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Disaster Geoarchaeology and Natural Cataclysms in World Cultural Evolution: An Overview

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ABSTRACT

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Human records of short-term, catastrophic, geological processes, mainly in coastal or fluvial environments, and related phenomena in historic and prehistoric times have to be considered as functions of event intensities and impacts (and damages) caused on ancient human settlements and lives. Catastrophic events, such as, floods, earthquakes, volcanic eruptions, tsunamis, and the collapse of ancient cultures, in particular, those allied to the birth of myths and legends, are the subject of long-lasting, vivid debate. Longer-term, more-or-less consecutive, geological processes and climatic fluctuations have a more pronounced effect on human history. Historical accounts provide many descriptions about cultural evolution in a recurrent manner. The geoarchives (geology, sedimentology, and geomorphology) and the human record (archaeology and history) are considered documentary evidence of these past events. Astronomical causes have introduced severe phenomena (warming, heavy precipitation, monsoons, droughts) imposed on ancient societies, including catastrophic meteor impact. Terrestrial upheavals and astronomical impacts have introduced a nonlinear character of a quasiperiodic nature in transforming human cultural evolution and reshaping the earth's surface. The transient nature of geological, geophysical, and proxy climatic indices, as well as, astronomical phenomena within the solar system, exhibit a wide spectrum of quasiperiodic frequencies as variable and effective environmental factors, which, in addition to anthropogenic factors, reshape the human context. Several conspicuous examples have been reported on mythological deluges and their relation to natural catastrophes. The Anthropocene sea level rise and climatic episodes have had a decisive and prominent role on coastlines and human settlements. Alluvial sediments, sedimentary deposits, and land modifications have drastic effects on settlements. These effects were memorized as floods, deluges, and fallen sky. World examples of disasters derived from the coastal Mediterranean, the Great Flood of Gun-Yu in China, and those from South America, Mesopotamia, and the Middle East and others, were critically assessed with scientific methods.

ADDITIONAL INDEX WORDS: *Tsunami, earthquakes, deluge, volcanoes, myth, flood, geomythology, geoarchaeology, Mediterranean, Late Bronze Age.*

INTRODUCTION

Disaster archaeology is a fast-growing field, which has established a unique area of study related to environmental studies, risk management, and policies for prevention and mitigation during the historical and prehistorical periods (Gould, 2007; Laoupi, 2016). The impact of disasters to both humans and to the ecosystems' resilience vary considerably in the causes and frequency and on the postdisaster effects they had on past human societies and ecosystems. This article focuses primarily on coastal natural disasters that directly affected human society, often to a catastrophic scale, and which resulted in the total or near-total extinction of that human society, a global phenomenon that has gone on since the dawn of hominoids and life on earth. World case studies are explored, including inland China and the relationship between the seismic fault lines and the Yellow River; the comparable relationship between seismic faults and river systems found in Mesopotamia; and the Mediterranean region, and, overall, the causes for coastal destruction of human settlement from the

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Paleolithic to the present day are explored. Such past events are understood today through environmental, geographical, geological, and archeological sciences. Modern societies are aware of seismic fault lines, flood plains, or typhoons that occasionally ravage lands, yet, in modern times, even with stronger architecture and engineering, organized aid, and international cooperation, can still produce fatal results in human societies, in lieu of potential resilience to the effects of the natural disasters that affect them. Ancient societies were not as resilient because they did not have early warning systems, strong housing construction, or many of the current supporting structures. However, as will be shown, in past societies, some rulers were keenly aware of the destructive potential that could one day befall their society. Either for cosmological, religious, or secular reasons, the ancient world was as concerned as modern world is today with the potential impending catastrophes that beleaguer human society.

Coastal destructions are primarily attributed to tsunamis and earthquakes, but can be caused by fluvial flooding, as well, including the gradual processes of silting or sea-level rise, accumulated stress, and outbursts in a "catastrophic" manner. Tsunamis can be born out of an earthquake at sea, a volcanic eruption, or even a comet impact (Bryant, 2001).

In the past four decades, the study of cosmic events and the impact of large meteorites has undergone a remarkable renaissance in being considered as potential triggers for radical change on geological timescales and in prehistoric cultures. In such theories, archaeological horizons indicative of destruction events are combined with evidence from geoarchaeology, ice-core analyses, historical accounts, and mythical traditions and are put forward as evidence for cultural disasters caused by cosmic events.

This article critically considers the underlying concepts of natural disasters and mythical deluges, as well as, the methods that are meant to corroborate them.

The definitions of the terms "catastrophe" and "disaster"—especially in connection with "culture"—are strongly disputed within the scientific literature. The least-common interpretation is that "catastrophe" means an abrupt, violent event, with human victims. Any further aspects, such as changes in political and societal coherence, abandonment of a region, or changes in material culture, are controversial if they are used to try to characterize a "catastrophe" (Torrence and Grattan, 2002). It is important to be aware of this fact because, in everyday speech, the term "catastrophe" is applied very loosely to any awful event, and a catastrophe can appear more disastrous, the more unthinkable its trigger is.

A "catastrophe" is defined as an abrupt event, and in the case of a cosmic event, *e.g.*, the impact of a big meteorite or a tsunami, "abrupt" does not mean within decades but within a few minutes (Rappenglück, 2008). However, a sequence of events may occur over a short period of a few decades that leads to the demise of a region.

Catastrophic events caused by floods, earthquakes, volcanic eruptions, and tsunamis, and current hypotheses concerning the Gun-Yu flood, Gilgamesh, Noah's flood, the loss of mythical Atlantis, and the collapse of the Minoan civilization, or more generally, with the birth of myths and legends, are the subject of long-lasting, vivid debate. Longer-term, continuous geological processes, such as delta progradation, land subsidence or uplift, and global sea-level and climatic fluctuations also have an impact and interrelate with the relatively short period of human history (Wiener, 2018).

The notion of natural events spelling the demise of a society can be traced back to the earliest form of written accounts, mythical or historical. The pyramid texts of Egypt contain many descriptions of the evolution of cultures during cyclical periods, which in the well-known graphical model presented by the Uroboros is explicitly evoked by the serpent's mouth (Bickel, 2007; Faulkner, 1969; Niwinski, 1981; Popielska-Grzybowska and Iwaszczuk, 2013).

The Stoics, the philosophical school that was founded by Zeno from Kition, Cyprus, around 308 BC, generally believed the world to be subject to periodic episodes of destruction and the emergence of new worlds from the ashes (see *Lives of the Eminent Philosophers by Diogenes Laërtius*, in Hicks, 1925).

Ancient geographers and historians provide valuable reports on destructive phenomena. In fact, one could assert that the memory or prophecy of cataclysmic destruction of a world is probably a consistent feature of human societies' memories and histories.

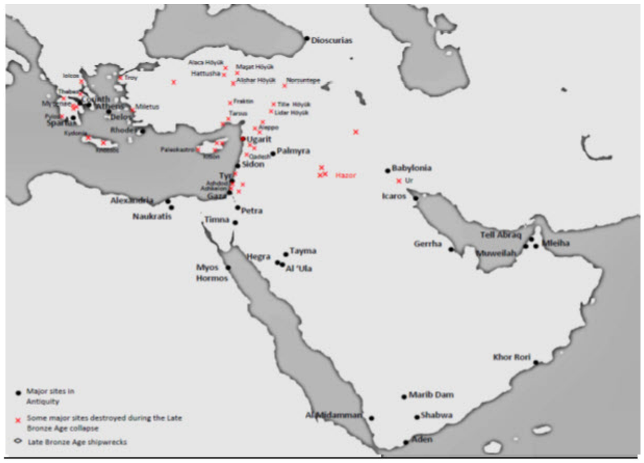
In modern environmental and archaeological science, a 1993 survey identified 47 major positions in mainland Greece, Cyprus, Crete, Asia Minor, and the Near East that had traces of the destruction at the end of the Late Bronze Age (LBA) between 1225 to 1175 BC (Cline, 2014; Knapp and Manning, 2016). Seismic events can be archived within the geological record; therefore, to understand their impact on the history of ancient populated areas, the geoarchives and the human record should both be considered. In the antiquity of the Mediterranean and throughout the world, there are a number of examples of the demise of settlements recorded in both human history and the archeological record (Figure 1).

Many volcanic centers around the world have erupted and caused damage to the immediate environment but also had effects over long distances, with their ultimate impacts on the climate. Thousands of people have been lost, the fauna and flora were destroyed, and the morphology of the surface was altered, and in the remote past, mountains were formed.

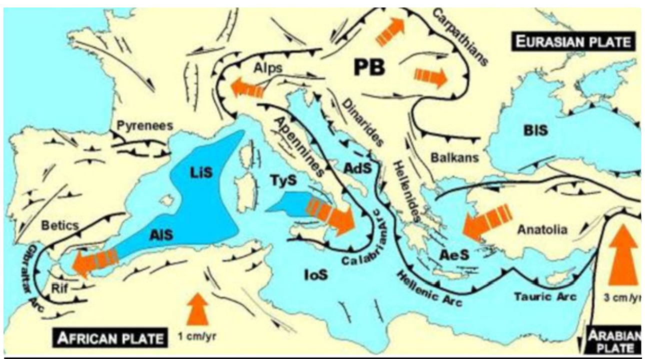
Volcanic events leave very strong signals in both the geological and human records, and they affect the climate through the gases and dust particles that emerge in the atmosphere after the explosions. The result is a heating or cooling of the earth's surface, which depends upon how sunlight interacts with the volcanic material.

Records provide information on a large number of tsunamis throughout historic and recent times. The impact of tsunamis on coastal constructions and the damage to human settlements can be very significant.

There is no doubt that disasters do happen and have happened in the past. Archaeological and geological research proves it. The modern experience of such phenomena further confirms the degree of damage, even on a local or regional scale. Disasters refer to ecosystems, to the many established crops, to the biodiversity, to the hydrological cycle and desertification, and to the sinking and flattening villages and death of thousands of people.



A.



B.

Figure 1. (A) SE Mediterranean and Near and Middle East major archaeological sites (copyright Liritzis, I. and Westra, A.). (B) Mediterranean, including (A), but with apparent tectonic plates of Eurasian–African converging plates and the Arabian plate, including thrusts, ridges, and strike-slip faults, with the major Anatolian Fault and Hellenic Arc. Around these faults lie volcanoes and earthquakes (based on Ozbeki, Govers, and Wortel, 2017; Wortel and Spakman, 1992).

There are also astronomical causes of destructions, *e.g.*, several craters were formed by catastrophic meteor impacts during the Holocene (Halliday, Blackwell, and Griffin, 1985; for greater detail, see below in the "Comets" section).

The aim of the present overview is to link the synchronism of recurrent environmental and social phenomena with environmental disasters (as a general term) that have caused the demise of ancient settlements and whole regions. It will be demonstrated that there is a correlation between archaeological witness, historical and mythological accounts (*via* geomythology), geoarchaeological documentation, and particular terrestrial and astronomical phenomena. Several examples shall be reported on the mythological deluges and their relation to natural catastrophes—beyond myth lies, among other issues of ethics and religion, a natural phenomenon.

Examples of destructions, *circum* the *Mediterranei maris orientalis* region, apparently in coastal sites, witnessed from archaeological deposits, mythological reports deciphered by geomythological elements, the role and importance of water, and the impact of environmental factors (climatic, terrestrial, and astronomical) shall be described briefly.

Considering history in ruins, the current overview focuses on cases of the natural destruction of ancient cultures around the world. Reports in ancient literature by various world cultures, especially those around the equatorial belt, where the greatest civilizations flourished, are a major source of information, which is outlined briefly below.

NATURAL DISASTERS AROUND THE EQUATOR REPORTED IN THE ANCIENT LITERATURE OF THE OLD WORLD

From ancient literature and scriptures, disasters that affected the course of civilization are mentioned in several places. In antiquity and prehistory, several earthquakes and tsunamis have been documented in the environmental record. In the National Oceanic and Atmospheric Administration (NOAA, 2018) database, many references to them are found from all over the world. Several such events occurred in the Mediterranean during the Classical and Late Antiquity periods, which have been well documented. In East Asia, Japan, Korea, and China, only China has detailed historical records of seismic activity and some tsunamis. Elsewhere in the world, it seems either a lack of historical traditions and/or a loss of historical texts or historical texts that remain to be understood as records of tsunamis or earthquakes are rare. Two case study regions are reported below—the Eastern Mediterranean and Eastern Asia.

Eastern Mediterranean

There is no doubt that earthquakes have wiped out plethora of settlements in the ancient world. In Greek and Latin antiquity, several philosophers attempted to explain the causes of the natural phenomena they witnessed through cosmic, astronomical observation, or reasoning within their own scientific traditions. The ancient Greeks had similar traditions related to disasters. Aristotle (384–322 BC, in his *Metaphysica*, 1074 *bl.*, *Fragmentum*, 18) describes destruction with the word *ekpyrosi* (=conflagration). Plato mentions three "disastrous floods which preceded the destructive deluge of Deucalion" (Critias, 112a). In another dialogue, Plato attributes extensive wildfires to heavenly powers when he refers to Solon's visit to Egypt (Timaeus, 22c–d. *cf*. Plato, Timaeus–Critias, in Jowett, 1892).

In the same dialogue, Plato describes the much-discussed Atlantis, as described by Egyptians to Solon, which was ruined 9000 years before his time. In any case, Plato did not mean a global flood because, in ancient times, there was no international information network that would confirm the universality of an event. The imaginary connection of the eruption of Thera in Plato's strange narrative causing a continent, Atlantis, to sink can easily be excluded because it contains three major errors, the size, the age, and the location, as well as, other less-serious inaccuracies. The distant memory of some actual fact, after so many falsifications, has not yet been found, but the occasional hypothetical "discoveries" have not been established (Papamarinopoulos, 2007).

Ancient geographers and historians (*e.g.*, Thucydides, Herodotus, Strabo, Pausanias, and others) provide valuable descriptions of the impact of major earthquakes and earthquake-related phenomena on human settlements and constructions in historical times. As early as 426 BC, the Greek historian Thucydides inquired in his book about the causes of tsunamis. He argued that such events could only be explained as a consequence of ocean earthquakes, and he could see no other possible causes (Thucydides, *History of the Peloponnesian War* 3.89.1–6, in Hobbes, 1843).

Settlements leveled by earthquakes have been found in excavations at Kourion, Cyprus, or the pirate port of Falasarna, Crete, where an earthquake lifted the land several meters above sea level (Frost 1998), and at many other archaeological sites around the world (Peiser, Palmer, and Bailey, 1998; Stefanakis, 2006).

One well-known account is from the Roman soldier and historian, Ammianus Marcellinus (*ca*. AD 325–330 to *ca*. AD 391–400), who recorded a powerful earthquake and tsunami on AD 21 July 365, in the eastern Mediterranean, centered near the Greek island of Crete, which destroyed nearly all the towns on the island and may have caused disasters in Palestine, Sicily, Cyprus, and even as far away as Spain. After that earthquake, a tsunami caused significant damage in Alexandria, Egypt (Stiros, 2001). Although this account has been heavily scrutinized, it does correspond with an apparent period of seismicity ("seismic storms") between AD 350 and 360s. At that time, the AD 365 earthquake was highly discussed by ancient authors who debated whether it was a "universal earthquake" (Kelly, 2004). That earthquake is widely regarded as an event of unprecedented scale in the 2500-year-long historical earthquake record of the eastern Mediterranean, a region regularly struck by strong earthquakes (Ambraseys, Melville, and Adams, 1994; Papazachos and Papazachou, 1997). However, how much is actually known about that major earthquake? It took place on the Hellenic fault line, west of the island of Crete, and was felt throughout the eastern Mediterranean, and the ensuing tsunami crashed into many coastal sites of North Africa, the Adriatic Sea, Greece, and the southern Italian peninsula (Shaw *et al*., 2008). However, ancient accounts were mostly interested in the meaning of the destruction and not in recording the actual destruction. Furthermore, later authors often made errors in their chronologies and with the date of the earthquake, which has, as a result, led to considerable confusion today about the facts of the AD 365 earthquake.

East Asia

The Korean Peninsula has been, regarding seismicity and tsunamis, very fortunate because it lies in a relatively stable zone. The seismicity on that peninsula is less than it is for Japan or northeastern China because the peninsula lies on the edge of the Eurasian plate and is controlled by the subduction of the Pacific and Philippine Sea plates (Jin and Park, 2007). The earliest reference in the NOAA database to a tsunami affecting Korea is in Gyeongju from a strong earthquake dated to AD 123. However, the Samguk sagi (*i.e. History of the Three Kingdoms*) lists the earliest recorded earthquake in AD 2 and lists several others in the following decades in which many people died, such as during the earthquake in the reign of King Onjo of Baekje in AD 27. Approximately 2000 years of earthquakes have been recorded historically; many of which took place in the southeastern region of Gyeongju-Ulsan (Houng and Hong, 2013). Located on the Yangsan and Ulsan faults, several earthquakes have been recorded during the first millennium. The deadliest earthquake, with 100 victims, was in AD 779 in Gyeongju during the Silla dynasty (57 BC–AD 935), which is described in the Samguk sagi (Lee, 1998; Lee and Yang, 2006). The historical records of Korea list more than 2000 earthquakes, and a compilation of several historical accounts from Korea is available in Korean (KMA, 2012). In Japan, some of the earliest accounts of tsunamis and seismicity date to the fifth century AD, and a deeper investigation into Korean or Japanese materials would be interesting. In Chinese antiquity, the picture is considerably clearer. Perhaps because of its long history, with extended periods of writing, which stretch back to at least the fifth century BC, there are more records and ancient evidence of earthquakes and floods that may have been the cause of changes in river courses, for example. China has one of the most seismic occurrences and has kept good records on these events for a millennium (Needham, 1959). The earliest historical accounts from China are believed to be from eighth century BC, as recorded in Sima Qian's (司馬遷) *Shiji* (史記), completed in the second century BC, with contributions added in subsequent centuries. The account records earthquakes, locations, flooding, drought, collapses, and confrontations of opposites (as yin-yang *etc*.) repeated throughout the three dynasties (Xia, Shang, and Zhou) (Sima Qian–Shih Chi, in Needham, 1959, volume 3, pp. 624–625).

More than 900 shocks had been recorded in China between the eighth century BC and AD 1644. The primary seismic regions are north of the Yangtze River and in the western provinces (Zheng, Xiao, and Zhao, 2013). Furthermore, ancient Chinese scholars explored the causes and reasons behind the earthquakes that occasionally shifted the courses of rivers causing great floods. The famous mathematician, inventor, philosopher, and poet Zhang Heng (AD 78–139) created a seismographic device (Needham, 1959) that could accurately record the direction of the epicenter of an earthquake as it happened. The earliest potential mention of an earthquake dates to the 23rd century BC, with the simple description of "earthquake and spring gushing." However, it is not until the Qin and Han dynasties, with the standardization of the writing system, that earthquakes were recorded with the entry "catastrophe." The first collection of earthquake records appeared in *ca*. AD 977. A total of 45 earthquake listings between the 11th century BC and AD 618 were compiled in a chapter of a book called *Taiping Yulan* ("Readings of the Taiping Era"; Wang, 2004).

The available archaeological testimony of ancient catastrophes caused by environmental agents follows per agent, along with a case study for Ur in Sumer, on the banks of the Euphrates River in what is now southern Iraq.

ENVIRONMENTAL AGENTS AND ARCHAEOLOGICAL EVIDENCE

From a geological perspective, these events are not catastrophes but merely the regular history of the earth and the geodynamics of its evolution. The disaster aspect of the present research, therefore, is restricted to the events of that natural geodynamicity that have affected the lives of human beings in ancient times. The cause of natural catastrophes documented in the archaeological record have always had an important role of scientific interest and also caused a great deal of speculation. Obviously, only actual documentation in the archaeological and stratigraphical record can reinforce any theory. Volcanic eruptions, earthquakes, and sudden floods (*e.g.*, tsunamis and river overflows) have influenced cultural changes, and a special case of natural disasters during the Bronze Age civilizations was presented by Peiser, Palmer, and Bailey (1998). Regarding the Bronze Age events, meteoritic impact hazards have garnered increased consideration, as well (*e.g.*, Peiser, Palmer, and Bailey, 1998). Selective archaeological and archaeometrical evidence of major catastrophes of flourishing ancient cities are provided below (see Figure 1), starting with Ur.

Ur: A Case Archaeological Record

The excavator Watelin at the Kish site in Mesopotamia first started an analysis of the archaeological material from the layers left by flooding in the Ur, southern Mesopotamia (once a coastal city near the mouth of the Euphrates on the Persian Gulf, the coastline has shifted, and the city is now well inland) found a "sludge of drinking water containing those elements that are expected from the water of the Euphrates River" (Woolley, 1929, 1955). However, the sludge caused some surprise "due to absence of molluscs such as drinking water and modern microorganisms, and the presence of terrestrial molluscs only in one sample" (Malycheff, 1931).

The deep deposits in Ur (about 3 m) and Shuruppak, Sumer (approximately 60 cm), are important because they allow the creation of conditions for lagoon formation for quite a long time, which further research supported as a submersion in Mesopotamia of "several tens of meters" plus "subsequent emergence" (Raikes, 1966) from the flooding of the sedimentary layers. In Ugarit, Syria, Claude F. Schaeffer (1948, 1955, 1962a,b) identified four layers of destruction from fires with fragmented walls of houses and alternating layers of declared peaceful conditions. He eliminated raids and suggested intense seismic activity, a theory that was subsequently abandoned until later, when disasters caused by earthquakes at Troy, Turkey, 900 miles away were discovered. Phase II of the Troy (approximately 2600–2490 BC) layers showed disaster periods similar to those of early Ugarit (Syria) II, which "disappeared from big fire from which no building was saved. What happened is still a mystery" (Blegen, 1963).

More material from the Schaeffer (1948) excavation found simultaneous destruction between Troy II and Tepe Hissar, Persia, but he could not explain the nature of those catastrophic events that destroyed ancient cities from Troy to the Caucasus.

However, even in the northernmost part of the eastern Mediterranean, relevant phenomena of successive disasters in the Bronze Age have occurred, *e.g.*, in the eastern Balkans and Greek settlements in the second and third millennia BC. It was during this period that Schaeffer was investigating the causes of simultaneous disasters that appeared in the book *Worlds in Collision* by Velikovsky (1950). The new theory argued that the traditions of ancient societies that spoke of cataclysmic floods and fires on a global scale were accurate. The scenario of planetary conflict he attributed to the battles of gods (theomachies).

However, the theory of disaster from extraterrestrial origin not only won regarding geological eras (*e.g.*, disappearance of dinosaurs *etc.*; Alvarez *et al.*, 1980; Liritzis, 1993; Raup and Sepkoski, 1984, 1989) but also was supported by the prevailing conception of catastrophic phenomena in the Bronze Age. However, several ambiguities and false views were identified in this theory. Today, almost no one accepts the theory of Velikovsky (1950, 1956). Indeed, Peiser, Palmer, and Bailey (1998), the editors of the *Proceedings of Natural Catastrophes during Bronze Age Civilizations*, noted emphatically, "... his faith [Velikovsky] that the planets Mars and Venus, now in stable orbits, it could have been much closer to the Earth in historical times to have created catastrophic phenomena on a global scale, is incompatible with the known laws of physics. ..."

Several world myths have evolved in world annals, which have been interpreted as allegorical descriptions of split large-comet collisions with earth. Some of the comet parts were thought to have hit the earth in the second and third millennia BC. A number of biblical events, especially events in "Exodus" and reports on the flood, describe the consequences of one or more collisions. Comets of short period, with typical half-lives of a few hundred to a few thousand years, not only break but also are driven away from planetary contacts. Today, it is estimated that there are 100 times more short-period comets than there are long-period comets captured by Jupiter and driven to the asteroid belt Apollo. That number is probably due to the explosion of new, short-period comets formed several thousands of years ago as a result of the splitting of a large comet, as described during the Apollo asteroid's arrest by Zeus, or in the proximity of its orbit at perihelion (Clube and Napier, 1982, 1984).

The integration of environmental and archaeological data along the Cypriot and Syrian coasts offers a first comprehensive insight into how and why things may have happened during that chaotic period. For example, the 3.2 ka BP regional, catastrophic event underlies the agroproductive sensitivity of ancient Mediterranean societies to climate and demystifies the crisis at the LBA–Iron Age transition (Kaniewski, Guiot, and Van Campo, 2015).

The LBA world of the Eastern Mediterranean, a rich linkage of Aegean, Egyptian, Syro-Palestinian, and Hittite civilizations, famously collapsed 3200 years ago and has remained one of the mysteries of the ancient world since the event's retrieval began in the late AD 19th century. A potential cause for the collapse of the LBA civilization in Greece through integrated land and sea studies can be found in Levy *et al.* (2018). Agricultural activity strongly declined around 1200 cal-y BC. Principal component analysis—a biplot of pollen-derived climatology—indicates that agriculture only became one of the main components of environmental dynamics after *ca*. 850–750 cal-y BC (Kaniewski *et al.*, 2013). By combining pollen data from coastal Cyprus and coastal Syria, it has been shown that the LBA crisis coincided with the onset of a *ca*. 300-y drought event at approximately 1200 cal-y BC. Interestingly, two major environmental changes occurred. Two main climatic steps isolated for the past 3550 years have been observed: a dry steppe and Mediterranean woodland, which corresponds to two contrasting environments. The first step was recorded at 1450–1350 cal-y BC, and the second step was reached at *ca*. 1200 cal-y BC. That climate shift caused crop failures, dearth, and famine (abrupt climate change–driven famine and causal linkage with the Sea People invasions in Cyprus and Syria), which precipitated or hastened socioeconomic crises and forced regional human migrations at the end of the LBA in the eastern Mediterranean and SW Asia.

Devastating effects on settlements have demonstrated the result of strong storm sequences of earthquakes. Such models map out both the tectonic and seismic activities of the LBA in the cities of Greece, Anatolia, and the Palestinian coast, which were destroyed or damaged by earthquakes accompanied by seismic sea waves (tsunamis). Earthquakes were certainly one of the main causes for the weakening and disappearance of settlements in antiquity. According to Nur and Cline (2000), earthquakes were the main cause of the end of the great civilizations in the eastern Mediterranean during the Bronze Age. The demise caused by specific natural causes is reviewed below.

Natural Environmental Agents Affecting Past Cultures

The case studies for floods, volcanoes, and earthquakes in world and regional case studies and those of tsunami and commentary impacts are reviewed below.

Floods

Most of the world's cultures have had some experience with floods, and hence, several similar legendary accounts attribute cultural destructions to water (cataclysms, floods). As outlined before, there are hundreds of recorded flood stories. However, archaeological evidence regarding floods has been recorded through paleoenvironmental studies. The examples and reports on ancient sedimentological records of floods are too many to cite here in full. The study of disaster archaeology then, especially when dealing with the notion of floods, must go through the study of palaeohydrology (Baker, 1987, 2008), in combination with archaeological dating records. Floods are associated with extreme climate changes; thus, they record major environmental events in history. Understanding the relationship between hydrological mechanisms, climatic change, geomorphologic evolution, and civilizations is very important (Zhu *et al*., 1997).

Sediments in the Black Sea region suggest that Mesopotamian and biblical flood myths originated when the rising Mediterranean suddenly broke through the Bosporus (Turkey), inundating the populous farmlands of the Black Sea basin about 7500 y ago (Figure 1). The hypothesis of the Black Sea flooding, a highly debated topic, involved its timing, rate, and mechanisms and whether such a geological event was gradual or sudden. It is thought that the Black Sea Lake was transformed into the Black Sea connected to the Mediterranean, which is thought to have occurred because of the flood of the Bosphorus (Yanchilina *et al*., 2017). However, there is some debate about the speed and force with which the Hellespont was breached. At any rate, most scholars believe the origin of the Black Sea was not a case of flooding but, rather, of gradual infilling, arguing against Ryan *et al*. (1997), and instead, a model of a noncatastrophic, progressive flood (or gradual inflow model) has been proposed to explain the Late Pleistocene sea level rise of the Black Sea (Ferguson *et al*., 2018). In any case, that rising was, by definition, not a tsunami, and the flood hypothesis, caused by river flaws and a spike in temperature rise and sea level rise from ice melt, in Bosporus and the Black sea, is a subject of high academic interest.

In Europe, however, the Danube has been occupied for many centuries, and it, too, flooded frequently during the Holocene (Mesolithic to Roman eras and later, as evidenced from prehistoric settlements along its riverbed; Bonsall *et al*., 2015).

In Egypt, the Nile floods, which have been important natural cycles that result from the annual monsoon causing enormous precipitation in the Ethiopian highlands, have also been well-known features in Egyptian paleoflood history (Hassan, 2007), with reports from pyramidal texts. Thus, Egyptians divided the year into three seasons the *Akhet* (inundation), the *Peret* (growth), and the *Shemu* (harvest), and that cycle was so consistent that its onset was determined by the heliacal rising of Sirius (the dog star), a key event to set their calendar (see Nickiforov and Petrova, 2012, and references therein).

For a pan-Mediterranean analysis of the timing of those periods and the driving mechanisms relating to climate and environmental changes connected to human impact, Benito *et al*. (2015, p. 13) demonstrated that, in different regions, periods of floods cluster into time intervals. Region-wide episodes of flooding occurred in 7400–7150, 4800–4600, 4100–3700, 3300–3200, 2850–2750, 2300–2100, 1700–1600, 1500–1400, 950–800, *ca*. 300, and 200–100 cal-y BP. That flooding pattern indicates that bipolar hydroclimatic conditions existed in the Mediterranean, where in the western Iberian region, periods of frequent floods coincided with cooler and wetter conditions, whereas in north Africa, it coincided with generally drier climate, and in the eastern Mediterranean, with a higher frequency of extreme floods because of the wetter climatic conditions.

For a synthesis of European palaeohydrology, Macklin *et al*. (2006) present dated fluvial units in Great Britain, Poland, and Spain and investigate the relationships among environmental change, flooding, and Holocene river dynamics. Further studies derived from that work are the CORDIS and EU-SPHERE projects, which aim to identify regional flood patterns through systematic review of historical and paleoflood data (Benito *et al*., 2004), including the Llobregat, Segre, and Ter rivers in Spain (Thorndycraft and Benito, 2006; Thorndycraft *et al*., 2005), and the Ardèche and Gardon rivers in France (Sheffer *et al*., 2003, 2008). Other areas in which palaeohydrology approaches have been used are in India with studies on the Holocene Era paleofloods of the Luni River, the Thar Desert of NW India, and from the Sakarghat on Narmada, central India (Kale, Mishra, and Baker, 1997; Kale *et al*., 2000). In addition, the 1500-y history of massive floods, as recorded in the slackwater deposits of the Kherlen River basin in Mongolia, are being studied (Kim, Tanaka, and Kashima, 2017).

The Chinese myth of Yu, who combated the flood in the Yellow River at *ca*. 2100 BC is famous. China's extensive river system and expansive lowland topography leaves much of the eastern, most densely populated, fertile, and economically vital regions of the country exposed to floods (Pang, 1987).

Palaeofloods are a recurring feature of the geographical history of China. Sedimentary deposits record extreme climatic and environmental events. China's rich historical tradition means that many of the ancient and historical floods have been well recorded. However, the sedimentologic records of palaeofloods in China is an ongoing study (YRHLF, 2018), and the number of Chinese rivers prone to flooding is known and supported by historic and palaeoenvironmental data on palaeofloods in China (Fan *et al*., 2015; Yang *et al*., 2000). Examples from the frequent flooding of the Yongding River by optically stimulated luminescence (OSL) dating of sediments show that palaeofloods took place frequently during the Holocene, with high concentrations in *ca*. 8.5–7.3 ka, *ca*. 2.8–2.4 ka, and 1–0.5 ka (Zhao *et al*., 2017).

Floods have frequently been recorded in the Yihe–Shuhe River basin, which both formed the alluvial plain and affected the evolution of the ancient civilization of Longshan, China. Through OSL and radiocarbon dating, it has been determined that frequent floods during the 4.1–3.8-ka period may have been directly responsible for the decline of the Late Neolithic Longshan culture situated in the Yihe River basin (Shen *et al*., 2015). In central-eastern China, the famous Jinsha civilization has been hypothesized to have experienced an abrupt end between 500 and 200 BC. The Sanxingdui culture, in the same area, is also believed to have suffered a similar catastrophic flood, which reinforced or catalyzed political upheavals that lead to the collapse of both civilizations in the same place but at an interval of *ca*. 1000 y (Liu, 1998; Wen *et al*., 2013). The two civilizations developed in the Sichuan plain in the area of the modern city of Chengdu, China, and are believed to be broadly part of the same Shu Kingdom. Archaeologically, they have been thoroughly investigated; however, the cause of their collapse, in *ca*. 1200 BC and *ca*. 200 BC, is still unknown (Lin and Wang, 2017), although environmental and political reasons have been suggested. The discovery of a 20–50-cm-thick, alluvial layer dating to the Zhou Dynasty (approximately 1100–770 BC) has led researchers to propose isotopic data on fluvial sediments as evidence of catastrophes related to dam bursts and other dramatic climatic changes (Wen *et al*., 2013). In addition, further paleoflood events have been recorded to have taken place between 4.0 and 3.6 ka BP and may also have influenced the decline of the Baodun culture in the same region (Jia *et al*., 2017; Zeng *et al*., 2016).

The coincidental identification of the onset of early Chinese cultures of Xia (*ca*. 2200–2000 BC) and Zhou (*ca*. 1050 BC), including the end of Zhou (250 BC) and the uprising of warfare activities of the Warrior States (*ca*. fifth–third centuries BC, which ended with Qin uniting China in 247–221 BC), are all connected, at least minimally, with severe and long-lasting flooding, which deserves particular attention. In addition, it has been observed that a period of flooding is followed by a period of drought. The most recent debate is about the correspondence between the Chinese quasimythical history of the great flood at the end of the Xia Dynasty and archaeological and environmental data, which suggests a date of 1920 BC (Wu *et al*., 2014, 2016).

Further analyses of palaeofloods in conjunction with archaeological data have been studied in the Yishu River basin (Gao, Zhu, and Cao, 2006), the Neolithic ruins in the Jinghe River Gorges, the Lajia ruins in the Guanting basin, and the Yanhe River valley of the Yellow River (Guo *et al*., 2017; Huang *et al*., 2010, 2013; Li and Huang, 2017; Pang, 1987). There are also palaeofloods recorded at the Zhongqiao Neolithic site in the Jianghan Plain and in the Hanjiang River valley in the Yangtze River (Huang *et al*., 2013; Wu *et al*., 2017). Furthermore, geoarchaeological research has further elucidated the destructive impact of floods and climate change toward the end of the Han Dynasty (206 BC–AD 220) on settlements around the Chaohu Lake near Hefei, Anhui Province (Wu *et al*., 2012).

Tsunami

Another natural agent is the tsunami. Many examples of events from both modern and ancient times confirm the recurrence of destructive tsunamis upon coastal societies (Papadopoulos and Chalkis, 1984; Smid, 1970).

The Cascadia Fault has been mentioned previously because the tsunamis that result from that rift have frequently damaged much of the NW North American coastline (Atwater *et al*., 2005; Ludwin *et al*., 2005). China also experiences tsunamis, and a relatively recent example was the 1969 earthquake in the Bohai Bay off the coast of NE China, which created a tsunami and affected the coastline (Lau *et al*., 2010).

Seaquakes and meteoritic falls in lakes can cause disastrous tsunami waves. Many coastal regions in the Mediterranean (Marriner *et al*., 2017; Papadopoulos *et al*., 2007), the Pacific (Imamura, 1949; Lockridge, 1996), fewer in the Atlantic (Bondevik *et al*., 2003; Lockridge, Whiteside, and Lander, 2002), and in the Indian ocean (Anawat *et al*., 2012) have frequently experienced the combined effects of earthquakes and associated tsunamis, till present era, with catastrophic results. Strong tsunamis are generated by shallow earthquakes in subduction zones because those are the most common earthquakes that distort the seafloor. The only subduction zones around the Atlantic are the Puerto Rico Trench, the Antilles Subduction Zone around the eastern Caribbean, and the South Sandwich Trench south of South America. These subduction zones are both smaller and much less active than the subduction zones that circle the Pacific, so the Atlantic has many fewer tsunamis. However, tsunamis have hit Puerto Rico and the Virgin Islands half-a-dozen times in recorded history (most recently in 1918). On 1 November 1755, a magnitude 8.6 earthquake at Gorringe Bank destroyed much of Lisbon, Portugal (Gutscher *et al*., 2006). Minutes after the earthquake, the tsunami arrived. At least three great waves, about 10 m high, entered the city. The waves also raked the nearby coasts of Spain and North Africa and did extensive damage in the Azores, Madeira, and Canary islands (*e.g*., historical tsunamis between 1530 and 2016 have occurred around the Caribbean, Central America, Mexico, and adjacent regions; CCAMAR, 2017).

In the Mediterranean, in antiquity, there have been many earthquakes and tsunamis that have affected several coastal and inland settlements to varying degrees. An example of the complete destruction by an earthquake is the case of the coastal Helice (or Heliki), central Greece, in the Corinthian Gulf, one winter night in 373 BC: "A tidal wave caused by an underwater landslide covered the valley and surrounded the city followed by the powerful earthquake that devastated the city in ruins burying their residents and then new wave caused by vibration covered the already submerged by the first landslide area taking this time at the bottom and the city with the dead inhabitants. Although abstained by two kilometers from shore it disappeared along with the intermediate plain" (Pausanias, *Achaica*, book 7, chapter 24, sections 1–12) (Katsonopoulou, 2005a,b; Liritzis *et al*., 2001). From written sources, it is known that the ruins of the city of Helice were visible until the Byzantine period, showing land subsidence, rather than landslides, from the city to the sea. Today, there is nothing visible in that region. The alluvial deltas of the rivers have been completely covered the area.

Much work has been performed through different periods in the eastern Mediterranean caused mainly from seaquakes and the Santorini Plinian volcanic eruption, *e.g*., along the Levantine coastline (Goodman-Tchernov *et al*., 2009; Goodman-Tchernov and Katz, 2016). Further, the Santorini LBA posteruptive, flood-producing calderas bear on the importance of caldera collapse in tsunami genesis (Nomikou *et al*., 2016), which devastated coastal regions of the Aegean and was the main agent destroying the Minoan civilization. Moreover, the Holocene evolution of some sites on the western Mediterranean has been strongly influenced by strong seismic events, which produced coseismic, vertical displacements and devastating tsunamis. A recent review of nearly a thousand sites of relative sea-level (RSL) data-points has resulted in the first quality-controlled database constraining the Holocene sea-level histories of the western Mediterranean, which identified historical and prehistorical tsunamis (Vacchi *et al*., 2016).

Volcano

The next natural agent is the volcano. The Mediterranean has two of the most famous volcanic disasters of the past. The first famous eruption known was of Santorini in the LBA eruption of *ca*. 1600–1620 BC, which buried Akrotiri, a settlement with excellent mural paintings, and contributing to the destruction of the famous Minoan civilization. The volcanic ash was detected in the islands of the SE Aegean lakes of Asia Minor, in the Nile Delta, and the ice of Greenland, although the latter signaling was not easily identified and confirmed (Coulter *et al*., 2012; Friedrich *et al*., 2006), and the ash caused a short, yearlong, global drop in temperature, which resulted in the Minoans being vulnerable and eventually being occupied by the Myceneans from mainland Greece. The second famous event was the Vesuvius eruption (AD 79) near Naples, Italy, which ejected a cloud of stones, ash, and volcanic gases to a height of 33 km. The pyroclastic deposits buried the Roman cities of Pompeii, Orlonti, Herculaneum, and several other settlements (Driessen and MacDonald, 2000) according to the description by Pliny, the Younger (AD 61–112 in his Letters 6.16 and 6.20, to Cornelius Tacitus), discovered in the 16th century (Radice, 1969).

Comets

Extraterrestrial impacts, such as comets, also create natural disasters. Comet impacts have, in the past, occurred and been recorded in surface sedimentary deposits or in historical accounts, which are occasionally conveyed as a myth of a fallen sky. A list of citations related to possible meteorites has been assembled by searching the ancient Greek and Latin literature up to the end of the west Roman Empire. The catalogue illustrates the attitude of ancient populations toward the fall of meteorites and extends the record of meteorite falls back in time (Piccardi and Masse, 2007, and references therein). In other reports, some evidence has been produced from measurements or alternative interpretations (Bobrowsky and Rickman, 2007; Masse *et al*., 2007).

With the comets that have streaked throughout the sky, almost every culture has a legend about a great flood, and, with a bit of searching for hidden meanings, many of them noticed something like a comet on an impact course with the earth, just before the disaster.

Current models demonstrate that the calamitous effects of asteroids and comets that have executed more than one-fourth of the earth's human populace have happened once in about every one million years, and smaller impacts, such as the 1908 Tunguska impact, which leveled in excess of 2000 km^2 of Siberian timberland, happen every 200–300 y. In this way, cometary effects most likely influenced hominine development and possibly prefigured in the Holocene period of human cultural history. Unfortunately, only a handful of archeologists are prepared to value the nature and potential impacts of cosmic effects. However, the effects of such impacts have been made into virtual-reality scenarios (Masse *et al*., 2010), and sea-bottom cometary traces have been reported in Río Cuarto, in central Argentina (Schultz and Lianza, 1992).

The Chiemgau impact in Bavaria is another more-convincing case (Ernstson *et al*., 2010, 2011, 2012; Liritzis *et al*., 2010; Rappengluck *et al*., 2010; Shumilova *et al*., 2018) over the arguments of some opponents (Doppler *et al*., 2011; Rappengluck *et al*., 2011).

The large Chiemgau meteorite impact in southern Bavaria (Ernstson *et al*., 2011; Hiltl *et al*., 2011; Liritzis *et al*., 2010; Rappengluck *et al*., 2006, 2010, 2011), which happened some 4000–2500 BP, affected a region that was probably densely populated, although the magnitude of the cultural implications is still being discussed (Rappengluck *et al*., 2006). Geologically, the conspicuous layer at Bavaria, inferred to be an impact-related, dimictic intercalation with intermixed artifacts of the Bronze Age, was probably during the Urnfield culture (*ca*. 1300–800 BC), as well as during the Hallstatt culture (*ca*. 800–500 BC). The layer is in a stratigraphical sequence that, so far, appears to lie between the Neolithic culture below and the Roman paving above, which presents a unique situation of a layer formed by a catastrophic impact and which was sandwiched between dated archaeological horizons. Typical archaeological objects and fractured bones and teeth have been uncovered from the various horizons.

However, despite historical accounts and mythological references and beyond admitted cometary fall in older times, this topic is still lacking concrete evidence from the Holocene. Extraordinary claims require extraordinary evidence, such as craters or unambiguous shock material. Such evidence is still lacking.

The timing of the Mediterranean Sea's flooding, as well as the flood's causation has also been revisited, and a cometary impact has been suggested, which is the presumed Younger Dryas (YD) event episode, marked by abrupt increases in snowfall and dramatic changes in flora, fauna, megafauna, climate, and the oceans. The precise cause remains unknown, although it has been attributed by some to a cosmic impact roughly 12,800 YBP that has yet to be identified (Firestone *et al.,* 2007; Wolbach *et al*., 2018a,b). The impact is reported to have induced YD effects across at least four continents (Kennett *et al*., 2015), and it also formed an associated layer of nanodiamonds (Kennett *et al*., 2009), microscopic diamond crystals that are created by very high-velocity collisions, found across most of the planet (Jaye, 2019; Kinzie *et al*., 2014).

Finally, additional cometary impacts may include the Ch'in-yang event of 1490 (or the Qingyang event; March or April 1490); meteor showers in China, *e.g*., the AD 616 meteorite recorded in the Sui-shu (*History of the Sui Dynasty*, AD 581–618), which destroyed a wall-attacking tower, killing several people (Yau, Weissman, and Yeomans, 1994); the potential impact crates of the Zerelia Twin Lakes (Thessaly, Greece; *ca*. 7000 BP minimum age; Dietrich *et al*., 2013, in addition, see the list in http://www.passc.net/EarthImpactDatabase/New%20website_05-2018/World.html).

Earthquakes

Earthquakes are the main cause of many frequent cataclysmic events around the world. Many societies in China, the Mediterranean, Central Asia, Polynesia, and the Americas have been severely affected by powerful seismic tremors for millennia. The destructions at Jericho or the opening of the Red Sea show that earthquakes are both responsible for the destruction of cultures and the strength of the natural force on the crust of the planet (see Nur and Burgess, 2008). Since the early 1990s, earthquake archaeology has developed into a discipline (see Galadini, Hinzen, and Stiros, 2006; Sintubin, 2011; Stiros, 1996; Stiros and Jones, 1996). Earthquakes are known globally as periodical occurrences. From coastal settlements in the Mediterranean, NW America, or the East Asian countries, such as Japan, to the inland societies in Central Asia in modern-day Afghanistan or in western China, all can face the same destructive effects of potent seismic activity on a society's organization, infrastructure, and resilience. The ensuing humanitarian disasters resulting from powerful earthquakes are known to this day (Shroder, 2014). The subject of earthquakes has overlapping, but distinct, approaches, including paleoseismicity, earthquake archaeology, and disaster archaeology. The geology, topography, and geography differ, as do the various human responses among the peoples of the Mediterranean, NW America, and Japan, as far as coastal societies are concerned. It is clear that, across the world, societies have coexisted with earthquakes (Zeilinga de Boer and Sander, 2004). Ancient earthquakes have been recorded historically (see Ambraseys, 1971; Guidoboni, Comastria, and Traina, 1994) and archaeologically (Jusseret and Sintubin, 2017; Rapp, 1986).

The eastern Mediterranean has featured prominently in palaeoseismicty and earthquake archaeology. However, coastal earthquakes and tsunami have also occurred in Japan and along the northern American coast. Although both China and Japan are "seismic cultures," unlike ancient Greece, there does not appear to be any evidence suggesting an antiseismic architecture (Barnes, 2010; see also, Stiros, 1995). That difference may instead be indicative of a "strategy' that is specific to Chinese or Japanese cultures, architecturally speaking. Japan's seismicity is a particular feature of that archipelago. Japan is located between the continental Amur plate in the west, which is part of the Eurasian plate, and the oceanic plates to the east (Barnes, 2010; Taira, 2001). Both subduction and active faults have been responsible for earthquakes in Japan. The earliest recorded event goes as far back as AD 599 and is recorded in the Nihon Shoke chronicle (AD 720), but most events are listed after the AD 10th century (see Ishibashi, 2004; Usami, 1988).

The case in China is different. Earthquakes are spread throughout the country, with specific areas of high seismic frequencies near the Tibetan Plateau and along the northern borders. The world's largest orogenic belt is the Himalayas and the Tibetan plateau, and there are at least 64 major tectonic zones in China (Yin and Nie, 1996). China is also where the Paleo-Asian Ocean, the Tethyan, and the western Pacific domains meet (Zheng, Xiao, and Zhao, 2013). Therefore, China is in a very active seismic region, which has caused numerous destructive earthquakes in the past. *The Catalogue of Chinese Earthquakes* (published in 1995) is a two-part catalogue that lists in only historically determined earthquakes in one part (Lee, Wu, and Jacbsen, 1976; Min *et al*., 1995). The earliest entry begins in 23 BC and ends in the 20th century and lists 1034 earthquakes of magnitudes greater than 4.7 (Figure 2).

Several societies in ancient China were affected by the disastrous effect of earthquakes. For example, the famous Bronze Age society at Sanxingdui was discovered in the 1980s and is believed to be the remains of the Kingdom of Shu in the SW province of Sichuan (Figure 2). Sanxingdui flourished between 2200 BC and 1500 BC and ultimately ended abruptly *ca*. 1200 BC (Jiang, Yan, and Li, 1997) (recalling here as well, the abrupt end of the LBA in the SE Mediterranean). Sanxingdui was succeeded by the Jinsha culture in the area surrounding Chengdu *ca*. 1000–500 or 200 BC. The Sanxingdui and Jinsha civilizations are part of the Shu Civilization that developed in the Sichuan Plain and whose chronology, material culture, and geographical extent have been well defined by archaeology. The causes of the collapse of these two civilizations are argued to be political upheavals or floods and, more recently, earthquakes along the active fault of the Longmen Shan thrust. Researchers have discovered that during the past 5000 y, major seismic events occurred at least another four times, at an interval of approximately 1000 y. However, the scale and extent of the impact and damages of those earthquakes have not been assessed in depth. In fact, archaeological evidence suggests that those seismic events were strong enough to cause many fatalities and destruction to the infrastructure and the economy and could be correlated to the collapse of Sanxingdui and Jinsha cultures (Lin and Wang, 2017).

In the Mediterranean, the buildings, destruction layers, and cultural remains are of concern as part of the case for the generalized destruction during the LBA, which seems to have been a "seismic storm," which ultimately ushered in the LBA collapse (see Nur and Cline, 2000). Mediterranean archaeologists, who deal with earthquake damage to buildings and site

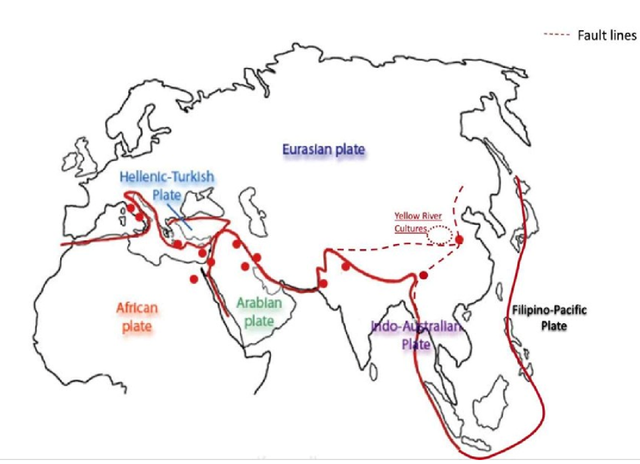


Figure 2. Tectonic plates converge in regions with great civilizations; volcanoes, earthquakes, and tsunamis are major issues in these coastal sites, with dots marking major sites. In central China, major cultural centers and fault lines coincide (based on Zhang, Liou, and Coleman, 1984; https://www.gnxp.com/blog/2008/08/earthquakes-progress.php).

destruction layers routinely consider this collapse odd (Barnes, 2010; Galadini, Hinzen, and Stiros, 2006).

The eastern Mediterranean is a highly seismic area in which the African and Euro-Asiatic lithospheric plates converge. The most famous case of seismicity in antiquity is the seismic storm that occurred at the end of the LBA, which may have been responsible for the so-called LBA collapse. The social decline at *ca*. 1200 to the 9th century BCE is attributed to drought and storms of earthquakes, and then, to the Sea Peoples (Kaniewski *et al*., 2013; Nur and Cline, 2000). However, palaeoseismicity and archaeology, for example, at the sites of Agia Triada and Phaistos (Crete, Greece), indicate that there were powerful and destructive earthquakes in Protopalatial (1700 BC) and Neopalatial (1450 BC) periods (Jusseret and Sintubin, 2017; Monaco and Tortorici, 2004). Another prominent earthquake is reported to have happened in *ca*. AD 365, with the epicenter somewhere south of the island of Crete, and several regions in the eastern Mediterranean were severely affected (see Figure 1) (Shaw *et al*., 2008; Stiros, 2001). However, it has been argued that between the AD fourth and sixth centuries, there were frequent earthquakes, which are recorded in historical texts, archaeological records, and palaeoseismic records (Stiros, 2001, 2010), a phenomenon of sequential seismic storms.

In Egypt and eastern Africa, the image of earthquake destruction is present deep throughout history. There have been several studies in earthquake archaeology (see Karakhanyan, 2010; Karakhanyan, Avagyan, and Sourouzian, 2010). There are many accounts of destructive historical earthquake in Thebes and middle Egypt in the Pharaonic times; however, there is little scientific evidence, and Maamoun, Megahed, and Allam (1984) did not identify any earthquakes exceeding 5.5 on the Richter scale from 600 BC to AD 1972. Temples, such as Tuthmosis III at Deir al-Bahari, are believed to have been destroyed by an earthquake, and at the time of Ramses III, the Nile's banks were nearly destroyed by a series of earthquakes. Incidentally, great cultures flourished along seismic zones, and although reminiscent relics have been found for many of them, the frequent holistic destructions wiped out others.

Earthquakes in South America. Kovach (2004) compiled archaeoseismic evidence from the Aztec, Incan, and Mayan cultures and has described structural damage from seismic shaking affecting corbelled arches, pre-Hispanic pyramids, walls, and tombs. When the Mayan Classic Period ended in the AD late ninth century, the cities of Quirigua and Benque Viejo (Xunantunich), now located in Guatemala and Belize, were suddenly abandoned. According to Kovach (2004), the cities could have been destroyed by a single earthquake centered on the Chixoy-Polochic and Motagua fault zones.

Other destructive events provide evidence of the high frequency of often destructive earthquakes in Peru (Cuadra, Karkee, and Tokeshi, 2008), the Trans-Mexican region with paleo-earthquake chronology (Ortuño *et al*., 2015), and Chile (Ruiz and Madariaga, 2018). Even though sparse, there are seismic data for ancient times from South America, and the historical records of the past 300 y and the subduction zones reinforce the existence and destructiveness of South American earthquakes.

Earthquakes in Central Asia. It has long been recognized that the Tibetan plateau was created by the collision, which began about 50 million y ago, of the northward-moving Indian plate and the relatively stationary Asian plate (Zhao *et al*., 2010).

The fate of the colliding Indian and Asian tectonic plates below the Tibetan high plateau may be visualized by, in addition to seismic tomography, mapping of the deep seismic discontinuities, such as the crust–mantle boundary (the Moho), the lithosphere–asthenosphere boundary, or the discontinuities at 410 and 660 km depth. The consequences of this fate to human settlements were severe along this convergence region throughout the past. Along the Central Asia Silk Road, the associated seismic faults from the convergence of Asian and Indian tectonic plates are evident. Earthquakes and disasters in this elongated region have been reported (Korjenkov *et al*., 2003; Shroder, 2014).

Earthquakes in the Pacific. In North America, on the western coast, is the Cascadia Subduction Zone or the Cascadian fault. A convergent plate boundary that stretches along the NW coast of North America, it has likely been responsible for tsunamis that affected both the NW coast of the United States and the eastern coasts of Japan periodically for at least 3500 y (Valentine *et al*., 2012). The earthquake of 1700 along the Cascadia fault was responsible for a tsunami that wiped out entire communities on the NW coast of Canada and NW United States (Kelsey, Hemphill-Haley, and Witter, 2002), from which, survivors' stories have survived orally (Atwater *et al*., 2005; Ludwin *et al*., 2005). Indeed, volcanic, seismic, and tsunami events are part of Japanese culture. The Nankia Trough has been responsible for periods of earthquakes recorded as far back as the seventh century (Ishibashi, 1999).

Such major destruction by earthquakes have been memorialized and retained through oral and sometimes written traditions from generation to generation and are expressed as myths, which can be unfolded by science.

DISASTERS AS MYTHS

Natural disasters may have initiated myths but science's contribution beyond the myth is intriguing; thus, through geomythology to geoarchaeology, archaeology is reinvented.

It is important to understand that these disasters can occur as a single event or as a chain of events, *e.g.*, a seismic shock can cause a tsunami, which floods part of the coastline, which then leads to systemic societal failure through the loss of labor, tools, equipment, or communications, as well as the loss of authority or legitimacy for the ruling caste (often described as divine punishment) and weakness against outside, violent incursions (hostile raids, abductions, slaughter, *etc*.), which can be exacerbated by crop failures and disease from lagoons and stagnant water; all of which ultimately can lead to near-total societal collapse. At that point, based on a risk-assessment logic-flow model proposed in next section, this period would be a "transition" phase, or perhaps, more poetically, a survivors' phase.

Natural events, such as earthquakes, tsunamis, tornados, fires, and so on, will occur on the surface of the planet, regardless of whether there is a human presence. Such events may cause ecological "disasters" and wipe out a large amount of the fauna and flora in the area. However, the disaster archaeology here is twofold. First, many fields have studied and synthesized global and local chronologies about temperature, silting, humidity or aridity, and polar magnetism as regular, constant geological and geographical processes, and have discovered and explored the abrupt events of nature that have occurred within recent geological times (Pleistocene and Holocene) and which have altered the environment dramatically and, relatively speaking, quickly. However, the Black Mat event in the Alps barely touched the glacial landscape, so that, when Hannibal passed through, the landscape he observed looked nearly the same as what it is seen in the area today (Mahaney, 2016). Second, in disaster archeology, researchers have to deal with the human understanding of the concept of disaster. Because they are dealing with the human past, archaeologists will primarily evaluate the disaster in ecological and cultural terms. Catastrophes or disasters are expected to occur periodically and within human memory, which can then be formed into data and statistics. However, the further back in time the research goes, the more there are accounts of disasters, such as floods and earthquakes, which have been adopted into religions and myths. Flood myths, about floods that have had the potency to eradicate entire cultures, are widespread in ancient human mythology and folklore. Flood events in the form of divine or natural retribution are described in many mythological and scriptural texts, such as the three surviving Babylonian deluge epics of Ziusudra (Eridu Genesis), Utnapishtim (Epic of Gilgamesh), and Atrahasis (Epic of Atrahasis); the river flood sediments in Shuruppak, Uruk; the WB 62 Sumerian king list recension (Rowton, 1960); the Genesis flood narrative (*Genesis* 6:9–9:17), which has been an enduring trope in Judaism, Christianity, and Islam; and the respective deluges in Deucalion and Pyrrha, which are the Greek versions (Hesiod in *Works and Days*, 109–200, Evelyn-White, 1914). According to *Theogony* of the Apollodorus' *Bibliotheca* (Frazer, 1921), the Bronze Age (the third age of the "five races of mankind") was ended by a deluge or great flood, created by Zeus when he was disappointed and outraged by the aggressive and cannibalistic behavior of the bronze race.

The natural disasters that caused the demise of ancient societies, as evidenced in the archaeological record, are linked to surviving historical sources, and all are linked, finally, with the traditional accounts that compose mythology. Many mythologies, traditions, folklore, and religions around the world have stories related to cataclysms or disasters, to special cosmic events, or about geological formations (rock formations, hydrological features, such as underground water, and volcanoes), and many other natural phenomena. Even though wholesale acceptance of myths as fact is ill-advised for scientific analysis, many myths carry moralistic or ethical lessons in them, but may also, potentially, be evoking actual historical or geological events. Good folklorists or ethnologists are aware of the dangerous pitfalls and shortcomings of exploring the facts behind myths. They must contend not only with centuries or even millennia of mistakes, mistranslations, and other corruptions of an original text, but also with questions about whether an original text or story even existed or whether there has been gradual amalgamation of narrative tropes and motifs. Combining folktales and mythologies with historical perceptions is not new, but it is a field that, nowadays, has few adherents because the enormous amount of pseudoscience, wishful thinking, and rushed deductions can be detrimental for respected scientists. In 1968, geologist Dorothy B. Vitaliano coined the term "geomythology" to mean the systematic study of geology and mythology (Mayor, 2004; Vitaliano, 1968).

Even though the rich history, archaeology, and mythology of ancient Greece has been a trying ground for the potential to match geological, environmental, archaeological, and mythological evidence, geomythology has grown to include oral and folk traditions from Australia (Hamacher, 2014). The field has enjoyed only limited interest in academia, but it has been one of the most popular topics of discussion in film, literature, and popular knowledge. However, because of the popular appeal of subjects such as euhemerism and geomythology, topics emerging from pseudoscientists often emerge with claims of extraterrestrial or futuristic pasts. One such theme is the eponymous and notorious topic of the lost city of Atlantis, mentioned by Plato in *Timaeus and Critias*. Vitaliano (1968) drew inspiration from the ancient Greek Cyrenaic philosopher of *Euhemerus*, the work of Greek archaeologist Marinatos, and the geologist Galanopoulos (Galanopoulos and Bacon, 1969; Galanopoulos and Chalkis, 1984; Marinatos, 1939). Euhemerus and the school of Euhemerism believed that the mythologies of the Dodekatheon, for example, were not works of fiction or religious scripture but were, in fact, historical events that, through the vagaries of time, have been warped into religious tale (*e.g.*, Brisson, 2004). Outside of the geography of Hellenic mythology, texts from China, India, and Egypt also survive. In societies with little or no writing traditions, oral traditions occasionally survive to this day, such as the case of the Black Sea Lake flood in the early Holocene and its potential connection with the concept of biblical floods. The most recent compilation of data by Yanchilina *et al*. (2017) suggests that, in fact, the Black Sea Lake was flooded once the isthmus of the Bosphorus was breached. It can be presumed that the flood of the Black Sea Lake, if it was a sudden event, would have a significant effect on the minds of the people of the region, which may have spurred other folktales of which the authors are unaware. Such a tale may fit differently into large human geography and historical reconstructions, or it may have been an event from which there were few or no survivors to recount the tale. In disaster archaeology, it is important to remember that there may be no survivors or no circumstances that allowed for the survival of the account of a particular destruction. The case for establishing matching factual historical chronologies between oral accounts and scientifically discovered natural events is difficult and is only rarely convincing to the scientific community.

At any rate, geomythology does not focus only on destruction but also on any significant geological phenomena, including cosmic events, such as observed astronomical phenomena, which the field of archaeoastronomy is pushing to better understand with greater resolution. Comet impacts on earth may become part of regional history and worship (Whiston, 1717), such as in the case of Australia, in which the relationship between impact craters and aboriginal oral tales has been explored (Hamacher and Goldsmith, 2013). Another ancient example of meteorite impact and its impression on ancient societies is found in *Aegos Potamoi* in Asia Minor, a place that has become a sacred location, worshipped and visited for many centuries (McBeath and Gheorghe, 2005).

So far, no serious attempts had been made in research to examine mythologies through science. For example, a preliminary step to any scientific understanding of the Greek religion (and its traditions) is a thorough study to demystify its rituals. This habit of viewing Greek religion exclusively through the medium of Greek literature without reference to the allegorical meaning of its message has brought with it an initial and fundamental error in method if it is to be properly proven scientifically. Beneath this splendid surface of mythology lies a stratum of religious conceptions, but practical functions and environmental issues as well, which are ignored, suppressed, or symbolically covered by ancient writers (Liritzis *et al*., 2017; Liritzis and Coucouzeli, 2008; Liritzis and Raftopoulou, 1999; Levy *et al*., 2015).

Engel (2012) has provided a synthesis of sedimentary evidence for prehistoric tsunamis, evaluating the long-term influence of extreme wave events on the coastal geoecosystems and improving the chronology of major prehistoric tsunamis for Bonaire, The Netherlands, and the southern Caribbean. These studies have given rise to a neocatastrophism concept, which developed as a new discipline (Morhange *et al*., 2014). Among other coastal areas of the world, geoarchaeological evidence for coastal change and vertical ground movements since the Roman period has been documented for the Phlegrean Volcanic District of Italy. The offshore geomorphology and archaeology of the Vivara and Procida islands, known to Aegean-Mycenaeans during the Bronze Age, provides several palaeocoastlines between 1 and 21 m below sea level, the lowest one assigned to *ca*. 5000 BC, whereas those between −18 and −10 m are thought to date to the 18th to the 15th century BC, based on the landing structures and other archaeological finds. Traces of other short-lived, relative, sea-level stands have been discovered. In fact, this area underwent discontinuous subsidence of about 15 m during the past 3800 y (Putignano *et al*., 2009).

The well-known deluges in both the holy Bibles and the traditional, intangible heritage convey bits of information if properly approached.

Mythological Deluges

Each site presents its own genesis, as modified by its immediate natural environment. In Greek mythology, three major cataclysms are listed: Ogygos (Attica-Boeotia), Deucalion (Thessaly and variations mentioned the Parnassus), and Dardanus (Macedonia). Other cataclysms include the periods of the famous pyrotechnologist Telchines in Rhodes (coming from Lemnos) and the Inachos deluge at Argolid. The former is transmitted from the Bronze Age, whereas the latter has been attributed to the early second millennium BC, *i.e*. both are from the same period.

This cataclysm has been proven from drilled bore cores dated to the Early Helladic (approximately 3000–2700 BC), revealing a sedimentary layer that was covered by 1–3 m of alluvial sediment (Liritzis and Raftopoulou, 1999). At the same time, a related phenomenon of sedimentation from floods is located in Attica in a conglomerate layer in *Cratylus* (3200–2600 BC). In both Argolis and Attica, the transgression phenomenon and floods were strong enough to be memorialized in the Inachus and Ogyges deluges. Thus, variations in local myths also display the deluge of Inachus, in the Argolida region (Grimal, 1991). In contrast to that period, the era of Inachus' son Foroneas was the time of a large population increase, which required the dispersal of peoples into different settlements and encouraged harmonious communication and the development of both local dialects and multilingualism.

The myth of Babel (*Genesis* 11.9) also refers multilingualism in such an unavoidable sociocultural event.

The Old Testament and the Sumerian tradition has an established lineage is patrology based on the myths and facts about a flood as the cause and the starting point. Noah, like Inachos, was a parent of humanity in the local tradition, as imagined by their respective people. Their descendants, Abraham and Foroneas, respectively, promoted the culture and society of their peoples.

Heracles is a characteristic LBA hero. Three of the 12 labors mystically ordained by the Delphian oracle to Heracles are related to hydraulic content. The Lernean Hydra or the clearing of the manure from the stable of Augeias reflects the concern for larger hydraulic works in prehistory. The immortal Hydra with seven or nine heads wreaked havoc on the fields of the Bronze Age farmers south of Argos, near the Lerna swamps. The extermination of the Hydra's heads coincides with the hydrogeological behavior of the karst springs of Lerna, with annual and long-term changes in the hydraulic system of the Argive Plain (Clendenon, 2009). On occasion, streams in the area would both flood the Lernaean Plain and form disease-infested swamps, as well as destroy much in their path by their sheer momentum (Mariolakos, 1998). Heracles' feat was the drying up of the marshes by leading the torrents into one head river, which, in turn, produced the famously fertile Argive Plain. Although some research on this area during that period exists (Walsh *et al*., 2017), there is not much geological work to determine it geomythologically. On the other hand, the clearing of the manure implies either a tsunami or the converging rivers into one strong, controllable stream.

Local climatic and geological phenomena accompanied by disasters result in the core of theogony and anthropogony of people. The cataclysmic meaning, therefore, of myths reflects a local geological or climatic event with serious consequences for the wider area concerned. With that in mind, the legends embedded in the wider environmental reality cease to serve exclusively as imaginary. The historical facts may well be mythologized and even more to build legends from the available archaeological data. The respective myths that imply a flood are also found in China.

The Chinese Parallel

The great flood trope and its large circulation in ancient civilizations have drawn many scholars to try and decipher the reasons for its widespread, nearly global, presence.

Chinese mythology is replete with water deities and deified individuals who acted on the order of the emperor to control a river. This practice is well known in the Han (AD 206–220) and Song (AD 960–1279) dynasties, in which individuals who were given the charge of undertaking engineering works to prevent floods were subsequently worshipped officially and even had shrines built in their honor. The most prevalent and well-known myth from China about a heroic character who tried to triumph over a pernicious and unpredictable river is that of the challenge of Gun Yu. The great flood of Gun Yu (Pang, 1987) is the story of a major flooding event, which allegedly lasted for two generations. Modern water engineers of China are well aware of rivers, such as the Yellow River, which are prone to flooding to this day, and extensive canals, irrigation, channels, dams, dykes, and other projects have been carried out to prevent and/or mitigate the devastating effects of floods.

The stories of the floods of Gun Yu and Da Yu are the stories of the founding of the Xia and Zhou dynasties (1700–260 BC), as quoted in the *Book of History*, describing the flood (Wu, 1982).

The interpretation of such endeavors against water (agricultural activities and protection of cultivated lands and irrigation systems) seems to be a common archetypal human expression, for similar natural drastic events that occurred throughout world cultures, from China to Greece and Egypt's Nile, from native Indians to aborigines in Australia and South America.

The frequent occurrences of natural disasters reshaped the Old World and continues to do so in the contemporary era. Attempts to investigate recurrence or a statistical elaboration of available proxy data by time-series analysis has some interest and reiterates a wise consideration of learning from history.

Having set the archaeological, historical, and scientific background of natural disasters in ancient societies, an attempt to model the evolution of the cradle of ancient civilization, based on the interaction between neighboring groups of people and environmental agents, unfolds below.

A MODEL FOR CULTURAL GENESIS

Geomythology investigates mythological reports. These stories of the mastery of water (dams, swamp drainage, coastal infrastructure) or pyrotechnology (ceramics, metallurgy, development of food preparation) refer to the technological progress of societies and to the subjugation of elements, quests for wealth, and so on are a historical aspect of humanity's unknown conquerors, city-founders, explorers, and leaders that form a common cultural substrate for example, of the Mycenaean and thereafter the Hellenic and European culture, as well as the achievements by heroes, such as Hercules, Gun Yu and Great Yu, Gilgamesh, and more, in various cultures.

The "model" for the genesis of a civilization is comparable from Mesopotamia, Egypt, Greece, and China, and rely on local geological or climatic events. Environmental phenomena, such as flooding (wet climate), drought, landslides, and seismic activity, display a serpentine, curved line, with an average duration (extreme wet and mild dry climate phenomena, *etc*.) of 80–120, 200–250, 500–700, or about 1000 y and longer periods with similar climatic cycles have also been identified in geoarchaeological research and in approximate climate indicators, such as changes in the thickness of tree rings, carbon-14 in the air, thick sludge ponds, geomagnetic fields, and solar activity. Superimposing these cycles then forms a network of periodic waves of "chaotic" changes in time (Liritzis, Diagourtas, and Makropoulos, 1995; Liritzis and Fairbridge, 2004; Liritzis *et al*., 1994; Liritzis and Kovacheva, 1992; Xanthakis, Liritzis, and Galloway, 1992). Careful analysis of climatic, geological, and solar parameters indicating such climatic cycles, and economic–social reasons are the main cause of the nonlinear fluctuation in ancient civilizations.

The recurrent model goes as follows: First, any closed system (*A*), a kingdom or a city, interacts with reciprocity with system (*B*), external societies, and with system (*C*), environmental agents (Figure 3). The latter (system *C*) includes all natural disaster factors already reported above (Figure 4).

Internal Circle (*A*)

The Internal Circle represents a population (a group of people that live together, a core of settlers or immigrants, an organized society or habitation), one that involves social unrest or revolt, limited and controlled food producing, religion, a hierarchical system of governance, an explorative character, and an economic system.

External Circle (*B*)

The External Circle is the near or distant population groups or residents, with which the given population (*A*) interacts directly or indirectly. An interesting critical assessment of humans in these two circles is made by Sass (2012).

Environmental Circle (*C*)

The Environmental Circle comprises elements such as geophysical and climatic phenomena (earthquakes, volcanic eruptions, floods, extreme and continuous drought, and rainfall) and the geomorphological and geographical setting. Specifically, exposure of humans to environmental threats is unevenly distributed. Some locations may pose greater risks than others, *e.g*., high latitudes, floodplains, river banks, marshy areas, small islands, and coastal areas. In addition, human exploitation or modification of the environment, such as deforestation, an increase in paved areas covered by buildings and roads, and river canalization, have created

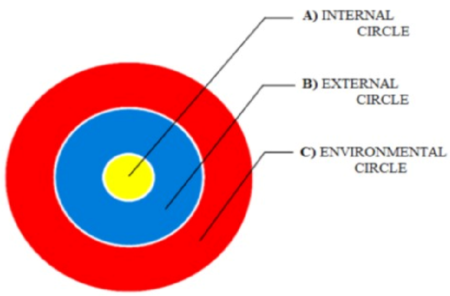


Figure 3. Three interacting circles (A, B, and C) that drive any cultural evolution (from Liritzis, 2013, fig. 1).

impacts that often affect areas a long way from the source of the environmental change.

The Model

Sporadically, within a cultural phase, paths may be linear but can gradually become a local outburst and saturation and the proceed to the threshold of the next phase, which is established by complex fluctuations of the three interacting domains and the internal strange attractors of circle A (Figure 5). In the end, a recurrent state is formed (Figure 6).

The flow of the overall evolution of a system, *e.g.*, a homogeneous population, follows irreversible processes. Thus, in times of equilibrium, for a homogeneous social group (the inner circle [A]) transition from one state ($K1$) to a next one ($K3$) happens because of the impact of the other circles, the external (B) and environmental (C) circles, goes through an intermediary stage ($K2$), where transitions $K1$ through $K2$ produces $K3$ are the so-called detailed balance (Graham and Haken, 1971). Then the ratio ($K1/K3$) = ε, which corresponds to the maximum entropy. Entropy is the measure of a system's thermal energy per unit of temperature that is unavailable for doing useful work.

An open system is a physical system that can exchange both matter and energy. This can be contrasted with an isolated system without any external exchange—neither matter nor energy can enter or exit but can only move around inside—and a closed system, which can exchange energy, but not matter, with its surroundings. Consider an open system, from the homogeneous social group, with different dynamic effects from the second and third circles in Figure 3; then, for every given state a and c, there are many possible states for the intermediate phase b. Among these, however, only one corresponds to the state of thermodynamic equilibrium and maximum entropy. That particular state can expand far from equilibrium in thermodynamics.

The energy change over time in a culture is reflected in the change of entropy $dS = dSs + dSi + dSp$, where, dSs describes the transport through the boundaries of social systems, dSi is the entropy generated within the social system, and dSp is the entropy (of that social system) with the environment (positive or negative [+ or −], depending on the type of exchange). The second law of thermodynamics certifies that $dS > 0$ ($dS = 0$ applies to an equilibrium). In cultural

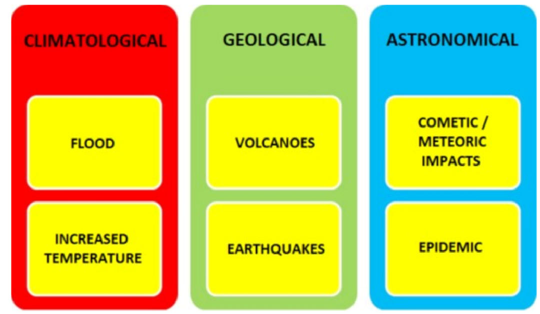


Figure 4. Circle C consists of environmental factors classified into three causes or sources: climatic, geological, and those of an astronomical nature (Liritzis, 2013, fig. 5).

evolution, the entropy production rate dS/dt (dt = entropy over time) is of interest, in conjunction with the rates and forces of various irreversible processes (wars, floods, earthquakes, fires, pollution, epidemics, migration, trades, invasions, and raids, *etc*.).

The structure and function of a social group (nomad, city, nation…) are inextricably linked. However, how the structure of a culture emerges in conditions of nonequilibrium sustained in a given mild interaction energy is the question. Stability is the crucial point here, which is, however, interpreted by is free energy, $F = E - TS$, where, E is energy, and S is entropy. F is minimized in an equilibrium in a way that even outliers in entropy and free energy ensure that cultural disturbances or fluctuations have no impact on its equilibrium.

Cultural evolution is based primarily on mutual interactions of different components, $f(ti)$, at variable time interval ($ti = t_0$ to t_1), derived from the three factors. Therefore, the cumulative result could be expressed as in Equation (1):

$$Y(t_i) = \int_{t_0}^{t_1} f(t_i)d(t) \tag{1}$$

The parameterization of mathematical expressions is not an easy task and the attributes that define cultural levels per time have to be defined quantitatively (work in progress).

Historical periods of such stability are reported at Mycenae in the Mycenaean civilization and at Athens in the age of Pericles, as well as in Middle East and elsewhere, *e.g.*, in China during certain periods: approximately 2000–1600 BC, 1600–1050 BC, 1053 to approximately 650 BC, and later, which mark dynastic transitions and coincide with major climatic, disastrous events (Fan, 2010; Wu *et al.*, 2016), in which the retention period for such new states leading to a centre of culture and development ranges from a few decades to 500 y.

The prediction (Yin, Yun, and Xiuqi, 2016) is that better times—warmer and wetter, with stronger monsoons—will predate or accompany the rise of dynasties, whereas worse times—colder and drier—will predate their fall.

The durations of alternative stability and perturbations caused by the two agents described above are mainly driven by

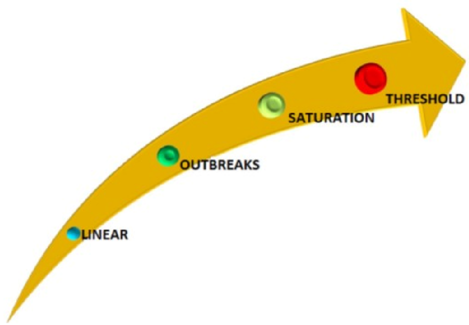


Figure 5. Trend of a cultural system toward a new state.

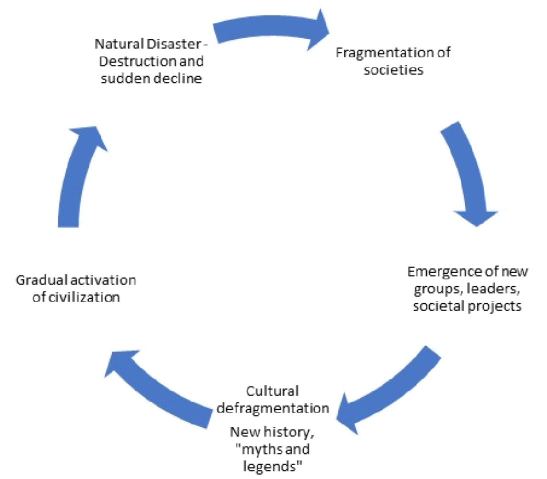


Figure 6. Recurrent state, from natural disaster to reactivation of civilization.

environmental factors—terrestrial and astronomical—as described below, although some of this follows environmental determinism (*e.g.*, seasonal changes, observations of natural phenomena).

The prediction of recurrent catastrophes is a matter of research, but their connection with periodicities in natural (terrestrial and astronomical) phenomena is examined below.

PERIODICITIES IN TERRESTRIAL AND ASTRONOMICAL PHENOMENA

The impact of environmental phenomena (terrestrial and astronomical) on cultural evolution seems to follow a synchronization with a periodic or quasiperiodic nature.

Various theories have been developed for the interpretation of the *how* and *why* in the evolution of social–cultural complexity, based on social, terrestrial, and astronomical causes (Liritzis, 2013).

Here, as a system, it means taking all manifestations of a group of humans that have a common conscience of similar rooting, ethics, religion, *etc*, which develop and create a culture. It is accepted that the development and trajectories of such cultures in the world depend on various factors in a synergistic way (Juarrero and Rubino, 2008; von Bertalanffy, 1950, 1976).

Dynamic, complex mechanics are operative in any culture's formation, and the complex systems present problems both in mathematical modeling and philosophical foundations. The study of complex cultural systems represents a new approach to nonlinear science that investigates how relationships among parts give rise to the collective behaviors of a system and how the system interacts and forms relationships with its immediate and/or distant environment.

Because all cultures have many interconnected components, the science of networks and network theory are important aspects for their study. Disaster dynamics in archaeology has been shown to be so powerful that they changed the course of human history. Mighty empires have collapsed, vanished, or been shocked irreversibly. Natural environmental factors triggered the fall of well-organized social systems. Drought or flooding; epidemic diseases, such as plague and other diseases; tremendous volcanic eruptions; and meteoritic impacts, tsunamis, and earthquakes influenced the circum-Mediterranean civilizations and the NW European, Asian, African, and American civilizations. The search and interpretation of such unknown disasters leading to unexplained results is based solely on interdisciplinary approaches. This recalls an earlier proposed thesis (Liritzis, 2013) that every theory should rest upon diverse, dynamic factors derived from the three following prominent concentric, interdependent systems or circles (see Figure 3).

The system's variables comprise the input of energy, the flow of energy, the transformation of matter, the concept of reversibility, and the organization of space and information.

Indeed solar, terrestrial, and cometary periodic factors have been well established as exhibiting a rhythmic occurrence, which spreads throughout a timescale from minutes to millions of years.

The longer periods in nature are recorded because of the onset of igneous and metamorphic processes (onset of continental drift, orogenic belts, *etc*.) that occurred during a succession of cycles of orogeny that may generally be described by a sequence of events, such as prolonged down wrapping of a long belt of the earth's surface (at subduction zones where one plate bends deep beneath another, and the sinking plate acts like a conveyor belt), metamorphism and folding of plutonic rocks, widening of the original geosyncline, and general uplift and erosion. The cause of this observation directs insight into a common, universal mechanism that drives such global phenomena (Liritzis, 1993).

A complete data set of globally distributed, shallow (about $h < 60$ km) earthquakes of magnitude $M \geq 7.0$ that have occurred throughout the entire Earth in 1898–1985 were converted into seismic energy and have been statistically analyzed, and they exhibit a network of periodicities with predominant periods at 3, 4.5, 6.5, 8–9, 14–20, and 31–34 years (Liritzis and Tsapanos, 1993). An additional overbalanced effect is the occurrence of earthquakes that may appear as a "coseismic storm" lasting a few decades. The AD mid-20th century "earthquake storm" unzipped the North Anatolian fault during a *ca*. 30-y period from 1939 to 1967 (Stein, Barka, and Dieterich, 1997, fig. 1). A similar event may have occurred in the Aegean and Eastern Mediterranean sites destroyed *ca*. 1225–1175 BC. Indeed, the same earthquake centers are superimposed on the maximum intensity of seismic ground motion in the Aegean and the Eastern Mediterranean during *ca*. 1900–1980, in which the intensity was greater than 7.0 on the Richter scale.

The region of synchronous destruction includes the mainland and Aegean Greece and Anatolia, having interconnected fault systems and, also, a causal relationship to global seismic energy release. The latter is reinforced by a statistical correlation study for the period 1917–1987, in which the Greek seismic activity exhibited a very significant, positive correlation to the preceding global activity with a time lag of 15 y. It seems that all of Greece and the two characteristic areas from which it was separated (Greece without the Arc and the area of the Greek seismic Arc), follow global seismic activity but with a time shift of 15 y. Moreover, an intrinsic interaction mechanism seems to exist between the Greek seismic arc and the rest of Greece, which may be deduced by their different behaviors exhibited when they are correlated with global activity, as well as from the correlation between themselves, where a very significant positive correlation has been found with a time lag of 3 y for Greece without a preceding arc. A quasiperiodic term of 30 y was also observed in these detailed four seismic time series.

The cross-correlation analysis of seismic time series, as shown, serves as a powerful tool to clarify the complicated space–time pattern of the worldwide mosaic of tectonic-plate motion. The implications of a spring-block model of the interaction of tectonic plates is invoked, which considers that the earth's rotation rate changes as its triggering agent (Liritzis, Diagourtas, and Makropoulos, 1995).

Particular emphasis may be given to the potential of such studies in earthquake prediction efforts from local or regional scales to global scales and *vice versa*.

Such strong hypotheses seem to show they interact with other (regional and global) forces at work in these areas *ca*. 1200 BC and merit consideration by archaeologists and prehistorians but also by geoarchaeologists.

Studies of such proxy-interlinked phenomena have been performed (Liritzis and Galloway, 1995; Liritzis *et al*., 1994, and references there in).

To facilitate the study of long-term variations in palaeoclimate (Lamb, 1977), physical measurements, which can be interpreted as proxy indicators of past climate, are important. A few examples of such measurements applicable within particular contexts include the variation in relative abundance of ^{18}O (Shackleton, Imbrie, and Hall, 1983), the variation of magnetic susceptibility (Da Silva *et al*., 2014; Kent, 1982; Robinson, 1986), and the variation in the relative abundance of ^{14}C (Sonett and Suess, 1984). The possible influences on past climate (or perhaps strictly the influence on the proxy indicators) can be considered. For many decades, astronomers and meteorologists have looked for clues to a causal connection between solar activity and climate (Centre National d'Etudes Spatiales, 1980; Roberts and Olson, 1973; Pecker and Runcorn, 1990; Stauning, 2011). Links between climate and geomagnetism have also been sought (Abrahamsen, 1986; Courtillot *et al*., 2007; Doake, 1977; Flohn, 1974; Gnevyshev and Ol, 1971). A sound relationship has been established among solar activity, ^{14}C relative abundance, and climate during the past 4 Ka (Lamb, 1977; Rampino *et al*., 1987; Sonett and Suess, 1984; Stuiver and Quay, 1980), whereas the variation in the natural radioactivity of lake and marine sediment as a depth dependence has been shown as a possible alternative-proxy climate indicator (Liritzis *et al*., 1994, 1999). In fact, lake sediments have shown a periodic nature in mud thickness and geomagnetic inclination values (Liritzis and Fairbridge, 2004; Xanthakis and Liritzis, 1989). An analytical representation and the application of maximum entropy spectral analysis of European archaeomagnetic inclination data of the past 2000 y revealed the possible existence of periodic terms of approximately 1000, 500, and 260 y (Xanthakis and Liritzis, 1989).

All the examples above show the environment broadly as a direct or proxy agent related to climate and severe changes in palaeoclimate having a strong impact and diminishing ancient cultures in prehistory, but Paleolithic, period (during the Quaternary), to the extent of creating archaeologically subdivided periods or cultural phases.

The issue of natural disasters as revealed in the archaeological record and historical sources, mainly of coastal sites, is an important topic to be developed as an inseparable part of archaeological investigation. The issue becomes vivid in the modern era with the consequences of catastrophes experienced and caused by extreme phenomena of weather and other environmental agents.

DISCUSSION

The evolution of human societies and, in general, of human history, does not follow a linear trend but rests mainly on mutual interactions among different components. Identifying the meaning of that complexity in human processes, which involve material, energy, and environmental factors, is cultural evolution as viewed *via* a complex-system approach of a collective result of nonlinear interactions, making a series of successive transitional phases along a trajectory. The interacting, multifactorial issues derive from three concentric circles or dynamical systems, the internal (*A*, issues derived from within a given society), the external (*B*, issues derived from interactions with neighboring societies), and the environmental (*C*, issues related to the context and other geological phenomena).

Chaos theory is intermingled with various identified attributes that define and affect the cultural evolution of a human organized system. Atlantis and other reported accounts (legendary and historical) are sufficient to stress the naturalistic methodology, which serves as the basis of for a synoptic and synthetic philosophy that involves art and culture, science and technology, and existence, corresponding to classical *techne*, *logos*, and *ethos* (Liritzis, 2013). So, drastic impacts on humans have initiated mythology and ideological evolution. Exploring the "unknown" has introduced poetical prose, heroic labor, mystical knowledge, and allegorical tales, such that the "myth" invented by the human race echoes something related to ethics, to a huge event, to deities, to imaginary conceptions. At any rate, it is a task for academia to decipher the myths, considering geological and environmental issues as the natural event that describe "reality" (Levy, 2010).

In the pyramid texts of Egypt are many descriptions of the evolution of cultures during cyclical periods. Ancient writers provide valuable descriptions of the impact of major earthquakes and earthquake-related phenomena on human settlements and constructions in historical times. Many volcanic centers around the world have erupted at times and caused damage to the immediate environment but also to long distances, with ultimate impacts on the climate. Volcanic events, in fact, leave very strong signals in both the geological and human records. Volcanoes affect the climate through the gases and dust particles that emerge into the atmosphere with the explosions. The result is a heating or cooling of the earth's surface, and the subsequent tsunamis and the damage to human settlements and coastal constructions can be very significant. Records provide information on a large number of tsunamis throughout historic and recent times. Thousands of people were lost, the fauna and flora were destroyed, and the morphology of the surface was altered, whereas in the remote past, mountains were formed. Several examples have been reported of mythological deluges and their relation to natural catastrophes (beyond the myth lies, among other issues of ethics and religion, a natural phenomenon). There are also astronomical causes of destruction, *e.g.*, several craters have been formed by catastrophic meteor impacts (Clube and Napier, 1984). These and many other events of modern and ancient times confirm the presence of destructive impacts in the past. There is no doubt that earthquakes, tsunamis, as well as typhoons have wiped out a plethora of major cultural centers of the ancient world. The cataclysmic disaster, therefore, of myths reflect a local geological or climatic event with serious consequences within the wider area concerned. With that in mind, the legend embedded in the wider environmental reality ceases to serve exclusively for the imaginary.

The position presented here is that not all disastrous events spelled the end of a civilization; however, several of them had much larger effects on human societies than previously considered. These events can lead to changes in, or even near-complete annihilation of, human societies and natural ecosystems when biological, environmental, political, technological, geographical, and cultural features were fiercely shook. Fortunately, these disastrous events leave distinguishable traces on the environment and even on the human psyche. The periodicity and cultural and ecological changes from these events tend to be observable in the archaeological sequences and stratigraphies, the mythohistorical accounts of deluges, and so on, and naturally through other proxies and data about past disasters and palaeoenvironments.

Disaster archaeology deals with a great deal of issues because it can cover every sort of known human disasters. Natural events, phenomena, or hazards and human societies' vulnerability or resilience and exposure to the hazards can be assessed in a field similar to that of risk assessment. Simply, risk can be summed by calculating the hazard (tornado, tsunami, earthquake, *etc.*), the exposure to the hazard (alluvial or flood plains, seismic activity, pressure systems), and the vulnerability of the settlement (construction material, prevention-warning-response systems, and strength of the ruling authority, *etc.*). Once that information is factored, the impact of the disaster on the environment and on human societies in the area can be estimated, and whether the event weakened a human ecosystem to the point of collapse can be determined. The after-effect of such a collapse can lead to decades or centuries of regional, if not global, political and demographic changes because large population migrations will often clash with, and supplant, their neighbors, thus, creating a large-scale cultural and demographic domino effect.

CONCLUSIONS

To explore, then, the relationship between human adaptive strategic and cultural responses to short-burst cataclysms that punctuate the long history of humanity, a great deal of interdisciplinary collaboration is needed. From environmental science, archaeometry, and archaeology to historical, mythological, and ethnological research is needed to produce comprehensive reconstructions. The archaeology of natural disasters, or disaster archaeology, as defined, is summarized like this: it defines the identity, the impact, and the dynamics of natural hazards into the evolution of human civilization, tries to find and analyze the kinds, frequencies, and magnitudes of the natural hazards discoverable within the archaeological landscape, and searches for the adaptation processes of past human societies against the new hostile and unfamiliar landscapes that are formed after the disaster (*i.e.* new shorelines, stagnant water, and a general ecological upheaval, among others). Floods, either riverine or coastal disaster events, in general, similar to most natural disasters, occur periodically with interrupted, unpredicted issues, as order in a chaotic pattern, which varies in frequency, potency, and the magnitude of the functional structure.

There is no doubt that disasters happen and have happened in the past. The archaeological and geological research proves it. The modern experience of such phenomena, however, confirms the degree of damage, even on a local or regional scale. Disasters refer to the ecosystems, to the many established crops, to the biodiversity, to the hydrological cycle, the desertification, to the sinking and flattening villages, and to the killed thousands of people.

In historic and prehistoric times, other disasters may have occurred, in addition to those mentioned above, from strong tectonic movements to hurricanes and to floods, mainly on local scales.

These more-local scale events have resulted in the decline of some civilizations and the flourishing and emerging of neighboring cultures, of development at different cultural stages, of migrations and the conveying of ideas, experiences, and knowledge to others, and the emergence of strong events with reverberations in myths and legends. Other events recall the ethical didactics of a myth, and that may apply to Plato's Atlantis, which he conceived an ideal State, in which arrogance and ethical decline perished because of that cataclysmic event.

Overall, there exists a network of variable systems that activates and self-organizes on a universal analogous law—a correspondence principle between micro- and macrosystems. In this case, the ancient artifacts and relics of socioculture reflect the dynamic interactions of humans themselves and the environment (with its broader, geographical sense), and any attempt to interpret the cultural evolution trajectory, and the remains that survived, by interpolation and/or extrapolation, need to account for the tools derived from an applied epistemology. Mythological legends reflect rather destructive events derived from the environmental factors of terrestrial or direct or indirect astronomical origin, depending upon how the related questions above are resolved.

Natural disasters are something that humanity has had to deal with since its inception. Beyond a myth lies, among other issues of ethics and religion, a natural phenomenon. The hermeneutics of cultural evolution with an overview of archaeological terms is basically founded upon the theory of complexity.

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