within this dynamic network is put central.

This contribution presents the first results of the investigation, and as such aims to function as a basis for the continuation and expansion of research into the Karakorum rock carvings datasets. The methodology uses a bottom-up approach to the data and bases subsequent findings and discussion on the results of the data analysis. In doing so, this study also addresses the issue of compartmentalisation that has remained long rooted in the methodological division between cultural studies and archaeological contexts that also include environmental factors. These are crucial especially for the dynamic archaeological record of the early Silk Roads networks. Frequently, interpretations of these early routes have followed narratives of a linear trade networks (referring to an ancient 'Silk Road', indicating a *singular* route) that stretched between two main dominant powers, the Roman Empire in the West and the Imperial Chinese Dynasties in the East, even though these two powers never actually, physically connected.[2] The only way to go beyond such dualist approaches to ancient Silk Roads archaeology, is to study the archaeological evidence of these early networks by focusing on the places in between—of which the Karakorum mountain routes may be a prime example and valuable source of information.

In order to achieve this, this study adopts a change of perspective for Gandharan archaeology in specific. Traditionally, studies predetermined or newly devised certain (cultural and/or ethnic) 'containers' to organise the data and thus enable interpretations from a top-down approach. In contrast, this research approaches the diverse data as *variables* of the dynamic networks of the ancient Silk Roads and hence bases any hypotheses and interpretations on the patterns and/or insights that these variables may reveal when studied empirically and within the scope of both their archaeological and environmental contexts. The analysis pertains to the iconography as well as carving methods of the relevant rock carvings, their archaeological contexts, and their distribution as part of the physical environment of the Karakorum mountains where they were encountered. For the latter, analysis of recent satellite footage has been used.

The second section provides a literature review of the Karakorum rock carvings, concerning their documentation and preliminary interpretations up until now. The third section presents the analysis results and discusses them, interpreting the carvings in terms of (1) their Buddhist iconography in comparison to early Gandharan Buddhist material culture, and (2) the significance of these carvings for reconstructing routes through the Karakorum mountains based on empirical evidence. The final section pertains the conclusion and explores next steps for continuing the research.

20.2 Early Buddhist Archaeology and the Karakorum Rock Carvings

The Karakorum mountain range borders modern-day India, Pakistan and China (Fig. 20.1). It includes the Gilgit-Baltistan region in Pakistan, the Ladakh region in India, and the south-western Xinjiang region of China, and is part of the western

[2]Despite the fact that no direct contact was ever made between Han China and Rome, the Han elite in particular was very interested in luxury products from the West and in particular from the Roman Empire (the discovery of an apparently Roman tapestry at Loulan in the Taklamakan desert excavated among Han silks suggests such a trade in Roman goods; Liu 2010, 18–19; Yu 1967), and a similar interest in Rome is recorded in several sections of the *Hou Hanshu*, the Book of the Later Han (for a recent translation and study of its implications for Silk Road studies, see Hill 2009). The Han even sent an envoy, Gan Ying, to learn more about the Romans, but he never arrived due to interceptions (most likely by Parthians) at the Red Sea (See: Beckwith 2009, 78–92; Liu 2010, 19; and most recently Poo et al. 2017). See also Miller (2014, 1–43) and Miller and Brosseder (2017, 470–487) for arguments against a dualist East–West approach in Silk Roads archaeology.

Fig. 20.1 Area of the Karakorum Mountains investigated as indicated in the square. Satellite footage NASA 2014

edge of the Himalayas along with the Hindu Kush range bordering Pakistan and Afghanistan in the West. From 1979 onwards, the Karakorum Highway (also known as the China–Pakistan Friendship Highway) has increased mobility between Pakistan and western China, and this likewise enabled accessibility to remoter mountain regions for archaeological campaigns. The presence of ancient rock carvings and epigraphy in the Karakorum mountains (then also known as the eastern Hindu Kush) was first noted by Hungarian adventurer Karl Eugen in 1884, who remarked on Buddhist carvings in the Baltistan area, and by Pakistani explorer Ghulam Muhammed in 1907, who visited the lower region of Diamer (Jettmar 1989; Fussman and Jettmar 1994; Hauptmann 2009). But no systematic or scholarly documentation occurred until the early twentieth century; between 1900 and 1944 Aurel Stein studied a concise but at that time unique sample of carvings (Stein 1944, 5–24). But only from 1979 onwards larger-scale explorations and documentations were possible because of the Karakorum Highway, and these campaigns have yielded a substantial data set of carvings.[3]

[3]As documented in the Materien zur Archaologie der Nordgebiete Pakistanscatalogues (MANP) catalogues, Band 1–11, edited by Gérard Fussman, Karl Jettmar, Ditte König et al. between 1989 and 1994, and more recently re-edited and published by Harald Hauptmann from 2003 to 2011, as part of the Heidelberg Academy. For the research described in this paper, I was able to access MANP Band 1, 2, 6–11.

Initiated by Karl Jettmar, these campaigns were overseen by the German Research Council and subsequently by the Heidelberg Academy. The long-running project entitled 'Rock Carvings and inscriptions along the Karakorum Highway' was initiated in 1983 as collaboration between the Department of Archaeology of Gilgit and the Heidelberg Academy.[4] From 1989 until 2013, Harald Hauptmann has overseen the continuing documentation of rocks carvings as well as the excavation of archaeological sites in these mountain range, especially in the Gilgit-Baltistan region.[5] Hauptmann confirms that the connections between Gandhara and the Silk Roads beyond the Hindu Kush and Karakorum mountain ranges, such as indicated by the Karakorum data since 1979, have been often neglected by more interpretative scholarship so far and represent 'ein ebenso altes wie dringendes Forschungsdesiderat'.[6] Unfortunately, recent plans for rescue excavations before the planned construction of the Diamer-Basha dam, not far west of the Chilas area along the Indus River, have been restricted: as confirmed by Hauptmann, the construction of this dam will inundate an estimate of at least 37,051 carvings on 5928 boulders or rock faces.[7] In addition, the region including the field stations at Chilas, Thalpan and Oshibat has become less accessible since 2013 due to increasing political unrest (which has already led to ancient carvings being vandalised, partially removed or destroyed in the region) and the likewise increased planning of corporate building projects following the Diamer-Basha dam; moreover, a lack of centrally organised research funding in Pakistan has made large-scale projects difficult at present, despite the presence of available expertise and many sites and data left to explore and document.[8]

However, the documented Karakorum rock carving data so far is substantial and give us a significant amount of material to work with at present. Hauptmann is currently preparing a synthesis of the archaeology and early history of the Upper Indus Region in overview, which will help future studies to connect sites as well as apply wider frameworks for interpretation. The available documentation from the Karakorum field stations so far has been thoroughly collected, yet due to the general lack of attention paid to these data by studies that consider wider historical contexts of the region, especially those concerning Silk Roads contexts and connections with Gandhara, there remains a lack of in-depth interpretative studies that incorporate these data sets. This paper looks at a selection of these data as primary sources (Sects. 3.2–4) to arrive at new insights not only into the mountain passes themselves and the diversity

[4] As documented and discussed in: Jettmar (1985, 1989, 1993), Fussman (1994), Bennmann and König (1994), Fussman and Bandini-König (1997), Bandini-König (2003, 2005, 2007, 2009, 2011, 2013), Hauptmann (2009).

[5] This included the re-editing of MANP vol. 1–11, as well as additional (incl. forthcoming) publications (Hauptmann 2009). Information was shared in personal communication with Prof. Hauptmann in Heidelberg, 2017.

[6] Cited from personal communication with Prof. Hauptmann.

[7] Cited in Pakistani newspaper *Dawn* (article by S. Yusuf, May 18, 2011) and from personal communication with Prof. Hauptmann.

[8] The above-cited *International Conference on the Archaeological Heritage of Pakistan: Challenges, Potential and the Way Forward* (20–22 October 2017, Lahore), is one initiative of the Pakistan's Higher Education Commission to tackle inherent issues.

of people that travelled through them, but also into these Karakorum routes as part of wider ancient Silk Road trade patterns. A selection of the data is necessary because of the great number as well as the remarkable diversity encountered in these rock carvings: apart from the many textual inscriptions (in languages varying from early Kharosthi to Chinese and with topics, when discernible, ranging from early Buddhist epigraphy to caravan travel notes),[9] there are carvings depicting wild animals and natural environments recognisable from the surrounding mountains (generally identified as prehistorical carvings),[10] decorative motifs that have generally been grouped together as belonging to 'Eurasian nomadic cultures',[11] decorative/symbolic Persian motifs,[12] and scenes of human life in the mountains (especially depicting travelling caravans and hunters with dogs, generally included in either the prehistoric or nomadic groupings).[13] But perhaps the most visually striking type of carvings in the data set and containing the largest-sized imagery discovered in these mountains so far, is Buddhist imagery.

The two prominent themes encountered in these Buddhist carvings are (1) architecture of traditional early Buddhist stupa monuments, and (2) anthropomorphic depictures of the Buddha with scenes from his life and followers. Despite the thorough documentation of these carvings in the Heidelberg Academy publications, contextual interpretations beyond the mountain sites have been limited beyond the studies of scholars directly involved with the project. Between 1989 and 1994, three volumes of *Antiquities of Northern Pakistan* (ANP) were published as part of the 'Rock Carvings and Inscriptions along the Karakorum Highway' project, edited by Karl Jettmar and Gérard Fussman, which contain in-depth analysis of the documented data, mainly concerning textual interpretations and determination of different carving types and chronologies as based on the available sources and the scholars' hypotheses (ANP Vol. 1–3: Jettmar 1989, 1993; Fussmann and Jettmar 1994). In their studies of the Karakorum carvings, Fussman as well as Oskar von Hinüber focused on the early Buddhist period, but predominantly concerning documentation of Kharosthi and Brahmi inscriptions that accompanied a variety of carvings (not necessarily Buddhist imagery, in fact) in order to reconstruct the often only partially preserved texts in terms of their content and translation to determine names and historical contexts as mentioned in these inscriptions, with some additional suggestions concerning the

[9] Relevant catalogue descriptions in: Bennmann and König (1994, 19–34), Fussman and Bandini-König (1997, 58–72), Bandini-König (2003, 91–103; 2005, 95–104; 2011, 102–103; 2013, 269–301).

[10] Relevant catalogue descriptions in: Bennmann and Konig (1994, 35–142), Fussman and Bandini-König (1997, 20–29); Bandini-König (2003, 103–172; 2005, 17–214; 2007, 19–251; 2009, 15–242; 2011, 21–257; 2013, 21–236).

[11] Relevant catalogue descriptions same as above: different genres are identified in the catalogue descriptions, but not ordered accordingly, except in: Fussman and Bandini-König (1997, 7–20, 30–57).

[12] Relevant catalogue descriptions same as above, except in: Fussman and bandini-König (1997, 36–53).

[13] Relevant catalogue descriptions same as above, except in: Fussman and Bandini-König 1997, 7–20, 29–30.

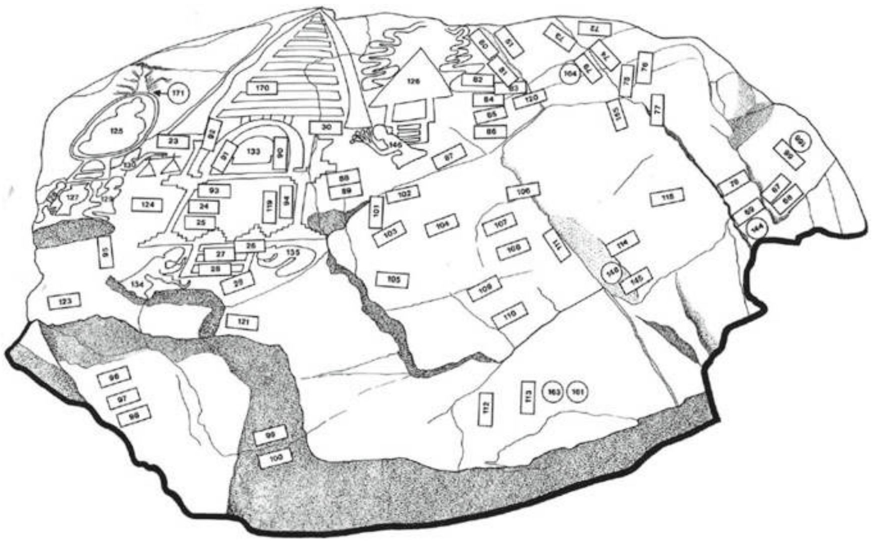

Fig. 20.2 Schematic of carvings (larger ones drawn and smaller ones rendered as circles) and inscriptions (squares) on the southwest side of the largest rock at the Shatial field station (stone 34; MANP vol. 2, Tafel D; Fussman and Bandini-König 1997)

travels of Buddhist monks and subsequent spread of Buddhist religious practice and scholarship to the East (Von Hinüber 1989a, b, 41–72, 73–106; Fussman 1993, 1–60; Fussman 1994, 57–72). As Jettmar puts forth in the first ANP volume from 1989, since their discovery in the early twentieth century up until the larger campaigns in the early 1980s, interpretative approaches to these data sets have been mainly ethno-archaeological, namely, aiming to identify different and specific cultural and/or ethnic categories among the variety of carving types (Jettmar 1989, XXII). This approach was also pursued by Dani, who encountered considerable issues in his attempts to categorise the many different types of images of animals, human figures and indeterminable architectural structures that were discovered alongside more distinctly recognisable Buddhist imagery—images that were 'not easily included in classical iconography' (Dani 1983, 230–231; cf. Jettmar 1989). Especially the larger rocks tend to be covered with a great number of carvings and inscriptions, apparently scattered at random across the surface, which makes categorical determination of specific ethno-cultural groups virtually impossible (Fig. 20.2). Alternatively, this may simply indicate additions on the same rock from wide-ranging time periods (from prehistorical times up until medieval Silk Road passages, roughly), but such chronologies cannot be tested based on the rock's material properties or geological composition, as these have remained unchanged regardless of the addition of carvings throughout time (Jettmar 1989, XX).

Because of these issues, in his 1989 study Jettmar moved away from ethno-archaeological interpretation that would directly imply a chronological distinction between Buddhist and non-Buddhist carvings; instead, his spatial-oriented approach considers the carvings as grouped together within bigger but still specific, contained mountain sites—for example, he suggests that there may have been a holy Buddhist site and festival tradition near the Thalpan field station to account for the many stupa carvings discovered there, but he also notes that this interpretation is speculative and not supported by textual sources or additional data (Jettmar 1989, XX–XXI). Other studies in this volume present detailed analyses of specific Karakorum carving types and interpretations of local contexts, thus providing an important basis for wider interpretative investigation[14]—however, no substantial scholarly contributions from outside the Heidelberg and Gilgit project appear to have taken that next step as yet. The 1994–2007 *Materialien zur Archaologie der Nordgebiete Pakistans* (MANP) publications of the Oshibat, Shatial, and Thalpan field stations, supervised by Hauptmann as part of the Heidelberg Academy project, focus on providing a detailed documentation of the great diversity of carving types encountered, without necessarily attempting to identify specific categories or cultural groups as part of the documentation method.[15]

This thorough level of documentation is very helpful towards attempting a more interpretative overview, such as this paper aims to do concerning early Buddhist imagery encountered among the documented carvings. In the second ANP volume, Fussman presents an initial study that compares Karakorum carving from the Chilas field station depicting anthropomorphic figures of the Buddha to bronze Buddha figurines found in the Kashmiri mountain valleys in the Karakorum range, as well as to content from the Sanskrit Hatun inscription in the Ishkoman valley near Gilgit-Baltistan (and recognises several coinciding motifs in the description and depiction of the Buddha, respectively; Fussman 1993, 1–60). In the third ANP volume, Fussman focuses on hypothetical carving methods used by the craftsmen and carvers that created the more elaborate Buddhist carvings in the Chilas-Thalpan region, suggesting the use of predetermined sketches, diagrams, and decorative patterns that were meticulously applied to these carvings to make sure they adhered to Buddhist style and iconography, such as encountered traditionally in the earliest-known Buddhist material culture of Gandhara, as well as being still recognisable in later-dated Buddhist art and architecture encountered at Tibetan holy sites (Fussman 1994, 57–72). His focus remains on the style and execution of the Karakorum carvings, however, and does not raise further questions regarding the possible spread and/or technical criteria of Buddhist art and architecture beyond the Karakorum region, or indeed the possible significance of Gandhara in these material culture connections. Also in the third ANP volume, Monique Maillard and Robert Jera-Bezard present a brief study that compares the style and iconography of Chilas-Thalpan stupa carvings

[14]Including additional studies on Chinese epigraphy, different animal species recorded in the rock carvings, and linguistic interpretations/translations: Jettmar (1989, 1993); Fussman and Jettmar (1994).

[15]Apart from MANP Vol. 2 (*Felsbildstation Shatial*, Fussman and Bandini-König 1997), which does categorize its documentation according different carving types, the other MANP catalogues offer a full overview of stones with lists of carvings as they were encountered, thus without separating categories or applying further interpretations.

to early stupa architecture and miniatures known from various Gandhara sites and museums, including Swat and Peshawar, and early Buddhist wall paintings from Xinjiang (Maillard and Jera-Bezard 1994, 173–200). Here, too, the focus remains on the detailed documentation of individual objects, providing a good basis for further study; but also this premise has so far hardly been taken on board by subsequent scholarship.[16]

The next section provides an analysis of the presently investigated data from the Thalpan, Oshibat and Shatial field stations. First, the data are presented in tables and distribution graphs. The first part of analysis considers the occurrence and appearance of the documented Buddhist carvings in detail and in the context of Gandharan archaeology (3.1). Next, the distribution of the documented carvings are analysed in the context of the Karakorum routes in terms of related environmental factors and connections with the wider region (3.2).

20.3 Karakorum Data: The Thalpan, Oshibat and Shatial Field Stations

The MANP documentation of the Thalpan-Chilas, Thalpan external, Shatial, and Oshibat field stations provide numbers of the stones studied, but not the number of individual carvings encountered (many stones contain multiple and often very diverse types of carvings); as a result, the total number of Karakorum carvings documented at this point remains by necessity an estimate. For the purpose of this study, the exact number of stones investigated has been taken as basic premise, and only the exact number of individual Buddhist carvings in the available documentation has been counted (hence, the individual carvings containing prehistoric, nomadic, animalistic or other types remain at this point uncounted). The statistical data pertaining the stones and exact number of carvings in question are represented in the tables and diagrams below. For the practical purpose of my initial analysis only (i.e. not intended as interpretative guideline), the types of Buddhist carvings in the data set have here been divided into (1) Buddha figures, (2) stupas, (3) worshippers, and the sub-division representing (4) combinations of Buddha figures and stupas. Further descriptions, analysis, and interpretation of the data follow after the graph (Fig. 20.3).

[16]Two follow-up studies are an article on stupa architecture by Bruneau (2007, 63–75) and a 2008 publication by Volker Thewalt, which presents a selected catalogue of notable stupa and related Buddhist architecture depicted in the Chilas and Oshibat field stations, offering detailed descriptions but no further interpretative overview or analyses of any wider contextual implications of the data listed (Thewalt 2008).

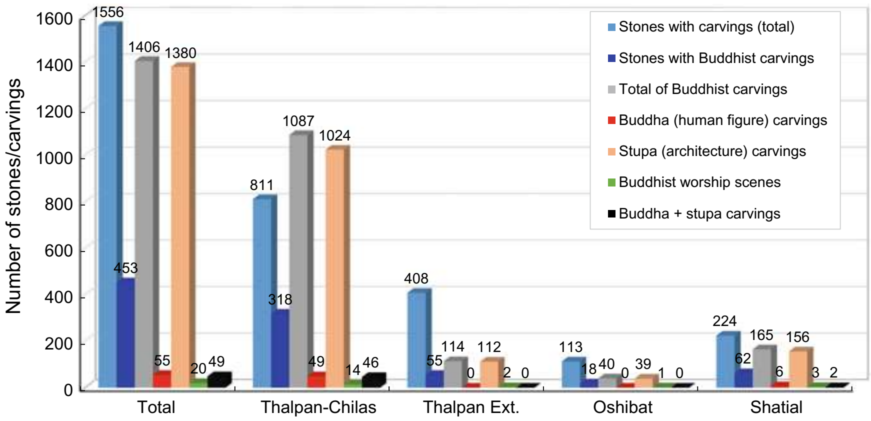

Fig. 20.3 Distribution of stones and Buddhist carvings in the Thalpan, Oshibat and Shatial data (Data based on MANP Vol. 1, 2, 6–11, documenting the Oshibat, Shatial, Thalpan-Chilas, Thalpan-external field stations: Bennmann and König 1994; Fussman and Bandini-König 1997; Bandini-König 2003, 2005, 2007, 2009, 2011, 2013)

20.3.1 Analysis and Interpretation: Early Buddhist Carvings

The following interpretation is based on these preliminary analyses only and is therefore intended to form an initial basis for future and more expanded studies concerning the Buddhist iconography and carving distribution of the Karakorum dataset. This initial step is particularly relevant as studies of the rise and spread of Buddhist material culture in and from the ancient Gandhara region, especially concerning the earliest anthropomorphic depictions of the Buddha in sculpture, have rarely incorporated interpretative analyses of imagery from Karakorum rock carvings.[17] Moreover, most comments on these Buddhist rock carvings tend to single out (the often visually striking) anthropomorphic figures of the Buddha and provide individual case studies and comparisons (Maillard and Jera-Bezard 1994, 173–200; Bhattacharya 1977; Dani 1983; Fussman 1993, 1–60). However, based on the datasets from the Thalpan, Oshibat and Shatial field stations, the number of anthropomorphic depictions of the Buddha is substantially lower than the number of carvings depicting stupa monuments. Many of these carvings seem scattered among the rocks at random sequences and can be as small as 2 × 4 cm; on the other hand, especially at the Thalpan-Chilas and Shatial areas, we also find a stupa carvings as large as 130 × 235 cm (MANP Band 1, 2: Bennmann and König 1994; Fussman and Bandini-König

[17]The significance of the carvings is indeed discussed in e.g., Carter (1993), Hauptmann (2008), Neelis (2011), but not as part of comprehensive interpretative or distribution studies as yet. Additionally, the Karakorum carvings have not been used for in-depth comparative studies with Buddhist carvings from e.g. Swat Valley and Hindu Kush, which would certainly present material for future research for which these initial steps will present an important basis (cf. Olivieri 2013, on Swat-Malakand carvings, and Kotera et al. 1971 on Hindu Kush carvings).

Fig. 20.4 Comparison of stupa architecture. Left: Thalpan-Chilas, stone 30:1, Tafel III a (Bandini-König 2003). Centre: schist reliquary stupa (centre), 83 cm height, from Gandhara, possibly Taxila, 1st–2nd century CE (Carlton Rochell Asian Art Gallery, private collection, New York). Right: Thalpan-Chilas, schematic of stone 41:3, Tafel 25 (Bandini-König 2003)

1997; and Band 6, 7: Bandini-König 2003, 2005). The amount of architectural detail of especially these larger carvings is noteworthy: Maillard and Jera-Bezard make comparisons with motifs and depictions of stupa architecture excavated at Gandhara sites in Swat and Peshawar as well as with the famous Buddhist wall paintings at Dunhuang (Maillard and Jera-Bezard 1994, 176–181). In fact, most comparisons consider architecture and imagery from the 3rd–4th century CE onwards; however, when we look at some of the earliest-known stupa architecture from Gandhara (i.e., Sirkap, Taxila), the direct parallels are no less striking (see Fig. 20.4; cf. Van Aerde 2018, 203–229).

Chronology for the Karakorum carvings tends to rely on stylistic features as well as surrounding epigraphical carvings that generally focus on such later periods; but the actual features of the depicted stupas in these data sets in fact suggest a chronology for Buddhist carvings from as early as the late 1st century BCE-early 1st century CE onwards. Possible parallels of stupa architecture depictions in rock carving from the Western Hindu Kush mountains (the region of Afghanistan generally referred to as Bactria in the antiquity) were discovered by a Japanese campaign in the 1970s, but they do not currently survive in situ; however, the surviving documentation of these carvings depict stupas that directly resemble those encountered in the Karakorum carvings at the Thalpan and Shatial stations (see Fig. 20.5), which likewise hints at a presence of Buddhist imagery in rock carvings in the mountain ranges surrounding Gandhara from the Bactrian and early Kushan eras onwards from ca. late 1st century BCE—early 1st century CE (Kotera et al. 1971, 40, Fig. 38; cf. Klimburg-Salter 1989, 150).

Due to this unfortunate lack of documentation from the Hindu Kush range, there is a danger that more prominent attention for the better-documented Karakorum

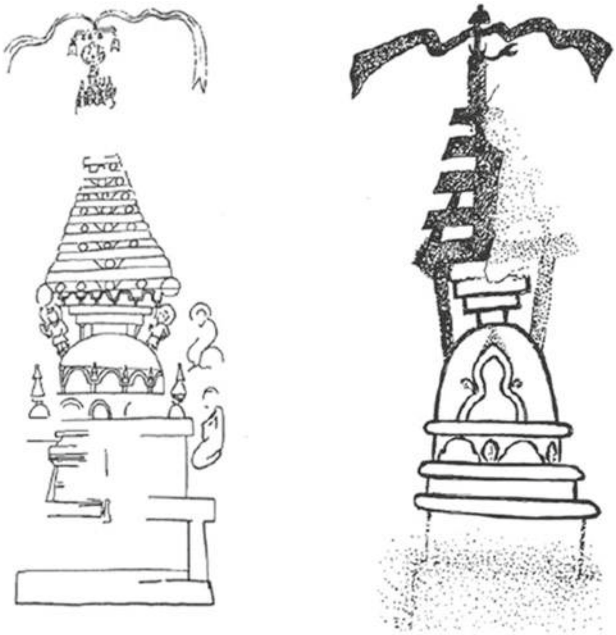

Fig. 20.5 Left: schematic of stupa carving at Bamiyan, western Hindu Kush, Afghanistan (Kotera et al. 1971, Fig. 38, pp. 40). Right: Schematic of stupa carving at Shatial field station, Karakorum, Pakistan (stone 164:7, Tafel 28, Fussman and Bandini-König 1997)

carvings would lead to an unbalanced interpretation of carving distributions (and subsequent mountain route reconstructions in the region) in favour of the eastern mountain ranges. Yet, while keeping in mind that at least hypothetically we should include the western Hindu Kush range in wider considerations of Gandhara's connectedness, it is equally important to focus in-depth on the Karakorum data sets now, as they seem likely to be the only available data at least in the foreseeable future.

One of the most important points that emerges from the Karakorum data, is the fact that the documented Buddha figures do not appear to be individual depictions of certain Buddhist scenes –the examples from this dataset, to be precise, appear to perhaps depict anthropomorphic *sculptures* of the Buddha, including statue bases and architectural contexts; to be more exact, nearly all images of the Buddha from the Thalpan, Shatial and Oshibat stations are images of Buddhist sculptures that were part of or position directly besides stupa architecture. This would mean that comparisons between these carvings and actual stupa architecture (indeed mainly from Gandhara) are much more correct in perspective than comparisons with wall paintings that visualise Buddhist narrative scenes (such as known from Xinjiang caves). Regrettably, most Buddhist sculptures and reliefs from Gandhara sites were removed upon excavation in the 19th and early 20th century, but some excavation reports still allow us to reconstruct larger monuments at least in part, and in some (but

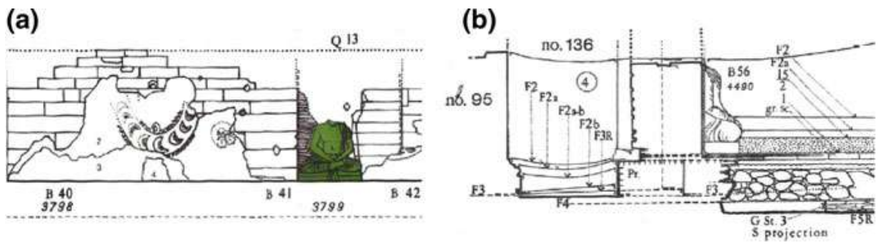

Fig. 20.6 Schematics of in situ Buddhist sculptural elements of stupa architecture at Butkara I, Gandhara, as documented by Domenico Faccenna and the IsMEO team in 1956 (Faccenna 1980, Plates XIV and XXXVI)

not many) cases sculptural elements of the architecture have been documented in situ, before they were removed, for example in the excavation reports of the Butkara I site (see Fig. 20.6), which represents the find spots of Buddha sculptures that have been interpreted as sculptures re-used in architectural stupa context (A) and as originally part of the architectural stupa context (B).[18]

Also smaller, reliquary stupa sculptures recovered from these same sites (as seen in Fig. 20.4) provide valuable comparative sources. Even when sculptures that are now taken out of their original contexts are considered, the visual similarities are directly noteworthy: in fact, the details of the execution and style of the anthropomorphic depictions, posturing, attributes and clothing of the Buddha carvings from the Karakorum data sets correspond acutely with those of sculptures recovered from relatively early Gandharan Buddhist sites, such as Butkara and Taxila (Fig. 20.7).

Later-dated Buddhist figures, generally dated to Gupta and Xinjiang origins, are distinctly different in visual detail; the earlier Gandhara Buddhas are less elaborate in terms of their amount and style of attributes, and posturing, and they tend to feature a distinct style of rendering clothing with many folds (previously regarded as a distinct criterion of ‘Greco-Buddhist’ art because of parallels with robed Hellenistic sculptures), as well as an apparently characteristic rendering of serene facial features and reflective expression (previously likewise regarded as example of a ‘Greek’ artistic filter) that in fact corresponds with early descriptions of the Buddha’s features as known from the *Jataka* tales, among other early Buddhist textual sources (see further Van Aerde 2018, 203–229). All these characteristics are recognisable in the Buddha carvings from the Thalpan, Oshibat and Shatial datasets—which would indicate another argument for a relatively earlier commence of these Buddhist carvings’ chronology in these mountains. Moreover, it would be a particularly clear indication that these carvings were indeed depictions of *sculptures* of the Buddha, rather than images depicting the Buddha’s life as in wall paintings. Even the few apparently individual Buddha figures in the data set show such direct resemblance to

[18]Faccenna (1980, Vol. 1–5) provide a thorough documentation of early Gandharan stupa architecture, including in situ anthropomorphic Buddhist sculptural elements. See also descriptions in: Marshall (1975) (concerning Sirkap, Taxila) and Faccenna and Taddei 1993 (concerning Swat valley).

Fig. 20.7 Left: rock carving of seated Buddha at Thalpan-Chilas (stone 195:65, Tafel 3, Bandini-König 2005). Right: sculpture of seated Buddha, Swat Valley, Gandhara (Lahore Museum, Cat. Nr. 572). Note esp. the similarities in posture, positioning of hands, facial features (rendering of eyebrows, urna dot, earlobes, topknot), the long robe with many folds, and halo

Gandharan Buddha sculptures (as shown in Fig. 20.6), that they, too, are arguably depictions of sculptures rather than human figures; in addition, the presence of kneeling worshippers surrounding these individual (and notably larger-than-life) Buddhas, which are directly comparable with the worshipper figures found surrounded many stupa carvings in the same data set, seems to indicate that these carvings indeed represented sculptures, i.e., stone monuments meant for worship and as incentive to meditation in the same way as stupas functioned.[19]

In sum, Buddhist imagery as found among the Karakorum carvings are (1) predominantly depictions of stupa architecture; (2) the far majority of anthropomorphic Buddha figures in the data set are directly related to stupas, i.e. representations of sculptures that were part of stupa architecture; (3) in execution and style, these Buddhas are directly comparable with the earliest-known anthropomorphic depictures of the Buddha from Gandharan sites. This suggests an actual ‘missing link’ between Gandhara and the rise of Chinese Buddhism in Xinjiang, with the Karakorum mountains as linking passageways (Maillard and Jera-Bezard 1994). But an important nuance is required here: by looking closer at the carvings, namely, by recognising them as carvings of architecture and sculptures rather than as merely Buddhist imagery, the question of their *functionality* becomes crucial. To explore this further, we need to look closer at possible distribution patterns as found within these original mountain environments.

[19]No full interpretative study has so far been done on the presence of worshippers in Buddhist carvings (some brief mentions are made in: Fussmann 1994; Maillaird and Jera-Bezard 1994).

20.3.2 Discussion: Distribution of Carvings in the Karakorum Mountains

When considering the documented data, as presented in Fig. 20.3, the main point of interest seems the fact that stupas are the most numerous type of Buddhist carving encountered *by far*; these data sets contain over a thousand stupas, but only fifty-five recorded anthropomorphic images of the Buddha. Depictions of Buddha are relatively rare in the dataset—though it is noteworthy that the recorded Buddhas in the data set tend to larger in size than the majority of recorded stupa carvings (the average for stupas is around 30–40 cm in height, with the exceptions being often triple in size but much fewer in number, whereas the average for Buddha carvings appears to be around 70–80 cm in height). Another noteworthy aspect is the fact that relatively few stones among the total documented stones feature Buddhist carvings, whereas the number of individual Buddhist carvings is much higher, respectively. However, most Buddhist carvings have been found grouped on single stones; i.e., multiple carvings appearing on the same stone, which are generally also the larger stones documented at the relevant field stations.[20] Another point of interest here is the fact that 49 out of the 55 documented Buddhas are clearly part of stupa carvings or placed in their direct vicinity, and all these combinations seem to feature surrounding carvings of worshippers, too. This would again confirm that these anthropomorphic Buddhas were indeed depictions of sculptures (either free-standing statues such as found at Gandhara Buddhist sanctuaries or architecturally incorporated into the stupa structures), as suggested in the section above, and not Buddhist narrative scenes that would be more comparable to wall paintings. Their role as part of stupa depictions seems indeed important for understanding their functionality; it would explain, for one, why the recorded Buddhist images were carved together on a fewer number of specific stones, and most likely with additions and alterations added over time on these same stones. In other words, these carvings should not be regarded as separate images, but as components of what appear to have been visualisations in the rock of physical stupa monuments, many of them very similar to those known from early Buddhist sites in Gandhara. As such, the function of these Buddhist carving groups may not have been so different from the function of Gandhara stupa architecture, if indeed at all. As visual monuments for worship and reflection, according to early Buddhist practices, these carving groups will have been much more effective in a recognisable group upon certain recognisable stones along the routes taken by Karakorum travellers, as opposed to having them scattered around on multiple rocks across the area. Moreover, the particular resemblance to early Buddhist architecture and sculpture from Gandhara does not necessarily imply that these carvings need all be of a relatively early dating; especially the larger and most detailed stupas and Buddhas are carved deeply in the rocks, which may indicate that the carvings were initiated in those early times, roughly around the early 1st century CE, and that the carvings were elaborated, deepened, even intentionally maintained (as a physical stupa

[20] Especially Fussman and Bandini-König (1997) and Bandini-König (2003, 2005) offer for documentation and reconstruction drawings of such large stones and carving groups.

monument would be) throughout the passage of time as part of worship by Buddhist practitioners that continued to pass them in the mountains ranges—perhaps as part of intentionally religious caravans, maybe simply as merchant travellers seeking to practice their religion along their trade routes through these mountains.[21] This brings in mind Fussmanns suggestion that the larger stupas were carved according to specific (most likely Gandharan) templates; but perhaps this is only true for the original layer of their carvings, which indeed is so directly comparable to Gandharan stupas and Buddhas that it would suggest the hand of certain craftsmen with knowledge of these sculptures and architecture. However, these carvings may subsequently have been maintained throughout many subsequent centuries by passing caravans instead, for example, by means of deepening the existing carvings, and perhaps also altered and expanded with worshipping figures and animal figures, of which most appear less directly recognisable in style and execution.

It also brings to mind Jettmar's suggestion of a possible Buddhist sanctuary at the Thalpan location; the spike in numbers of stupas and related Buddha depictions in the Thalpan-Chilas data sets would seem to support this option (Jettmar 1993, XX–XXI). Hauptmann has also noted that 5th-century Chinese pilgrims mentioned travelling to Buddhist sanctuaries near a specific 'trade emporium' they refer to as 'Talilo', and suggests this may have referenced Thalpan—especially since this part of the Karakorum Indus indeed appears to have functioned as passage to and from prominent Gandharan cities such as Taxila (by then under Kushan administration), the Kashmir valley, and ultimately Xinjiang in the east, with the number and scope of traffic roads with checkpoints and possibly even forts continuously expanding along these routes throughout the first five centuries CE (Hauptmann 2009, 8–9). However, there are no currently known archaeological or textual sources that would support the former presence of such a larger Buddhist sanctuary (which would have included architecture and physical monuments, according to the above-mentioned Chinese sources) at the Thalpan area, or indeed remains of a large-scale trade emporium.[22] This current lack of evidence might have been solved by more extensive excavations in the area, but especially due to the building of the Diamer-Basha dam, this does no longer seem feasible in the near future. Yet, hypothetically, the mere possibility of a physical 'Gandharan-type' early Buddhist sanctuary outside of Gandhara is something that traditional Gandharan scholarship never considered and therefore never looked for—but it is also something that the distinct presence, execution, and detailed style of the Karakorum stupa and Buddha rock carvings in this area certainly seem to make more plausible to at least consider.

[21] As initially noted by Fussmann (1994), and subsequently also remarked upon by Neelis (2014a, b, 45–64). This would be an interesting and possibly important topic for future research.

[22] A trade post or traffic station may have been built out of wood and other less durable material (e.g., textiles), but objects such as coins, pottery etc. may be expected to remain. It is also a reasonable deduction that such a Buddhist sanctuary would have featured more than only rock carvings. Excavations near the Diamer-dam site may have given more insight into this, but they have now become impossible. Apart from gathering more as yet undocumented carvings throughout the region, other excavations projects may have given us more indications of this sanctuary hypothesis; unfortunately, also such plans do not seem feasible in the near future.

Fig. 20.8 Recent satellite image of the area between Shatial (west) and Thalpan-Chilas (east), along the flow of the Indus. All main field stations where rock carvings have been discovered between 1979 and 2013 have been marked: Shatial, Harban, Diamer-Basha, Khanbari, Thor, Minar-Gah, Oshibat, Hodar, Chilas and Thalpan (GoogleEarth 2017)

On the other hand, it is no less important to closely consider the natural environment of the relevant valley in our interpretations and hypotheses.[23] When we return to the documented data, we can in fact observe an increase in the number of stupas documented at the Shatial field station that is quite similar to the increase noted at Thalpan-Chilas; that is, the number of recorded stones with Buddhist carvings outside the Thalpan banks is relatively smaller overall, yet the similar pattern (i.e., the spike in stupas) is still noteworthy, especially in context with the data from Oshibat, which is in fact much closer in vicinity to Thalpan than Shatial (see Fig. 20.8).[24]

Other than the still unsupported hypothesis of a physical Buddhist sanctuary, these stupa spikes at Shatial and Thalpan may instead, or at least also be connected to the fact that both locations are near remarkably sharp bends in the Indus (namely, flowing southwards from Shatial, down towards the slopes of Gandhara, and northwards from Thalpan, up towards the Gilgit-Baltistan region). These specific locations may have indicated more important stations along the route, marking the significant bends they announced; perhaps they functioned as notable road stations where mountain

[23]Similar hypotheses concerning waystations have already been advanced by Stein (1944), Jettmar (1985). In addition, possible parallels could be sought with data from the Hindu Kush mountain range for future research (cf. Neelis 2014a, b, 3–17).

[24]The Heidelberg Academy team charted several more clusters of carvings (but not all currently available in MANP) along the Indus riverbanks in the valley passage reaching from Shatial in the west to Thalpan in the east, but so far these do not appear to have been as numerous in terms of specific Buddhist carvings nor do they seem to have been grouped together like at Thalpan or, in lesser degree, Shatial.

caravans could stay overnight, hence allowing travellers more time for worship and reflection such as the stupa and Buddha carvings appear to have accommodates—perhaps, indeed, that may have been their original functionality, to accommodate the needs of those passing by the more important road stations. And as a result, with the increasing centuries and the similar increase in Buddhist followers in the region, these initial carved early Buddhist, 'Gandharan' stupas may indeed have developed into larger-scale religious sanctuaries known as far as midland China, in the same way as that the road stations may have developed into emporia that became known across the region. This is of course directly relevant for challenging the compartmentalised tendencies of Gandharan Buddhist archaeology, in proving the opposite. As it is, the archaeological and textual sources available at this point seem only to support these early Buddhist origins of the carvings as well as their apparent connection with the structure of the natural environment of the Karakorum Indus; in specific, the river's flow and bends along the mountain valleys and the way the travellers' route appeared to have followed it. Therefore, concerning the tradition division between cultural and environmental approaches, this indeed suggests the necessity of an interdisciplinary bridge between the two.

While hypothetical reconstructions of sanctuaries along the river are difficult from an archaeological perspective at this point, reconstructions of the *route* itself are more feasible, especially when taking the environment as part of the consideration. This is where the approach of archaeological data as *variables* comes into play more concretely and can indeed become a tool to work with; the consideration of (complex and hence unpredictable) variables instead of predetermined categories simply does not allows for a separation of archaeological, contextual, environmental, textual sources, etc. On the contrary, all these aspects are variables of both the physical region *and* the wider process of connections and interactions under examination here. Even when some variables by necessity remain hypothetical (such as the possibility of a larger sanctuary at Thalpan), the incentive for that hypothesis (i.e., the notable spike in stupa carvings recorded) is yet another variable in itself, which in turn appears closely connected, indeed even a result of the structure of the surrounding natural environment (i.e., the fact that Thalpan was located at one of the most major bends of the Karakorum Indus). In effect, none of these aspects and/or data can nor should be studied in separation. Similarly, the direct similarities in style and execution of the depicted stupas and Buddha sculptures in the studied data sets should not merely be 'singled out' as a topic of study, thus suggesting a linear line of cause and effect; instead, when we consider the Gandharan origins of these carvings are yet another variable in a dynamic process of interregional interactions, it becomes clear that we cannot denominate a single 'function' or 'intention' to them, as such. Whereas these early Buddhist carvings may have originally been intended as opportunities for worship for travellers passing through the mountains, they appear to have also come to function as landmarks at certain prominent changes in the environment and help travellers navigate their routes, and as a result these Buddhist images were spread not only *alongside* a more deliberately religious expansion of early Buddhism from Gandhara to the east (such as traditionally derived from textual sources) but also as additional *incentive* to as well as constituent of that ever-expanding process.

In other words, the appearance and subsequent increase in early Buddhist imagery along the Karakorum routes, especially when we keep in mind above-mentioned comparisons in style and content with both early Gandhara sites and the earliest Buddhist depictions in Xinjiang and Gansu, appears to have been a dynamic and distinctly non-linear variable in what is still mainly considered a linear line of cause-and-effect: Buddhism being carried to China. Whereas the original intention of the earliest Karakorum stupa carvings may have simply been to offer Buddhist travellers a place for worship along their passage, the unintended effect of these carvings seems to have been to increasingly raise awareness of and interest in Buddhism in regions east of Gandhara—moreover, the possible presence of larger, famous Buddhist sanctuaries at these same landmarks along the Karakorum route in the 5th century will have been another originally unintended result of that same dynamic and ongoing process. Such non-linear variables can only be charted in hypothetical (phase space) models, as mentioned in the introduction; however, the consideration of these variables, as opposed to a compartmentalised approach, also allows us to hypothetically chart the *physical* route(s) in more detail.

One of the main variables involved here is one that appears relatively fixed, or at least logically deducible: namely, the fact that the distribution of rock carvings follows the flow of the Indus River. The convenience, even necessity of proximity to water while traversing these mountains, combined with the lower, more accessible grounds of the river valleys, would make the river's flow the most sensible route to follow for any travellers, either in larger caravans or not. As far as these data sets have recorded, no rock carvings have been discovered higher up the surrounding mountain slopes, which also suggest an absence of travellers there (again the most sensible, practical option). The structure of the natural environment is the most determining variable in this case, directly affecting people's choices for the routes they travelled—and in consequence likewise affecting their choices of where to carve their stupas along the way (for hypothetical route, see Fig. 20.9).

Ideally, the next step would now be to document more data from along the Karakorum Indus. Up until recently, explorations and studies have been conducted up until the Gilgit and Gilgit-Baltistan areas, in a northern upwards direction from the Thalpan field stations; unfortunately, no catalogues or very thorough documentation of carvings have yet been possible. Earlier this year, German scholars Horst Geerken and Annette Bräker published a memoir of their travels around the Gilgit area up until 1998, featuring several photographs and reports of rock carvings that very strongly resemble those so far documented by MANP, including early Buddhist stupa imagery (see Fig. 20.10a), but also carvings that more closely resemble Buddhist depictions from Chinese paintings of the much later Tang Dynasty, 618–907 CE (Fig. 20.9b; Geerken and Bräker 2017, 224–225).

The latter presents yet another possible argument for the increasing role that Buddhist carvings and perhaps indeed sanctuaries came to play along these mountain routes since the first appearance of early carvings of Gandharan-type stupas; it is noteworthy, too, that most if not all Buddhist depictions as now documented in the lower Indus Karakorum valleys, from Shatial to Thapan, directly resemble much earlier Buddhist depictions from Gandhara. For example, if a famous Buddhist sanctuary near Thalpan was known by the 5th century, perhaps such later styles would

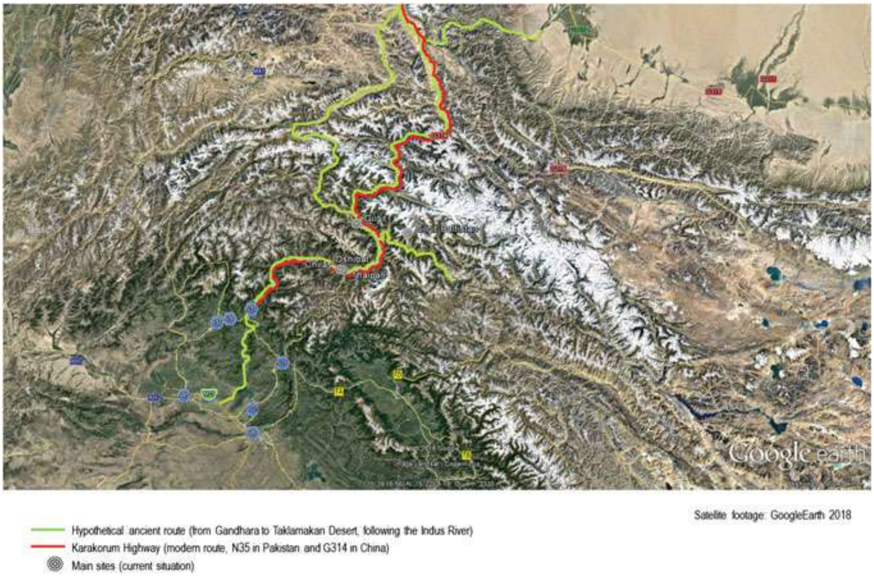

Fig. 20.9 Hypothetical ancient route through the Karakorum mountain range (GoogleEarth 2017)

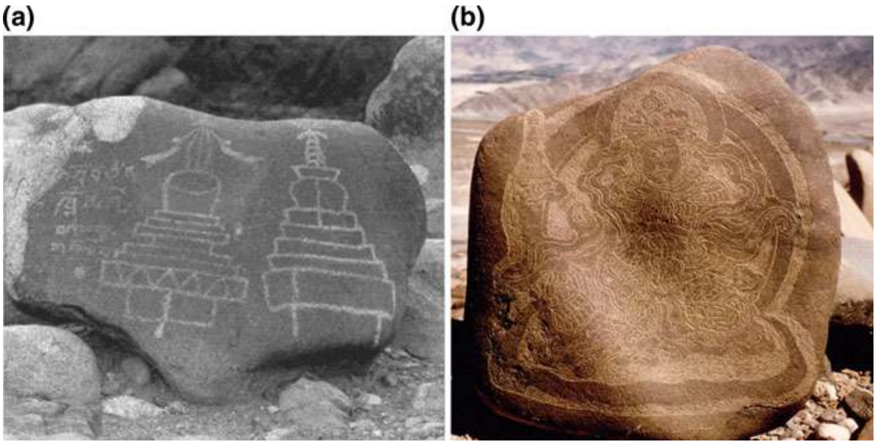

Fig. 20.10 **a** Stupa rock carvings recorded near Gilgit (Geerken and Bräker 2017, Ill. 132, pp. 225). **b** Buddha rock carving near Gilgit, (Geerken and Bräker 2017, Ill. 33.2, pp. 48)

also be expected here. This may be an indication that such a sanctuary may be sought closer to Gilgit, and the upper flow of the Indus, after all. In either case, it does show a continuation of Buddhist carvings along this river-guided route. And hypothetically, if the above-mentioned variables are likewise considered for the as yet undocumented ranges of the mountains (i.e., accessibility of the natural environment, continuation of human presence and passage, religious needs of Buddhist travellers), we can plot the most likely routes that would from as early as the late 1st century BCE onwards to have been actively traversed arteries allowing travellers and trade caravans back and forth through these mountains. As such, these routes physically allowed access from the Gandhara region in the west to the Xinjiang region of China in the east, and vice versa, thus connecting important nodes in the increasingly expanding Silk Roads networks, especially following the Han Dynasty's opening of the Jade Gate for trade across the Tarim Basin and the Kushan administration's expansion of trade networks in Gandhara in the 1st century BCE. And the Karakorum rock carvings, as recorded so far, provide us actual evidence of these important connections.

In order to achieve a more empirical reconstruction of these routes (building on the hypothesis proposed in Fig. 20.9), a continuing documentation of rock carvings is needed along the Karakorum Indus, going beyond the Gilgit region up until the first ranges of the Tarim Basin in the northeast. As reported by scholars and explorers alike who have visited these parts, a great number of carvings remain unrecorded and most likely many more still undiscovered across these parts; moreover, additional excavations would help reveal new archaeological data concerning the trade posts and sanctuaries that came to mark these important Silk Roads routes. But as mentioned above, due to increasing issues in the region at present, mainly dam constructions and political unrest, such campaigns seem unlikely to be possible in the near future. An additional, but no less worrying factor is the effect of climate change in these mountains; recent data predicts such a significant rise of temperatures in the Himalayas, including the upper plateaus of the Hindu Kush and Karakorum ranges, that many glaciers are expected to melt within the next several decades (most recent data: Cogley 2017, 166–167). This is of course a primary concern for the water resources of Central Asia, but it is also a direct threat to any archaeological remains, including rocks carvings, in these regions, which will either be destroyed or made inaccessible due to excessive melt water and shifting glaciers. In addition to these problematic modern variables in the region, modern technology does allow different ways of access; satellite imagery and drones may become the best available tools to keep studying this region in the near future. For that reason, further in-depth analysis of the so-far documented data from the Karakorum Indus valleys is important for a variety of interdisciplinary studies, among which archaeology and environmental science.

20.4 Conclusions

This contribution explored the results of a preliminary interpretative study of this particular Karakorum rock carvings dataset, in order to form a basis for future research that uses these data within the wider frame of studying the dynamics of early Silk Roads networks. The results constitute the following main points.

(1) Concerning the *functionality* of the documented Buddhist carvings: the depictions in this dataset can be interpreted as visual representations of physical early Buddhist architecture and anthropomorphic sculpture that closely resemble architecture and sculpture encountered in Gandhara from the 1st century BCE onwards. As such, especially the numerous stupa carvings, may have

functioned as religious monuments for travellers to enable their worship and meditation according to their Buddhist practices. This could subsequently raise further theoretical considerations concerning the meaning and/or intention of such religious monuments: namely, were they simply material monuments of religion, or should we regard them as material monuments that are *simultaneously* cases of 'lived religion'?[25] In addition, multiple Buddhist carvings collected on certain large stones appear to have also functioned as landmarks along the main routes undertaken by travellers and caravans through these mountains, with apparent higher numbers appearing at notable changes in the flow of the Indus River along these routes.

(2) The data subsequently present insight into the direction of the *routes* through these mountains. Especially many stupa carvings followed the main route along the Indus river directly, even if their function as physical landmarks may have not been their initially intended function (as opposed to religious function for travellers); this connection to the natural environment, which determined the best mountain routes, allows us to hypothesise the continuation of these routes beyond the documented data that is currently available; namely, the stupa carvings can be considered important variables in the development of these trade routes between Gandhara and the Tarim Basin. Moreover, as a result of both their religious functionality and visibility as landmarks, these cravings may add evidence or at least arguments for the presence of larger Buddhist sanctuaries and trade emporia along these same routes over time (so far unexcavated).

(3) The dataset also provides insights concerning *Gandhara* itself—in terms of its early Buddhist archaeology as well as the wider connectedness of the region. The stupas and especially depictions of the Buddha closely resemble architecture and sculpture from early Buddhist Gandharan sites, such as Taxila and Butkara, in terms of style, execution/manufacture, attributes, and architectural features. This suggests not only that Buddhist carvings would have begun to appear in the Karakorum range from the late 1st century BCE onwards, but also provides evidence that Gandharan Buddhist material culture reached well beyond the Gandhara region already since its earliest appearance. The data so far suggest a process of connectedness: at the same time that the earliest anthropomorphic depictions of the Buddha become prominent in Gandhara, featuring certain Hellenistic features and sculpting techniques as variables contributing to that development, those images also became variables in the interregional exchange enabled by the increasingly dynamic traffic of the Silk Roads. This traffic and exchange became especially important in Gandhara from the 1st century BCE, with the opening of the Jade Gate by the Han Dynasty and subsequently by the Kushan focus on trade networks in and from Gandhara. Initial 19th-century Gandharan scholarship considered Gandharan Buddhist art as a unique (and inherently Hellenistic) category, and as such distinct from Buddhist art that developed in East Asia later. The Karakorum carvings strongly underline the fault in these traditional studies by means of empirical evidence, which supports

[25] An interesting parallel here may be recent studies of 'lived religion' concerning Ancient Roman religious monuments, such as presented by Jörg Rüpke (2016).

the important trend of both Buddhist and Silk Roads scholarship moving beyond such predetermined interpretations.

(4) Subsequently, these data have implications for studies of the *spread of Buddhism*, as well. Unlike the focus of textual sources concerning missions by monks to spread the religion, we here find an at least simultaneous process of a seemingly non-intentional spread of Buddhist stupas from Gandhara throughout the Karakorum range, most likely all the way northeast to the Xinjiang and Gansu areas in Western China—where the subsequent earliest Buddhist imagery are known from the Duanhuang caves. The Karakorum carvings may present an empirical 'missing link' between the Gandhara and these Chinese sites. The most interesting feature here appears to be the unintentionality—-namely, the fact that the Karakorum stupa carvings that would originally have been intended for practical use for Buddhist travellers may indeed have incited such an increased accessibility to Buddhist imagery and content that they subsequently also increased a wider interest in the religion, hence also increasing calls for Buddhist monks to travel east to fulfil these new religious interests. Rather than distinct or contradictory, these seem to have been simultaneous processes. An interesting example is put forth by Lars Fogelin in his recent overview of Buddhist archaeology throughout the Indian peninsula, demonstrating that the archaeological data frequently paint a picture of reality that notably defers from historical narratives that are based on textual sources.[26] When stepping away from fixed compartmentalised perspectives, such contradictions instead seem to indicate the occurrence of dynamic processes that did not necessarily exclude one another at all, but coexisted and indeed influenced each other in flexible and unpredictable (at least often unintentional) ways. This, in turn, may indicate a certain level of 'agency' of early Buddhist imagery, in the sense that their *effect* seems to go well beyond the original intentions with which they were created. This, too, would be interesting to pursue in future research. This contribution's exploration of how multiple variables continuously influenced the functionality, subsequent effects (intended and unintended), and developments of the Karakorum Buddhist carvings is merely one example of dynamic interactions that happened along and were made possible because of these mountain routes.

Whereas preconceived concepts and categories have often 'proven useful in ordering things', to return to the words of Albert Einstein, we should be wary of tendencies to compartmentalise, as that can truly make 'the path of scientific progress impassable' (Einstein 1916; see note 2). As this preliminary study of Buddhist carvings

[26]One interesting example of this pertaining specifically to the interpretation of archaeological data, is Fogelin's presentation of a case where textual sources have suggested the rise of early Buddhist monasteries as much later than the tradition of ascetic, travelling monks, whereas the archaeological evidence points at a much earlier rise of monasteries that would have coincided with the ascetic traditions (it appears that the contemporary texts and scriptures highlighted the importance of ascetics because of a scholarly and religious interest in the tradition, which subsequently led modern scholars to consider this literary/religious choice of reference as empirical and chronological evidence, thereby ignoring any contradicting archaeological evidence). See: Fogelin (2015, 14–15; 111–120; 158–169).

hopes to have shown, this particular dataset strongly indicates that the Karakorum Mountains were not quite so impassable in either empirical or theoretical sense.

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Chapter 21
Steppe and Sown: Eurasianism, Soil and the Mapping of Bukhara in the Light of Soviet Ethnographic Accounts

Susanne Marten-Finnis

Abstract This chapter reveals how ecological zones and their division into steppe and sown, nomadic and sedentary people, helped Russian ethnographers to understand the heritage and urban neighbourhood principles of Bukhara. It charts the launch and significance of ethnographic enquiry into this former oasis city within the context of Eurasianism, and illuminates the notion of soil in Russian thought, together with the central role it played in the study of the interrelationship between environmental factors and socio-cultural changes. The evidence will be used to present ethnographic accounts as a way of transferring knowledge between Asia and Europe, and argue in favour of a flexible approach negotiating between nature and culture, and as a process of hybridization, whereby cultures come together and, by learning from each other, create a pathway towards Eurasian integration and global intellectual interaction.

Keywords Eurasianism · Notion of soil · Mapping Bukhara
Ethnographic accounts · Sukhareva · Heritage · Cosmopolitan citizenship
Knowledge transfer between Asia and Europe

21.1 Introduction

A few years ago, the Silk Road concept was rejuvenated by the Central Asian states, notably Kazakhstan, and Belarus, when they formulated plans for a regional economic partnership with Russia, which led to the foundation of the Eurasian Economic Union. Those countries possess three precious things: space, geographical proximity to economic centres—Europe, China and the Arabian Gulf—and vast reserves of energy and other natural resources that their neighbouring markets—Europe to the west and China to the east—are keen to share. These are highly motivating factors for the promotion of knowledge transfer between Asia and Europe.

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Underpinning their moves towards Eurasian integration is the concept of 'Eurasianism', a school of thought arguing that Russia is uniquely qualified to bridge the gap between Asia and Europe, Orient and Occident. Eurasianism built a case for the geographical unity of Russia-Eurasia, drawing on evidence from research into ecological zones grouped into the four geographical categories tundra, forest, steppe and dessert.

Today, the renewed discussion of Eurasian integration provides us with the opportunity to revisit the school of Eurasianism and, along with it, some aspects that deserve further scholarly attention, namely the embedding of these geographical categories within the Europe-Russia-Asia juxtaposition and the impact they had on socio-cultural change.

These are the strands of this chapter, which in its first part, will shed light on Eurasianism as a school of thought, and the legacy of Russian Orientalist scholarship among Soviet-trained ethnographers. Significant in the present context is their concept of mapping a new area on the basis of the four ecological zones tundra, forest, steppe and dessert, in particular the division into steppe and sown, nomadic and sedentary societies. What is the relevance of this concept for the study of the interrelationship between environmental factors and social change? And what role might it play in today's renewed discussion on Eurasian integration?

These questions will be discussed on the basis of original ethnographic accounts on Bukhara assembled during the years 1948 to 1976, and on the basis of the earliest reported observations indicating the Russian interest in this former oasis city, published by Russian civil servants and government emissaries in memoranda, brochures and periodicals. Drawing upon this rich and long-neglected body of knowledge, the second part will highlight the role of Bukhara in the historical Silk Road and in modernizing Imperial Russia. This will be a point of departure to elucidate, in the third part, the pioneering contribution of Soviet-trained ethnographers, of Olga Sukhareva in particular, and their systematic enquiry into the "mores of the land" [нравы земли]. This is a key concept in Russian ethnographic enquiry, which means the study of cultural and behavioural habits, normally pertaining not just to a place or region and its inhabitants, but also to a particular era, i.e. comprising geography, history and sociology—heterogeneous fields of research to cross both the humanities and social sciences. In today's research landscape, it might be at home under the umbrella of Area Studies.

The aim of this chapter is to demonstrate how this concept helped to understand Bukhara's neighbourhood principles and heritage, and how the city positioned itself between steppe and sown, human development and environment. The evidence will be used to present ethnographic accounts as a way of transferring knowledge between Asia and Europe, and argue in favour of a flexible approach negotiating between nature and culture, and as a process of hybridization, whereby cultures come together and, by learning from each other, create a pathway towards global intellectual interaction.

21.1.1 Eurasianism Versus Europeanism: The Notion of Soil in Russian Thought

Ethnographic expeditions enjoyed government patronage in both Imperial and Soviet Russia. Their reports were a valuable source of knowledge about the empire's remote areas and its population. Their importance thus increased in the aftermath of imperial expansion in the last third of the nineteenth century, as the knowledge they mined helped to administer the newly acquired lands, the Caucasus, Central Asia and the Middle Volga region: a huge oriental space that Russia needed to reconcile with the cultural historical space the Russian nation had called its own to date (Bassin 1991). One way of coping with this task was to collect data about these lands and its subjects, almost entirely Muslims, mapping the area and completing fragmentary charts by way of ethnographic enquiry.

Russian politicians and intellectuals agreed that, as a civilized empire, Russia had the duty to unravel the complex and poorly understood customs of its subjects in order to grasp their ways of life and beliefs. As a result, the role of ethnographers, linguists and geographers rose to prominence during the Era of the Great Reforms initiated under the reign of Tsar Alexander II (1855–1881). During this period, ethnography turned out to be the principal science in the Russian Modernization project of Turkistan.

A few years ago, the Silk Road concept was rejuvenated and led to the foundation of the Eurasian Economic Union, and suddenly the concepts of Russian Orientalist scholars, specifically those of ethnographers, were back in focus (Kamp 2010; Stronski 2011; Tolz 2011; Huhn 2016; Sartori 2016). Of particular relevance in this respect is their view that Russia formed a continental bridge between Asia and Europe. This significance of soil in Russian thought goes back to the concept that the earth's land surface is divided into discrete territorial massifs, which originated with ancient Greek geographers who first identified the three continents of Europe, Asia and Africa as natural geographical entities (Bassin 1991).

As cartographic accuracy improved, more and more interpretations of geographical space were articulated in Russia. Among the variety of contrasting geopolitical self-images Russia invented for herself as a particular geographical entity stretching between Asia and Europe, the notion of soil kept its relevance. This was in contrast to Europe whose geographical realm since the fourteenth century was increasingly identified with the spirituality of Christendom, and a civilization whose ideologies claimed cultural and political exclusiveness and, ultimately, superiority (Bassin 1991).

21.1.2 The Scythian Theme

The notion of soil and the understanding of Russia as a land-based empire bridging the two continental entities, Asia and Europe, with no major body of water separating them—is central to the concept of Eurasianism. While pre-Petrine Russia remained largely untouched by the dogma of European superiority, the reign of Tsar Peter the Great saw the emergence of two rather contradictory viewpoints. On the one hand, Peter acknowledged an orientation towards European values and the unconditional pre-eminence of European civilization. On the other hand, the expeditions he sent out to southern Siberia in order to explore the area in search of natural resources and new trade routes, unearthed the existence of the Scythians, a pastoral people who populated the grassy steppe of Eurasia over 2500 years ago. The discovery of their lifestyle in the 1720s, and the more accurate maps led to greater interest in the geography and history of the peoples populating Russia-Eurasia and subsequently, to a new identity framework. With the exploration of the vast region stretching between northern China and the Black Sea, the identification with the Scythians and the idea of Russia-Eurasia as a third continent, entered Russian consciousness. As a result, modernizing Imperial Russia saw an increasing number of intellectuals looking to Asia rather than Europe, for self-identification.

As a School of thought, however, Eurasianism was formally established only in 1921 by Russian emigrants in Berlin, i.e. outside Russia, yet as an identity framework foreseen to include the entirety of Russian society (Riasanovsky 1967). The verve of Eurasianism displayed the profile of its founders' professional expertise[1] (Savitsky et al. 1921). In their manifesto, they created an original interaction between geopolitics, economy, philosophy and history, and generated a positive discourse about the Orient. Based on the argument that Russia was closer to Asia than to Europe, Eurasianists advocated a concept that saw the economic future of Russia in the comprehension of its continental nature and in the appreciation to this nature with all its regional variety and considerable natural resources, rather than in what they called "the aping of the oceanic policy of the western colonial powers" (Laruelle 2007). It was the enormous Eurasian plain stretching between the two continents that qualified Russia to bridge the gap between Orient and Occident, they argued. In their view, the decisive significance of Russia's ethnic and cultural complexity lay not in the interaction between nations, but between steppe and forest societies inhabiting Russia-Eurasia, and thus in the major and organic contribution of the eastern peoples to Russian culture (Halperin 1983).

This attitude, prevalent in Russian thought long before the formation of Eurasianism in 1921, had also influenced the approach of Russian scholars to study Orientalism, i.e. its individual aspects, its aesthetic assumptions, religious quests, intellectual priorities and political entanglements and their interrelationships. Their contribution will be considered here in the light of what they shared with the Eurasianists, rather than in the light of debates surrounding the contribution of Russian Orientalist scholars to the historiography of Central Asia, or their position within the wider field of power in Imperial or Soviet Russia.

With the Eurasianists, Russian Orientalist scholars shared two things: the positive discourse about the Orient and the supremacy of geographical over ideological space,

[1]The economist N. S. Savitsky (1895–1968), the ethnographer and linguist N. S. Trubetskoi (1890–1938), the musicologist and art critic P. P. Suvchinsky (1892–1985), and the historian and theologian G. V. Florovsky (1893–1979).

i.e. understanding socio-cultural changes while prioritizing territorial and environmental factors over ideology. The significance of this approach to mapping a new area increased as early as following the competition for supremacy in Central Asia between the British and the Russians, known as "The Great Game", and the subsequent Russian advance into the territories of the ancient Silk Road in the 1860s.

21.1.3 The Legacy of Russian Orientalist Scholarship: A Transcultural Perspective

Not surprisingly, the decades to come saw the rise of Oriental Studies in Russian Universities. First influenced by the impact of nationalism on European scholarship, Russian Orientalists, in particular those of the Rozen School,[2] eventually turned from their western orientation and developed their own approach to reconciling national aspirations and imperial governance within the Russian context, rather than reproducing the agenda of their Western European peers (Tolz 2011, 13–19). This is all the more remarkable as none of the Rozen disciples was ethnic Russian; and it was perhaps this very condition that enabled them to look at the oriental heritage of Russia's new subject nationalities with a transcultural perspective.

These scholars argued in favour of forging a multi-ethnic community (Jersild 1997, 101; Yaroshevski 1997, 61, 65–72), based on the principles of civic nationalism in the sense of social integration and shared political values and responsibilities among Russians and non-Russians despite linguistic, cultural and religious differences. Their pathway to citizen-building foresaw cultural and political integration through educational projects shared with the subject nationalities in the eastern and southern borderlands, with the aim of fostering among the country's entire population a sense of community and unity. This was to be achieved through political and spiritual fusion built on common, state-derived (Russian) civic norms and shared between Russians and indigenous people (Tolz 2011, 13–19).

Not only did their recommendation differ from the ways of national community building pursued by the maritime powers Britain and France, whose remote Muslim lands could be reached only by sea. It also articulated a pathway towards integrating ethnic minorities with their emerging nationalisms, into the imperial structures that would have a significant impact on Soviet nationalities policies during the 1920s (Hirsch 2005).

The educational projects scholars put forward entailed a regulated transfer of knowledge that was based on teaching the native population in textbooks specifically developed in their own languages, about their local histories and heritage. This way, they claimed, the latter would first develop an ethno-cultural awareness of their own

[2]Referring to the disciples of Viktor Romanivich Rozen (1864–1908), Professor of Arabic at the Faculty of Oriental Languages at St. Petersburg University: they include Vasilii V. Barthold (1869–1930), Nikolai Ia. Marr (1864–1934), Sergei F. Oldenburg (1863–1934) and Fedor I. Shcherbatskoi (1866–1942).

fatherlands [*маленкая родина*], which would eventually bring them closer to the Russian motherland [большая родина]. In other words, minorities were not simply absorbed into the Russian Empire, but become more knowledgeable of their own histories and heritage. An appreciation of their own ethno-cultural particularities would raise the awareness of their heritage and subsequently foster awareness and loyalty to all-Russian concerns bringing them into a better position to contribute to pan-Russian activities.

However, Eurasianism, as an alternative to Bolshevik rule, did not leave the realms of Russian Emigration; and the concepts of citizen-building advocated by Russian pre-revolutionary Orientalist scholars were largely neglected by tsarist politicians. Nevertheless, the notion of soil and the positive discourse they had created about the Orient, in particular their recommendations about furthering Eurasian integration by transferring knowledge via ethnographic enquiry, was put into practice by their Soviet successors (Tolz 2011, 3). Under Soviet conditions, their pathway to citizen-building, foresaw the training of indigenous people for information, administration and ethnographic research in order to learn about Russia's remote periphery, and adapt government instructions and services to local culture, with the overall aim to facilitate integration rather than breed separation. A consequence of this policy, was the initiation, as early as in 1918, of the *Turkestan Institute of Oriental Studies*, intended to bring scholars from Russia's European centre to Central Asia in order to train experts of heritage, history and languages from among the indigenous population. In order to facilitate this policy, the *Department of Practice* (*практический отдел*) was established in 1923 (Biulleten Sredne-Aziatskogo Gosudarstvennogo Universiteta 1924; Sirazhdinov 1970).

21.1.4 The Steppe and Sown Dichotomy

Another concept that remained popular among those who studied the social history of Central Asia referred to the symbiotic relationship between the steppe and the sown—between the domestic lifestyle of the settled people in the oasis cities and the nomadic lifestyle in areas where severer climatic conditions made civilization more fragile.

According to this concept, Central Asian history is defined largely by the dynamics of nomadic-sedentary relations often hostile, even violent, but always mutually interdependent (Foltz 1999, 23–24). Pastoral peoples would provide raw materials, e.g. wool or leather from the steppes, to be processed by the technologies of the oasis-dwellers, who would offer manufactured goods in return. On a different level, nomads would often attack and plunder the settled folk. They might then either withdraw to the steppes or, seduced by civilisation, remain and become assimilated (Grousset 1970).

From this outset, Tsarist administrators in Turkestan had established that religious ritual manifested itself mainly through the rituals of everyday life among the settled people, which was why Islam had gained a firmer stance in the Central Asian cities than among the nomads of the steppe region. In their view, townspeople therefore required more attention, as their fervent piety was linked to the backwardness and isolation of Central Asia, to which Russian social policies had to bring modernity by strengthening secular practices and eliminating undesirable manifestations of religious fanaticism (Brower 1997).

Another motivation for the division of ethnographic enquiry into steppe and sown was the fact that it corresponded to peoples' self-perception even until after the Bolsheviks had launched the process of citizen-building. When ethnographers started to affix to the people of Turkistan and the steppe national labels such as Kazakh, Kirgiz or Uzbek, people were hesitant to apply them to themselves. While the nomadic element was exclusively Turkic being made up of Kazakhs, Turkmens and to a minor extent Kirgiz, the sedentary peoples included both Iranian (Tajiks) and Turkic (Uzbeks, Karakalpaks etc.) elements. Yet, individuals would tend to think of themselves as members of a (nomadic) tribe or a (city) clan rather than as belonging to a whole people (Schuyler 1966, XIII–XIV). Questioned about their national affiliation many Bukharans would respond that they "used to be Tajiks but now they had become Uzbek", with further variations between female and male parts of a family, and a tendency of the former to see themselves as Tadjik, and the latter feeling predominantly Uzbek (Sukhareva 1966, 122).

It was on this basis—citizen-building, indigenization and prioritization of urban over rural studies—that the Bolshevik government launched the programme of ethnographic enquiry into the inner structure of Bukhara's residential neighbourhoods, their workforce, social composition and ethnogenesis (Sukhareva 1966, 21). In the process of working towards this target, however, it turned out that the division into steppe and sown could not be maintained and the study of the region's rural settlements (Sovremennyi kishlak 1926) was prioritized over the study of urban neighbourhoods (Sukhareva 1966, 15).

Only in 1948, the leading Soviet Orientalist scholar Ilia P. Petrushevskii, at the time heading the Oriental Department of the University of Leningrad, recorded that despite long-lasting efforts, the historical study of the Central Asian city was one of the thinnest chapters in Russian Orientalist historiography (Petrushevskii 1948, 85). The history of Bukhara in particular had been grossly neglected, he argued, and its recording was by then overdue. According to Petrushevskii, the mapping of Bukhara would need to embrace the city's historical topography at the crossroad of ancient trade routes and the impact of population influx on the ethnic composition of this diverse urban community and the variety of goods they produced. Such an approach, he suggested, should then be a point of departure for a close examination of individual neighbourhoods, the professional realms of their residents, their interaction, heritage and religious rituals (Petrushevskii 1948, 85).

It is with a view to this heritage and the entanglements between steppe and sown, ethnogenesis and occupation, that the mapping of Bukhara will be discussed in the second part of this chapter. The particular role Bukhara occupied in the Soviet construction of ethno-national territories and identities, and the politics and historiography of Islam in the region (Khalid 2007, 2015) will not be considered here.

21.2 Mapping Bukhara

Along with Petrushevskii's plea came the proposal to widen the scope of research and study the rise of the city in all its facets, including its heritage: its material culture, local artisanship and preserved customs on the basis of testimonies and personal accounts (Jakobovsky 1951, 3–4). It was recommended that, due to the dearth of written records, interviews with Bukhara's residents should be conducted by Soviet-trained, indigenous scholars of ethnography whose command of local languages and customs would qualify them as the best protagonists of a knowledge transfer from their native homelands, to the centre in Moscow (Barthold 1927; Shishkin 1936, 1943; Umniakov 1923).

Reports on testimonies and personal encounters could be the result of short-term assignments commissioned to government emissaries, in which case they would take the form of well-qualified memoranda. They could also appear as a piece of scholarly work that relied on systematic academic enquiry, assembled over an extended period of time by scholars who reviewed a city's history, geography, ethnography and sociology. The latter are under scrutiny here. Composed by Soviet-guided indigenous ethnographers, many of them female, they reflect the privileged access they were granted to the city's individual neighbourhoods, in particular the inner courtyards, which were exclusively the domain of women. Their meticulously logged reports are the topic of this subchapter, which will introduce the launch and significance of Soviet ethnographic enquiry into Bukhara, discuss its prior observations, and provide a periodization.

21.2.1 The Role of Bukhara in the Historical Silk Road: A Network Topology

What was it that attracted Soviet ethnographers to Bukhara in particular? Tracing the links to its past was the best way, Soviet ethnographers argued, to understand the structure of the oriental city, its neighbourhoods with their traditions, heritage and the behaviour of its residents (Rabinovich and Shmeleva 1981).

The city of Bukhara stands out as a centre of trade, scholarship, religion and Muslim culture, and as part of the backbone of the ancient trade networks stretching from Northwest China through Central Asia, the Middle East as far west as Rome. In that respect, the term Silk Road, coined in retrospect is grossly misleading, as the concept of a road is usually associated with movement along a line. However, the system under discussion here has a network topology—an arrangement of nodes together with their connecting lines that enabled the exchange of commodities and transmission of knowledge between Asia and Europe.

Bukhara appears as an active node in this network—a node in the sense of a permeable construct of civilization, rather than a closed entity. Situated in the irrigated area between the Amu Darya and Syr Darya rivers, formerly known as Transoxania and corresponding roughly to modern-day Uzbekistan, it is usually referred to as a former oasis city. But again, this term is misleading, because the boundaries between the city and the surrounding steppe, or between nomadic and sedentary societies were much more permeable than the rhetoric suggests, as described in Sect. 1.4 on the dichotomy between steppe and sown.

Bukhara thus emerged within a network of mobile relations stretching between the Muslim and the Christian worlds, and as a place whose dynamics were conditioned by different modes of interaction between steppe and sown, nomadic and sedentary societies, material culture and technology. This condition, together with the influx of migrants from other urban centres, largely determined the structure of the city and its neighbourhoods. The concept of 'neighbourhood' is indeed key to understanding the dynamics of Bukhara as discussed in the following.

21.2.2 Understanding Urban Neighbourhood Principles

In the European understanding, 'neighbourhood' relates to a number of houses in the city, grouped around a square. The square is surrounded by streets that form the boundary between neighbourhoods. The houses on each side of a street thus belong to different neighbourhoods. This is in contrast to the traditional Central Asian city where a street forms the core of a neighbourhood and unifies the people living on both sides of it, rather than separating them. A neighbourhood may also include small side-walks and cul de sacs branching off from the main street (Sukhareva 1966, 40–41). Neighbourhood boundaries were thus formed by the back walls of houses and their courtyards. Gates sealed the main street; their closure overnight could turn a neighbourhood into a real fortress (Sukhareva 1966, 16–17, 38). Such seclusiveness was both functional and necessary as it protected inhabitants from unrest, menace, robbery and other dangers of the surrounding steppe. This system of defence, through street gates rather than city walls, is typical for many Central Asian cities including Bukhara, and was maintained up to the early twentieth century (Barthold 1966, 157). Hence, it is the courtyards and gates that are the most distinctive features in the neighbourhood of an oriental city, rather than an open square.

With regard to their social composition, neighbourhoods might be inhabited by compact colonies of tribal groups having arrived in Bukhara from one and the same place. Or, they could emerge as a concentration of manufacturer or artisan guilds. Representatives of these guilds formed the majority and lived among other social layers of a local population, such as merchants, clergy, nobility or the descendants of slaves. Frequently, the emergence of local craftsmanship was linked to the arrival of a certain ethnic group.

While Europeans may perceive such cohabitation of the well-to-do and the less privileged as unusual, it worked out much to the advantage of the local population as it neither affected the estate system nor the class privileges. Quite the opposite: well-to-do families profited from the indigent people in their neighbourhood, as they could always source from them servants, messengers, porters or tailors at short notice, for casual labour (Sukhareva 1966, 18–19).

Starting from this observation, ethnographers concluded that the study of the entanglements between occupation, ethnic composition and the growth of the city in terms of neighbourhoods and population density must form the departure to their enquiry. The testimonies they based their enquiry on covered the late nineteenth and early twentieth centuries. Although during this period Bukhara had remained under the rule of the Emir, it was kept in the focus of Russian observation until it was besieged by the Red Army in 1920. The task of mapping the city and integrating its Muslim population were thus left to the Soviet government. Hence, the period of the accounts under discussion roughly coincides with the decades between the Russian arrival in Turkestan in the 1860s and 1920.

Outstanding among these testimonies were those compiled in the accounts of Sukhareva who analysed the memoranda of imperial government envoys and previous ethnographic expeditions and eventually completed the abortive ethnographic charts of her predecessors in pre- and post-revolutionary Russia. The reasons for this extended research stretching over more than three generations of scholars were manifold, as were the obstacles they encountered to be outlined in the following periodization.

21.2.3 Towards a Historical Topography: Knowledge Transfer and Periodization

The Russian interest in Bukhara, the city the Russians considered its most important economic and political stronghold, had started well before the annexation of Turkestan in the 1860s. Fuelled by "The Great Game", an animation of relations with Bukhara began in the early nineteenth century (Sukhareva 1966, 5).

The term "animation" [оживление] points to a changing pattern of knowledge transfer between Russia's European centre and her Central Asian periphery. Knowledge transfer is used here in the sense of social practice, referring to how people from different cultures interact, what languages they use, and whether their interaction is spontaneous or planned. The periodization suggested below will help to differentiate between these different modes of interaction. Referring to the Russian observations on Bukhara, four stages of knowledge transfer can be identified.

Stage I (1800–1839): Random observations by travellers

The random observations of merchant-travellers, pilgrims and prisoners at the beginning of the nineteenth century were the point of departure for a more focused knowledge transfer. Important in this respect is the role as a mediator between East and West that Russia had taken on for herself, with the aim of contributing to both popular enlightenment and scholarship in the countries of Western Europe. In 1820, the letter of Jakovlev, a Russian envoy, points out:

> The fact that Russia has, for more than a century, been in touch with Bukhara, Khiva and Tashkent has made foreigners demand from us information about these cities, and rightly so. They require comprehensive knowledge from us separating solid facts from rumours, […] interesting news about the mores of the lands. This is why we have to do our best to enlighten our fellow citizens about the historical and geographical facts in this part of the world. Who – if not us Russians – would inform European scholarship about present-day Bukhara? (Jakovlev 1824, 50–52)

Stage 2 (1840–1867): Regulated observations inspired by the search for new markets

During the second stage, coinciding roughly with the second third of the nineteenth century, Russia needed to develop commerce with Central Asia, and had a particular interest in the trading of silk fabrics, cotton and dyestuffs (A.P. [sic] 1825). That is why this period saw a more active and deliberate transfer of cultural and political knowledge delivered by trained civil servants, military specialists, diplomats and government emissaries. Their observations are documented in a rich body of sources, nearly all of them in Russian. They include newspaper articles issued particularly in the Orenburg region, and essays for periodicals.[3] Their authors were either Russian professionals or foreigners in Russian service. The few Western publications on Central Asia include the writings of Meiendorff (1820) in French, Eversmann (1823) in German, and Burnes (1842) in English.

Stage 3 (1868–1920): Disciplined observations related to citizen-building

The third stage—the period following the annexation of Turkestan saw the dispatch of elite emissaries of the tsarist government to the southern periphery, mostly to the cities of Tashkent and Samarkand. These cities lay within the annexed territories, while Bukhara remained under the rule of the Emir. Surrounded as it was, however, by the Governorate General of Turkestan, which constantly expanded, it remained in the focus of Russian politics and influence (Khalid 2000), and became a Russian protectorate in 1873.

During the decades to come, the building of national communities occurred alongside the building of commercial relations with Central Asia. Economic ambitions had to give way to political concerns, of which the policy of citizen-building [гражданственность], i.e. the integration of Russians and non-Russians into a unified community of staunchly Russian citizens, was the principle element.

Stage 4 (after 1920): Systematic ethnographic research as academic enquiry

A systematic ethnographic enquiry into Bukhara started only under Soviet rule in 1923–24, with a preliminary statistical record on the former Khanate of Bukhara where a census had so far not been conducted. This rough estimate revealed 180,000 residents in Bukhara, compared to an estimated number of 251,800 in 1913–14 (Bukhara v gosudarstvennom khoziaistvennom plane 1923). According to the 1926 census, there were 11,901 homes in Bukhara inhabited by 13,491 families, with

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[3]Journals include *Sovremennik*, *Otechestvennye Zapiski*, *Vestnik Evropy*, *Severnaia Pchela, Aziatskii Vestnik*, *Sibirskii Vestnik*, *Aziatskii Zhurnal*.

the total number of residents amounting to 46,706, of which 41,839 were native (Materialy vsesoiuznoi perepisi 1927).

The years 1922–28 saw the restoration of the irrigation system in the region, and the return to the pre-revolutionary policy of exclusively growing cotton on irrigated land. The subsequent period of the first Five-Year plan (1928–32) foresaw the industrialization of the Bukhara region, with a particular focus on cotton production. This included "a speedy inclusion of women into the production process" (Iusupov 1930, 47–49). The plan's directives were chiefly targeted at the female reserve army of labour. Campaigns against religious practice (Kamp 2010), above all against wearing the veil, alternated with the attempted promotion of women into leading positions (Iusupov 1930, 47–49). Literacy campaigns and the provision of medical care were to keep women away from the mullahs.

Thereafter, the mapping of Bukhara was interrupted (Grenet 2013–14, 2015) and only returned to in the late 1930s by the ethnographer, linguist and archeologist Mikhail S. Andreev (1873–1948). The testimonies of elderly Bukharan citizens "as the living carriers of the tradition" (Sukhareva 1966, 19), he suggested, would shed light on their roots, occupations, domestic environment and neighbourhood principles and enable scholars to study the historical topography of a city that had retained many characteristic features from antiquity and medieval times (Sukhareva 1966, 20). However, the field research he had set up in 1940 under the patronage of the Central Asian State University ended prematurely after just one season, as no funds were available to complete the evaluation of their findings (Sukhareva 1966, 20) due to the Great Patriotic War. As a result, the study of Bukhara had to be shelved for a third time, until 1948 when it was restarted following Petrushevskii's call.

21.3 Ethnographic Enquiry as Systematic Research

21.3.1 The Emergence of Sukharava

As a result of Petrushevskii's call, the material gathered by Andreev and his team was unearthed, and handed over in trust to Olga A. Sukhareva (Fig. 21.1) who turns out to be the first heir to his broadly conceived collective fieldwork (Sukhareva 1966, 19).

As one of the first graduates (1925) from the *Turkestan Institute of Oriental Studies*, and with a Ph.D. on Islam in Uzbekistan (Sukhareva 1960), she qualifies as a classic representative of the policy of indigenization. The outcomes of her research included a historical study of the cities in the Khanate of Bukhara (Sukhareva 1958) and a comprehensive survey on Bukhara's craft-oriented industries on the basis of a meticulously composed description of the city's distinct neighbourhoods (Sukhareva 1962). Based on those works, she submitted a social history of Bukhara's individual neighbourhoods together with the interaction of their agents (Sukhareva 1966), in which she concentrated on the division of labour across-neighbourhoods and along

Fig. 21.1 Olga A. Sukhareva, 1903–1983 (Sukhareva 1969, back cover)

the lines of gender in both amateur and professional practice (Sukhareva 1976). In her later works, she linked the historical topography of neighbourhoods to the history and arrival of their residents with a particular focus on the changing perception of women in the oriental city (Sukhareva 1969, 1979). Her achievements were commemorated in a publication launched in 2006 on the occasion of her centenary in 2003 (Abshin and Bushkov 2006). The main source of her findings were the testimonies gained from questionnaires and interviews with Bukharan residents.

As someone who grew up in their midst she spoke their language. Tracing their past enabled her to scrutinize the entanglements between ethnic composition, occupation and the arrival of certain groups in a particular neighbourhood, and thus to expose the growth of the city, both in terms of geographical expansion and population density.

By 1947 when Sukhareva launched her enquiry, the division into small neighbourhoods had been replaced by 16 larger administrative unites (домоуправления). Nevertheless, she could trace individual neighbourhoods on the basis of their architecture (Sukhareva 1976, 11), including dwellings, cemeteries and sanctuaries, together with the ethnic and social composition of its residents: merchants and craftsmen, native and resettled people (Sukhareva 1962, 113). Among them were Turkmens, Arabs, Farsi, both Muslim and Jewish—a colourful mix of people of multiple origins who found themselves living in proximity to each other. Their testimonies, Sukhareva maintained, were the most appropriate, if not the only, avenue to understanding the complexity of urban neighbourhood principles and the heterogeneity of residents whose cosmopolitan heritage forms the underlying theme in all her accounts.

21.3.2 Textiles and Bukhara's Cosmopolitan Heritage

Figure 22.2 shows the distribution of local craftsmanship between Bukhara's different neighbourhoods.

The above legends clearly display the dominance of neighbourhoods inhabited by weavers. What they do not reveal is the dynamics of cross-neighbourhood interaction. Of particular relevance in this respect were the work-related patterns of exchange taking place between the majority Muslim and the minority Jewish communities, who lived in separate neighbourhoods, but allied their talents for the manufacture of complex textiles.

Colourful fabrics held a place of primary significance in Muslim culture while the secrets of their fabrication and dyeing had been in Jewish hands since antiquity. The history of textile weaving and dyeing is thus very much a history of a shared heritage that characterized the cosmopolitan communities of Central Asian cities, particularly Bukhara, both as the stronghold of textile weaving and a centre of Jewish culture in Central Asia.

Today, we associate with 'cosmopolitanism' a mobile society whose people and communities were linked by the 'now' of their social bonds rather than the 'here' of their shared, age-old attachment to a place or tradition. From this follows that mobility would challenge stability. As a former oasis city, Bukhara owed its prosperity, and

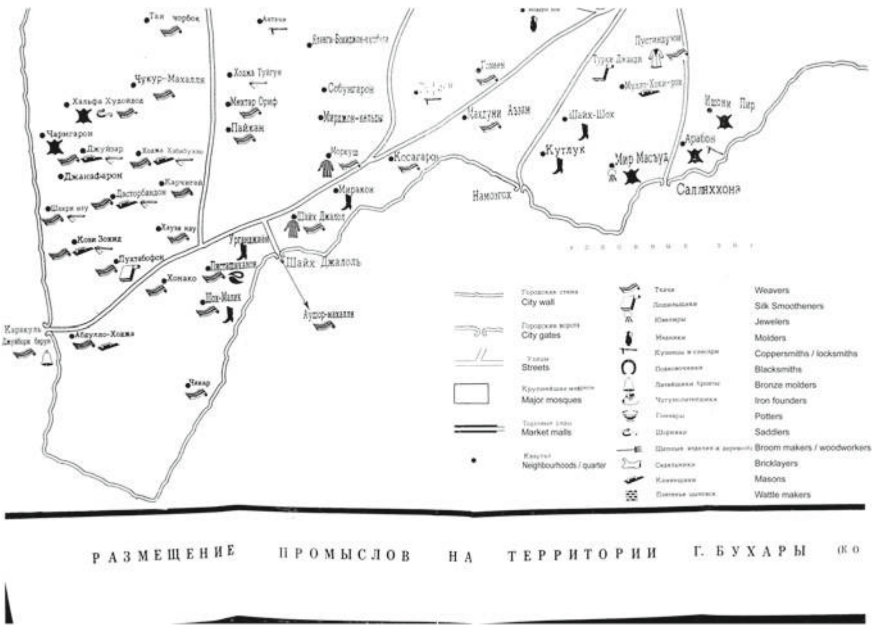

Fig. 21.2 Distribution of local craftsmanship between Bukhara's neighbourhoods (Sukhareva 1962, 16, supplement)

perhaps its very existence, to the mobility along the Silk Road. Although the Silk Road had been declining in importance for over 400 years when Sukhareva's sources were active, mobility related to trade and textiles (Jacoby 2004)—both intrinsically linked to Muslim and Jewish cultures—was still a dominant factor in professional life after the Russian arrival in Turkestan, which even gave it a boost.

The place of Jewish dyers and textile merchants within the silk trade and their influence upon it were disproportionate to their relatively small numbers. Jewish dressmakers were the first to bring sewing machines to Bukhara to distribute them among the local Muslim population (Sukhareva 1962, 76–77). Moreover, Jews held the monopoly of the dying of silk and cotton yarn and cloths because of their access to rare and precious dyestuffs and techniques (Krauze 1872).

21.3.3 The Jewish Presence in Bukhara

The Jewish presence in Central Asia goes back to the times of the Silk Road (Foltz 1998). From the advent of Islam in the seventh century, Jewish traders known as *Radanites* held a privileged status within the topology of trade networks stretching between Asia and Europe. Their intermediacy allowed them to move freely between Muslim and Christian worlds, and their activities spanned the Carolingian Empire, the Islamic World, the Chinese Empire and the Kingdom of the Khazars (Fischel 1952). In the ninth century, the Persian geographer Ibn Khurdadbih described the *Radanites* as

> … merchants (who) speak Arabic, Persian, Roman (Greek), the language of the Franks, Andalusians, and Slavs. They journey from west to east, partly on land, partly by sea. They transport from the west eunuchs, female and male slaves, silk, castor, marten and other furs, and swords. (Rabinowitz 1948, 51)

As alleged non-believers, Jews were not allowed to marry Muslims. They were excluded from living in the *Guzars*,[4] the Muslim neighbourhoods, in order to prevent private interaction with the Muslim population (Loewenthal 1961). Instead, they had been allocated areas at the margins of the city, the so-called *Slobodas* or *Makhallias*—terms that the people of Bukhara, Samarkand and other Central Asian cities associate with isolated quarters (Kantor 1929, 9), similar to the Jewish *Shtetl* in Eastern Europe, where Jews lived separated from other residents.

The close-guarded knowledge of dying methods referred in particular to indigo and kirmiz dyes (Fitz Gibbon and Hale 1997, 182), both greatly appreciated by the Arabs and in the rest of the Islamic world (Butler Greenfield 2005, 19; Kurdian 1941). Russians envoys registered these conditions as early as during the reign of Peter I. In 1724, Florio Beneveni, Russian ambassador to the Emirate of Bukhara from 1718–25, reported to the Russian Ministry of Foreign Affairs:

> In this Bukhara land, there is a special type of tree with worms located in a steppe. An expensive dye of *kermez*, called coushenina [cochineal] in German, can be derived from this

[4]Guzar is an Urdu word, it means "a pass, a living, a road".

> tree. This dye costs eight roubles a pound in Russia. There is plenty of this dye in Bukhara. The Bukharians [sic], however, do not know the secret of manufacturing this dye. They only collect worms and sell a lot of them to the Jews. And the Jews use those worms to produce the dye. (Beneveni 1986, 85)

Figure 21.3 is an illustration of what Beneveni described in his report.

Nevertheless, the Bukhara government was neither able nor willing to protect the Jewish community against day-to-day harassment, including refined methods of provocation aimed at forced conversion, which represented an imminent danger (Sukhareva 1966, 172). Jews were frequently charged with capital crimes and could only escape death by abjuring their faith (Amitin-Shapiro 1931, 15–36). These con-

Fig. 21.3 Cochineal parasites feeding on moisture and nutrients from the fruit-bearing prickly pear cactus (genus Opuntid), native to tropical and subtropical Mexico and South America (Phipps 2010)

verts were known as Muslim-Jews or *Chala*.[5] They were forced to leave their quarters and cut off all their family links to live in allocated areas. The *Chala* communities have been described as the most miserable and tragic of all residents in the Khanate (Babakhanov 1951).

A variety of other crafts existed in Bukhara, many of them in the hands of family workshops (kustari) (Sukhareva 1962, 16–30) that produced fabrics for export to be sold in Samarkand (Grebenky 1873; Sukhareva 1981). However, not all these crafts can be discussed here in detail.

21.3.4 Mobility Versus Stability: Suzani Expressing a Distinct Sense of Place

Having shed some light on the male-dominated mobility that was a feature of Bukhara's textile-making and trading, the remainder of this sub-chapter will be devoted to the stability associated with an exclusively female product: suzani—the art of embroidery. As distinctly urban creations, suzani embroideries mirror the female attachment to a place and a tradition of the settled communities in the oasis cities.

Suzani are the most widespread form of household decoration in Bukhara, although the name is applied to all Central Asian embroideries. Suzani means needle-work. The term is derived from *suzan*—the Tajik word for needle (Sukhareva 2013, 5). Suzani-making was the provenance of amateur-artisans working for pleasure rather than profit. According to Sukhareva, it was a typically female way of artistic expression. Women, she argued, were able to reveal their creative abilities more freely than men, whose artistic expressions were generally influenced by their training as craftsmen or in skilled trades and this training would tend to restrict their choice of forms (Sukhareva 1983; Chepelvetskaia and Sukhareva 1991, 75–81).

Suzani embroideries decorated tapestries, bed and bolster covers—the most precious items in the dowry to be used for the nuptial bed (Cootner 1986). They represented fashion and tradition of a place, labour and luxury thereby giving the bride a reassuring memento of her family. Their patterns displayed abstraction from nature, cult or magical meanings that were conveyed by love of ornament, emphatic colour and vigorous line, or from wellbeing, fertility and abundance in a garden, as demonstrated in Fig. 21.4 (Nauchno-issledovatel'skii institute iskusstvoznaniia Uzbekskoi SSR 1955, 89–104).

They could also evoke more dramatic associations with apotropaic images that were understood as protecting oasis inhabitants from the threats in their environment: the surrounding steppe. Some of their images have become widely known, as for example the *kalamafur* or *bodom* motifs (Fig. 21.5). *Kalamfur* refers to the paprika pepper, *bodom*—to the almond.

Both were thought to afford protection due to their pepperiness and bitterness respectively. They decorated the carpets of vulnerable people, such as pregnant

[5]Tajik for 'neither-nor'. Name applied to Bukhara Jews forced to convert to Islam.

Fig. 21.4 Suzani displaying fertility and abundance in a garden. State Museum of Applied Arts, Tashkent

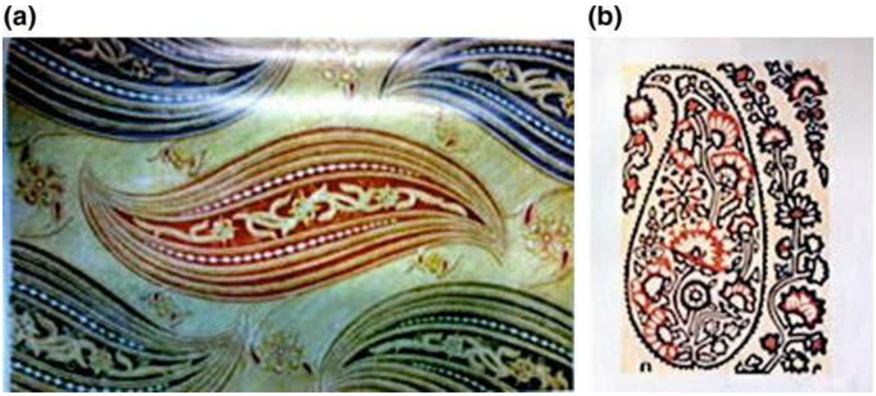

Fig. 21.5 Bodom motif. **a** is a popular design used on many embroideries (Goncharova 1986, 61). **b** shows an embroidered bodom motif (Nauchno-issledovatel'skii institute iskusstvoznaniia minesterstva kultury UzSSR 1954, 51)

women or new-born babies. When the pattern became commercialised it travelled to Norwich for the factory production of shawls, and then further to Paisley, where the eponymous pattern was made (Karpinski 1963).

21.3.5 Messengers from an Ancient Past

Suzani belong to the artistic creations of the settled communities in the oasis cities, rather than of the nomadic tribes. While their flowering period falls into the years 1850–80 (Chepelvetskaia and Sukhareva 1991, 27), the tradition of their creators had far more ancient origins. These origins should be sought in the sedentary cultures of the ancient centers of Sogdiana (Liu 2010, 67). “Sogdiana” is the earliest name of the country between the rivers Amu Darya and Syr Darya (Sukhareva 2013, 11).

Among these settled communities, a sense of ethnic identity remained undeveloped until well into the Modern Age. This is reflected in the suzani, in which no ethnical peculiarities can be traced, as they emerged as the art of compact settlements, with centres of production crystallizing in Bukhara and Samarkand, besides Tashkent and Shakhrisyabz. In the steppe regions with the ancient irrigated farming outside Bukhara, there were no suzani-type embroideries (Sukhareva 2013, 11).

Suzani patterns could express the energy of spring in the steppe oasis. Or they could display a more immediate concern of the women who made them: the longing for rest and coolness provided by a shaded garden. The general theme is ‘Water and Shade’ (Taube 1994, 17–18), not surprisingly since Islam spread in a hot and arid climate. Plants implied water, and water was associated with healing, beauty and wealth.

Gardens were important for leisure, for supplying fruit and vegetables to the family, and for their symbolism, as an earthly representation of paradise (Franses 2000, 25–26). They meant an oasis of freedom for urban women; inside their walls, women could enjoy the beauty of nature in the company of friends and family unencumbered by heavy veils. As the most important outward symbol of the wealth of a family, they were enlarged at every possible opportunity. Hence, no discussion of urban life in Bukhara could be complete without mentioning the magnificent gardens in the city’s western part (Sukhareva 1966, 32–33).

Suzani came to belong to the universal style of Islamic art, with the infinite repeating and enlargement of patterns. Their embroideries are not concerned with details but rather with the abstract qualities of nature (Franses 2001) and motifs of the universe, both astral and vegetal (Fig. 21.6).[6]

Stitched on a background of cotton or silk, they dissolve into huge central medallions, rhombuses and concentric circles, representing sun and stars, stylized flowers and petals, continuing branches and garden segments suggesting a human desire to live in harmony with the natural environment and the universe.

Given the nature of the dowry gift itself, many of the weavings bore symbols of fertility, such as pomegranates (Fig. 21.7). While the function of suzani, and their motifs have evolved like a living language since ancient times, they could also take on new meanings with new times and generations. Their use could even change during the lifetimes of the family members who made them.

[6]The claim that the representation of living forms in art is forbidden by the Koran can be neglected here, as it is not applicable to textiles. Unlike sculpture and painting, textiles have always been neutral ground for images.

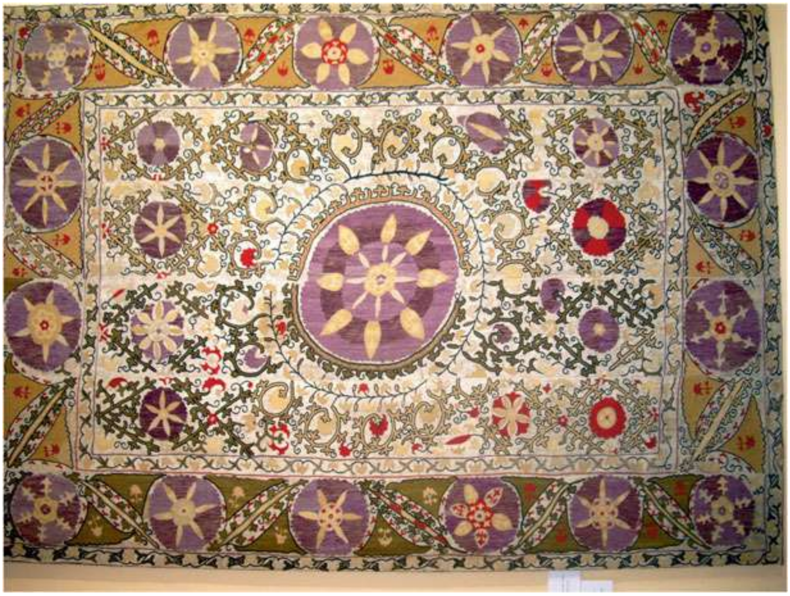

Fig. 21.6 Astral and vegetal motifs stitched on a suzani from mid-19th-century Bukhara (cotton). Samarkand Museum fort the History and Art of the Uzbek People

Fig. 21.7 Stylized pomegranate (Goncharova 1986, 68)

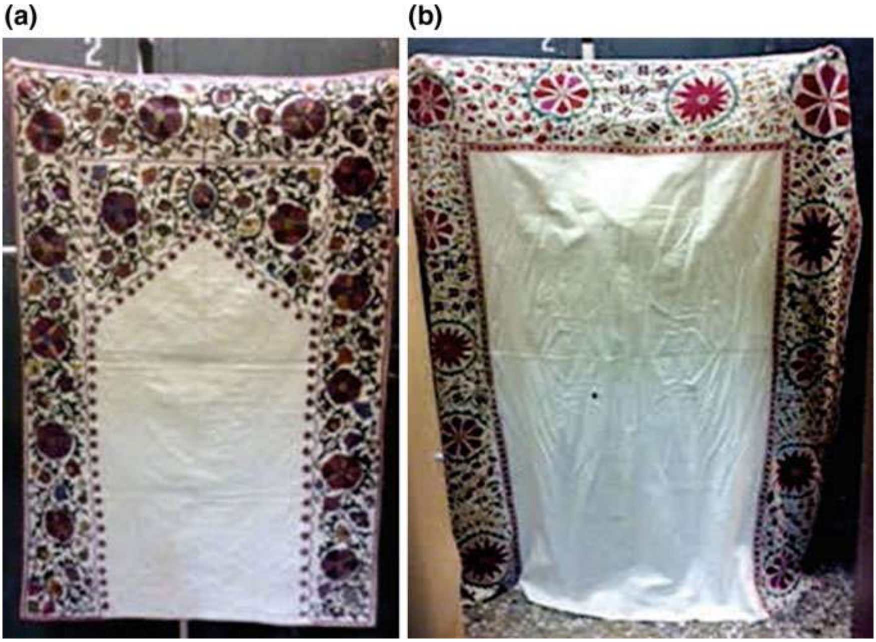

Fig. 21.8 **a** shows a prayer mat (dzhai namaz) made in Bukhara around 1850, and **b** shows a bedspread (dzhai push), literally: place cover and part of a dowry suit. According to Sukhareva, it was made in Bukhara between 1850 and 1880. The п-shape of the *Mihrab* is well recognizable. Both pieces belong to the archival collection of the Russian Museum of Ethnography, St. Petersburg: **a**: no. 58–133; **b**: no. 58–153. The explanations have been provided by O. A. Sukharva on 24/25 May 1956, written down by A. S. Morozova and M. B. Sazanova

Further functions of suzani included the decoration of a niche in the wall where bedding was stored during daytime. They could decorate a table or bread cloth, a sandal quilt (*Sandali-push*)[7] or a prayer mat (*Namazlyk*—or *Dzhai-namaz*). The shape of a prayer mat invites embroidered embellishments in the form of a п-shape imitating the Russian letter п (p), i.e. featuring on just three sides of a rectangular mat. In many prayer mats, they dissolve into a bold arch motif—the two-dimensional representations of the *Mihrab* (михраб), thereby recreating an ornament typical for Muslim architecture (Fig. 21.8a).

The *Mihrab* imitated a niche in the wall of a mosque indicating the direction of Mecca, the direction that a person should face when praying. With regard to Bukhara, there is a peculiarity about the *Mihrab*, as it embellished not only prayer mats, but also bed covers (*Dzhai-push*) (Fig. 21.8b).

This *Mihrab* shaped embroidery on a bedspread is exceptional, because no *Mihrab* shapes graced the bed covers in the other cities (Sukhareva 1956), which suggests

[7] A small wooden table placed over a charcoal brazier set in a hole in the kitchen floor with covering quilts channelling the heat to the legs of people sitting around it. During the short, but cold winters families gathered around the sandal and slept near them (Bacon 1966, 61).

that the Muslim tradition was deeper rooted among Bukharans than among the settled communities of Sakhrizabs, Samarkand and Tashkent.

21.4 Conclusion

What is the relevance of the ethnographic accounts on Bukhara under discussion in this chapter for our understanding of the interrelationship between environmental factors and socio-cultural changes in the area around the ancient Silk Road? What role might they play in today's renewed discussion on Eurasian integration? And to what extent can they serve as a guideline to global intellectual interaction?

Firstly, the ethnographic accounts expose an approach that distinguished between the domestic lifestyle of the settled people in the oasis cities and the nomadic lifestyle in areas where severer climatic conditions made civilization more fragile. The accounts discussed here unravel the various layers of Bukhara's cosmopolitan heritage. In their way of juxtaposing mobility and stability, they reveal that this heritage was conditioned by the city's geopolitical situation through time, a shared Muslim-Jewish history of textile weaving and dyeing, and the division of labour along lines of gender linked to amateur and professional practice.

Secondly, said accounts relied on testimonies, reported observations and scholarship. In their confrontation of lived knowledge conveyed linearly by generations of residents, with the systemized knowledge of academic enquiry mined vertically to deepen insights, the transcultural perspective of the local agents who assembled them turned out to be a crucial factor.

Thirdly, these accounts of human agency appear as discursive events. The way they were assembled and presented demonstrates that knowledge was acquired as an act of cooperation, in which the will to understand and to communicate was considered a prerequisite for dialogue, appreciation, academic reorientation and joint action.

The momentum of such knowledge acquisition and transfer was related to the speed and permanence of its flow via the continental bridge. This points to the notion of soil and its significance in the school of Eurasianism; it is still relevant to our understanding of knowledge flowing between Asia and Europe, and hence for the Eurasian integration project as an intensified process of cultural interaction between Asia and Europe. Advancing this project implies a change of perspective, and a flexible approach that allows agents to negotiate between soft and hard skills, cultural theory and local practice, between the history of ideas and the history of geographical space. This balancing act is as significant today as it was during the times of the ancient Silk Road.

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Chapter 22
A Karez System's Dilemma: A Cultural Heritage on a Shelf or Still a Viable Technique for Water Resiliency in Arid Regions

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Shalamu Abudu, Zhuping Sheng, James Phillip King and So-Ra Ahn

Abstract Karez system is considered as the global human heritage since it is not only a traditional water supply system of exploiting groundwater, but also it reflects the culture, socio-economy, and history of the ancient civilizations that had utilized them for thousands of years in arid and semi-arid regions of the world. However, with the explosive population growth and rapid development of pumping technology in the last century, the karezes dried up or were abandoned as pumping wells lower the groundwater table. This poses a dilemma to policy makers whether to facilitate large-scale utilization of pumping well technology over karez system and treat karez as a cultural heritage which is non-functional for food production, or to keep using and preserving the karez system as a sustainable way of groundwater management as part of the integrated water supply systems in the arid regions. In this paper, we reviewed the historical, socio-economic, and cultural importance of karezes in the arid regions. We also discussed the distribution of karezes in the world, their unique geographical characteristics, technological advantages and limitations. We observed that the karez system is not only economically robust over the long term, but also a viable water supply technique for irrigation and domestic uses. The karezes should be protected as indigenous human heritage, and at the same time, they can be utilized as a sustainable way of water resources management in the arid regions to enhance water resiliency under changing environment.

Keywords Karez system · Groundwater · Sustainable · Arid region
Cultural heritage · Viable technique · Pumping well

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22.1 Introduction

The ancient history of the world shows that civilizations centered near convenient sources of water. As humanity developed permanent settlements where they practiced agriculture and husbandry, a need for a reliable, permanent source of water became a necessity. As a result, in arid regions due to the scarcity of surface waters, people developed new systems to exploit groundwater. One of these systems is known as a “Karez”, and also called as “Qanat”, which has been used for several thousand years and is still being used as a main source of irrigation and domestic water supply in some arid regions of the world, particularly along the ancient silk road extent from Europe to China. A karez is a gently sloping underground tunnel that conveys groundwater using gravity to the land surface. Comparable to the vertical pumping well in our time now, the karez is essentially a horizontal well that extracts the groundwater by gravity, and therefore it is a sustainable way of management of groundwater resources. A typical karez system and its components are shown in Fig. 22.1.

A karez is constructed by digging a tunnel into a cliff or a base of the mountain for reaching a water-bearing formation. The tunnel is approximately horizontal with a slope to allow the groundwater to flow by gravity. The air shafts provide ventilation and access to the tunnel for construction and maintenance operations. A “mother well” is located at the high end of the karez which intersects at the groundwater level. The storage pond that is usually used to regulate the discharged water may not be included in all karezes. Figure 22.2 shows the distribution of vertical shafts, a closer look to a vertical shaft, the main tunnel, and a covered distribution canal for karez water for drinking purpose (the pictures were taken in Kageqak village, Tohsun County in Turpan Prefecture of Xinjiang, China). The length of the horizontal underground tunnels varies greatly, from 3 km up to 50 km. The size of the tunnel is between 0.5 to 0.8 m wide and 1.2 to 1.8 m high. The vertical shafts are located approximately 10–20 m apart in the lower reaches and 30–70 m apart in the upper reach for ventilation and maintenance of the karez. A storage pond (pool) located at

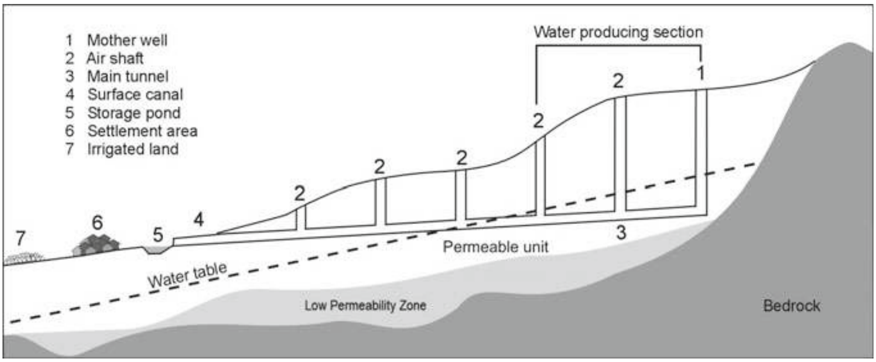

Fig. 22.1 Schematic view of a typical karez system (after Todd 1980)

Fig. 22.2 Vertical shafts, main tunnel, and covered canal of a karez system in Tohsun county, Turpan, Xinjiang, China

the end of the horizontal channel is used for storing water at night and may also be used for measuring and dividing water among different users (Sun et al. 2009).

Karez system is not only a way of extracting groundwater, but also represents the culture, history, and unique civilization of its builders in early times. The karez technology, from the construction process to management and maintenance and its adoption in agricultural production and ecological systems was based on the ingenious knowledge of people in the past that was supported by strong beliefs and traditions. Nearly 3000 years of its known history prove that the art of constructing, utilizing, maintenance of karez system was a tremendous success. Through the course of history, it has played invaluable role in the development of local society, ancient trading along the Silk Road, and more recently as the boomed tourist attraction in the karez irrigated areas that brings great social and economic benefits to the local community (Abudu et al. 2011, 2014). Karezes, by their very nature, have encouraged sustainable water use for many years since they can keep the underground water at a reasonable level and prevent depletion even in worst drought situations (English 1998). Karezes also prevent evaporation in arid regions and serve as drainage systems. Drainage through karezes has been beneficial and has prevented the rising of groundwater levels after intense precipitation. Karezes also play an important role in balancing the salinity of the water and protecting the downstream agricultural lands (Cenesta 2004). Throughout the history of humanity, karezes not only played an role in the formation of the cultural identity, but also remained as a major source, or the only source in some cases, of irrigation and domestic water supply in arid regions.

However, with the explosive population growth and rapid development of pumping technology in the last century, the karezes are facing rapid abandonment and disappearance due to the widespread utilization of pumping wells to meet the needs of increased food production. This traditional water supply technique for irrigation and domestic water supply for human society that has proved viable for hundreds or even thousands of years are disappearing like endangered species. The main reasons for abandonment are, but not limited to, the introduction and widespread use of electric and diesel-pumping wells, agricultural expansion, growing demands of domestic and industrial water use, the difficulty of karez construction and maintenance operations (Beaumont 1989). Even though the current use of karezes is getting limited due to the improvements in technology that allows the use of pumping wells and high-power pumps, karezes are still being considered as one of the main ways of procuring water for irrigation and agricultural development in rural areas of countries along the Silk Road, such as Turkey, Syria, Jordan, Iran, Pakistan, Afghanistan, Uzbekistan, and China. With its known long history, the karez not only is a sustainable way of using groundwater, but also is a unique system illustrating the use of ingenious knowledge and wisdom in the sustainable management of land, water, and agricultural biodiversity (English 1998; Abudu et al. 2011; Manuel et al. 2017).

It is obvious that there are ongoing dilemma and arguments for policy makers and water managers on preserving karez system as cultural heritage which is non-functional for irrigation and domestic water supply, or continuing to use and preserve the karezes as a sustainable way of groundwater management in agricultural production as a portion of the integrated water supply systems in the arid regions. To illustrate the different perspectives, the authors reviewed the historical, socio-economic, and cultural importance of karezes in the arid regions. We summarized the distribution of karezes in the world, their unique geographical characteristics, inter-connections with the arid environment, contributions to agricultural biodiversity, and sustainability. The discussions throughout the paper were supported by the review of the literature regarding the karezes in worldwide, particularly in China. Some examples were illustrated based on the author's research and working experience in the Turpan Region, Xinjiang Uyghur Autonomous Region, China to support the perspectives that were sketched in the paper. Finally, some recommendations were proposed for proper utilization and preservation of karezes in the arid regions of the world.

22.2 Distrubution of Karezes and Geographical Characteristics

22.2.1 Distribution of Karezes in the World

Karez is a traditional irrigation system that built in the arid and semi-arid regions of the world. Many factors should be considered in constructing such a system, such as a climate, topography, hydrology, geology, and geographical characteristics of the regions (Abudu et al. 2011; Remini et al. 2014; Goes et al. 2017). Previous research on the distribution of karezes indicates that they can be found in over 30 countries in the world (Baboli and Labaf 2000; Motiee et al. 2006; Mostafaeipour 2010; Remini

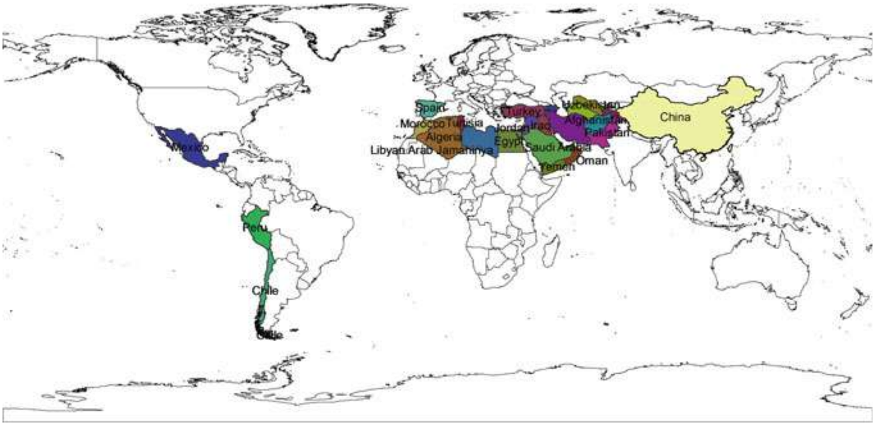

Fig. 22.3 Distribution of karezes in the world. Reproduced from Mostafaeipour (2010)

and Kechad 2012; Rozi and Azizi 2016). The distribution of karezes by country is shown in Fig. 22.3 based on the literature (Mustafa and Usman 2007; Hussain et al. 2008; Wilkinson et al. 2012; Taghavi-Jeloudar et al. 2013; Remini and Kechad 2012; Abudu et al. 2014; Goes et al. 2017; Remini and Achour 2017). Their geographical extent has been documented from Western China to as far west as North Africa and Spain, and some parts of South America.

As can be seen from Fig. 22.3, three main regions were identified. They are (1) Silk Road regions, along the ancient Silk Road that connected Euro-Asian continent, spreading over the western region of China, Afghanistan, Pakistan, Iran, Iraq, Syria, Armenia, and Turkey. (2) Arabian Peninsula and Northern African Region, including countries such as Saudi Arabia, Oman, Yemen, United Arab Emirates, Egypt, Libya, Algeria, Morocco. (3) All other sporadic distributed arid and semi-arid regions, such as southern part of Spain and Mexico, and in Southern America Peru and Chile. The Arabs brought the karez (qanat) idea into Spain, and the Spanish brought it to the New World. Karez-like water-collecting tunnels are present in Los Angeles and elsewhere in Southern California. These countries are in the arid and semi-arid regions of the world, where characterized by an arid climate and limited surface water resources. Hence, the development of oasis-based societies in these regions is closely linked to the extraction of groundwater to meet agricultural and domestic water demands. This is the primary reason and motivation why karezes had been developed and utilized in this part of the world for thousands of years.

Based on the previous research and rehabilitation reports on the karezes (Baboli and Labaf 2000; Motiee et al. 2006; Abdin 2006; Mostafaeipour 2010), it was concluded that the highest number of karezes are built in the Silk Road countries. The largest numbers of karezes are in Iran, which has about 36,888 active systems with a total discharge of about 7 billion cubic meters of groundwater and account for 11% of annual aquifer discharge in the country (Estaji and Raith 2016). In the east end of Silk Road, there were over 1784 karezes with 5272 km underground channels in

Xinjiang, Western China based on 2003 survey data. Unfortunately, only 614 karezes are still flowing in 2003 at a total discharge of 9.58 cubic meters per second (or 302 million cubic meters per year), irrigating 11,500 ha of land (Wang et al. 2008). Many karezes are still being used in Afghanistan, Pakistan, and other countries along the ancient Silk Road (Hussain et al. 2008; Rozi and Azizi 2016). In the Arabian Peninsula and Northern African Region, there are still considerable karezes are in use (Motiee et al. 2006). According to a report on the distribution of karezes in northern Africa (Mostafaeipour 2010), there are about 200 karezes that are still in use in the Tafilaft area of Morocco, about 600 karezes are in use in the Garamantes area near Jarma, Libya. The total length of karezes in Algeria is estimated to be thousands of kilometers. There are also many karezes that are still in use in the Arab world with about 4200 that are still operational out of 11,500 in sixteen Arab countries (Remini and Kechad 2012). The existence of sporadically distributed karezes in Mexico, Peru, Chile in southern America, in some European countries such as Spain, Cyprus is also documented in the literature (Motiee et al. 2006; Mostafaeipour 2010).

22.2.2 Geographical Characteristics and Features

Most of the karezes were constructed in semi-arid regions receiving less than 400 mm of annual precipitation. Lightfoot (1996) states that karezes are found in abundance in the regions that have a great discrepancy between precipitation and evapotranspiration (ET). For example, the Turpan Depression, Xinjiang, China, has a continental and extreme arid climate with average summer temperatures reaching 38 °C, has low annual precipitation (9–25 mm), well below the potential evaporation (about 3000 mm). Such climate conditions make the Turpan oasis an ideal place for developing karez irrigation system (Haakon and Shen 2006). Besides annual precipitation and ET, other factors must be considered for the existence of karezes in different areas such as topography, hydrology, geology, and the agricultural activity nearby. A typical karez system consists of a group of wells and a roughly horizontal tunnel intersecting with the wells located on a very gentle slope that enables drainage of groundwater by gravity. These gentle slope areas are mainly bounded by mountains and hills with mountain-front recharge zones to provide the water supply for the karez. Alluvial fans or synclinal rock structures at the base of mountains and hills form shallow aquifers that present favorable construction sites for karezes. Similarly, margins of large stream channels coming out of the mountains are the places along which shallow aquifers occur. These aquifers are the natural environments wherein karezes were developed. The combination of shallower aquifers with high transmissivity provides the best conditions for building karezes (Lightfoot 1996).

For example, the hydrologic setting in Turpan region presents a perfect example of such favorable conditions for karezes. In Turpan region, the surface water and groundwater are supplied from the glacier and snowmelts of northern and western Tianshan Mountains. As the rivers flow from the mountains, most of the water seeps into the Gobi Desert that has thick sediments of gross texture materials. At the northern Gobi Desert, the depth of groundwater table declines from 100 to 150 m in piedmont to 20 to 30 m near the Flaming Mountain area. Except for certain gorges that water can pass through, the Flaming Mountain mainly acts as an obstruction for both the surface water and groundwater flows. After the flows leave the Flaming Mountain, part of the water recharges the shallow aquifer and becomes the water source for the karez in the south Flaming Mountain area. As there is a natural slope from the foothills at 900 m above sea level towards the deepest part of the Turpan Basin at 161 m below sea level, the topography of the area is favorable for this sophisticated irrigation system (Rozi and Azizi 2016). Thus, the unique combination of a desert climate, abundance of groundwater and suitable topographic conditions in the region provided ideal conditions for the development of the karez system in the Turpan Depression (Nuridin 2008).

Geology is another important factor for site selection of karezes. For example, in most of the steppe and desert regions of Jordan and Syria, deposits of silica such as quartz, chert, and flint often form impervious layers beneath the permeable calcium carbonate formations that are closer to the surface. In early ages, water-bearing strata were exploited to build karezes, by excavating most of the channels through solid beds of limestone or other calcium carbonate formations. In most of Syria, limestone and chalk aquifers are relatively shallow from a few meters to tens of meters deep, which represents favorable conditions for karez construction compared to the volcanic rock formations. Even though volcanic soils of the banks are better for agriculture than limestone soils, karezes were never dug through basalt zones due to the difficulty of excavating karezes through these stronger rock units (Lightfoot 1996). High tectonic activity zones do not provide favorable conditions for the karezes since the tunnels, and vertical shafts of karezes are not reinforced, they are susceptible to damage from natural events, such as earthquakes.

22.3 Historical, Cultural and Socio-economic Significance

22.3.1 Historical and Cultural Significance

Karezes had existed for several thousand years in the arid regions of the world. In some parts of the world, they had long become a way of life, a part of the cultural identity. They can be considered as a global heritage by their unique history, that reflects the social and cultural background of communities that relied on them for a living. Besides their cultural value, their contribution to water conservation and continuity of life in arid and semi-arid climates make this environmental-friendly method an important means of extracting groundwater. Many karezes can be used for several centuries through proper maintenance and operation. For example, the complicated karez system in the Xinjiang Uyghur Autonomous Region of China is considered as one of the three great construction projects in ancient China, along with the Great Wall and the Beijing-Hangzhou Grand Canal (Rozi and Azizi 2016). They are mainly distributed in Turpan and Kumul districts in Xinjiang Uyghur Autonomous Region, where Turpan District is known as the location of large numbers of karezes. The total length of these karezes would exceed 5000 km if they linked together. Hence, the system has also been called “the underground Great Wall” (Abudu et al. 2011).

In the past, the social arrangement in karez-based communities had been directly related to the karez system (Bonine 1989). The importance and value of people were judged according to their ownership rights to the amount of water from the karez, which also created a social hierarchy among them. The household location used to be a good indicator of the social or economic status of its residents. For example, in Iran, the residents of more eminent households of landlords, merchants, and religious leaders were in the upper section of the karez-based settlement areas where the water is clean and plentiful (Bonine 1989; English 1998). In karez-based communities, water rights and distribution of water were directly related to rules of ownership. Since each region had its unique ownership and management rules, the water rights and distribution schemes varied from one place to another in the past. However, the common tendency of communities was to use karez water cautiously, that helped this traditional system last hundreds of years without harming the ecological balance. The simple, yet effective, water distribution system was dependent on the share owned by each farmer. In other words, the amount of water was determined by the land rights that the landowner owned. The rule was that each landowner or farmer could only cultivate the area of land that he was able to irrigate with his share of water. This rule had brought a balance between water rights and the area to be cultivated. Once the water rights were fairly addressed, the descendants of the owners could divide their land in agreement according to inheritance laws. Emigrated people lost their rights to irrigation water unless they returned and claimed them back. This rule did not apply if the land was sold to somebody else (Wessels and Hoogeveen 2002).

Karezes have created strong cohesion among people owing to the traditions and beliefs attached to them (Goes et al. 2017). Religious beliefs and cultural traditions also helped the karezes to be protected and handed down from the past as a legacy. For instance, karezes were given genders depending on their nature. Ceremonies that resemble actual wedding events were performed between subtle, gentle karezes (female) and gushed, spurting karezes (male) as a ritual. These ceremonies usually took place when there is a dried up “mother well.” Some of the rituals are still being followed to some degree in the rural settlements and villages of Iran (Cenesta 2004). In Turpan region of China, the local people see karezes as the part of their history and cultural identity. The local people treat the karez builders as local heroes, braving the desert and bringing life to a village (Nuridin 2008). The difficulty in construction, the clean water and eco-friendly feature of karezes are the main topic for local Uyghur songs and other cultural celebrations in the local community (Nuridin 2014).

22.3.2 Socio-economic Importance

Karezes not only had a deep root in the life of people and were a strong part of cultural identity but also were an important part of the continuous development of the local economy and agricultural production. According to a report by the Cenesta (2004), about nine billion cubic meters of karez water is still being used for agricultural production in Iran. Hence, the restoration and maintenance of karezes can be a very effective strategy in food production there. Karezes remain one of the main sources of irrigation water in the Turpan region of western China. Despite a large decrease in the number of karezes used in the Turpan region, karezes are still contributing to the irrigation of more than 30% of agricultural land. More than 50,000 households and 100,000 livestock benefit from the karez system as a drinking water source (Nuridin 2008). Without the karez system, the landscape in the region would be desert (Haakon and Shen 2006; Sun et al. 2009).

Thousands of karezes were built by governments, local investors, even farmers in the arid regions throughout history, and they are diffused into every corner of many arid regions that are suitable for karez construction. However, with the introduction of well technology, construction of new karezes seems impossible due to the time, intensive and skillful labors, and cost of construction. Compared to the cost of pumping well drilling, the expenditure for the construction of a karez may be 8–9 times more than that of a well (Cenesta 2004). However, considering the lifespan of both, karezes are more economical since their service life can be more than ten times that of a well through proper maintenance. According to the cost and benefit comparison reported by the Cenesta (2004), the level of income of a farmer from a karez is 30% more than that from a well, and it has been shown that a karez is more economical in the long-term for agricultural and environmental purposes. Karezes have other economic advantages besides their use in irrigation and as a source for domestic water use. Due to their historical and cultural value, karezes can be a good attraction for tourists when combined with other cultural aspects that are unique to specific regions. For example, karezes are one of the most important tourist spots in the Turpan region of China with an annual contribution of 20 million Yuan (about 2.5 million U.S. dollars) to the local economy (Nuridin 2014; Pei et al. 2008).

22.4 Advantages and Limitations of the Karez Technology

22.4.1 Karez System Ensures Diversified Ecosystems

The main function of a karez system is to provide irrigation water for agriculture. A cultivation system in karez-irrigated agriculture is based on the principle of making the best use of limited water. To prevent karez water from being wasted, a collective system of cultivation needs to be followed by the farmers. The selected crops need to be diverse and complement each other in terms of water requirements. In addition, the seasonality of crops helps make maximum use of available water resources throughout the year and thus sustains the livelihood of farmers all year long. Hence, a sustainable cultivation system is practiced under karez-irrigated agriculture, that considers the crop types and seasonality to achieve multiple purposes of water saving, as well as improving soil texture and quality (Cenesta 2004). In this way, karez-irrigated areas have formed their unique collective system of agricultural management.

The diversity of crops is one of the main features of the karez-based agricultural system in arid areas. Karezes are not only used for the irrigation of agricultural crops but also used for large numbers of orchards and community and private gardens. The idea of making good use of karez water has resulted in a wide diversity of crop types. For example, in the Iranian plateau, the traditional orchards have always been dependent on karezes, especially those that were closer to karezes or nearer to villages (Cenesta 2004). The villagers use the karez water to irrigate a community garden to grow crops such as onions, cucumbers, tomatoes, and other vegetables. The garden also contains fruit trees such as mulberry, fig, and pomegranate. These perennial crops depend on the reliable supply of the karez for sustainable production. Moreover, they grow irrigated barley to provide feed for their sheep. Besides the irrigation of the garden, the karez water was also used to irrigate small-scale private plots for growing vegetables and herbs (Wessels and Hoogeveen 2002).

Karezes have provided a refuge for freshwater fishes for thousands of years in Iran. The good karez water quality and hydraulic features of the karez waters are influential in sustaining the diversity of the aquatic life. Since it is a covered system, water in a karez has a temperature that is not subject to extreme changes, unlike the surface waters. Also, shade within the karez provides protection against predation on adults, young and egg stages of freshwater fish species (Coad 2017). In the Golestan National Park in Iran, the karezes provide water to wildlife. This park is a living museum incorporating various plants and animals including diverse mammals, birds, reptiles, amphibious and aquatic species. Due to its favorable conditions, the park has been registered as an important world wildlife habitat by international organizations. Besides the natural waterfalls and springs in the park, the Mirza Bayloo karez provides significant amount of water to wildlife and the green landscape of the Museum of Wildlife in the park's territory (Coad 2017).

The karez system has created favorable growing conditions for a variety of species, including high value crops, fruits, and trees and other plants in an area where is supposed to be Gobi Desert, barren or very sparsely vegetated. Under karez water supply, the agricultural production and ecosystems and their coexistence are still well maintained in some well-preserved karez-irrigated areas in the Turpan Oasis of China. The key to crop diversity in the region is attributed to the traditional knowledge of the karez system management, which links irrigation water distribution to agricultural management, ensuring continuous biodiversity conservation and management according to indigenous knowledge of local people in food production throughout the history. The karez system becomes an important part of the ecosystem in the oasis. Karez itself is a unique ecosystem, which not only provides water for native vegetation in the oasis, but also plays an important role for the survival of wild lives by providing habitats through underground tunnels, shafts, and pools (Zhao et al. 2009).

22.4.2 Karez System Maintains Good Water Quality

Karezes have usually been the main source of good quality domestic water supply for the people, livestock, and wildlife in karez-based communities. There is a close relationship between the quality of karez water and the topography of the region. The groundwater available farther from the mountains is more likely to be poorer in quality due to varying recharge zones or probable point and non-point source contamination. Closer to the mountains, the quality of groundwater is better as its quantity. It is known that the excess sedimentation and silting are the main threats to the sustainability of a karez unless the maintenance is performed periodically to clean up the tunnels from the sediment accumulated by the falling material through the air shafts. Since karez water travels a long distance under the ground very slowly, silt and clay particles tend to settle along the tunnel before the water reaches to the storage pool, which makes the karez water free from suspended particles and better for drinking.

It is not possible to prevent sedimentation and to silt completely along the main tunnel. Hence, maintenance and cleaning operations are vital and must be performed on a regular basis to keep karezes viable. Haeri (2003) states that the recharge through karezes keeps the salinity level of the soil under control since the fresh water is transferred from mountain plateaus to the lower plains that have saltier soils. A study performed by Cenesta (2004) reported that the karez water has positive effects on crop quality. The experience in Iran showed that crops irrigated with karez water were usually of better quality than crops irrigated with local groundwater. In Turpan region, karez water is also used as a drinking water supply due to its high quality. According to Nuridin (2014), all the karez water in the region meets requirements of China Sanitary Standard for Drinking Water (People's Republic of China National Standard 1985). Table 22.1 shows water quality parameters of a typical karez (Mehim Haji Karez) in Turpan sampled on June 27, 2006. As indicated in Table 22.1, most the measured water quality parameters were significantly below the maximum allowable limits or were in the desirable range.

22.4.3 Limitations

As illustrated in the previous sections, the karezes have many advantages such as energy efficient, less evaporation, eco-friendly, and have strong historical, cultural, and other social values. However, as with any other water management system, the karez system has its disadvantages, notably the challenge to make it an efficient and effective alternative in a modern society that increasingly overwhelmed by new

Table 22.1 Measured water quality parameters in Mehim Haji Karez in Turpan, China

Parameters	Units	Measured values	Desirable range/maximum values
Color	Hazen units	0	5
Odor	–	No odor	Unobjectionable
Taste	–	No taste	Agreeable
Turbidity	NTU	<3	5
pH value	–	8.0	6.5–8.5
Total hardness (as $CaCO_3$)	mg/l	91.9	300
Iron	mg/l	<0.03	0.3
Chlorides	mg/l	12.5	250
Dissolved solids	mg/l	204	500
Copper	mg/l	<0.01	0.05
Manganese	mg/l	0.02	0.1
Sulphate	mg/l	44.4	200
Nitrate	mg/l	20	50
Fluoride	mg/l	0.22	1.0
Mercury	mg/l	0.0001	0.001
Cadmium	mg/l	0.01	0.01
Arsenic	mg/l	0.007	0.05
Cyanide	mg/l	<0.004	0.05
Lead	mg/l	0.01	0.05
Zinc	mg/l	<0.04	5
Chromium	mg/l	0.004	0.05

Reprinted from Nuridin (2008)

technologies and rocketed population growth (Khan et al. 2015). Karezes are usually unable to provide enough water for large-scale agricultural and human consumption (Qureshi 2002). This limits the capacity of the karezes to be only alternative and limited water supply for extensive agriculture. In addition, the karez system requires continuous cleaning to prevent silting and collapse. Its maintenance is thus a labor-intensive activity, which can be both difficult and dangerous (Hussain et al. 2008). Karezes require maintenance every year to keep karezes perform well. Karez excavation and maintenance are a hard-low-income job; sometimes there is a risk of life loss for the excavation and maintenance workers. This is one of the main factors that result in karez disappearance in the modern society.

The introduction of modern construction technologies in karez construction and maintenance is still a challenging issue. Although the modern technologies and developments can be utilized in karez maintenance operations up to some extent for safety, it may still be limited to the larger karezes rather than very small communities relying on karez water due to some financial and traditional concerns. Some socio-economic factors are also less favorable for the utilization of karezes in modern society. For example, the urbanization process has accelerated, new generations prefer to work in the urban environment and have lost interest in traditional karez-based farming. Many karezes have been left without maintenance for a long time, and as a result, they have collapsed, malfunctioned, or eventually been abandoned as the flow rates decreased, and eventually, they have been abandoned. With the abandonment of karezes, the indigenous knowledge and community cooperation critical for karez preservation have also irreversibly disappeared, and more karezes have collapsed or dried up. This vicious cycle has been revolved very fast in the last decades with the widespread application of modern deep well technology in the karez-irrigated regions of the world. As a result, karezes that flourished for thousands of years have been disappearing at an alarming rate worldwide.

22.5 Dillemma—Cultural Relics or Viable Technology?

22.5.1 Karez System Versus Pumping Wells

The primary difference between the karez system and pumping well is the means of extracting groundwater. As we discussed earlier, the karez system does not require external energy to extract groundwater, the rate of flow of water in a karez is controlled by the level of the water table. The extraction of groundwater flow is restricted naturally, limits the human intervention on the groundwater exploitation, which ensures its sustainability and renewable resource. Pumping well, on the other hand, requires external energy to extract groundwater, it may extract groundwater based on demand regardless of recharge rate of the aquifer, and enables maximum intervention of human impacts if there are no strict and effective policy or law enforcement, that can lead to unsustainable groundwater resources due to overexploitation. In addition, to be sustainable-friendly, the karez system is energy-efficient as compared to pumping wells. As a karez uses the force of gravity for groundwater extraction, there is virtually no need for electric power, diesel, pump spare-parts or oil products for lubrication leading to cost recovery and significant energy savings. When compared with diesel motor-equipped pumping wells, karezes also contribute to the reduction of greenhouses gases emissions (Nasiri and Mafakheri 2015). Properly maintained karezes could have a significantly longer lifespan than modern pumps/wells. Pumps and wells have a lifespan of about 20 years while karezes have been known to function for centuries (Qureshi 2002).

The advantages and drawbacks of both karezes and pumping wells are a relative concept. Sometimes limitations can be advantageous depending on the problem. English (1998) stated that the self-limiting features of karezes that make them a sustainable technology could, however, be their biggest drawback, particularly when they are compared with the range of deep well technologies available today. Hence, in the areas where karezes still exist, the coexistence of karezes and pumping wells is a challenging and complex issue. In some areas, pumping wells can also be utilized with no interference with karez; but in some areas, pumping wells destroy karezes. From the sustainability management point of view, the karez system has superiority over pumping wells that can naturally ensure the sustainability of the groundwater utilization. The ability of pumping wells to withdraw water more than an aquifer's recharge rate makes this modern technology very attractive for the short term. As a result, however, groundwater is becoming a non-renewable resource in areas where pumping wells are used due to lack of strictly sustainable management strategies or policies/regulations are not in place. From the point of meeting growing water demands, karezes may be considered as an insufficient source of water. In arid regions, increasing water demands resulted from the rapid population growth and agricultural expansion needs cannot be fulfilled by karezes anymore (English 1998). The pumping wells may facilitate the growing water demands of the population but may not be in a sustainable way. The pumping wells must be employed by establishing restricted extraction policies and regulations to sustain groundwater uses.

22.5.2 The Dilemma

These disadvantages of karez system, particularly the incapable of meeting the needs of the fastest growing population nowadays, resulted in the replacement of this ancient technology by the more productive pumping well technology for agricultural production and domestic needs. However, the pumping well technology has been used for about a half century. Although the use of well technology for groundwater exploitation has made a substantial contribution to the food production in arid regions over the decades, the rapid development of pumping wells has led to the overexploitation of groundwater resources and associated water quality problems. Eventually, the overexploitation of groundwater may pose a major threat to the environment, health, and food security. However, in the modern society, with the increased population and economic globalization, the farmers tend to shift to cash crops and of large-scale agricultural production, which, in fact, inhibit the use of limited karez water and consequently contributes the abandonment of the karezes. Therefore, governments and other investors in the karez-irrigated areas have abandoned these traditional, sustainable but less productive systems in favor of modern, more productive pumping well systems that contribute rapid and irreversible drawdowns in groundwater reservoirs (Beaumont 1989; English 1998).

In some regions of the world, policy maker and water managers no longer perceive karezes as the water management techniques/tools but rather treat them as a cultural heritage that is a non-functional system for water supply, and in turn, use them as a tourist destination and historical and cultural research sites. For example, in the Turpan region of China, the part of the management of karez system has been assigned to Bureau of Cultural Relics at different governmental levels instead of keeping the karez system management in the Water Resources Management Bureau. Similar trends are observed in the other regions of the world where karezes exist, such as in Iran. This is an example of the indication of seeing karezes as a cultural relic as opposed to treating them as a functional water supply system that can contribute to the food production and domestic water supply for humans and livestock. This is the foremost dilemma for the policy makers in the karez irrigated area to preserve karezes as cultural heritage which is non-functional for irrigation and domestic water supply, or to keep using and preserving the karezes as a sustainable way of groundwater management in agricultural production as a portion of the integrated water supply systems in the arid regions.

22.5.3 Recommendations

From the sustainability perspective, many researchers argued that karezes should not only be considered as an indigenous human heritage but also, they are contributing to sustainable management of groundwater (Abdin 2006; Nasiri and Mafakheri 2015; Manuel et al. 2017). In most cases, the karez system is not only a hydraulic engineering structure to extract groundwater for both domestic uses and agricultural production, but also an integration of the history, culture, and unique knowledge of its builders (Cui et al. 2012). Even though the increasing number of pumping wells have resulted in permanent depletion of aquifers in some areas, the karezes can still be viable alternative means of water supply for irrigation and domestic water use in the arid and semi-arid regions. Some researchers (Nasiri and Mafakheri 2015; Abudu et al. 2011) advocate that karezes should still be used for irrigation in arid regions, as it may further improve the performance of this water supply system in its long and low maintenance service life in combination with the modern technology and tool for construction, maintenance, and management.

At present, the overexploitation of groundwater is becoming a global issue that poses a major threat to the environment, water quality, food security, and sustainable development. We believe that proper utilization of karezes as a part of integrated water supply systems in the arid regions where the karezes exist can be one of the most efficient ways to ensure sustainable exploitation of the groundwater and enhance the resiliency of water supply under changing environment such as climate change, frequent drought, land use change and increasingly water demand by rapid population growth. The government and local communities should join efforts to preserve and restore this ancient water supply system. There are successful stories in China's Turpan region and other parts of the world, such as Syria, Iran and Oman about rehabilitation of karezes through the local people participation in the state-led preservation and development programs where customary norms and values present within local water culture can coexist with laws and policies promoted by the government (Wessels 2008; Hussain et al. 2008; Abudu et al. 2011; Nuridin 2014; Middle East Institute 2014; Rozi and Azizi 2016). These success stories of the restoration of karezes should be shared among researchers, engineers, water managers in karez-irrigated regions of the world through various media platforms to develop confidence in the continued utilization of karezes and to raise the awareness of policy makers seeing karezes as a viable tool in securing sustainable food production and harmonic community development.

We recommend following measures and strategies in addressing the dilemma between the preservation as cultural relics and development as a sustainable water use technique: (1) Raise the awareness and knowledge of the policy makers and water managers in utilizing the integrated water resources management approach and tools by accepting the concepts of conservation, sustainability, environmental responsibility, and most importantly preserving cultural identity of local people that attached to the karezes for thousands of years. (2) Encourage and convince them that karez system restoration is not only economically feasible but also environmentally sustainable. Previous and ongoing research and engineering projects concluded that karez system restoration may increase the quantity and improve the quality of the karez water. In addition, it can help developing eco-tourism, provide income for the local community and most importantly can contribute to social cohesion and unity among its users. (3) To integrate the karez irrigation system in the holistic water resources management approach in the arid and semi-arid region with karez tradition, following measures can be recommended for the policy makers and water managers: First, combining karezes with modern irrigation techniques would be beneficial in terms of meeting the growing water demands and would also extend the life of karezes. Second, due to their historical and cultural values, encouraging karez tourism in some karez regions would provide alternative income for the locals and governments. Finally, the establishment of comprehensive local databases on karez usage and maintenance of those databases by local governments would help improve understanding of these systems and keep them as a reliable source of water for irrigation and household use in arid regions.

22.6 Conclusions

Karez system is the traditional approach of exploiting groundwater, that also reflects the culture and history of the ancient civilizations that had utilized them for thousands of years. They have provided water for domestic consumption and agriculture and maintained a unique oasis ecosystem in the desert. They can enhance social and cultural diversity and may be considered as a global heritage. The advantages of karezes such as their ability to prevent evaporation losses, good water quality, and availability of water all year long make them attractive for the small communities in rural areas. They are also environmentally friendly systems that are still being utilized for irrigation and domestic water supply in many arid and semi-arid regions of the world. However, with the rapid population growth and changing environment, in the regions with karez tradition, pumping wells have been widely preferred on the last century for uncontrolled, unsustainable extraction of groundwater resources over the more sustainable karez water supply system. Protection and preservation of existing karezes was, in general, never a consideration in formulating groundwater use plans, laws, and regulations. As a result, karezes have been abandoned and been disappearing rapidly within the past few decades. The overexploitation of groundwater, the introduction of pumping well technologies due to increasing demands and natural disasters are among the factors that accelerate the abandonment of the karezes. Furthermore, socio-economic changes in the communities significantly affect the construction, maintenance and eventually existence of karezes.

There is a dilemma for the policy makers in the karez irrigated arid and semi-arid regions on whether preserving karezes as cultural heritage which is non-functional for irrigation and supply, or continuing to use and preserve the karezes as a sustainable way of groundwater management in agricultural production as a portion of the integrated water supply systems in the arid regions. In that sense, we reviewed the distribution, geographical characteristics, historical, cultural, and socio-economic importance of karezes in the arid regions of the world. The successful karez restoration projects and efforts around the world provided us insights and confidence in preserving karezes as a practical water supply system to continue to serve for food production and community development in karez-irrigated regions. Increasing the awareness of policy makers is very important in reinvigorating karezes and their continued operation in the local community. The karezes should be protected as a great human heritage, and at the same time should be utilized as viable technology and tools that combine the concepts of conservation, sustainability, environmental responsibility, and most importantly preserving the cultural identity of local people that attached to the karezes for thousands of years. They can be incorporated as an inseparable component of the integrated water resources management approach in the karez-irrigated arid regions to enhance water resiliency under climate change, frequent drought, land use change and rapid population growth.

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