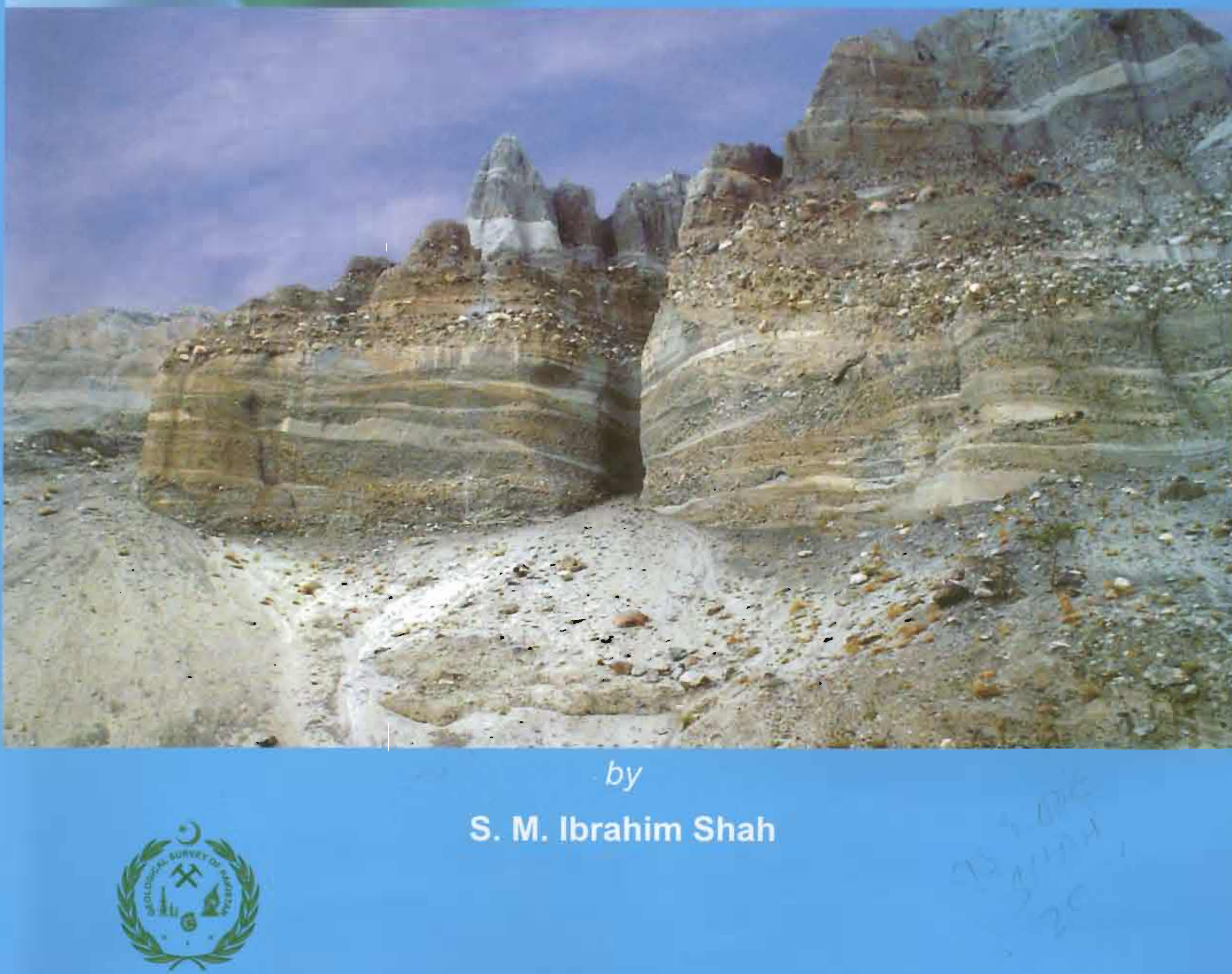
# STRATIGRAPHY OF PAKISTAN

GSP Memoirs Vol. 22



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GEOLOGICAL SURVEY OF PAKISTAN

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ADVISOR TO THE PRIME MINISTER

## MESSAGE

It gives me immense pleasure to see the publication of the Stratigraphy of Pakistan by the Geological Survey of Pakistan. I congratulate GSP and its scientist, particularly the author of this publication for having produced such a monumental work of research.

Several areas of Pakistan had significant data about their stratigraphic settings and natural resources potential. It was quite difficult in the past to have a quick and easy access to these sources of information, mainly because of absence of any reliable data base. Now with this comprehensive stratigraphic data and updating of the previous work, the problem has been resolved to a great extent. I am particularly glad to know that GSP has a plan to soon launch an electronic version of this excellent work on CD's and also make it available on its web site.

A reliable geological data base is pre-requisite to attract investment in the mineral sector. This document produced by GSP provides a solid foundation for such a data base. This publication is another milestone in implementation of the National Mineral Policy (NMP) that aims to attract and facilitate domestic and foreign investment in the mineral sector of Pakistan. The scope of this publication will not only be confined to mineral, gemstones and coal only but it will also be equally useful to oil and gas companies. In fact, this new stratigraphic version will convince every investor of tremendous natural resources potential that Pakistan's fascinating geology offers as new and emerging avenue for exploration and development.

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SECRETARY

## FOREWORD

It is a great pleasure for me to know that Geological Survey of Pakistan is publishing the new volume of 'Stratigraphy of Pakistan'. The vast collection of stratigraphic data not only reflects the details of geological studies carried out in this part of the world but also provides a scientific rationale and impetus to more vigorous effort to research and explore new mineral and hydrocarbon deposits in Pakistan. The new stratigraphic data cited in this volume will also be helpful in formulating national policies and open several new vistas of further research. The availability of this publication in both print and electronic form will provide researchers and exploration companies a data base to better plan their future studies and programs.

It is hoped that this publication will be a prelude to GSP's on-going activities for setting up an efficient system that should allow easy and economical access to authorized data entities for a dependable facility of multi-user retrieval. Mineral exploration is a continuous process and dependent upon a reliable geological data base. Minerals are regarded as generators of economic growth; therefore, their systematic exploration and development is an area of high priority for revival of the national economy. The structural organization and revitalization of the role and activities of the Geological Survey of Pakistan within the framework of National Mineral Policy (1995) has also been the most significant and important endeavor to the realization of the objectives. The Ministry of Petroleum and Natural Resources has been providing every possible help and assistance to the Geological Survey of Pakistan in its all activities aimed to realize these national objectives.

With this highly commendable publication, the GSP's researchers and scientists can rightfully take pride in the enormous human potential that they have and which I am sure, will very significantly contribute in future development of Pakistan.

**(Mahmood Salim Mahmood)**

Director General

Government of Pakistan
Ministry of Petroleum and Natural Resources
GEOLOGICAL SURVEY OF PAKISTAN

# PREFACE

Enormous practical value of stratigraphic knowledge cannot be denied, besides, knowing the historical facts buried in rocks, it certainly allures the human mind and its continued research helps one to ascend onto the philosophical heights. Ultimately, it provides the material basis for understanding not only the past history including evolution of life but also means to reconstruct durable civilization by having glimpse of destructive and creative processes through ages in the shape of paleogeography, paleoclimatology, paleoecology, as well as the source of material for human consumption.

The science of stratigraphy has a central place in realm of geological sciences. It was because of the realization of its importance that the Geological Survey of Pakistan published an earlier version of Stratigraphy of Pakistan in 1977, which served as a text book for over three decades. With the advancement of the science of Geology and incorporation of several new techniques for research in stratigraphy, it is the need of the time to provide the students and researchers a much more improved volume of the Stratigraphy of Pakistan. The increase of geological activities within the last two decades has proved that the stratigraphy is rapidly growing subject in Pakistan in which there is still lot to learn. Dr. S.M. Ibrahim Shah, the author of this Memoir has gathered up to date information scattered elsewhere in piece meals, and framed it as a "Must book" for stratigraphic knowledge of Pakistan. It is very difficult for a researcher working on the Geology of Pakistan to avoid Dr. S.M. Ibrahim Shah's, tremendous contributions on the subject.

Besides updating the last Memoir alongwith his views and reviews, the author has introduced the subject of paleogeography during the Eras of Mesozoic and early Cainozoic. It is believed that the exposure of paleogeographic maps to the geoscientific community and their interest

# PROLOGUE

Stratigraphy is the basic and the most fundamental branch of geology and is defined as "which treats of the formation, composition, sequence and correlation of the stratified rocks as parts of the earth's crust; and that part of the descriptive geology of an area or district, which pertains to the discrimination, character, thickness, sequence, age and correlation of the rocks of the district or an area". In its simplest form, therefore, the stratigraphy is scientific knowledge acquired from the study of sedimentary attributes and the constituents of an area circumscribed for examination as well as basis of their formation and existence enumerated as principles of sedimentation. The most fundamental part of the stratigraphy is to infer the conditions under which the sedimentary rocks were formed and to establish their mutual correlation involving the use of fossils (biostratigraphy), rock units (lithostratigraphy), or geological time units or intervals (chronostratigraphy). This inference provides the basic building blocks for almost all the branches of the science of geology.

The principles, which control the stratigraphic research, were worked out primarily in the sedimentary rocks in the initial period of the development of geological discipline. Nevertheless, they are now equally useful in the study of such rocks as ash falls, lava flows, and other layered igneous rocks especially in contact with sedimentary rocks or such metamorphic rocks, which reflect an original sedimentary character.

The present volume is the revised, enlarged and updated version of the Stratigraphy of Pakistan published in 1977, which summarized the stratigraphic knowledge of that time and the book so produced had been the largest circulated volume on the list of the publications of the Geological Survey of Pakistan. This reality together with vast amount of stratigraphic research conducted in Pakistan subsequent to 1977 necessitated the improvement, updating and through revision of the earlier volume, and hence the present book.

The stratigraphic knowledge of the rocks of Pakistan is now relatively well acquired and its fruitful utilization in the geoscientific activities is on the increase. It is now an acknowledged fact that the earlier volume did promote a confident use of stratigraphic knowledge in oil, gas and mineral exploration; extensively used by geoscientists as well as teaching institutions of Pakistan, the Stratigraphy of Pakistan 1977 remained the only book in the field of geology for two decades. Then, Bender and Raza (1995) published a fairly good account of Geology of Pakistan. This was followed by two more books namely Geology and Tectonics of Pakistan by Kazmi and Jan 1997 and Stratigraphy and Historical Geology of Pakistan by Kazmi and Abbasi (2008).

Now that many areas in the northern Pakistan have been mapped anew or studied afresh and the stratigraphy of that area has been described by several authors including those from Geological Survey of Pakistan, universities, oil companies and other geoscientific organizations of Pakistan and the foreign researchers and expeditions. Indeed, for the last more than two decades geological research in Pakistan has been intensified throughout the country, including deep subsurface drilling in the southern Pakistan. Because of these activities literature on the geology of Pakistan has brought out useful stratigraphic information. The knowledge so generated cannot be ignored and therefore, all the available information has been collected, synthesized and included in this Memoir for future advance research work. Thus, the present Memoir not only incorporates advances made in the already existing formations, but also significantly added a large number of new formations.

More specifically stated again, is that, in the last volume, the pre-Mesozoic geology was written by Shah (1977), both chapters on Precambrian and Palaeozoic are now completely rewritten and ended up to fourfold in size as well as in number of formations as compared to the previous volume. Mesozoic was written by A. N. Fatmi who had covered the then available all the information of the Southern and Central parts of Pakistan. In the present volume the Mesozoic stratigraphic information of entire Pakistan, are included, and as a result the chapter on Mesozoic has increased four times as compared to that of previous edition. In addition to the description of the formations, special treatment is given to the Cretaceous Kohistan island arc in the context of geodynamics, petrology and geochemistry. The Cainozoic was written by M. R. Cheema, Habib Ahmed (late) and S. Mahmood Raza, is now increased to about one and a half in size as compared to previous volume. The chapter on Mineral Deposits earlier outlined by Hilal A. Raza and M. W. A. Iqbal has been revised and enlarged in which special treatment is given to energy minerals with stratigraphic control under tectonic framework.

The stratigraphy is described basin wise. Simplified basin architect of northern areas is also given. Reconstruction of Paleogeographic map is attempted. To begin with maps of the Triassic, Liassic, Cretaceous, Paleocene and Eocene (together with its isopach and lithofacies representation) are given. The maps are of basic nature. Purpose of their propagation is to popularise and encourage advance and applied side of stratigraphy.

Prior to year 1965, stratigraphic column of Pakistan lacked the presence of the Ordovician, Silurian, Devonian and Carboniferous periods. However, the presence of Mid Palaeozoic was indicated in the remote regions of Gilgit and Chitral Districts, where Hayden (1898-1915) and Desio (1930-1963) had measured Devonian sections. The first authenticated Silurian and Devonian rocks discoveries in the easily accessible areas of Pakistan were made by Teichert and Stauffer (1965) near Nowshera. This was followed by Shah (1969), who collected samples of Devonian and Carboniferous rocks from the eastern Khyber Agency. Results have been published by Molloy et al. (1997). Earlier, conodont fauna was identified by Molloy (1979, unpublished). A party headed by M/S J. A. Talent and R. A. K. Tahirkheli from the Baroghil area, Chitral District and the results were published later, made the first record of Ordovician beds in 1973 Talent et al. (1981-1982). Finally Pogue and Hussain (1986) discovered Ordovician and Silurian beds in the accessible areas near Nowshera. Important contributions to the Palaeozoic stratigraphy of northern Pakistan have also been made by several foreign researchers notably among them are Desio (1963), Gaetani (1997) and Le Fort and Pecher (2001). Pakistan now has the representation of all the eras and all the periods of Phanerozoic and large number of the epochs in its stratigraphic column. In this Memoir, the task of describing and summarizing stratigraphic formations has been attempted as far as has been practically possible to be within the ambit of the Stratigraphy Code of Pakistan (1962) and the International Stratrigraphic Guide of the International Union of Geological Sciences (1999). At various occasions the description is also accompanied by the information directly provided by the field workers visiting some specific areas. In other words, views and reviews are offered wherever were possible or required.

It is said, that diverse as are the strata of the earth and their properties, they are certainly no more diverse than are the ideas and conceptions of the persons who study them. Some of these diversities together with the lack of full field information, demanded by the code, pose difficult management. In other words, all these sectors make influence for a good or poor definition and description of a formation; while their correct appreciation control the unwanted profusion of nomenclature. However, I have honoured the concepts of the authors and brought them within the permissible extent of deviation from the Stratigraphic Code of Pakistan. Thus, it is felt, that I have reasonably covered the subject matter without any prejudice to the code and without changing the original meanings, concepts and feelings of the original author.

Some stratigraphic terminologies not covered by the code and used in this Memoir as well as the requirements of the code for the formalization of a formation are also given. The most important factor emphasised in this Memoir is to express the Stratigraphy of Pakistan in terms of Stratigraphic Codes of Pakistan coupled with the recommendations, in term of approved nomenclature of the formations, deliberated from time to time by the Stratigraphic Committee of Pakistan.

The stratigraphic committee is represented by all the geoscientific organizations of Pakistan. The main function of the committee is to formalize the nomenclature of stratigraphic units so as to create unison, to be maintained, in practical use throughout Pakistan. This committee has, so far, approved the nomenclature of Indus Basin, Axial Belt, parts of Balochistan Basin, and parts of Peshawar Basin. Thus, only approved nomenclature of the said areas are enumerated and discussed in this Memoir and all other names, which are either discarded, or synonymised by the committee are not included. However, for the Northern Areas of Pakistan, units proposed in the literature and not yet taken up by the Stratigraphic Committee of Pakistan are presented, as those exist today. Nevertheless, these formations shall finally be, subjected to the scrutiny, examination and formalization by the Stratigraphic Committee of Pakistan.

The present revision of the Stratigraphy of Pakistan was suggested to the author by the then Director General, Syed Hasan Gauhar in a meeting of all the senior officers of the Geological Survey of Pakistan held at Islamabad in late 2002. Considerable time was spent in collecting, analysing and refining important information published at home and abroad by scientists working on the problems of Pakistan's stratigraphy. Their work is duly acknowledged and has been discussed in their proper context.

In the preparation of this work, I have received help from many sources. I am especially indebted to Dr. Imran Khan, Director General, Geological Survey of Pakistan, who then as Director, GSP, Islamabad provided all possible logistical support in preparation and now, took keen interest in the publication of this volume. I gratefully acknowledge the help of Dr. S. Mahmood Raza for his very useful comments on various stratigraphic problems who published the Stratigraphic Chart of Pakistan in 2001. The critical review and valuable information provided by Dr. Prof. M. Nawaz

Chaudhry of the University of Punjab, Dr. Shahid Hussain and Hamid Daud of the Museum of Natural History on the Kohistan island arc chapter is gratefully acknowledged. Special thanks are due to Mr. Nusrat Kamal Siddiqui of Pakistan Petroleum Ltd. for reading Cainozoic chapter with keen interest and for providing valuable subsurface stratigraphic correlation chart of southern Pakistan, which I acknowledge with thanks. Mr. Iftikhar Malik of Pakistan Mineral Development Corporation read the Palaeozoic chapter and mineral deposits with very useful comments. M/S Hilal Raza, Dr. M. Mujtaba and Manshoor Ali of Hydrocarbon Development Institute of Pakistan examined mineral deposits and Mesozoic chapters with fruitful comments. Mr. Asif Khan of Oil and Gas Development Corporation and Dr. N. A. Bhatti of GSP are thanked for reading the chapter on sedimentary basins of Pakistan. Mr. Tahir Karim, Dr. Said Rahim Khan, Dr. Tahseenullah Khan and Mr. Ayub Khan of the Geoscience Advance Research Laboratories, GSP are thanked for the critical review and also for an expedient helping hand in the process of printing of this manuscript.

Islamabad, 26th April 2009 **S. M. Ibrahim Shah**

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# SEDIMENTARY BASINS OF PAKISTAN

Sedimentary basin is defined as "Geologically depressed area with thick sediments in the interior and thinner sediments at edges". This definition is precisely applicable on present day configuration of Indus and Balochistan basins, where stratigraphic sequence is normal and stratigraphic record is not much influenced by tectonic activities. On the other hand, the intervening area between Indus and Balochistan basins affected by tectonism shows only a linear representation of different attenuated stratigraphic units of both the basins and is called Axial Belt. Similarly, 'Northern Montane Area' lacks any true form of sedimentary basin. With this situation in the later two areas, most workers do not use the word basin, but describe the stratigraphy, where applicable, under various terms like province, block, belt, domains, zones, island arc, folded belt, thrust belt, complexes, ridges, terrane, valleys and ranges. Very few workers used the term 'Basin' but probably as an informal term, as for example "Peshawar Basin", "Hazara Basin" etc. Therefore, these areas with sedimentary fill do not conform to the strict sense of sedimentary basin, nevertheless, in one form or the other stratigraphy is there and workers have described it. Stated in other way, originally these haphazardly placed sediments were deposited in a true sedimentary basin but most of them away from their present day situation under different latitudes and longitudes. Now these units are accumulated at one place with long history of tectonism.

As for example, the filled up original basins of "Northern Montane Area", West Himalaya was subjected to epeirogenic and orogenic movements. The orogenic movement triggered by plate tectonic activities brought in, interalia, heat and upheaval, which obliterated the original sedimentary basins beyond all repairs. Ultimately, the present day scenario presents the area as buckled, folded and faulted with nappe and thrust sheets and warped in a manner of alternating basins and swells. As for example, the southern part of the Himalayan Tectonostratigraphic basin contains, parautochthonous units characterized by folds and wedge structures directed towards south. Compressional forces, post-dating the nappe movements produced, steepening of the beds, steep reverse faults and thrusts, in this region, it is a characteristic of the nappe that their aerial extent shows much variation along the strike. Because of their sheet like form, nappe are eroded in axial culmination and are preserved in depressions, imposing a prerequisite of tectonostratigraphic resolution before the stratigraphy of basin and ridge like structures is worked out. The parautochthonous units override the Tertiary belt along a rather straight thrust line Main Boundary Thrust (MBT), also called Murree Thrust as noted by Fuchs (1982). Displacement in some of these nappes and other faults as measured or indicated, from the Indian side of the basin, is of the order of several kilometres.

Further, north, alien stratigraphic sequences, belonging to different interacting continental plates form a collision zone. Here, presence of abnormal stratigraphic sequences is a common feature. In the entire northern area including Chitral, Gilgit and Hunza, large-scale allochthons are present, which thrust over the apparently normal stratigraphic section, at various places also pinching of the formations, crushing of the strata are seen on the ridges as well as in the valleys.

Thick slabs, slices and slivers of lithological units are assembled one above the other without any relation to adjacent strata. Here only palaeontology can come to the rescue. In fact, close coordination of structural and paleontological investigations becomes imperative for the construction of a correct stratigraphic section.

To summarize the discussion it is obvious that some of the sequences are less disturbed but lack age assignment due to non availability of fossils and most are tectonically much disturbed and the workers get bewildered as to what is stratigraphic and what is tectonic sequence specially when the units are non fossiliferous. Isolated exposures showing only a part of the original stratigraphic sequence, highly attenuated and repetition of strata are there to deal with. Therefore, at the outset workers have to understand the tectonostratigraphic evolution of the area and its contents before the proper stratigraphic knowledge is achieved.

This makes it different from those of other areas, where sequence is normal, with little or no diastrophism, having obvious and easily understandable stratigraphic set up with all the attributes of original sedimentary basin. This difference between the two areas is enough to designate them different domains with each having a characteristic mode of stratigraphic investigation. Therefore for the sake of convenience in the description of stratigraphy and for ready reference, the former domain is informally termed here as tectonostratigraphic basin and the later as stratigraphic basin. Definitions of tectonostratigraphy and stratigraphy are given below:

**Tectonostratigraphy**: Study of the relations of major lithostratigraphic units, e.g. sequences, with emphasis on tectonic effects on the stratigraphic record.

**Stratigraphic record**: The geologic record based on or derived from a study of the stratigraphic sequence; the rocks arranged chronologically as in a geologic column.

**Stratigraphy**: The word stratigraphy comes from the Latin stratum and the Greek graphia, which means the descriptive science of layered rocks. It deals with the form, arrangement, distribution, chronologic succession, classification, and relationship of rock strata (and other associated rock bodies), in normal sequence with respect to and/or all the characters, properties and attributes, which rocks may possess. It thus involves origin, composition, environment, age, history, relationship to organic evolution and innumerable other features of rock strata. The stratigraphy is mainly exercised on sedimentary rocks, but it is also applicable to igneous and metamorphic rocks as far as they pertain to stratigraphy and related to stratigraphic classification. Some non-Stratford rock bodies are considered under stratigraphy because of their association with or close relation to rock strata.

Research in stratigraphy is governed by a set of authoritative regulations, which are usually contained in a booklet, called stratigraphic code of a given country. Evidently, Pakistan has also prepared and printed its own stratigraphic code, Rahman (1962) that lays down the principles of stratigraphic classification as well as important and required terminology. Fundamental and most common item in the stratigraphic research is the lithostratigraphic description of the rock strata in which rock strata is divided into formations, member, bed, group and super group. All of these are defined in the Stratigraphic Code of Pakistan (1962). The items not given in the code and used in this report are defined below. These are selected from "An International Guide to stratigraphic classification terminology and usage, (Int. Sub Comm. on Stratigraphic Classification Report-7, 1972).

**Stratum**: A geologic stratum is a layer (a generally tabular body) of rock characterized by certain unifying characters, properties or attributes, distinguishing it from adjacent layers. Adjacent strata may be separated by visible planes of bedding or parting, or by less perceptible boundaries of change in lithology, in mineralogy, in fossil contents, in chemical constitution, in physical properties, in age, or in any other property of rocks.

**Stratigraphic unit**: A stratigraphic unit is a stratum or assemblage of adjacent strata, recognized as a unit (distinct entity) in the classification of the Earth's rock sequence, with respect to any of the many characters, properties, or attributes which rocks may possess. Stratigraphic units of one category will not necessarily coincide with those of any other category and it is therefore, essential to keep their named units distinct. Clear definition of stratigraphic unit is of paramount importance.

**Complex**: A lithostratigraphic unit composed of diverse rock types of any class (sedimentary, igneous, metamorphic) or classes, and characterized by highly complicated structure may be called a Complex, e.g. Kirana Complex, Besham Complex. The rank of a complex may be equivalent to a Group, Super group, Formation or Member.

**Stratotypes**: Many kinds of stratigraphic units are best defined by reference to a designated type in a specific sequence of rocks strata a stratotype. The value of a stratotype is that it provides a clear, uniform, and unchanging definition, which should mean the same thing to everyone and to which everyone can return for reference. It is essential that a stratotype be carefully selected and clearly marked, and it is desirable that it to be officially approved by the highest-ranking pertinent organization of stratigraphers. In the case of Pakistan, Stratigraphic Committee of Pakistan formalizes the names and stratotype of stratigraphic units.

Some other stratotype related terms used in the literature are given below:

1. A unit-stratotype is the type section of strata serving as the standard for the definition and recognition of a stratigraphic unit. The upper and lower limits of a unit-stratotype are fixed by boundary-stratotypes.
2. A boundary-stratotype is a specific point in a specific sequence of rock strata, which serves as the standard for definition and recognition of a stratigraphic boundary.
3. A composite-stratotype is a unit stratotype formed by the combination of several specified component-stratotype.
4. A hypostratotype (reference section) is a secondary stratotype used to extend the knowledge of the unit or boundary established by a stratotype to other geographic areas or other fancies.
5. Type locality: The type locality of a stratigraphic feature (unit, boundary, or other feature) is the specific geographic area in which its stratotype is situated, or, lacking a designated stratotype, the area where it was originally defined.

**Formal versus Informal Stratigraphic Terminology:** A formal unit is named representative of an established or conventionally agreed scheme of classification. An informal unit is based only in the sense of a general noun without being necessarily named or without being part of a specific scheme of classification. The initial letter of a named formal unit-term is capitalized, e.g. Bara Formation that, of an informal unit except for the geographic ones, are not capitalized e.g. Khyber limestone, Pasu slate etc.

**Formal Lithostratigraphic Unit**: In other countries of the world, it requires publication, in a recognized scientific medium of a statement of intention to establish a new unit, together with a description whereas in Pakistan; formalization of the unit is the responsibility of stratigraphic committee of Pakistan. However, in both the cases the description of stratigraphic unit, which desirably includes the following, where applicable:

(a) Name; Definition; general geographic area

(b) Kind and rank of proposed unit

(c) General concept. General lithology; historical background; synonymy; previous treatment; reasons for proposal

(d) Stratotype (or specific type locality)

(e) Hypostratotype or reference sections

(f) Regional aspects. Extent of unit, geomorphic expression, thickness variations, lateral changes in character, stratigraphic relations, relations to other units, dimensions and shape

(g) Age and correlation

(h) Distinctive or identifying features. Criteria to be used in extending the unit away from its stratotype and particularly criteria to be used in extending its boundaries from the boundary-stratotypes

(i) As already stated that in Pakistan the formalization of a stratigraphic unit is authorized to the Stratigraphic Committee of Pakistan. Thus, authority is composed of members/representatives from all the geoscientific organizations of Pakistan. The Committee approves the formalization after a thorough discussion

# TECTONICS OF PAKISTAN

Tectonics play an important, rather a basic role in the configuration of basins. As an example this can particularly be seen in the case of Pakistan, where the end product of the tectonics play produced diastrophism of unprecedented order and unique in style showing basins of alien origin converge and illustrated with text book tectonic structures; past life of the far flung provinces tends to one point, showing spectacular crustal shortening of hundreds of kilometres of the lithosphere.

The geological setting of Pakistan, in the framework of the modern concept of Plate Tectonics, is rare and matchless in the world. It is in the sense that within an area of about 800000 $km^2$ critical tectonic junctions of different interacting plates and micro-plates are present in a unique environment, where field exposures are excellent and the accessibility is easy. Two types of active plate boundaries are distinguished (Abul Farah written communication 1985).

(i) Convergent Boundaries: Characterized by continent - continent collision, obduction and thrusting in the Himalayan region and by oceanic crust subduction with a volcanic arc and wide trench gap and thrusting in the southern region of Chagai arc and Makran margin. About 6 km thick sequence on the floor of the Arabian Sea is largely carried along with the down going plate when it enters the Makran trench and only about the upper third part is being scraped off to form an accretionary prism.

(ii) Transform boundary of Chaman Transform Zone characterized by mega strike-slip and obduction. The Chaman Transform Zone connects the Makran convergence zone, where oceanic lithosphere is being subducted beneath the Lut and Afghan microplates, and the Himalayan convergence zone, where the Indian lithosphere is under-thrusting Eurasia.

The available geological and geophysical evidence of the development and demeanour of these plate boundaries lead to the conclusion that in Pakistan, Atlantic type (Spreading) plate boundaries have been present since the Early Mesozoic until the Late Cretaceous and Indian type (subduction, collision, obduction, convergence) boundaries are present with the Transform zone (Early Eocene-Oligocene?) connecting the Makran and Himalayan zones.

Many models elucidating the evolution of the tectonic framework with enormous details are available in the published literature but to summarize or even to outline the tectonics of Pakistan is neither possible nor convenient. In fact, dealing with the details of tectonics of Pakistan is beyond the scope of this book. Only the gist as applied to the emergence of sedimentary basins of Pakistan is presented here.

Beginning with Late Palaeozoic and throughout Mesozoic, the north-western part of the Indian plate, continued to be occupied by the great Tethys Sea, as a result, this region had been the site of geosynclines/ epicontinental sea where sediments accumulation took place since Permian to Late Cretaceous and the rest of Indian Plate, probably, remained an island throughout its northwards drift.

On the withdrawal of the bulk of Tethyan Sea, the area represents the site of epicontinental remnant seas during Paleocene and Eocene times. The continued northward movement of the Indo-Pakistan plate ultimately resulted in collision with Eurasian plate in Late Paleocene-Eocene times (See also Tethys in the Chapter of Kohistan island arc).

The drift in the Gondwana fragments is believed to have begun in Jurassic; during which fast northward movement of the Indian plate during Cretaceous followed by its counter clockwise rotation, formed a part of collision process. Transform Zone (Chaman rift) resulted following renewed spreading in Indian Ocean during post collisional northward movement of the Indian plate. The resultant compressional forces produced some of the syntaxes, arcs and oroclines throughout Pakistan, probably in Early Oligocene.

The structure, so produced, had probably been earlier influenced by pre-collisional tectonic elements in the miogeosyncline and the shield areas of the Indian plate. The pre-collisional tectonic elements include the development of welt like structures probably within geanticlinal areas in the western part of Indian plate, which was probably initiated in Jurassic and were fully emerged in Cretaceous. These narrow, but sometimes, sharp ridges and belts along with their associated intrusives and volcanic emplacements have been compared to island arcs by Hunting Survey Corporation (1961) and with the worldwide oceanic ridges in their origin (Zuberi and Dubois, 1963). The most significant among these strips is named as the **Axial Belt,** which divided the geosynclines and initiated the establishment of the two great basins of Pakistan. The belt developed marginal to the western part of the Indian shield and now to its east lies the **Indus Basin** and to its west the **Balochistan Basin** and to the north great tectonic zone of the **Tectonostratigraphic Basins** and **Tectonostratigraphic Ranges,** where each range or chain of mountains and associated depression indicate a unique tectonostratigraphy (Fig. 1).

In the light of the above mentioned brief tectonic history and events, the earlier basin map, Shah (1977), under which the stratigraphy of Pakistan was described, lacked the tectonic details of the northern areas of Pakistan; with the advancement in the geological knowledge of the northern areas of Pakistan, the old basin map has now been revised (Fig. 1.)

It may be added; that the new map of sedimentary basins presented here is broadly compatible with the "regional map of tectonic framework" of Shah and Quennell (1980) (Fig. 2). The revised map of basins presenting the architectonic of Pakistan has twofold usefulness. It provides convenience for the description of the stratigraphy of Pakistan and it is suitable for correlation of the formations with the regional countries.

### *A. Southern Stratigraphic Basins and Belt:*

I. Indus Basin

- a. Kohat-Potwar Province
- b. Sulaiman-Kirthar Province

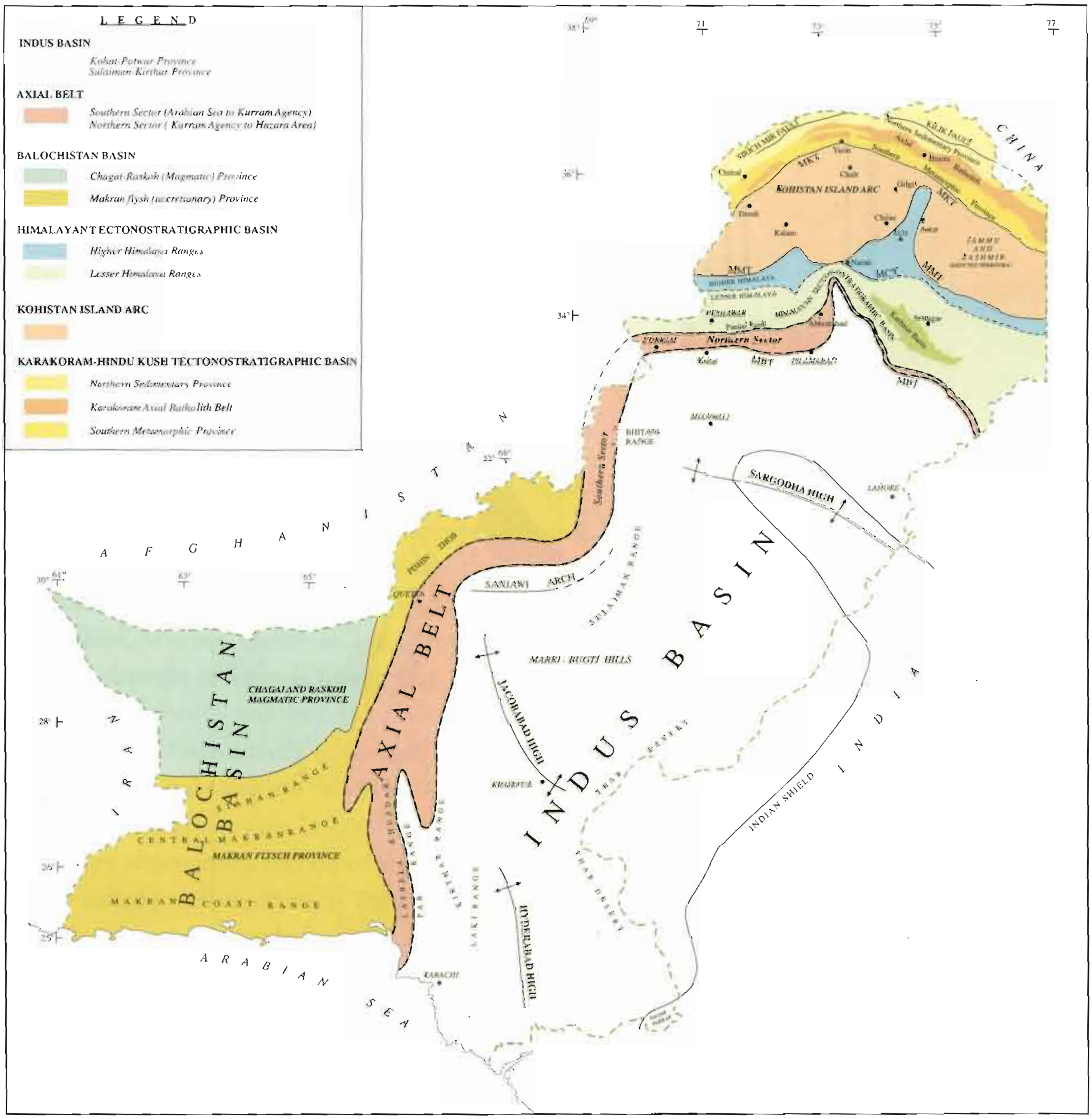



Fig. 1. Basins of Pakistan. UPDATED AFTER SHAH

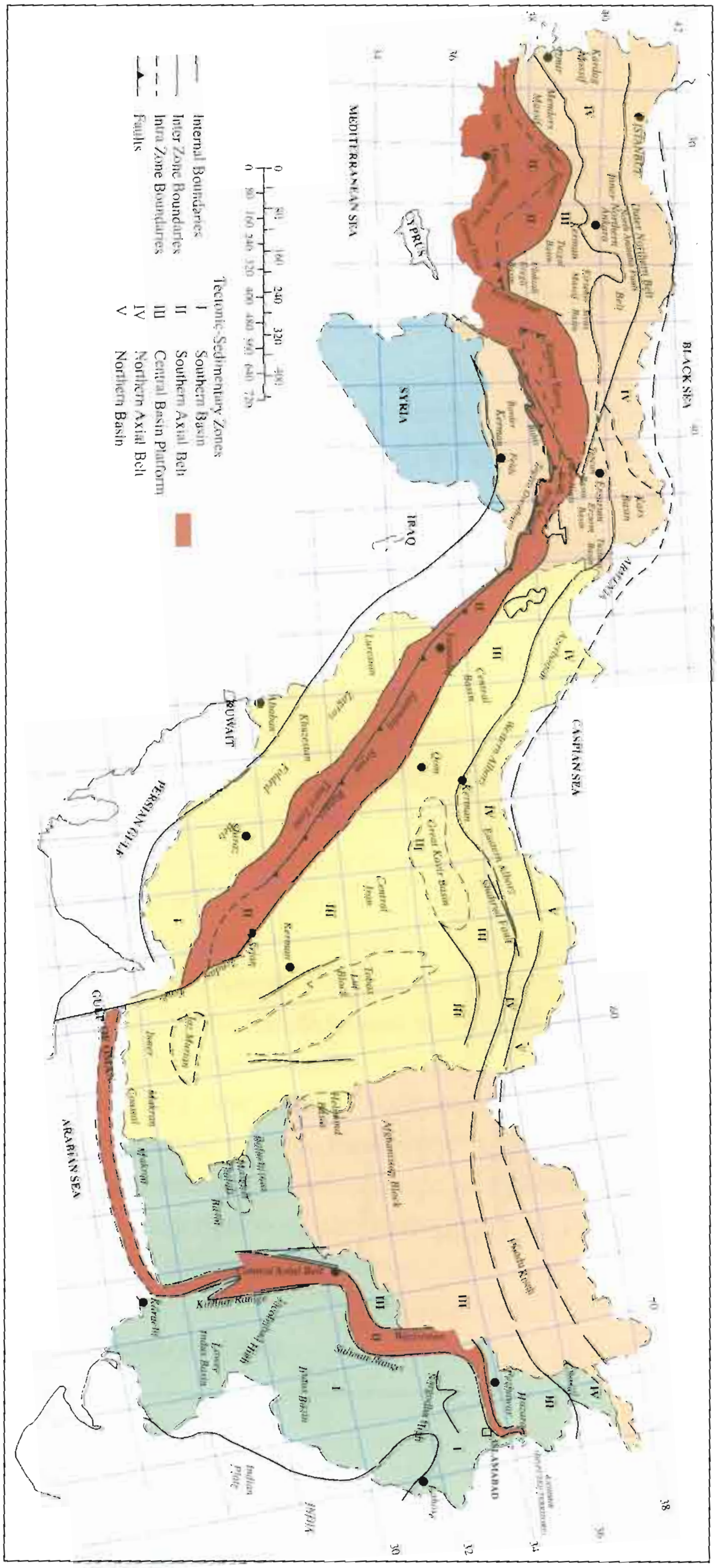



Fig. 2. Structural framework of Turkey, Iran and Pakistan, showing regional extent of Axial Belt.

After Shah and Quenell, 1980

II. Axial Belt
- a. Southern Sector (Arabian Sea to Kurram Agency)
- b. Northern Sector (Kurram Agency to Hazara Area)

III. Balochistan Basin
- a. Chagai-Raskoh Province
- b. Makran Accretionary Province

***B. Northern Tectonostratigraphic Basin and Range Terrene:***

IV. Himalayan Tectonostratigraphic Basin
- a. Higher Himalaya
- b. Lesser Himalaya

V. Kohistan Island Arc

VI. Karakoram-Hindukush Tectonostratigraphic Basin
- a. Northern Sedimentary Province
- b. Karakoram Axial Batholith Belt
- c. Southern Metamorphic Province

**Indus Basin**: The Indus Basin is the largest and more thoroughly studied basin of Pakistan. It trends NE-SW for over 1600 km along its axis and the width varies considerably with an average of 300 km. The basin contains sediments ranging from Precambrian to Tertiary with marked absence of Ordovician, Silurian, Devonian and Carboniferous. This basin is characterized by well-developed platform deposits of Jurassic throughout. The basin is divided into, the Upper Indus-Basin located north of 30th parallel and the Lower Indus Basin situated south of 30th parallel. Approximately, the Upper Indus Basin covers more than 50,000 $km^2$ area and in many ways the structural and stratigraphic conditions are different from those of Lower Indus Basin. The Lower Indus Basin covers an area of more than 250,000 $km^2$ where along with other rocks excellent exposure of Jurassic to Tertiary sedimentary section of about 13 to 16 km thickness, are present in its deeper part, it is ideally suited for oil exploration. Distinctly except for some Tertiary continental deposits, almost the entire sequence of Lower Indus Basin is of marine origin.

The Indus Basin as a whole is characterized by syntaxes, irregular ridges or promontories of the Indian Shield; almost all of them trend NW. These promontories played an important role in controlling the sediments and acted as barriers in the shelf or neritic parts of the Indus Basin in different geological ages and thus subdivided the basin into two recognizable stratigraphic provinces: The Kohat-Potwar and the Sulaiman-Kirthar Provinces. Indus Basin is equated with Southern Basin Zone 1 in the regional Tectonic framework of Shah and Quennell (1980; Fig. 2).

**Axial Belt**: Axial Belt is a long narrow sinuate-shape belt, which runs from Arabian Sea through Bela, Khuzdar, Quetta, Zhob, and Waziristan. Further, the belt in its northern extension covers the areas of Kurram Agency, Attock-Hazara folded belt (Fig. 1). It follows from this that the Axial Belt can be divided into two sectors, the **Southern Sector** with N-S alignment and **Northern Sector** with E-W alignmont.

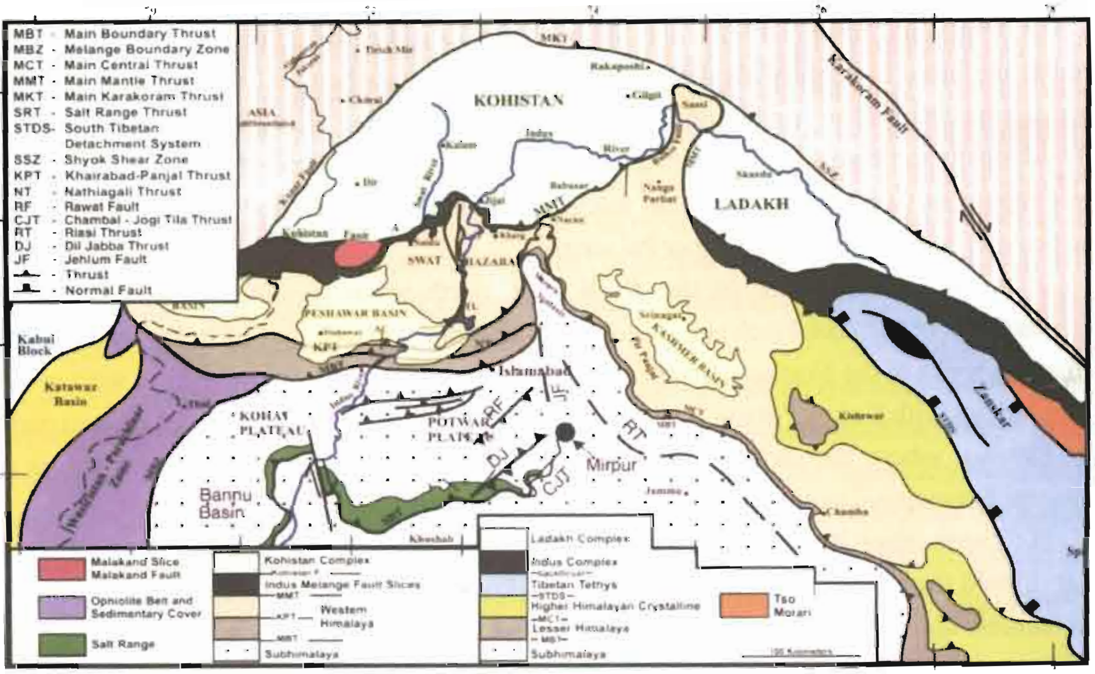
The Southern Sector of the Axial Belt is an area of widespread allochthons. Littoral deposits as well as radiolarites and olistostromes occupy it. Ophiolites are associated with pelagic sediments, which contain gabbroic and soloaritic intrusions. Oligocene-Miocene molasses covers a considerable part of this sector in Zhob area.

The Southern Sector can further be divided into western part, the *Arenaceous Zone* where the rocks are almost the same as those of eastern Balochistan Basin and the *Calcareous Zone* in the eastern part, the rocks of which are identical to those of Indus Basin. This last two-fold division is extremely convenient for correlation purpose.

Shah and Quennell (1980) in their stratigraphic correlation of Turkey, Iran and Pakistan, equated this belt with "Southern Axial Zone II", a component of their regional structural framework. They linked and described the Axial Belt of Pakistan as follows. "The Makran, from the Zendan Fault to the (southern) sector of the Axial Belt of Pakistan, occupies a break in the continuity of the Southern Axial Zone (and this break can now be joined via the Arabian Sea), which in Pakistan is resumed by the Axial Belt. The Axial Belt of Pakistan has a double sigmoidal plan and extends from the Arabian Sea to the Hazara region in the north".

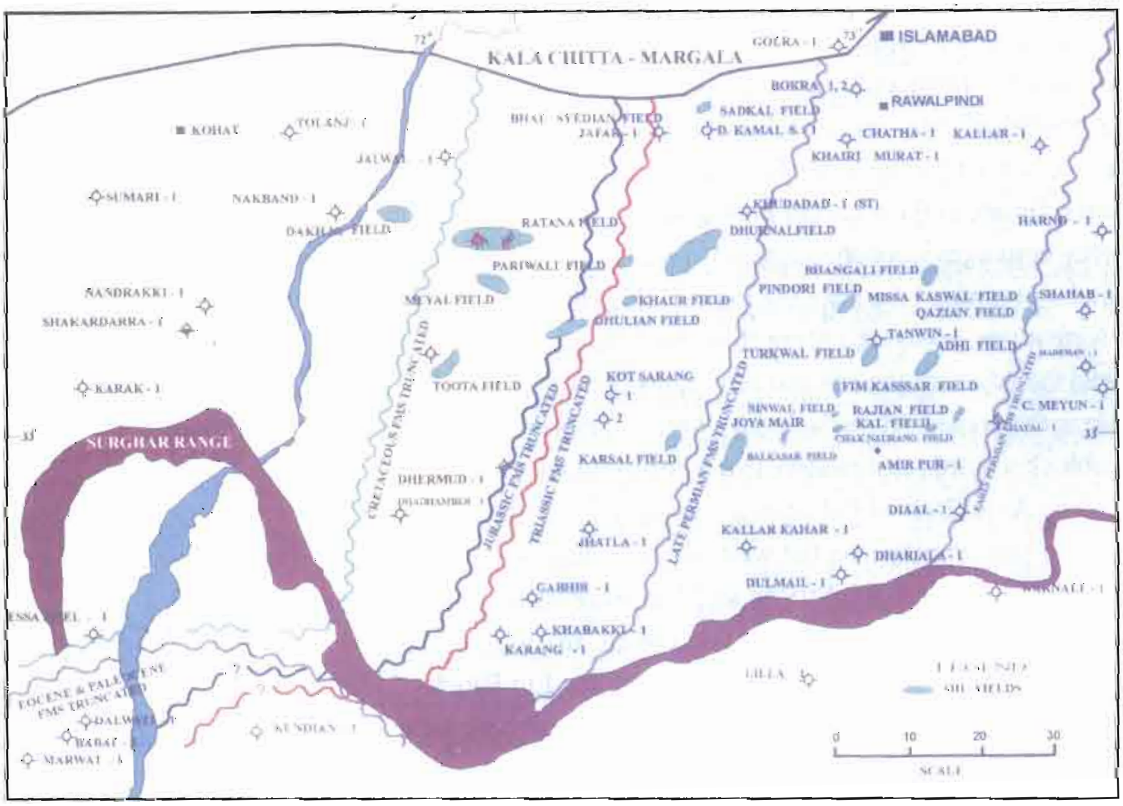
The structural evolution of the Axial Belt began in the Jurassic, culminated in the Eocene and continued locally until the Pleistocene. The meridionally trending Southern Sector separates the Indus Basin from Balochistan Basin. There is westward gradation from the shelf type deposits of the Indus Basin to the oceanic and ophiolite suite rocks of the belt, which include mafic-ultramafic rocks of Cretaceous-Paleocene age, complicated by Low-angle thrust faulting. The Northern Sector generally has a thrust fault (MBT) relationship with the Upper Indus Basin" and approximately the Panjal Thrust delimits it in the north. The area covered by the Northern Sector of the Axial Belt is almost the same, which has been delineated by La Fortune et al. (1992) as their "Hill ranges". They defined this area as "where shelf sediments on the northern margin of the Indian continent were thrust southwards over the Potwar Plateau, along the Main Boundary Thrust (MBT)", which is of Late Tertiary age (Yeats and Hussain, 1987).

This belt is differentiated from Indus Basin on the abrupt change in the tectonics and orographic grounds as well as change of facies and diastrophic style, which are in marked contrast. Cambrian-Precambrian and Mesozoic flysch-type sediments, carbonates and clastic rocks, and very low-grade metamorphic and small amount of igneous intrusives, make up the Northern Sector of the Axial Belt. Parautochthonous sediments of Attock - Cherat Range are different both from the northern and southern stratigraphic set up. In other words this area, structurally and stratigraphic different from Peshawar Basin as well as they are in marked contrast with the Indus Basin. The Northern Sector of the Axial Belt has been separated by almost all workers of this region, some called it "sedimentary zone of lesser Himalayas", the others differentiated it on grade of metamorphism and still others on faults zone between MBT and Punjal Thrust. Stratigraphically, the sequence of rocks in this zone extends from platform type deposits to oceanic crust similar to the *Southern Sector* of the




Courtesy: Ahmad Hussain

Fig. 3. Tectonic map of northern part of Pakistan.




Courtesy: M. Mujtaba (HDIP, 2005)

Fig. 4. Surface and subsurface map of Potwar area and west of it. Light blue colour shows the non-existence of Jurassic and Cretaceous formations in the subsurface of most of the Potwar region. Light green colour displays the presence of Jurassic and Cretaceous formations in the subsurface of western Potwar-Kohat region and on the surface of southern Hazara hills.

Axial Belt. Major and trace elements and Mg of the rocks indicate that the Panjal magma has been evolved as tholeiitic to slightly alkalic in composition with geochemical signatures similar to mid-ocean ridge basalts and ocean island tholeiites. The interbedded chert, limestone and associated turbidite deposits indicate shallow marine environment during the time of eruption of magma. The volcanic represent rifting of the northern margin of Indian continent and development of shallow marine oceanic conditions during Upper Palaeozoic".

In the Southern Sector of the Axial Belt, north-south running exposure (with in the Calcareous Zone of the Axial Belt) has similarities with the western part of Indus Basin. Similar to this situation, rocks of the Northern Sector of the Axial Belt extending laterally from west to east also have similarities with Kohat-Potwar Province on either side of MBT, except in the eastern part of the Potwar Plateau, where the absence of Mesozoic rocks have always been considered as a non-depositional or erosional event, but are present on the northern side of the MBT.

In recapitulation it can be said that the Axial Belt started developing on the margins of Indo-Pakistan Shield during Jurassic (probably post Callovian) times with mild tectonic activities, but violent tectonic activities during post collisional times pronounced it into its present shape. Despite its position as a separate entity, the encroachment of Mesozoic stratigraphic sequence from the adjoining basins is frequent. Nevertheless, major structural episodes during post depositional times have made the Northern Sector of the belt as alien to the adjoining basins.

According to Mujtaba (2004), typical Jurassic and Early Cretaceous formations, i.e., Datta, Samana Suk, Chichali and Lumshiwal Formations are observed as Far East as Thandiani formation of the Abbottabad area. These rock units are well exposed throughout the southern Hazara hills, Kala Chitta and then across the Indus River in the Samana Range. However, the situation across the Main Boundary Thrust, in the adjacent Potwar area, was found quite different as no formations of Jurassic and Cretaceous ages were encountered in wells, drilled in eastern and central Potwar region (Fig. 4). In Mujtaba's opinion "the possible logic of this sharp contrast of presence and absence of the above noted formations, across the Main Boundary Thrust in the southern Hazara hills (including Margala hills) and the adjacent eastern and central portion of Potwar region, could be right-lateral strike-slip fault along the present Main Boundary Thrust. Thus resulting probably in the lateral displacement of Hazara block towards east relative to the Potwar block.

The Axial Belt of Pakistan is the folded zone between the Indian plate on the east and the Afghan and Iranian plates on the west, and thus has the same tectonic relationship as the Toros and Zagros segments have to the African and Turkish-Persian plates (Shah and Quennell, 1980).

**Balochistan Basin**: Balochistan Basin covers an area of 250000 km$^2$ and is roughly delineated between Axial Belt of Pakistan to the east and the Lut Block of Iran in the west. The Balochistan Basin is bounded by Afghanistan in the north and Arabian Sea to the south. Over-simplified version of Balochistan Basin is that it is a mosaic of Lut-Afghan plates superimposed at their southern end by the Makran Flysch.

According to Searle (1991), the evolution of Balochistan Basin is obscure prior to Jurassic, nevertheless, during Late Jurassic, Cretaceous and Cainozoic, the oceanic floor subducted below the stable Lut and adjacent Iranian blocks and consequently origination of the submarine volcanic as well as deposition of subordinate limestone and clastic material. This was followed by sub aerial volcanic episode, which was succeeded by continental sedimentation, and ultimately coming under alluvial cover. At the same time, intrusions from depths of igneous massifs took place intermittently.

The Balochistan Basin shows distinct segments; e.g. the Arc Trench system of Chagai including the Chagai Eruptive Zone, where a volcanic arc developed with chain of volcanoes, in the Koh-i-Sultan, Koh-i-Taftan and Koh-i-Bazman. Tentatively included in it is the Raskoh Range with Cretaceous volcanic flows, pyroclastic rocks, some sedimentary rocks with granodiorites. This is called the **Chagai-Raskoh Province**.

The above-mentioned Chagai-Raskoh Province is suggestive of an Andean type arc-trench system developed on the southern margin of the Iran-Afghanistan micro-continental plates. In this area, rapid northward subduction during Late Cretaceous gave rise to profuse andesitic volcanism on the sub-parallel ENE trending arc massifs of the Chagai hills. Searle (1991) stated that the Raskoh represents an uplifted slice of the basement rocks; comprising mantle derived material, Cretaceous volcanic, post-Middle Eocene igneous intrusions, Paleocene sedimentary rocks and younger conglomerates.

South of Raskoh, a crescent shaped plain of wind-blown sand is present including Hamun-e-Mashkhel and Jaz Murian regional depressions noted by Farhoudi and Karig (1977) as Fore Arc Basin. The region may have reservoirs of groundwater and hydrocarbons (Searle, 1991).

Southern part of the Balochistan Basin, the **Makran Province**, has been interpreted as a large sedimentary prism accreted during Cainozoic and has been compared with the modern arc-trench gap (Farhoudi and Karig, 1977). About 200 km in the south, occurs the Gulf of Oman abyssal plain. It is more than 3000 m deep and marks the location of the subduction of oceanic crust dipping northwards (Searle, 1991).

Balochistan Basin, in fact, represents Lut-Afghan micro-continent of the Asian Mass and it is not a part of the Indo-Pak plate. This basin is equated, with "Central Basin platform zone II' in the regional tectonic framework by Shah and Quennell (1980).

**Northern Tectonostratigraphic Basin and Range Terrene**: The Indus Basin in its north is delimited by the Northern Sector of the Axial Belt (Fig. 1), north of which the entire area, earlier known as "Northern Mountain Area", is a very broad zone of complicated tectonic activities. It is here named, informally, as the Northern Tectonostratigraphic Basin and Range Terrene. The name implies that basins of different origin are huddled together in the intermountane region. The Northern Basin and Range Terrene have a complicated diastrophic history, while many puzzles are still to be worked out; the area represents the most critical segment of the Pakistan geology. A tectonic sketch map exhibiting megashears is shown in Fig. 3.

It represents subduction overtaken by continent's collision, obduction and thrusting, where Indian lithosphere is under thrusting Eurasia. Part of the area comprising Kohistan Terrene has been interpreted as a fossil island arc. The Northern Basin and Range Terrene comprises dominantly of Precambrian, Palaeozoic and Mesozoic stratigraphic units and the plutonic product of collision during Tertiary period. Generally, the rock units of this area are thrust southwards. Allochthons in numerous numbers cap some of the autochthons and then in some cases both of them are thrust southwards. Examples can be seen especially in the northern most area of Pakistan. This area is a large tectonostratigraphic domain and no single criterion can be made for its further break-up or division, however, sedimentary, metamorphic and igneous complexes individually maintain their dominance in certain areas and help in delineating the zones of respective rock type. Nvertheless, a sharp boundary cannot be drawn, because predominantly sedimentary rocks, with few igneous bodies, may still be present in some areas. Similarly, a long belt exclusively formed of metamorphic rocks may have some igneous complexes. Stated in another way, the area displaying a single characteristic or similar characteristics and unified in some way is considered as a whole.

Thus, for the sake of stratigraphic description, classification and correlation, the entire Northern Tectonostratigraphic Basins and Ranges Terrene can roughly be divided into different basins, belts and provinces so as to equate or compare the region (by parametric analogy) with Indus and Balochistan Basins. A brief description of its component parts is given below.

**Himalayan Tectonostratigraphic Basin**: This is a large intermontane basin, extending from Punjal Thrust to Main Mantle Thrust (MMT). The area covered in this basin (Fig. 1) lies north of Axial Belt, covering northern Hazara and Kashmir in the south-east and Peshawar Basin in the south-west, comprising mostly of sedimentary and metasedimentary rocks, and the Malakand, Saidu and Kaghan-Naran in the north comprising mostly metamorphic and igneous complexes. The metamorphism gradually increases from south to north. The dominant rock throughout the metamorphic zone is greenstone in mélange zone, and blue schist and large bodies of serpentine in adjacent areas.

Chaudhry et al. (1994) divided this basin into Higher and Lesser Himalaya based on the position and partition made by Main Central Thrust (MCT). The position of MCT in Pakistan is controversial. It is however, tentatively being used here for a rough or approximate division of Higher and Lesser Himalayas.

***Higher Himalaya:*** The range of the Higher Himalaya include areas between MMT and areas north of Batal and Naran in Kaghan Valley and north of Luat in Neelum Valley, the Besham Block and areas north of Girarai in Swat and Malakand Pass. The MCT passes close to the localities mentioned and constitutes the southern boundary of the Higher Himalaya (Zaka et al., 1997).

The Higher Himalaya is composed of a lower basement and an upper cover. Detailed work in this region has been carried out by Greco (1989); Spencer et. al (1990); Spencer (1993); Greco and Spencer (1993); Pognante and Spencer (1991) and Chaudhry et al. (1994, 1997). According to Chaudhry et al. (1997), the lower basement (known as Purbinar group east of Thakot fault and the Pacha formation to the west) is composed predominantly of granitoid, migmatites, pelites and psammites. Minor carbonates, calc-pelites and amphibolites are also present. The upper cover (Burawai group in upper Kaghan east of Thakot fault and the Alpurai group to the west in Lower Swat) is composed predominantly of marbles and calc-pelites with subordinate pelites, amphibolites and psammites. The whole block has undergone metamorphism in upper amphibolite facies, with minor relics of eclogite facies within this predominant metamorphic grade.

***Lesser Himalaya***: The Lesser Himalaya is delimited to the north by MCT and to the south by Punjal Thrust. It covers the areas of Kashmir, Kaghan, parts of northern Hazara and parts of Swat. The Precambrian and Palaeozoic sediments have, in general, suffered low-grade metamorphism and are overlain by younger sediments in various places in Peshawar, northern Hazara and Kashmir basins, (and by high grade Precambrian metasediments and gneisses occurring as nappes eastwards in Shimla and Gharwal of Indian Himalayas). The brittle deformation is characterized by tight to overturned folds and a schuppen structure or imbricate faulting (Chaudhry et al., 1994). In this review, the Lesser Himalaya broadly covers metamorphic zone from Punjal Thrust to MMT. Chaudhry and Ghazanfar (1993) divided the Lesser Himalaya into Northern Metamorphic Zone and the Southern Sedimentary Zone. The Southern Sedimentary Zone is considered as part of Axial Belt in this review.

**Kohistan island arc**: The area of island arc extends northward from Main Mental Thrust (MMT) and ends at Main Karakoram Thrust (MKT). The Kohistan island arc is alien to the Gondwana element of Indian Plate as well as to the Asian Plate.

Enormous work on the island Arc is available in the literature. A list of contributors is given in the chapter of Kohistan island arc sequence. The predominant rock type in the Kohistan island arc is amphibolite. In fact, the amphibolite in this area is present in the form of belts, on southern and northern sides of the island arc. Briefly, the island arc is composed of basic rocks, metasedimentary formations, volcanic series, younger clastic sediments and intrusions of deep-seated igneous rocks. A comparable situation is found also with Chagai area in the Balochistan Basin: both having been formed because of crustal subduction and represent fossil island arcs.

According to Treloar et al. (1996), the rocks of the dominantly Cretaceous age extend across the northern part of the arc, where they are divided into three intrusive complexes, the Kamila Amphibolite belt, the Jijal and the Chilas complexes. The Kamila Amphibolite belt consists of amphibolite and subordinate hornblendite, diorite and plagiogranite. The Jijal complex is divided into a southern part composed of ultramafic rocks and a northern part dominated by garnet granulite (Jan, 1979).

The core of the arc is marked by the Chilas complex, a massive body of locally layered, gabbronorites up to 50 km wide and 300 km long. Extrusive volcanic activity spanned from the Mid-Cretaceous to Eocene (Treloar et al., 1989). As to the origin of the Kohistan island arc, Treloar et al. (1989), added that it was initiated offshore of Asia during Midddle Cretaceous and was sutured to Asia between 100 and 85 Ma. Subduction of Tethyan oceanic crust beneath the island arc continued until ca 60 Ma when finaly the subduction seized and the collision occured (Beck et al., 1995).

**Karakoram-Hindukush Tectonostratigraphic Basin:** This basin represented the southern edge of the Asian Plate prior to the collision of the continents. A large-scale deformation has brought together several slivers of geological formations, which originally belonged to a separate geographic and geologic entity. To define Karakoram or Hindukush stratigraphically is a difficult job, especially in the terminal areas of the geographic borders.

The word Karakoram is the most commonly used term by workers engaged in the northern most areas of Pakistan. They have included most of these areas in the Karakoram. Even a substantial part of the Hindukush is included in the Karakoram with the plea that geological boundaries overlap geographic boundaries and vice versa. Several times, the boundaries of the two ranges have been defined, revised and redefined. However, working boundaries are always there, as for example, Desio (1979) defined the borders of Karakoram in the following words.

The term "Karakoram mountain belt" most commonly refers to the bundle of mountain ranges located between the upper Yarkand and upper Indus River to the north and south respectively, and between the upper Shayok and the western divide of the upper Hunza River to the east and west respectively, between these limits, the Karakoram Range is about 600 km long, with an average width of 150 km. Four of its peaks exceed 8000 m; one of these is K2 (8611 m), which is the second highest peak in the world.

Other workers in the region bring its western limit up to Trich Mir fault or include Chitral fault as the western limit, northwest of which is undisputed Hindukush. Similar situation prevails in the central part of the Karakoram, where workers feel that geology of other mountain ranges is easily mixed with Karakoram. To give an example, the statement of Kravchenko (1979) is recorded here, who categorically stated, "The Tien Shen, Pamir and Karakoram are situated in different mountain belt systems, they resemble each other in their regional structure. In all three mountain belts the geosyncline and subsequent orogeny become younger toward the south, reflecting the consolidation of the Eurasian continental massif, and its collision with the Indian plate, as the result of the northward drift of the latter".

Gaetani (1997) stated that the southern geological boundary roughly coincides with the Shayok Suture Zone, and extended it to join MKT. They added that to the west, the geological boundary should extend beyond the geographical one drawn at the Karambar Valley. They also added, that "The Hindu Raj Range should be included because both magmatic and sedimentary units continue, fairly homogeneously, throughout the Yarkhun Valley". Gaetani et al. (1997) cited that several options are present in setting the western geological boundary. The first, followed by Searle (1991), is to merge the geographical east Hindukush (Trich Mir included) into the western Karakoram. This interpretation has recently been abandoned by Searle and Khan (1996). Second, the western boundary of the "geological' Karakoram could be set either at the Chitral fault or preferably at the Trich Mir fault".

From the foregoing discussion, it can be stipulated that workers do face difficulties in confining their geologic description to the borders of the geographic limits. Consequently, some of them used the combine term 'Karakoram-Hindukush' to be at ease in the description of their palaeontology and stratigraphy. This part of convenience is suitable to follow for the description and correlation of stratigraphic units.Therefore, the stratigraphy is described under the combined heading of Karakoram - Hindukush Tectonostratigraphic Basin. The boundaries of this tectonostratigraphic basin are as follows: The southern limits are marked by MKT and the northern boundary extends into Badakhshan Province of Afghanistan but the details presented here stop at

Pak-Afghan border in the west and the Pak-China border in the east. Length wise the western boundary crosses the border with Afghanistan and the eastern border is across K2 and extends into Kashmir.

Geologically, this tectonostratigraphic basin is extremely complex. The aftermath of the events of the collision of plates has brought disastrous effect on the stratigraphic sequences. Workers get bewildered, when they do not find any head and tail on any stratigraphic sequence from a montage of rocks. Talent et al. (1999) viewed the scenario of Karakoram Hindukush Tectonostratigraphic Basin in the following words: "The structure of Chitral is like a scrambled deck of cards, a montage of slivers, slabs and slices; unscrambling these would be inconceivable without paleontologic control". They further emphasized, "Close co-ordination of stratigraphic, structural and paleontologic investigations is imperative, if ultimate meaning (a valid context for mineral exploration) is to be wrung out of structurally complex areas of Phanerozoic rocks like those of the Himalaya".

It cannot be denied that the classification of a basin promote critical analysis of the characteristics of sediments as well as it provides convenience for the description of stratigraphy and the correlation is made easy. Attempts to divide the Karakoram-Hindukush Tectonostratigraphic Basin have been made by many workers; Gansser (1980) divided it into three units or zones. Pudsey et al. (1985) made three units and included Kohistan island arc as their third unit and the other two pertain to the Karakoram-Hindukush Tectonostratigraphic Basin. Their northern unit extends from Reshun fault to the borders of Pakistan with Afghanistan. The central unit is delineated from Reshun fault southwards to MKT. Buchroithner and Gamerith (1986) followed the same suite and finally Gaetani (1997) made three units compatible with stratigraphic concepts.

Making divisions of this basin is not an easy job. The presence of plutons with their metamorphic associates appear like mushrooms all over the basin, which has marred the face of the basin creating difficulties for clean partition to be based on different attributes of the basin. Bearing this in mind, it is only right to say that any attempt to divide the basin has to be based on the predominance of a certain characteristic of the basin. In view of the above-mentioned state of affairs of the basin, it is understood that boundaries of each unit have to be arbitrary.

Lithologically, this terrane is composed of a pelite-psammite-granitoid basement with overlying pelitic and carbonate cover rocks with amphibolites followed southwards by a Palaeozoic to Mesozoic package. The latter low-grade sediments are composed of slates and meta-greywacke sequences overlain by a thick sequence of shelf carbonates. This sequence is intruded by the Karakoram Axial batholith.

The Karakoram-Hindukush Tectonostratigraphic Basin can roughly be divided into its geologically separate three component parts: the central or axial part is a granitic batholith, and forms the core of an anticlinorium. The emplacement of which parted the basin into the Northern Sedimentary Province, which contains mostly unmetamorphosed to anchimetamorphic rocks of Palaeozoic to Late Cretaceous age and the Southern Metamorphic Province predominantly composed of metamorphic rocks of Palaeozoic (or Precambrian) to Upper Tertiary. They are named and described below:

***Northern Sedimentary Province***
***Central Axial Batholith***
***Southern Metamorphic Province***

***Northern Sedimentary Province:*** This province comprises the northern platform sediments of Gansser (1980). The province is bounded by Central Axial Batholith in the south, Pak-Afghan border in the west and across the northern border of Pakistan in the north, (although it extends in Badakhshan of Afghanistan and also extends into China). Eastwards, it crosses the K2 and extends into Kashmir (Fig. 1).

The stratigraphy of western part of this sedimentary province is very poorly known. However, Devonian carbonates and shale are abundantly present and Gaetani and Leven (1993) have described a shallow water marine succession of Permian age (spanning from the Samarian to Midian) in the Rosh Gol and Trich Mir areas. They have also reported Upper Triassic dolomites and some Cretaceous carbonates.

Eastwards in the central part of the Karakoram Range, the sedimentary basin deepens and according to Gaetani et al. (1996), the northern Karakoram records the evolution of a crustal block, largely under marine conditions, over a time span of not less than 400 Ma. They recognized six major tectonostratigraphic cycles, "Ordovician to Late Devonian, Late Devonian to earliest Permian, Early Permian to earliest Jurassic, Early Jurassic, Middle Jurassic to earliest Cretaceous, and Late Cretaceous. The cycles are distinguished on the basis of accumulation and subsidence rates, major discontinuities and deformations. Further east in the central Karakoram, as stated above, the basin deepens and continues northwards through southeast Pamir. According to Kravchenko (1979), the central Karakoram is a large anticlinorium, with Precambrian (?) crystalline rocks in its core. It is in contact with the Aghil synclinorium, which is related to the southeast Pamir.

***Axial Karakoram Batholith***: It is a large body of batholith, called leucogranite by Gansser (1979), and is known as the "Kesu Koghozi, Buni Zom Pluton etc. Eastwards, many different names are applied to this batholith. Granite intrusion is typical. The Kesu-Koghozi Pluton in the Drosh/Shishi area is highly complex and has steeply foliated dioritic rocks with minor acidic intrusions. The northern margin is migmatitic granodiorite gneiss. Eastwards, the continuation of the batholith known as the Gamu Bar, also named as Dobargar and Zagar-Umalsit plutons by Le Fort et al. (1997). Granitoid rocks in further eastern part are the hornblende-biotite granodiorites to granites. They have yielded K-Ar ages of 56 to 40 Ma (Casnedi et al., 1978).

Further east in the central part, the ages of the granitoid rocks are much older; infact, according to Belyaevskyi (1965), the axial part of the Central Karakoram is a geanticline, which was an island arc at least from Silurian to Late Jurassic or later.

***Southern Metamorphic Province***: Gansser (1979) defined it as South Karakoram schists, marble and gneiss zone. Searle (1991) named it Karakoram Metamorphic Complex especially the eastern part, and Gaetani et al. (1996) named it Southern Metamorphic Belt.

This province is exclusively metamorphic with some plutonic rocks. The province extends from Drosh in the west and continues northeastwards along the southern edge of Karakoram Axial Batholith. Stratigraphic units mapped in the western part of the province, in one form or the other, are largely the portions of the Darkot Group of Permo-Carboniferous age. Further northeast in the Lower Hunza Valley, lie the rocks of a pre-Himalayan (Hercynian) oceanic belt composed of carbonates, shales and sandy formations. Towards north, these contain marble beds, which host the Hunza rubies belong to the Baltit group. Southwards, the Northern Suture Zone delineates this province from the Kohistan island arc

## PALEOGEOGRAPHY

Paleogeography and its illustration in form of map of Pakistan are described in this volume covering only the area of Indus Basin and Axial Belt. The reason for the selection of this area is apparently simple in the sense that this area is a single and one piece of land in which except for the marginal areas, the entire Indus Basin and Axial Belt provide information unmixed with chaotic state resulted from plate tectonics. In other words, in situ deposition of sediments is still present in these areas. However, frequent changes in depositional environment including constrictions and restrictions in the marine basin played their full roll. Details of the events are worked out and interpreted somewhere else. But a broad and very simplified picture of this area since Triassic to Middle Eocene is presented in this volume on which attributes then present are shown on each map.

Beginning with the northern part of Indus Basin, covering the Kohat-Potwar area, it is generally seen that the sea near Kohat was deepest in Jurassic, some what shallower in the Cretaceous and became progressively shallower throughout the Paleocene and Early Eocene and died out in the Middle Eocene (Kohat Limestone), it is also observed that very likely the basin of deposition was more restricted in Paleocene and Early Eocene time than in Cretaceous time (Fritz in Meissner et al., 1974).

In the Lower Indus Basin covering Sulaiman and Kirthar Provinces, it is interpreted that beginning with the Early Tertiary time to Early to Middle Miocene the sediments are divisible into basal transgressive phase, middle regressive phase (culminating in terrestrial red beds) and final marine phase. This subdivision is equivalent to the three traditional subdivisions of Early Tertiary in southern Pakistan, the Ranikot, Laki and Kirthar series that are defined more or less by unconformities in the Lower Indus Basin. Many authors have attached these series with or made equivalent to Paleocene, Early Eocene and Middle Eocene (Wells, 1984).

# PRECAMBRIAN

Precambrian lithostratigraphic units of Pakistan, recorded in the first addition of the Stratigraphy of Pakistan (Shah, 1977), were only half a dozen in numbers. Since then researchers from different organizations working in different parts of the country have come up with more than two dozens of them. In some cases single formation originally known and described with wide distribution and facies variation has, hitherto been split up into different groups and formations. In most of these cases, it is justified but in a few cases unwarranted, multiple splitting of a previously named one unit into number of formations with the addition of new names has also been seen. They may also have some merit. However, at the time of the formalization of the rock units, many of these extra names are likely to be synonymised.

A large number of radiometric ages dating data are now available for many of the igneous and metamorphic rocks of Pakistan, which have now placed some of them as old as Early Proterozoic. These Precambrian rocks provided basement for the lower Palaeozoic sediments and in certain cases, they served as the source of terrigenous clastics, a provenance for the younger rocks of the adjoining areas.

In the southern half of Pakistan, the Precambrian assemblage within the Indus Basin constitutes volcano-plutonic rocks of Late Proterozoic age, which were earlier considered Indian Shield elements, and with the belief that the orogenic activities of this shield had ended during Precambrian age, thereupon, assuming the character of a stable mass. Detailed work on these rocks shows that the concept of stable Indian Shield is challengeable; details are given in the succeeding topic of Indian Shield elements.

The southern most exposures of this so-called shield crop out near Nagar Parkar, Sind, where granite and basic igneous rocks represent the assemblage. The other exposures of the Proterozoic exposures are present in the isolated hills extending from Shahkot to Sargodha, Punjab. These rock units are composed of metasedimentary complex with acid and basic igneous rocks.

Lastly, in the Indus Basin, the rocks close to the Precambrian-Cambrian boundary are exposed in the Salt Range, Punjab. They are composed mainly of marl, salt, dolomite and gypsum deposits. They occupy probably the sloping part of the Indian Platform and overly the metamorphic rocks of the Late Proterozoic age.

In the Northern areas beginning with the Axial Belt and Himalayan Tectonostratigraphic Basin, the assemblage of Precambrian rocks occupies a large area in the Hazara Folded Belt. Here, they are composed mostly of sedimentary and metamorphic units and frequently intruded by acidic and basic igneous rocks. It is here that the largest expanse of Precambrian rocks has been recorded in Pakistan. The Hazara Formation occupies considerable part of the eastern Hazara area and represents lithologics of slate, phyllite and shale. In fact, in the northern part of the Hazara Folded Belt, the rocks are mostly comprised of phyllite, quartzite with minor amount of limestone. Westwards, in the Attock-Cherat Range, similar exposures have been recognized as Manki and Dakhner Formations. Earlier the later rocks were collectively known as Attock slate. The age was highly problematic, only recently, the question of age has been settled and they are now considered mostly Precambrian similar to the rocks of Hazara area (Hussain et al., 1990).

Further north in the upper Hazara, Salkhala and Tanawal Formations of Precambrian age had been recorded by earlier workers. These formations consist of schist, gneiss and marble with minor amount of carbonaceous material. A large part of the exposures of these formations have now been thoroughly revised and studied in detail, whereupon host of Precambrian basement rocks are now described to be present in the form of metasedimentary, igneous and metamorphic complexes.

**Indus Basin**

**Indian shield:** The concept of Indian Shield along with its stability and boundaries has been an interesting topic of discussion among the students of South Asian geology. Some workers in Pakistan also have their reservation to the use of Indian Shield elements for the Kirana and Nagar Parkar complexes.

Literally, the shield is defined as continental block of the earth's crust that has been relatively stable over a long period of time and has undergone only gentle warping in contrast to the strong folding of bordering geosynclinal belts. They are essentially Precambrian rocks and practically synonymous with craton.

The earliest concept of Indian Shield had been attributed to the ancient crystalline rocks, extremely contorted and largely intruded by plutonic rocks, with well-defined foliated structures. These rocks are of Archaean age and often they are called "Fundamental Complex" and "Basement Complex" (Wadia, 1957). Some workers have included rocks of Middle Proterozoic age within the sphere of "Basement Complex" which includes all the rocks of "Aravalli Super Group", "Delhi Super Group" and the overlying "Erinpura Granite" and ultrabasic intrusives present in the western Rajasthan, (Paliwal, 1992). Some others have included Vindhyans to make Indian Shield stratigraphically spanning up to the end of Precambrian Era, where great unconformity exists before the advent of great marine transgression of Cambrian.

A. M. Heron in twenties and thirties and of the last century mapped Rajasthan area and worked out its Precambrian history in detail. His four-fold classification of the pre-Vindhyan rocks of the area included Banded Gneissic Complex (Bundel-khand gneiss), Aravalli System, Raialo Series and Delhi System. This assemblage continued northwards from Peninsular India and formed the northwestern part of Indian Shield with Kirana and Nagar Parkar igneous complexes as deeply eroded outliers of Aravalli chain.

Workers of South Asian geology have questioned the status of Indian Shield many times, and it has not yet been completely resolved. A short history narrated by Varadan (1976) is quoted here. "In recent years certain questions have been raised regarding the stratigraphic status of the Banded Gneissic Complex, correlation of gneissic rocks of isolated areas. Doubts have also been expressed on the validity of maintaining a separate stratigraphic status of the Raialo Series. However, remapping in the Udaipur area during sixties by Geological Survey of Indian (GSI), has confirmed the existence of a basement of the Aravalli supracrustals as postulated by Heron, but the geographic spread of this basement may be much restricted than what had been envisaged by Heron. The recognition of the gneissic rocks of different orogenic cycles is one of the crucial problems, not only in the Precambrian of Rajasthan, but also elsewhere in the Shield areas. Revision of geological mapping carried out in western Rajasthan since 1960's (by GSI) has indicated that the so-called Trans-Aravalli Vindhyans overlying the Malani Rhyolite are not homotaxial with the Vindhyans of eastern Rajasthan and Madhya Pradesh. Geo-chronological dates have ascribed an age of about 1400 Ma for the Vindhyan and Chitorgarh-Bundelkhand, whereas the Trans-Aravalli Vindhyans (West of Aravalli) appear to be younger than 700 Ma by virtue of their overlying the Malanies, which have been dated at about 700 Ma.

An important contribution made by the Geological Survey of India in recent years is the discovery of stromatolites, phosphorite and syngenitic sedimentary sulphides of possible biogenic derivation in the Aravallies, hitherto, considered being barren of fossils.

According to Varadan (1976), "Auden's classic work on the Vindhyans of Son Valley has served as a modal for subsequent studies. Recent radiometric dating of glauconite and kimberlitic intrusives into them has indicated an age of about 1200 to 1400 Ma for the base of the Vindhyan in central India. However, a younger age of less than 700 Ma is ascribed to the Trans Aravalli Vindhyans. The age date has necessitated a rethinking on the history of stabilization and subsequent fracturing of the Indian Shield".

Detailed work on Vindhyans Super Group of Peninsular India has shown that the Vindhyans are not only known as Precambrian, but also the upper part of it is clearly Phanerozoic, apart from other organic remains, spores of vascular plants, fossil wood of primitive organization and other microfossils, the stromatolites reported from the Vindhyan are usually regarded as early to middle Riphean age. The Jodhpur Group of Trans Aravallies, western Rajasthan correlated with the uppermost Vindhyan unconformably overlying Malani volcanic is dated as 745 Ma (Acharaya, 1976). According to him, the upper most Vindhyan exposed in the Trans-Aravalli region is similar to the eastern extension of the Cambrian sea of Salt Range, which is well correlated by the occurrence of lithological similarity, occurrence of salt pseudomorphs, gypsum-anhydrite-halite succession and above all "Cambrian-Late Palaeozoic Hiatus" in both areas. Paliwal (1992), defining the basement stated, that besides the main Aravalli Range and isolated hills to the west, deformed Aravalli and Delhi metasediments cropout at several places, forming the basement. He further stated that at Khatu, sandstone and shale sequence directly overlies the deformed Aravalli slates with the intervening Malani suite of rocks missing completely. Here the unconformity is marked by the presence of a conglomerate horizon. Granites and granitic gneisses belonging to the "Banded Gneissic Complex" are also encountered at a number of places along the western flank of the Aravalli Mountain Range".

La Touché (1902) and Heron (1932) have grouped Malani rhyolite, ignimbrite and associated welded tuffs under Malani suite of rocks. According to Paliwal (1992), this acid volcanic, representing an early eruptive phase of the Malani suite, are spread over a large area (55000 $km^2$) along the western flank of the Aravalli Range, and extend subsurface up to Tosham hills of Haryana and Kirana hills of Pakistan. Paliwal quoting Kochhar (1973, 1983) stated that the presence of ring dykes and vertical lines of some flows in rhyolites "indicates a zone of extension and the release in stress associated with the Aravalli-Delhi orogenic movements" which began in 2000 Ma and ended between 1500 to 1700 Ma, giving final shape to the Aravalli Mountain Building, which produced linear zones of crustal weakness along which the Malani suite was triggered by mantle plumes. MacDonald (1974) considered such ring dykes as continental representatives of mantle plumes and hot spots occurring in cratonic areas of crustal extension.

All that happened long after the Aravalli orogeny had ended and according to Paliwal (op cit.) "a tensional tectonic setting preceded this early fragmentation of Pangaea in Late Proterozoic period to initiate the process. During the period, a number of linear zones of crustal weakness developed in the northwestern part of the Indian Peninsular Shield, parallel to the Aravalli trend. Because of these linear faults and high heat flow, the magmatism of the Malani suite was triggered by mantle plumes (Kochhar, 1983) about 745 ± 10 Ma. This became the site of volcanic activities and later depositional basin of a shallow epicontinental sea west of Aravalli Range". On the other hand, Chaudhry et al. (1999) postulated that in the post Aravalli period at about 1000 Ma rifting started in the area. This was due to mantle plume, which resulted in widespread igneous activities in Rajasthan, Haryana and Kirana. He further added, "Extension of the crust not only resulted in the widespread volcanism and plutonism but also the subsequent deposition of sedimentary packages of Marwar Super Group in India and Machh Super Group in Pakistan".

In conclusion, Chaudhry et al. (1999) recorded that the Kirana complex of Late Proterozoic rocks, exposed in Indus Basin including rocks of Kirana, Nagar Parkar in Pakistan and Proterozoic exposures at Jodhpur, Malani, Tosham, Mount Abu and Erinpura in Indian, are composed of volcano-plutonic and sedimentary packages. According to them, they represent a distinct "Cratonic rift assemblage" which was deposited in an extensional basin formed because of rising of the mantle plume around 1000 Ma. They named this entire outcrop area as "Malani-Kirana Basin" and ascertained that this basin neither belongs to Vindhyan System nor it is a part of Aravallies. Previously, however, it was believed that Kirana hills are highly eroded outliers of the Aravalli chain (Wadia, 1957) and was included in the Indian Shield.

***Lower Indus Basin***

***Nagar Parkar igneous complex***: Jan et al. (1997) named and described a sequence of acid and basic igneous rocks exposed near Nagar Parkar in Sind as "Nagar Parkar igneous complex". Earlier Kazmi and Khan (1973) had called it as "Nagar Igneous complex", "Late Proterozoic rocks of Nagar Parkar" by Butt et al. (1994), "Nagar Parkar granite" by Shah (1977), and "Nagar Parkar Massif" by Muslim and Akhtar (1995). None of these names have yet been formalized by Stratigraphic Committee of Pakistan. Area at a glance shows granite of grey and pink colours, intruded into basic igneous rocks, which are in turn intruded by mafic dykes.

Butt et al. (1994) mapped and described the rock sequence as follows: "The oldest rocks are metamorphosed basic igneous rocks. Acid dykes have intruded these metabasites, which have the level of epidote amphibolites metamorphism. Acid dykes range from rhyolite to quartz trachyte in composition. Metabasites are intruded by grey granite, which contain the xenoliths of the former rock type. Pink granite intrudes the grey granite, and also carries xenoliths of mafic rocks, finally all the major rocks including both the granites are intruded by mafic dykes". Jan et al. (1997) made detailed and critical petrographic studies and produced a geological map of the area. According to them six major magmatic episodes of intrusive and extrusive activities have been identified:

(1) Amphibolites and related dykes: the amphibolites, apparently forming host rock for the subsequent intrusions, show low-grade metamorphism. Geophysical survey carried out by Farah and Jaffrey (1966) in the area indicates that they cover large subsurface area and evidently form the basement for the later rocks; they are metamorphosed up to amphibolite grade.

(2) Riebeckite-aegirine grey granite: The riebeckite-aegirine grey granite is essentially composed of perthitic feldspar and quartz, with a small amount of plagioclase and presence of sodic minerals including characteristic riebeckite and aegirine. The best exposures of the grey granite are at Karunjhar Hill. It is mostly undeformed; also contain iron oxide, zircon and many other accessory minerals. Jan et al. (1997) correlated this unit with Warsak and Sheva-Shahbaz Garhi granite in the northern Pakistan.

(3) Biotite-hornblende pink granite: The biotite-hornblende pink granite is mostly medium to coarse-grained. Jan et al. (1997) termed it as "generally leucocratic and commonly homogeneous". It is generally made up of "light minerals" like perthitic feldspar, local microcline, quartz, and minor plagioclase (oligoclase), with some biotite, hornblende and iron oxide. Some rocks contain sufficient plagioclase to be termed quartz monzonite or adamellite.

(4) Acid dykes: This unit includes porphyritic microgranite dykes, rhyolitic dykes and rhyolite porphyry and with leucogranitic and equigranitic aplite dykes. In brief, this unit ranges from aplite to microgranite to quartz trachyte. It contain phenocrysts of perthite, plagioclase and quartz in an allotriomorphic matrix of these minerals and it induces in it accessory minerals, like iron oxide, blue-green amphibole (riebeckite), biotite, zircon, apatite, fluorite, sphene, allanite and secondary epidote. These rocks generally occur as small bodies but locally (as in Dhedhvero), form up to 6 m thick dykes extending for more than 2 km.

(5) Rhyolite Plugs: The rhyolites occur in two small, domel outcrops surrounded by alluvium. They are dark grey to black, glassy looking rocks with whitish bands and consist of phenocrysts of feldspar and quartz in a very fine-grained matrix. The rocks are fine-grained and porphyritic to sub porphyritic, contain phenocrysts of K-feldspar, mainly perthite and quartz with small amount of plagioclase and accessory minerals like zircon and apatite.

(6) Basic dykes: All the major rock units of the complex are intruded by undeformed basic dykes, mostly less than 3 m thick. They show considerable petrographic variation and range from hornblende microdiorite to gabbro and dolerite, some of which contain titanian augite suggestive of alkaline affinity (Jan et al., 1997).

Broadly, two types of dykes have been encountered in the area: lamprophyric and alkaline gabbro/dolerite dykes. These mafic dykes are the youngest cutting across all the exposed rock units in the area. The Nagar Parkar granite is believed to be the continuation of the Proterozoic granitoids of the Indian Rajasthan.

***Upper Indus Basin***

***Kirana Complex***: Sedimentary and igneous rocks of Kirana hills of Late Proterozoic age are exposed in Punjab, covering the areas from Sargodha to Shahkot, (Lat. 31° 58' 30" N: Long. 72° 34' 30" E to Lat. 31° 34' 30" N: Long. 73° 32' 30"). Major exposures are located near the towns of Sargodha, Chiniot, Shahkot and Sangla hills.

The area, mentioned above, is exclusively occupied by exposures of Proterozoic age with no Phanerozoic rocks; however, it is believed that this complex serves as basement rocks for the Eo-Cambrian to Palaeozoic rocks of the Salt Range, which crop out about 100 km north of this complex. The complex is composed of metasedimentary, grey slates, red and grey quartzite, conglomerate, volcanic and metavolcanic. No plutonic rocks in the complex yet have been reported from anywhere. The complex contains some mineralized zones of hematite, copper, gold, silver and cobalt. Except hematite all other minerals are in minor quantities.

In the lower part of the sequence, the metasedimentary rocks are interlayered with andesite, rhyolite and tuff beds and solid volcanic lava flow at the base. This sequence is composed of rocks of diabasic composition. The basic rocks are highly weathered and altered. Thin section study indicates sericitized plagioclase, chlorite, epidote and a little quartz. The basic dykes contain gold and silver in minor amounts. Pockets of red green and yellow ochres are also found in quartzite and slate beds (Shah, 1973).

Davies and Crawford (1971) made petrographic and geochronologic studies of the volcanic rocks of a part of the Kirana complex. In addition to the detailed studies of acid and basic rocks, they have also reported the presence of an unusual ankeritic rock. The ankeritic carbonate bodies are explained to have been produced by the late stage autometasomatic concentrations developed by the cooling doleritic magmas.

Studies were carried out to determine the possibility that the ankeritic carbonate bodies may have been carbonatites but according to the authors 87Sr/86Sr ratios determined, were very different from those in typical carbonatites. They gave the following analysis of a typical sample of the ankerite rock from Bulland Hill. "Calcium Oxide 29.2%, total Iron as Ferric Oxide 21.0% and Silica 17.4%". The sediments of the Kirana complex are devoid of fossils and they are largely non-calcareous. The absolute age for the Kirana volcanic rocks given by Davies and Crawford (1971) is 870 ± 40 Ma. This places the Kirana complex in the Late Precambrian age. It has been correlated with the Malani Volcanic of India (Heron, 1913). It may be noted, that volcanics in the Kirana area are not as common as in the Malani, where the predominant rock units are volcanics.

Davies and Crawford (1971) placed the Kirana complex as younger than the geosynclinal rocks of the "Aravalli Mountains" and older than the "Malani Rhyolite Series" of India. They suggested that the correlation of Kirana complex with the Malani Rhyolite must be abandoned. However, Virdi (1997) suggested that the Kirana and Nagar Parkar complexes are Malanies and part of Aravallies.

Following the outlines of Shah (1973) and Alam (1987) carried out detailed mapping, section measurement, petrographic studies, and divided these rocks into Kirana and Sharaban groups. He further divided these groups into five formations (Table 1) and Sharaban group is composed of two formations, named as Sharaban conglomerate underlain by the Hadda quartzite. Kirana group consists of three formations viz., Asianwala quartzite, Taguwali phyllites and Hachi volcanic. Asianwala quartzite is the youngest, which is underlain by Taguwali phyllites. Alam (1987) named the Hachi volcanic as the oldest unit in the Kirana group.

This stratigraphic scheme has been revised by Chaudhry et al. (1999), and refined by Ahmed et al. (2000) which is as follows: Hachi Volcanic is separated from the rest of Alam's formations of Kirana group; they argued that the Hachi volcanic are genetically different from the other formations and constitute a very distinct lithostratigraphic unit as well as it is separated by an unconformity from the rest of the Kirana group. This unconformity is represented by polymicitic conglomerate.

Overlying the Kirana group, Alam (1987) had named and described Sharaban group combining the upper most two formations to which Chaudhry et al. (1999) resisted with the plea that neither the top nor the bottom of the group is known and also the Sharaban group is very small and exposed at only two places, Sharaban and Chandra hills. They further added that giving it a status of a group is not justified and thus they rearranged the stratigraphic set up and combined all the formations in a Super Group (Table 1).

Chaudhry et al. (1999) coined the term "Machh Super Group" to correlate the rocks of Kirana area with similar rocks of Marwar Super Group of India. They included all the formations of Alam (1987), except Hachi volcanic and eliminated the name Kirana group and yet, they named no group of any kind to go along with their super group (Table 1).

Table 1. Classification and correlation of the Units of the Kirana complex by various authors.

| Alam (1987) | | Chaudhry et al. (1999) and Ahmed et al. (2000) | | This review | | |
|---|---|---|---|---|---|---|
| Sharaban group | Sharaban conglomerate, Pebbles of quartzite, slate, limestone embedded in calcareous matrix. 119 m. | "Machh Super Group" | a. Sharaban formation (conglomerates with slate intercalations).<br>b. Hadda formation; calcareous quartzite.<br>c. Asianwala formation, mainly quartzite with subordinate quartz wackes, gritty quartzite and slates, often showing ripple mark and cross bedding.<br>d. Taguwali formation. slates, fine-grained and quartz wackes.<br>Chak 112 conglomerate; polymictic (polymicritic) conglomerate with clasts of dolerite and acid volcanic | Machh Super group | Sharaban group | Sharaban conglomerate; conglomerate with calcareous slate intercalation<br>Hadda formation; predominantly quartzite. |
| Kirana group | Hadda quartzite, dull rusty brown fine grained with minor conglomerate beds, Asianwala quartzite; light grey medium to coarse grained, cross bedded, with minor intercalations Taguwali phyllite; Phyllites, light grey, with minor intercalations of quartzite. 1190 m. | | | | Kirana group | Asianwala formation; quartzite with slate intercalations.<br>Taguwali formation slate and quartz wackes<br>Chak 112, conglomerate; polymict conglomerate with acid and basic volcanic layers.<br>—unconformity |
| | Hachi volcanic. Slates, minor quartzite, with abundant tuff and lava flow of acidic composition. 404 m. | Hachi volcanic | a. Volcanic; dolerites, andesite, dacite, dacitic tuff, rhyolite and rhyolitic tuff.<br>b. Volcanogenic; Slate, often interbedded with rhyolite/rhyolitic tuff and dolerite | | Hachi group | a. Volcanic; dolerites, andesite dacite, dacitic tuff, rhyolite and rhyolitic tuff.<br>b. Volcanogenic; Slate, often interbedded with rhyolite/rhyolitic tuff and dolerite<br>c. Volcanic; predominantly Lava (glassy rock) with minor slate |

Table 2. Correlation of Machh Super Group with Indian "Marwar Super Group" (Chaudhry et al., 1999).

| Machh Super Group with Indian Marwar Super Group | |
|---|---|
| Kirana complex | Marwar Complex |
| Machh Super Group | Marwar Super Group |
| ------------ | ---------------- |
| ? | * Bilara Formation (cherty dolerite, limestone and ferruginous breccias. |
| ** Sharaban conglomerate | -------------- |
| ** Hadda quartzite | -------------- |
| ----------- | -------------- |
| *** Asianwala formation | *Jodhpur Formation |
| *** Taguwali formation | Sonia Formation |
| *** Chak 112 Conglomerate | Basal Formation |
| ------------ | --------------- |
| Hachi (Volcanic) group | Tosham-Malani Volcanic |

* Now they are called groups in India ** Sharaban group *** Kirana group

Admittedly, "Machh Super Group" named by Chaudhry et al. (op. cit.) fits very well in correlation with "Marwar Super Group" of India, however the stratigraphic code of Pakistan does not allow the establishment of a "Super Group" without having its component groups. Only informally, however, it can be applied. Nevertheless, for formalization, it is required that at least two or more than two groups (not formations) be named in the thick lithostratigraphic pile of Kirana complex. Moreover, altogether elimination of the name Kirana from this pile appears odd, specially, when it is realized that Kirana group has its roots embedded deep in the geological literature and is popularly used in it, therefore, if at all super group is to be used then both the groups i.e. Kirana and Sharaban must be retained.

Incidentally, it is also noted that the "Marwar Super Group" of India also comprises Nagaur, Bilara, Jodhpur groups sitting on the Malani suite of igneous rocks.

From the description given for Hachi volcanic as detailed by Alam (1987) and Ahmed et al. (2000), it is evident that the Hachi volcanic can be split into predominantly sedimentary unit and predominantly volcanic unit, however, more information is required to establish the formations within the Hachi volcanic. At present, the Hachi volcanic is informally referred here as the Hachi volcanic group. Tentatively, the Sharaban and Kirana groups are retained to fulfil the requirement of "Machh Super Group". This scheme is based on the depositional environmental and genetic grounds. To illustrate this point, it may be emphasized that the Sharaban group is calcareous, while the Kirana group is non-calcareous, which means each of these two groups had a separate depositional environment. Kirana group clearly differs from older rocks of Hachi (volcanic) group, since the later is purely volcanogenic, while the former is purely sedimentary. In view of the above facts, it is concluded that genetically there are three groups: first is Sharaban group of calcareous nature with rare lava flows, the second is Kirana group of non calcareous type and devoid of volcanic material and the third is Hachi group composed of volcanogenic rocks. With this stratigraphic arrangement, the units are described as follows:

**Hachi group:** Hachi volcanic of Alam (1987) is described here as Hachi group after the Hachi Hill north of Sikhanwali Railway Station. Ahmed et al. (2000) divided the Hachi volcanic into the following two units. Volcanic (dolerites, andesite, dacite, dacitic tuff, rhyolite and rhyolitic tuff) Volcanogenic slates, often interbedded with rhyolite/rhyolitic tuff and dolerite. At the base of volcanogenic (b) more than 90 m thick, grey, glassy lava and tuff is present; in this subunit lava flows predominate.

A general look on this group shows that the unit is composed of tuffite, which includes mixed clastic sedimentary pyroclastic material. However, it is difficult to demarcate clear stratigraphic units in the Hachi group except for marking the units as dominantly lava beds or dominantly slate or tuff beds. Lithologically, the group in general is composed of quartzite, slates, phyllite, tuffs and lava flows. Elsewhere, small hills located just in the Chiniot Town, the unit is entirely composed of lava of rhyolitic composition. Such examples encourage differentiating and naming of some formations within the group, but this can only be done after detailed survey and the establishment of the sequence in Hachi package. It is ascertained, that the unit better be called Hachi group due to its varied lithology. This unit is the oldest in the Kirana complex. The base of the group is not exposed and the top is unconformable.

The Hachi group contains quartzite layers, which are light-to medium-grey, medium-grained, being composed mostly of sub rounded to rounded grains of quartz with sericite and clay minerals. Tuffs and volcanic breccias are widespread throughout the group and the best exposure of them is present at Hachi Hill. The tuffs and volcanic breccias are light grey in colour and are present at different stratigraphic levels interlayered with lava and metasediments. The volcanic breccias are course-grained with abundant rock fragments and large phenocrysts of feldspars and quartz set in fine matrix. The composition of the rock is rhyolitic.

The tuffs are interlayered with quartzites and slates. In general, the bedding is not distinct but at a few places, clear bedding is also present. The rocks are slightly metamorphosed but unusually retain the original texture. The slates interbedded with tuffs seem to have been derived from volcanic ash and other fine volcanic material.

Lava is interlayered with the metasediments. Nowhere, pillow structure has been found in the lava flows. Mostly, the lava is of acidic composition and is represented by rocks such as rhyolite, dacite and minor andesite.

Exposures in Hundawali Hill represent dark grey massive rock. Under the microscope, the rock is holocrystalline and fine grained with porphyritic texture. The phenocrysts of feldspars are set in groundmass of oligoclase, orthoclase and quartz.

The lower contact of this unit is not exposed anywhere. The upper contact with Taguwali phyllite and slates is also obscure. However, the field relationship suggests that it represents the oldest formation of Kirana complex, which passes into the overlying Taguwali formation of Kirana group. Its thickness is 404 m at the type locality. Its age, as discussed under the section of Kirana complex, is Precambrian.

Bulland Hill rocks are considered representative of Hachi group from where, Davies and Crawford (1975) picked up the samples for absolute age dating and determined the age at 870 Ma. On the basis of above results, the rocks of Hachi group probably lie within the time range of Vindhyan System, which is as old as 1400 Ma in the east and around 700 Ma (in the Trans Aravalli Vindians) in the west. The two Vindians, however, may not be homotaxial.

**Kirana group:** This review divides the rocks of Kirana group (mentioned before by Kazmi (1964) and Shah (1961 [unpublished] and 1973), into two units: namely Asianwala quartzites and Taguwali slates and phyllites. These two units are in succession and have no connection to other formations or groups in the area.

**Taguwali formation:** The name has been assigned after a small place Taguwali. The type locality and type section of this unit is on southern part of Kirana Hill at grid reference E 862462 (Alam, 1987). Lithology of this unit is phyllite/slate and fine-grained quartzites in the lower part. Phyllite is light silver-grey, fine-grained, thin-bedded, partly thick-bedded at places and shows cross bedding. In the upper part of the formation, phyllite is the dominant rock type with minor slate. The middle part is composed of slate with little shine on the surface.

According to Alam (1987), this formation is quite wide spread in the area. It is exposed in Chandra Hill (E 891426), where it is represented by fine-grained quartzites in Machh Hill (E 912395), about 4 km southeast of Taguwali, where it is mostly represented by fine-grained, thin-bedded phyllite. In Chiniot-Rabwah area, fine-grained quartzite and thin-bedded slates represent this unit. In Chiniot area, small exposure of phyllite represents this formation.

Its upper contact with the Asianwala quartzite is gradational. The lower contact with Hachi group is nowhere clear. Ahmad et al. (2000) indicated that and outcrop of polymictic conglomerate point out an unconformity between Taguwaly formation and Hachi group. At the type locality, the formation has been measured 1189 m. The age of the formation is Precambrian.

**Asianwala quartzite:** This unit is named after the canal rest house Asianwala located at 11 km on the Sargodha-Faisalabad Road. The type section is designated at the main Kirana Hill, where it is exposed in the northern part of the hill, at about 4 km from Asianwala rest house, (Grid reference, G 879490); Alam (1987).

Lithologically, the formation is predominantly quartzite with minor intercalations of slate. The quartzite is generally coarse-grained; partly pebbly at places the quartzite is dirty white to light-grey, mottled brown, thick-bedded. It is cross-bedded and ripple marked. At places, joints and fractures are filled with brown hematitic material. The interbedded slates are light grey in colour and occur as thin layers in-between the thick beds of quartzite.

The formation extends to Chiniot, Sangla Hill and Shahkot areas. The exposures of quartzite at Sangla Hill are of medium to coarse grained, thick bedded which are similar to and included in the Asianwala formation. In Shahkot area, this formation is exposed at about one kilometre west of the town, and is represented by light-grey, medium-bedded, coarse-grained quartzite.

At the type locality, the upper contact of Asianwala formation is with alluvium. The lower contact is gradational and passes into Taguwali slates. The thickness measured in the type section at

Kirana Hill is more than 248 m. The age of the formation is Precambrian.

**Sharaban group:** According to Alam (1987), "new Sharaban group has been proposed comprising of two units: the upper unit is Sharaban conglomerate, which is characteristically calcareous in nature and the lower unit is Hadda quartzite, which is also calcareous. These two units have not been included in Kirana group, because nowhere in the area their direct contact and relationship with Kirana group could be found. The rocks of these units are exposed only in isolated hills called Sharaban. These units are considered younger than the Kirana group based on regional trend/structure.

**Hadda quartzite:** It has been named and described by Alam (1987). Quartzites are the main lithology of the formation, which are dull rusty brown, fine-grained, calcareous, typical of shallow marine origin or deltaic, containing minor conglomerate beds, rare lava flows. The formation has been named after the canal rest house Hadda located about 20 km ESE of Sargodha and about 10 km north-east of Sharaban Hill. However, the type locality is at Sharaban Hill.

These quartzites occur in beds varying from 1 to 13 m. They are calcareous in nature, sometimes cross-bedded, and show complex contorted layering on the exposed surface due to slumping before consolidation.

Conglomerates in minor quantities occur in the upper part of the formation, interbedded with quartzites ranging in thickness from 1 to 2.5 m. These conglomerates are similar to Sharaban conglomerate and are composed of pebbles of quartzites, slate, with minor limestone, vein quartz and jasper, set in fine calcareous matrix of rusty-brown colour. The pebbles are flattened, and arranged with their long axis parallel to the bedding.

The middle part of the formation is composed of quartzites, light grey to brownish-grey, fine-grained, thin-bedded, and some parts are phyllitic. Lava flows of greenish-grey colour are present within the quartzite beds. The lower part of the formation is represented by quartzites of light grey colour, which are highly ferruginous at places. Some parts are being mined as hematite ore for use as pigment.

Its upper contact with Sharaban conglomerate is gradational, while the lower contact is concealed. At the type locality, it is 372 m thick (Alam, 1987).

The formation is unfossiliferous. However, Alam recorded "an algal like slung structure." This structure may very well be stromatolitic material, which has been found in the Late Proterozoic rocks of the Lesser Himalaya. Based on regional trend and structure, the isolated exposures of this unit are thought to be lying above the rocks of Kirana group. This assumption places this unit above the Asianwala quartzite, with Late Proterozoic age.

**Sharaban conglomerate:** Sharaban conglomerate is named and described by Alam (1987). Lithologically the formation is predominantly conglomerate of rusty brown colour with minor (0.3 m thick) stringers of fine-grained quartzite. According to Alam (op cit.), it is dull rusty brown containing pebbles of quartzite, slate, limestone embedded in calcareous matrix. The type locality is designated at the Sharaban Hill, where the outcrop of this formation is shown in the form of isolated low-lying exposure. The upper contact of the unit is terminated by alluvium.

Clasts of quartzites and slates make up about 85% with only a small percentage of limestone and few vein free quartz and red jasper fragments. The formation is bedded and individual beds are 5 to 10 m thick. The quartzites and slates pebbles are similar to the rocks exposed in the area and the origin of limestone pebbles is not known. The general size of the pebbles is in the range of 1-3 cm diameter.

The limestone pebbles, present in the conglomerate pose problem to their origin, as nowhere limestone beds have been found in the entire Kirana complex. The limestone pebbles are light grey, fine-rained, and microcrystalline. The pebbles are flattened due to stress and are arranged with their long axis parallel to the bedding. Thin beds of rusty brown quartzite are intercalated with the conglomerate. The quartzite is fine-grained, calcareous in nature, and is similar to the matrix present in the conglomerate bed. The lower contact of the Sharaban conglomerate passes into Hadda quartzites. The exposed thickness of the unit is estimated to be 118 m. No fossil or any trace of organic remains has been found in this unit. The exact relation of this unit with Kirana group is not known (Alam, 1987). However, these rocks are regarded as the youngest in the area. Shah (1973) also stated that this conglomerate unit is the youngest in the area, based on stratigraphic position.

***Kohat-Potwar Province***

Rock units ranging in age from Precambrian to Cambrian are exposed in the Kohat-Potwar Province of the Indus Basin, where the Salt Range Formation with salt marl, salt seams and dolomite forms the basement for the fossiliferous Cambrian sequence of the Salt Range. As indicated by the lithology, the deposits of the Salt Range Formation represent an evaporite sequence similar to the Hormuz Salt Formation of Iran (Shah and Quennell, 1980). Probably a large part of the Indus Basin is occupied by this formation. Although, its exposures are restricted to the Salt Range, deep drill holes have confirmed its presence to the north and south of the exposures.

**Salt Range Formation:** Wynne (1878) named and described the formation as 'Saline Series'. Gee (1945) called the same unit as the 'Punjab Saline Series'. Asrarullah (1967) has given the present name 'Salt Range Formation' after the Salt Range. Khewra Gorge in the eastern Salt Range has been designated as the type section.

The lower part of the Salt Range Formation is composed of red-coloured gypseous marl with thick seams of salt, beds of gypsum, dolomite, greenish clay and low-grade oil shale are the constituents of the upper part. A highly weathered igneous body known as "Khewra Trap" has been reported from the upper part of the formation. The "Khewra Trap", also known as "Khewrite" by Mosebach (1956), is six meters thick and is purple to green in colour. It consists of highly decomposed radiating needles of a light-coloured mineral, probably pyroxene.

The red-coloured marl consists chiefly of clay, gypsum and dolomite with occasional grains and crystals of quartz of variable sizes. Thick-bedded salt shows various shades of pink colour and well-developed laminations and colour bandings up to a meter thick. Minor amounts of potassium and magnesium sulphates are found in association with the shale beds. The gypsum is white to light grey in colour. It is about 5 m thick, massive and is associated with bluish grey, clayey gypsum and earthy, friable gypseous clay. The dolomite is usually light colour, it is flaggy and cherty. It is associated with dolomitic shale, bituminous shale and low-grade oil shale.

Asrarullah (op. cit.) made a detailed study of the Salt Range Formation and divided the formation into three members in the following succession: Sahiwal Marl Member: (a) Bright red marl beds with irregular gypsum, dolomite beds and Khewra Trap (3-100 m) and (b) Dull red marl beds with some salt seams and 10 m thick gypsum bed on the top; (more than 40 m). Bhandar Kas Gypsum Member: Massive gypsum with minor beds of dolomite and clay; (more than 80 m). Billianwala Salt Member: Ferruginous red marl with thick seams of salt (more than 650 m). The formation represents evaporite sedimentation, which took place in an enclosed basin in arid conditions. The clastic material was transported from Peninsular India and deposited under oxidizing conditions.

The Salt Range Formation is exposed along the southern flank of the Salt Range, from Kussak in the east to Kalabagh in the west. In the subsurface, the rock unit has been encountered as far in south as Karampur in the Punjab plains and in the north at Dhulian oil field in the Potwar area. The thickness of the Salt Rang Formation in the type section at Khewra Gorge is more than 830 m. It has been found by drilling that the thickness is more than 2000 m at Dhariala.

The base of the Salt Range Formation is only known from the Karampur well, where the formation overlies the metamorphic rocks, presumably of Precambrian age. The contact with the overlying Khewra Sandstone is generally normal and conformable. The age of the Salt Range Formation, its paleontological record and its contact with the overlying rocks has long been a controversial topic. Details of this controversy are beyond the scope of this report. Sahni (1939, 1945, 1947) and others have reported Tertiary microfossils from it. Gee (1947) has very reasonably differed with the interpretation of a Tertiary age of the formation. More recently Schindewolf and Seilacher (in Teichert, 1964) have supported the views of Gee. They suspected that the Tertiary fossils reported from this formation by Sahni (1947) that were due to contamination. The overlying Khewra Sandstone is probably of Early Cambrian age, as observed by Gee (1945); Schindewolf and Seilacher (1955). The Salt Range Formation is therefore, assigned an Early Cambrian to Late Precambrian age.

**Axial Belt (Northern Sector):**

Northern Sector of the Axial Belt is bound by Main Boundary Thrust (MBT) in the south and approximately marked by Panjal-Khairabad thrust in the north; the areas included are Waziristan, Kurram, Attock-Cherat Range and southern Hazara (Fig. 1).

***Attock-Cherat Range*:** Hussain et al. (1989) divided the Attock-Cherat Range into northern, central and southern blocks bounded by thrust faults, for the convenience of the description of stratigraphy. They described the Precambrian rocks from the Attock-Cherat Range as following.

**Manki Formation:** The name Manki Formation was introduced by Tahirkheli (1970) and has been derived from the village of Manki in the Attock-Cherat Range. The formation has been redescribed by Hussain et al. (1989) as a sequence of phyllite, slate and slaty shale with lenticular sandy bands exposed in the northern block of Attock-Cherat Range.

The entire northern block of the Attock-Cherat Range, consists predominantly of Manki Formation. The formation in this block is mainly dark-grey to black sericitic slate and phyllite with subordinate lenses of yellowish-grey limestone and quartzite. Hussain et al. (1989) recorded that the estimated thickness of the formation is about 950 m. It is the oldest formation in the area. The Manki Formation resembles the Hazara Formation to which Crawford and Davies (1975) and Calkines et al. (1975) have assigned Precambrian age. The Manki Formation has a gradational contact with the overlying Shahkot Formation, while its lower contact is not exposed.

**Shahkot Formation:** The formation consists of light brownish-grey limestone and interbedded dark, greenish-grey phyllite. Limestone near the top of the formation, south of Uch Khattak Village yielded fossils tentatively identified as bryozoans of Lower Palaeozoic age (Tahirkheli, 1970). Hussain et al. (1989) added that the formation is yellowish, brown-grey and thin- to thick-bedded, sandy, crystalline limestone with pitted and grooved features, underlain by green and greenish-grey, sandy and slaty shale contains dolerite sills. The thickness according to Tahirkheli (1979) is about 75 m. Hussain et al. (1989) could not find any trace of life and declared the age of the formation as Precambrian.

**Uch Khattak Formation:** The formation as described by Tahirkheli (1970) is composed of thin-bedded to massive, grey to sooty-black, crystalline limestone with argillaceous streaks and laminations. Dolerite intrusions are present. The formation comprises predominantly of rubbly and stromatolitic limestone with grey to buff argillaceous laminations. Near Khairabad, at Raja Hodi railway tunnel, the Uch Khattak Formation contains clasts of Shahkot and Manki Formations and therefore younger than both. The age of the formation as described by Hussain et al. (1989) is Precambrian.

**Shekhai Formation:** This formation, as described by Tahirkheli (1970), is thin-bedded to massive, crystalline, dolomitic limestone with thin-bedded quartzite and slaty shale at the base and contains igneous intrusions. Hussain et al. (1990) recorded that formation is the youngest unit of the northern block and is represented by medium- to thick-bedded and massive limestone with subordinate quartzite. The limestone is brecciated in the middle and upper parts. It is lithologically similar to Precambrian Hazara Formation. It has locally gradational contact with Manki Formation. Hussain et al. (1990) suggested that all the formations in the northern block are of Precambrian age. Dolerite dykes and sills are commonly found in this block.

**Dakhner Formation:** Hussain et al. (1989) have renamed "Attock shale" of Tahirkheli, (1970) as Dakhner Formation. According to them, the central block is principally underlain by Dakhner Formation, which consists of a thick sequence of siltstone, argillite, quartzite and subordinate limestone. Tahirkheli (1970) considered the age of this sequence to be Middle Jurassic-Cretaceous on the basis of fossils in the limestone that he considered to be interbedded within the formation. Hussain et al. (1990) stated that all the fossils found during their study including Tahirkheli's locality, are in Cenomanian or Paleocene limestone that overlies the Dakhner Formation unconformably or in thrust contact with the Dakhner Formation. At Hassanabdal, east of Attock-Cherat Range, the Jurassic limestone lies unconformably above Dakhner Formation. Consequently, they rendered the formation as Precambrian in age on the basis of lithological correlation with the Hazara Formation for which Rb/Sr dates of 740 ± 20 and 930 ± 20 Ma have been reported by Crawford and Davies (1975). Unlike the northern block, the central block contains no intrusion of dolerite Tahirkheli (1970), except for one occurrence in limestone, east of Indus River. A thin cover of Jurassic, Cretaceous, Paleogene and Miocene rocks unconformably overlies the Dakhner Formation. The thickness of the Dakhner Formation is more than 1000 m (Hussain et al., 1990).

**Hazara Formation:** Marks and Ali (1961) have given several names to this formation including "Slate series of Hazara" by Middlemiss (1896) and "Hazara Slates Formation". Prior to these names, Waagen and Wynne (1879) described them as "Attock Slates". Calkins et al., (1969) named it "Hazara Formation". Latif (1970) named this formation "Hazara Group", in which he included the "Tanawal Formation" of Calkins et al. (1969) as a part of it.

The Hazara Formation consists of slate, phyllite and shale with minor occurrences of limestone and graphite layers. Slate and phyllite are green to dark green and black, but are rusty brown and dark green on weathered surface. Some thick-bedded, fine- to medium-grained sandstone is also present. Limestone beds with maximum thickness of 150 m and a sequence of calcareous phyllite and gypsum ranging from 30 to 120 m thick are found in southern-most Hazara and Azad Kashmir (Calkins et al., 1969).

Marks and Ali (1961) regarded the formation as a turbidite deposit. Calkins et al. (1969) disagreed with that concept, contended that the beds of limestone, graphite and gypsum are unlikely to occur in a turbidite sequence, and regarded most of the formation as probably a shallow-water argillaceous sequence. The Hazara Formation is equivalent to the 'Dogra Slates', which are overlain by fossiliferous Cambrian rocks. On this basis, Calkins et al. (1969) assigned a Late Precambrian age to the Hazara Formation. Latif (1970 a) has reported fossils similar to Protobolella in the Hazara Formation showing that it may be early Palaeozoic in age.

Latif (1973) correlated the Hazara Formation with the Salt Range Formation based on evaporite facies found in both the formations. Crawford and Davies (1975) analyzed three samples of low grade, fine-grained, clastic rocks from the Hazara Formation for age determination by the Rb/Sr method as whole rock samples. Data for the two samples gave the age of 765 ± 20 Ma in addition, the third one indicated the age of 950 ± 20 Ma. This age determination places the formation in the Precambrian.

***Himalayan Tectonostratigraphic Basin*:**

Originally, in this area only Salkhala, Tanawal and little igneous rock were described about three decades ago. This situation was due to inaccessibility and lack of mapping in this area and only roadside reconnaissance work was available. Detailed research work began in late seventies and subsequently, a large number of formations have now been described. This basin is delineated by Panjal Thrust in the south and Main Mantle Thrust (MMT) in the north, and includes Lesser and

Higher Himalayas with the Main Central Thrust (MCT) in between them.

**Salkhala Formation:** Wadia (in Pascoe, 1953) introduced the name; Salkhala Series' to a sequence of schist, phyllite, quartzite and carbonaceous material exposed in Kashmir and designated the type section at Salkhala Village on the Kishanganga River, Kashmir. Offield and Abdullah in Calkins et al. (1969) adopted the same name with little modification as "Salkhala Formation".

The formation occupies a large area extending from Kashmir to Gilgit. Stauffer (1968) made a detailed study of the rock unit in the Gilgit-Hispar Valley. Lithologically, the rock unit in northern areas consists of slate with prominent graphitic beds interbedded with marble. The formation includes quartzite, garnet-biotite, quartz schist and talc schist at various places. Marble is found throughout the formation. In Hazara area, the Salkhala Formation crops out around the apex of the syntaxis. Near Balakot the formation thins out to only a few hundred meters. According to Calkins et al. (1969) the formation occupies both sides of the Indus River from Tarbela to Swabi. Marble, graphite schist, quartz schist and quartz-feldspathic gneiss are the main constituents of the formation in the Hazara area. Southwards, in the Kashmir region the formation is intensely folded and consists mainly of schistose rocks. Just north of Salkhala Village across the Neelum River, Ghazanfar et al. (1983), have now mapped Salkhala beds indicated by Wadia as Sharda group (See Sharda group).

During the course of the mapping of Swabi-Rustam area, Khan S. R et al. (1994) found that fold structures other than the Indus re-entrant might also contain Salkhala Formation in their cores. One of these fold structures in Swabi-Rustam area, is termed as the Kundal anticline by Khan et al. (op cit.), which trends WNW-ESE and runs for over 15 km from Tarbela dam in the east up to the Ghurghushtu Village in the west. The core is occupied by the Salkhala Formation.

Khan S. R et al. (1994) divided the Salkhala Formation into two units; the basal part of the formation is referred to as the Gandaf unit, while the upper part of the formation, exposed at the apex of the Kundal anticline at Kundal and from where it extends to the west, all of these exposures are called as the Kundal unit. The Gandaf unit consists of graphitic and pelitic schists, phyllites, calcareous rocks, quartzites and quartz schists. The overlying Kundal unit in its lower part (100 m thick) predominantly consists of fine mud alternating commonly with silt layers. The two alternating layers on mm scale yield spectacular lamination. Graphitic schist is locally present. In the upper part, the Kundal unit (300 m) is green-coloured chlorite bearing quartz-mica schist, with quartzite and phyllite interbedded.

The upper contact of the Salkhala Formation with Tanawal Formation is transitional in the Swabi-Rustam area. The lower contact of the Salkhala Formation is nowhere exposed in the Swabi-Rustam area. Basement gneisses on which the Salkhala Formation overlies are not exposed in this area, Khan S. R et al. (op cit.). The formation is 1800 to 3000 m thick in the Kashmir area, still thicker in the Nanga Parbat area. The formation has an intrusive contact with the Kailas Batholith. At the type locality the Salkhala Formation is overlain by "Dogra Slate" known in this volume as equivalent to Hazara Formation, which was radio-metrically dated as 750 Ma Crawford and Davies (1975). The "Dogra Slate" is, in turn overlain by fossiliferous shale and slate of Cambrian age. The age of Salkhala Formation derived from the super positional order and correlation is considered

Precambrian.

**Tanawal Formation:** Wynne (1879b) described the rocks of this formation as "Tanol group". Middlemiss (1896) called them "Tanol quartzite" and believed that they formed the lower part of the over lying 'Infra-Trias' (see Abbottabad Formation). Marks and Ali (1962) and Latif (1970) named them "Tanol formation"; Calkins et al. (1969) made a detailed study and used the name Tanawal Formation for this unit of rocks. According to them, the Tanawal Formation consists mainly of quartzose schist, quartzite and schistose conglomerate. The unit is well exposed in the south and southeastern margin of the 'Mansehra Granite' and in a narrow belt to the northwest along the western flanks of the Balakot syntaxis. To the South of the 'Mansehra Granite', the Tanawal Formation mainly consists of medium-grained quartzite and fine-grained mica-quartz schist. In the area of the "Mansehra Granite" and northward, the grade of metamorphism in the Tanawal Formation is higher than in the south. In these areas, granite, biotite- muscovite-quartz schist, and andalusite-staurolite schist constitute the greater part of the Tanawal Formation (Calkins et al., 1969).

The thickness of the Tanawal Formation is difficult to measure due to structural complications. Marks and Ali (1962) estimated the thickness as 1666 m. At quite a few places, the Tanawal Formation is missing and the Hazara Formation underlies the Abbottabad Formation. The Tanawal Formation underlies the Abbottabad Formation and overlies the Hazara Formation in the area between Abbottabad and the Indus River. The contact between the Abbottabad Formation and the Tanawal Formation, in this area is marked by an unconformity, which is represented by a boulder bed known in the literature as Tanakki conglomerate. Calkins et al. (1969) further stated that between Abbottabad and Garhi Habibullah the lower contact of Tanawal Formation with the Hazara Formation is marked by only a lithologic change from slate to quartzite, which in places is gradational. In northeastern part of southern Hazara, the Tanawal Formation directly overlies the Precambrian Salkhala Formation with an unconformity.

Calkins et al. (1969) tentatively correlated the formation with the 'Muth quartzite' of Silurian-Devonian age exposed near Shimla, India. The Tanawal Formation is devoid of fossils. However, from the above-mentioned contact relation, it is evident that the Tanawal Formation is younger than the Hazara Formation of Late Precambrian age and older than the Abbottabad Formation. In the light of a new find of Cambrian fossils in the Abbottabad Formation, the age of the Tanawal Formation may also be Cambrian or Precambrian. Tanol is considered here a synonym of Tanawal and it is interesting to note that exposures of Tanol at Mansehra are older, not younger than Hazara Formation (Chaudhry and Ghazanfar, 1993).

**Sharda group:** The Sharda group (Fig. 4) has been described from Neelum Valley as well as from Kaghan Valley. Ghazanfar et al. (1983) named and described the Sharda group from Neelum Valley, Kashmir and in 1987 Chaudhry and Ghazanfar ascertained that the rocks of upper Kaghan Valley are in physical stratigraphic continuation of the same (Fig. 5). According to them, Sharda group of rocks is characterized by ubiquitous development of generally large size garnet, calcareous material, marble bands and generally with gneissic texture, which is better developed in the north". The group is divisible into two formations namely the **Sharda formation** and the **Gamot formation**

in the Neelum Valley and from where Wadia (1930) has originally described the Salkhala Formation. Analyzing the Wadia's description, Ghazanfar et al. (1983), stated that from Tithwal to Loath, over a road distance of many miles, some of the lithologies recorded by Wadia are barely present and that Wadia's definition of Salkhala Formation does not fit precisely here in the Neelum Valley. Instead, good part of the Neelum Valley section compares reasonably well with Wadia's own definition of the Tanol (Tanawal) formation. Therefore, they added, that the section between Tithwal and Loath "must be considered Tanol and not Salkhala".

Incidentally, this section covers Salkhala Village from, where Wadia (1930) had named and described the Salkhala Formation. Consequently, Ghazanfar et al. (1983) divided the Neelum Valley section into Tanol formation, exposed between Tithwal and Loath, comprising pelitic arenaceous material of the sub unit of Tanol formation such as the **Tithwal schists, Kundal Shahi - Nagdar schists and Athmuqam biotite chlorite phyllites.** While north of Loath in the Neelum Valley a sequence of a calc-pelitic material is named by Ghazanfar et al. (op cit) as Sharda group. As already stated, the Sharda group, according to Ghazanfar et al. (1983), Chaudhry and Ghazanfar (1987) is widespread in the Neelum and Kaghan valleys. In brief, the rocks in Neelum and Kaghan valleys as worked out by structural interpretation based on geologic mapping, are shown in attached geological/tectonic map, which includes stratigraphic order in Sharda group in upper Kaghan and Neelum valleys (Fig 5).

Sharda group as described by Ghazanfar et al. (1983) in Kashmir, from Neelum Valley is as follows: "Upstream of Loath there is a huge and extensive development of garnet mica schists and gneisses, calc-schists and marbles, garnet amphibole-calc gneisses, and kyanite bearing gneisses, calc-gneisses, graphite schists and paraamphibolites cut by Kel granite gneisses. This group of rocks extends over vast areas north and northwest of Dorian, Sharda, Kel, Gamot and Tarli Domel". The above definition applies only to the calc-pelite facies of the Kashmir section, which represents the Sharda group called earlier as "Salkhala" of Wadia. As opposed to the above sequence, the other pelitic arenaceous stratigraphic sequence of the Tithwal schists, Kundal Shahi-Nagdar schists and of the Athmuqam, biotite, chlorite phyllites collectively represent the Tanol (Tanawal) formation. Ghazanfar et al. (1983) added that the remarkably sharp contact between the two is marked by a fault along the north margin of a quartzite band just upstream of Tarli Loath. The fault is marked by the presence of cataclastics.

According to Ghazanfar et al. (1983), the Sharda group of rocks indicate original lithology of shales, calcareous shales, carbonaceous shales, marls and limestones, which have been metamorphosed to garnet-mica schist and gneisses, calc-schists, marbles, garnet-amphibole-calc-gneisses, graphite schists, gneisses, kyanite schists and paraamphibolites intruded by meta dolerites and granite gneisses. From south to north, the whole group shows an increasing intensity of regional metamorphism.

The Gamot formation is generally non-calcareous, although they are interbedded with bands of marble. On the other hand, the pelites of the Sharda formation are generally calcareous. Both the Sharda formation and the Gamot formation contain graphitic bands but the proportion and number

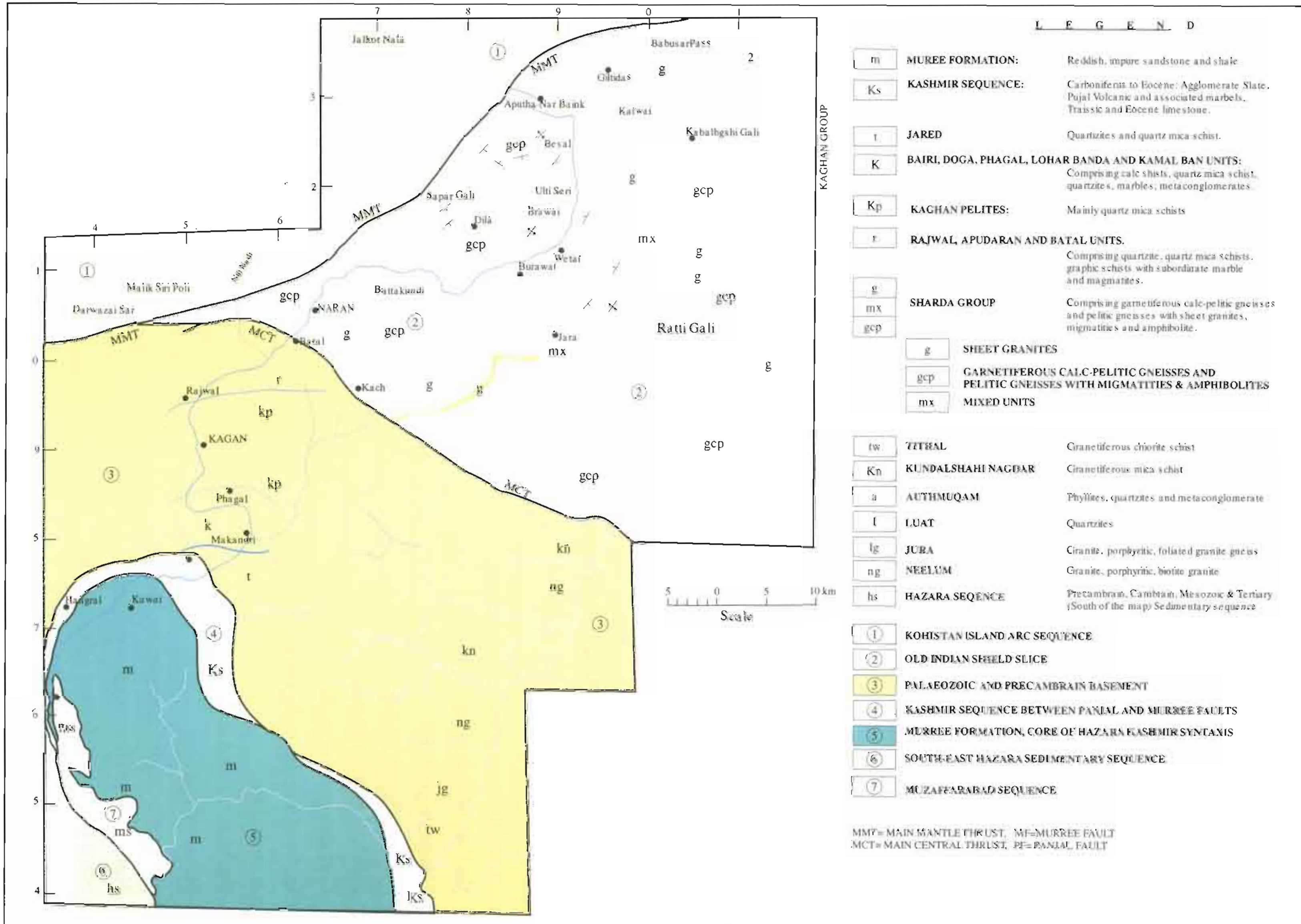



Fig. 5. Generalized geological map of Neelum and Kaghan valleys.

After Chaudry and Ghazanfar, 1983

increases in the Gamot formation.

**Sharda formation:** Sharda formation is named and described by Ghazanfar et al. (1983). According to them, the formation occurs on the roadside between Loath in the south and Kel Seri and Sheikh Bela in the north. It is comprised of garnet mica schist and gneisses, minor graphite schists, marbles, calc-schists, gneisses, garnet amphibole and calc-gneisses. However, southwards toward Dorian, this rock unit predominantly comprises garnet-mica schists and gneisses with a few bands of non-calcareous graphitic schists/gneiss. Schistosity at places is developed but commonly the rock is massive gneissose. Broadly, different lithologies can be grouped into number of units in the southern part, between Loath and Dorian. These are garnet-mica schists and gneisses with rocks from schistose to gneissic and porphyroblastic to poikioblastic and calcareous quartz mica gneisses, which are strongly gneissic and often sub porphyroblastic. The petrographic studies indicate an original composition varying from calcareous pelites argillaceous carbonates with occasional sandstone bands. In general, the formation indicates two important members in Sharda area, they are:

**Sharda gneisses:** Garnet-amphibole, calc-gneisses, some bands of marbles and a few minor graphitic bands represent the rocks of the Sharda formation near Sharda. The Sharda metagneisses are medium bluish grey on fresh surface and light earthy brown on weathered surface.

**Changan marbles:** It is present near Changan, where Sharda formation is distinguished by the predominance of marbles with alternating bands of calc-schists and gneisses. The marbles are generally light grey to medium-grey in colour with white bands.

Table 3. Sharda group of Kaghan Valley (after Ghazanfar et al., 1983).

Amphibolites
Migmatites and Granite gneisses including:
- Saif-ul-Maluk granite gneiss
- Dadar migmatites
- Badun granite gneiss
- Jalkhad granite gneiss
- Gittidas granite gneiss

Lulu Sar feldspathised porphyroblastic Gneiss
Mixed unit including:
- Purbinar mixed unit
- Basal mixed unit

Garnetiferous calc-pelitic gneisses including:
- Naran garnetiferous calc-pelites
- Burawai garnetiferous calc-pelites

Dhak graphitic gneisses (in Jalkhad Nar)
Bans pelitic gneisses

Dabukan marble
Dumri calc-pelites

***Kaghan Valley***: Sharda group at Kaghan Valley is exposed on the roadside from Batal to Babusar. Chaudhry et al. (1986) described the main lithologies of the group under geographic names, where the units are best exposed (Fig. 5).

**Dumri calc-pelites:** West of Sobhai Mahli between Bans and Batakundi, it occurs as a distinctively calcareous sequence on the right bank of Kunhar River. It also extends on the left bank below Dumri Maidan at Batakundi and mainly comprises of white pale yellow marbles intercalated with light grey to greyish brown pelites.

**Dabukan marble:** It is a distinctive white, massive, thick band of marble with subordinate layers of calc-pelites. Dabukan marble is present at Dunga Katha, Dabukan Katha and Dadar Nar north of Reori. In higher areas of Khaba Nar, it appears to be intruded by a number of amphibolite bands.

**Bans pelitic gneisses:** This lithology occurs in the area of Dharir (near Rakhan), Bans and Dila. It comprises of pelitic gneisses with subordinate psammites and occasional bands of marble.

**Dhak graphitic gneisses:** This unit is composed of dark-grey to black graphitic gneiss associated with feldspathised pelitic gneiss showing tourmaline needles and at places, kyanite lathes. It occurs as a small band on both sides of Jalkhad Nar near Dhak village.

**Garnetiferous calc-pelitic gneisses:** Garnetiferous calc-pelitic gneisses, is the principal lithology among the metamorphosed sedimentary rocks between Naran and Babusar. There are two main outcrops, one around Naran and the other around Burawai. Other lithologies like pelitic gneiss, calc-pelites and marbles are relatively minor. Greco et al. (1993), the Naran and Burawai formations, with the age of Permo-carboniferous, have later described these two units of Ghazanfar et al. (1983) as formations.

**Naran garnetiferous calc-pelites:** The calc-pelitic gneisses are generally light grey and light brownish grey on fresh surface and dark brownish grey or yellowish brown on the weathered surface. They are banded and show differential weathering with the micaceous and schistose layers appearing as ribs on the weathered surface. Their texture is gneissic and porphyroblastic and they are composed of calcite, garnet, biotite, muscovite and quartz. At times more than 50% of the rock is comprised of garnet in the Naran area from where the name has been derived. The unit is best exposed here, to which Greco et al. (1993) have named it as Naran formation and comprised mainly of metapelitic-metagreywacke gneisses and assigned lower Palaeozoic age.

According to Chaudhry et al. (1987), this unit of calc-pelitic gneisses is interbedded generally with amphibolite and impure bands of marble. They considered it Precambrian. The amphibolite bands are fine to medium-grained, well foliated, dark-greenish with shining on fresh faces and are garnetiferous. The interbedded marble bands constitute a subordinate lithology. They are white, light grey, or yellowish and yellowish-grey on fresh surface and greyish-brown or yellowish-brown, mustard or brown on weathered surface. They are generally medium-bedded and medium-grained.

**Burawai garnetiferous calc-pelites:** Burawai garnetiferous calc-pelites unit is pelitic gneiss and calc-pelitic gneiss with large sized garnets. At places, it shows alternation of pelites with thin bands of marbles or with thin laminae of quartzofeldspathic type. There are numerous quartz veins, which contain tourmaline needles. Occasionally, thin bands of paraamphibolite are developed. Generally, the rock unit resembles the description of Naran garnetiferous calc-pelites. The Burawai garnetiferous calc-pelites occur in the form of an elliptical outcrop, near Burawai, from where the name Burawai garnetiferous unit has been derived. Under the Mixed Unit, Chaudhry et al. (1987) described the lithologies exposed at Tatti Gali Nar, the Purbi Nar and a part of the Gittidas Nala. They have divided this mixed unit into Purbinar and Basal units.

**Purbinar mixed unit:** This unit occurs in the upper reaches of Purbinar, Tatti Gali and Dadar Nar. It is, generally a mixture of granite, gneiss and granitized feldspathised gneiss. These lithologies, at places can sometimes be mapped as separate units but mostly are inter-fingered and inter-woven. The granites are generally light grey and the gneiss shows shades of brown.

**Lulusar feldspathised porphyroblastic gneiss:** This unit is exposed on the roadside around Lulusar Lake and its outcrop is present in Khote Nar and Putha Nar. It is pelitic gneiss, which at most places shows development of feldspar porphyroblasts along with small sized garnets. The general colour is light brown.

**Migmatites and granite gneiss:** A number of granite bodies occur mostly associated with the metamorphic sequence. These bodies are sheet like and conformable as well as folded with the metamorphic rocks. Nearly all of them may be termed garnet tourmaline granite gneisses and especially near the contacts may show variable degree of migmatization. There are also some leucocratic younger garnet-tourmaline granite bodies. These are generally small and occur associated with granite gneisses and migmatite horizons.

**Gittidas granite gneiss:** Granite and gneisses with amphibolite bands and patches make the principal lithology of this unit. The granite is fine-grained and leucocratic, light grey to white on fresh surface. The gneisses are garnetiferous and high grade. They may contain sillimanite.

**Babun granite gneiss:** Leucocratic microgranite gneiss and granite occurs near the contact with Lulusar feldspathised porphyroblastic gneiss at Babun. The unit has a gradational relationship, away from the contact however, it is more massive. It occurs near Babun, Wear and Jobra, however, from north and south it joins with other granite gneiss bodies.

**Dadar migmatites:** These rock bodies occur in Dadar Nar and near Dharir. These are migmatites formed by anatexis of meta-pelites, meta-arkoses, acid meta-tuffs (?) and meta-feldspathic psammites. They show a wide variety of structures within leucosomes. They show stromatitic, phelabitic and neublitic structures. The palaeosome and metasomes show a particularly complex relationship. Agmites and restites are also common. Schilleren, ghost structures and stratigraphy can be seen in the neubilites. The restites are orthoquartzites, calc-pelites, amphibolites and marbles. The pelites with minor carbonate contents also tend to survive anatexis.

**Saif-ul-Maluk granite gneiss:** The Saif-ul-Maluk granite/gneiss is a non-porphyritic, fine-to medium-grained, strongly foliated biotite granite gneiss/migmatite with thin pegmatite veins. The granite gneiss at many places contains abundant relics of transformed (granitized) metasediments and screens. It is extremely well foliated dark coloured biotite granite gneiss/migmatites with irregular leucocratic bands. It appears to be a trans-formed granitized paragneiss. The modified metamorphic element appears to be considerable, especially in the dark granite gneiss. The gneiss is granitized and aplitised frequently.

**Gamot formation:** The other formation of the Sharda group is Gamot formation named and described by Ghazanfar et al. (1983). To the north of Surgam and Dokharian, the Gamot formation is represented by kyanite gneisses, marbles, calc gneisses, graphitic gneiss and paraamphibolite.

**Manglaur group:** Basement rocks of the Mingora-Dagger area have been named as Manglaur group by Chaudhry et al. (1992). This name originates from Manglaur formation of Kazmi et al. (1984).

Manglaur group constitutes a lower Pacha formation and an upper Swat granite gneiss formation (Fig. 6), the later is intruded into the former. The group is mainly composed of augen/porphyroblastic granite gneiss, pelite-psammite schists, graphitic schist, marble, migmatites, amphibolites and non-porphyritic tourmaline bearing granites gneiss. The base of this group is not exposed. Its top is unconformable with the overlying Alpurai group of Chaudhry et al. (1992). The Manglaur group extends from the Pak-Afghan border in west, continues towards east up to Besham area, and covers the area south of Kohistan island arc.

**Pacha formation:** The name Pacha formation was given by Chaudhry et al. (1992) to the Manglaur schist of Kazmi et al. (1984). Earlier Kazmi et al. (1984) had separated this unit from Swat gneiss or lower Swat-Buner Schistose group of Martin et al. (1962). The constituent lithologies have been described from type section at Pacha, where this formation is well exposed. According to Chaudhry et al. (1992), the Pacha formation is a heterogeneous suite of rocks composed predominantly of pelite-psammite, and quartzite. Marble, calc-silicate marble, graphitic-schist with amphibolite occurs as subordinate lithologies.

Orthoquartzites and quartzites are off white to dirty white in colour and thick-bedded. The weathering colours are rusty-yellow to rusty-brown or greyish-brown.

The pelite-psammite unit is siliceous and composed of bands rich in quartz, mica and garnet. It is light grey to off white or earthy looking. It weathers to rusty-grey colour.

The marble beds in the Pacha formation are earthy grey or white. The grey beds are thick-bedded and weather to rusty-grey colour. The white marble is thin- to thick-bedded. The thinner beds are impure and the foliation planes show shining and radiating to fibrous or bladed crystals of tremolite. These beds are cut by abundant quartz veins (3-10 cm thick), which occur along as well as across the foliation. The thicker beds contain much less quartz and show a granular/sugary texture. These marble beds weather to off white to dirty white colours. Rusty and rusty grey colours are less common.

Amphibolites are garnetiferous and rare. These are black to dark grey rocks with red garnet spots and white quartzofeldspathic grains and whether to rusty-grey. Due to intrusion of granite

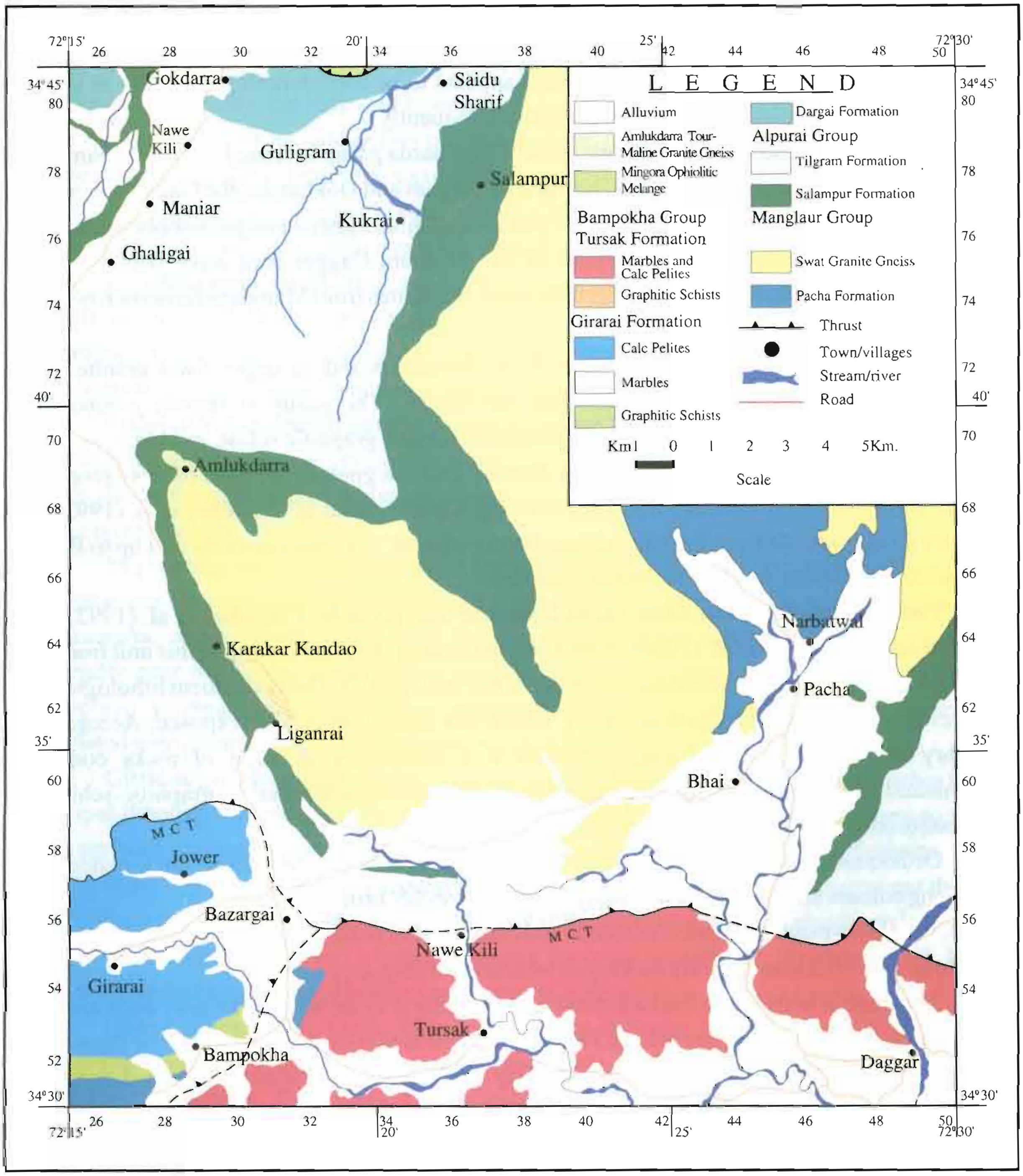



Fig. 6. Geology of Saidu Sharif - Daggar area, Swat, N.W.F.P., Pakistan.

Courtesy: Shahid Hassan and Hamid Dawood, 2006 bodies, metasomatism and partial anatexis, migmatization is common in Pacha formation.

Pacha formation is exposed mainly in the cores of the anticlines. The base of this formation is not exposed and the top beds are intimately admixed with the overlying porphyroblastic Swat granite gneiss. In Puran-Chakesar region, old basement garnet tourmaline bearing non-porphyritic granite gneisses and migmatites occur.

In view of mixed zones between porphyroblastic Swat granite gneiss and Pacha formation and the upper age constraint on the former, the later must be Proterozoic in age. The Choga granite (Alpurai area) and Loe Sar dome granite (near Manglaur) cut these metasediments. On the basis of U-Pb zircon age of Choga granite (468±5 Ma) and Loe Sar dome granite (268±7 Ma), these metasediments can be considered Early Cambrian to Precambrian age (Anczkiewicz et al., 1998).

Chaudhry et al. (1992) correlated this formation with Lulu Sar gneisses of Precambrian age. The granite gneisses in Puran and Chakesar (the non-porphyroblastic garnet-tourmaline old basement gneisses) may correlate with parts of Besal-Di-Khari granite gneiss and Saif-ul-Maluk granite gneiss of Kaghan.

**Swat granite gneiss:** Granitoid of Swat cut through the Pacha formation and mostly overlie it as extensive sheets, which are folded along with enclosing metasediments into broad NS trending basins and domes.

A massive sheet like body intruded into the Pacha formation has been named Swat granite gneiss by Kazmi et al. (1984), distinctive feature of this unit is the occurrence of beryl in it. Chaudhry et al. (1992) described this rock unit in sufficient details.

In Swat area, Pacha formation forms migmatites and mixed zones with the porphyroblastic granite gneisses (a part of Swat granite gneisses). There occurs basement garnet tourmaline bearing non-porphyritic granite gneisses and migmatites, in Puran Chakesar area, which had entered Besham antiformal structure and are exposed mainly in the deeply eroded core areas. These may be regarded as lower levels of Manglaur group.

According to them, the formation is of heterogeneous character and is composed of the following rock types:

(i) *Porphyroblastic granite gneiss*: This is the predominant unit in Swat. It contains porphyroblasts of microcline, which generally range from 2 x 4 cm to 5 x 8 cm. These are generally white in colour and set in a groundmass of quartz, albite, muscovite and biotite. Some tourmaline and occasionally a little garnet may also be present. The porphyroblasts are stretched and at places, augen shaped. This type is off-white to pale-white with black biotite flakes. It shows light rusty to grey weathering colours. It also shows boulder weathering. Presence of psammitic xenoliths is very common. Screens, measurable up to a few meters across are also noticed in these granitic gneisses.

(ii) *Massive biotite granite*: It is relatively fine-grained and may contain porphyroblasts of K-feldspar up to 4 cm. Its mineralogy is similar to that of porphyroblastic granite gneiss. However, it is fine-grained and massive looking though foliated. It is pale to off-white and weathering to light rusty-grey to grey. It forms cliffs. It is probably this massive unit, which has been dated as Cambrian by radiometric methods.

(iii) *Tourmaline-garnet granite gneiss*: It is fine-grained and occurs as massive looking but foliated bodies. Its fresh and weathering colours are similar to the type (ii) above. It forms cliffs.

(iv) *Rapakivi type biotite and sphene bearing granites*: These granites have been described by Humayun (1985), it contains pink K-feldspar. The megacrysts are up to 2 cm. The formation forms a mixed zone at its lower contact with the Pacha formation. The upper contact is unconformable with Salampur formation. In other words, the upper contact is tectonised with the development of mylonite zones.

The granite gneiss exposed in Malakand Agency can be divided into (i) Kot-Malakand gneiss, (ii) Selai Patti granite gneiss and (iii) Kolangi granite gneiss. The first two gneisses are two mica bearing non-porphyritic gneisses whereas, the Kolangi granite gneiss is porphyroblastic granite gneiss. The granite gneisses comprise of quartz, feldspar, muscovite, biotite garnet±amphibole±epidote and ±chlorite. The presence of migmatites and pegmatites associated with Kolangi granite gneiss indicates these rocks as representing deeper levels of the basement. Gneissosity in general is well developed. These rocks at places represent multiple intrusions, which may be identified based on texture and mineralogy. Pegmatites quite often cut these rocks. The mineral composition of pegmatites also varies in the above-mentioned varieties of granite gneiss.

Generally, the porphyroblastic Swat granite gneiss has been correlated with late Precambrian to Cambrian Mansehra granite. Chaudhry et al. (1992) added that the Mansehra granite has age dating of 515±16 Ma. The Mansehra pluton is composite and heterogeneous body and covers a large range of age, which goes older than Cambrian. More clearly it may be stated that with the exception of tourmaline granitic facies, the Mansehra pluton is Cambrian and older. Chaudhry et al. (1992) also indicated that except for their porphyritic nature, comparison between Mansehra granite and porphyroblastic Swat granite gneiss is superficial. "The later is a part of granite gneiss sheet, which occurs in Higher Himalayan rather than Lesser Himalayan setting". Thus the two also occur in very different tectonostratigraphic framework. The constraint on the upper age limit of Mansehra pluton is lower Cambrian (Chaudhry et al., 1992). Based on U-Pb-zircon dating, the Choga granite and the Loe Sar dome granite, which are apparently parts of Swat granitoid gneissic complex have 468±5 Ma and 268±7 Ma age (Anczkiewicz et al., 1998).

Table 4. Stratigraphic sequence of Higher and a part of Lesser Himalaya in Swat, west of Besham syntaxis (Fig. 6).

| | | |
|---|---|---|
| MINGORA OPHIOLITIC MÉLANGE | Talc carbonate, greenschist, amphibolite, serpentinite, gabbro, siliceous and graphitic schist. | Cretaceous to Eocene |
| | ------------------ Indus Suture ------------------ | |
| LESSER HIMALAYAN SEQUENCE BAMPOKHA GROUP | | Upper Palaeozoic to Lower Mesozoic |
| Tursak formation | Marble, calc-pelite and graphitic schist | |
| Girarai formation | Calc-pelite and graphitic schist | |
| | ------------------ Unconformity? ------------------ | |
| 2nd Cover | | |
| Dargai formation | | Palaeozoic (Eo-Cambrian)/ Mesozoic |
| | ------------------ MCT (or Unconformity?) ------------------ | |
| HIGHER HIMALAYAN SEQUENCE ALPURAI GROUP | | |
| 1st Cover | | Late Proterozoic to Palaeozoic/Mesozoic |
| Tilgram formation | Garnetiferous calc pelite, graphitic garnetiferous Calc-pelite and marble | |
| Salampur formation | Psammite, pelite and amphibolite | |
| | ------------------ Tectonised Unconformity ------------------ | |
| MANGLAUR GROUP | | |
| Pacha formation | Pelite-psammite schist and gneiss, calc-silicate marble, graphitic schist, migmatite and amphibolite (The sequence is cut and migmatized by granitic bodies Precambrian in addition, amphibolites). The sequence falls in upper amphibolite facies and sillimanite grade. | Late middle to Early Proterozoic. |
| | ------------------ Unconformity ------------------ | |
| SWAT BESHAM BASEMENT GNEISSES | Mainly non-porphyritic garnet-tourmaline and often zircon bearing granite gneiss, some paragneiss, old migmatite and their enclaves with intruded and interbedded almandine amphibolite. The whole sequence is cut by gneisses of 1400 Ma. 900 Ma. 510-550 Ma, 468 Ma. 268 Ma. and Tertiary granites and migmatite. | Early to Middle Proterozoic |
| Base not exposed | | |
| | | (after Chaudhry et al., 1994) |

**Alpurai group:** Alpurai schist of Kazmi et al. (1984) has been raised to the rank of group as Alpurai group by Pogue et al. (1992). Pogue et al. divided the group into four formations. The oldest one is Marghazar formation overlain by Kashala formation followed by Nikanai Ghar formation and capped by Saidu formation, with age of the group as Palaeozoic to Mesozoic on the other hand Chaudhry et al. (1992) divided their Alpurai group into psammites, pelites and amphibolites in lower part named it as Salampur formation and the upper part containing garnetiferous calc-pelite, marble, graphite, garnetiferous calc-pelites as Tilgram formation, with a pronounced unconformity between the two formations. The age of Alpurai group of Chaudhry et al. (1992) is stated to be Precambrian (Fig. 6).

**Salampur formation:** The Salampur formation is named and described by Chaudhry et al. (1992). It is a very distinct unit, which persistently overlies the Swat porphyroblastic granite gneiss and underlies the Tilgram formation. It is nowhere cut by this granite gneiss. However, it is intruded by Tertiary Amlukdarra tourmaline-garnet microgranite gneiss and its aplitic facies. DiPietro et al. (1999) described a similar formation in the same area and to the west and named it Marghazar formation.

The Salampur or Marghazar formation is composed of about 70% amphibolite and 30% pelite-psammite. It falls in the upper amphibolite facies of regional metamorphism. The metasedimentary part is in fact a turbidite sequence, which often shows graded bedding. The layers are silvery-grey to off white. The mica rich layers are silvery in colour and are often studded with small reddish-brown garnets. The quartzitic layers are dirty white, off white and light grey. At places they may show small scale cross bedding. The weathering colours are rusty yellow, rusty brown and rusty grey to grey.

The amphibolite beds are generally black to dark-greenish grey. They may have white specks, grains and filled vesicle like spots, composed of quartz or feldspar. Red garnet shows erratic distribution. Its size varies from 2 mm to 1 cm. It is fine- to medium-grained, well foliated to schistosed/mylonitised. Rarely small patches and areas of retrogressed amphibolite with pale-green to green epidote and dark-green chlorite may occur. At places medium- to coarse-grained patches and pods of amphibolite may be present. Weathering colours of amphibolites are rusty-grey, rusty brownish grey and dark-grey. The metasedimentary part may contain 7 to 10 cm thick veins of quartz, which are generally parallel to S 1. These may be boudinaged, compared with granitic rocks and the garnetiferous calc-pelites and marbles of overlying Tilgram formation. It weathers readily and forms gentler slopes and gullies. The thickness of this unit varies from tens of metres to more than a kilometre.

This unit lies over the Swat formation (porphyroblastic granite gneiss). However, the contact has been strongly tectonised and at places intruded by Tertiary granitic rocks. The upper contact of this formation with Tilgram formation is also very abrupt. It is marked by an amphibolite horizon (metavolcanic). The age of the formation is determined as Precambrian by Chaudhry et al. (1992). DiPietro et al. (1999), based on the stratigraphic position, determined the age of the Marghazar formation as Permian.

**Tilgram formation:** Chaudhry et al. (1992) described the formation as composed predominantly of banded garnetiferous calc-pelites with subordinate grey to white or bicoloured (grey and white) marbles. Pelitic horizons are rare. It has a high grade and falls in upper amphibolite facies of regional metamorphism. DiPietro et al. (1999) mapped the same unit as Kashala formation comprising calc-garnet schist, schistose marble, calcic marble, dolomitic marble and calcareous phyllite.

Describing the details of the Tilgram formation, Chaudhry et al. (1992) stated that the calc-pelite is coarse grained and garnetiferous. It is mostly banded. The bands are generally 0.5 to 5 cm thick. Alternating bands are rich in garnet and carbonate. The carbonate rich bands are light grey to off white but weather to rusty (light) colour. There are two varieties, medium to dark-grey variety is graphitic but graphite does not exceed 3-5%. Garnet stands out as brown to red crystals. These are subidioblastic. At some places, there are crystals and aggregates of elongated crystals of amphibolite, which are black to dark-green in colour and can be seen along the foliation planes. The rock is banded, with alternate garnet rich and garnet poor bands. The garnet poor bands are carbonate rich and weather to rusty colours. The garnet crystals range from 0.5 to 2.5 cm in general. Rarely, crystals as big as 4 cm are also present. The rock is composed of calcite, garnet, mica, quartz, amphibole and graphite. Iron oxides may also be present. The second variety is greyish silvery light grey. It is rich in muscovite. It is also distinctly banded. The bands are cent metric (up to 3.4 cm). It often does not contain amphibole. The size of garnets is normally 0.5 to 2.5 cm. Garnets bigger than 3 cm are rare. Quartz is more abundant in this type as compared with above-mentioned graphitic variety. This rock is also coarse-grained and rich in garnet.

The marble bands are subordinate but may form a distinct horizon. The marbles are medium- to thick-bedded, grey, white or bicolour black and white. They weather to dirty off white to light rusty grey colours. The marble beds are generally pure carbonate horizons.

Pelitic horizons are rare. They are silver-grey and weather to rusty off white to dirty off white to yellow. At places, they may contain kyanite. Coarse-grained garnetiferous amphibolite bodies, though present, are rare. These are blackish in colour with white feldspar and quartz and red garnet crystals. These bodies are usually concordant.

The marble horizons are cliff forming, whereas garnetiferous calc-pelite stands out as steeper slopes.

The lower contact of this formation with Salampur formation is abrupt. It is marked by amphibolite (metavolcanic). The upper contact is faulted against either Girarai formation or Tursak formation. Towards north, this formation may be (unconformably) overlain by Dargai formation (Chaudhry et al. 1992).

This formation overlies the Salampur formation and underlies the Bampokha Group (with a major fault). The Tursak formation of this Bampokha group contains fossils regarded by King (1961) as of possible Silurian/Devonian age. This Tilgram formation is regarded, however, as Precambrian in age and in fault contact with Tursak formation by Chaudhry et al. (1992). Hussain et al. (1998) reported that the marble sampled from the middle part of Kashala formation yielded Carnian (Late

Triassic) conodonts.

**Dargai formation:** Dargai formation is named and first described by Chaudhry et al. (1974a and 1976) as Dargai schist. The Dargai formation is named after the town of Dargai, where it is composed predominantly of dirty grey to greenish grey graphitic pelites with subordinate marble and calc-pelites. At places, thin greenschist horizons of volcanic/hypabyssal (intrusive) nature of unknown origin may be present. Psammite horizons are minor. Based on mineral assemblages, these rocks are placed in the lower greenschist facies.

The pelites are comprised of quartz, muscovite, biotite and variable amounts of graphite. Chloritoid is rarely encountered. Zircon, sphene, tourmaline and pyrite occur as accessories. In graphite, poor rock graphite also occurs as an accessory mineral. Milky coloured quartz veins, which may show pinch and swell structure, or may be intricately folded, are quite common.

The calc-pelites are composed of calcite, dolomite, muscovite and biotite. At places, grossularite garnet is also present. The marble horizons are often dolomitic. The entire sequence falls in greenschist facies of medium pressure metamorphism. The Protolith of metasediments are black shales, marls and dolomites/dolomitic limestones.

The schists just north of Dargai contain tectonic slices of talc-carbonates, greenschist/ greenstones that may be of sutural origin (i.e. Indus Suture Mélange). However, volcanic/hypabyssal sills/dykes may also be present, (Nawaz Chaudhry written communication 2003).

**Saidu schist:** Named and described by Kazmi et al. (1984), earlier it was called phyllitic schists of Martin et al. (1962), graphic schists of Ahmed et al. (1987) are pelitic and arenaceous rocks, calcareous metasedimentary rocks of Malakand and Dargai area of Chaudhry et al. (1976). All of these rocks are, in fact, similar in their internal morphological characters. Chaudhry named them as Dargai formation, and according to Chaudhry et al. (1976), these schists unconformably overlie the Tilgram formation. In Saidu area, the upper contact is marked by MMT. The rocks near Saidu are grey to dark-grey pelites with a very small portion of interbedded calcareous schists and marbles. The less graphitic rocks have, somewhat, greenish hue and are chloritic. The common weathering colour is rusty grey. At places, these may have millimetric to centimetric quartz veinlets. Folding and faulting is observed in these rocks especially closer to their contact with overlying Mingora ophiolitic mélange zone. Based on its mineral assemblages, these are placed in the lower greenschist facies. These rocks appear to have gradational contact with the underlying Tilgram formation but the abrupt decrease in the metamorphic grade of these rocks suggests an unconformity or a tectonic break between the two rock units. These schists tend to weather readily and form slopes and gullies. They generally do not form cliffs. In Saidu area, these rocks are mylonitised/tectonised.

Kazmi et al. (1984) have correlated Saidu schist with the Indus Suture flysch. However, according to Chaudhry (1992) this formation does not exhibit flysch character anywhere. It rather resembles restricted water facies representing anoxic conditions. Based on its stratigraphic position, its age according to Kazmi et al. (1984) may be between Palaeozoic to Mesozoic. Chaudhry et al. (1976) nevertheless, regard the formation as Precambrian. They correlated Dargai formation with Attock slates.

**Besham block / Besham complex:** Many workers describing the rocks of the Besham area have used the word block or complex. Here the word complex is used to describe the rocks of Besham area, where assemblage of rocks of different origin have been folded together, intricately mixed, involved or otherwise complicated. Martin et al. (1962) first described the geology of part of this area. This work was of reconnaissance type and they covered only the surroundings of Karora Village. Jan and Tahirkheli (1969) studied the area in more details covering a large area of the lower part of the Indus Kohistan. This was followed by Shah (1976), who published a brief note on the metamorphism and pre-existing structure of the section between Thakot and Shatial Bridge. Jan (1977) summarized petrographic studies of the basic complex of Kohistan. Ashraf et al. (1980) reported the detailed work on mineralization and included in their studies, the work carried out by Engineers Combine Limited (ECL) on the geology and economic mineral investigation in Besham-Kohistan area. Fletcher et al. (1986) established the nomenclature of the rock units of the area. Baig et al. (1989) and Baig (1990) gave the details and dates of the Besham group and divided the group into lower Thakot formation comprising quartzofeldspathic gneisses and graphitic schists and the upper Pazang formation with banded quartzite, marble and calcareous schists.

La Fortune et al. (1992) like many previous workers, also produced a geologic map covering the area between Karora and Besham villages and restricted their mapping up to the western bank of Indus River (Fig. 7).

Stratigraphically, they divided the sequence of the Besham complex into five units. The oldest is the Besham group as defined and named by Fletcher et al. (1986). It is composed of heterogeneous gneisses and metasediments. Among the heterogeneous gneisses, Ashraf et al. (1980) have named the sodic quartzofeldspathic gneisses of Besham group as Lahore granite.

The second oldest rocks, according to La Fortune et al. (1992) are the mafic dykes, which intruded Besham group. These dykes have been metamorphosed to amphibolite grade. The third group of rocks includes cogenetic small granitic intrusions and associated pegmatites. The granitic intrusions have been named as Shang and Dubair granodiorite, these intrusions have been named and considered as "late stage differentiates" of Lahore granite by Ashraf et al. (1980). La Fortune et al. (1992) named the pegmatite as Shorgara pegmatites.

The fourth unit in the Besham Area is 'Karora group' which rests unconformably over the earlier three units. Jan and Tahirkheli (1969) and Ashraf et al. (1980) described the Karora group and identified an unconformity between Besham and Karora groups. The fifth unit is leucogranite that intrudes both the Karora and Basham groups, as described by La Fortune et al. (1992).

The creation of a new formation by DiPietro et al. (1999), the "Kishar formation" may have its merits. Its isolation from the Besham group is rather little earlier. The work, in these areas, is still in progress and every thing below the Amlo metaconglomerate is considered as part of Besham group including the Kishar formation, until positive and convincing reasoning becomes apparent. As of now, here, the present status of Kishar formation is one of the units of Besham group.

**Besham group:** Thus, La Fortune et al. (1992) has lithologically defined the Basham group, as predominantly composed of quartzofeldspathic gneisses, soda granite gneisses, and graphitic schists and minor quartzite and carbonates. No units older than the Besham group have been found in the Besham complex. The gneisses are light grey, medium-grained, equigranular and contain 5% to 12% biotite. Other minor and trace minerals include muscovite, epidote, magnetite, zircon, sphene and apatite. The mineral assemblage of the gneisses is broadly representative of epidote-amphibolite facies metamorphism.

The second most abundant lithology within the Besham group is pelitic metasediments. They include very fine- to medium-grained graphitic schists and mica schists (Fig. 7).

Graphitic schist is highly sulphurous within the Besham group and occurs as laterally discontinuous layers and pods up to 30 m thick. Contact of the graphitic schist with the gneisses is generally sharp. The mineralogy of the schist consists of very fine-grained quartz, feldspar, biotite, muscovite and 4% to 10% graphite, with small crystals of pyrite.

The mica schist varies from fine to medium-grained and from schistose to a weakly gneissic fabric. Mica schist of the Besham group commonly grades laterally into graphitic schist.

In addition to pelitic metasediments and quartzofeldspathic gneisses, the Besham group includes minor beds of quartzite, carbonate and rare calc-silicate gneiss. The quartzites are impure and consist of quartz, feldspar and muscovite, with traces of sphene, zircon and rutilated biotite. Rarely pure quartzite pods also occur as lenses of a few meters dimension within the Besham group. At many locations, minor lenses of dolomitic carbonate up to 10 m thick are in sharp contact with the quartzite and pelitic metasediments of the Besham group.

The protolith for the calc-silicate gneiss was probably a calcareous arenite (quartz-dolomite-feldspar-clay) (La Fortune et al., 1992).

Ashraf et al. (1980) described the presence of skarn bodies within the Besham group. Thin skarns are formed; where pegmatites have intruded the metasediments especially carbonate bodies. Important among these skarn bodies are magnetite carbonate skarn, siliceous magnetite skarn and magnetite silicate skarn.

The upper contact of the Besham group with Karora group is unconformable. The base of the Besham group is not exposed and no unit older than Besham group is present in the Besham complex.

Oldest metamorphism occurred at >2000 ± 6 Ma, > 1950 ± 3 Ma, 1865 ± 3 Ma and at 1887 ± 5 Ma (Baig et al., 1989). They further added, "These metamorphic and deformational phases were post-dated by approximately 1500 Ma graphic tourmaline-bearing muscovite sodic granites (Baig et al., 1989). This data confirms that the sedimentation, mafic and felsic magmatism, polyphase metamorphism and deformation in the Besham basement complex occurred before Middle to Late Proterozoic, unconformable, deposition of the Karora group".

**Kishar formation:** Interesting and striking is the creation of a new formation i.e., the Kishar formation, named and described by DiPietro et al. (1999). They claim to have isolated it from the Besham group, whereas these beds were considered to be the part of the Besham group by previous workers. Undoubtedly, the formation unconformably underlies the Karora formation. The Kishar formation has been located at only two small separate localities. One of them lies in a road cut along the Besham-Karora road ~ 5 km west of Besham. The second is along the Karakoram Highway about

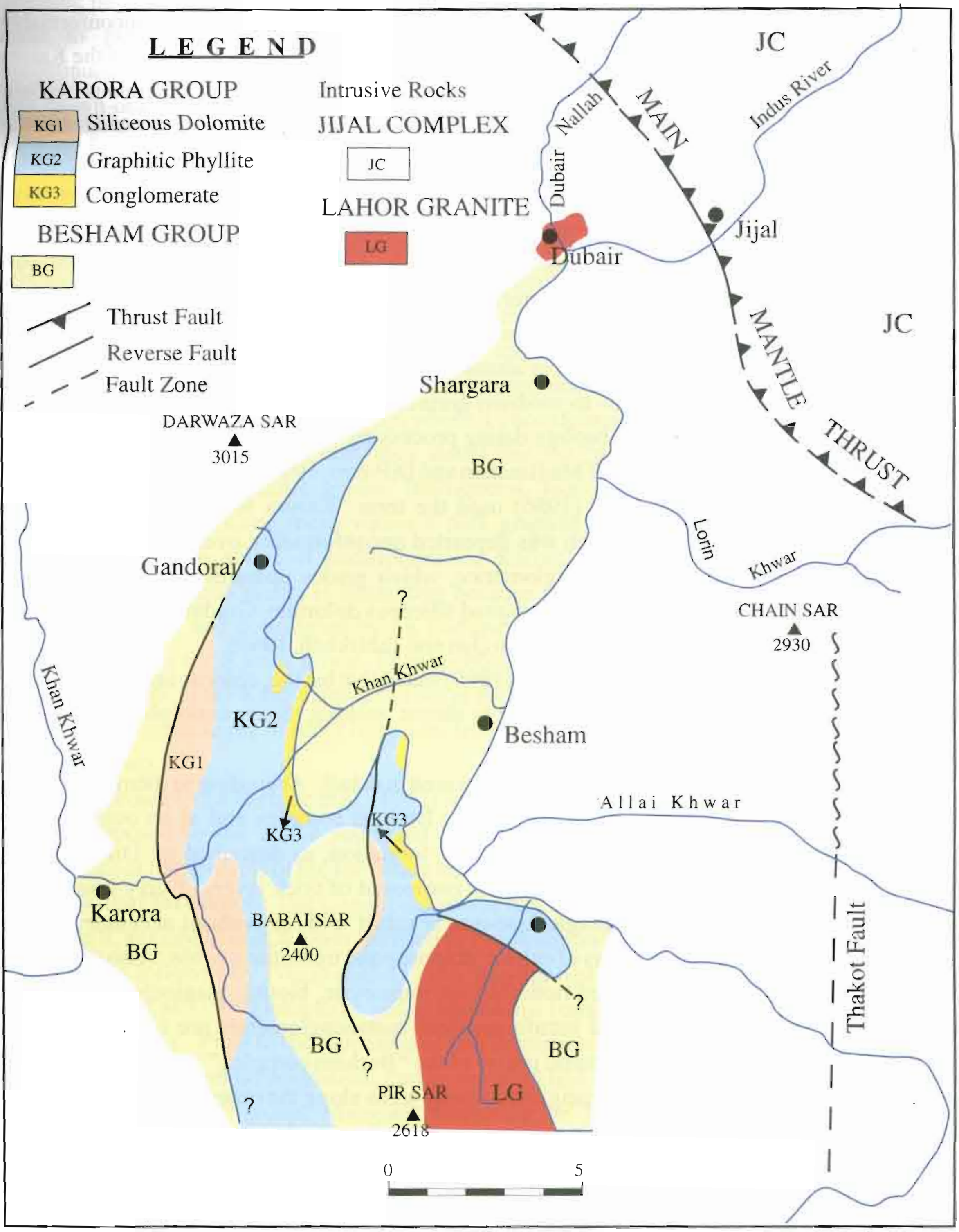



Fig. 7. Geological map of the Besham area, Northern Pakistan.

6 km north of Besham.

According to DiPietro et al. (1999), the sequence of the Kishar formation is unconformably overlain by the Amlo metaconglomerate of Baig (1990), which is the basal member of the Karora group. They recorded that along the Besham-Karora road, the Amlo metaconglomerate is overlain by thick sequence of undifferentiated Karora group. This situation gives the impression that the unconformity is regional, and that the Kishar formation is characteristic of the Besham complex. On the other isolated exposure, they added that the road cut along the Karakoram Highway by contrast is isolated structurally overturned and surrounded by intrusive rocks of the Besham group.

Lithologically, the Kishar formation as described by DiPietro et al. (1999), is as follows: "The Kishar formation in both areas is characterized by two lithologies of unknown protolith. The first is a dark-grey, very fine-grained nonschistose biotite quartz plagioclase rock without obvious foliation that in thin section shows pervasive alteration of plagioclase to sericite and calcite. The second is a dark-grey, granular, fine- to medium-grained biotite bearing quartz plagioclase K-feldspar rock with weak foliation. Absolute dating processing of zircons grains from the Kishar formation yielded a U-Pb age of 2175 ± 7 Ma (Isachen and DiPietro, 1997 in DiPietro et al., 1999).

**Karora group:** Fletcher et al. (1986) used the term "Karora formation" to describe a sequence of marine metasediments which was deposited unconformably over the Besham group. This unconformity is marked by metaconglomerate, which grades upwards into a thick unit of graphitic phyllite and in turn, is overlain by a jointed siliceous dolomite. Gradations between these units and wide variations within them are common (Jan and Tahirkheli, 1969).

La Fortune et al. (1992) and earlier Baig (1990) stated that biotite, chlorite and muscovite are present in the Karora group of rocks and garnet is absent, making the metamorphic grade of the Karora group as of greenschist facies.

DiPietro et al. (1999) mapped and studied the area in detail. According to them the "Karora formation" (group) occurs as an inner belt within the Besham complex and as an outer belt that surrounds the Besham complex. The lithology of the formation, as described by DiPietro et al. (1999) is characterized by graphitic schist, which is composed of thick layers of very fine-grained dark quartz rich graphite-muscovite-plagioclase-quartz schist with or without accessory biotite. This schist is associated with thick layers of calcite, dolomite and tremolite marble. Also present are subordinate layers of dark, fine-grained nonschistose muscovite, biotite, plagioclase and quartz metapsammite. At places quartzite and intraformational metaconglomerate are found. Intrusive contacts with the largely underlying granitic gneiss of the "Besham complex" are present along the inner belt of the Karora group, east of Shang and at many areas along the outer belt especially on the eastern limb of the Indus River anticline. Intrusive contacts are characterized by: interlayered granitic gneiss and schist, small plutons in the Karora group, dikes that crosscut schist and marble and xenoliths of graphitic schist and marble in the Besham complex.

La Fortune et al. (1992) in the description of the Karora group stated that graphitic phyllite commonly grades into extremely fine-grained, black, dirty quartzite and /or metapelite. The best exposures of these two lithologies occur along the Kurmang Khwar on the road near Gandorai.

Graphitic phyllite locally grades into metapelite, ranging from medium-grained psammitic-biotite schist to extremely fine-grained muscovite-biotite metapelite. The metapelite occurs as discontinuous beds less than 20 m thick. The muscovite-biotite metapelite typically weathers to light brown-orange colour, and is locally aphanitic. Quartz, feldspar and micas compose the major minerals, with traces of zircon, graphite and sphene.

La Fortune et al. (1992) reported that the carbonate is exposed in an elongate north-trending unit that reaches its maximum thickness of about 500 m between Upal and Panial villages. It pinches out laterally to the south of Upal and to the north of the Besham-Karora road. The most abundant carbonate is a dark-grey to black siliceous metadolomite that is well exposed along the Besham-Karora road. The rock has quartzose interlayer in vein-like segregations up to 4 cm thick. There are many lithologic variations within this relatively extensive carbonate sequence.

According to DiPietro et al. (1999) the Amlo metaconglomerate member named by Baig (1990) is at the base of the inner belt of Karora group, where it unconformably overlies the "Kishar formation". Describing the lithology of the unit, they stated that the "metaconglomerate contains pebble to boulder size clasts of granitic gneiss, leucogneiss, leucogranite, amphibolite, metapsammite, quartzite and quartz sericite rocks within a dark graphite bearing psammitic matrix that grades upward into graphitic schist of undifferentiated Karora group. The occurrence of leucogranite pebbles and leucogneiss pieces is interesting because leucogranite sills are found intruded in the Besham area rocks and considered by La Fortune et al. (1992) as the youngest unit of Besham complex including the Karora group. These pebbles may be expected within the intraformational metaconglomerate of the Karora group but not at the base of it. However, it is also possible that these pebbles of leucogranite are of older intrusion, from within the Besham group, and much older than the Karora group.

According to La Fortune et al. (1992) leucogranite and leucogneiss are younger than Karora group as opposed to the above statement of DiPietro et al. (1999). Either they are different leucogranites or the contacts of the formation have created confusion.

**Gandaf formation:** The Gandaf name was first used by Khan, S. R and Khan, Asif (1994), who called it, as Gandaf unit, a lower division of Precambrian Salkhala Formation in Swabi-Rustam area. This was followed by Pogue et al. (1995), who applied it to Precambrian rocks in the Tarbela area. DiPietro et al. (1999) adopted it and extended this formation northward along the Indus River to the Besham area. Prior to the extension of this formation into the Besham area and inclusion of certain beds in the Gandaf formation, earlier workers had mapped and included these beds into Besham group, Karora group, Manglaur formation or Tanawal and Salkhala Formations of Precambrian age Calkins et al. (1975); Williams (1989) and Baig (1990). The type locality is designated near the village of Gandaf in the Tarbela Lake area by DiPietro et al. (1999).

Lithologically, at the type locality, the formation consists of dark schists interlayered with graphitic slate, phyllite schist, marble, calcareous phyllite and schist and nongraphitic marble. The base of the formation is not exposed at its type locality.

According to DiPietro et al. (1999), the Gandaf formation can be traced up to southwest of

Darband, where garnet appears in the dark schist. North of Darband, the formation contains thick layers of garnet schist with dark garnet, biotite, muscovite, plagioclase and quartz schist typically with quartz veins. This garnet schist can be used as a horizon marker along the eastern and western limbs of the Indus River anticline, where it occurs at more than one stratigraphic horizon. Associated with the garnet schist are thick layers of fine-grained nonschistose plagioclase biotite quartz metapsammite. This metapsammite is similar to metapsammite in the Karora formation but is typically lighter in colour and more schistose and grading to medium-grained quartz feldspathic schist. In addition to garnet schist and metapsammite, the Gandaf formation contains thick layers of graphitic schist and subordinate dark muscovite schist, calcite marble, tremolite marble and quartzite. The abundance of garnet schist with insignificant graphitic rock distinguishes the Gandaf formation from the more graphite and calcareous Karora formation.

The lower contact of the Gandaf formation with Karora formation is well exposed along the eastern limb of the Indus River anticline east of Bar Kabulgram and in a locality along the western limb west of Chakesar. The contact appears to be transitional. Over a few meters graphitic schist of the Karora formation grades into lighter coloured metapsammite and garnet schist of the Gandaf formation. The contact along the eastern limb of the Indus River anticline near Thakot is difficult to place due to intrusions of granitic gneiss.

According to DiPietro et al. (1999) the Swat and Mansehra granitic gneisses intrude the Gandaf formation along its upper contact. North of 34° 45' N, schist and metapsammite are interlayered with concordant sheets of augen gneiss. Contacts in this area are locally sheared along both brittle and ductile fault. South of 34° 45' N, the contact is discordant and there are abundant xenoliths of schist and metapsammite within augen gneiss. A discordant relationship is particularly evident in the Black Mountain, where compositional layers in the Gandaf formation are truncated by Mansehra granitic gneiss.

Gandaf formation according to DiPietro et al. (1999) contains abundant intrusive rocks. These rocks include biotite orthogneiss and mafic rock of the Kotla complex and a pegmatite mafic dike and sill sequence similar to the Besham complex. Numerous additional bodies of granite, granitic gneiss, pegmatite and mafic rock are also present. The smaller intrusions of the granite bodies are particularly abundant in the northern part of the Gandaf formation north of 34° 30' N.

Earlier, the above-mentioned beds were mapped as the Tanawal Formation by Ashraf et al. (1980), Williams (1989) and Baig (1990). But DiPietro et al. (1999) include these beds in Gandaf formation and argue, "Interlayer of graphitic rock marble and orthogneiss (including the Kotla complex) that are typical of the Gandaf formation and not typical of the Tanawal Formation".

**Kaghan group:** Ghazanfar and Chaudhry (1986) named the unit by raising their Kaghan formation to the rank of group. All the major sub units described in the Kaghan formation by Ghazanfar and Chaudhry (1985), have also been given the status of formations. They mapped the Kaghan Valley and adjoining areas at the scale of 1:17000 for the first time and described at least five major stratigraphic units present in the area. Among them, the Kaghan group is a new addition. The group is predominantly composed of quartz schists, calc-schist and quartzite. It is named after the

Kaghan Valley from where all the three constituent formations have also been described. The oldest unit of the Kaghan group is named Rajwal formation, overlying it is the pelites unit named Julgran formation largely and monotonously greenish-grey quartz mica schists unit. The top one is now called Mahandry formation. These names have been established by Chaudhry et al. (1997). The type section of the group and that of the formations is stated to be the exposures across Buttle fault in Kaghan. Age of the group is considered Precambrian to Cambrian (Fig. 5).

**Rajwal formation:** This is the oldest unit of the Kaghan group described by Ghazanfar and Chaudhry (1986). The formation is further divisible into the following three subunits:

a) Rajwal quartzite

b) Paludaran graphitic schist

c) Batal quartzite subunit

**Batal quartzite subunit:** This subunit is dominantly quartz mica schist and quartzites with thin sheet of granites, subordinate marble and some thin amphibolite bands with a few chlorite schist patches. Bulk of the unit is light grey to brownish-grey on the fresh surface and grey to dull brownish-grey on the weathered surface.

Associated with Batal quartzite is quartz mica gneiss, the main lithology of which is brownish grey quartz mica gneiss with the development of garnet at a few places. At other localities the garnet cannot be seen with the naked eye.

Ghazanfar and Chaudhry (1985) reported an old volcano-sedimentary sequence within quartz mica schists. They stated, "Within the quartz mica schist, some distinctive green chlorite schist patches are found, which may either represent retrogressive metamorphism or metagneisses material of volcanic affinity. These along with the presence of the amphibolite bands may also indicate the presence of an old volcano-sedimentary sequence".

**Paludaran graphitic schist:** This subunit is mainly composed of graphitic schist, quartz mica schists and gneisses with some calc-schists and occasional marbles.

Graphitic schist is dark-grey on fresh surface and dark-grey to dark-brownish-grey, at places rusty-brown on weathered surface. Pyrite crystals are present which weather out leaving square cavities behind. Associated with graphitic schist are lepidioblastic quartz mica schist and gneisses. It is composed of muscovite, graphite and quartz with many other accessory minerals predominantly composed of quartz, feldspar, biotite, mica and some garnet. Tourmaline, graphite and calcite may occur as brownish-grey on the weathered surfaces. Apart from quartz veins and boudins, some fine pegmatite veins are present.

This subunit also contains subordinate bands of calc-schist and schistose marbles, intercalated with graphitic schist. The marbles are white and cream colour on fresh surface and weather yellowish-brown to dark-brown.

**Rajwal quartzite:** Upper part of the Rajwal quartzite is mainly composed of quartzites, quartz mica schist, pegmatites, aplite and granite. This unit is composed of the following lithologies: Metapelites are comprised of garnetiferous quartz mica schist and gneisses and make up the principal lithology of this subunit in the almandine grade. Quartz and micaceous minerals, almandine garnet, and tourmaline make up the bulk of metapelite.

Metapsammites are well developed in both pure and impure forms and are comprised of feldspathic quartzites.

Migmatites are well developed in the lower part of the Rajwal quartzite exposed in the lower reaches of Bhimbal Katha. Sometimes the migmatites are banded with bands of quartz mica gneiss and of acidic material.

Pegmatites/Aplite: The most distinctive characteristics of the lower and middle part of this subunit are the presence of pegmatites/aplite. The pegmatite/aplite bodies, which are present in the form of veins and patches, can vary from a few cm to over 15 m. Especially the main components are feldspar, quartz, muscovite and biotite, with smaller amount of chlorite, tourmaline and garnet. The pegmatites are simple in composition.

Granites: Granites are in veins and patches and are much smaller in proportion to the pegmatites. They are subporphyritic to porphyritic.

Marbles: Marbles constitute a subordinate lithology and are present mainly in the upper part of the subunit, in the form of thin bands or intercalations. They are composed predominantly of carbonate but small amounts of quartz, pyrite and muscovite may also be present.

Microaugen gneisses: This lithology is present in the uppermost part of the sub unit after a graphitic horizon. It is well exposed at Kudi Ka Maidan. It contains complicated and variable lithology and contains garnetiferous quartz mica gneiss, quartzofeldspathic microaugen gneiss, aplite and pegmatites. The garnetiferous layers contain occasional needles of amphibole.

Rajwal formation is Precambrian to Cambrian in age. The upper contact of the formation is with Julgran formation and the lower contact ends against MCT.

**Julgran formation:** This formation is named by Chaudhry et al. (1997) to the unit, which was earlier named Kaghan formation by Ghazanfar and Chaudhry (1985) as one of the three units of Kaghan group.

Ghazanfar and Chaudhry (1985) described this unit as composed of at least four distinct subunits. They are quartz mica schist, graphitic schist, marble and gypsum. Among them, the most abundant is the quartz mica schist. The formation is well exposed on the roadside for about 13 kilometres between Rajwal and Khannian upstream and downstream of Kaghan Township. Several villages are located on the formation. The formation further extends to greater heights and peaks, where inhabitation is not possible.

About 90% of the formation is exclusively quartz mica schist. It is the oldest subunit of the Julgran formation and has a distinctive silvery-greenish-grey on the fresh surface and is greenish-grey to greenish-brown or creamish on weathered surface.

The quartz mica schist is garnetiferous, the garnet is almandine. The size of the garnet is small (1 to 3 mm) and decrease stratigraphically upwards.

The quartz mica schist of Julgran formation is also characterized by well-developed schistosity, and is composed mainly of quartz and micaceous minerals (biotite, muscovite and chlorite). Minor amount of tourmaline, pyrite and graphite also occurs.

According to Ghazanfar and Chaudhry (op. cit) occasionally the quartz mica schist is graphitic. One such band occurs below gypsum on the right bank of Kunhar River, between the villages of Asman Banda and Putandes. The graphitic schist occasionally shows square cavities produced by the weathering out of pyrite crystals.

The occurrence of marble and gypsum, in more than one band has been noticed especially in the upper part of the formation, where it is the most distinctive. Marble is generally yellowish on weathered surfaces and cream or white on fresh surfaces. It is intercalated with thin gypsum.

A well-developed gypsum outcrop occurs on the path from Kaghan to Putandes on the right bank of the Kunhar River. However, the best development of gypsum is to the southeast of Kaghan at a height of over 348 m below Sirul Danna. The gypsum here is generally found as thick bands, interbedded with yellow weathering micaceous marble. The main bands of gypsum together are over 80 m thick. This high-level outcrop can be seen on a clear day looking southeast from the roadside near Kaghan.

The upper contact of Julgran formation is faulted on the roadside against the lower quartzites of Mahandry formation. The lower contact is also sharp and abrupt and faulted against the Rajwal quartzite unit of Rajwal formation.

The formation is correlated with Hazara Formation based on its dominant pelitic compositions and the presence of gypsum.

**Mahandry formation:** Mahandry formation has been named by Ghazanfar and Chaudhry (1985 and 1986). They described this rock unit under the following five subunits.

Kamalban quartz mica schist that includes quartzites, calc-schist and marbles: This subunit is dominantly composed of lithologies indicated by its title.

Quartz mica schist make up the main lithology but quartzites, marbles and calc-schists are more striking and prominent. The quartz mica schist indicates a biotite grade. At places, porphyroblasts of chlorite can be seen.

The pure quartzites are white, cream or light green and grey and generally banded on the fresh surface, while on the weathered surface, they are creamish-yellow, rusty-brown and yellowish-grey.

The calc-schist is generally greenish-grey on fresh surface and brownish-grey, yellowish-grey or dark-grey on weathered surface. It may be banded in the form of schist and marble bands. Occasionally there is a gradation between calc-schist and marbles. It is common to find schist and thin bands of marble intercalated in varying proportions.

Marble layer within this subunit of Kamalban are small bands. Rarely massive marble layers are only few and are about 6 to 10 m thick. The other marble horizons individually are 2 to 3 m thick and are generally associated with calc-schists.

**Lohar Banda marble:** Lohar Banda marble subunit overlies the Kamalban subunit. It is a thick marble band and has been mapped separately by Ghazanfar and Chaudhry under the name Lohar Banda marble, which is distinct and acts as a marker horizon for control in the field mapping. It is mainly white, light-grey and light green-banded marble with some calc-schists. At least two distinct outcrops of the Lohar Banda marble can be traced over a long distance.

**Phagal quartz-mica-schists and quartzites:** This subunit overlies Lohar Banda marble and comprises of quartz-mica-schist and quartzites with subordinate calc-schists and marble. On the weathered surface, it is generally dark-brownish-grey and rusty.

On the roadside, the Phagal subunit is exposed at the back of the road bend in Lohar Banda Katha, where its pelitic and psammitic nature is quite apparent. Away from the road, the outcrop occurs in an arcuate fashion between Kandlan in the west and Manur Katha in the east.

The quartzites are present in the form of pure ortho and micaceous type. They are grey and white on fresh surfaces and brownish to rusty-brown on weathered surfaces. It is medium-grained and often granoblastic. The grains are welded and sutured.

The quartz mica schist is greenish-grey on fresh surface and dark-brownish-grey on the weathered surface. They contain veins and boudins of quartz. The quartz mica schists are poorly to moderately schistose.

The marbles are also present in this subunit. They are medium-grained and granoblastic. They are composed mainly of carbonate with accessory to trace amounts of muscovite, chlorite, pyrite and magnetite.

**Doga schists:** Doga schists consists of marbles, quartzites and metaconglomerate. It is the forth subunit of Mahandry formation. The schists include both quartz mica schist and calc-schist. The subunit is much like Kamalban subunit with main difference from the Kamalban subunit in having fine metaconglomerate and quartzites with porphyroblasts of chlorite and biotite and differs from overlying Biari subunit in having much less metaconglomerate. The subunit occurs in a limited area, exposed at south of the ridge top between Parhti, Doga and Danna.

The Doga quartzites are banded, light greenish-grey with green porphyroblasts and some intercalations of grey micaceous marble. Marble is banded light grey and white with schist partings and weather to light earthy-brown, greenish and grey colours, occasionally the marble band may be white.

**Biari quartzites and metaconglomerate:** This subunit also contains schists, calc-schists and pegmatites. It is the fifth and youngest subunit and the top part of the Mahandry formation. It resembles the Doga subunit but differs in having ubiquitous pegmatites and considerable amount of metaconglomerate. The subunit is banded grey, brownish-grey and greenish-grey. In this subunit, the calc-schists are subordinate and the metaconglomerate are much more prominent. The quartzites of Biari subunit as well as that of Doga subunit are mostly micaceous and in this respect differ from the quartzites of Kamalban subunit, which are mostly orthoquartzites. Some quartzites in Biari unit are impure and look porous. This unit is also characterized by the general absence of graphitic schist (Fig. 5).

The quartzites present in this subunit are generally banded grey, brownish-grey, greenish-grey and whitish on fresh surfaces and dark-brownish-grey and rusty-brown on weathered surface. They are generally micaceous, containing porphyroblasts of green chlorite and sometimes brown biotite and intercalations of quartz mica schist.

Metaconglomerate is also important constituent of this subunit, the pebbles of which stand out on the weathered surface. The pebbles are generally dark-grey or dark-greenish-grey in colour while the ground mass is light grey to light greenish-grey. Other lithologies in the subunit include quartz mica schist, which is generally light-grey, greenish-grey and brownish-grey on fresh surface, while on the weathered surface, it is dark-brownish-grey to dark-grey. It is interbedded with quartzites, metaconglomerate and marbles. They contain some quartz veins in the form of thin boudins. Chlorite and biotite are prominent flaky minerals. In addition, calc-schist and marbles are few thin grey and white marble bands present, especially towards the Doga subunit. The marbles have thin micaceous partings. The calc-schists are distinguished by differential weathering.

The Biari, like the Rajwal unit is distinguished by the ubiquitous presence of pegmatites. However, these pegmatite bodies are generally small (at times only few inches thick veins) compared to those of Rajwal subunit of the Rajwal formation and appear badly crushed and sheared, especially near the faulted contact. The age of the formation is Precambrian to Cambrian.

**Jobra formation:** A small lens of wollastonite bearing calc-silicate rock was named Jobra formation by DiPietro (1990). It is exposed on the Leosar dome west of Pacha, southern Swat. It is interlayered with tremolite marble, garnet-biotite schist, quartzite, and amphibolite and overlies with sharp contact the Swat granite gneiss and is unconformably below the Marghazar formation. According to DiPietro (1999) the Jobra formation is not in "contact with the Manglaur formation but overlies Swat granite gneiss structurally above the Manglaur formation". The age of the Jobra formation was originally considered Devonian (by Pogue and DiPietro) and later they discovered a calc-silicate marble lithologically similar to the Jobra formation that occurs as a xenolith within the Swat granite gneiss in the area northeast of Saidu. This xenolith was first described by Shams (1963), which would imply that the Jobra formation is Cambrian or older. He also correlated it with sandy dolomite of the Cambrian Ambar formation. It may well be Early Proterozoic.

# PALAEOZOIC

Exposures of Palaeozoic rocks are present in the Kohat-Potwar Province, adjoining parts of Axial Belt and in northern areas including Hazara and Chitral. Although, Palaeozoic geology of the Northern Pakistan is largely revised, however it is still not adequately dated and the stratigraphic correlation in many areas is very difficult with the current knowledge.

The oldest record, of sedimentary rocks of Palaeozoic in the northern areas, is probably the upper part of Tanawal Formation or its equivalent. They represent metasedimentary and metamorphic complexes and range in age from Late Precambrian to Cambrian. Evidence, based on diagnostic fauna for Ordovician and Silurian rocks, has been found at only two places, viz. western Lesser himalaya and in the Northern Sedimentary Province (Fig. 1). Similar is the case with Devonian and younger rocks, i.e. the fauna is plentiful in Khyber area as well as in Chitral and parts of Gilgit. In eastern part of Lesser Himalaya, which includes Kashmir and Hazara, only sparingly record of the Palaeozoic life is preserved, especially of the Cambrian. Southward in the Kohat-Potwar Province, Cambrian and Permian rocks with rich faunas occupy a considerable area in the Salt and Khisor ranges. The Palaeozoic sedimentary sequence in the Kohat-Potwar Province is of the order of several hundred meters in thickness but with a pronounced unconformity indicating the absence of the Ordovician to Carboniferous systems. Outcrops of upper Palaeozoic are reported in Balochistan; they are found as allochthons and are present in a linear belt marginal to the Axial Belt and the Balochistan Basin.

## CAMBRIAN

The Cambrian System of Pakistan has been best studied in the Salt and Khisor ranges, where the sequence is well developed (Fig. 8). Although in northern areas, some rocks have been assigned Cambrian age; yet plentiful fossil evidence is lacking. However, in Lesser Himalaya, a division of Himalayan Tectonostratigraphic Basin, the presence of the Cambrian rocks in the Kashmir and Hazara areas has been undoubtedly recognized.

Lithologically, the Cambrian of Kashmir is mainly composed of foliated clay, slate, greywacke and limestone containing Late to Middle Cambrian fauna, while that of the Salt Range, it is composed of sandstone, shale and dolomite beds with Early to Middle Cambrian fauna. The sediments of the Hazara area have some lithological similarity with Salt Range, especially on evaporative style of deposition but scanty Cambrian fauna which is found in the Hazara area has not yet been reported either from the Salt Range or from Kashmir.

Formations occurring in the Indus Basin, Axial Belt and the Northern areas are described basin wise in the following pages.

**Indus Basin**

***Upper Indus Basin (Kohat-Potwar Province)***

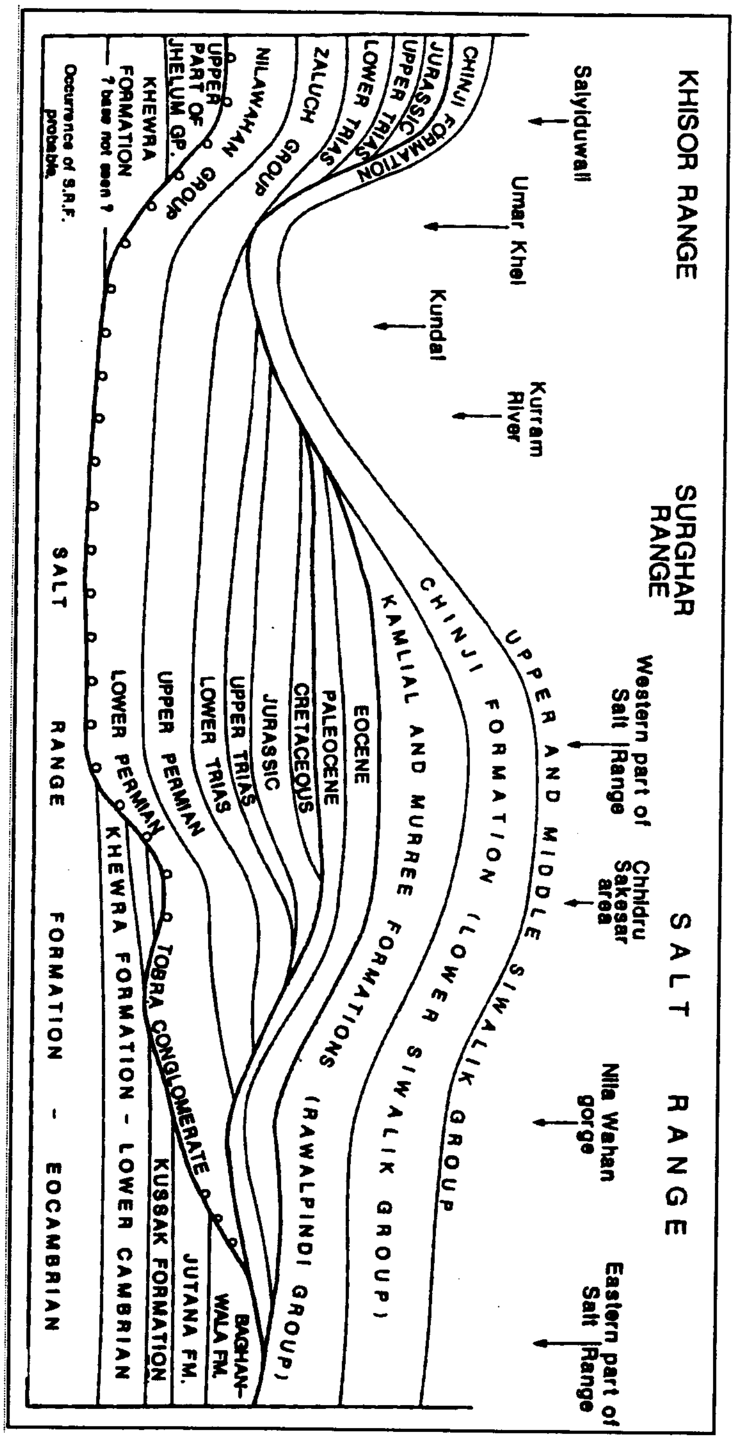
The area discussed in this basin covers the Kohat-Potwar Province (Fig. 8), which includes Salt Range and Khisor Range. The Cambrian formations recognized in these regions are as follows; (serially numbered, oldest No. 1):

5. Khisor Formation
4. Baghanwala Formation
3. Jutana Formation
2. Kussak Formation
1. Khewra Sandstone

The Cambrian rocks of the Khisor and Salt ranges consist of sandstone, shale, and dolomite with glauconitic interbeds, which were essentially deposited in shallow water, except for the lowermost and uppermost formations, which represent transgressive and regressive facies respectively.

**Khewra Sandstone:** The name "Khewra group" was originally proposed by Noetling (1894). Prior to that, Wynne (1878) called the formation "Purple sandstone series". The latter name continued until recently, when the name of the formation was formalized as "Khewra Sandstone" by the Stratigraphic Committee of Pakistan, Fatmi (1973). The type locality is in Khewra Gorge near Khewra Town, Salt Range.

The formation consists predominantly of purple to brown, yellowish-brown, fine-grained sandstone. The lowermost part of the formation is red, flaggy shale. The sandstone is mostly thick-bedded to massive. Sedimentary features like ripple marks; mud cracks etc. are common in the formation. The contact of the Khewra Sandstone with the underlying Salt Range Formation has long been the subject of controversy, which arose because of age dispute of the Salt Range Formation. Sahni (1947) and his school of thought regarded the age of Salt Range Formation as Tertiary and postulated a thrust at the contact between Salt Range Formation and the Khewra Sandstone. Gee (1945, 1981) mapped the entire Salt Range and concluded that the contact between the two formations is sedimentary. The formation is predominantly sandstone in the Khewra Gorge; however, in the Khisor Range the upper part of the formation grades upward into glauconitic sandstone, which is taken to mark the base of the overlying Kussak Formation. The Khewra Sandstone is widely distributed throughout the Salt Range. Thickness at the type locality is about 150 m. In the western Salt Range, it is 200 m and the exposed thickness in the Khisor Range is about 60 m. The formation contains only a few trace fossils in the Salt Range, which have been interpreted as trilobite trails by Schindewolf and Seilacher (1955) and are not indicative of any particular age. However, as the overlying Kussak Formation is not older than late Early Cambrian, the age of the Khewra Sandstone is almost certainly Early Cambrian.




After Gee, 1983

Fig. 8. Diagrammatic illustration of the major unconformities in the Eocambrian to Tertiary sequence of the Salt Range-Surghar Range-Khisor Range.

Baqri et al. (1991) carried out a detailed study of the Khewra Sandstone and they were of the opinion that Khewra Sandstone represents a deltaic sequence with distinct bottom-set, fore-set and top-set deposits of the ancient Cambrian delta. Khewra Sandstone can be texturally divided into sandstones, silty sand, sandy silt and siltstones, and consequently, may be termed as Khewra Siltstone. The sandstone appears to be a good reservoir for oil, gas and water and may be exploited for its hydrocarbon potential in the subsurface.

**Kussak Formation:** Wynne (1878) applied the name 'Obolus beds' or 'Siphonotrata beds' to a predominantly greenish-grey, glauconitic, micaceous sandstone and siltstone. Waagen and Wynne (1895) used the name "Neobolus beds" for the same unit. Noetling (1894) proposed the name "Kussak group" and finally the Stratigraphic Committee of Pakistan formalized the name of the unit as Kussak Formation (Fatmi, 1973). The type locality lies near Kussak Fort in the eastern part of the Salt Range.

At the type locality, the formation is composed of greenish-grey, glauconitic micaceous sandstone, greenish-grey siltstone, interbedded with light grey dolomite and some oolitic, arenaceous dolomite. Numerous layers of intraformational conglomerate are also present. Pink gypsum lenses are present near the top. The formation contains 5 to 25 cm long thin lenses of fossil asphalt (gilsonite) as observed by the present author. The general lithology throughout the Salt and Khisor ranges is uniform. However, thicknesses vary at different places. The formation is widely distributed throughout the Salt Range with its best exposures in the eastern part. Thickness at the type locality is 70 m but varies from 6 to 53 m at other places. In the Khisor Range the formation is 55 m thick.

The formation is fossiliferous and has yielded the following fauna: Neobolus warthi, Botsfordia granulata, Lingulella wanniecki, L. fuchsi, Hyolithes wynnei, Redlichia noetlingi. Schindewolf and Seilacher (1955) regarded the age as Early Cambrian. However, Teichert (1964) has shown that R. noetlingi is allied to or perhaps even identical with R. forresti that occurs in Australia in beds of early Middle Cambrian age. The age of the formation is, therefore, either late early or early Middle Cambrian.

**Jutana Formation:** Fleming (1853) named this unit "Magnesian sandstone". Noetling (1894) described it as Jutana stage. The Stratigraphic Committee of Pakistan formalized the name as Jutana Formation. The type locality lies near Jutana Village in the eastern Salt Range.

At the type locality, the lower part of the formation consists of light green, hard, massive partly sandy dolomite, while the upper part is composed of light green to dirty white massive dolomite. In the upper part, brecciated dolomite is also present with matrix and fragments of the same rock. In the eastern Salt Range the formation is conformably underlain by the Kussak Formation and conformably overlain by the Baghanwala Formation. In the western-most Salt Range, it is not present. However, farther west in the Khisor Range, the formation is conformably overlain by the Khisor Formation ("Khisor gypsiferous beds"), which is equivalent to the Baghanwala Formation of the eastern Salt Range.

The formation is thickest in the eastern Salt Range, whereas at the type locality it is 80 m thick. It thins westward. Its exposures in the Khisor Range have a thickness of 50 m. The formation is fossiliferous. Schindewolf and Seilacher (in Teichert 1964) collected and described some fossils from the shale unit in the middle part of the formation exposed in the eastern Salt Range including Lingulella fuchsi, Botsfordia granulata, Redlichia noetlingi and also a gastropod identified as Pseudotheca cf. subrugosa. The age of the formation is described as late Early Cambrian to early Middle Cambrian.

**Baghanwala Formation:** The name Baghanwala Formation is now given to the rocks of the "Pseudomorph Salt Crystal Zone" of Wynne (1878) and the "Baghanwala Group" of Noetling (1894), which overlies the Jutana Formation. Holland (1926) called these beds "Salt Pseudomorph beds" and Pascoe (1959) named them "Baghanwala Stage". The type section is located near Baghanwala Village in the eastern Salt Range.

The formation is composed of red shale and clay with alternate beds of flaggy sandstone. The flaggy sandstone exhibits several colours including pink grey or blue green, especially in the lower half of the formation. Sedimentary structures such as ripple marks and mud cracks are common. Numerous pseudomorphic casts of salt crystals, which are found along the bedding planes, are the diagnostic feature of this formation.

Presence of casts of salt pseudomorphs coupled with the absence of fossils indicates lagoonal environment and arid climatic conditions for the deposition of the formation. The formation is mainly developed in the eastern Salt Range. The outcrops disappear a few kilometres west of Makrach but reappear at Chittidil and Chhidru localities in the central Salt Range. The formation has been encountered in the sub surface at Karampur village. Near Baghanwala, its thickness ranges from 100 to 116 m. The same thickness has been reported from northeast of Khewra, but in the Khewra Gorge, it is reduced by erosion to only 40 m. The upper contact of the Baghanwala Formation with the overlying Tobra Formation is unconformable, whereas the lower contact with the Jutana Formation is conformable.

The formation contains only trace fossils. Since the Baghanwala Formation rests conformably on the Jutana Formation, which is considered as early Middle Cambrian in age, the same age may be assigned to the Baghanwala Formation.

**Khisor Formation:** Gee (1945) described a unit of rocks composed of gypsiferous dolomitic shale and dolomite lying between the Jutana Formation and the Tobra Formation in the Khisor Range as "Gypsiferous Series". Hussain (1960) undertook a detailed study of the unit and named it "Khisor gypsiferous beds". The Stratigraphic Committee of Pakistan approved the name Khisor Formation. The Khisor Formation is limited only to the Khisor Range, where it is exposed only at one place near Saiyiduwali. This formation is not present in the Salt Range. However, its stratigraphic equivalent, the Baghanwala Formation, is fully developed in the eastern Salt Range.
At the type locality Hussain (1960) divided the rock unit into two parts. The lower part consists of massive white gypsum, with few thin beds of fine, grey, crystalline dolomite. At the base of the formation, a meter thick band of dolomite and dolomitic shale occurs.

The upper part is composed of light coloured, bedded shale, with finely crystalline dolomite and white gypsum. The shale is light grey in colour and is thin- to medium-bedded. The dolomite is medium to thick-bedded and the gypsum is massive.

The formation has conformable contact with the underlying Jutana Formation, whereas the upper part of the formation is terminated by disconformity with the Tobra Formation.

The formation is devoid of mega-fossils. However, the rocks have not been examined for micro fauna. Since the formation occupies the same stratigraphic position as the Baghanwala Formation of the Salt Range, it is assumed that it represents early Middle Cambrian age.

**Axial Belt**

The formations discussed in this belt lies in the Attock-Cherat Range and southern Hazara. The unit of Darwaza, in Attock-Cherat Range, while Tanawal, Abbottabad and Hazira Formations are exposed in southern Hazara. Although Tanawal Formation is of Precambrian to Cambrian age, which is only partly exposed in the Axial Belt, the main body with its type sections is well developed in the adjoining Himalayan Tectonostratigraphic Basin, therefore, it is described in the Precambrian chapter, and here only the Abbottabad and Hazira Formations are described.

***Attock-Cherat Range***

**Darwaza formation:** Darwaza formation of Tahirkheli (1970) has been renamed as Darwaza formation by Hussain et al. (1991). According to them the formation is exposed in the southern block and consists of a north dipping homoclinal sequence. The Darwaza formation is the oldest unit and is represented by limestone and dolomite that grades upward into grey-green, thin-bedded maroon shale. In the lower part white to light green and yellowish green dolomitic limestone, with dendrites, is present. The minimum thickness of the formation is 280 m. The age of the formation is considered as Cambrian (Hussain et al., 1990).

**Hazara Area**

In recent years workers have extracted some Cambrian fossils from Abbottabad and Hazira Formations and found the basis for new age concepts. Although the fossils found by different workers are customarily considered to be Cambrian in age, yet they have not so far been reported from the other Cambrian rocks of Pakistan.

Since, this is the first time that the Cambrian fossils have physically been extracted from Abbottabad Formation as compared to conjectural and hypothetical age assignment by the earlier workers, it is desired that the formations be described in detail. The stratigraphic order of Cambrian rocks of the Abbottabad area is given below:

Hazira Formation (Cambrian)
Abbottabad Formation (Cambrian)
Tanawal Formation (Precambrian to Cambrian)

**Abbottabad Formation:** Waagen and Wynne (1872) studied the sequence of dolomite and quartzite rocks well exposed in the Sirban Hill near Abbottabad and named it "Below the Trias". Middlemiss (1896) renamed it "Infra-Trias". Marks and Ali (1962) suggested the name Abbottabad Formation. Calkins et al. (1969), who mapped southern Hazara, studied all its exposures and adopted the name Abbottabad Formation. Latif (1970a) named this unit of rocks as "Abbottabad group" and divided it into constituent formations.

The type section of the Abbottabad Formation is designated near Abbottabad town. The formation consistently extends to Garhi Habibullah, Sherwan and the Indus River. Exposures are also found between Muzaffarabad and Balakot and in the apex area of Balakot syntaxis.

Calkins et al. (1969) described the Abbottabad Formation as consisting mainly of dolomite, quartzite and phyllite, with many lithologic changes and inter-fingering facies from place to place. For example, in the Tarbela area the main constituents of the formation are thin phyllite and conglomerate at the base followed by quartzite, dolomite and again quartzite, which caps the formation. In the Abbottabad area, the lower phyllite unit is replaced by conglomerate named as Tanakki by Latif (1970a) followed by alternating shale, sandstone and dolomite representing two units as Kakul and Sirban formations within his "Abbottabad group". In the Muzaffarabad area basal conglomerate is overlain by quartzose sandstone followed upward by alternating dolomite and limestone.

Besides, the above-mentioned lithologic units, the formation contains beds of thick marble containing workable phosphate deposit especially in the Abbottabad area. The marble of the Abbottabad Formation is generally laminated or thin-bedded, it ranges in colour from white and grey to blue. It is siliceous and at many places interbedded with quartzite. The quartzite is thin-bedded in the Manda Kuchha syncline, tan to snow white, and which weathers to white quartz sand.

In the Sherwan area the Abbottabad Formation has an unconformable contact with Tanawal Formation. At places the unconformity is determined by the presence of a boulder bed, but elsewhere, there may be only lithologic change. In the eastern part of southern Hazara across the Panjal fault, the underlying Tanawal Formation is missing and the Abbottabad Formation resets unconformably over the Hazara Formation. The thickness of the formation is about 660 m at the type section of Sirban Hill near Abbottabad. Marks and Ali (1962) estimated the thickness as 200 m in the Tanol area, 833 m northeast of Muzaffarabad. It is only 100 to 130 m on the eastern flank of Garhi Habibullah syncline (Calkins et al., 1969). In the Balakot and Mahandry areas the Abbottabad Formation is interbedded with agglomerate slate (Probably tectonic event), which further east in Kashmir, contains a fauna of Carboniferous to Permian age (Calkins et al., 1969). According to these authors, the formation is most probably Carboniferous to Permian in age.

Research in the area has revealed the presence of small conical tubes in the formation. They are identified as *Hyolithelminthes (Hyolithellus spp).* The same horizon in upper part of the Abbottabad Formation has yielded *Hyolithes* spp. *Hyolithellus* has been reported from the Early Cambrian of North America, Sweden and Russia and from the Middle Cambrian of Great Britain, Norway and Argentina. It is more characteristic of Lower Cambrian rocks on a worldwide basis

(Shah, 1977).

**Hazira Formation:** The name Hazira Formation was introduced by Gardezi and Ghazanfar (1965) for a predominantly shale-siltstone unit exposed near the village of Hazira. The type section has been chosen near the said village in Hazara area. The Hazira Formation as described by the above authors is composed mainly of dirty grey and yellowish brown calcareous, shaly siltstone containing earthy concretions. The yellowish brown colour of the Hazira Formation becomes reddish near Banda Pir Khan, where the formation also contains some quartzite beds.

The Hazira Formation shows glauconitic facies near the base. Gardezi and Ghazanfar (1965) have included the "Hematitic formation" (Galdanian formation) in Hazira Formation and showed that this "Hematitic formation" is laterally replaced by the Hazira Formation in the Abbottabad region. Latif (1970 a) on the other hand, separated the "Galdanian formation" from the Hazira Formation and correlated the "Galdanian formation" with the "Panjal series" of Kashmir.

The Hazira Formation attains a maximum thickness of 300 m. It overlies superpositionally the Abbottabad Formation and is overlain by the basal Jurassic arenite. Fuchs and Mostler (1972) made detailed palaeontologic and stratigraphic studies of the formation and extracted the following fauna from the insoluble residues; *Porifera, Allonia tripodophora, Archiasterella pentactina,* "stauractinid" *Archiaster;* Calyptoptamatida: *Hyolithes* and a representative of the family Orthothecidae; Annelida : *Lapworthella* spp. and *Rushtonia* spp. This fauna according to Fuchs and Mostler (1972) indicates not only Cambrian but also very clearly shows that the fossiliferous part of the Hazira Formation is most probably Early Cambrian.

Latif (1972) reported the presence of Hyolithid from the Hazira shale. Rushton (1973) re-examined the material of Latif and confirmed the presence of Hyolithids *(Circotheca ? and Linevitus)* and identified the spicules of the *Heteractinellid* sponge *Chancelloria,* which is known from the Middle Cambrian of North America, the Cambrian of Australia and from the Early Cambrian in England. Rushton confirmed the Cambrian age for the Hazira Formation.

***Himalayan Tectonostratigraphic Basin***

The area included in this region lies in northeastern part of Pakistan (Fig. 1). No authoritative documentation of Cambrian fossils is available. However, rocks of this age are fully developed in eastern Kashmir, Spiti and Tibet. According to Gansser (1964) these formations in part extend around and over the Himalayan syntaxis into the Hazara Range, north of the Indus Basin.

Cambrian rocks in Kashmir are composed of greywacke, shale and thin lenticular limestone, which grades imperceptibly into massive, bluish slate and oolitic limestone from which trilobites and brachiopods have been, reported (Gansser, 1964). The fauna is strictly provincial with no relation to the faunas of the Salt Range or the Spiti area, but it does have affinities with the Cambrian of Indo-China (Gansser, 1964; Wadia, 1957).

***Peshawar -Swabi area***

**Ambar formation:** Ambar formation was named by Pogue and Hussain (1986) for a carbonate rocks suit exposed in isolated outcrops of Peshawar area between Turlandi and Swabi.

Earlier, Stauffer (1968 a) included these rocks in Nowshera formation especially those exposed in Turlandi area. Much earlier Martin et al. (1962) included all the outcrops of Amber formation in Swabi area in their "Kala Limestone and Dolomite". Type section suggested by Pogue and Hussain (1986) is exposed at Amber Village (Lat. 34° 03' 02" N: Long. 72° 24' 46" E) along Swabi Jehangira Road.

Lithologically, the Ambar formation is predominantly composed of dolomite, dolomitic limestone, calcareous quartzite and subordinate argillite. Chert in the form of veinlets, nodules and stringers is found at few places. The dolomite contains algal laminations and poorly developed stromatolites. The lower contact of the formation is unconformable with Tanawal Formation in Swabi area. The contact is locally marked by a conglomerate bed with cobble and pebble size in a matrix of dolomitic quartzite and argillite. South of Swabi, the lower contact of the formation is covered under the alluvium of Peshawar Valley. The upper contact of the formation is also unconformable with Misri Banda quartzite and is marked by 5-10 m of maroon coloured shale. In Chingalai area, however, the unconformity is represented by about 10 m thick conglomerate bed containing pebbles and cobbles of quartzite and dolomite in quartzitic matrix.

About 425 m of dolomite is exposed at the type locality. Between Turlandi and Mian Dheri only 165 m of the upper most part of the dolomite is exposed (Pogue and Hussain, 1986).

The formation is unfossiliferous except for microscopic shell debris in the interstices of pisoliths at the Ambar section. Based on its stratigraphic position resting above the Tanawal Formation of Precambrian age and below the Mistri Banda quartzite of Ordovician period, the age of the formation has been suggested as Cambrian by Pogue and Hussain (1986). The formation has been correlated with Abbottabad Formation in the Hazara area based on its stratigraphic position and lithological similarly.

**Bampokha group:** Chaudhry et al. (1992) named and described Bampokha group, which is considered distinct and different from the 'Alpurai schist group' in its tectonostratigraphic position as well as age. According to Chaudhry et al. (1992) this group lies to the south of MCT in the Lesser Himalaya and is composed of low grade calc schists, marble and graphitic schist. These rocks fall in greenschist facies of regional metamorphism. The group has been divided into two formations, i.e. Girarai formation and the Tursak formation.

**Girarai formation:** The Girarai formation is named and described by Chaudhry et al. (1992). Basically, the unit shows low-grade metamorphism and falls in greenschist facies of regional metamorphism. The rocks are composed of graphitic schist, which is, in turn interbedded with abundant calc schist intercalated with thin (20 cm to a few meters) marble horizons. A few thicker (70 to 140 m) light to dirty grey marble horizons are also present.

The northern side of the contact of Girarai formation with high-grade metamorphic rocks of Tilgram formation is very sharp. Near the contact, the low-grade calc-schist and associated thin marble beds are strongly folded (microfolds). Here, mylonitisation is apparent. The low-grade metamorphic sequence shows extensive calcite and calcite-quartz-carbonate veins. These veins may show pinch and swell structures.

The graphitic schist is generally medium to dark-grey in colour. However, rare intercalation of grey and light greenish grey is also present. The schist is composed of quartz, muscovite, graphite and iron oxide (mainly goethite/limonite and hematite). Pyrite may occur as relics. The weathering colour of these rocks is rusty yellow to rusty red. The calc schist is predominant and has intercalated marbles in it.

The calc schist is light grey to light greenish grey in colour. It weathers to light rusty-to-rusty red colours. The interbedded marble occurs as thin horizons (generally 0.25 to 1m). Marble is generally light grey to medium grey. At places it is pale grey. The unit shows macro to micro folding. This unit is often cut by quartz-carbonate veins. In these veins the carbonate component is 12 to 20%. Quartz is milky-white; the carbonate is rusty yellow and forms small sized aggregates of coarse carbonate.

The calc schist is composed of calcite, quartz, muscovite, chlorite, biotite and traces of graphite. The impure marble is composed of calcite with some muscovite, biotite and quartz (Chaudhry et al., 1992).

The marble horizons tend to form cliffs. The calc-pelitic horizons form steep slopes. The graphitic/pelitic schists form gentle topography and gullies. Its lower contact is faulted against Tilgram formation, while its upper contact is with Tursak formation.

In the Mingora-Dagger area this formation overlies Tilgram formation with a major thrust (MCT). Overall studies carried out in Swat area show, that this formation is younger than Dargai formation and is therefore Lower Palaeozoic in age.

**Tursak formation:** The formation has been named and described by Chaudhry et al. (1992). According to them the Tursak formation is composed predominantly of white, black and white and grey or white and black marble. Calc-schist and graphitic schist are subordinate lithologies. The marble horizons are generally thick-bedded, pure white or grey or bicolour white and grey or white and black. These may often be dolomitic. These are generally fairly pure carbonate horizons. They weather to off white, light rusty brown and dirty off white colours.

According to Chaudhry et al. (1992) the Tursak formation contains considerable amount of calc-pelites, which are layered and banded. They are off white to light greyish or pale greyish with green tinges, at places. These rocks weather to rusty brown and grey colours. The graphitic schist horizons within Tursak formation are grey to dark-grey in colour. At places the rock shows silvery grey sheen. Rarely, it may also be greenish grey. Weathering colours are rusty and rusty brown and rusty red. Tiny pyrite weathers to small orange colour powdery aggregates. The rock contains <5.0% graphite and it does not soil (stain on) the hand. It may contain thin millimetric to centimetric (<3 cm generally) calcareous layers. The rock itself is composed of quartz, muscovite, rare chlorite, graphite (<5%), pyrite (<3%) and calcite. Biotite is hard to recognize in hand specimen. The marble horizons form steep slopes and cliffs, the pelitic horizons form low ground and gullies and the calc-pelites form low to moderate angled slopes.

This formation may also be regarded of a probable Lower to Middle Palaeozoic in age (Chaudhry et al., 1992).

***Hindukush-Karakoram Tectonostratigraphic Basin***

***Northern Sedimentary Province***

**Chikar quartzite:** Le Fort and Gaetani (1998) discovered a large metasedimentary unit composed of dark grey siltstones and quartzites, in 30 to 60 cm thick beds; some of the beds have small asymmetric ripples. The quartzites appear to have been derived from well-sorted quartz arenitic sandstone deposited in a shelf marine environment. Being sealed by the non-metamorphic Yarkhun formation their age is considered as pre-Early Ordovician, Cambrian or even older.

The Chikar formation along the Yarkhun Valley, contains more pelitic layers, which often appear scattered with black dots of metamorphic minerals. Under the microscope, these dots are completely altered to very fine-grained micaceous material.

Le Fort and Gaetani stated that "Southeast of Chikar, up to the right bank of the Darkot glacier, this metasedimentary rock is intruded by increasing numbers of granitic and pegmatitic dykes that developed a recrystallisation of coarser grain and the appearance of muscovite in the quartzitic material. Within a few kilometres, it passes gradually to migmatites and up to anatectic granite, engulfing masses of nebulitic gneiss and agmatitic amphibolite. In addition to the abundant quartzitic material, the migmatised paragneiss contain pelitic two mica-garnet gneiss, a few levels of saccharoidal marble, and some masses of amphibolite generally affected by boudinage.

The unit is intruded by a swarm of basic dykes of micro quartz diorite. The dykes are up to several meters thick. The basic dykes are themselves crosscut by the abundant granitic pegmatites that intrude some of the quartzite, and more profusely, the gneisses and migmatites. These dykes are decimetre to meter thick and contain two micas, or often, muscovite and tourmaline ± garnet.

The Chikar quartzite represents a basement rocks unit, which has been intruded by the pre-Ordovician Ishkarwaz granite, NW of Chikar as well as NW of Kashmanja. The formation is overlain by thrust Yarkhun formation of Ordovician to Silurian age. The base of the formation is not exposed. The age is evidently Cambrian or Precambrian.

**Aghost formation:** Le Fort and Gaetani (1998) named and described a large metasedimentary unit, which forms the northern half of the Ghamubar crystalline mass and is made up of quartzite, gneiss and migmatites.

Lithologically, the formation is largely composed of quartzites especially in the northern edge of the mass, close to the contact with the Darkot group. Quartzite is fine-grained, well banded, with a greenish-brown dark colour in a few cases, cross-bedded giving the impression that they pertain to the Darkot group if they were not irregularly cut by two-micas or muscovite tourmaline aplitic and pegmatitic strongly foliated dykes. Close to the northern contact, characteristically, the quartzites have developed curious euhedral scattered K-feldspars, a few cm-wide, moulded by the foliation, which look like metasomatic crystallizations. The foliation of quartzite sometimes bears quartz-sillimanite plates. In addition, the foliation is deformed by crenulation folds with WNW-ESE axes gently plunging E or W. The stretching lineation usually dips gently to the east. The banded gneiss contains both clear coloured orthogneiss, is usually medium-grained and contains biotite ±

muscovite and garnet; coarse-grained occurrences correspond to foliated pegmatites. The formation contains paragneiss, which is a heterogeneous mixture of abundant quartzite, biotite gneiss and mica-schists, thin with continuous beds of marble and minor amphibolite. In addition, it is injected by abundant granitic and pegmatitic dykes. Amphibolite is often garnet-bearing. The granitic dykes contain muscovite, biotite, frequent garnet, tourmaline and even amphibolite.

A good outcrop of the migmatitic gneiss lies about 6 km north of bridge of Umalsit, along the dirt road to Darkot. Towards the top of the gneiss, a continuous set of marble layers are interbedded with the gneiss. They continue in the upper Das Bar where they form big blocks in a large torrential fan of the right bank between Chhelish and Shatikuto. Stray boulders from them have been found in the Darkot section, which makes this formation at least older than Permo-Carboniferous. Blocks of banded marble are made up of layers of massive calcite alternating with quartzitic layers. Le Fort and Gaetani (1998) added that "In the Das Bar valley, shepherds have shown and given us samples of graphite, a few centimetres large, that came from the Aghost gneiss on the left bank slopes, upstream from Chhelish settlement".

According to Le Fort and Gaetani (1998), Casnedi et al. (1978) have obtained K-Ar ages on whole-rock, biotite and K-feldspar of one sample of sillimanite-bearing Aghost migmatitic gneiss collected between Darkot and Umalsit as, 62.5 ± 1.9, 51.4 ± 2.4, and 49.9 ± 1.5 Ma respectively. All ages are younger than that of the Ghamubar granite. With this age discussion we are dealing with the intruded/injected material, but the age of the original material i.e. quartzite, etc. still remains a mystery. Indirect evidence based on the stray boulders found in the Darkot section, as mentioned above, possibly indicate a Palaeozoic age of the original formation.

## ORDOVICIAN - SILURIAN

Sedimentary rocks of Ordovician and Silurian are found only in the Peshawar Basin and Chitral District of Pakistan, while Indus and Balochistan Basins are devoid of these rocks. In the Axial Belt, where some rocks without fossils are correlated with known fossiliferous rocks of Peshawar Basin, are also recorded.

### Axial Belt

#### *Attock-Cherat-Range*

**Hisartang frormation:** Hussain et al. (1991) described the formation in details as consisting of dark grey to black argillite and light grey quartzite that display impressions of worm burrows. Hisartang Formation consists of an upper and lower quartzite and intervening argillite. The quartzite is white to light grey, fine-grained, and is a ridge and ledge former. The argillite is dark-grey to black and thinly laminated. The upper conformable contact of the Hisartang Formation with the Inzari limestone is sharp. Earlier Tahirkheli (1970) divided the rock sequence into lower quartzite and compact sandstone and the upper limestone with thin argillaceous and arenaceous bands. The thickness of the formation is 136 m with Cretaceous age, assingned to the formation by Tahirkhely (1970).

Hussain et al. (1991) stated that the formation is devoid of fossils and it is tentatively correlated, on the basis of lithologic similarities, with the Early to Middle Ordovician Misri Banda quartzite. Maximum recorded thickness is 760 m (Hussain et al., 1991).

***Himalayan Tectonostratigraphic Basin***

***Khyber Area***

**Landikotal formation:** Names such as "Attock Slates", "Khyber Slates" etc. are widely used in literature for this formation. Stauffer (1968b) described the unit in detail and proposed the name "Landikotal Slates" since a thick section is exposed at Landikotal. Lithologically the unit is predominantly phyllite and slate intruded by basic dykes and sills. The formation is an assemblage of slate, phyllite, limestone, quartzite, basic rocks, and in places, dolomite. In the presence of such varied lithologies. Shah (1969) proposed that the entire unit appropriately be called as the Landikotal formation, with the section exposed north and east of Landikotal being considered the type locality.

At the type locality, the formation is composed predominantly of greenish-grey to yellowish-grey phyllite and slate with abundant basic igneous dykes and sills. Quartzite beds at the type locality are thin and form insignificant part. At a few places the slate is distinctly calcareous. Most of the slate at the type locality is very fine-grained and its composition cannot be determined even with the help of a microscope. In places, weathering of the slate has produced a yellowish, greyish green colour and has emphasised the cleavage and in some places weathering has produced "pencil slates".

Minor limestone layers interbedded with the slate are grey, weathering light yellowish-grey. At the type locality the limestone is medium-bedded, elsewhere platy to medium bedded. It is fine-grained, in places medium-grained, but everywhere re-crystallised. It seems to be completely devoid of fossils. Samples dissolved in acetic acid failed to yield microfossils in the residues.

Almost everywhere in the Khyber Agency, the Landikotal formation underlies the rest of the rock sequence, in most places; the contact with the overlying formation is sheared or faulted. At the type locality the formation has a faulted contact with the overlying Khyber limestone, the intervening Shagai limestone and the Ali Masjid formation being absent. In the Loe Shilman area, the formation is in direct contact with the Ali Masjid formation, while the Shagai limestone missing.

As the entire area is structurally disturbed with frequent repetitions due to folding and faulting, it is not possible to measure the thickness of the formation with accuracy at the accessible places. Stauffer (1968) estimated it to be 3300 m thick. This figure seems excessive; Shah et al. (1970) stated that the exposed thickness is perhaps nearer to 1600 m than to 3300 m but nowhere the base of the formation is exposed.

The Landikotal formation extends deep into Afghanistan, where German geologists mapped part of the formation as Loger Formation (Shah et al., 1970). They reported the presence of

Ordovician conodonts in the Loger Formation and assigned the age from Late Ordovician to middle Ludlow (Shah et al. 1970). As the Devonian formation overlies the Landikotal formation in the Gandagallah area, Khyber Agency, the formation is thus Pre-Devonian, which may range from Silurian to Ordovician or may even be older.

*Nowshera Area*

**Misri Banda quartzite:** The term Misri Banda quartzite was proposed by Stauffer (1968a) for calcareous quartzite overlying Nowshera formation of Early Devonian age. Pogue and Hussain (1986) restricted the name "Misri Banda quartzite" to dominantly arenaceous sequence lying between Ambar dolomite and Panjpir formation (Kandar phyllite of Stauffer). The quartzite at Misri Banda is lithologically distinct from the calcareous quartzite overlying Nowshera formation and also contains cruziana ichno fossils of Ordovician age. The extension of the quartzite outcrop towards the eastern part of Peshawar sub-Basin was named by Martin et al. (1962) as "Swabi quartzite" and "Chamla quartzite" in the respective areas. The type section of Misri Banda quartzite is designated near Misri Banda (Lat. 34° 01' 02" N: Long. 72° 06' 05" E) located 10 km northeast of Nowshera town.

According to Pogue and Hussain (1986) the quartzite is light grey to pinkish-grey and contains fine to medium-grained quartz and feldspar in siliceous and calcareous matrix. Cross-bedding, ripple marks and graded bedding are common features of the formation. In some parts of the quartzite sequence vertically oriented tube-shaped burrows are preserved. A dark grey, thinly laminated argillite is commonly associated in the upper part of the formation. The upper contact of the Misri Banda quartzite is unconformable with the overlying Panjpir formation. The unconformity is marked by a, conglomerate bed, which is composed of rounded to sub-rounded cobbles and pebbles of quartzite and dolomite in calcareous quartzitic matrix. The unconformity is well exposed at about 1 km east of Turlandi Village. From some of the samples of the calcareous quartzite collected from the conglomerate horizon, conodonts Ozarkodina excavata and Ozarkodina remschidensis of late Ludlovian-Pridolian age have been extracted. Thickness measured is about 300 m.

Pogue and Hussain (1986) reported cruziana rugosa in the interbedded argillite of upper part of Misri Banda quartzite indicating an Early to Middle Ordovician age (Tremadocian to Llandeilian). The Misri Banda quartzite is tentatively correlated with the quartzite member of the Abbottabad Formation.

**Panjpir formation:** Kandar Phyllite of Stauffer (1968 a) has been given a new name of Panjpir formation by Pogue and Hussain (1986) for the dominantly argillaceous rocks lying below the Nowshera formation and above the Mistri Banda quartzite. This change occurred on the basis of its greater thickness and presence of other lithologies along with the phyllites as well as variable lithologies from place to place. This situation is especially present at the type locality proposed by Pogue and Hussain, located near the village Panjpir (Lat. 34° 05' 32" N: Long. 72° 29' 49" E), 4 km southeast of Swabi Town. Martin and other (1962) termed it "Swabi Shale and Chamla Shale" for the similar rocks in the area which have now been placed as synonyms.

Lithologically the Panjpir formation is composed predominantly of argillite and phyllite with interbeds of crinoidal limestone, meta-siltstone as well as argillaceous and calcareous quartzite. These rocks are generally dark-grey to greenish-grey, silty fissile and chloritic. The upper part of formation is characterized by interbedded argillite and crinoidal limestone. The Panjpir formation has a conformable contact with the overlying Nowshera formation. Pogue and Hussain (1986) placed the contact at the base of massive limestone of Nowshera formation, which usually occurs at the top of the interbedded argillite and limestone of the Panjpir formation.

Pogue and Hussain (1986) located fossiliferous locality (Long. 34° 01' 12" N: Lat 72° 09' 07" E) northwest of Mistri Banda, where a crinoidal limestone lens in the basal part of the Panjpir formation yielded Distomodus sp. of Llandoverian Early Wenlockian age. This discovery provides the first evidence for the rocks of Early and Middle Silurian age from Pakistan. On the basis of previous and present conodonts finds, the age of the Panjpir formation is regarded as Early to Late Silurian. The formation strongly resembles the phyllite and interbedded limestone sequence exposed below the Ghundai Sar "reef complex" (Khan, 1969), located at about 17 km northwest of Peshawar (Pogue and Hussain. 1986).

### *Hindukush-Karakoram Tectonostratigraphic Basin*

#### *Northern Sedimentary Province*

**Baroghil group:** Quintavalle et al. (2000) have described this group. They included all the rocks stratigraphically below the dolomitic Chilmarabad formation, the lower part of the sedimentary succession of Northern Sedimentary Basin, which is composed mainly of terrigenous, mostly shaly material. Prior to this, Tahirkheli and Talent, in (1973) (unpublished), measured a small section commencing 2.5 km WNW of the bridge over the Yarkhun River at Ishkarwarz in the Baroghil area. Desio (1979) referred it as Istigar slate. It is Baroghil unit of Tahirkheli (1982) and later it was named as "Baroghil formation". Quintavalle et al. (2000) raised the formation to the rank of group in agreement with Talent et al. (1999). The group is comprised of two formations, lower Yarkhun formation and the upper Vidiakot formation.

**Yarkhun formation:** Named and described by Quintavalle et al. (2000), the formation represents mixed quartz-arenitic/slaty sediments. The type section is designated along the eastern slope of the ridge located between the Vidiakot Gulley and the Baroghil depression. Detailed measured section and lithology described by Quintavalle et al. (2000) in the Vidiakot Valley is given below.

"Since the area is tectonically highly disturbed and it becomes very difficult to trace the location of the section of the formation, for this reason a complete measured section with position of the occurrence of fossil beds is presented here".

| | | |
|---|---|---|
| 13 | 5 m | Alternating shale, siltstone, and li tharenite in 10 cm thick beds. Shale largely subordinate. |
| 12 | 11 m | Light coarse arkose and microconglomerate in m-thick cross-laminated beds. |
| 11 | 12 m | Brown altered siltstone, poorly exposed. |
| 10 | 37 m | Dark splintery bioturbated siltstone alternating with very fine sandstone. |
| 9 | 3 m | Medium grained sandstone |
| 8 | 23 m | Arenaceous siltstone with subordinate black splintery slates and occasional sandstone beds. |
| 7 | 14 m | Light grey, splintery arenaceous bioturbated siltstone with frequent intercalations of very fine sandstone. *Cruziana*-like traces. |
| 6 | 21 m | Fine light arkose and sublitharenite in amalgamated beds 50 -70 cm thick, with faint parallel lamination. |
| 5 | 13 m | Silty slate poorly exposed, locally deeply bioturbated, with *Cruziana*-like traces. |
| 4 | 7 m | Very fine arkose sandstone in 20-40 cm thick beds. |
| 3 | 4 m | Splintery siltite and very thin sandstone |
| 2 | 14 m | Black splintery slate, steeply dipping to the north. |
| 1 | 6 m | Coarse arkose in thick, poorly defined beds. |
| 0 | 0 m | Deeply altered Ishkarwaz Granodiorite. |

Lower contact of the Yarkhun formation is with the Ishkarwaz granodiorite from the top of which the above section has been measured. The upper contact with Vidiakot formation is conformable. The thickness of the formation is 170 m (Quintavalle et al. 2000).

Yarkhun formation is well exposed in the Ishkarwaz-Baroghil areas, slabs of dark shale, slate and siltstone several hundred meters thick are thrust on the Chikar quartzite and on the Ishkarwaz granodiorite on the north slope of Hindu Raj south of Zirch and Shost (Le Fort and Gaetani, 1998). The Yarkhun formation here consists of fine-grained slates and siltite with intercalations of quartz-arenite. The bulk of the thrusted Yarkhun formation here shows horizontal and cross lamination especially in the intercalated quartz-arenite. They are barely metamorphic just having a distinct shine on their bedding/ schistosity planes when lying under the sun. Here the formation is unfossiliferous.

Age of the formation is late early Arenigian (Ordovician) to Early Llanvirnian (Middle Ordovician) this age is based on the occurrence of Acritarchs. Quintavalle et al. (2000) divided the Acritarchs collection in three assemblages. It is the first time of the detailed study of Ordovician Acritarchs pollen in Pakistan. They are recorded here to locate and explore, the Ordovician rock in other areas of Pakistan as well.

The first assemblage of Quintavalle et al. (2000) from Vidiakot section (VK1) is characterized by the following Acritarchs: *Arbusculidium filamentosum Coryphidium bohemicum Dactylofusa velifera* forma *bervis-sensu, Striatotheca rarirrugulata* and *Vogtlandia flosmaris.* Characteristic attributes of this assemblage include numerous diacrodians (principally referable to the *Acanthodiacrodium costatum* group), as well as the common presence of Polygonium spp.

The second assemblage from Vidiakot section (VK2) is characterized by the first occurrence of the Acritarchs Arkonia tenuata, Apreotesta clathratra var. simplex, Dicrodiacrodium ancoriforme, (Burmann, 1968) emend., and Orthosphaeridium sp. (possibly referable to *Oternatum).*

In addition, the following taxa also appear in assemblage VK2: *Cymatiogalea deunffi Multiplicisphaeridium* sp. cf. M. delicatum *M sp. cf. M. inconstans Poiklofusa spinata and Striatotheca* sp. cf. *S. prolixa.*

This third assemblage of Quintavalle et al. (2000) (VK3) is very poor in both taxonomic diversity and preservation state. Owing to the poor state of preservation and the small number of specimen recorded, a specific attribution is precluded in most cases. The most significant fossils are the acritarchs *Arkonia tenuata* and the chitinozoan *Lagenochitina esthonica.*

Talent et al. (1981) identified the following conodonts; Baltoniodus cf. *medius plectodina* sp. *Drepanoistodus basioralis Drepanoistodis* sp. *coruedus sp. cf. c. longibasis paraprioniodus? Lenodus?* sp. They also suggested Arenigian (Ordovician) age for the Yarkhun formation.

**Vidiakot formation:** This formation is the upper part of the Baroghil group, described by Quintavalle et al. (2000). It is mostly composed of slate with siltstone. Cleavage near parallel to the bedding. The formation contains siltstone flattened nodules. The entire formation is isoclinally folded and faulted which makes it difficult to measure the section. he estimated thickness is approximately 700 m. The formation is fossiliferous. Talent et al. (1999) recorded Russophycus from the fine sandstone of the formation and algal straps, repichnia and two isthtopraican trilobite free cheeks.

Quintavalle el al. (2000) reported acritarchs of Ordovician age. According to them the most significant acritarchs is Arkonia tenuata and the chitinozoan Lagenochitina esthonica, A. tenuata appear during late Arenigian and extends into the early Llanvirnian and the fossil L. esthonia occurs world wide from the lower Arenigian as well as in the lower most part of Llanvirnian. Thus according to Quintavalle et al. (2000) the lower most part of the Vidiakot formation contains these fossils and therefore the age of the formation is Early Ordovician to Middle Ordovician. Since the formation is more than 700 m thick the age extends from late Ordovician to Silurian. The section of the lower part of the formation which overlies the Yarkhun formation conformably, as measured by Quintavalle et al. (2000), is shown below:

| | | |
|---|---|---|
| 15 | 17 m | Black slate with very fine sandstone intercalations |
| | 20 m | Not exposed |
| 14 | 23 m | Splintery black slate with flattened siltstone nodules. (Vidiakot formation base) |
| 13 | 5 m | Shale, siltstone etc of Yarkhun formation. |

## DEVONIAN

The Silurian and Devonian Systems are reported from the Axial Belt doubtfully and definitely from Khyber and Nowshera-Swabi areas. They are represented by limestone with reefs, quartzite, shale, slate and phyllite sequences of considerable thickness. No exposures of Silurian and Devonian rocks have been recorded in the southern and southwestern part of Pakistan. The best exposures, containing several Devonian formations, are lying in thrust sheets, in Chitral District. Some Devonian units along with other formations are shown in (Fig. 11).

## AXIAL BELT

### *Attock-Cherat Range*

**Inzari limestone:** The Inzari limestone is named and described by Hussain et al. (1991). It is yellowish grey to light greenish grey and contains black lamination of weathered surfaces. According to Hussain et al. (1991) it is finely crystalline and thin to thick bedded. Manganese staining and dendrites are common. The upper beds are traversed by wavy stylolitic fillings. The upper contact of the Inzari limestone is faulted. The formation may be equivalent to limestone of the Nowshera formation of Early Devonian age. Minimum thickness is 650 m. Hussain et al. (1991) categorically stated that despite a prolong search and repeated sampling for conodonts, no fossils have been found in the Darwaza, Hisartang and Inzari sequence. However, certain lithologies, particularly the maroon shale of the upper Darwaza and worm burrow impressions in the quartzite of Hisartang, suggest a correlation with the Palaeozoic rocks of the Nowshera area. Recently however, Pougue et al. (1999), have come up with Precambrian age based upon strontium isotope analysis (initial seawater ratios).

### *Himalayan Tectonostratigraphic Basin*

### *Lesser Himalayas*

Areas in Lesser Himalayas include parts of FATA Tribal Belt, Peshawar Valley, Hazara, Malakand, Swat and parts of Kaghan Valley and lower reaches of Kashmir. The access to undertake geological investigation especially in the Federally Administrated Tribal Areas (FATA) is quite difficult and generally looked upon by the local inhabitant with suspicion.

### *Khyber Agency Area*

Khyber Agency is part of the tribal belt that forms the northwestern boundary of Pakistan with Afghanistan. It is usually said that working in this area is difficult and may call for trouble during the execution of work. This fear was far greater before partition of the subcontinent, during British Rule, but has gradually decreased now. However, proper arrangement may be made before visiting the tribal territory to avoid any rare untoward incidence. After permission, the Political Agent provides security staffs, who accompany the visitor to the selected or permitted part of the tribal belt. In this way, with no free movement, work can be carried out only for a few hours of the day. The above-described situation with restrictions has been the cause of the poorly known status of the geology of the tribal belt. Under these conditions Shah visited the area in 1968 and again in the next season. Shah and Siddiqui of the Geological Survey of Pakistan managed to work for some time in the tribal belt and completed the reconnaissance mapping, section measurement and insitu sampling of rocks. Every thing had to be done hurriedly, and hence many quarries, follow-up checks and questions remained unanswered till to date.

First reconnaissance mapping of the area was undertaken by Stauffer in 1968, whose movement was strictly restricted to a few feet on either side of the Khyber Pass Road. His mapping is based mainly on photo interpretation of the units present in the area. At the end of 1968, Shah initiated his mapping work both physically and photogeologically (Fig. 9a). He also faced the same restrictions but comparatively to a lesser degree and soon discovered fossiliferous sequence loaded with fossils in the Gandah Gala Mountains. It may be noted that, prior to the work of Shah (1968-1969) all the fossils reported from the area were either collected from stream beds or astray boulders which could not be securely tied up with bed rocks.

Hardly any notable geological investigation in the Khyber Agency was undertaken for almost another two decades, till Khan et al. (1989) remapped eastern part of Khyber Agency (i.e., East of Khyber Pass Highway) with better access to the interior of that region. The geology of the Khyber Agency is quite problematic; hence it is just natural that disagreement exists between various workers. However, under these circumstances more future work with free access to critical places has become a must.

Accordingly, in this Memoir, in order to facilitate the future workers all possible information including detailed lithological measured sections of rock units exposed in the area are recorded from the field notes of Shah. Thus, in this memoir a little diversion is adopted from the conventional or customary style of the description of stratigraphy.

**Stratigraphic set up of Khyber area:** The Khyber Pass area was divided into four units, viz the oldest is Landikotal slate overlain by Shagai limestone which in turn is overlain by Ali Masjid formation and finally the top most formation is Khyber limestone. These four units are completely unfossiliferous, and earlier workers had given doubtful ages to these units extending from Ordovician to Permian.

Shah (1969) extended these names beyond the Khyber Pass Road Section to a set of similar lithological units, having fossils, exposed near the village of Misrikhel on the slopes of Gandah Gala Mountains. After two decades Khan et al. (1989) having greater freedom of movement in the tribal belt remapped the Khyber Pass, and the areas to the north of it. Altogether they covered the territory that lies in the east side of Khyber Road and ended their mapping almost at the Khyber Pass Road. It appears that probably, they also could not make way into the interior of the territory lying west of Khyber Pass Road where Shah had reported the highly fossiliferous beds.

Thus, they rearranged Shah's four formations present in the eastern Khyber Pass area into only two formations. In other words they combined the exposures of unmetamorphosed Landikotal slate exposed in the Ali Masjid Valley eastern part of the Khyber Pass, Shagai limestone and Ali Masjid as one formation and named it Shagai formation and eliminated the names of Landikotal slate and Ali Masjid formation in describing the sequence of the Ali Masjid Valley (in eastern Khyber Pass). Many workers followed Khan et al. (1989). Their sequence in the Khyber Pass area is as follows:

According to Khan et al. (1989), Landikotal slates exposed in Landikotal area are the youngest in the sequence because they consider, the Landikotal formation is directly sitting over Khyber limestone in the Haidry Kandao and Landikotal area, the type area. Secondly, they added that

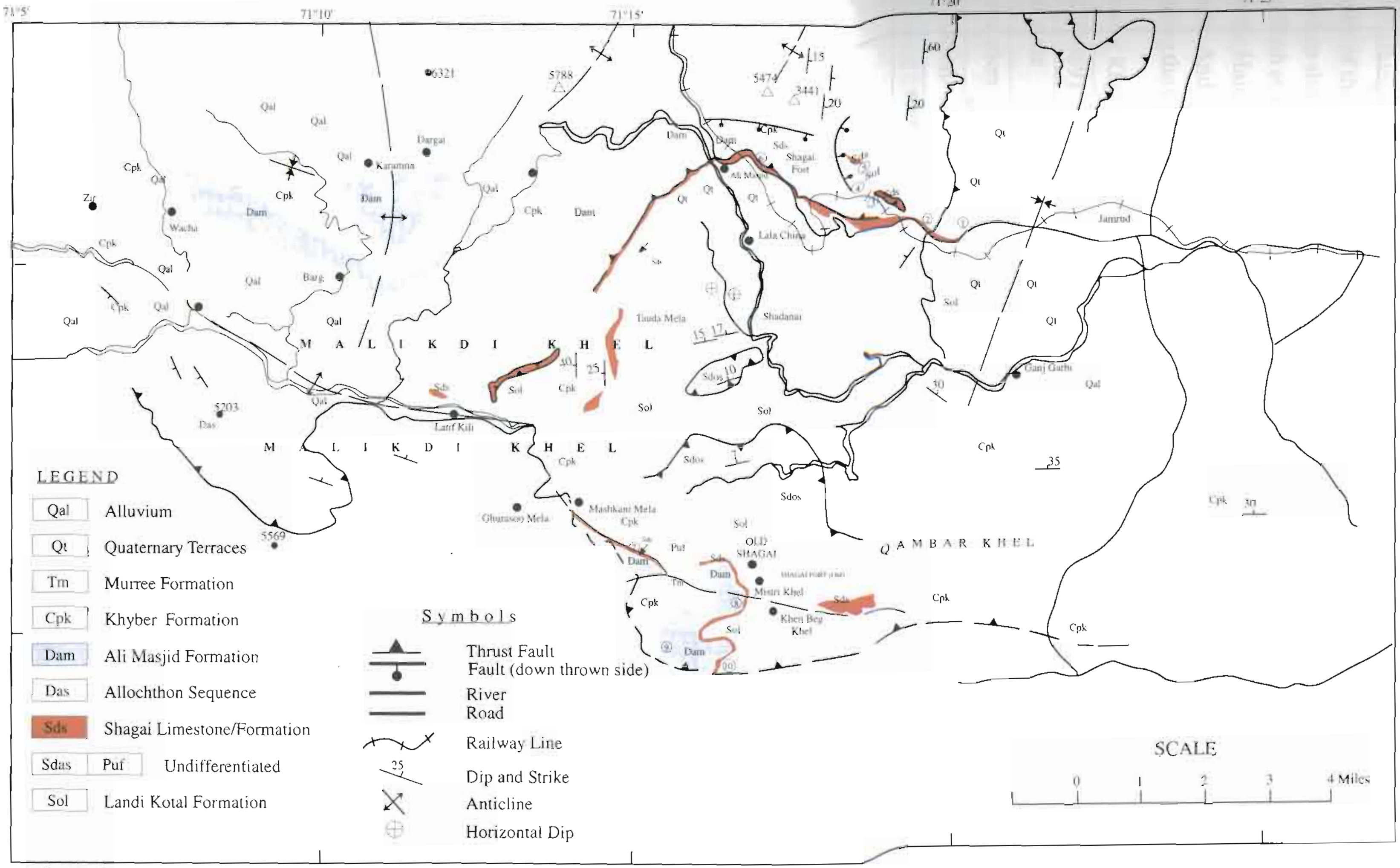



Fig. 9a. Geological map of (part of) the eastern part of Khyber Agency, Pakistan.

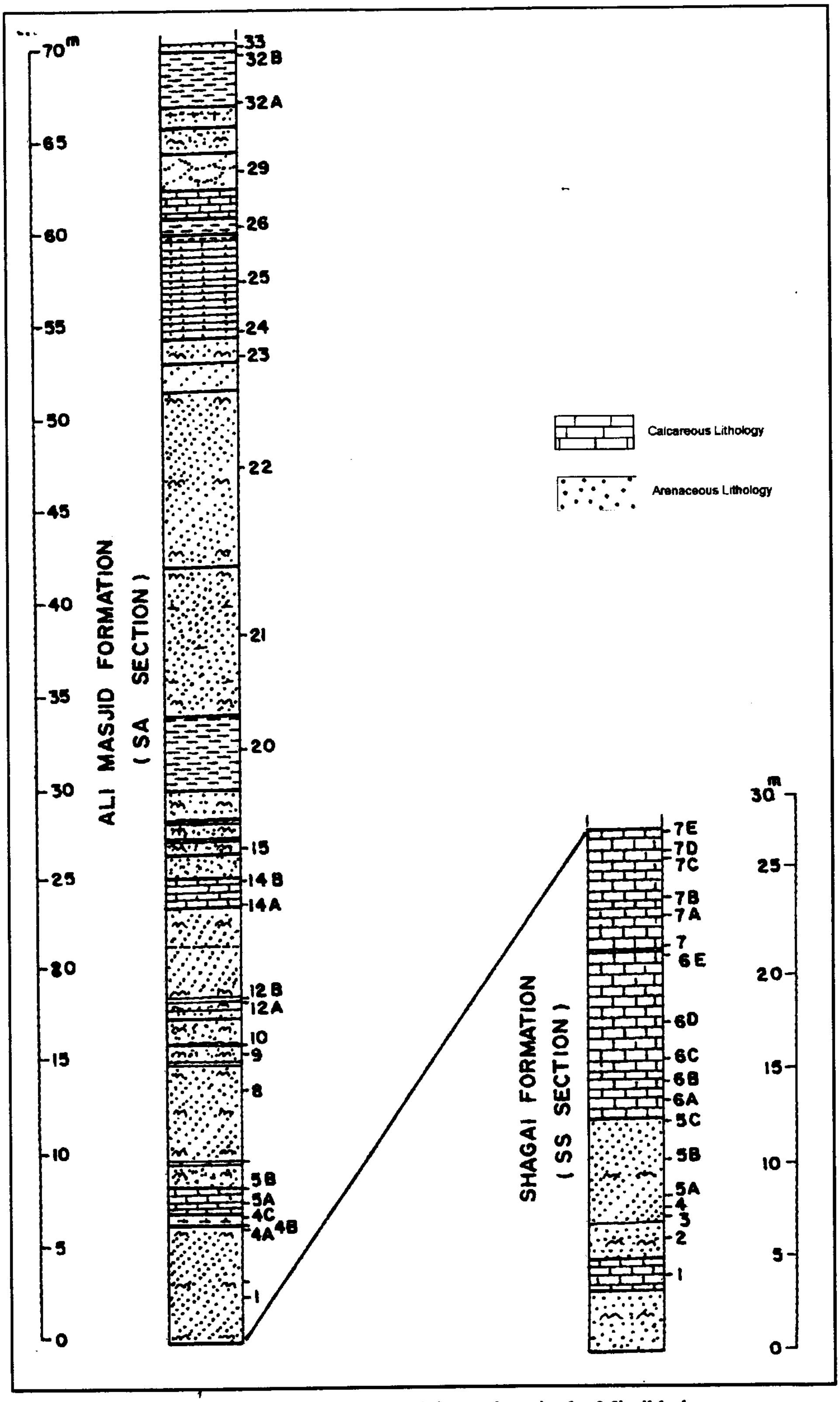



Fig. 9b. Lithology of Ali Masjid and Shagai formations in the Misrikhel area.

there is no such thing as the Ali Masjid formation while the beds described by Shah et al. (1980) as Ali Masjid are part of their "Shagai formation which also includes slate shale sequence at the base. This sequence of slate shale is the unmetamorphosed Landikotal formation of Shah and Stauffer. Stauffer (1968b) and Shah et al. (1980) interpreted the sequence comprising the Landikotal slate over Khyber limestone at the Haidry Kandao as well as in Landikotal area, as an overturned limb of anticline with a thrust fault. And therefore, the sequence is the same everywhere; which show, Landikotal formation being the oldest and provides the base for all other formations.

Table 5. Showing Khyber sequence by different authors.

| Khan et al. (1989) | Shah et al. (1980) |
|---|---|
| Landikotal slate | Khyber limestone |
| Khyber formation | Ali Masjid formation |
| Shagai formation | Shagai limestone |
| | Landikotal formation. |

The age of these unfossiliferous units exposed in the Khyber Pass is not known. After having discovered fossiliferous beds in the western part of the map area, Shah et al. (1970) extended all the four units of the Khyber Pass to the west, where similar lithological set up was found near Misrikhel. Close lithological similarities between the two sections became the reason for adopting the same name for Misrikhel area. Now that doubts have been created in the correlation between unfossiliferous beds in the Khyber Pass Road and those of fossiliferous beds, in the Misrikhel it is only right that all the stratigraphic units of unfossiliferous and fossiliferous sequences be redescribed separately, so as to keep affiliation and connection with previous literature it is proposed here to retain the geographic part of the lithostratigraphic nomenclature, but suffix it by the name "unit" lithology for the unfossiliferous sequence of the Khyber Pass Highway and suffix the name "formation" for the fossiliferous Misrikhel section for instance, for the fossiliferous beds it is Shagai formation in the Misrikhel area and for the unfossiliferous it is Shagai unit in the Khyber Pass Highway as shown in Table 6.

Table 6. Stratigraphic sequence of the Khyber Agency.

| Unfossiliferous sequence at Khyber Pass Highway | Fossiliferous sequence at Misrikhel/ Mashkani Mela |
|---|---|
| Khyber limestone | Khyber formation |
| Ali Masjid unit | Ali Masjid formation |
| Shagai limestone | Shagai formation |
| Landikotal slate | Landikotal formation |

Khyber formation is described at some other place, here only Ali Masjid and Shagai limestone units are discussed.

**Ali Masjid formation:** The name Ali Masjid formation was coined by Stauffer (1968b) after the village of the same name in the Khyber Pass Highway. Type sections, suggested by Stauffer (1968b), Shah (1969) and Shah et al. (1980) were chosen along the northeastern defiles of the Khyber Pass. Unfortunately, this section is not only faulted but the formation has been thickened due to repetition of beds caused by step faulting with a few beds missing. However, the unit can only be measured here by shifting of the line of section measurement at several places along the strike of the beds. Type section suggested in the defiles of Khyber, by Stauffer and Shah is completely devoid of fossils. Despite all efforts and acidization of many rock samples from these sections, no identifiable life remains were found in the Ali Masjid unit exposed along the eastern side of Khyber Pass Highway. These samples were collected by Shah and processed and acidised at the Macquari University paleobiological laboratory (Australia) under the supervision of Professor J.A. Talent and the results have been reported in Shah et al. (1980). "Approximately 100 kg of limestone from a measured section through a 21.28 m thick lens of limestone outcropping above the highway 0.8 km northwest of Shagai Fort were acidised, but proved barren. The only macrofossil found was portion of an unidentifiable spiriferid brachiopod". Thus, the presence of spiriferid like shell does indicate at least Palaeozoic age.

Immediately west of Ali Masjid Village a, similar lithology like that of Ali Masjid Unit continues westwards. It is exposed in the core of a large anticline and only two to three kilometres west of Khyber highway, some beds resembling Ali Masjid lithology are fossiliferous near Tauda Mela caves and further west as well as south of these caves (Fig. 9a). Here the sequence is unmetamorphosed. They appear similar to and are divisible into the four units like that of Khyber Pass Highway sequence viz. Landikotal, Shagai, Ali Masjid and Khyber units. In other words, full and a complete sequence can be differentiated in the Gandah Gallah Mountain, north and west of the villages of Mashkani Mela and Misrikhel. Since sections at Misrikhel are complete, less disturbed and full of fossils, the biostratigraphy can be reconstructed with precision. It is easily accessible and can be seen with permission from Political Agent of Khyber Agency. Thus, with all these merits the section at Misrikhel is justified to be declared as type section as against the earlier type section in the northeastern defiles of Khyber Pass Highway. The section at the Khyber Pass Highway is now suggested to be treated as Principal Reference Section and not the type section. Earlier it was vice-versa; Shah et al. (1980, p. 15).

**Description of the Ali Masjid formation at Misrikhel:** A sequence of arenaceous (quartzite) with small amount of clay in the lower portion and limestone in the upper part exposed just west of Misrikhel and through Mashkani Mela village is designated as the type locality of the Ali Masjid formation (Lat. 33° 56' N: Long. 71° 10' E).

Ali Masjid formation at the new type section is mainly composed of limestone, quartzite and shale. The section starts with quartzite that lies at the top of thick limestone of Shagai formation with Haxagonaria. This quartzite is grey, weathering to light brown, thick bedded and medium to fine grained. The quartzite is unfossiliferous and it is about 7 m thick. Quartzite is underlain by limestone unit (2), which is 1.6 m thick. It is grey in colour and unfossiliferous. This is overlain by thick-bedded quartzite. This unit (3) is white weathering to light brown, medium to thick bedded, fine to medium grained, some beds are cross bedded. It is interbedded, in its upper part, with thin (0.07 m) layers of clays of grey colour. The unit is about 13 m thick and only rarely fossiliferous. It is cross-bedded and contains about 0.3m of sandstone.

Overlying this unit is again quartzite unit (4) of 8 m thickness similar to the underlying unit but comparatively more fossiliferous.

Highly fossiliferous quartzite unit (5) overlies unit (4). This quartzite is 4.2 m at one section and 9 m thick at the other section. It is light grey to white, weathering to yellowish brown. In the upper part of the unit friable shale is interbedded. The most interesting feature of this unit is that it contains 2 to 3 m thick red coloured quartzite in the upper part, full of druses. This bed is highly pitted with holes. It is present in all the sections of Gandah Gallah as well as in the unfossiliferous Khyber Pass Highway section. This drusy bed has almost become a marker horizon for Ali Masjid formation. Although the "Drusy" word is generally used for volcanic rocks, we are using it here only for shape and size of holes that show "resemblance" with druses of igneous rocks. This peculiar quartzite bed is caped by predominantly shale (unit 6), mostly platy-bedded shale. It has sharp but normal sedimentary contact with lower lying drusy quartz bed. The shale bed is highly silty in the lower part and slightly calcareous in the upper part. This unit has thin and swell structures and ranges in thickness from 4 to 6 m. It is generally platy bedded, fissility developed in it is only to the extent that rock readily splits in platy form. The upper 2 m of the shale unit is limestone, thin to medium bedded and interbedded with thin shale and quartzite layers. It is brown in colour.

Overlying the above unit is 17 m thick quartzite unit (7), with lower part rarely fossiliferous and upper part adequately fossiliferous. General colour of this unit is light grey. The quartzite is thick bedded and medium grained. Quartzite is overlain by shale bed of about 6 m thickness. Next, the unit (8) at the base contains dark grey or carbonaceous bed of about 0.7 m thickness. This thin carbonaceous bed is also present at southwest of Ali Masjid Village, where completely unfossiliferous Ali Masjid unit is exposed. The overlying unit (9) is heterogeneous and limonitic. It is 7 m thick. The limestone (1.4 m) at the base is brown spotted with limonitic specks, it is silty and medium bedded. The term limonitic is used here to indicate haematite material showing yellowish, various shades of orange, brown and red colours. This unit contains upwards 2 m of calcareous sandstone, 1.4 m of quartzite and 3 m of shale and limestone at the top. This is followed by unit (10) predominantly limestone. The entire unit (10) is although mainly limestones, but thin (1 to 4 m) beds of quartzite, shale and sandstone are infrequently interbedded throughout. This last unit is 56 m thick and finally the formation is terminated by an unconformity.

The internal morphology of unit (10) is predominantly limestone but begins with cross-bedded sandstone (1 m), and alternates with shale and sandstones up to 4.5 m. Individual shale beds range from 0.15 to 1.2 m, and sandstone beds range from 0.22 m to 0.78 m medium grained, rarely fossiliferous and ornamented with yellow brown specks. This sandstone is overlain by 0.3 m limestone bed highly fossiliferous (brachiopods), followed upward by 5.5 m of shale bed with 0.6 m sandstone at the top. The sandstone is overlain by 0.6 m of yellow coloured quartzite bed, medium to thin bedded, fossiliferous. This is overlain by alternating limestone and shale (1 m) with 0.6 m thick dark red limestone bed. This limestone bed is followed upward by 3 m of alternating limestone and very thin shale. Above is a highly contorted limestone of dark red colour, which initiates the haematitic zone. These beds are overlain by limestone (5 m) of yellow and brown colour containing hematitic material, over this starts rich haematitic zone of about 4 m. This zone contains thin beds rich in oolitic and pisoliths; mostly limestone with very thin shale, and one thin bed of nodular sandstone. Overlying this rich hematitic zone, 5 to 7 m thick is crinoidal zone with cephalopod bed at the base. Limestone of grey, red and yellow colour covers the rest of the section up to a fault. A total of 33 m was measured in this section out of 56 m unit. Rest of remaining 23 m was measured in another adjacent section where similar beds of mainly limestone with occasional shale and quartzite are interbedded. The colour of the beds is grey with occasional red, yellow and brown. Limestone is medium to thick bedded and partly thin bedded. Some of the beds are highly fossiliferous. Some beds of limestone, besides, being nodular weathering, show peculiar rectangular weathering. The upper most bed is 3 m thick limestone of brown colour. Top of this bed is covered; it is probably zone of unconformity above which fossiliferous Khyber formation begins.

The above said description is that of Ali Masjid formation at the type locality in the Misrikhel area. The age of the formation is discussed under age and correlation.

From Misrikhel area the fossiliferous Ali Masjid formation extends westwards through Mashkani Mela onto the Chora and Bazaar Valleys; towards this direction all the beds of Ali Masjid formation are fossiliferous, as well as to Tauda Mela caves. At Tauda Mela Caves, the fossiliferous Ali Masjid formation has its last exposures from where lithologically similar exposures take right angle turn and extend eastwards up to Khyber Pass Highway where apparently it joins Principal Reference Section. The bed extending eastwards is totally unfossiliferous.

**Lithological description of Ali Masjid unit in the Khyber Pass Highway:** The Ali Masjid unit near Ali Masjid Town has 12 m of sandstone and siltstone with thin beds of volcanic ash exposed at different stratigraphic levels in the unit. The unit is grey, weathering to rusty yellow, thin to medium bedded and fine to medium grained. The volcanic ash is also present as patches and in the interstices of sandstone with cryptocrystalline particles of glass. Lower part of the unit is slightly calcareous. Overlying this unit is quartzite of grey colour, intercalated with volcanic ash and claystone. It is about 24 m thick. Same lithology persists upwards for about another 24 m. This is overlain by predominantly quartzite of 12 m thickness and followed upwards again by predominantly quartzite alternating with thinly bedded sandstone. At the top of this last unit lies a 4.5 m thick conglomerate bed. The conglomerate is composed of clasts of sandstone, limestone and quartzite. This unit weathers into lateritic appearance of red and yellow colours. The conglomerate unit is overlain by 11 m thick sandstone in the lower part and quartzite in the upper half, which is overlain by another quartzite bed of 3 m. This last quartzite weathers into red material. Infact red colouration of the formation begins with this bed and intermittently persists upwards. Immediately above this unit, 2 m thick quartzite bed occurs which is highly speckled with red coloured holes making the surface of the bed drusy similar rather identical to the one encountered at the type section at Misrikhel. It is regarded as easily diagnostic horizon mark in the Ali Masjid formation.

Drusy bed is overlain by siltstone mostly covered and indicates the presence of minor sandstone. Upwards claystone with minor sand and siltstone of light yellowish brown colour, weathering to dark brown, occurs. This unit is 16 m thick. Limestone unit, 31m thick overlies the above-mentioned unit. The limestone is dark grey, medium grained, hard and compact, contains calcite veins occasionally. In the middle of the unit 0.2 to 0.3 m thick shale layer of greenish grey colour occurs. These shale partings increase in frequency upwards. Over this unit lies a shale bed of 5m thickness, which is olive grey colour and weathers to brown with some layers of greenish colour.

Sandstone, 10 m thick, light grey, weathering to dark-green, overlies the preceding shale unit. Quartzite is highly compacted, medium- to thick-bedded. Upper part contains 0.3 m thick creamish colour shale with haematitic fragments. Onwards shale of 3 m thickness, greyish white sandy hard and compacted with iron stains occurs. This unit contains siltstone of light grey colour weathers to maroon colour in the upper part. Next higher unit is 24 m thick, composed of shale, clay and siltstone. Claystone predominates with volcanic ash which weathering to reddish brown. The top most unit is a quartzite layer with slightly metamorphosed multicoloured sandstone, siltstone and clay beds. The colour of the fresh rock is generally grey but the unit on weathering shows predominantly red brown and green colours. In other words, generally the weathering colour may be said as brownish red. These colours are present all along the contact of Ali Masjid unit and the overlying Khyber Pass limestone unit.

This has been the surface log of Ali Masjid unit exposed at the Principal Reference Section in the defiles of Khyber Pass Highway.

**Shagai formation:** The term Shagai limestone was named by Stauffer (1968b) after the name of Shagai Fort situated on Khyber Pass Highway. Type section was designated in the northeastern defiles of the Pass. Shah (1969) and Shah et al. (1980) followed the same name to the similar strata exposed in the western direction carrying them to the Misrikhel area where this name has been applied to fossiliferous beds lying above the Landikotal slates just like Khyber Pass Highway section and elsewhere in Khyber agency. In other words the beds lie at the same stratigraphic position and with almost same lithology.

Stauffer (1968b) and Shah et al. (1970) applied the Shagai limestone to all the beds lying between Landikotal slate and the Ali Masjid formation. The type section designated by Stauffer (1968b) and Shah et al. (1970) does not fulfil the requirements of stratigraphic code. Because, here it is thrust or say a reverse fault, contains 0.3 m thick white powder and fault breccia at the contact. Also the lower most beds of the Shagai unit are missing; slate beds of Landikotal slate below this fault are badly fractured and deformed and thus, section here is not fit to be named as type section in the Khyber Pass area.

Over and above, this, many later workers have also declared it as problematic e.g. Molloy et al. (1997) who stated that this formation may be included as a part of Landikotal slates. We suggest that it should remain as it is, since at Tauda Mela, this limestone is present and sitting on the slates at the same stratigraphic position and from thence it continues southwards and lie in a straight and undeviating strike direction up to Chirgarch Greh as well as to Misrikhel areas which at the time of field work Shah had called them "Shagai Section" at Chirgarch Greh section but later it was overlooked and erroneously included as the lower part of the Ali Masjid formation. It follows from this, that this section is that of Shagai formation (Fig. 9).

**Description of Shagai formation at Misrikhel:** Shagai formation forms the basal part of the sequence at Misrikhel where a complete and highly fossiliferous stratigraphic section, extending from the top of Landikotal slate to Khyber formation, is present. It is present here between Landikotal slates and thick quartzite bed of the Ali Masjid formation. It is thus, recorded here and is designated as the type section of the Shagai formation. The section lies less than one km west of old Shagai Fort (Lat. 33° 56' 30" N: Long. 71° 10' 30" E) (Fig. 9a).

Shagai formation at most of the places in Misrikhel area is faulted, thrusted and also absent. However, there are still a few places where Shagai formation is present and seemingly in normal contact with Landikotal slate. Such sections have been found in Chirgarch Greh area as well as in the Khan Bekhel Mela area WSW of Misri Khel. The lower contact of the Shagai formation is seemingly normal and placed at the base of 0.7 m thick sandstone. The upper contact with the Ali Masjid formation is placed at the top of thick limestone bed (Fig. 9b) containing abundant Haxagonaria. Over this bed, the terrigenous material of Ali Masjid formation begins containing red, maroon, yellow coloured ochre and haematitic material.

Lithologic surface log at the type locality is as follows. The section begins with 0.8 m of brown sandstone lower part intercalated with clays. The bed is impersistent sandstone and the clays show limonitic colour in part. The contact of this unit with slates appears normal sedimentary. The unit is overlain by 3.18 thick white coloured, medium to fine grained and medium to thick-bedded quartzite beds. Over it appears the first limestone bed. The limestone is grey weathering to brown, thick bedded and persistent. This limestone bed is 1.7 m thick. Again 1.9 m thick quartzite bed lies on the limestone unit. This quartzite is grey, weathering to dirty white, medium to fine grained and medium bedded. This quartzite bed is overlain by 1.36 m of clay bed. It is brown, calcareous and thin bedded. The clay bed is interbedded with limestone layers of brown colour in the lower part. A thick unit of limestone of 6 m overlies the clay bed. The limestone is light grey, weathering to brown, dolomitic, fine-grained, very thick bedded and unfossiliferous. This limestone bed has a few lenses of clay and quartzite. Above this unit is 1.3 m of white quartzite. It is grey, weathering to dirty white or light brown, slightly calcareous and very rarely fossiliferous. Next, upwards, is a 3.5 m thick limestone unit. It is grey, fine grained and thick bedded in the lower part and upper one meter is thin bedded. A very thick unit of 16 m of limestone lies above thin-bedded limestone unit. This massive limestone unit is fossiliferous and lower 10 m are highly fossiliferous full of corals and contains abundant Hexagonaria along with many other corals. It gives the impression of a coral reef. The limestone is grey weathering to brownish grey, thick bedded and persistent.

The area is tectonically disturbed. Nevertheless, at several places in the Gandah Gallah Mountain these reefs like masses are present. These masses sometimes do have bedding and are interbedded with sand and clay. This reef limestone ends the Shagai formation. Average thickness of the formation in Misrikhel area is 30 m.

Reefoid beds are deposited close to shoreline probably in a lagoon, where deposition of red bed and oolitic beds, proceeded immediately above the reef beds of Shagai formation. However no evaporites are seen and only terrigenous quartzite sandstone and finally red beds of Ali Masjid formation, which overlie the reefoid beds. These reefoid deposits were earlier included in the Ali Masjid formation by Shah et al. (1980). Now they are separated and placed in Shagai formation. Age of the Shagai formation is derived from the following coral fauna collected from Misrikhel, which were identified by John Picket in Shah (1980). *Hexagonaria brevilamellata (Hill), Alveolites minutus Lecompte sensu (Yanet), Cladopora* cf. *vermicularis var. clara (Yanet), ?Rhombopora* sp., *Endothyra* sp., *?Nodosinella* sp. Based on these fossils, the age must be near to the Eifelian-Givetian boundary i.e. Middle Devonian.

Molloy et al. (1997) worked on the conodonts fauna from the same formation and states "All but one of the twelve samples proved barren. Sample SS7D (Shagai Section No. 7D). This is the uppermost sample of the section collected by Shah from the top most bed, of the Shagai formation, yielded fragments of Icriodus and Polignathus, indicating only a broad Emsian or Famennian age. Late Middle Devonian age for Shagai formation is, thus, apparent.

Distribution of the Shagai formation is such that it follows the trail of Ali Masjid formation from Misrikhel in the west to Ali Masjid area in the Khyber Pass Highway. The beds of Shagai formation appear mixed with Ali Masjid formation northeast of Mashkani Mela. They are mapped in a combined form. At the Tauda Mela Caves, almost complete section of the Shagai formation appears. Here the formation seems to be fossiliferous. It is grey weathering to yellowish brown limestone occasionally contains white crystallized fossils as well as rare re-crystallised brachiopod shells. The formation here is comprised of thick-bedded limestone only and is overlain, by the first appearance of quartzite of Ali Masjid formation. Eastwards between Tauda Mela and Illacha, the formation continues in patches along with the Shagai thrust and at Illacha, it is represented by thin-bedded limestone, similar to that present at Bagiari picket at Khyber Highway where this thin-bedded limestone is the upper part of the Shagai unit. Further east the exposures continue along Shagai Thrust. This section within the Khyber Pass Highway is now considered Principal Reference Section. The log of the Principal Reference Section is as follows.

**Lithological description of Shagai unit in the Khyber Pass Highway:** At Khyber Pass Highway the Shagai unit begins in thrust contact with Landikotal slates. At the contact a sill (volcanic rock) is present on the road at a point half a km, west of Shagai Fort. The lowest unit is 5 m of limestone, light grey weathering to brown, platy to thin bedded and medium to fine grained, decorated with numerous calcite veins, completely recrystallized, it is a dolomite; overlying this unit is 16 m thick dolomitic limestone of light brown colour. At various stratigraphic positions the limestone is massive. Darker beds increase upwards. At other places it weathers platy to thin bedded. The limestone is usually micritic, but in the middle of the unit the beds show coarse-grained texture.

Above this unit a 1.7 m thick limestone is present. It is grey coloured, weathering to light yellow, thin bedded, fractured, and fine-grained with abundant iron filling probably replacement of organic matter. It is dolomitic limestone. Over this unit is, 1.5 m thick limestone, grey weathering to dark grey, banded with brown coloured limestone, dolomitic brown bands range in thickness from 0.02 m to 0.04 m. The top most unit of the Shagai unit is a 4.5 m thick dolomitic limestone, light grey weathering to light yellowish grey. It is thick bedded and massive, fine to medium grained, highly fractured, ferruginous, chertiferous with nodules, and a film on the surface with calcite veins.

The Shagai unit, east of Shagai Fort of Khyber Pass is present as rubbles and at many places the unit is covered by screes, while at few places the unit is found in thrusted blocks. The Shagai unit in this region of Khyber Highway is completely unfossiliferous.

**Stratigraphic Correlation of Khyber Pass Highway and Misrikhel Sections:** Before the correlations and ages of the Ali Masjid and Shagai stratigraphic units are described, it is to discuss the position of the units within the stratigraphic column.

In the east central Khyber Agency, the entire sequence was divided into four formations viz. Landikotal slate is the oldest followed upwards by Shagai, Ali Masjid units and finally capped by Khyber limestone. They are very well exposed in the Khyber Pass Highway near the town of Ali Masjid. Elsewhere, away from the town, small changes occur in these units, these changes are brought in by three factors. The first is the metamorphism which increases from southwest to northeast, the second is structural complications in which several beds of the units are missing and the third is facies change which is a minor change. As a result, several stratigraphic names and sequence appear in the literature, e.g. Shah et al. (1980), Khan Ashraf et al. (1989), Tahirkheli (1996) and Khan et al. (2003).

The fact of the mater is that these problem will remain till the area is easily accessible, giving freedom of movement to all workers, otherwise bit by bit information currently being gathered will take long time to evolve correct and undisputed solution to these problems. At present only a few observations are presented in this Memoir.

Starting with the Landikotal slate, it is observed that slate formation is widespread extending from the eastern edge of the Khyber Pass to Pak-Afghan border as noted by all earlier workers, like Hayden, Greisbach of the nineteenth century and then Stauffer (1968b), Shah (1969), Shah et al. (1980) in the recent times. Thus, Landikotal slate is considered the oldest formation, which provides base for all other formations. Different appearance of the slates is due to change of the grade of metamorphism. The grade of metamorphism increases from east to west. Its exposures in Ali Masjid Valley are less metamorphosed than at Landikotal. The type section, giving a doubtful impression of two different formations, otherwise they are one and the same formation. Accordingly, combination of Landikotal slate, Shagai limestone and Ali Masjid unit, all exposed in Ali Masjid Valley, Khyber Pass Highway, presented by Khan A, et al. (1989) as only one formation, "Shagai formation", is not stratigraphically acceptable units. All the three units mentioned above show separate and clear identity and are mappable. Their "Shagai formation", including all the three units, can at best be called group but not as one formation.

In a normal sequence, in the Ali Masjid Valley (Khyber Pass Highway), the Khyber limestone capes the entire stratigraphic sequence. Two to three meter thick reddish brown clay and quartzite beds are present in the top most part of Ali Masjid unit of Shah et al. (1980). They are present all along Khyber Highway in the same position, e.g. at the base of Khyber limestone, exceptional situation occurred in the Haidry Kandao and to its east and west, where above mentioned red beds and quartzites are sitting directly over Khyber limestone unit indicating the reversal of the sequence. All along the northwestern and northeastern periphery, the Khyber Thrust has delimited the continuity of Khyber limestone. Close to this fault, a large scale recumbent folding within the Khyber limestone occurs. The recumbent folding associated with thrust fault has caused the overturning of the plunging part of the anticline exhibiting reversal of the beds. Therefore, the sequence in the entire east central Khyber Agency is considered the same as shown in Table 6. Significantly, it is also noted that such red beds are not found in any other unit of Khyber Pass area than the Ali Masjid unit.

Westwards in the Misrikhel area, similar sequence of rocks occurs which are highly fossiliferous divisible or splitable into three rock units i.e. Shagai, Ali Masjid and Khyber units with similar lithology and even close thicknesses to the sequence at Khyber Pass Highway. Here again the sequence, like any other place, is developed on the Landikotal slates. The contact appears to be normal.

Due to their close similarities in lithologic character and stratigraphic position these units both from Khyber Pass Highway and Misrikhel, were given same names. This correlation is now considered doubtful and uncertain based on a single strontium isotopic age determination. All the formations are now described in the previous pages, in which same geographic names are used for both areas, but the second name for the fossiliferous beds is given as formation (such as Shagai formation) and an informal second name of "unit" is given to the unfossiliferous beds, e.g., Shagai unit. This is desired to avoid confusion in referring to the place of their origin as well as over all reference (Table 6).

Lithologically both the sequences are comprised of quartzite, sand, silt, shale and limestone. The amount of these lithologies in a given section may be little different. Overall colour of both the sequences is generally brown and red. Arenaceous material is little more in the west, in the lower portion of sequence, while limestone predominates in the upper part as compared to the east, i.e. in the Khyber Pass sequence. The main difference in the sequence of east and west is that the eastern sequence is slightly metamorphosed probably contact metamorphism, while the sequence in the west is completely unmetamorphosed.

At the unit level, the main lithological difference between the two units is that Shagai unit contains layers of volcanic ash and the Shagai formation is devoid of volcanic ash. At places the lower part of Shagai unit is missing in the east where at one locality a doleritic sill is present at the contact of slate with Shagai unit, while the Shagai formation starts with a layer of sandstone. Thickness of the Shagai unit or Shagai formation is close to 36 m.

Ali Masjid formation at both the places, i.e. Misrikhel and at Khyber Highway is lithologically very similar; the only difference is that Ali Masjid formation of Khyber Pass Highway contains volcanic ash while that of Misrikhel is devoid of volcanic ash. But arenaceous and argillaceous materials at both the places are similar. Both have quartzite throughout their stratigraphic height. The upper half of both the units contains red beds; both have hematitic and lateritic material in the upper half, both have drusy filled quartzite beds, both the units terminate at an unconformity above which both have thick to massive limestone. Both have brownish red zones within the unconformity zone.

Age of the formations: The sequence of rocks at Misrikhel is highly fossiliferous, whereas the sequence of rocks on the Khyber Pass Highway is completely unfossiliferous. Shah et al. (1980) considered the sequence at Misrikhel as an extension of the sequence present on the Khyber Pass Highway. The field work, mapping and systematic collection of samples by Shah and Siddiqui were given to Professor John Talent, of Macquarie University, Australia for further Paleontological work. They published this work in a paper by Molloy et al. (1997). This is a detailed paper on the palaeontology and biostratigraphy of the Misrikhel sequence of Ali Masjid and Shagai formations. Figure 9b shows the biostratigraphical position of the samples and zonation. The age of the Ali Masjid formation, according to Molloy et al. (1997) is as follows:

This is the first detailed biostratigraphical zonation, which covers the entire east central Khyber Agency. The authenticity of measured sections is here testified from the statement of P. Molloy (op cit) who added, "The conodonts biostratigraphy inferred from the fauna of the Ali Masjid Formation is coherent, consistent with lack of major repetition of strata in the area where the sampled sections are located. These results provide some basis for believing that a sustained program of systematic sampling of limestones for conodonts, mounted under appropriate auspices and carried out throughout the Khyber region, could well result in a major breakthrough in understanding of the structural and tectonic evolution of the region."

On a regional scale similar beds and fauna of Ali Masjid formation are present in Gundi Sar area from where Pogue et al. (1992) described a hand picked sample containing late Famennian (Expansa zone). This means Gundi Sar and east of it more of Ali Masjid formation is present from where Khan, A. (1970) had already described "Ali Masjid group". This marks the eastern limit of the Ali Masjid formation. Western limit of the formation in Bazaar Valley where late Tournaisian (in a limited area) recorded by Khan, F. et al. (2003), has been described. Thus the Misri Khel section becomes the central point of the Ali Masjid formation.

It is important here to note that in the Khyber Highway area, a spur-like body of limestone of great thickness is present, below which, all the lithologic units exposed are unfossiliferous. The towns of Ali Masjid and Shagai Fort are the only places, where the later mentioned unfossiliferous units can be seen. Shah et al (1980) have correlated this sequence with Misrikhel sequence. This spur-like body is bounded by faults on either sides, and interrupts the continuity of Devonian strata of Gundi Sar in the east and Misrikhel in the west. Spur is mainly a large carbonate body referred here as Khyber limestone has about 1200 m stratigraphic thickness and capes the lithologies of Ali Masjid and Shagai units. This sequence rests over the Landikotal slate just in the same manner as those of Devonian sequence of Gundi Sar and Misrikhel.

Recently, this correlation has been subjected to controversy on the basis of strontium isotopic constraints on the age of metasedimentary rocks of Khyber area. Pogue and Hussain (unpublished) collected and picked random samples of Khyber limestone and processed for the sea water ratio of $^{87}Sr/^{86}Sr$, and came out with a value of 0.7064 showing Proterozoic age. This age of Khyber Limestone implies that the entire section below the Khyber Limestone i.e. including unfossiliferous Ali Masjid, Shagai unit and Landikotal slates are Proterozoic or older. Consequently, many workers have revised the stratigraphic column of the Khyber Pass Highway. Some declared Khyber limestone and Landikotal slate as Precambrian but placed Shagai Shale (Shagai unit) in post Permian age (Tahirkheli, 1996). Others, e.g., Khan, A. et al. (1989) and Khan, F. et al. (2003) consider all the formations of Khyber Pass Highway as Precambrian, but placed Landikotal slate at the top of Khyber limestone. All the workers have eliminated the Ali Masjid unit of Khyber Pass Highway from the sequence. Elimination of Ali Masjid unit from the sequence and merging its strata in Shagai formation, of Khan et al. (1989), may be acceptable, but union of Ali Masjid, Shagai units together with and metamorphic facies of Landikotal slate as one formation in the Khyber Pass sequence is stratigraphically unacceptable; they may, however, be combined in an informal Shagai group.

The age of the unfossiliferous sediments mentioned above is based on methods used in strontium isotopic stratigraphy. Derivation of age of rocks by strontium isotopic method is now a reality, but its authentic usefulness is limited only in Cainozoic Stratigraphy. Well-defined Sr sea water curve is now available in the literature limited to carbonate rock samples particularly of the Tertiary age. In older rocks such as in our case, covering Palaeozoic and Precambrian rock this method is still unrefined and its credibility is viewed with doubts. The value of 0.7064, as in our case, has also been noted in Archaean, Neo-Proterozoic, Palaeozoic rocks of various places around the world, depending upon different geologic set up.

As a matter of fact many workers in this field have enunciated cautions and condition in the process of strontium isotopes for age determination. Faure (1982) stated that "because the $^{87}Sr/^{86}Sr$ ratios of marine carbonate minerals are assumed to be identical to those of seawater at the time of deposition, provided that they have not been altered during diagenesis, dolomitization, regional metamorphism, or during selective dissolution of the carbonate minerals in the laboratory prior to analysis.

With these conditions and control, the work in the age dating is in progress. According to Faure (1982) "the bulk of the available evidence supports the conclusion that Sr in oceans has been isotopically homogeneous throughout Phanerozoic time. The isotopic homogeneity of Sr in the oceans may allow us to use the observed time dependent variation of the $^{87}Sr/^{86}Sr$, ratio to date the marine carbonate rocks. Faure (1982) reviewed the history of this proposal but concluded that the usefulness for dating rocks of Palaeozoic age is limited by the frequent fluctuation of $^{87}Sr/^{86}Sr$ ratio during that era. However, the method may be suitable for dating marine carbonate rocks ranging in age from Middle Jurassic to Pleistocene, because of the almost uninterrupted increase of the $^{87}Sr/^{86}Sr$ ratio during this interval of time.

It is further observed that the available data are not sufficient to recognize small-scale fluctuations of the $^{87}Sr/^{86}Sr$ of marine strontium of Precambrian age. However, people have made some seawater curves for Precambrian as well.

A team of scientists comprising Julie Trotter, Tory Allan, Mike Korsch and David Whitford of SCIRO Exploration and Mining, Australia, engaged in high precision resolution of strontium isotopic stratigraphy have summarized the problem in the following words.

"Strontium isotope stratigraphy relies on recognized variations in the $^{87}Sr/^{86}Sr$ ratio of seawater over time. Because of the combination of relatively short mixing time with a much longer residence time, Sr in seawater is isotopically uniform. Long term variations in the crustal and mental derived Sr entering the oceans, has resulted in a seawater Sr isotope evolution curve that has important scientific implications for understanding the evolution of the crust, but also significant practical applications in stratigraphic correlation".

They further added, "in Cainozoic sequences, particularly in the mid to late Tertiary, Sr isotope stratigraphy is widely used for dating and correlation and may yield higher resolution in limited stratigraphic intervals than more conventional biostratigraphic correlation techniques." To a great extent their work is in the Tertiary rocks with particular focus on Miocene sediments yet their well acquired experience in the older rocks is equally important, as has been, pointed out in a classic statement where they say **"In older sequences however, diagenetic alteration combined with greater uncertainties in estimating absolute ages leads to greater uncertainties in the exact shape of the Sr isotope seawater curve."**

Stressing the need of the use of geochemistry, petrography and biostratigraphy in strontium isotopic stratigraphy they recorded that, "it has been argued that Sr isotope stratigraphy can be reliable, applied only when the carbonates meet a number of geochemical criteria including, for example, a relatively restricted concentration range for Sr. The unthinking application of such criteria may result in the loss of valid age information. Each sample needs to be considered in the context of its geological setting and the detailed petrography for its suitability for Sr isotope dating. Of critical importance is the timing and duration of diagenesis and associated fluid flow events, which are determined by petrographic examination. Biostratigraphy also provides an important control on the precision and accuracy of the isotope stratigraphy."

Pros and cons of the strontium age determination have been given in the foregoing paragraphs, however, to establish doubt free age of the sequence, it is desired to use other sources to confirm this age of Precambrian for Khyber unfossiliferous sequence. The strontium age determined, so far, has been carried out for Khyber limestone unit only and has presumably been applied to the entire Khyber road sequence. Since the area is tectonically disturbed and the application of determined age may not prove to be correct for other formations of the Khyber sequence. Thus the age of Ali Masjed and Shagai formations must be determined independently. Alternatively, the presence of volcanic (tuff) both in Shagai and Ali Masjid units of the unfossiliferous sequence exposed on the Khyber Pass Highway, have been reported in their formational description. Samples can be collected from the units and be processed for the isolation of some radioactive minerals to be used for absolute age determination. This will resolve the problem once for all.

Alternatively, considering the age of the unfossiliferous sequence as Precambrian, the correlation of fossiliferous sequence with unfossiliferous sequence is to be ruled out. In that case the names of the formations of the unfossiliferous sequence of the Khyber Pass Highway may be changed whereas those of the fossiliferous sequence be retained, because, as against the unfossiliferous sequence, the formations of the fossiliferous sequence fulfil the requirements of the stratigraphic code of Pakistan, viz contact relations, age by fossils, presence of complete stratigraphic record with presence of all strata as certified from the biostratigraphic investigations and detailed lithographic description. In other words the Ali Masjid Formation of Misrikhel area is a proved Devonian sequence. It must be considered different from that of Khyber Pass Highway section.

Therefore, consequent upon the confirmation of the Precambrian age of the unfossiliferous sequence, it shall be assumed, that the entire unfossiliferous sequence, now bound by faults from all sides, is a large sized horst "rift block or mountain" an allochthon, which is now flanked by exposed Devonian stratigraphic sequences on its either sides.

***Nowshera Swabi Area***

**Nowshera formation:** Teichert and Stauffer (1965) described the first Palaeozoic reef in Pakistan near Nowshera. This preliminary account was followed by a better documented description by Stauffer (1968a), who named the rocks Nowshera formation and selected the type locality 5 km east of Nowshera, on Nowshera-Risalpur Road. The formation, mainly composed of limestone and dolomite, has been subdivided into three units by Stauffer (1968a):

i. Reef core
ii. Carbonate containing reef breccia or fossil debris
iii. Carbonate containing few or no fossils

**Reef core:** As described by Stauffer (1968a), the reef cores are made up of fossils with calcareous sediments and fossil debris in and around them. This framework forms the main masses of the reef complex and occupies the topographic highs of outcrops near the type section. The reef core at the type locality is highly fossiliferous. A clear vertical change in the fossil assemblage has been noticed with hardly any change in the lateral direction. Stauffer (1968a), dealing with the reef core at length, described that stromatoporoids cephalopods and gastropods become more common towards the top, while the branching coral Thamnopora which forms up to 40% of the layer lying in the eastern extremity of the reef decreases sharply in the western exposures, while brachiopods become less common towards the top and delicate dendroid favositid corals are present only in the easternmost outcrops of the reef.

**Carbonate containing reef breccia or fossil debris:** Carbonates containing reef breccia or fossil debris have been divided by Stauffer (1968a) into (a) crinoid banks (b) carbonate with dominant reef breccia or fossil debris and (c) carbonate with subordinate reef breccia or fossil debris.

The crinoid banks are composed of single crinoid ossicles. In part, the stem sections consist of up to 10 ossicles. Associated with these crinoidal stems are few brachiopods and cephalopods.

Dominant reef breccia or reef debris is composed of limestone and dolomite, commonly thin-bedded and lenticular. The most common fossils in the smaller breccia and debris accumulation are crinoid ossicles with few stromatoporoids rugose corals, brachiopods, gastropods, and straight cephalopods.

Carbonates with subordinate reef breccia and fossil debris are similar to the above mentioned carbonates except that the quantity of breccia and fossil debris they contain are generally less than one quarter of the rock volume. Most of these carbonates consist of pale red, light grey, medium to fine grained dolomite, with pockets of breccia and lenses of fossils and fossil fragments.

**Carbonates containing few or no fossils:** They consist of pale red or light grey fine to medium-grained dolomite and contain few corals (favosited), brachiopods and crinoids.

The reef complex is present near Nowshera as a series of east-west striking ridges. Continuous outcrops of the reef belt extend over a distance of about 20 km but scattered outcrops are present throughout the Peshawar plain. The following important fauna have been reported by Stauffer (1968a) from the formation.

Among coelenterata the most common are Stromatoporoidea, which usually form 10 - 30% of the reef core and in places as much as 90%, Rugosa include Zelophyllum? Tryplasma ? and Mucophyllum; Tabulata are represented by Favosites, Thamnopora, Heliolites, Cladopora and Alveolites. Among brachiopods are Ambocoelia, Atrypa, Gypidula and Coelospira? cf. elytha. The cephalopods represent the superfamily Orthoceratacea of the order Orthocerida.

Among the conodonts the most important are Lonchodina greilingi, Ozarkodina media, Trichonodella excavata, T. inconstans and several others indicating an age from Late Silurian to Early Devonian. Therefore the age of the Nowshera formation as indicated by Stauffer ranges from Late Silurian to Early Devonian. The formation is correlated with the Early Devonian of Chitral and with the Khyber Devonian formation.

**Pir Sabak formation:** The term Pir Sabak formation was introduced by Shah (1977) for the limestone unit described by Latif (1970d) as "Lower Carboniferous rocks near Nowshera". The formation is light to dark grey. The lower part of the formation is thick-bedded dolomitic limestone, in part marmorised; the middle part is thin- to thick- bedded limestone of light grey colour and the upper part is grey limestone, coarse grained, partly dolomitised and marmorised. The formation is highly fossiliferous. Stauffer (1968a) regarded it "undifferentiated reef core". Latif (1970d) collected some fossils, one of which was tentatively identified as Amplexus sp. which is found in the Lower Carboniferous rocks of Europe only. The formation is intruded by thick igneous sill bodies. The contact with the lower Misri Banda quartzite of Devonian age is conformable, while the upper contact is terminated by alluvial cover. A poorly preserved amplexoid coral from Pir Sabak formation, as described above, has been recorded to indicate a possible Carboniferous age for the beds but a fauna collected from the upper part of the formation contains species of Acanthophyllum and Favosites indicating a Devonian (pre-Late Devonian) age for the sequence (Shah et al., 1980). This indicates that the Pir-Sabak sequence is an integral part of the Nowshera succession. The formation is correlated with Lower Devonian rocks of Chitral and with parts of the Khyber Devonian formations.

***Hindukush Karakoram Tectonostratigraphic Basin***

***Northern Sedimentary Province***

North of central (Karakoram) Axial batholiths is roughly delineated as Northern Sedimentary Province where metamorphic crystalline basement is capped by a thick sedimentary cover of more than 2000 m with the rock units spanning from Ordovician to Cretaceous in age. The sedimentary cover does not form any succession but they are mostly stacked in the form of thrust sheets. Internally some stacks do have sequential order. Based on fossil evidence from different stacks many workers have worked out the stratigraphic sequence of Devonian age, best among them is reconstructed by Gaetani et al (2004) from the eastern part (Table 7; Fig. 10a). For the description of stratigraphy of the Northern Sedimentary Province, the area is divided into eastern and western parts. In the western part the following sequence is worked out from different thrust sheets the area that extends from Chitral to Baroghil. Wakhan formation is the youngest formation in the area and Charun quartzite is the oldest the base of which is not exposed.

5. Wakhan formation
4. Owir formation
3. Lun shale
2. Shogram formation
1. Charun quartzite

**Charun quartzite:** Stauffer (1971) proposed the name Charun quartzite for the quartzite exposed between the Devonian dolomite Shogram formation and the red beds in the Reshun area and suggest the type locality of the formation along Charun Gol (Lat 36° 13' N: Long 72° 12' E).

According to Stauffer the Charun quartzite at the type locality consists of white, medium-grained quartzite present in layers ranging from 2.5cm to 15cm in thickness. The quartzite weathers to a light yellow-brown colour and its total thickness in Charun Gol is about 75 m. Charun quartzite is thin bedded than Shogram formation, which lies above it. Stauffer traced the formation on aerial photographs from Parpish to Buni, a distance of about 32 km and it seems to be about the same thickness along most of its extent. In Reshum Gol, it is about 90 m thick. Khan, et al. (2000), mapped Charun quartzite undifferentiated from and together with Shogram formation. Although their mutual contact is unconformable as indicated by Stauffer; the contact of the quartzite with the overlying Shogram formation in Reshun Gol is marked by a 3 m thick, yellow laterite layer. The laterite, which

Table 7. Stratigraphic nomenclature of Mesozoic rocks of Balochistan and correlation with Upper Indus Basin.

| AGE | | | | AREAS: BALOCHISTAN (AXIAL BELT) SOUTHERN | CENTRAL | NORTHERN | UPPER INDUS BASIN SHAIKH BUDIN HILLS | SURGHAR RANGE | WESTERN KOHAT |
|---|---|---|---|---|---|---|---|---|---|
| MESOZOIC | CRETACEOUS | Late | | PAB Ss | MORO FM | | | | |
| | | | SENONIAN: COMPANIAN | MONA JHAL GROUP: MUGHAL KOT FM | MONA JHAL: MUGHAL KOT FM | MONA JHAL: MUGHAL KOT FM | | | KAWAGARH FM: TSUKAIL TSUK MEM |
| | | | SANTONIAN | | PARH Ls | | | | |
| | | | CONIACIAN | PARH Ls | | PARH Ls | | | CHALOR SILLI MEM |
| | | | TURONIAN | | | | | | |
| | | | CENOMANIAN | GORU FM | | GORU FM | | | |
| | | Early | ALBIAN | | | | | | |
| | | | APTIAN | SEMBER FM | SEMBER FM | SEMBER FM | SURGHAR GROUP: LUMSHIWAL FM | SURGHAR GROUP: LUMSHIWAL FM | RGHR GROUP: LUMSHIWAL FM |
| | | | NEOCOMIAN: BARREMIAN | | | | CHICHALI FM | CHICHALI FM | CHICHALI FM |
| | | | | | | | | | |
| | | | VALANGINIAN | | | | | | |
| | JURASSIC | Late | TITHONIAN | | | | | | |
| | | | KIMMERIDGIAN | | | | | | |
| | | | OXFORDIAN | | | | | | |
| | | Middle | CALLOVIAN | | | | | | |
| | | | BATHONIAN | | CHILTAN Ls | TAKATU FM | BAROCH GROUP: SAMANA SUK FM | BAROCH GROUP: SAMANA SUK FM | SAMANA SUK FM |
| | | | BAJOCIAN | FEROZABAD GROUP: ANJIRA FM | FEROZABAD GROUP: ANJIRA FM | ALOZAI GROUP: LORALAI FM | SHINAWARI FM | SHINAWARI FM | BAROCH GROUP: SHINAWARI FM |
| | | Early | AALENIAN | | | | | | |
| | | | TOARCIAN | | | | DATTA FM | DATTA FM | |
| | | | PLIENSBACHIAN | MALIKHORE FM | MALIKHORE FM | SPINGWAR FM | | | DATTA FM |
| | | | SINEMURIAN | KHARRARI FM | SHIRINAB FM | | | | |
| | | | HETTANGIAN | | | | | | |
| TRIASSIC | | | | Base not exposed | Base not exposed | WULGAI FM; KHANOZAI GROUP: GWAL FM | MUSA KHEL GROUP: KINGRIALI FM, TREDIAN FM, MIANWALI FM | MUSA KHEL GROUP: KINGRIALI FM, TREDIAN FM, MIANWALI FM | |

Modified after Anwar, M., Fatmi, A.N and Hyderi, I.H., 1991 is also found on the ridge south-southeast of Reshun Village most probably indicates an unconformity at the top of the Charun quartzite. The formation is well exposed in Reshun area and extends westwards up to the point south of Parpish and in the eastern direction from Reshun it touches the Buni town and to some distance further east where isolated quartzite and minor limestone beds have been considered by Aslam et al. (2000) as Shogram/Charun outcrops (Fig. 11).

Stauffer found some external brachiopod impressions in the Charun quartzite. Some of these impressions closely resembled *Rhipidomella* and some other impressions of rhynchonellid brachiopod are also present in the loose block of quartzite. Stauffer thought them to be probably of Palaeozoic age. Presence of Palaeozoic fossils coupled with the stratigraphic location of the formation, in which Devonian dolomite lies over it with an unconformity, the age of the Charun quartzite is also Devonian or perhaps Silurian.

Based on the suggestion of Hayden (1915) who first correlated this quartzite with the "Muth Quartzite" of Himalayas, Stauffer (1971) pointed out that recent stratigraphic studies have shown that "there is indeed a white Devonian and perhaps partly Silurian quartzite throughout most of northern Pakistan and Kashmir."

**Shogram formation:** Desio (1955, 66) described the "most important Devonian section in Pakistan" as the Shogram formation from Mount Shogram and Korag spur and established stratigraphic succession of limestones and quartzitic sandstones. Stauffer (1971) redescribed the formation and its distribution. The type locality is the same as was chosen by Desio at the southeastern slope of Mount Shogram (Lat. 36° 11' N: Long 72°). This section was selected because the strata are well exposed and appear comparatively undisturbed by folds, although the top of the section is bounded by a nearly vertical fault.

Desio (1966) measured the sections and made 19 units of various coloured limestone and quartzite, with red ochre, red haematitic quartzite and mylonitised breccia. Stauffer (1971) divided the Shogram formation into three units: a lower massive dolomite; a middle unit of bedded dolomite, fossiliferous limestone and black shales; and an upper quartzite. According to him the lower-most unit consists of a massive, at least 200 m thick, light to dark grey fossiliferous dolomite in beds 75 cm to 9 m thick. It is well exposed on the ridge one half mile due east of Reshun and along the banks of Gabaro Gol.

The middle unit of the formation consists of well-bedded dolomite and grey, extremely fossiliferous limestones in beds as much as 1.8 m thick, separated by thinner beds of black shale. The upper part of this unit contains fine-grained quartzite beds. These beds gradually, stratigraphically upwards, increase in thickness from a few centimetres to more than 6 m.

The upper unit of the Shogram formation consists of massive, light grey, hard, fine to medium-grained quartzite and some dolomite beds, particularly in the basal part. Individual quartzite beds range in thickness from less than 3 cm to more than 2 m. Worm burrows and cross bedding are fairly common and show that the formation here is not overturned.

The thickness of Shogram formation at Mount Shogram is about 675 m. It may be more and at least 800 m according to Desio (1966).

According to Stauffer the Shogram formation extends for a distance of at least 56km, along the Mastuj Valley from the village of Partsan (Lat. 36° 3' N: Long. 71° 53' E) to the ridge between the Mastuj and Turikho rivers east of Buni. The same formation may continue northeastward up to Baroghil area where dark-grey or black compact limestone crops out. Which may be representing part equivalent of Shogram formation from which Major Grant collected Late Devonian fossils in 1898 (Hayden, 1904; p. 31; Reed, 1911; p. 86-100).

The Shogram formation overlies Charun quartzite with unconformity which is marked by a yellow ferruginous layer, about 3 m thick. This layer has the appearance of a weathered soil interval, indicating an unconformity; the upper contact of the Shogram formation wherever present is faulted against the Sarikol shale.

Shogram formation is exposed, both at Mount Shogram and Korag spur. Fossil collection has been made more from the Shogram Mount and less from the Korag by many workers including (Hayden, 1915; Reed, 1922; Schouppe, 1965; Sartenaer, 1964; Vandercammen, 1964; Desio, 1966; Gaetani, 1967). The age of the "Korag Dolomite" has been determined as Late Devonian (Frasnian) by Reed (1922, p. 130) on the basis of fossil assemblages collected by Hayden from two localities. One locality is on and near the top of the high hill behind Shogram (Lat. 36° 11' N: Long. 72° 7' E) (Hayden, 1915; p. 283) and the other is on the ridge just behind and due south of Korag. The fossil assemblages from these two localities are very similar and consist largely of colonial and rugose corals and brachiopods, but also include some bryozoans, crinoids, mollusc, trilobites, a gastropod and a straight cephalopod, Reed (1922). On the south-western end of the ridge between the Mastuj and Turikho Rivers near Roman Dur (Lat. 36° 12' N: Long. 72° 11' E) a fossil assemblage suggestive of a reef was seen. This reef has been correlated with Nowshera formation (Stauffer, 1971).

According to Talent et al. (1981) sequence exposed along the Korag spur had not previously been measured and its important faunas were known mainly from float. They collected rock samples and isolated conodonts fauna and established biostratigraphy including the marking of (Givetian Frasnian) boundary which lies in gypsiferous shale unit. In other words presence of Middle Devonian fossils in the Shogram formation is confirmed.

According to Talent et al. (1981) the base of the Devonian section at Korag is truncated by a steep fault. The oldest strata are micaceous quartzite (about 20 m) followed by 10 m of fine recessive black shale with occasional thicker interbeds of siltstone. This is followed by massive buff-weathering crinoidal and crystalline dolomite; the only macrofossils found were fairly abundant crinoid ossicles, occurring through an interval of about 20 m. This horizon referred to above has yielded a small, winnowed, poorly preserved conodonts fauna including the species Ozarkodina denckmanni Ziegler, Trichonodella sp., and some other conodonts comparable with Spathognathodus linearis Philips. These suggest, roughly, a general Emsian age. This fauna indicates early Devonian strata between the crinoid bed and the next important fossiliferous horizon (of Late Givetian age) are dominantly sandy-grey siltstone and rusty-weathering flaggy quartzites. Loose material from this interval includes bivalves (cf. Modimorpha), vascular plant straps and unidentified trails (repichnia). There is no evidence as yet for a major sedimentary gap within the unit, Talent et al. (1981).

**Lun shale:** Desio (1966) named Lun shale formation to the thick series of "Paper and needle-shale" and quartzite which lies further back (north) of the Shogram exposures at Shogram and at the village of Lun. The shales are in faulted contact with Shogram formation.

Lithologically the Lun shale, as described by Desio (1966), is composed of black calcareous shale and quartzite beds and contains thin beds of limestone full of crinoidal stems. The age of the Lun shale as described by Desio is Carboniferous to Permian and for correlation Desio said, "The author is inclined to compare this series with that underlying his "Pamir Limestone" attributing it to Carboniferous".

The Lun shale north of Shogram lies in tectonic slices, in which the upper and lower Devonian rocks are stacked together. This was pointed out by Hayden (1915, p.287) who mentioned the existence of a bed of Late Devonian with Sarikol shale of older age near Lun. Talent et al. (1981) confirmed the presence of the Late Devonian beds in Lun shale on his physical inspection of these beds and described the age of Lun shale as Early Devonian.

Desio (1963) stated that the Shogram fault brings Late Devonian quartzites and carbonates of Shogram formation against slates and quartzites; a sequence, which is poorly known but earlier named as the Lun shale. These beds were thought to be probably of Carboniferous age by Hayden (1915). Talent et al. (1979, 1981) visited the area and stated, "Very dark grey slates and silty slates outcrop around the crest of Mount Shogram, on the first small knob to the south and approximately 100 m distant from the triangulation point Talent collected Iridistrophia iris? (Barrande), Strophochonetes cf. Plebius (Perner), unidentified bivalves, Dalmanites sp. nov., cf. Phacops, homalonotid gen. nov., phacope ostracodes indet., Monograptus cf. uniformis, Feeding trails or algal straps, burrows and vascular plants. The two graptolite specimens are incomplete, both lacking a sicula but despite poor preservation the course of the interthecal septa and the morphology of proximal and distal thecae can be made out; these features suggest closer affinity with M. uniformis than with, for instance, M. thomasi or M. praehercynicus. The fauna, therefore, is taken to be of probable earliest Devonian (Lochkovian) age. This is the first record of graptolites from Pakistan and is the first record of Devonian graptolites from the Indo-Pak subcontinent".

They further introduced Emsian fauna from the exposures of Lun shale. The localities lie at about 7 km northwest of Shogram up the Mastuj Valley and on the right bank of the river is the tiny hamlet of Gosh Lasht. Approximately 1.5 km along the mule track from Gosh Lasht towards Lasht (and over looking Gosh Lasht) is an outcrop of Pinacotrypabearing carbonates from which Molloy has identified the following conodonts: Hindeodella equidentata, H. priscilla, Ozarkodina denckmanni, Plectospathodus extensus extensus, P.robustus, Polignathus dehiscens?, Spathognathodus inclinatus inclinatus, S. steinhornensis steinhornensis, S. sp. undet., and Synprionodina sp. the fauna is probably of middle Emsian age. The age of Lun shale is therefore, late Early Devonian.

Pudsey et al. (1985) reported the Lun shales briefly in the Turikho valleys north of Buni. Slates are predominant overall but a few several tens of metres thick fine-grained quartzite's thin beds are present in the unit. Bioturbation is widespread and the burrows are mainly bedding-parallel. Sedimentary structures include trough and tabular cross-bedding variable in orientation and some current ripple cross-lamination; mud drapes and Planolites burrows are very abundant in some quartzitic units. Grey micritic limestones contain layers of highly fossiliferous biomicrite with bryozoa, corals, brachiopods, crinoids and fusilinids of Permian age.

Dolomite units thousand of metres thick occur within the terrigenous successions but their precise outcrop was not defined, therefore they are not differentiated. They may represent tectonic repetitions of the Devonian strata and constitute some 20% of outcrops, dying out towards the north.

According to them, relatively soft, dark grey to black shales and slates underlie most of the poorly exposed ground west of Buni. They are mainly non-calcareous and contain quartz, albite, illite and chlorite. The southwestern equivalents of these dark grey slates are green phyllites with thin schistose conglomerates exposed from Lutkho valley south through Kafristan called Lutkho formation by Leake et al. (1989). The colour change occurs along strike over about 1km in the Shoghot valley. The green phyllites have a higher chlorite-illite ratio and more iron in the chlorite. The green beds then become gradually coarser southwards with increasing numbers of thin gritty phyllites and conglomerates.

In the Lutkho Valley, green slates are succeeded to the west by grey slates about 4 km west of the Reshun fault, the slates are increasingly metamorphosed to mica schists near the south-western tip of the Trich Mir pluton. Leak et al. (1989) has defined Arkari formation, in this general area, with mica schist facies.

However, with the inclusion of green grey and black slates beds of Lutkho and Arkari beds of Leak et al. (1989) the age of the Lun shale may be extended through Permian to Jurassic.

**Sarikol shale:** The name Sarikol shale was introduced by Hayden (1915) to an essentially slate sequence extending from Chinese Turkistan to Chitral. The name is evidently taken from Sarikol Mountain Range at the boundary between USSR and China. In the type area, Kara Chukur Valley, Sarikol Range, the formation as described by Hayden (1915) and Stauffer (1971) is predominantly slate at places calcareous with subordinate quartzite and some limestone beds. Stauffer described them as "needle shale." The formation is intruded by granite bodies and generally forms the highest portions of mountain ridges. As a result of intrusive bodies, the formation is slate near the intrusive bodies and away from it the formation shows "needle shales". It is very well exposed in Sarikol Range, Little Pamir Mountain, in part of Muztagh Ata Tange in China. According to Stauffer (1971), the metamorphic equivalent of Sarikol slate is known as 'Wakhan slate', which covers most of the area in Wakhan Range of Afghanistan.

Hayden (1915) recognised Sarikol shale in the northern most Chitral in Baroghil area and to further west. Talent et al. (1981) believed that Sarikol shale does not extend across the northern border of Chitral into Pakistan. They further stated that Hayden (1915; p.32), nevertheless, applied this name to sediments in Mastuj Valley opposite to Reshun and in Upper Hunza Valley.

In Chitral the formation is best exposed on the right bank of the Mastuj River. The most accessible place is near the village of Shogram where the formation is exposed on flat topped rolling hills. Here the formation is mostly black shale and slate with minor limestone beds. The formation is fossiliferous and has yielded nautiloids to which Tipper (in Pascoe, 1924) has assigned Devonian age. Further north, near Korag the Sarikol slate tectonically lies over Frasnian beds. Hayden (1915) found Triassic fossils in overlying Pamir limestone in Pamir area. The age is considered Late Palaeozoic, most probably Devonian to Permian.

**Lun shale versus Sarikol shale:** Use of names of both the formations is still in practice. Only a few authors substitute Lun shale for Sarikol shale. Distribution of both the formations is given above and more details are given below as follows:

The description of the Lun shale given by Desio (1966) who named the formation is as follows: "The Upper Devonian beds opposite Reshun and above Shogram are overlain by a thick series of "paper and needle-shale" and quartzite. One thin bed of crinoid limestone was also observed in the shales. Further back in the hills, and below the village of Lun, the shale series run to the foot of a line of cliffs formed of the Upper Devonian limestone evidently repeated by a fault. Above this is shale similar to the series just referred to. Above the village of Lun, shaly and slaty beds predominate, passing up eventually in the high ridge above the village into quartzite with some slaty calcareous beds". He further added, "if the thick series of paper and needle shales and quartzite represents the upper stratigraphical series of the Shogram formation, it will undoubtedly constitute a different formation, to which the name of Lun shales can be applied". On the other hand the description of Sarikol shale given by Stauffer (1971) and Calkins et al. (1981) is as follows:

The name Sarikol shale was first applied by Hayden to dark slates found throughout the south-western corner of China. Hayden specifically described this formation from the Sarikol Range, whose crest forms the southernmost part of the boundary between the USSR and China, where its type area is considered, Stauffer (1971). Lithologically in the type area the Sarikol shale has been described by Hayden as consisting largely of black slates, in places calcareous, but also containing quartzite, volcanic rock, "needle shales" and some beds of limestone.

Hayden believed that the same lithological unit occurs in northernmost Chitral in the area of the Baroghil Pass and farther west. According to Stauffer (1971) the work of Tipper (in Fermor 1922, p. 56-57) later confirmed the presence of the Sarikol Shale in much of Chitral area, including the Mastuj Valley. He traced these rocks from Shah Jinali Pass (Lat. 36° 47' N: Long. 72° 50' E) in the uppermost Turikho River valley, southwest for more than 81 km to the ridge above Kosht Gol in the Mastuj Valley (Lat. 36° 15' N: Long. 72° 10' E).

The Sarikol shale in the Mastuj Valley is found only on the northwest side of the Mastuj River where it forms a continuous outcrop in grey, softly rounded hills. On the ridge north of Kosht Gol, the formation contains beds of quartzite and a few limestone layers. Between the villages of Lon and Barumk, the shales have been so much tectonically disturbed that they have no coherent form and most hill slopes are merely piles of rubble. The hummocky topography of some areas suggests that landslides have contributed to the incoherency. From the above two definitions described independently by Hayden (1915), Tipper (in Pascoe, 1924) and Stauffer (1971) on the one hand and on the other hand Desio (1966), Talent et al. (1981), and Tahirkheli, (1982), it appears that both the groups of field workers are dealing with the same unit. In other words, "paper and needle shale" of Desio and "needle shale" of Stauffer are the same; same are the localities of the exposures of these units within the Chitral district. Style of tectonics of the unit is the same as discussed by Desio and Stauffer, i.e., everywhere the unit is faulted against Shogram formation. Tahirkheli (1982), however, stated that the unit is faulted against Chitral slate in the southwest of Chitral.

Sarikol shale has its type section out side the territory of Pakistan, while the Lun Shale has been described from the village of Lun, Chitral District. Some workers prefer to have the Pakistani name over alien names in the stratigraphic nomenclature of Pakistan e.g. Talent et al. (1981). Therefore the name Sarikol does not fit in precisely with the stratigraphic procedures of Pakistan. Therefore, it is suggested that the name Sarikol shale should be abandoned. The unit may be called Lun shale. The age of the Lun shale, as discussed in detail by Talent et al. (1981) may be considered Early Devonian.

**Owir formation:** Upper Palaeozoic sequence, containing rare fossil of Receptaculites neptuni (Difrance), is described here as the Owir formation. The fossil Receptaculites neptuni was first discovered in Iran Flugel (1961) and then from this (Chitral) region, Receptaculites neptuni described by Vogelanz (1969), is thus, only the second finding in Asia. The mother rock of the Receptaculites is the upper most member of a characteristic rock sequence, which is described by Vogelanz (1969) as follows, from top to bottom:

Fossiliferous limestone partially oolitic
Siliceous limestones and quartzites
Red argillaceous shale
Quartzose conglomerate
Siliceous shale

According to Diemberger, who collected the specimen described by Vogelanz (1969), this fossil locality lies "at the west end of this series which covers the Trich Mir (granite) Pluton with vertical dipping". Earlier these beds have been referred to as "Sedimentary Series of Owir" by Hayden (1915) and "Chitral Series" by Mc-Mahon and Huddleston (1902). Buchroithner and Gamerith (1986) retraced these beds and designated the unit of these Receptaculites bearing beds as "Series of Owir". In accordance with the stratigraphic code of Pakistan it may be called Owir formation. The type section of the formation is designated between Ojehor Valley and Owir An. From the location of the fossil site and the sequence given above, it is determined that the sediments fall within the "Devonian-Jurassic" mapped unit by Calkins et al. (1981). This unit includes many formations. It is, infact, composed of a wide variety of metamorphic and sedimentary rocks to which Calkins et al. (1981) presented as undivided 'Devonian to Jurassic' rocks. The Owir formation, thus, is a part of the sedimentary suit mapped combined as Devonian Jurassic Unit of Calkins et al. (1981). Buchroithner and Gamerith (1986) described these beds as typically composed of the "frequent limestone intercalations, which are characteristic feature of the formation". According to them, the formation consists of medium- to dark-grey, locally greenish to brownish grey, anchimetamorphic, coarse-grained, biosparite with oolitic parts. This light weathered, frequently dolomitised limestones, locally show encrinites (crinoidea) and iron inclusions.

Tracing Devonian rocks, Talent et al. (1981) reported from just west of Owir An, development of quartzites, siliceous limestone, red argillaceous shale, limestone, conglomerates and shales. Conaghan (in Talent et al., 1981) has collected blocks of red oolitic limestone with Receptaculites from Ojehor Gol about 1km above its confluence with the Lutkho River. Since Vogelanz's locality is within the Ojehor Gol watershed, they also suspected that these blocks may be derived from the horizon in question. According to them the blocks have yielded the conodonts Angulodus walrathi (Hubbard), Ancyrodella curvata (Branson and Mehl), Ancyrognathodus asymmetricus (Ulrich and Bassler), Belodella triangularis (Stauffer), Hindeodella austinensis Stauffer, Neoprioniodus prona (Huddle), Palmatolepis unicornis Miller and Youngquist, Polygnathus normalis Miller and Youngquist and species of Hindeodella, Icriodus and Polygnathus. Talent stated that the fauna is indicative of assignment of the upper part to the zone of Palmatolepis gigas, i.e., low in the Famennian of the Belgian stage succession. The age of the series, therefore, is determined as Late Devonian.

Sewakht formation of Leake et al. (1989) with greenschist limestones dolomitic carbonate and sandstone may correlate with the western continuation of Owir formation. The same author introduced the term "Lutkho formation" for the monotonous greenish phyllite cropping out between "Sewakht formation" and the Trich Mir Pluton. These rocks have been related previously by Pudsey et al. (1985) to the Lun shale. The position of all the above mentioned rock formations is shown in the map exhibiting undifferentiated part of Wakhan formation exposed south east and west of Trich Mir pluton (Fig. 11).

**Wakhan formation:** Hayden (1915) named and described "Wakhan Slates" extending from many kilometres east of Baroghil through Trich Mir area westwards up to Pak-Afghan border. The formation has been mapped by many workers including Buchroithner and Gamerith (1986) (only Sketch map) who mapped it as Wakhan formation and finally detailed mapping and compiling was done by Khan et al. (2000), which includes many other units (Fig. 11).

The Wakhan formation comprises of multiple lithologies. The predominant lithology is slate. The formation is composed of dark-grey, homogenous slates, siltstone, and quartzite with some minor intercalations of calcareous schists. In the north the Wakhan formation grades into gneisses indicating comparatively higher grade of metamorphism. Desio et al. (1966) studied it as "Khandut Slates". He also correlated the Wakhan formation with Misghar slate and Kilik formation as well as with Sarikol shales.

The age of the formation as described (from only a part of the formation), by Buchroithner and Gamerith (1986) is Early Triassic. It may extend to Late Permian as indicated by Kafarsky and Abdullah (1976) in Afghanistan. The formation is in faulted contact with a huge carbonate rock body named **"Atark formation"** by Buchroithner and Gamerith (1978) and redefined by Gaetani and Leven (1993). The carbonate stack runs parallel within the contact of Wakhan formation and may be part of Wakhan formation.

The oldest rocks include deformed granitoids, possibly Cambrian in age (Debon et al., 1987), the Qal'a-e Ust gneiss (Buchroithner, 1980), which are always in tectonic contact with the Palaeozoic-Mesozoic metasedimentary successions. Most of the belt consists of the Palaeozoic Wakhan slates which record accumulation of thick terrigenous sediments coming from the Gondwana supercontinent in rapidly subsiding rift basins (Gaetani, 1997). In Chitral the very thick and monotonous succession delivered only bryozoans and brachiopods of Palaeozoic affinity Gaetani et al. (1993), although Triassic conodonts may occur at the top of the unit in Afghanistan (Kafarsky and Abdullah, 1976); Buchroithner (1980). Large tectonic slices of carbonate with Late Palaeozoic fusilinids occur close to the Afghan border in the upper Khan Kun Gol within the Wakhan slates forming a widespread thrust sheet extending to the north of the Baroghil Pass.

A Permo-Triassic shallow water carbonatic terrigenous succession, the Atark formation, possibly deposited on the rift shoulders Gaetani et al. (1993). The unit records the evolution from a continental/marine terrigenous plain to a carbonate ramp with fusilinids in the Early Permian, followed by a wide carbonate platform in the Upper Triassic. In the upper part of the Atark Valley from the intrusive contact with the Trich Mir Pluton down to the village of Shogram, a very low-grade metabasits, mainly including lava flows interbedded within the terrigenous successions of the unit. This layer is 100-150 m thick. The Atark unit is locally sealed with a conglomerate similar to the unconformable Cretaceous conglomerates of the Karakoram (Zanchi et al., 1997).

The Atark unit is also present in the Arkari Gol close to the Trich Mir pluton, where bioclastic limestones with strongly recrystallised fusilinids have been recognized at the top of the Dir Gol within a steeply dipping succession of very low-grade metapelites. This exposure is very similar to the Wakhan slates and has been shown as Wakhan formation by Khan et al. (2000). In this area the Wakhan slates pass into a composite metamorphic succession reaching medium-grade conditions, named the Arkari formation by Leake et al. (1989). The formation includes mica schists, phyllites, marbles, quartzites and feldspathic gneisses, which may be derived from the Palaeozoic Wakhan slates. A few Belemnite remains found 75 Ma ago near Besti (Tipper in Pascoe, 1924) suggest a Mesozoic age for at least part of the protolith of the metamorphic complex.

**Chilmarabad formation:** Gaetani et al. (1996) named and described this predominantly dolomite unit from the upper Yarkhun Valley, Chitral District.

Lithologically the formation is predominantly dolomite, with dolomitic limestone and slates. The formation shows cyclothematic depositional style in Vidia Kot Valley eastwards in Chillinji area. The arenaceous intercalations comparatively increase where the formation represents fine clastics alternating with arenaceous limestone.

The formation essentially constitutes peritidal carbonate platform, with development of patch reefs with compound corals and show cyclothematic sedimentary sequence (Gaetani, 1997).

The upper contact of the formation is terminated by an erosional event, which is well developed in Karambar valley. Marked by beds of conglomerates and coarse sand the unconformity lies at the middle Upper Devonian boundary (Gaetani et al., 1996).

The Lower contact of the Chilmarabad formation is gradational with Vidiakot formation of "Baroghil group". The formation is about 200 m thick.

The age of the formation has been determined from poorly preserved stromatoporoids and bryozoans not younger than Middle Devonian. The Chilmarabad formation is, therefore, assessed as Devonian or Silurian.

## CARBONIFEROUS - PERMIAN

Carboniferous and Permian rocks are found more or less in almost all the basins of Pakistan. Rocks known to be restricted to the Permian system are located in the Kohat-Potwar, Axial Belt and at some places in the Northern Sedimentary Province. All the rocks are sedimentary with lithologies of shale, sandstone and limestone and metasedimentary lithologies having thicknesses of several hundred metres.

Rocks of Kohat Potwar Province have been studied in detail. Previously they were dated as Permo-Carboniferous and since mid sixties these rocks have been authoritatively declared as Permian exclusively.

Carboniferous and Permian rocks are located in the Lesser Himalayas including Khyber Agency, Swabi and Hazara areas and in the Karakoram-Hindukush Tectonostratigraphic Basin including both the Southern Metamorphic Province and Northern Sedimentary Province.

### INDUS BASIN

#### *Kohat-Potwar Province (UPPER INDUS BASIN)*

Permian rocks located in the Salt Range and Khisor Range in the Upper Indus Basin have long been known for the richness of fauna and for their relationship with the rocks of the Triassic System. The strata near the boundary of the two systems are marine and were formerly regarded to have a conformable relationship. However, in spite of lithologic conformity, there is a significant break in the continuity of faunas at the contact. This boundary problem has been the subject of discussion for a number of years and more recently it has been studied in detail by Kummel and Teichert (1966, 1970), who established paraconformity at the boundary of the two systems.

The Permian strata have been divided into two groups, the Nilawahan Group and the Zaluch Group. The Nilawahan Group represents a dominantly continental deposit consisting of arenaceous and argillaceous sediments with marine intertonguing in the upper part which passes conformably into the overlying marine Zaluch Group. The lowermost beds of the Permian rocks rest disconformably on Cambrian rocks, while the upper part is separated from the Triassic rocks by paraconformity.

**Nilawahan Group:** The name "Nilawahan Series" was proposed by Gee (in Pascoe, 1959) for rocks conformably underlying the Zaluch Group and disconformably overlying the Cambrian succession of the Salt Range (Fig. 8). Gee's proposal has been formalized as Nilawahan Group. The group includes the following formations in the sequence; Tobra Formation being the oldest.

4. Sardhai Formation
3. Warchha Sandstone
2. Dandot Formation
1. Tobra Formation

Some of the formations of the group have yielded bryozoans, brachiopods, molluscs, spores, pollen, and micro plankton indicating Early Permian age.

**Tobra Formation:** The name Tobra Formation refers to the lowest formation of Nilawahan Group previously known in the literature as "Talchir Boulder Bed" or "Talchir Stage" of Gee (in Pascoe 1959), and "Salt Range boulder bed" of Teichert (1967). The type locality is located near Tobra Village in the eastern Salt Range.

The Tobra Formation depicts a very mixed lithology in which the following three facies are recognized (Teichert, 1967):

1. Tillitic facies exposed in the eastern Salt Range. This rock unit grades into marine sandstone containing Eurydesma and Conularia fauna (Dandot Formation).
2. Freshwater facies with few or no boulders. It is an alternating facies of siltstone and shale containing spore flora. This facies is characteristics of the central Salt Range.
3. The unit with complex facies of diamictite, sandstone and boulder bed increases in thickness in the western Salt Range and Khisor Range.

In the eastern Salt Range, the Tobra Formation exhibits true tillite, the rock unit is composed of boulders of granite with fragments of quartz, feldspar, magnetite, garnet, claystone, siltstone, quartzite, bituminous shale, diabase and gneiss. The matrix of the conglomeratic bed is generally clayey, sandy and at some places calcareous. A few pebbles and boulders are polished and scratched. According to Teichert (1967) the ice sheet that deposited the tillite in the eastern Salt Range was probably not a part of an extensive inland ice sheet but of a local glaciation. The ice sheet did not extend into the area now occupied by central and western Salt Range. The formation at the type locality in the eastern Salt Range is about 20 m thick. The thickness in the adjoining areas varies greatly and at places it is totally missing.

In the central Salt Range, the Tobra Formation is mainly composed of freshwater facies comprising of siltstone and shale. It contains flora and fauna including Glossopteris, Gangamopteris and several species of freshwater bivalves and ostracods (Reed, 1936). According to Teichert (1967), the formation in the central Salt Range was deposited in lacustrine environment, which was only moderately modified by the glacial conditions, an inference based on the scarcity of boulders in the formation.

In the western Salt Range, the formation is divisible into 3 units: (a) lower part composed of a brownish green, massive unit consisting of unsorted clastic material including clay, silt, sand and boulders, (b) a middle part, composed of medium to coarse-grained, thick-bedded, dark to light olive grey sandstone containing conglomeratic beds at the base and conglomerate pockets near the top and

(c) upper part is similar to the lower one and consists of dark green, grey clay and sandstone with pebbles and boulders. According to Teichert (1967), the formation in the western Salt Range and in Khisor Range shows evidence of periodic intensive ice rafting of glacigene material alternating with deposits made by melt water streams, possibly, at least partly, in a marine or estuarine environment.

In the Khisor Range, the lithology of the Tobra Formation is similar to that of the Zaluch section, but its thickness is reduced to 67 m. It rests on dolomite of possibly Cambrian age and the basal bed consists of one metre of fine-grained, yellow sandstone without boulders.

In the eastern Salt Range, the formation grades into the overlying Dandot Formation but in west of the Salt Range and in the Khisor Range, it is overlain by the Warchha Sandstone. Its lower contact with the Cambrian rocks is disconformable.

The formation attains the maximum thickness in the western Salt Range at Zaluch Nala where it is more than 133 m. In the eastern Salt Range, it is about 33 m and in the central Salt Range it varies from 0 to 25 m.

The lower part of the formation in Zaluch Nala contains pollen and spores out of which the following have been identified: *Punctatisporites* cf, *P. gretensis, Leiotriletes* spp., *Acanthotriletes* cf. *A. tereteangulatus, Apicnlatisporites* sp., *Protohaploxypinus* sp., *Striatopodocarpitrs* sp., *Potonieisporites* sp., *Kraeuselisporites* sp., *Nuskoisporites* sp.

On the basis of *Striatopodocarpites* and *Ptotohaploxypinus* the age is considered to be Early Permian (Balme, in Teichert, 1967).

**Dandot Formation:** The name Dandot Formation is formalized after the " Dandot Group" of Noetling (1901) and includes the "Olive Series" "Eurydesma beds" and "Conularia beds" of Wynne (1878) and the "Speckled sandstone" of Waagen (1879). The type locality is near Dandot Village, eastern Salt Range.

The lithology at the type locality consists of light grey to olive green yellowish sandstone with occasional thin pebbly beds and subordinate dark grey and greenish splintery shales. The Dandot Formation is well developed and exposed in the eastern Salt Range and thins out westward. It is not developed in the western Salt Range and Khisor Range. The maximum thickness of the formation has been recorded in the Makrach Valley, where it is about 50 m. The formation has a gradational contact with the underlying Tobra Formation and is terminated at a sharp but conformable contact with the overlying Warchha Sandstone.

The Dandot Formation is fossiliferous and the basal part in the eastern Salt Range, has yielded brachiopods including Discina sp., Martiniopsis sp. and Chonetes sp; bivalves include a rich fauna of Eurydesma and several species of Conularia. Many species of Bryozoa and Ostracoda have also been described from the formation. The age of the Dandot Formation on the basis of this fauna and its superpositional order with the Tobra Formation of Early Permian age is considered Early Permian.

**Warchha Sandstone:** The name Warchha Sandstone was coined by Hussain (1967), which has been approved by the Stratigraphic Committee of Pakistan. Prior to the formalization of this name other terms were used such as the "Warchha Group"of Noetling (1901), which included the overlying "Lavender clays" (Sardhai Formation) with it. The names such as "Speckled sandstone" of Gee (1945) and middle speckled sandstone of Waagen (1879) were also prevalent in the literature. Its type section is in the Warchha Gorge in the Salt Range.

The formation consists of medium-to coarse-grained cross-bedded sandstone, conglomeratic in places and has interbeds of shale. The sandstone is red, purple or shows lighter shades of pink. The sandstone is arkosic. The pebbles of the unit are mostly of granite of pink colour and of quartzite. The formation is locally speckled which caused the previous workers to call it as "Speckled sandstone". The formation at Burikhel, in the western Salt Range, contains some carbonaceous shale with impersistent coal seams. This coal is being mined but the production is very low and quality is poor. This, however, is the only Permian coal in Pakistan. The Warchha Sandstone is widely distributed in the Salt Range and Khisor Range. Its thickness in these areas ranges from 26 to 180 m. Variable thickness together with the strong cross bedding suggests that the formation is a fluviatile deposit and was laid down in a large alluvial flat.

The Warchha Sandstone conformably overlies the Dandot Formation. In Zaluch Nala and Saiyiduwali sections, however, the formation directly overlies the Tobra Formation. It is overlain by the Sardhai Formation with a transitional contact and the contact is placed at the top of the highest massive sandstone bed. Some plant remains have been reported from this formation. On the basis of its stratigraphic position with the overlying and underlying Early Permian formations, the same age may also be assigned to it.

**Sardhai Formation:** The name Sardhai Formation as approved by the Stratigraphic Committee of Pakistan, was given by Gee. Prior to this Gee (in Pascoe 1959) had called it "Lavender clay stage ". Wynne (1878) had called it "Lavender clays" and Noetling (1901) called it the "upper part of Warchha Group". The type section as suggested by Gee is in the Sardhai Gorge in the eastern Salt Range.

The formation is composed of bluish and greenish grey clay, with some minor sand and siltstone beds. It also contains some carbonaceous shale. The clay prominently displays lavender colour and contains some copper minerals including chalcopyrite. Minor jarosite, chert and gypsum are found disseminated in the formation, with occasional calcareous beds in its upper part.

The Sardhai Formation changes facies from predominantly lavender colour clays in the Salt Range to black shale and brownish argillaceous limestone in the Khisor Range. The formation is 50 m thick in the Khisor Range and 65 m in the western Salt Range. At the type locality in the eastern Salt Range it is about 42 m thick. It has a lower transitional contact with the Warchha Sandstone. The upper contact with the Amb Formation is conformable, though lithologically well defined. The formation is largely unfossiliferous, though occasional plant remains and fish scales are found in exposures in the Salt Range. Well developed limestone beds in the Khisor Range have yielded determinable brachiopods and bryozoans.

Hussain (1967) reported the following fossils from sandy limestone beds exposed at Saiyiduwali in the Khisor Range: Anastomopora sp., Fenestella sp., Athyris sp., Spirijer sp. The age of the formation is Early Permian.

**Zaluch Group:** The name Zaluch Group, derived from Zaluch Nala in the western part of the Salt Range, was introduced by Teichert (1966). The group includes the Amb Formation, Wargal Limestone and Chhidru Formation, which were previously known as Lower, Middle and Upper Productus limestone respectively. The rocks consist of sandstone, shale, and sandy limestone of the Amb Formation, followed by rather pure, occasionally argillaceous limestone and dolomite of the Wargal Limestone. The top consists of sandy limestone and calcareous sandstone of the Chhidru Formation. The thickness of the entire group at the type section is more than 300 m. The group is highly fossiliferous and almost all the invertebrate phyla are represented, Waagen (1889; 91); Reed (1941); Pascoe (1959). The brachiopods are by far the most abundant fossils except in the lower part of the Amb Formation, where fusilinids are prevalent.

The age of the group ranges from Early Permian to Late Permian on the basis of Monodiexodina kattaensis in the lower part and Cyclolobus oldhami in the upper part. The lower contact of the group with the Sardhai Formation is conformable, while the upper contact is terminated by paraconformity. A brief description of its constituent formations is given below:

**Amb Formation:** Waagen (1891) introduced the name "Amb sandstone beds" to a sequence of limestone, sandstone and shale exposed near the village of Amb. Teichert (1966) suggested the name Amb Formation to the same unit, which was formalized by the Stratigraphic Committee of Pakistan. As indicated above, the name has been derived from the village of Amb in the central Salt Range, which is designated as the type section for the formation.

The formation consists of sandstone, limestone and shale. The sandstone is brownish grey, medium-grained, calcareous and medium to thick bedded. These sandstone beds occupy the lower part of the formation. The calcareous bed associated with the sandstone contains abundant fusilinids. Upwards in the sequence limestone with some shale appears. The limestone is sandy, brownish grey, medium-bedded and richly fossiliferous with large productus such as Derbyia and Neospirifer. The shale is grey to dark grey and contains some flora, including Glossopteris and Gangamopteris. In the Khisor Range, the lower part of the formation is composed of dark coloured shale containing thin bands of limestone. This limestone has yielded some brachiopods. Hussain (1967) named it Saiyiduwali Member of the Amb Formation. This member is about 33 m thick and is transitional between Sardhai Formation and the Amb Formation. The upper contact of the formation is conformable with the Wargal Limestone and is placed above the plant bed (Teichert, 1966). The formation is well-developed in the western Salt Range and thins out eastwards. The formation is 80 m thick in the type locality and 47 m in the Khisor Range.

The Amb Formation is richly fossiliferous and has always been an attraction for the palaeontologists. Recently, detailed biostratigraphy has been worked out by Kummel and Teichert (1970), in which Balme (1970) has reported abundant pollen and spores. Pascoe (1959) described the presence of rich fauna from the formation, which consists of fusilinids, bryozoans, brachiopods, bivalves and gastropods. The brachiopods include Orthotichia spp., Derbyia spp., Dictyoclostus spp., Marginifera spp., Neospirifer spp., Strophalosia spp., Dielasma spp., and others. Ostracods have been reported by Kummel and Teichert (1970, p. 66). The most important index fossil is

Monodiexodina kattaensis which indicates Artinskian age (Dunbar, 1933; Teichert, 1966; Douglas, 1968). The age is also equivalent to the Darvasion stage of the southern USSR (Miklukho, 1958).

**Wargal Limestone:** Noetling (1901) coined the term "The Wargal group" to a predominantly calcareous unit overlying the Amb Formation in the central Salt Range. The name Wargal Limestone, as approved by the Stratigraphic Committee of Pakistan was introduced by Teichert (1966). For the same rock unit, the name "Middle Products Limestone" was used by Waagen (1879). The type section is near Wargal Village in the central Salt Range. Zaluch Nala in the western Salt Range has been designated by Teichert (1966) as the tentative standard section/ principal reference section.

The lithology comprises of limestone and dolomite of light to medium grey brownish grey and olive grey. The detailed lithology of the formation in Zaluch Nala is summarised with thickness as under (Teichert, 1966):

10. Limestone, light to olive grey, argillaceous thin- to medium-bedded, rubbly, highly fossiliferous; 28 m
9. Limestone, light olive and yellowish grey with chert nodules towards the base and silicified fossils; 19.5 m
8. Dolomite with crinoides and bellerophon; 4.4 m
7. Limestone, light grey to olive, thin- to medium-bedded, dolomitic in the lower half, with chert nodules in the upper part; 40 m
6. Dolomite, pinkish grey and yellowish grey, brecciated and massive; 13.5 m
5. Limestone, light grey to olive grey, medium- to thin-bedded, dolomitic in the middle, with chert layers; 14 m
4. Dolomite, finely crystalline to saccharoidal, massive to bedded; 59.6 m
3. Limestone, argillaceous, finely crystalline, rich in brachiopods; 1.5 m
2. Sandstone, greyish orange, fine grained; 1.5 m
1. Limestone, light brown, finely crystalline, sandy; 0.8 m

In the Khisor and Marwat ranges the average thickness is about 174 m. The lithology is similar to that in the Salt Range. The contact of the Wargal Limestone with the underlying Amb Formation is well-defined and is placed at the basal sandy limestone of the formation above the uppermost shale unit of the Amb Formation. The upper contact with the Chhidru Formation is transitional.

The fauna consists of abundant bryozoans, brachiopods, bivalves, gastropods, nautiloids, ammonoids, trilobites and crinoids. In addition Kummel and Teichert (1970) reported pollen and spores, ostracods and conodonts from the formation. Among the brachiopods, there are many species such as Enteletes, Derbyia, Waagenoconcha, Richthofenia, Oldhaminia, Linoproductus, Spirigerella and others Trilobites, (Grant, 1966), occur in the upper nodular beds and include Kathwaia capitorosa and Ditomopyge fatmii. On the basis of presence of Xenodiscus and

Pseudogastrioceras, obtained from the upper part of the formation, the age is determined as Late Permian. The Late Permian age is further supported by the occurrence of Leela, Condonofusiella, and Nipponites in beds 66 m above the base of the Wargal Limestone in Nammal Gorge (Rao and Verma, 1953). Ustritsky (1962) placed the formation in the Late Permian on the basis of brachiopods. The Wargal Limestone correlates with the Guadalupe series of western Texas and the Murgabian stage of the southern USSR (Miklukho-Maklai, 1958).

**Chhidru Formation:** The name, "Chhidru beds" was given by Waagen (1891) and "Chhidru Group" by Noetling (1901) to the topmost beds of commonly known "Productus Limestone" and is derived from Chhidru Nala. The name Chhidru Formation was introduced by Dunbar (1933), which is now formalized. Teichert (1966) studied the formation at a number of places. Kummel and Teichert (1970) made detailed biostratigraphic studies of the formation and discussed its age and relationship with the Triassic rocks. They brought forward evidence for the paraconformity at the Permian-Triassic boundary.

The formation at the base, as described by Kummel and Teichert (1970) has a shale unit of pale-yellowish grey to medium dark grey in colour. The thickness of this unit ranges from 6 to 13 m. It contains rare small phosphatic nodules. Overlying this unit are the beds of calcareous sandstone with few sandy limestone. One of the beds is richly fossiliferous. According to Kummel and Teichert (1970), this "uppermost richly fossiliferous unit" is light grey, hard, sandy limestone or calcareous sandstone. The fauna of the bed includes brachiopods, bellerophontids and *Plagioglypta,* a scaphopoda. This bed is the top most in the sequence of calcareous sandstone beds. It is generally less than a metre thick. Thin section study of the samples taken from this bed shows presence of mostly quartz with minor amounts of feldspar, muscovite, biotite and iron oxide.

The top most part of the Chhidru Formation is a white sandstone bed with oscillation ripple marks. The sandstone is medium- to fine-grained with subordinate dark shale partings. According to Kummel and Teichert (1970) at Chhidru the sand-shale ratio is 3:2 but at Wargal the ratio is almost 1:1; elsewhere the shale is insignificant. Sandstone shows ripple marks. It is hard at places and the hardness increases with the increase in the calcium carbonate content. In the softer part of this unit, the terrigenous material makes up as much as 85% of the rock. Quartz and feldspar ratio is 4:1 and 5:1 in a thin section of rock samples with biotite, muscovite and iron oxide in minor amounts. The white sandstone is, in places, richly fossiliferous. This sandstone overlies richly fossiliferous beds of Chhidru Formation, and the top of it terminates the formation. Total thickness of the formation is about 64 m.

The formation is fossiliferous contains following important fauna (Kummel and Teichert, 1970). Brachiopods: *Aulosteges* sp.. *Callispirina* sp.. *Chonetella* sp.. *Cleiothyridina* cf. *C. capillata, Derbyia* cf. *D. plicatella, Dielasmatids.* sp., *Enteleles sp., Hemiptychina* sp., *Hustedia* sp., *Kiangsiella* sp., *Linoproductus* sp., *Lyttonia* sp., *Martinia* sp., *Neospirifer* sp., *Orthotichia* sp., *Richthofenia* sp., *Spiriferella* sp" *Spirigerella* sp., *Waagenoconcha* sp, and *Whitspakia* sp. Ammonoids: *Stacheoceras antiquum, Cyclolobus oldhami, Eumedlicottia primas, Episageceras wynne, Xenodiscus carbonarius, X. plicatus* and others.

The genus Cyclolobus is restricted to this formation. It has been reported from levels of 18 to 48 m below its top. Episageceras was found below the middle of the formation. The age on the basis of the ammonoids is considered to be Late Permian (Chhidruan Stage). The formation is correlated with "Pamirian Stage" of the southern USSR (Miklukho, 1958). Grant (in Kummel and Teichert, 1970) conc luded that the brachiopod fauna is typically found throughout the Chhidru Formation and assigned the age of Guadalupian fauna.

**Axial Belt**

The Permian rocks of the Axial Belt are exposed as isolated outcrops in the core of anticlines. The exposures have been described from Wulgai, Ghazaband and Kalat areas of Balochistan.

***Permian of Balochistan:*** The presence of Permian rocks in Balochistan was recognised by Vredenburg (1904) who reported some limestones with crinoidal remains, brachiopods and fusilinids from the Wulgai area ("pre-Triassic sedimentary rocks" of Williams, 1959). Later, Vredenburg (1909b) mentioned some additional outcrops of Permian rocks northwest of Kalat. Hunting Survey Corporation (1961) included the Permian limestone of Wulgai in the basal part of their undifferentiated "Alozai Group" which has a time range from Permian to Early Jurassic. They also mentioned Permian limestone from the lower part of their Shirinab Formation exposed at about eleven kilometres southwest of Sar Jungle, northwest of Kalat. These beds contain brachiopods such as Notothyris praelecta, Dielasma rara and Athyris sp., which Cox (in Hunting Survey Corporation, 1961) correlated with the "upper or middle Productus Limestone" Chhidru Formation or Wargal Limestone of the Salt Range. Sokolov and Shah (1965) described some 25 m of dark grey, greenish weathering limestone with marl and clay partings, containing brachiopod Marginifera sp. from the Ghazaband section, 30 m west of Quetta.

All these isolated outcrops of Permian rocks are located in the Axial Belt of Balochistan and are overlain by Triassic rocks (parts of "Shirinab Formation" and "Alozai group" of some authors). The contact with the Triassic rocks is regarded as disconformable in the Ghazaband section by Sokolov and Shah (1965) while in the Shirinab section of Kalat the Permian limestone (lower part of "Shirinab Formation") seems to underlie the Triassic conformably, Hunting Survey Corporation (1961). The fusilinids, productids, and other brachiopods present in these rocks indicate a Permian age. The units are correlated with the Zaluch Group of the Salt Range. In Gwal area, the Permian limestone beds containing fossils occur within the lower part of Wulgai Formation, as an olistostrome. This exotic block of Permian age is found in Triassic shale and limestone formation, named Gwal Formation (Anwar et el., 1993).

***Himalayan Tectonostratigraphic Basin***

***Lesser Himalayas***

***Khyber Area***

In the Eastern Khyber Agency a limestone of a great thickness caps all the rock sequence on the Khyber Pass Highway. It is completely unfossiliferous and presents problems for its age assignment. Similar limestone in the west near Misrikhel occurs. These two limestones viz Khyber Pass limestone in the east and the occurrence of similar limestone in the west were thought to be same by the earlier workers. In both the areas general picture of the lithologies is such that in the east it is 95% limestone, in the west it is 70% limestone and 30% shale at Gandah Gallah Mountain. Further west the shale content increases. Highly folded and trust structures with recumbent folding and overturning and reverse faulting are common in the east. Normal faulting and minor thrusting characterizes the western sequence. Cherty beds, lateritic material indicating unconformities in the eastern sequence and simple marine sequence and rarely chert and lateritic material is observed in the west. And finally unfossiliferous beds in the east and fossiliferous beds in the west of this unit also make difference. Eastern beds are intruded with basic dykes and sills. No such thing is visible in the western exposures of Khyber limestone.

Correlation of the two limestones (east and west) is based on huge thicknesses on both sides. This limestone caps red beds on both sides i.e. occupy the same stratigraphic position, on both sides. There is a short distance between their occurrences and large fault if any, present between them, is not clearly visible.

Khyber limestone was named by Stauffer (1968), from the defiles of Khyber Pass. Shah (1969) and Shah et al. (1980) followed the same name for this thick unit which caps the entire sequence present in the Khyber Pass area as well as Tauda Mela and Misri Khel in the west. They followed this limestone as far as west as Chora Kandao and part of Bazar Valley and southwestwards up to the Gandah Gallah Mountain. They collected fossils and measured sections only at the slopes of Gandah Gallah Mountain. The area was largely mapped by photographic interpretations throughout, with a few spot checks.

The correlation made between the two fossiliferous and unfossiliferous sections, has been put to controversy in the past few years, see also Ali Masjid formation. It is therefore, desired that both the sections be described separately. Geographic name is kept same but the unit name is changed, e.g. for fossiliferous Khyber formation, and for unfossiliferous it is Khyber limestone.

**Lithostratigraphic description of Khyber limestone in the defiles of Khyber Pass:** A thick limestone series exposed in the defiles of the Khyber Pass was first noticed by Griesbach in 1892 and by Hayden in 1898. Stauffer (1968) proposed the name Khyber limestone and designated the type section near the village of Ali Masjid, Khyber Pass. According to Shah et al. (1971, 1980), the unit at the type locality is predominantly composed of limestone with negligible argillaceous and arenaceous partings. The limestone grades into marble and dolomite.

The limestone is grey, weathers to greyish yellow shades. It is thick-bedded medium- to fine-grained and completely recrystallised. Clays and arenaceous limestone beds are comparatively more common in the lower part of the formation than in the upper part. The dolomite is grey, medium-grained and massive. The marble is almost white, thick-bedded and fine-grained. The marble is alternately interbedded with the limestone and beds of the marble at one place could be as much as 30 m thick. Original depositional structures can be seen in the limestone, especially in the eastern entrance of Khyber Pass. According to Stauffer (1971) part of the limestone unit was originally an Oosparite. The unit contains intraformational breccias and calcarenites ranging from 0.3 to 0.7 cm in thickness. Thick solution breccia is also present.

The unit in the middle part of the section shows yellow bands and contains limonite-rich arenaceous beds suggesting disconformities. These beds are not more than one metre in thickness. Exposures of the Khyber limestone mapped only by photo interpretation in the western direction appear to be widespread extending from Bara Fort to Loe Shilman in a north-south direction and from Ghund Garh to Bazar and perhaps beyond in an east-west direction. The formation is remarkably uniform from north to south but changes facies with the inclusion of shale and sandy beds from east to west.

North of the Khyber Pass sections, the formation is penetrated by many basic dykes and sills. These dykes appear to be connected with the formation of marble and may even be responsible for the increased proportion of it in the same direction. The dykes are altered dolerite with deeply weathered baked zones on both sides.

All dykes and sills are found in the upper part of the formation and are considered younger than the sequence of the Khyber Pass area. The dykes are 5 to 6 m thick. Some of them can be traced for a few hundred metres. Shah et al. (1980) estimated the thickness of Khyber limestone in the Khyber Pass area to be about 1000 m. The age of the unit considered by Shah et al. (1980) is Carboniferous to Permian but recently it has been assigned Precambrian also.

To the west of the Khyber Pass section, at Tauda Mela, the section is composed of grey and yellow limestone, with fossils and interbedded with minor shales. Southwards near Misri khel (Gandah Gallah Mountain) the limestone is interbedded with shales. Limestone at Tauda Mela appears to be link between the unfossiliferous section of Khyber Pass and fossiliferous section of Gandah Gallah Mountain. The section here is highly fossiliferous and was considered as the extension of Khyber Pass section based on the close similarity of lithology, colour and stratigraphic position. Since the age of the Khyber Pass section has been suggested to be Precambrian and the section at Gandah Gallah is Permian, therefore, separate description for the fossiliferous section is recorded here with a little change in the unit name as Khyber formation.

**Description of Khyber formation in the Gandah Gallah Mountains:** The name Khyber formation is here assigned to fossiliferous beds of Permian age. The formation is typically exposed on the slopes of Gandah Gallah Mountain west of Misri Khel village. The village is accessible by road from Bara town. Lithologically, the Khyber formation is dominantly composed of limestone with shale beds interbedded with it. The limestone is grey, weathers of yellow and light grey. Some beds of limestone are crystalline. It is medium to thick bedded and mostly medium grained. The limestone is highly fossiliferous. A small collection is made from the Shagai town situated at the base of Gandah Gallah Mountain, where the lower part of the formation is interbedded with thick shale and the upper part of the formation is predominantly limestone with minor shale. Among the fossils are several species of Productus and foraminifera of Permian and Carboniferous age. Khyber formation is exposed at many places on the slopes of Gandah Gallah. One of the section to the west of Shagai Village is recorded here.

Starting from the top of Ali Masjid formation, which is terminated by an unconformity; above the unconformity, the Khyber formation begins with a 2.1 m thick limestone of grey which weathers to yellow colours. This bed is overlain by 33.3 m grey, fossiliferous limestone. Both of these subunits are fine- to medium-grained, the lower subunit is thin- to medium-bedded and the upper medium- to thick-bedded and fossiliferous, siphonodella conodonts indicate lower Carboniferous age. A crystalline limestone unit overlies this unit, which is 28 m thick of light grey colour. This limestone unit is followed first by shale unit, which is 6.3 m thick, which is grey occasionally interbedded with thin limestone. Shale bed is overlain by thick bedded crystalline 21 m of limestone of grey colour then again shale bed of 13 m, overlain by 34 m highly fossiliferous limestone. This limestone is slightly sandy, medium-grained followed upwards by 14 m of shale at the top of which is 1.5 m reddish brown limestone, finally 33 m of limestone yellowish and brownish in colour which is terminated by a fault bringing Murree Formation against Permian beds. Permian section, however, continues on the south western slops of the mountain, but access was prohibited.

Collections of fossils were made from the upper part of the Khyber formation, which yielded the following taxa:

*Pseudovermiporella* sp., *Nodosaria* sp., *Geinitzella* or *Geinitzina* spp., *Glomospirella* sp., *Robuloides* sp., *Palaeotextularia* sp., and *Frondilina* sp.

The age of the Khyber formation based on these fossils range from Carboniferous to Permian.

Khyber limestone of the Khyber Pass area is completely unfossiliferous, while that Khyber formation of western exposures is fossiliferous. The fossiliferous sections have been dated by Shah et al. (1980) as Carboniferous to Permian. But its correlation with the Khyber limestone of Khyber Pass road poses problem. Recently the few hand picked samples were used for stable strontium isotope analysis and Pogue et al. (in press) have come out with the ratio of 0.7064 and according to them it indicates Proterozoic age. This rule out the correlation of Permian fossiliferous bed of Misrikhel with Khyber Pass limestone. See also chapter on Devonian for details on age and correlation.

***Nowshera-Swabi Area***

Nowshera-Swabi area was brought into light with the discovery of Devonian reef in the early sixties. In the construction of stratigraphic order, all the rest of the Palaeozoic was described based on conjectural, stratigraphic position and correlation. On the discovery of Carboniferous, Silurian and Ordovician fossils, a new stratigraphic order in the Nowshera-Swabi area was reconstituted by Pogue et al. (1986). In this arrangement, Swabi shale of Martin et al., 1962 was divided and Kandar phyllites and Misri Banda quartzite of Stauffer (1968a) were redefined. With this order, fossiliferous Ordovician, Silurian, Devonian and Carboniferous periods can now be clearly seen in Nowshera-Swabi area.

**Jafar Kandao formation:** According to Hussain et al. (1991), the name Jafar Kandao formation has been used for the upper part of the Swabi shale of Martin et al (1962). The rest of Swabi shale has also been named as Panjpir formation by Pogue et al. (op cit). The type locality of the formation is designated at Jafar Kandao section (Lat. 34° 18' 40' N: Long. 72° 17' 56" E) along Machai Canal, about 5 km southeast of Rustam.

According to Pogue et al. (1992), Jafar Kandao formation is primarily composed of argillite with subordinate interbeds of limestone, argillaceous quartzite and conglomerate. Based on distinct lithological character, the formation is divided into lower, middle, and upper parts. The lower part consists of argillite with lenses of limestone, argillaceous quartzite and conglomerate. The conglomerate occurs in channels and contains clasts of granite and quartzite. The middle part is dominated by interbedded argillite, calcareous quartzite, and sandy limestone. The upper part contains argillite with lenses of argillaceous quartzite and conglomerate. The formation is overlain by greenschist, which is the southern extension of an amphibolite, which was interpreted as metamorphic tholeiitic basalt (Ahmed et al., 1987).

Following taxa have been extracted from the formation *Protognathodus* sp., of Late Devonian-Early Mississippian age and *Gnathodus psedosemiglaber, Eotaphrus sp.* of Mississipian age and *Neogondolella* cf. *N. donbasica, Rhachistognathus* sp. of Pennsylvanian age. The age of the Jafar Kandao formation is, thus, Carboniferous (Kinderscoutian stage). Pogue et al. (1992) has provided a list of fossils in which the conodont fauna have been identified by Robert G. Stamm, Bruce R. Wardlaw and Anita G. Horris of the United State Geological Survey Ruston, Virginia.

***Hazara Syntaxis Area***

**Panjal formation and agglomerate slate:** Middlemiss (1910) named the belt of "volcanic greenstone and agglomerate slate" that occurs around the apex of the Hazara syntaxis, as 'agglomerate slate'. Earlier, Lydekker (1878) had included more volcanic rocks and named the entire suite as "Panjal system". This rock unit has also been called the "Panjal Trap" and "Panjal volcanic". Wadia (1957) called it Panjal volcanic series '.

Calkins et al. (1969) divided the whole rock unit into two parts, Panjal formation and Agglomerate slate. They described the agglomerate slate consisting of black carbonaceous slate or shale, glassy quartzose and agglomeratic sandstone with small amount of phyllite and conglomeratic sandstone. They noted regional metamorphism of low intensity and found porphyroblasts of andalusite, which is now completely altered to sericite. Closely associated with the agglomeratic slate is the volcanic greenstone of the Panjal formation. These rocks are metamorphosed lava flows and tuffs of intermediate mafic composition. They are light greenish brown to bright green and contain chlorite, epidote and feldspar as main primary minerals constituents.

The volcanic greenstone, according to Calkins et al. (1969) generally displays a weakly developed schistosity in most places parallel to the original layering. The presence of amphibolite in the Panjal volcanic rocks is considered to be an indication of a more highly metamorphosed state.

The amphibolite is well-foliated and the dips of the foliation define the Manda Kuchha synclinal structure where the amphibolites are very well exposed. The amphibolite is fine- to medium-grained and composed of variable proportions of bright green plagioclase and biotite with magnetite and sphene (Calkins et al., 1969).

Khan et al. (1997) stated that the Panjal volcanic structurally lie between the Panjal Thrust and the Main Boundary Thrust at the upper and lower structural levels, respectively. The agglomeratic slates and the Panjal volcanic were formed in two phases. In the first phase, agglomeratic slates were deposited during Late Carboniferous and were followed by the second phase cruptions of basaltic lavas that took place during Permian to Triassic. The feeders to basaltic lavas in the northwest Himalaya (of Pakistan) have been dated at 284 ± 4 to 262 ± 1 Ma by previous workers.

The volcanic arc characterized by massive lava flows and pillow lavas with intercalations of limestone and bedded chert. The volcanic were metamorphosed to lower greenschist facies during Himalayan orogeny. The Panjal volcanic are variably vesicular and altered to chlorite, epidote, iron oxides, sodic plagioclase, actinolite and calcite. Petrographic and chemical data of the less altered volcanic indicate that they were originally pyroxene and plagioclase phyric tholeiites. The geochemical data indicate that the Panjal volcanic are dominantly tholeiitic to mildly alkalic basalts, Khan et al. (op. cit).

The ages of the Panjal formation and agglomerate slate range from Carboniferous to Permian in western Kashmir and to Triassic in eastern Kashmir (Calkinss et al., 1969). According to these authors fossils of Late Carboniferous to Permian age have been found in agglomerate slate by Holland in 1926. Stauffer (1968c) correlated parts of this formation with the "Greenstone complex" of the Gilgit area.

## Karakoram Hindukush Tectonostratigraphic Basin

### *Southern Metamorphic Province*

#### *Darkot Area*

**Darkot group:** Ivanac et al. (1956) named and described the rocks of Darkot group exposed between Darkot Village and Darkot Pass. In this section slate, limestone, quartzite and garnet mica schists comprise the group. They extended this name to all the rocks having similar depositional conditions, e.g. Khyber series and Misghar limestone etc. Prior to Ivanac et al. (1956), Hayden (1915) described lithologies of Darkot group in the Yasin and Darkot areas and collected fossils from Darband but did not name or map the group. He collected fossils from limestone and shales near Darband and correlated them with the fusulina limestone and associated beds of Baroghil areas. The group is widespread extending up to Hunza Valley and parts of Chitral. Metamorphism in the group increases from west to east with the result that parts of the group loose their identity. Stauffer (1968c) divided the group into Chalt schist, Baltit group and Pasu slate.

Lithologically, the Darkot group is composed of limestone, quartzite, conglomerate, marble, slate, schists, gneiss and volcanic rocks. The group is intruded by Darkot Pass and Karakoram granodiorites. Close to Rawat village, the sediments have been metamorphosed to black micaceous slate and garnet mica schist with highly altered basic and ultrabasic intrusives. These rocks form the contact metamorphic zone of Darkot Pass granodiorite and are the metamorphic equivalent of sediments, which crop out immediately south of Rawat. The group is fossiliferous, important fossils are *Fenestella* sp. *Fistelipora yasienis, Thaminiscus* sp. etc.

Casnedi (1979) suggested lithological correlations of Darkot group with the north Karakoram sedimentary series; but most of the authors tend to consider the Darkot group to exclusively Permian in age. Le Fort et al. (1998) state that this is not entirely true and they proposed subdivisions of the group and cautioned that subdivisions represented are by no means the original stratigraphical order. Folding, faulting, and thrusting most probably complicate the apparent linearity of the mapped units. In addition, as it has been observed in the northern Karakoram sedimentary succession, coeval units may have very different development.

Le Fort et al. (1998) divided Darkot group into five units exposed in the vicinity of Darkot village, (Fig. 12). Majority of these units contain Permian fossils. They divided these units in northern and southern tectonic stacks. The northern stack comprises the Rawat formation and the white marble unit; the southern stack is composed of the Barum formation and the Basal shale.

**Rawat formation:** Le Fort et al. (1998) named and described a series of slate with thick marble from the upper Darkot Valley, the formation's type section is near Rawat where it has major development. Eastwards, to the northeast of Darkot it is clearly trusted on the Gum formation. To the west, it progressively thins out (Fig. 12).

Lithologically, as stated by Le Fort et al. (op cit) the formation is mainly splintery dark slates, often sulphur-bearing and dark limestones, locally interbedded with silty to fine arenitic thick marble layers. Northwards in the Darkot section, the formation becomes richer in arenitic and rusty calcareous (oolitic in places). At the contact with the Darkot Pass porphyritic granite, the quartzite and schist become dotted; staurolite, and sometimes, garnet-muscovite, has grown in the carbonaceous shale levels. In the Gum section they are followed southwards by siltites and fine arenites, forming isolated beds up to a few meters thick, litharenite to quartzarenitic in composition. Hayden (1915) quoted the presence of bryozoans, fusilinids and crushed brachiopods in the Rawat formation. A list of mostly bryozoans was added by Dickins (1952) quoted by Ivanac et al. (1956), who noted the existence of rounded granite pebbles within the slates. The Permian fossils come from grey dark arenaceous limestone horizons of the Rawat formation.

**White marble:** White marble seemingly constitute the upper part of Rawat formation, Le Fort et al. (1998) gave no name to it and described it as follows:

"This unit is cropping out mostly between the Qalandar Gum and the Kerun Bar glaciers. They form huge cliffs of saccharoid whitish, yellow when altered, marbles with a heavy reaction to the hydrochloric acid. They further added that the marbles are also intercalated within the slates and fine arenite of the Rawat formation and tend to increase in thickness towards the north". This indicates that the marble is associated with Rawat formation and the white marble may well be the upper part of the Rawat formation. The total thickness of this unit is over 150 m (Fig. 12).

**Gum formation:** Le Fort et al. (1998) described a thick sequence of metasediments of Darkot group from Qalandar Gum glacier area (a left bank tributary of the Aghost glacier), where it is widely developed and its apparent thickness exceeds thousand meters.

Lithologically the formation is thin-bedded, grey-dark limestones, often intercalated with slates and marls, building packages of some 50 to 100 m, apparently stratigraphically repeated three times on the left side of the Qalandar Gum glacier, at 3950 m above sea level, Le Fort et al. (1998) found a badly preserved fauna dominated by bryozoans and subordinate brachiopods of Permian aspect. This part is thought to reach 300 m in thickness.

They added that the grey and light grey limestones, sometimes dolomitised and fetid, forming the spectacular cliffs of this belt. They may consist either of thin-bedded platy grey limestones packed in thickened layers, or more frequently in thick massive grey limestones and dolomites, locally recrystallised and saccharoid, rising to the highest crests of the mountain.

In the Darkot section, rather abundant dolomitic beds contain intraformational breccia, and a few levels present black cherty ovoidal concretions. This is the area of many tight folds. Due to the deformation, the thickness is difficult to assess, but they assessed the thickness to be about 700 m. In the same section, they found thin lustrous shaly joints, variously coloured (purple to apple-green), probably talc-bearing. This talc occurrence and the recrystallisation of the limestone testify of the low-grade metamorphism imprint. The age of the Gum formation determined by Le Fort et al. (1998), who based it on the occurrence of thick shelled bivalves, which may be identified with megalodontids. Large gastropods have been observed along the left side of the Thui glacier at about 4600 m above sea level, and from the debris two blocks crowded with big shelled fossils, possibly caprotinid rudists. The Gum formation spans the Permian to the Triassic period, but even Cretaceous with a mollusc fauna dissimilar from the fauna from Yasin Valley. It is to be noted that along the Qalandar Gum glacier the beds with Permian fossils lie to the north of the limestone with Triassic megalodontids, which is in apparent reverse order. To the south, this Gum unit is usually in tectonic contact with the next unit called Barum formation.

**Barum formation:** The name Barum has been derived by Le Fort et al. (1998) from the Barum glacier, a left bank tributary of the Aghost glacier. Lithologically the Barum formation is mainly consists of grey dark sandstone slightly metamorphosed in 10 to 50 cm thick beds, often amalgamated, intercalated with siltstone and slates. The sandstones, mostly litharnites rich in quartz, contain thin beds of microconglomerate, but no black chert pebbles have been observed. The grain size seems to decrease in the lower part of the unit, where the slaty intercalations increase. Near Darkot, the finely banded shale contains thin layers of rusty limestone and abundant quartz exudation.

According to Le Fort et al. (1998) in this region, the Barum formation has suffered at least two phases of deformation as shown by a first penetrative schistosity lying close to the bedding planes, deformed by crenulation folds, with axes around N75° E dipping 15° SE and probably south verging. The crenulation also affects the quartz exsudations. Thickness of the Barum formation is difficult to assess, it may range between 300 and 500 m. No fossils have been found.

**Basal shale:** Le Fort et al. (1998) gave no name to this formation and described it as a shale bed with some limestone that lie at the geometrical base of the Darkot group throughout most of the metasedimentary belt. Lithologically, Basal shale consists of black splintery shales and slates, passing to coarser siltstone. Being soft rock it is prone to easier erosion and form saddles. The formation contains whitish dolomitic marble forming discontinuous lenses up to 50 m thick and a few 100 m long, cropping out at some 50 to 100 m from the basal tectonic contact (Fig. 11).

The thickness of Basal shale is only a few hundred metres. The thickness is mostly cut-off by faults and is present at places highly attenuated. Le Fort et al. (1998) made a brief petrological study of the lowest part of the formation as follows, "a finely banded mylonitic texture in which undeformed crystals of dominant quartz and some plagioclase are dispersed, and present marked dissymmetrical pressure shadows. The darker the banding, the more phyllonitic the texture appears. A few tiny more crystallized levels are composed of granulated quartz or carbonate". They further added that "in a unique sample from the west side of the Thui pass, has spindle-shaped biotite and rounded euhedral garnet zoned by concentric inclusions of quartz, in a finely banded mylonitic schist. These occurrences seem to be limited to the first metres, up to some 30 m, above the pseudotachylite-bearing gneisses, and interpreted them as being the result of the contact metamorphism of the pseudotachylite.

### *Gilgit area*

**Chalt schist:** A group of rocks exposed southwest of Chalt extending as far as the village of Tashot has been named Chalt schist by Stauffer (1968c). Ivanac et al. (1956) have described part of this formation as "Darkot group". Schneider (1957) introduced the name "Chalt schieferseries" for all metamorphic rocks south of the Karakoram granodiorite, including the "Chalt schist" and "Greenstone complex" of Ivanac et al. (1956). The formation is dark-grey quartz biotite schist. Part of the formation is very fine-grained and may be called phyllite. Stauffer (1968c) studied thin sections and recorded the presence of crystals of biotite, most of which show sieve structure, in a fine schistose groundmass of quartz, feldspar, ilmenite, magnetite, green biotite and actinolite. Calcite also occurs in the groundmass. At places the formation gives a smell of sulphurated hydrogen caused by weathering of pyrite cubes in the schist.

The rock unit includes small portions of quartzite, marble and conglomerate. The quartzite beds are 65 m thick; the marble beds are as much as 30 m thick and are exposed along the Hunza River. This marble contains organic material. Conglomerate beds form a small portion of the unit and are composed mainly of crushed and sheared limestone pebbles. Ivanac et al. (1956) found some fossils in the upper part of the formation and assigned it Carboniferous to Permian age. In fact, they attributed this age to almost all the schistose rocks found in the Hunza Valley. Stauffer (1968c) disagreed with most of correlations of Ivanac et al. (1956) as no fossils of any kind have yet been found in the Chalt area. He, however, accepted some of the fossil evidence, which was found in rocks identical to the Chalt schist at Şandhi in Yasin Valley, Gilgit. Dickins (in Stauffer 1968c) identified some of the fossils as poorly preserved bryozoans, such as Fenestella, Rhombopora cf. R.

lepidodendroides, a large crushed productids and also a crushed coral. They are found in the thin limestone beds. The age of the Chalt schist is believed to be Carboniferous to Permian.

**Baltit group:** The name Baltit group was proposed by Stauffer (1968) for the rocks exposed in the Hunza and Hispar River valleys south of the "Karakoram granodiorite". The rocks are well exposed in the vicinity of Baltit, Hunza Valley and Gilgit. Ivanac et al. (1956) included this rock unit in "Darkot group".

Lithologically, as stated by Stauffer (1968), the Baltit group is composed of garnet-staurolite schist, garnet-mica schist, garnet amphibolite, coarsely crystalline marble and micaceous quartzite. The garnet crystals are large and enclose all other minerals indicating that they were the last to form. Several lenses of gneiss are found within the Baltit group, a typical lens being about 66 m thick and having lateral extent of at least one kilometre.

The contact between the Chalt schist and the Baltit group is faulted and Stauffer (1968c) placed it at the first appearance of gneissic lenses. The contact between the Baltit group and the "Karakoram granodiorite" is gradual. Tongues of granodiorite are found for several kilometres within the formation. The contact relationships are further complicated by many cross cutting aplite, granite intrusions and lamprophyre dykes. The frequency of gneissic lenses increases near the granodiorite contact.

Lenses of marble and quartzite are also present in the formation. These lenses have been interpreted as "free moving xenolith" in the granitic intrusion by Stauffer (1968c). According to him well exposed examples of this can be seen at about the 5,000 m altitude on the southern slopes of Khinyang Chhish. A characteristic of these xenoliths is virtually total absence of resorption along their knife-sharp contact with the granitic rock. At some places prominent northeast dipping, coarse-grained marble is exposed. These beds range in thickness from 16 to 66 m (Stauffer, 1968c).

The Baltit group is devoid of fossils, because the rocks have suffered considerable metamorphism. Desio (1963) and Desio and Zanettin (1970) have mapped these rocks as part of the "Dumordo schists" of unknown age. Ivanac et al. (1956) have included them in the, "Darkot group" of Permo-Carboniferous age. Stauffer (1968c) correlated them with the sedimentary rocks of the Yasin Valley about 80 km west of Chalt, where Carboniferous and Permian fossils have been found. A review of the literature indicates that the most probable age of this formation is Carboniferous to Permian.

**Pasu slate:** Desio (1963) and Schneider (1957) named a group of dark grey to black slates as Pasu slate. They are exposed north of the Karakoram granodiorite. Ivanac et al. (1956) considered the unit to be part of the "Darkot group". Stauffer (1968c) made a detailed study of the unit near Pasu Valley on the northern flank of the Karakoram granodiorite body in Gilgit and accordingly it is composed of predominantly dark grey and black slate interbedded with quartzite and limestone. The formation is exposed all along the entire length of the Karakoram granodiorite body. From the higher ridges of Khinyang Chhish, rocks with distinct layering can be seen on the west flank of Kanjut Sur and the eastern slopes of Disteghil Sur. The contact with the Karakoram granodiorite is sharp with the intrusive rocks penetrating the slate. The slate apparently dips steeply towards southwest under the granodiorite. The contact of quartzite and limestone with the slate is usually faulted. Fossils are not very common in the unit. However, sixteen kilometres north of Karakoram granodiorite, Ivanac et al. (1956) found Permo-Carboniferous fossils in similar rocks, and consider all the metamorphic rocks along the Hunza River north of the Karakoram granodiorite to be of Permo-Carboniferous age. Therefore, the Pasu slate is considered to be Permo-Carboniferous in age.

***Northern Sedimentary Province***

**Chitral slate:** The "Slate Series of Chitral" of Hayden (1915) and Chitral slate of Tipper (in Pascoe) (1924) "Chitral slate series" of Tipper (Fermor, 1922) have been studied in detail by Stauffer (1971). Earlier, Desio (1963) described it as Chitral formation. All of them described the rock unit near the town of Chitral, (Lat. 35° 51' N: Long. 71° 47' E). Type section has been proposed by Stauffer along Chitral Gol northwest of the town.

The Chitral slate consists predominantly of fine-grained black slates with subordinate thinly laminated dark grey phyllite, quartzite and dark limestone or grey marble layers. The quartzite layers are medium-grained and only a few centimetres thick, although at places it may be up to 9 m thick. The limestone within the Chitral slate range in thickness from less than 15 cm to more than 6 m; they are generally dark grey to black, medium-grained, recrystallised and unfossiliferous (Stauffer, 1971). According to Stauffer (1971) the formation continues into Gilgit Agency, where it is equivalent to all or a part of the Darkot group of Ivanac et al. (1956). Stauffer further stated that in the Reshun area, the Chitral slate is found on the southeast side of a five to 10 km wide band of complexly faulted Devonian and Cretaceous to Tertiary rocks. The contact between the slates and this band of rocks is a major fault. This major fault has been mapped by Khan et al. (2000) between Reshum marble (Cretaceous) and older rocks.

Stauffer (1971) included few other outcrops within the Chitral slate, while mapping on photos. However, Khan et al. (2000) mapped a part of the area and compiled the map of the entire Chitral District, where they separated the Chitral slate from other units (Fig. 11).

Desio (1963) stated that he traversed several times over the Chitral slates and suggested a good section exposed along the Rombur and Bombret valleys south-west of Chitral and that the sequence is mainly composed of black slate passing into glittering grey shale with some beds of light quartzite and upwards this sequence into ashy grey and greenish shales with few beds of limestone intercalated. Probably, these limestone yielded Palaeozoic fossils to Tipper. Desio estimated the thickness of the formation as 5000 m and assigned the age as Palaeozoic. Exposures north and south of Chitral city i.e. Bomboret and Birir Gols and in Lutkho Valley up to Krinj are easily accessible and can be studied thoroughly, in these areas limestone has much less development and/or totally absent. Total thickness of the original sedimentary rock from which the Chitral slate was formed was undoubtedly a good deal less than in apparent thickness in this area today because it has been greatly multiplied by tight isoclinal folding and probably by faults (Stauffer, 1971).

The fossils collected from the Chitral slate by Tipper (in Fermor, 1922) in a calcareous band within the slates in Chitral Gol, were a Spirifer, small Dielasma, and two unidentified corals of

Permian affinity. Stauffer (1971) stated "the great thickness and extent of the Chitral slate, precludes the assignment of a definite age of this formation. The best that can be said is that the Chitral slate is Palaeozoic and probably in part Late Palaeozoic."

**Krinj limestone:** This overlies the Chitral slate and interfingers tectonically with the Reshun formation east of the Lutkho River (Pascoe, 1923; p. 44). At the north-eastern end of the outcrop, where the base becomes a thrust, Desio (1959) described shaly grey and black limestone with species of orbitolina overlain by a few meter thick black limestone with rudists, then many meter of grey and white limestone with shale intercalations. The formation attains 2.5 km thickness. From the Lutkho River southwards each of the valleys is a gorge, where it cuts this formation and access can be hazardous. The limestone is massive to very well banded, grey, cream to white, micritic to finely recrystallised. It is locally dolomitic along the western margin and appears to be related to the proximity of the Kafiristan granite. In the Lutkho gorge, there are rudists bivalve fragments and a 20 m thick breccia involving finely laminated black cherty layers.

**Dobargar formation:** Le Fort and Gaetani (1998) named and described Dobargar formation from the northern slope of the Hindu Raj range which displays a very peculiar structure made up of a narrow band of slightly metamorphic sedimentary rocks, almost vertically dipping. According to them one of the characteristics of this sedimentary band is to maintain its hectometre-width more or less constant from east to west as well as from top to bottom (a relief of nearly between 3000 to 5800 m on the Shetor-Ponarillio crest, and 2900 m when crossing the Yarkhun Valley).

The Dobargar formation, the Chikar formation or the Sakirmul granodiorite to the north, are intensely deformed. Le Fort and Gaetani (1998) measured two detailed section of it: one on the left bank of the Darkot glacier, at around 3900 m and the second one on the right bank of the Pechus glacier, at around 3700 m. Sequence for the Darkot one, from north to south is as following:

- Very cataclased granite
- Grey thick bedded dolomite with ghosts of crinoids; 0.70 m
- Splintery slate with altered? limonitic nodules, strongly folded, with a nearly vertical stretching lineation; 0.90 m
- Grey marble with thin parallel laminations, locally with boudinage; 1.90 m
- Lack of exposure, 0.40 m
- Grey green siltite, possibly tuffitic with small nodules (accretionary lapilli ??); 3.0 m
- Grey strongly cataclastic limestone in thin beds, poorly exposed; about 1 m
- Light grey dolomite in 40/60 cm-thick beds, cliff forming; 19 m
- Massive white to reddish quartzite, usually with a strong down-dip lineation; 69 m
- A slab of amphibolite and biotite-bearing granodiorite, fractured, limited on both sides by a thick fault zone; around 500 m

For the Pechus one, again from north to south is as follows:

- Injected Chikar quartzite, moderately deformed, contact not observed
- Poorly exposed schists; 12.5 m

- Dolomitic layer; 0.9 m
- Dark blue schists; 10 m
- Fine banded limestone; 0.7 m
- Dark-coloured schist; 1.0 m
- Banded quartzite; 1.6 m
- Black schist; 1.0 m
- Massive dolomite, with boudinage, 3.5 to 8 m
- Black schist; 2 m
- Finely banded quartzite; 0.6 m
- Greenish-bluish schist; 4 m
- Finely banded, massive quartzite; 6 m
- Alternating schist and quartzite; 3 m
- Quartzite; 1 m
- Black schist; 5 m
- Quartzite; 3 m
- Poorly outcropping zone, apparently, dominant schist and subordinate quartzite; 15 m
- Lacuna; 24 m, ending with dark-coloured schist
- Sporadic outcrops of schist in scattered bush; 8 m, contact not visible
- Schistified, phyllonitised, and silicified porphyritic granite; outcropping continuously for 30.5 m

Only the crinoid fragments as fossils from the Darkot section were found. They correlated the above rock assemblages with the Permian calcareous/shaly succession of the N. Karakoram (Gaetani et al., 1995).

According to Le Fort and Gaetani (1998), the formation extends westwards from the Darkot glacier to the right bank of the Yarkhun Valley, opposite to Dobargar, and then to the western most crest. Eastward, the band plunges into the Darkot glacier in the direction of the Darkot Pass and continues for a while on the exact prolongation of the Dobargar band.

**Nialthi formation:** Le Fort and Gaetani (1998), coined the term Nialthi formation to a metasedimentary sequence, very thick package dominated by dark grey slates, often fissile and splintery, alternating with dark arenite beds and mud supported conglomerates, with dark and light arenitic, poorly sorted and rounded clasts, maximum size up to 30 cm. Some of these conglomeratic layers may be interpreted as mud flow. Thick calcareous intervals are cropping out to the south of Nialthi and in front of Sandhi, where Ivanac et al. (1956) report the finding of fusilinids.

According to Ivanac et al. (1956) and Huzita (1965), the sedimentary rock sequence occurring between Umalsit and Yasin belong to the Darkot group. Ivanac et al. (op cit) in particular, stress the similarity of appearance and fossil assemblage of interbedded slates and limestones out cropping at Sandhi, just to the south of Nialthi with those of the banded limestone, slate, and arenite formation of the Darkot group. The direct continuity of the Nialthi series with the Darkot group has been suggested by Ivanac et al. (1956) in their cross-section, by Huzita (1965) in his text, and in the map of Buchroithner and Gamerith (1978), actually, this continuity is disrupted by the tectonic lineament of the Hundur conglomerate (Fig. 12).

The Nialthi formation according to Le Fort et al. (1998) is not correlative with Darkot group and stated "we consider them as overall different from the metasediments of the Darkot group".

***Carboniferous of Karambar and adjacent areas***: Karambar area lies in the central part of the Northern Sedimentary Province (North Karakoram Sedimentary basin of others), which is the most remote basin of Pakistan. It is bound in the north by the Afghan / Pakistan and in the east by the Chinese / Pakistan borders. Karambar area is the only place in Pakistan where maximum of Carboniferous, more particularly Tournaisian, Bashkirian, Moscovian and Kasimovian can be studied. Importance of this section lies in its additional contribution towards the concept of plate tectonics. The study of the Carboniferous of the area by Angiolini et al. (1999) added the idea that it may be one of the peri-Gondwana microplates, which separated from Gondwana during the Late Palaeozoic and was accreted to the southern Eurasian margin during the latest Triassic-Middle Jurassic, well before the collision of the Indian plate. This concept has also been advocated by Gaetani et al. (1990); Searle (1991); Crawford and Searle (1992) and Zanchi et al. (1997).

The Northern Sedimentary Province includes a thick sedimentary cover cropping out north of the Karakoram Axial Batholith (Fig. 10b), these sedimentary rocks contain Ordovician to Permian successions (Fig. 10a,b,c) and upwards comprising Jurassic sandstones are unconformably overlain by the Tupop and Reshun formations of Late Cretaceous to Early Tertiary age. They have recorded all formations showing a complete pattern of microplates and arcs docking to the Eurasian margin before the collision of India (Gaetani et al., 1997; Angiolini et al., 1999).

These stratigraphic units are separated from the Wakhan slates by the "Tash Kupruk Unit", of Angiolini et al. (1999), which is a thick tectonic slice including massive basalts and dolostones of the uncertain paleogeographic provenance possibly of Late Devonian to Carboniferous age (Kafarsky and Abdullah, 1976; Gaetani et al., 1996). The entire sedimentary succession escaped strong metamorphism during the Meso-Cainozoic collisional events, nevertheless intensive deformation of the sedimentary units is testified by polyphase folding and intensive thrust-stacking resulting in a complex tectonic setting.

Carboniferous of this province as summarized by Angiolini et al. (1999) is the best exposed in the Karambar area and attenuated exposures of the successions are present in Baroghil, Lasht, Chillinji, Buattar and upper Hunza areas. The Carboniferous successions present in these areas belong to different tectonic units. Gaetani et al. (1996) and Angiolini et al. (1999) have successfully worked out the tectonostratigraphy of these stacks, while they have dated them with fossils.

The Carboniferous sedimentary succession of the eastern part of Northern Sedimentary Province displays significant lateral variations in thickness, lithology and fossil content. Up to now a number of different Carboniferous successions have been discovered and studied by Gaetani et al. (1995); Gaetani et al. (1996); Gaetani et al. (1997) and Angiolini et al. (1999). According to Angiolini

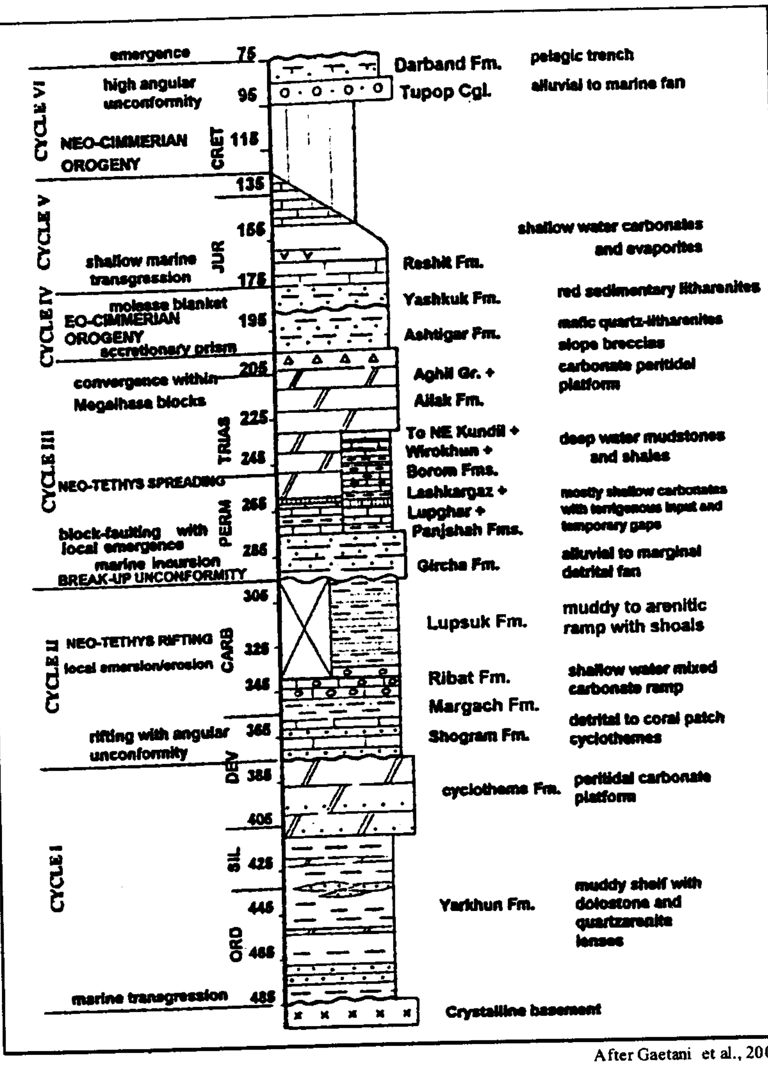



Fig. 10a. Synthetic column of the formation of Northern Karakoram sedimentary cover.

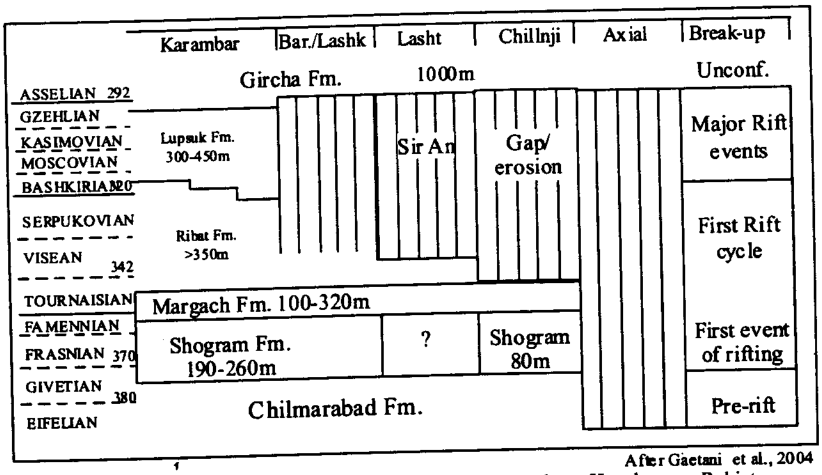
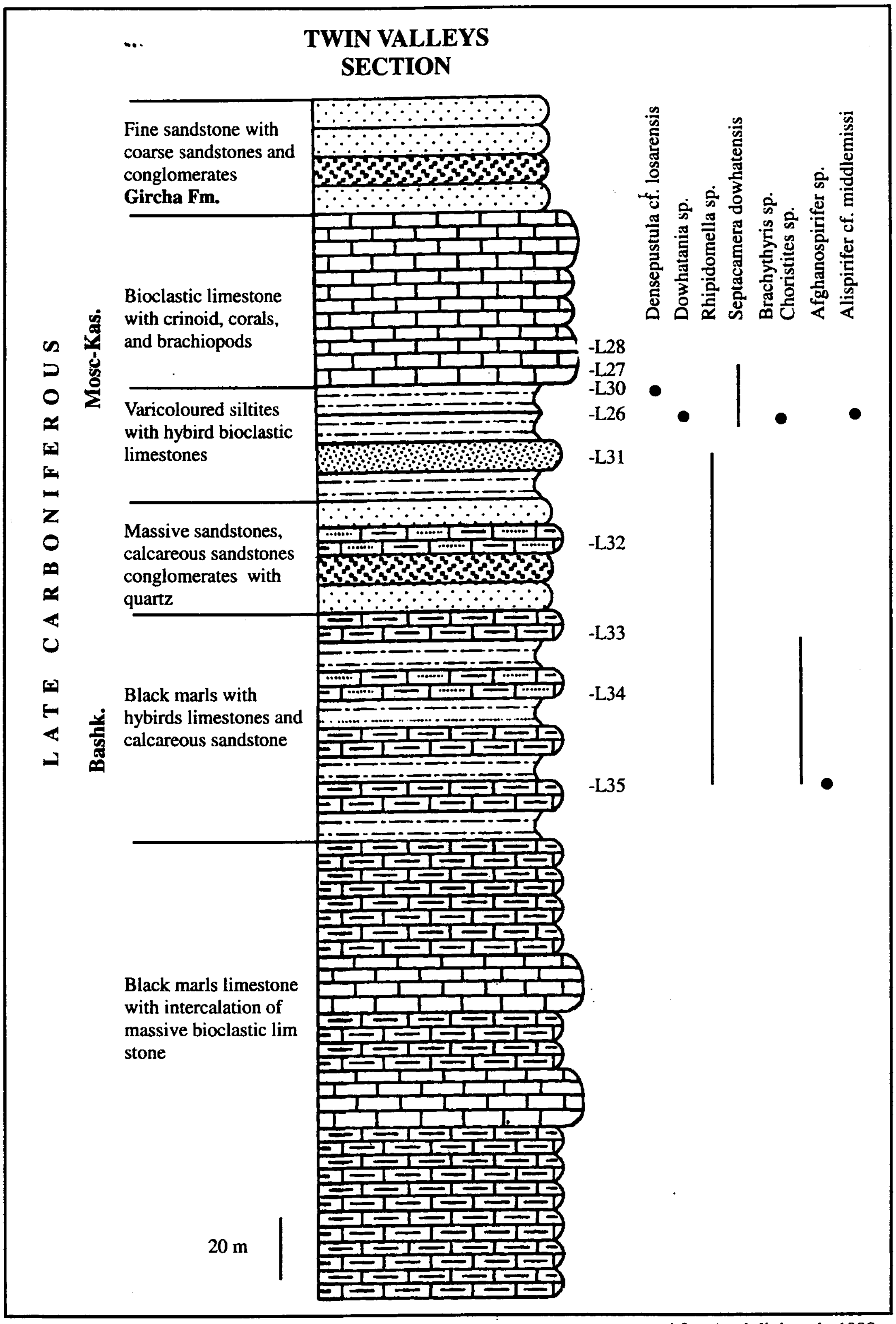



Fig. 10b. Correlation of Carboniferous formations in Northern Karakoram, Pakistan.




After Angiolini et al., 1999

Fig. 10c. Carboniferous of Karambar area (Twin valleys section, Northern Karakoram Pakistan).

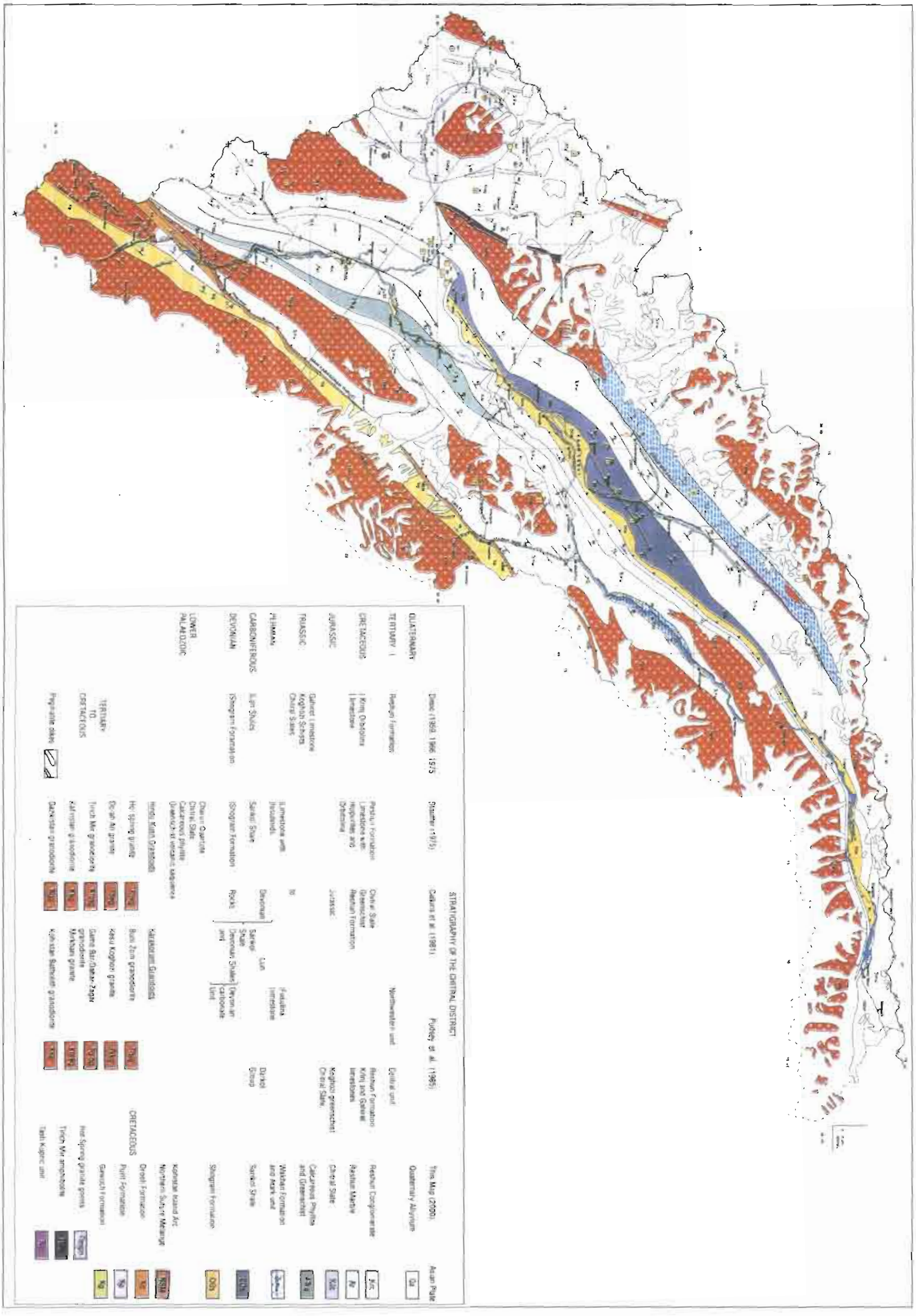


Fig. 11 Geological map of the Chitral District, N.W.F.P., Pakistan (after Khan and Khan, 2000)

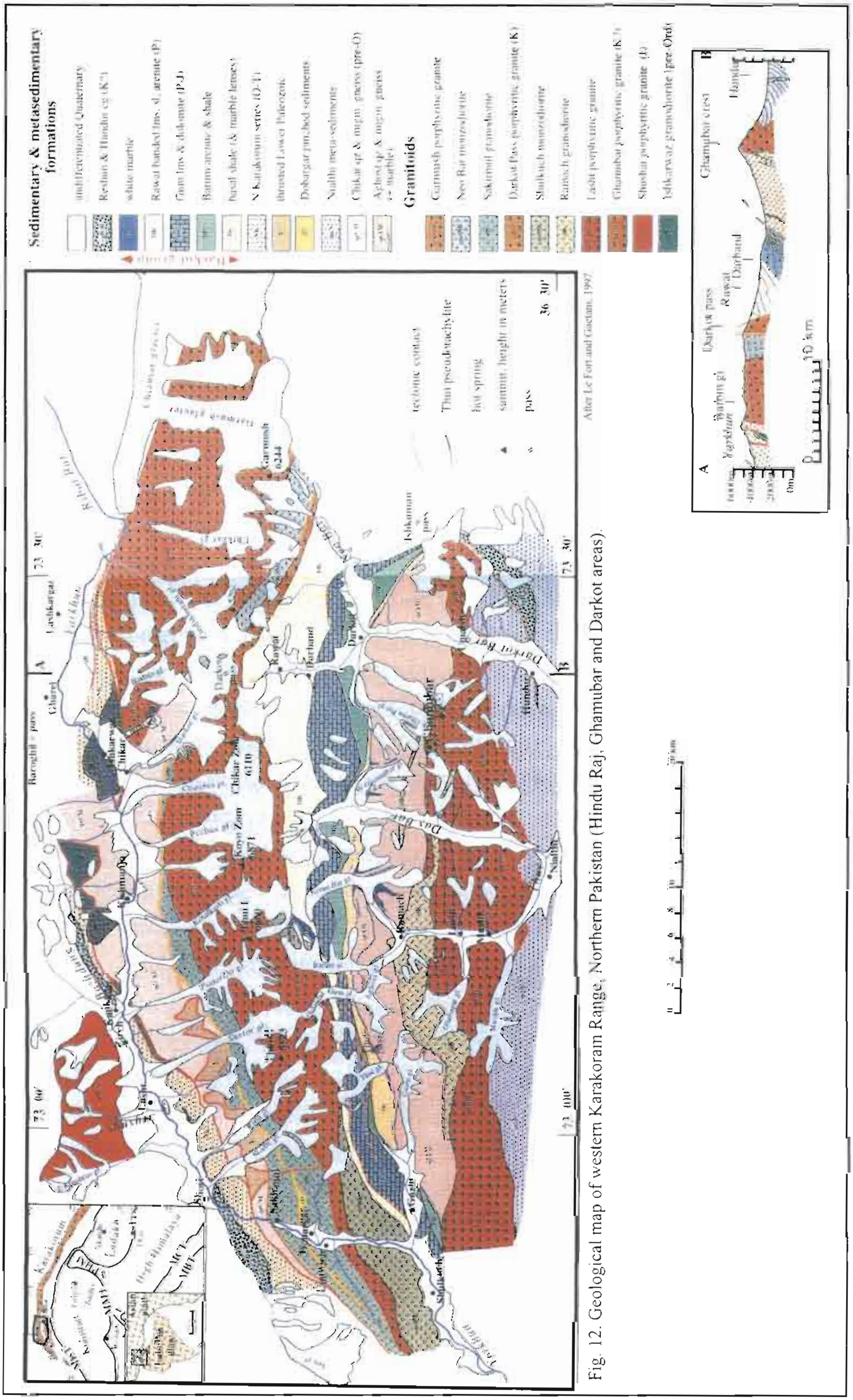



Fig. 12. Geological map of western Karakoram Range, Northern Pakistan (Hindu Raj, Ghamubar and Darkot areas).

et al. (1999) these successions belong to different tectonic units whose mutual relationships are still unclear. From west to east they are:

Lasht: In the Lasht area, Gaetani et al. (1996) measured 180 m thick crinoidal limestones with fragments of brachiopods and bryozoans, cropping out at Rukut around Lasht. They tentatively gave an Early Carboniferous age, based on their stratigraphic position. In fact, those are erosionally overlain by the arenites and shales of the Upper Carboniferous-Lower Permian Gircha formation.

Baroghil: In the Baroghil area about 80 km east of Lasht in the upper Yarkhun Valley, near Gharil, they reported 50 m thick crinoidal limestones with shaly intercalations, which crop out between the Late Devonian Shogram formation and the Gircha formation.

Karambar Pass-Lashkargaz: As described by Angiolini, et al. (op cit) here the fossiliferous Carboniferous succession belongs to two tectonic units displaying overall similar characters; the "Upper N-Karambar Unit" and the "Lower N-Karambar Unit" separated by a complex system of faults. Westward, the "Upper N-Karambar Unit" is located north of the exposures of the Baroghil group and stacked above the "Lower N-Karambar Unit" along SSW-vergent thrust. The "Lower North Karambar unit" is also in tectonic contact with the S-Karambar unit, which is located south of the Karambar pass and comprises a thick terrigenous succession; this succession includes the Carboniferous, and lies stratigraphically over the Shogram formation of Devonian age.

Carboniferous rocks of the "Upper N-Karambar unit" have been studied in the Lashkargaz Gulley, where the succession is truncated at the base by ENE-WSW trending reverse fault. In fact, only the upper fossiliferous horizon has been found in marly limestones about 20 m above the thrust plane. According to Angiolini et al. (op cit), the "Lower N-Karambar unit" contains the most complete Carboniferous section measured up to now in the North Karakoram.

Eastward, the Carboniferous succession passes to a monotonous sequence of black slates and arenites belonging to the Gircha formation of Permo-Carboniferous age. The Twin valleys section, studied by Angiolini et al. (op cit) located just northeast of the Karambar lake (36° 53' 00" N: 73° 45' 36" E), represents one of the best outcrops of the Carboniferous succession of the "Lower N-Karambar Unit" and it comprises from the base to the top as follows (Fig. 10c).

a. At least 200 m of black marly limestones with thick intercalations of massive bioclastic limestones;
b. 100 m black marls, calcareous siltites, calcareous sandstones and marly limestones containing bryozoans, corals, and Bashkirian brachiopods such as *Rhipidomella* sp., *Choristites* sp., *Martiniopsis* sp., *Afghanospirifer* sp., *Gypospirifer* sp., *Composita* sp., and an undermined Schuchertellid;
c. 30-50 m of massive, cross bedded coarse sandstones, bioclastic sandstones and conglomerates with rounded quartz pebbles;
d. 20-40 m of varicoloured calcareous siltites and fine arenites with intercalation of marly limestones containing bryozoans, corals and Moscovian to Kasimovian brachiopods such as *Densepustula* cf. *losarensis, Dowhatania sulcata n.* sp.,

*Brachythyris* sp., *Rhipidomella* sp., *septacamera dowhatensis,* and *Alispirifer middlemissi.* Very large crinoid stems have been detected in green and red siltites;

c. 30-100 m of massive bioclastic limestones containing bryozoans, crinoids and recrystallised brachiopods and corals. This calcareous unit shows sharp lateral variations in thickness.

Chillinji unit: In the Upper Karambar Valley, around Chillinji, a tectonic unit, named "Chillinji unit", crops out below the "Tash Kupruk unit". The "Chillinji unit" comprises Ordovician to Permian sediments transgressive onto the crystalline basement (Ishkarwaz granite). However the Carboniferous part of the section is devoid of diagnostic fossils and has been dated only on the basis of its stratigraphic position. In fact, a 500 m thick terrigenous unit affected by faults and folds is bracketed between the Upper Devonian Shogram formation at the base and Permian dolostones at the top (Gaetani et al., 1996, p.697). The first 80 m of this unit consist of fine-grained arenites, hybrid arenites, siltites and dark slates and yield, at 3.2 m from the base, a poorly preserved Schuchertellid; they have been ascribed to the Carboniferous. Above, a polygenic conglomerate followed by a monotonous, thick sequence of burrowed siltstones with intercalations of fine-grained quartzarenites probably belongs to the Gircha formation (Gaetani et al., 1995).

**Buattar Glacier:** On the south-eastern slope of the Chillinji Pass, on the left side of the Buattar Glacier at 4420 m, black marly limestones and bioclastic limestones yielding poorly preserved specimens of Rhipidomella sp. (resembling the species collected in the Karambar Pass area), corals and large crinoids form thrust slices along the hanging wall of the Upper Hunza fault. These limestones represent the easternmost outcrop of fossiliferous Carboniferous rocks found in the region and are very similar to the Upper Carboniferous bioclastic limestones of the Karambar Pass-Lashkargaz area (see above), (Angiolini et al., op cit).

Other areas of Carboniferous outcrops include Upper Hunza Valley and its side valleys, where over thousand meter of terrigenous Gircha formation of Late Carboniferous to Early Permian age is present.

From the description given in the foregoing paragraphs, it becomes amply clear that the sequence, between Shogram formation below and the Gircha formation above, is bracketed as Carboniferous succession. Applied this conception to the above described localities, Gaetani et al. (2004) provided a set of nomenclature for the Carboniferous rocks of this region. According to them, the lowest Carboniferous rock is named as Margach followed upwards by Ribat and at the top Lupsuk formation. Earlier, Angiolini et al. (op cit) have discussed the same Carboniferous sequence but have not given any nomenclature except that they have dealt them as "Tectonic Slices".

**Margach formation:** The Margach formation, according to Gaetani et al. (2004) forms the base of the Carboniferous succession. Best exposed in Karambar, the formation is dominantly a unit of terrigenous material alternating with coarser arenites. Petrographic studies of the sandstone indicate that the sediments are accompanied by the tectonic uplift of the metamorphic rocks in the provenance. They related it to the onset of the rifting with a sedimentation rate, which may reach 30 m/my.

The formation is 100 to 300 m thick and is shown to be present in Karambar, Baroghil, Lasht, Chillinji and Axial zone. Lower and upper contacts of the unit with Shogram and Ribat formations respectively are conformable especially in the Northern Karambar area. The age of the formation is shown to extend from Famennian to (with greater part in) Tournaisian age of the Carboniferous Period (Fig. 10b).

**Ribat formation:** Ribat formation is named and described by Gaetani et al. (2004). According to him the formation is predominantly composed of dark grey crinoidal limestone deposited on shallow water mixed carbonate ramp. The limestone is marly and in the upper part some terrigenous (shale and sandstone) material is present. In a vertical extent of the formation, a few tens of meter above, the sandstone (well sorted arkoses and quartzarenites) of Gircha formation (Permian) directly follow in the Northern Karambar. The formation is shown to thickens (< 350 m) in the northern part of Karambar and present in an attenuated form in the southwards in the Lasht area. It has normal contact with the overlying Lupsuk and underlying Margach formations. The age of the formation extend from Visean to Bashkirian age (Fig. 10b).

**Lupsuk formation:** Gaetani et al. (2004) named and defined the Lupsuk formation from Karambar Valley. The formation is largely composed of arenite. Petrographically, it has been established that the arenite of the Lupsuk formation documents active volcanism, which has been further confirmed by the presence of interbedded Mesolithic spilites. In fact, the entire deposition of the Lupsuk formation represents muddy to arenitic ramp with shoals. This has been deduced by noticing local emersion and erosion in the formation. The formation also records major rifting events and ends at an unconformity (Gaetani et al., 2004). Fossils found in the formation indicate Moscovian and Kasimovian age. These fossils are, recorded above in the section described by Angiolini et al. (1999) (Fig. 10c).

**Gircha formation:** Desio (1963) introduced the name Gircha formation to terrigenous sediments composed of shale and sandstone with minor conglomerate near the village of Gircha in the Upper Hunza Valley. It is mainly composed of brown and black arenaceous slate with small intercalations of dolomitic limestone and in the lower part light coloured quartz sandstone. Gaetani et al. (1995) redescribed this formation from the same area with more details and proposed reference section at the village Ashtigar, upper Hunza. The position of Gircha formation in the stratigraphic columnar section is shown in Fig. 10a.

Gaetani et al. (1995) consider Pasu slate of Schneider (1957), as a synonym of the Gircha formation being a local facies mostly shaly, with few sandstone intercalations in the upper part. Shimshal slates of Casnedi and Nicora (1985), is also considered as a synonym, even though this name could be applied to the slates with spectacular ductile deformations exposed in the lower part of the valley. They also rejected Kilik formation of Desio (1963) "because Permian and Jurassic tectonic slices including four formations are juxtaposed in the type locality at least".

The Gircha formation according to Gaetani et al. (1995) is composed of shale and sandstone with rare micro conglomerate. In the Upper Yarkhun-Baroghil area, sandstones and shales are rather homogeneously, interbedded throughout the section, with coarser grained more lenticular beds showing festoon cross-lamination in the upper part. In Karambar and Hunza area, the basal part is more shaly and coarse-grained intervals become more common upwards. Fossiliferous, arenaceous limestones occur in the lower-middle part in Hunza area. Lateral facies changes are common.

The formation is 600 m thick in Baroghil area and tend to increase eastwards in Karambar An, and in Chapursan the unit exceeds 1000 m (the Ashtigar section alone, including only the central part of the unit is 650 m thick), but the base is not exposed; thickness seemingly increases further in Shimshal area.

Reference section measured at (Ashtigar) Hunza Valley exposes mostly the middle part of the formation, while the lower part of the unit is not exposed; here a few thin beds of fine-grained subarkose with bioclastic storm lags yielding Early Permian brachiopods are intercalated.
Two reference sections as designated by Gaetani et al. (1995) are one in the east of Baroghil and the other in the east at Ashtigar.

Reference section in the east Baroghil area begins with interbedded siltstones and thin lenses of coarse-grained quartzarenites with mudclasts, passing upwards to medium-grained quartzarenites in lenticular metric intervals (about 20 m). Next, thin-bedded, medium-grained grey quartzarenites (between 25 and 50 m thick) are followed by a partly covered coarsening-upward sequence (about 60 m). It is represented by burrowed siltstones with intercalated fine to medium-grained quartzarenites which becomes thicker and wider upwards. The top of the Gircha formation consists of medium-grained quartzarenites with high-angle cross-bedding (4 m), followed upward by three coarsening sequences (about 30 m) of dark burrowed siltstones. This in turn passes upward to a very fine-grained feldspathic quartzarenites and medium-grained quartzarenites locally displaying soft sediment deformations ("balls and pillow") (Gaetani et al., 1995).

The Gircha formation is wide spread in Hunza, Chapursan and Baroghil areas. The total thickness is estimated as 6000 m by Desio (1963) in Hunza Valley, elsewhere the formation is folded, trusted over the other formations. The base at the type section is not exposed. The upper contact with Chapursan group is transitional. The age of the Gircha formation, based on the faunal collection made by Desio (1963) from the middle lower layers containing black limestone is Permian. Gaetani et al. (1995) stated that in Upper Yarkhun-Baroghil and Karambar no fossils have been found within this unit. Only a poorly preserved specimen of Trigonotreta was found in the debris suggesting a possible correlation with the Asselian-early Sakmarian fauna of the Gircha formation in Chapursan.

In Chapursan, Gaetani et al. (1995), found fossils in the Spinje Gulley and near the Ashtigar meadows at the top of the lower part of the formation. The fauna includes: brachiopods: *Lyonia* sp. ind., *Rhynchopora* sp. ind., *Trigonotreta stokesi* Koenig, *T. lyonsensis* Archibold and Thomas, *Spirelytha petaliformis* (Pavlova), *Punctospirifer afghanus Termier,* Termier, de Lapparent and Marin and *Tomiopsis* cf. *T. bazardarensis* (Grant); bivalves: ? *Etheripecten* sp., *Deltopecten* sp., *Leiopteria* sp., *Eurydesma* sp. A similar assemblage, dominated by *S. petaliformis* was collected by Zanchi in 1991 in the Gircha formation cropping out at about 4000 m on the left side of the Yashkuk glacier. Angiolini (1994, 1995) identifies this as an assemblage zone with *T. lyonsensis* and *P. afghanus* as index-species. All of above discussion indicate Permian age of the formation. But

Gaetani et al. (1995) also stated that in the Yashkuk glacier area found a big *Apyllum* specimen in the debris on the slope near the trial along the Yashkuk left moraine. It was embedded in shales like Gircha shales, which has been considered not younger than Devonian by Flugel (1995a).

**Kilik formation:** Desio (1963) named and described this formation after a small stream, which is a tributary of the Hunza River. According to him, Kilik formation is lithologically composed of dark limestone, dolomitic limestone and dolomite. These beds are separated by red and dark grey arenaceous slate with brown coloured quartz sandstone. The Kilik formation shows frequent lateral facies change. The type section of the Kilik formation has been designated in the south side of the mid Kilik Valley. The section extends to Chapursan Valley in the Upper Hunza Valley. The age of the Kilik formation has been determined as Permo-Carboniferous by Desio (1963). Gaetani et al. (1990) included Kilik formation into the description of their Gircha formation.

**Guhjal formation:** The name "Guhjal" was introduced by McMahon (1900) for the carbonate rocks exposed south of the Upper Hunza Fault. Gaetani et al. (1995) described the same unit with corrected and prevailing spelling as Guhjal formation. The formation is mainly composed of huge mass of carbonate mostly dolostones. The presence of megalodontids and colonial scleractinians points to a Late Triassic age, but the following findings indicate that the unit starts in the Permian.

This tectonostratigraphic unit lying on the northern flank of the Pasu syncline as, described by Zanchi and Gaetani (1994), is slightly metamorphic slates of the Gircha formation (Pasu slate of Desio 1963) which passes gradually into the peritidal dolomites of the Guhjal formation. The transitional lithofacies consists of slates alternating with 20-50 cm thick marly limestones, increasing upwards with respect to the slates. The thickness of this lithofacies is about 20-30 m. Along the path leading from Pasu to the right side of the Batura glacier, a fusilinid assemblage dominated by Parafusulina sp. has been found in the marly limestones of the transitional facies between the Gircha and Guhjal formations suggesting a middle to Late Permian age. Zanchi and Gaetani (1994) added that "intricacy of the structure, poor accessibility of the outcrops, rare fossils and metamorphism hamper stratigraphic reconstruction and precise mapping".

**Chapursan group:** Gaetani et al. (1995) introduced this group, to include the mixed terrigenous/carbonate units, rich in shallow water fossils, like fusilinids, brachiopods, bryozoans, corals, bivalves and gastropods, which characterize the central part of the Permian in northern Karakoram. The group may have some affinities with the Darkot group of Ivanac et al. (1956). Included in the Chapursan group are three units namely: Lashkargaz, Lupghar and Panjshah formations.

**Lashkargaz formation:** Gaetani et al. (1995) introduced this formation and designated the type-section at Lashkargaz in the Upper Yarkhun area. However, the base is missing, because of the Yarkhun River braided plain, nevertheless the lower part of the formation has been measured in the Baroghil east section. In other words, they measured sections both at east of Baroghil and at Lashkargaz Village in the Yarkhun area.

The Lashkargaz formation consists of shales, with subordinate sandstones and limestones.

Its total thickness is estimated as more than 1000 m in the eastern side where the unit is thicker and more complete in its part. The formation has been divided in four members, which from bottom to top these are:

Member 1: According to Gaetani et al. (1995), this member, exposed in the Baroghil E section is about 300 m thick. "It starts with siltites with calcareous cements and small phosphatic nodules showing spread of Zoophycos-like burrowings. Calcareous siltites and few quartzarenites continue upwards, to give way in the upper part to calcareous siltites with well washed crinoidal lenses and marls with calcareous nodules containing fairly abundant brachiopods and bryozoans and rarely conodonts". Gaetani et al. (op cit) have identified biostratigraphic zones based on the index species. As for example top most part of this member contains *'Hunzina electa'* range zone. In this zone, besides index fossils, it contains *Derbyia* cf *baroghilensis* (Reed) *geobiella* cf. *rossiae, Cleiothyridina ailakebsis, Cleiothyridina globalina, spirigerella* sp. ind. *Trigonotreta paucicostulata (Reed), Gjelispinifera aff. Cristata (Schlotheim).* The assemblage is dominated by spiriferids. The thickness of *Hunzina electa* zone is 20 m.

Member 2: Rich in fossils, this member is dominated by calcareous sediments, more washed and coarser westwards and richer in clay eastwards. It is only 108 m thick in the Baroghil east section, whilst it reaches 368 m further east in the Lashkargaz section. In the lower part, packstones dominate with locally abundance in fusilinids. It is commonly dolomitised in the Baroghil area where dark grey wackestone/packstones with rare fusilinids and corals continue upwards. At Lashkargaz, there is an imposing continuous alternation of dark grey wackestone/packstones, locally very rich in oncoids up to 3 cm in size. Marly layers commonly separate these wackestone/packstones horizons. Gaetani et al. (1995) have identified three fusilinid assemblages in this 'member', they are as follows:

First fusilinid assemblage lies in the lowermost part of this member, which contains a poorly preserved fusilinid fossils dominated by the genera *Pseudofusulina* and *Pseudoendothyra.* They are associated with small foraminifers belonging to genera *Globivalvulina, Tetrataxis, Glomospira, and Deckerella.* Thickness of this zone is about 40 m. A second fusilinid assemblage, well developed in Lashkargaz, is dominated by *Chalaroschwagerina, Pseudofusulina,* and *Pamirina.* The central part of the second member in the Baroghil East section, where Tabulata have also been found, is correlateable with this assemblage. *Protomichelinia multitabulata* (Yabe and hayasaka) and *Protomichelinia siyangensis* (Reed) are described from this assemblage by Flugel (1995b). The thickness of the Zone is about 70 m.

Partly coincident with a third fusilinid assemblage *(Darvasites* cf. *zulumartensis* Leven, *Pseudofusulina norikurensis krafftiformis* Leven) is a brachiopod coral assemblage, the *Orthothetina convergens/Aldina exilis* brachiopod assemblage zone. The following brachiopod species are also present: *Derbyia grandis* (Waagen), *Neochonetes (N.) costellata* (Angiolini), *Neochonetes (Sommeriella) baroghilensis* (Reed), *Magniplicatina* cf. *inassueta* (Reed), *Compressoproductus* sp. ind. amongst the corals, besides fairly abundant *Protomichelinia, Sinopora?* cf. *syrinx* (Etheridge) and *Yatsengia bangchowensis* (Huang) were seen, Flugel (1995b). The assemblage is dominated by chonetids and productids; rhynchonellids may locally form

significant clusters. The thickness of this zone is about 45 m.
Member 3: This member is characterized by renewed terrigenous input. At Baroghil there are two major arenitic horizons separated by concoidal packstones and marly limestones, it has a total thickness of 144 m. At Lashkargaz, sandstone intercalations are rarer and intermingled with the shaly and marly horizons.
Member 4: The member is extremely rich in fusilinids and dark with chert nodules. The base of this member has been traced with the appearance of well-bedded grey wackestone/packstones. Corals and brachiopods, as well as crinoids and bivalves, may be locally abundant in the lower part. The topmost part is largely dolomitised in the Baroghil section, where this member is 224 m thick. Instead, wackestone with dark chert nodules are mainly developed at Lashkargaz, where the member reaches 450 m in thickness.

Biostratigraphical studies carried out by Gaetani et al. (1995) showed that there are a few fossil assemblages at the base of Member 4. They named it as "brachiopod assemblage zone" based on identification of the *Waagenoconcha (Gruntoconcha) macrotuberculata Callytharrella sinensis*. This zone also contained another fusilinid assemblage together with bivalves and conodonts.

Among the brachiopods *Enteletes* sp., *Orthothetina convergens* Merla, *Neochonetes (N.) (S.) baroghilensis, N. (S.) vialis* (Reed), *Paramesolobus sinuosus, Retimarginifera praelecta, Transennatia reedi* Angiolini, *Reticulatia chitralis* Angiolini, *Chaoiella* sp., *Magniplicatina johannis* Angiolini, *M. vindicata* (Reed), Permophrycodothyris sp. are also present.
Foraminifers are represented by *Chitralina undulata* Angiolini and Rettori, *Globivalvulina* sp. and by the fusilinids *Parafusulina (Parafusulina) jarkhunensis* (Reed), *Parafusulina (Skinnerella) yunnanica* Sheng, *P. (Sk.) asiatica* Leven, *P. (Sk.) quasigruperaensis* (Sheng), *Misellina parvicostata* and *Pseudofusulina* cf. *postkraffti*.

The bivalves *Girtypecten sp., Etheripecten* sp., *Permopecten* sp. and two new genera of pectinid together with gastropods of the subfamily subulitinae and some bellerophontids have also been detected (det. J.M. Dickins). The conodont *Sweetognathus* aff. *whitei and Gondolella* cf. *idahoensis* have been detected in this zone in the East Baroghil section. The thickness of this assemblage zone is about 55 m. Between 50 and 60 m from the top, in the Lashkargaz section, transitional forms between *Gondolella idahoensis* Youngquist, Hawley and Miller and *Gondolella phosphoriensis* Youngquist, Hawley and Miller have been found.

At 3 m from the top of the Member 4 in the Lashkargaz section, the conodonts *Anchignathodus* sp. *and Iranognathus* sp. assemblage have been detected. The age of the Lashkargaz formation spans from the Sakmarian to the Kubergandian with a suggestion for the Murgabian at the top, in the Lashkargaz area (Gaetani et al., 1995).

**Lupghar formation:** Gaetani et al. (1990) described a formation and named it as "Panjshah formation" with three members exposed in the Upper Hunza area. Because of a possible hiatus between member 2 and 3, they revised the sequence and in 1995, Gaetani et al. (op cit) kept only the upper part of the sequence in their Panjshah and separated the lower part below the hiatus as the Lupghar formation. The type section for this formation is designated on the either sides of Lupghar

Valley near Raminji. In the present case, the Lupghar formation has been divided into two parts (members), a lower one having alternate beds of shales / sandy shales with well-bedded mudstones/wackestones and a second one mostly or exclusively calcareous, loaded with fusilinids at the base. The total thickness of the Lupghar formation varies between 300 and 380 m. The members of Lupghar formation described by Gaetani et al., 1990 are as follows:

Member 1: In the Chapursan valley it is possible to recognize three lithozones. At the base, grey-green clayey siltites with phosphatic and ferruginous nodules are followed by dark grey, bioclastic or hybrid calcarenites and by marly-silty mudstones. Bedding is mostly thin and poorly defined. Parallel, hummocky and cross laminations characterize these lithofacies. The central part of the member has locally evident cyclothemes, 7 to 20 m thick, from fine terrigenous up to carbonates. In the upper part, a 10 m thick bioclastic intercalation is rich in brachiopods, molluscs, and crinoids. Fragments of corals and oncoids have been also observed. The maximum thickness is about 210 m.

This first member of the Lupghar formation is characterized by the occurrence of H. electa range zone in its middle-upper part (Angiolini, 1995). This unit has its equivalent in Member 1 of the Lashkargaz formation. Besides the index-species, the brachiopods *Permochonetes pamiricus, Reticulatia* sp. ind., *Globiella* cf. rossiae, *Costatumulus irwinensis* Archibold, *Cleiothyridina ailakensis* Reed, *Cleiothyridina* sp., *C. aff. semiconcava* (Waagen), *Spirigerella* sp., *Trigonotreta paucicostulata, Cyrtella* cf. *nagmargensis* Bion have been collected. In the Shimshal section *Hunzina tenuisulcata* (Merla) and *Trigonotreta paucicostulata* characterize the brachiopod assemblage. The thickness of this zone is about 65 m.

Member 2: It is a carbonate dominated succession. In the Chapursan-Khudabad area, four lithozones have been recognized: a) basal bioclastic, thick-bedded calcarenites with local cyclothemes (1-2 m thick) with a basal crinoidal layer and at the top prevailing fusilinid and bryozoans calcarenite bars; b) oolitic limestones passing upwards and laterally to c) peritidal dolostones and at the top d) to subtidal grey dark-grey limestone. The thickness varies between 150 and 280 m.

The second member is characterized at the base by fusilinid assemblage with *Pseudofusulina plena Leven,* P. cf. *psharti Leven, P.* cf. *karapetovi* Leven, *P.* cf. tumidiscula Leven, *P. incompta* Leven, *P.* cf. *sedujachensis* Konovalova and Baryshnikov, *P.* cf. *callosa* Rauser-Chernousova, *P.* cf. *granuliformis* Leven, *P.* aff. *syniensis* Konovalova, *Eoparafusulina* sp., *E.* aff. *pamiriensis* Leven. This assemblage is fully expanded here and may correspond to assemblage 2 of the Lashkargaz formation, where it is not so well preserved. Further more, this assemblage is very similar to the *Pseudofusulina* assemblage of the Rosh Gol, East Hindukush (Gaetani and Leven, 1993). The thickness of this zone is about 35 m. The Lupghar formation is mostly Sakmarian in age. The brachiopod assemblage of Member 1 contains *P. pamiricus and C. ailakensis,* which occur in the Sakmarian? early Artinskian of SE Pamir (Gaetani et al., 1995).

**Panjshah formation:** The name Panjshah was proposed by Gaetani et al. (1990) to a sequence of shale, limestone and marl and sand stone, which is subdivided into two members. The type-section has been designated above the Panjshah Shrine, in the lower Chapursan Valley.

Member 1. Grey-green, calcareous siltites and splintery marls with rare biocalcarenitic horizons increasing at the top. In the lower part, there dark shales, thin-bedded siltites, lenticular, coarsening upward, matuřc feldspathic quartzarenites with festoons and erosional base. Wave ripples and hummocky cross-laminations are also present. Sandstone layers are more abundant in the upper section of the Borom Valley. Upwards, the unit is mostly covered because of the prevailing shaly lithology. The thickness varies from 70 to 100 m. The first member of the Panjshah formation is characterized by abundant *Callytharrella sinensis* (Sun), which crops out 18 m above its base. This is an index for the *Waagenoconcha (Callytharrella sinensis* assemblage zone. Besides the index-species, *Derbyia grandis, Orthothetina convergens, Costiferina* sp. ind., *Magniplicatina johannis* are also present. This assemblage corresponds to assemblage 5, lying at the base of member 4 of the Lashkargaz formation.

Member 2. This is a composite terrigenous-carbonate unit; as stated by Gaetani et al. (1995), it is characterized by three main calcareous horizons separated by marls and shales. The lower carbonate horizon is characterized by prevalent subtidal, fossiliferous dark grey limestones with porostromata, bryozoans, crinoids, brachiopods, locally with corals and oncoids. The central portion is made of marls and marly limestone alternances. The more calcareous horizons consist of grey bioclastic packstones to wackestones in thick beds, making transition to marls, by increasing mud pollution. The bioclastic lags may preserve asymmetric ripples. These levels are rich in brachiopods, crinoids and bryozoans. The marl and shale horizons are commonly thicker than the calcareous horizons and contain a few more thin discontinuous calcareous layers. The upper part of the member is mostly terrigenous in the Gircha area, whilst it contains mixed lithofacies in Chapursan Valley, with frequent bioclastic bioturbated carbonate intercalations (oncoids, crinoids, bryozoans, brachiopods). The topmost portion of the member consists of 10 m of dark marls and dark grey limestones in thin beds, with rare brachiopods and nautiloids.

The second member is rich in echinoderms, bryozoans, corals, and fusilinids (? *Lantschichites* sp., *Boultonia* sp., *Minojapanella* sp., *Neofusulinella* sp.), small foraminifers *(Chitralina undulata, Globivalvulina* sp., *Deckerella* sp., *Langella* sp., *Climacammina* sp., *Geinitzina* sp.) and brachiopods *(Stenoscisma armenica/Chapursania tatianae* assemblage zone). Besides the index-species the brachiopods *Retimarginifera* sp., *R. gaetanii* Angiolini, *Magniplicatina* sp. ind., *Compressoproductus* cf. *mongolicus* (Diener), *Lirellaria* sp. ind., *Martinia* sp. ind., *Tiramnia tschernyschewi* and *Martiniopsis* sp. ind. have been collected. Amongst the corals, Flugel (1990) identified *Duplocaninia* sp., *Ufimia hunzensis* Flugel, *Paracaninia similes* (Schindewolf), *Paracaninia* sp. A. *Paracaninia* sp.

The Panjshah formation is up to 160 m thick in the lower Chapursan Valley, decreasing eastward and westwards (Lupghar, Gircha); it is about 130 m thick in the Shimshal Valley. According to Gaetani et al. (1990), the age of the Panjshah formation, spans from the Kubergandian to the Murgabian and possibly also to the Midian. However, the conodonts recovered in the basal part of the overlying Kundil formation seem still to be late Murgabian/early Midian age.

**Gharil formation:** The term Gharil formation was introduced by Gaetani et al. (1995) for a thin sequence of terrigenous but persistent and significant fossiliferous rocks in the Baroghil area.

The rock is named after a small village Gharil, in the Upper Yarkhun Valley. It corresponds to the ironstone horizons quoted by Hayden (1915, P. 292).

According to Gaetani et al. (1995), the Gharil formation is fairly different from west (Baroghil) to east (Lashkargaz). In the west it consists of two fining-upward sequences 12 to 17 m thick. The basal sequence scours deeply (up to 7 m) into the underlying Lashkargaz formation and is overlain by moderately to poorly-sorted microconglomerates followed in turn by dark-red hematitic sandstones with significant cross lamination. In the east, the lower lithozone (up to 80 m thick) consists of extensively burrowed grey siltstones to very fine-grained sandstones and marls locally bearing brachiopods. The upper lithozone is represented by 4.7 m of pebbly conglomerates to microconglomerates with scoured base and yielding very angular carbonate and more rounded silty lithoclasts, passing upward to sparsely bioclastic hybrid arenites and quartz-bearing dolostones (1.2 m). These two lithozones may correspond with the two sequences around the Baroghil pass. Age diagnostic fossils have not been found in this formation. However, based on stratigraphic position, the Gharil formation is placed between the Kubergandian and the Midian.

**Ailak formation:** Gaetani et al. (1995) introduced the name Ailak formation to designate a huge pile of massive dolostones, at least 1000 m thick, which forms the continental divide ridge to the north of Baroghil, Ailak and Lashkargaz. The top of the formation is exposed on the Afghan side of the ridge and therefore, only a small outcrop above Lashkargaz is described here.

Gaetani et al. (1995) measured a section on the eastern slope of the peak conspicuously present to the west of the Baroghil Pass, at an average altitude of 4350 m. Other cursory sections have been made along the ridge between Baroghil Pass and the Gharil area and NW of Lashkargaz. According to them, the Ailak formation consists mainly of thick-bedded dolostones. Also present are stromatolitic dolomites with planar to wavy stromatolites or grey, as well as dark grey dolomitised wackestones. Some of the darker wackestones are less dolomitised and may be considered as dolomitic limestones. More rarely, there are dolomitised packstones with high angle cross-lamination. Small breccia lenses, made by dolomitic clasts are also rare. Distribution of facies seems to be fairly random, with a prevalence of darker wackestones to the east, especially in the middle and upper part, whilst stromatolitic layers seem to be more abundant to the west. An interesting discovery has also been made by Gaetani et al. (1995), who observed huge Paleokarst on the east side of the Chitral/Wakhan boundary, which extend up to the Baroghil Pass, where cavities, up to 100 m deep and 70-80 m wide with polyphasic infillings were observed by them.

The age of the Ailak formation has been derived from forums, 160 m above the base, in the Baroghil West section. Gaetani et al. (1995), located a small foraminifer assemblage with *Paraglobivalvulina?* sp., *Dagmarita chanakiensis, Langella* sp., which characterizes the Late Permian, more frequently the Midian or the Dzhulfian. Higher up for several hundred meters, no fossils have been found, the age, however, has been suggested to extend up to Late Triassic.

**Kundil formation:** A cherty limestone succession that crops out from Chapursan to the Shimshal Valley has been named and described by Gaetani et al. (1990). This formation is missing in Chillinji and in the Baroghil area of the Upper Yarkhun Valley. The type section has been suggested and measured following the base of the buttress, which closes the entrance of the Kundil Valley on its right side.

In their refined definition of the Kundil formation, they ascertained that the unit is predominantly composed of stratified cherty limestone with marls and locally huge piles of megabreccias. Megabreccias bodies may be intercalated in the middle or upper part of the Kundil formation. The thickest (about 100 m thick) forms the buttress closing the entrance of the Kundil Valley on the right side. It consists of polymictic, angular cobbles, and 15-30 cm in size, forming megabreccia bodies up to 10 m in thickness. The most abundant is cherty limestone from the lower part of the Kundil formation, which also contains clasts with fusilinids from the Lupghar formation. The abundance of megabreccia intercalations are considered as subaqueous gravity debris flow and are the characteristic features of the Kundil formation. Gaetani et al. (1995) subdivided the formation into three members, which are as follows:

Member 1: "Dark grey, locally nodular limestones with a few thin marl interbeds. In this lithofacies, there are intercalated frequently litho-bioclastic calcarenites and rudists, up to 4 m with erosional base and reverse grading. Rounded lithoclasts contain fusilinids and crinoids; white chert nodules and silicification processes are common. Upwards, grey cherty crinoidal calcarenites prevail, with reworked fusilinids and dark grey limestones. The top of the member is characterized by coarse grained calcarenites prevail, with chert nodules, fining upwards and a few fine megabreccia with scour base and reverse grading (10-20 cm blocks with crinoids and fusilinids)." Thickness is up to 76 m. Conodonts found in this member of the Kundil formation are characterized at its base by the presence of reworked fusilinids *Pseudofusulina* sp., *Cancellina* etc originating from the underlying formations.

Member 2: "Well bedded, locally squeezed, with thin marl interbeds and abundant white cherts. Grey limestones in 20-40 cm thick beds, locally nodular, sometimes amalgamated to form thicker layers. Coarsely recrystallised, they contain fairly abundant nodules of whitish chert, brown when altered, by intrastratal solution. Occasionally recrystallised dark grey calcarenites with crinoid and small fusilinids with parallel and cross laminations (current ripples) are present." Thickness is about 65 m. In this second member the conodont *Sweetognathus* cf. *hanzhongensis* is present, associated with *Gondolella bitteri* and *Gondolella phosphoriensis*.

Member 3: "Thin bedded grey limestone, with grey or white chert nodules rarely elongated to form lenses. In the middle and upper part, thicker beds may be occasionally intercalated. The matrix of the nodular limestone may consist of pale green, very fine grained tuffs. Thickness of this member is 40-50 m." At the base of this third member the conodonts *Gondolella bitteri* and *G. phosphoriensis* are fairly common, while higher up conodonts are extremely rare. According to Gaetani et al. (1995) the age of the Kundil formation may be late Murgabian to Midian, based on the conodont associations, occurring in the three members.

**Wirokhun formation:** Gaetani et al. (1995) proposed the name Wirokhun formation for a suite of shale and marl sequence from Wirokhun Gulley on the right side, when entering in the Kundil Valley.

According to Gaetani et al. (1995), lithologically, the formation can be divided into three lithozones. The lower one is 26.5 m thick consists of dark shale and marl with grey dark mudstone. The middle lithozone is characterized by 6.4 m of thin bedded cherty-limestone with a shaly partings followed by about 21 m of grey-green recrystallised, sometimes tuffitic limestone alternating with cherty limestone (27.4 m). The upper part is characterized by the reappraisal of black splintery shale and marl followed by intercalations of mudstone layers (20 to 70 cm thick). Total thickness of the Wirokhun formation is not less than 96 m. The upper contact of the formation is normal sedimentary with the Borom formation and is placed at a thick and more persistent-calcareous beds with 'gently nodular' or parallel laminations.

The formation is highly fossiliferous and Gaetani et al. (1995) extracted the following conodont from the Wirokhun formation. From the base *Gondolella orientalis* and representative of the *Gondolella subcarinata* (Sweet) are found. From just below the middle of the unit, *Gondolella subcarinata subcarinata, Gondolella subcarinata changxingensis* and *Hindeodus minutus* are present. From the middle of the unit in the calcareous lithozone *Iranognathus* cf. *unicostatus* Kozur, *Gondolella orientalis* and representatives of the *G. subcarinata* group have been found from the top of the formation *Neospathodus dieneri* Sweet, *Gondolella carinata* Clark, and *Hindeodus* sp. The age of the Wirokhun formation spans from Dzhulfian to Dienerian (Early Triassic).

**Misghar slate:** Desio (1963) described the Misghar slate from northern side of the middle Karakoram Valley and Khunjerab Valley in the Upper Hunza area. The formation consists of monotonous black argillaceous-arenaceous slate with few intercalation of greyish-arenaceous quartzite. The sequence contains porphyritic sills and is in contact with a mass of rosy quartzose syenite "the Giraf syenite". According to Desio, the formation is 5000 m thick and the age of the formation is unknown, and that it may probably be Palaeozoic.

Gaetani et al. (1990) described Misghar slate from Misghar Valley as mainly slate sequence with only very few metacarbonatic and quartzitic intercalations. The thickness here exceeds thousand meters. No fossil have been found. The formation has suffered only low grade metamorphism, which probably took place in the Early Cainozoic during the main Himalayan orogeny. According to Gaetani et al. (1990), the Misghar slate is characterized by an arkose to quartz arenite (medium sand) clastic suite testifying to continental block provenance and deposited in a rift or passive margin geodynamic framework. Gaetani et al. (1990) correlated this formation with Gircha sandstone based on the presence of sporadic granitoid and volcanic rock fragments deposited in a rift trough fed from granitoid source rocks located to the south.

**Staghar formation:** The name Staghar formation was coined by Flugel and Gaetani (1991), who measured a section at Staghar Gol in the south of Aghil Range, northern Karakoram. The formation is essentially a debris and/or grain flow from active carbonate platform of Dzhulfian times. According to these authors, the formation begins with cherty limestones increasingly polluted with calcarenites at the base followed upwards by huge megabreccia bodies from nearby carbonate platforms. In the adjoining Shaksgam Valley, the succession records the passive margin history of transgression on a clastic wedge with shallow water carbonate/arenite stage, then sinking to deeper water with huge resedimentation episodes from carbonate platforms.

Within the resedimented calcarenites, calcirudite and megabreccia, abundant fusilinids including *Neoschwagerina simplex* and *Dunbarula nana* together with the genera *Misellina, schubertella, Khalerina, Cancellina* and *Condofusiella* have been collected by Flugel and Gaetani (1991). On the basis of above fauna a Murgabian-Dzhulfian age has been assigned to the Staghar formation.

**Shaksgam formation:** The Shaksgam series introduced by Auden (1938) to a "carbonatic-arenitic" unit exposed in the Shaksgam Valley lying between Karakoram and Aghil ranges has been named by Desio (1963) as Shaksgam formation, from the same locality. Desio subdivided into two parts, lower dark fossiliferous limestone interbedded with marl, highly fossiliferous and the upper white yellow limestone with marl and shale, brown sandstone and arkose with brachiopods and pelecypods. Flugel and Gaetani (1991) described index coral in three-fold division. The lowest member is shallow-water skeletal carbonate sand with *lophophyllidium* (lophibillidium) martini and *Verbeekiella australis*. This member is more terrigenous in the northwest of Shaksgam Valley and show more calcarenitic facies in the southeast. The discovery of rugosa originates from the base of this member in Urdok Doors section. Flugel and Gaetani (1991) measure two section for this member, one at Urdok Doors and the other Staghar, the section at Staghar proved more fossiliferous and yielded rugosa at a higher level along with *Enteletes* (brachiopods), *Sulcoretepora* (bryozoan); conodont fauna includes *Merillina* aff oertli, fusilinids include *Minojapanella wutuensis* and *Monodiexodina* from the Staghar section.

The second or the middle member is predominantly thin-bedded arenaceous limestone and festooned cross bedded litharnites and quartzarenites. This member is very rich in fusilinids and *yielded Parafusulina Japanica, Monodiexodina Caracorumensis (Karakoramensis) and Pseudofusulina Shaksgamensis Chalaroschwagerina sp. Triticites sp.* The top of the member yielded Boultonia Willsi. The third member, the upper most one, was a pelagic deepwater carbonate basin with grain flows and turbidites. It contains few brachiopods with no fusilinids. The total thickness of the formation is 200 m (Flugel and Gaetani, 1991), while Desio (1963) mentioned it to be more than 1000 m. The upper contact with Staghar formation is transitional, while the lower contact with unnamed Permian is sheared.

**Shaksgam Valley sandstone:** Flugel and Gaetani (1991) described Permian sandstone which is a submerged shelf sandstone overlain by coastal sandy bars and channel filling unit from Urdok Gol Shaksgam Valley. The formation is unnamed and lies immediately below Shaksgam formation of Artinskian. This Shaksgam Valley Permian sandstone is actually composed mainly of quartz arenitic to litharenitic (one meter thick) alternating with dark grey mottled siltites and slate. The arenitic lenses are more carbonatic in the upper part of the formation. The formation is 120 m thick and contains brachiopod and bryozoan. The age of the formation has been determined on stratigraphic bases. Since this formation lies below Shaksgam formation, Pre-Artinskian is assigned to it by Flugel and Gaetani (1991).

**Singhie shale:** Desio (1963) named and described Singhie shale from upper Shaksgam

Valley between Karakoram and Aghil ranges. The formation is composed of thick sequence of black foliated shales often grading into black slates, which are interbedded with dark coloured limestone or marl and quartz sandstone.

It is interesting to note that the shale formations are by for the most abundant lithological units exposed frequently all over the northern areas of Pakistan. Different authors have used different nomenclature in different areas, even though it may be one and the same unit. This fact is realized by many workers including Desio (1963); Norin (1976), but still use different name provisionally to distinguish from each other even on minor accounts. The intensity of tectonism and metamorphism are, however, the two main factors, which add to the degree of confusion along with the absence of fossils in slate/shale series. With this situation the best that can be done is to place this shale/slate either in Mesozoic or Palaeozoic as Desio placed Singhic shale in Palaeozoic.

**Zait formation:** The name Zait limestone was coined by Talent et al. (1981) to the extensive outcrops of massive carbonate, mainly dolomite, typically exposed on the left flank of Mastuj Valley along the Reshun-Korag road between Torman Gol and the Zait Gol.

As described by Talent et al. (1981), the Zait formation is composed of massive carbonate, black weathering to grey, micritic and dolomitic throughout with pisolitic ironstones, (about 6 m thick), occurring about 25 m above the base in both Reshun and Zait gols. Carbonate breccia occurs high up in the sequence exposed on the side of Torman Gol has also been recorded and interpreted as of intraformational solution-collapse origin by Talent et al. (1981). It is a mappable unit and provides some accessible points forms a 350 m thick mesa between Reshun-Korag Road and Zait Gol and extends NE across Zait Gol outcropping boldly in cliffs and road sections around and also forms a spur 1.5 km SW of Reshun Bridge. The formation further extends northwards through the road section between Korag and Buni, the unit here is exposed from the ford over Charun Gol almost to Diryanu.

The unit is about 600 m thick on the north side of Torman Gol, where it is principally dolomite. The section of the Zait formation in Reshun and Zait Gols are especially interesting because the unit rests over the early Devonian sandstone with a normal sedimentary contact (Talent et al., 1981). They discussed the age of the formation in detail in many cases floats have been used but these authors were sure of these floats to be derived from the Zait formation. The account of floats is as follows:-

An angular block (float) of dark grey limestone collected from the Reshun-Korag road about 300 m towards Zait from crossing over Torman (Dorman) Gol. These samples yielded (identified) as: *Anchignathodus typicalis, A.* cf. *Typicalis. A. isarcicus, Lonchodina triassica, L. inflata, L. cf. inflata, Prionodina mulleri and Ozarkodina* sp. According to them, this fauna unquestionably represents the zone of *Anchignathodus typicalis* at the base of the Triassic- somewhere in the Otoceras and *Ophiceras* ammonoid zones of the Griesbachian, probably the latter on the presently known range of A. isarcicus.

Several insitu fossils have been collected. Their age range spans very large. The acid insoluble residues from Zait Gol and the exposures towards Girim Lasht have yielded interesting but low diversity faunas of agglutinated foraminifers, but these lack precision for stratigraphic correlation: species of *Ammodicus, Glomospira, Ammodiscella,* and *Schizammina* from the latter. Talent et al. (1981), however, stated that "We are thus not in a position to proffer an unequivocal age assignment for the Zait limestone but circumstantial evidence suggests that it may include horizons on either side of the Permian-Triassic boundary and if the fusilinid limestone encountered by Desio and members of our party on the Reshun-Korag road, should have had their origin in the Zait limestone, then its age includes horizons from at least as old as the zone of *Cancellina* in the Permian to at least as young as the *Anchignathodus typicalis* zone of the Early Triassic".

**Ganchen formation:** Desio (1963) named and described Ganchen formation from south of the Karakoram along the Lower Hunza Valley. According to Desio, the formation is defined as follows:

"Biotite-amphibole garnet and epidote bearing gneiss associated with biotite-muscovite gneiss, tourmliniferous muscovite gneiss and garnetiferous amphibolite and thick beds of marble and crystalline dolomite". Ganchen formation, according to Searle (1991), is dominantly pelite and forms the substantial part of the metamorphic exposures south of Aliabad and Nagar. The constituents minerals of the pelites are mainly comprised of biotite, plagioclase and quartz and minor amounts of almandine garnet and hornblende. The accessory minerals include sphene, aplite, calcite and opaque minerals. The metamorphic grade indicators, or "important Barrovian facies index", minerals include: staurolite, kyanite and sillimanite. Amphibolite with garnet and biotite and at places marble is interbedded with the pelites. The occurrence of the "rare marble" differentiates- Ganchen formation from Dumordo group, which is heavily loaded with marble. Dumordo group was named by Desio (1963, 1979) and is as follows:

**Dumordo group:** Desio (1963) described Dumordo group named after a tributary of the Biaho River in the upper Braldu Valley. Lithologically, the Dumordo group is a complex variously metamorphosed collection of rocks represented by crystalline limestone-marble, mainly white and saccharoid, but sometimes grey and coarse-grained intercalated with thick beds of grey and blackish calc-schist and with plagioclasic-biotitic gneiss, biotite-amphibolite-garnet gneiss, garnetiferous-mica schist and kyanite-mica schist.

The Dumordo group is predominantly crystalline limestone specially the middle part of the formation, downwards and upwards; the limestone beds are gradually replaced by mica schist and gneiss. The garnets are widespread. This is one of the characteristics of this group. The thickness of the Dumordo group amounts to several thousand meters. According to Searle (1991), east of Askole and south of Baltit River over 60% of this unit is considered to be pure marble, locally with interbeds of minor amount of graphitic schists, garnet-biotite amphibolites and pelite layers. Metamorphic grade of the pelite content of the Dumordo group is such that it spans from low grade chloritoid chlorite and chlorite biotite schists that appears around the Chingkang Valley to high grade kyanite and sillimanite bearing gneisses around the upper Braldu River.

Among other lithologies, the lithic grey and matrix support conglomerate beds with abundant carbonate shale and quartz clasts are an important facies. Layers of quartzite may be as much as 200 m, which was encountered by Searle (1991) on the west side of Barkor Das. High grade marble with interbedded pelites and amphibolites occur around the snout out of the Biafo Glacier at the junction with the Braldu River (Searle, 1991).

The age of both units i.e. Dumordo and Ganchen is not known and according to Searle (1991), the indirect evidence indicates that Dumordo group is older than Jurassic as determined from Jurassic granodiorite that intrudes them. Rough idea of the age of these two units may be that they are spanning from Late Palaeozoic to Triassic.

**Skamri limestone:** Desio (1963) named Skamri limestone after a mountain range of the same name in the Panah and Dumultar glacier valleys. Earlier in 1936, he had called it 'Skamri series'.

Lithologically the Skamri limestone is a white and yellowish, subcrystalline limestone occasionally intercalated with dark and black slate. The lower portion of the limestone grades into calc-schist. The formation is more than 2500 m thick.

In the Dumultar Glacier which is small branch of the Panah Glacier, the great mass of Skamri limestone gradually thins out downwards and the thin beds or stringes of the sub crystalline limestone are interbedded with thick bedded calc-schists, which are named by Desio (1963) as Dumultar calc-schist. This calc-schist is fossiliferous and contains Fenestella indicating Permian age.

**Dumultar formation:** It is calc-schistose-slaty-arenaceous, dark-brown associated with dark slate interbedded with few thin beds of sub crystalline limestone. It is about 30 m thick and the base is not exposed. The contact between the Dumultar calc-schist and Skamri limestone is gradational and for this reason the age of Skamri limestone is also tentatively considered as Permian but may extend into Triassic.

# MESOZOIC

Mesozoic rocks of Pakistan are widely exposed in the country. They depict great variation in lithology both in the interbasin and intrabasin stratigraphic set up. Southern part of country is sedimentary and northern part exhibits great variety of metamorphic and igneous rocks.

Maximum development of Mesozoic rocks has been recorded from the Lower Indus Basin with several thousand metres of calcareous and argillaceous sediments. They are extensively exposed in the Sulaiman-Kirthar Province and in the Axial Belt. In the Lower Indus Basin, the predominant lithology is limestone, dolomite, shale and mudstone, whereas substantial part of the suite of the Upper Indus Basin is arenaceous. According to Fatmi (1977), the disconformities between the systems and within the systems are less pronounced in the Lower Indus Basin than in other areas of Pakistan and in many cases the sedimentation is believed to have been continuous from Triassic to Jurassic. Near the top of the Middle Jurassic, however, an important break exists with the overlying Upper Jurassic rocks. According to Hunting Survey Corporation (1961), the Axial Belt region became tectonically active towards the close of the Early Jurassic and developed into a pre-orogenic geanticlinal structure, which controlled the sedimentation on either side of the Axial Region. Thus, the Khuzdar area is marked by great facies changes particularly in the Cretaceous and Tertiary formations.

Comparing the regional stratigraphic set up, Fatmi (1977) described "The Kohat-Potwar Province (Upper Indus Basin), as contrasted to the Sulaiman-Kirthar Province (Lower Indus Basin) and the Axial Belt, lay at the margin of the geosyncline and represents shelf or even continental deposits, which are comparatively thin (1060 m) and are characterized by important hiatuses that are present at the base of the Triassic and between Triassic and Jurassic, within the Jurassic and Cretaceous and on the top of the Cretaceous. The sediments are mostly of shallow water marine and of continental origin consisting of shale, sandstone, limestone, dolomite with carbonaceous material, fireclay and ferruginous horizons". The depositional behaviour of Mesozoic rocks in eastern part of Kohat-Potwar Province (Salt Range and Potwar Plateau) is shown in Fig. 13.

In Hazara, Jurassic rocks disconformably overlie rocks of various Palaeozoic and Precambrian ages. In Kurram Agency, some units exposed in the Northern Sector of Axial Belt show that they are the extension of Mesozoic rocks of Upper Indus Basin, e.g., particularly in the Miran Shah area, as well as, in the east of it, however, due to considerable variation in the facies, some workers have given new names to the Mesozoic rocks of this belt. North of the Axial Belt, Mesozoic is mostly represented by metamorphic and igneous rocks. An island arc, further north in Kohistan area, represents alien sequence as compared to the sediments, south and north of it.

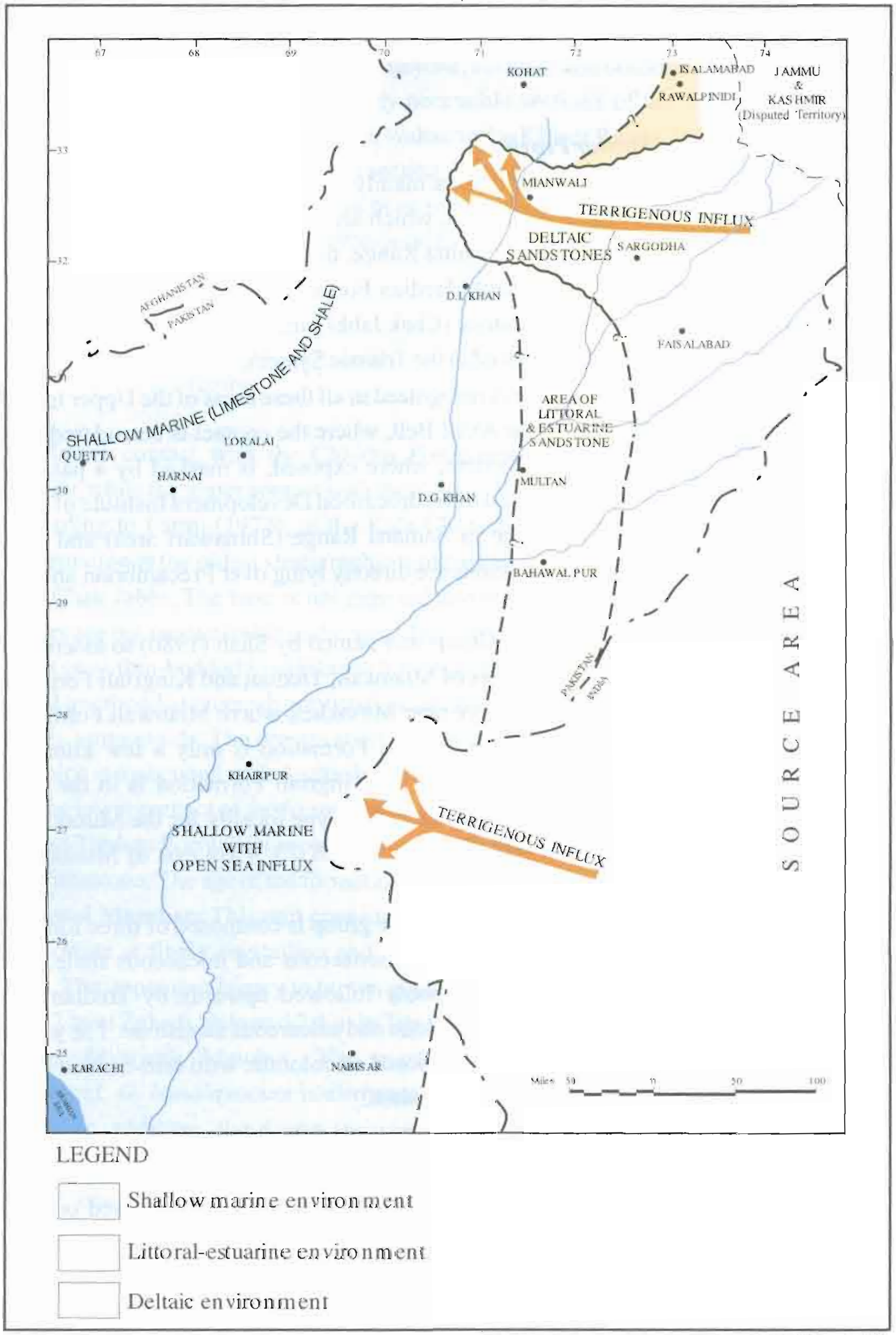



Fig. 13. Paleogeographic sketch map of Lower Triassic.

Modified after Flynn (1972)

limestone" and topmost limestone and dolomite beds. The formation represents a great wedge of varied facies consisting of marl, limestone, sandstone, siltstone and dolomite, which is thickest in the west and wedges out towards the east. Easily accessible sections of the formation are located in Zaluch Nala western Salt Range and in Tapan Wahan in the Khisor Range. Its thickness in the Zaluch section is 121 m, while in the Tappan Wahan section, it ranges from 135 to 187 m.

The following three members have been recognized by Kummel (1966) in the Salt Range and Trans-Indus ranges, which broadly correspond to the three sub-divisions recognized by Waagen:

(iii) Narmia Member
(ii) Mittiwali Member
(i) Kathwai Member

The lower contact with the Chhidru Formation of Late Permian age is marked by a paraconformity, while the upper contact with the Tredian Formation is sharp and well defined.

According to Fatmi (1977), in the Kala Chitta Range to the north of the Salt Range, the Mianwali Formation is the oldest stratigraphic unit exposed in the cores of the anticlines near Bagh and north of Chak Jabbi. The base is not exposed and the Chak Jabbi outcrops are faulted and the three members are not recognizable in the area. The formation in Kala Chitta (exposed thickness 39 m) consists of grey, thin-bedded fossiliferous limestone (9 to 1 m), which is underlain by thin-bedded limestone and interbedded greenish grey marl or calcareous shale. The fossils are abundantly present and are mostly ammonoids. The preservation is, however, poor. The most significant ammonoid is Owenites, which is associated with Anakashmirites, Meekoceras and occurs in the middle part of the formation. The lower contact of the formation is not exposed. The upper contact with the Chak Jabbi Limestone and Tredian Formation is palaeontologically sharp and is placed at the last fossiliferous thin-bedded limestone. The age of the formation is Early Triassic (Scythian).

**Kathwai Member:** This unit consists of dolomite in the lower and limestone in the upper part. The dolomite is finely crystalline and includes fossil fragments (mainly echinoderms) and quartz grains. The upper unit is grey to brown glauconitic limestone. The total thickness of Kathwai Member is 3.7 m in Zaluch Nala and 2.4 m in Tappan Wahan. Fossils are much less common than in the overlying Mittiwali Member. The most significant fossil is *Ophiceras connectens. Glyptophiceras* cf. *G. himalayonum* is also reported. These ammonite species indicate an earliest Scythian age. In addition, the fauna includes endothyracean foraminifera, *Lingula borealis,* rhynchonellids, pectinids, ostracodes, crinoid and ophiuroid fragments, echinoids *(Miocidaris, pakistanensis),* conodonts, fish teeth, and a rich palynological assemblage of pollen, spores, and acritarchs (Kummel and Teichert, 1970; Balme, 1970; Sarjeant, 1970). *Permian-Triassic boundary:* In a self-contained brief, Fatmi (1977) described the boundary as follows:

"Prior to Kummel and Teichert's work (1966, 1970), Permian boundary was placed by some at the top of the dolomite unit of the presently described Kathwai Member which is above the *"Ophiceras Zone"* while according to Schindewolf (1954) the boundary was placed in the middle of a white sandstone unit which is the highest bed of Chhidru Formation. Kummel and Teichert (1966) shifted the boundary to the base of the dolomite unit of Kathwai Member on the grounds that it contains *Ophiceras* and that the contact with the underlying white sandstone unit of Chhidru Formation is sharp, representing an environmental change. They were of the view that the Permian-Triassic boundary is a paraconformity equivalent in magnitude to at least a stratigraphic stage.

The most surprising element of the fauna of this lower unit is an assemblage of brachiopod genera otherwise known only from Permian rocks. These brachiopods occur in the basal 15 to 30 cm of the dolomite unit, though the genus *Crurithyris* was found about 2 m above the base. The brachiopods include *Lingula* sp. *Linoproductus* sp. *Spirigerella derbyi, Orthothetina* sp. *Enteletes* sp. *Orthotichia* sp. and *Martinia* sp. Cooper *(in* Kummel and Teichert, 1966), who identified these brachiopods commented that "these are the product of reworking" with which Kummel agreed, but Teichert was reluctant to do so. Particularly he rejected this interpretation for the occurrence in Khan Zaman Nala, where *Crurithyris* was found about 1.5 m above the base of the Kathwai Member. More recently, Kummel and Teichert (1970) have discussed the age and fauna of the Kathwai Member in detail with particular reference to Permian-Triassic boundary. The fauna consists of bryozoans, brachiopods, cephalopods, bivalves, ostracodes, crinoidal stems, conodonts, fish, palynomorphs, acritarchs, algae and trace fossils.

The brachiopods from the dolomite unit of Kathwai Member were studied by Grant (1970), who recognized *Lingula, Orbiculoidea, Enteletes, Orthothetina, Ombonia,* and *Martinia* and concluded that the fauna was different from that of Chhidru Formation and considered it to be of Dzhulfian age. According to Grant two interpretations are possible. One interpretation is that Dzhulfian beds were deposited but later eroded and their brachiopod fauna incorporated in the basal dolomite unit. According to other interpretation, the Permian brachiopods and Triassic ammonoids occur at the same level if it is assumed that the basal dolomite field is continuous. The field occurrences suggest that the basal 30 cm of the Kathwai Member is Dzhulfian at some localities (e.g. Narmia) and Triassic at other localities (e.g. Munta Nala, Kathwai) with apparent mixing at a few places (e.g. west side Chhidru Nala). The mixing could be due to erosion of Dzhulfian beds, and incorporation of their fauna in the basal Triassic transgressive sea. The Permian-Triassic boundary, according to Grant (1970), would be drawn at the base of the Kathwai Member by the first interpretation and about thirty centimetres above in the dolomite unit in other localities. According to the second interpretation where mixing has taken place (e.g. west of Chhidru) it would be drawn at the occurrence of the lowest Triassic ammonoids Permian brachiopods being assumed to have been reworked.

The studies of other fossil groups have shown a change in composition across the boundary but some fossil groups show less change. The conodont fauna (Sweet, 1970) from top beds of Chhidru Formation and basal Triassic dolomite unit fall in one zone namely Anchig- nathodus typicalis. The main evolutionary line of Late Permian continues in the Triassic without much change. The acritarchs of upper most Permian have a strongly Mesozoic aspect. On the other hand a strong break in palynological succession is indicated at the boundary (Balme, 1970). Kummel and Teichert

(1970) favour Furnish and Glenister (In Kummel and Teichert, 1970) for a smaller break (absence of uppermost Permian stage "Changhsingian stage" near the boundary) than a large break as contended by Grant (1970).

**Mittiwali Member:** Fatmi (1977) described this member as the thickest (98 m in Zaluch Nala) unit of the Mianwali Formation and represents Waagen's (1895) "Lower Ceratite limestone" "Ceratite marl" "Ceratite sandstone" and "upper Ceratite limestone". The lithology consists of grey, fine-grained, non-glauconitic limestone with abundant ammonites. The basal beds consist of limestone, which is less than two metres thick in the Salt Range, but up to 8 m in the Khisor Range. The ammonite fauna indicates a Gyronitan age (lower Scythian). The rest of the unit consists of greenish to greyish shale, silty shale with some sandstone and limestone interbeds. The unit is richly fossiliferous, but most of the fossils are restricted to lenticular limestone beds.

In the upper part of the member the fauna is dominated by ammonoids and a few nautiloids. The ammonoids include *Ambites, Proptychites, Koninckites, Gyronites, Prionolobus, Kymatites, Kingites and Paranorites*. The remainder of the fauna consists of pectinids *(Pecten discites)*, ostracodes and conodonts from the middle part of the unit (which is micaceous, massive to thin-bedded sandstone in the section east of Nammal Gorge) in addition to ammonoids, the following fossils have been recognized: *Pseudomonotis* sp., *Nucula* sp., *Rhynchonella* sp. and *Bellerophon (Stachella)* sp. In the central Salt Range, this sandstone grades into upper "Ceratite limestone" which contains beds of sandstone and shale. The unit contains bivalves but the ammonoids are still dominant. They include *Anasibirites, Prionites, Hemiprionites* and others. The bivalves are represented by *Gervillia* sp. and *Pecten* sp. These sub divisions of the Mittiwali Member are, however, not recognized in the area east of Nammal Gorge, where the lithology consists of shale interbedded with limestone and sandstone.

**Narmia Member:** The Narmia Member is equivalent to the "Bivalve beds" and "dolomite unit" of Waagen (1895). The basal bed of the Narmia Member is a 3m thick limestone, which in Zaluch Nala consists of dark grey to brown fragmental limestone, sandy in part, and containing brachiopods, bivalves and ammonoids. The rest of the unit consists of grey to black shale with interbeds of sandstone and lenticular limestone or dolomite. The top most bed is a grey to brown, massive dolomite, but in the Surghar Range it is a pisolitic dolomite, 2 m thick with Spirijerina and other brachiopods. The thickness in Zaluch Nala is 23 m.

The member is fossiliferous and contains brachiopods, ammonoids, nautiloids, echinoid spines and crinoidal remains. Ammonoids species include *Subvishnuites* sp. indet., *Xenoceltites sinuatus, Xenoceltites* sp., *indet., Procarnites kokeni, Isculitoides* sp. indet., *Stacheites* sp. indet., *Dagnoceras* sp. indet., *Nordophiceras* sp. indet., *Nordophiceras planorbis, Arctomeekoceras* sp. indet., *Tirolites* sp. indet., *Prohungarites* cf. *P. crasseplicatus* (Fatmi, 1977). The fauna indicates Late Scythian age.

**Tredian Formation:** The name Tredian Formation was introduced by Gee (in Kummel 1966) to replace, in part, his earlier name "Kingriali sandstones" (Gee, 1945). The Tredian Formation is essentially a non-marine unit that succeeds the Mianwali Formation. Its thickness is

1560 m in the Tapan Wahan section of the Khisor Range and 76 m in the Zaluch section of the Salt Range.

According to Fatmi (1977), the formation comprises two members; the lower is *Landa Member* (Kummel, 1966) and the upper the *Khatkiara Member* of (Danilchik and Shah, 1967). The *Landa Member* consists of sandstone and shale. The sandstone is micaceous and varies in colour from pinkish, reddish grey to greenish grey. It is thin to thick-bedded, with ripple marks and slump structures. The thickness varies from 19 to 29 m in Zaluch and Tapan Wahan sections, respectively. *The Khatkiara Member* is massive, thick-bedded, white sandstone that grades into the overlying Kingriali Formation with the inclusion of some dolomite beds in its upper part. The thickness varies from 38 to 59 m in the Tapan Wahan and Zaluch Nala sections respectively.

The formation contains plant microfossils described by Balme (1970). The Lower *Landa Member* contains acritarchs whereas the *Khatkiara Members* yielded only spores, pollen grains and wood fragments. Some of the essential elements of Palynomorphs of Tredian Formation are: *Calamospora landiana, Cyciogranisporites arenosus, Aratrisporites paenulatus, Falcisporites stabilis, and Platysaccus queenslandi.* On the basis of its stratigraphic position over the Mianwali Formation of Early Triassic age, the microfossils, and its conformable contact with the overlying Kingriali Formation, the age is regarded as Middle Triassic.

**Kingriali Formation:** The name "Kingriali Dolomite" was used by Gee (1945) and later amended as Kingriali Formation, because several lithological facies are represented. The name originates from Kingriali Peak in the Khisor Range. Good sections of the formation occur in Zaluch Nala in the western Salt Range, Landa Nala in the Surghar Range and in Tapan Wahan and Gori Tang Nala in the Khisor Range.

The formation consists of thin to thick bedded, massive, fine to coarse textured, light grey brown dolomite and dolomitic limestone with interbeds of greenish dolomitic shale and marl in the upper part. This upper unit, which consists of thin to medium bedded, fine grained dolomite, dolomitic shale and marl is well developed, 12 m in Gori Tang Nala. The thickness of the formation varies from 76 to 106 m. In the Kala Chitta Range, the formation is 91 m thick.

Anwar et al. (1992) divided the formation into two members. The lower member is named Doya and the upper member Vanjari member. Their description is as follows:

**Doya Member:** The name Doya Member is derived after the Doya Village (Lat. 32° 27' 16" N: Long. 71° 09' 59" E, 38P/1) in the Surghar Range. It consists of sandstone and dolomite interbeds with fossiliferous limestone and minor shale. The sandstone is light grey to greyish white, pinkish, weathering brownish grey, fine to medium grained, thick bedded, soft, micaceous, dolomitic, friable and cross-bedded. The dolomite is brownish grey to brown, coarse grained, hard, sandy, jointed and fractured. The limestone is grey to brownish grey, medium bedded, dolomitic, sandy crinoidal, hard and contains spiriferina, crinoids, echinoids, gastropods and other benthonic fossils. The shale is black, carbonaceous and micaceous. It is 34 m thick in the Trakai Nala section, 30 m in the Narmia Nala section and 40 m in the Landa Nala section.

**Vanjari Member:** The name Vanjari Member is derived after Vanjari Village (38P/1) in the

Surghar Range. It mainly consists of dolomite. The dolomite in the lower part is brown, purple to purplish grey, weathering dark brown to brownish grey, coarse grained, massive, hard, highly brecciated, jointed, fractured and forms cliffs. The dolomite in the upper part is whitish to light grey, micritic, thin bedded to flaggy, medium hard, lithographic, fractured and at places marly. This member is 58 m thick in the Trakai Nala section, 78 m in the Narmia Nala section and 64 m in the Landa Nala section.

The total thickness of the Kingriali Formation is 92 m in the Trakai Nala section, 108 m in the Narmia Nala section and 104 m in the Landa Nala section. The lower contact with the Tredian Formation is conformable and the upper contact with the Datta Formation is disconformable. The formation is widely developed in the Salt Range, Trans-Indus ranges, part of Kala Chitta, Kohat, and in southern Hazara. It overlies conformably the Tredian Formation in the Salt Range and Trans-Indus ranges and the Chak Jabbi Limestone (Tredian Formation) in Kala Chitta. It is absent from the eastern Salt Range and eastern Khisor Range. The lower contact with the Tredian Formation is marked by interbedding of sandstone and dolomite. The upper contact with the Datta Formation is disconformable and shows the development of a ferruginous dolomite and uneven surface at the contact.

Fossils are rare and poorly preserved. Some brachiopods, bivalves and crinoidal remains have been reported. Its transitional contact with the underlying Tredian Formation or Chak Jabbi Limestone, and disconformable contact with the overlying Datta Formation of Jurassic age places it doubtfully in the Late Triassic. The formation is correlated with the upper part of the Wulgai Formation.

**Chak Jabbi Limestone:** The name Chak Jabbi Limestone was proposed by Fatmi (1972) for a Triassic Unit in the Kala Chitta Range and parts of Hazara which has been previously referred to by him (1966, 1968) as "Kala Chitta limestone" and Bagh limestone" (the two names being preoccupied). These rocks were included by Cotter (1933) in the lower part of the "Kioto limestone ".

The formation is exposed in faulted outcrops north of Chak Jabbi Forest Rest House (Lat. 33° 41' N: Long. 72° 16' 30" E), but a complete section designated by Fatmi (1968) as the principal reference section lies one kilometre east south east of Bagh Village in the Kala-Chitta Range. The lithology consists of thin of medium bedded (in bed of 15-60 cm) grey, light grey, weathering brownish grey, sub lithographic limestone which has not yielded any recognizable fossil. The limestone is exposed in the core of Bagh and Chak Jabbi anticlines in the Kala-Chitta Range and forms the lowest beds exposed east of Hatter Cement Factory where it is mined as raw material for cement. The thickness in Bagh and Chak Jabbi sections of Kala Chitta Range is about 30 m. The formation is slope forming, with characteristic light grey weathering colour. It is gradational with the overlying Kingriali Formation and the underlying Mianwali Formation. Its stratigraphic position is similar to that of the Tredian Formation of the Salt Range and Trans-Indus ranges. The limestone is unfossiliferous but as it overlies the Lower Triassic Mianwali Formation and underlies the Upper Triassic Kingriali Formation; its age is considered doubtfully as Middle Triassic.

## AXIAL BELT

### *Zhob Valley*

**Khanozai Group:** This group has been proposed by Fatmi (1986). The group comprises the earlier described Triassic rocks including Wulgai Formation from Wulgai and Gwal sections. It is composed of clastic and carbonate turbidites of deep water origin and it is found in thrust sheets. The Khanozai Group is divisible into two formations. The lower newly proposed Gwal Formation is of Early Triassic age (Late Middle Scythian). The overlying Wulgai Formation is of Late-Middle Triassic in age, while the Middle Triassic is based on the radiolarians and conodonts with some Spiriferinid branchiopods in the Trakai-Gwal section. The group is more than 530 m thick.

**Gwal Formation:** The name Gwal Formation comes from the village of Gwal, 60 km northeast of Quetta. According to Anwar et al. (1993), the formation is composed of variegated shale and limestone interbeds with marl intercalations and occasional mafic intrusions in the Takai Gwal area. The shale is dark grey to olive, maroon, greenish grey, silty, non calcareous, friable and fissile. The limestone is grey to dark grey, weathering brownish grey, micritic, dense, platy to thin bedded and, at places, it is dolomitised and sandy with some calcite veins and including diabase flow. The formation contains exotic blocks of Permian limestone containing brachiopods, corals etc.

The base of the formation is not exposed. It is more than 350 m thick in the Trakai-Gwal section. Its upper contact with the Wulgai Formation is sharp with fossiliferous limestone (conglomeratic) at the base in some areas. On the basis of ammonites including *Meekoceras, Owenites, Anakashmirites, Anasibirites, Durgaites, Hemiprionites* etc the age of the formation is Early Triassic (Late-Middle Scythian). The Gwal Formation includes a thin to medium bedded micritic limestone unit in the upper part and is correlative with Narmia and Mittiwali Members of the Mianwali Formation of the Salt Range.

**Wulgai Formation:** The Wulgai Formation is defined to include the Middle to Late Triassic rocks named originally by Williams (1959) after the Wulgai Village.

This formation consists of shale with limestone and siltstone interbeds with dense, thin to medium bedded limestone at the base (conglomeratic) in the Trakai-Gwal and Wulgai areas. The shale is purple, olive, brownish grey to greenish grey, well-bedded, argillaceous, hard, silty, splintery, non-calcareous, siliceous, laminated and fissile. The limestone is grey to dark grey, weathers brownish grey, micritic, tufaceous, platy to thinly bedded siliceous, fine grained, hard and at places recrystallised and sparitic with occasional siltstone beds.

The thickness of the formation is 180 m in the Trakai-Gwal section. Its lower contact with the Gwal Formation is sharp with fossiliferous limestone at the base and the upper contact is faulted against Sembar (Goru ?) Formation. The fossils that include radiolarian and conodonts and some Spiriferinid brachiopods indicating Middle Triassic age occur in the basal limestone unit and *Halobia, Daonella* (Bivalves) and ammonites like *Cladescites, Jovites, Arietoceltites, Anatomites, Juvavites, Arcetes* indicating Late Triassic. The Wulgai Formation is correlated with Tredian and Kingriali Formation of the Salt Range.

It is also correlated with the lower parts of the Shirinab and Zidi formations and lower part of the Windar Group of Hunting Survey Corporation (1961). The Wulgai Formation shows close similarity with the Triassic rocks of the Mount Everest region (Wager, 1939). Lithologically the Balochistan sequence is distinct from the Salt Range and seems to belong to a different depositional basin, which presumably extended in Afghanistan and parts of Himalayas.

***Kurram Agency Area***

Thrust sheets comprising Triassic sequence are exposed in the western most extension of eastwest trending Northern Sector of the Axial Belt, which further east becomes the Attock-Hazara folded and Thrust belt. This last section is devoid of Triassic rocks.

**Spalga formation:** The name Spalga formation is introduced by Ahmed et al. (2000) for a sequence of sandstone and shale exposed in the Kurram Agency and designated type section near the village of Spalga, 17 km southeast of Miran Shah (Lat. 32° 55' 45" N: Long. 70° 07' 45" E).

According to Ahmed et al. (2000) the formation consists of sandstone, siltstone, and shale. The sandstone is light to dark grey and weather to rusty brown colour. "It is fine to medium-grained, thin to medium-bedded and exhibits circular rims, due to colour variation called as liasegang". Slump structure and worm burrows are commonly found in the sandstone beds. The shale is greenish grey and weathering to brownish grey with well-developed fissility planes. The siltstone is greenish grey to dark and weathering to rusty brown". The base of the formation is not exposed in the Mirali-Miran Shah area, while its upper contact with the Sarobi formation of Triassic age is faulted.

The formation has some lithologic similarities with the middle unit of the Wulgai Formation of the Axial Belt of Early to Late Triassic age. They also correlated it with the Datta Formation exposed in Kohat-Samana area, which consists of interbedded shale, sandstone and limestone. The Datta Formation is mainly of continental origin. "Commonly found worm burrows" here in this unit under discussion may also indicate continental origin of the part of Spalga formation and may well be correlated with parts of Datta Formation of Jurassic age, but Ahmed et al. (2000) stated that no fossils have been found in the formation. However, they assigned Triassic age to the formation based on its stratigraphic position and lithological similarities with the Late Triassic rocks in the Balochistan.

## TRIASSIC PALEOGEOGRAPHY

Triassic formations of Indus basin and Axial Belt are mainly represented by Mianwali, Tredian, Kingriali, Chak Jabbi Limestone and Wulgai Formations. The site of the deposition of these formations was a marine shelf, upon which limestone, dolomite, shale and sandstone were deposited. It was bordered to the southeast by the Indian shield. This shield was the source of the terrigenous clastics for the basin (Fig. 13).

The lower part of Mianwali Formation is paraconformable with Permian formations. The upper part of Mianwali Formation is a carbonaceous turbidite sequence, which indicates prodelta facies before the deposition of Khatkiara Member of Tredian Formation. The Khatkiara Member is upper part of Tredian Formation and is composed of massive, thick-bedded white sandstone of probable late Scythian to early Anisian age. The Khatkiara Member has, as its basal part, laminated quartzose sandstone with minor amounts of ferruginous and carbonaceous material. Based on primary sedimentary structures, present in the Tredian Formation, Amoco geologists interpret this formation especially Khatkiara Member as representing a change from the prodelta and distal delta platform environments of the upper Mianwali Formation, to an on-delta environment where deposition was dominantly occurred within distributaries channels and inter-distributaries bays of the westward prograding delta, Flynn (1972). The uppermost sediments comprised of arenaceous siltstones, sandstones, and dolomitic or calcareous sandstones, which may represent an abandonment of the delta lobe with final phase of winnowing by wave action of sediments subsiding along the seaward margin of the delta.

The overlying Kingriali Formation, of early Anisian to Norian age, represents continued marine transgression over the subsiding Tredian delta. Local restriction, possibly by barrier bars along the old delta front, may have occurred, and thin evaporites were probably formed along the eastern margin of the sea. The presence of abundant disconformities within the lower part of the Kingriali Formation indicates several periods of emergence (Flynn, 1972). The upper contact of the formation is unconformable with the overlying Jurassic Datta Formation. This last period of emergence into the vadose zone may account for the dolomitization and extensive leaching of the formation and the apparent absence of sediments of Rhaetian age.

Triassic Formations end up with an unconformity before Datta Formation of Jurassic age, exposed in substantial part of Indus basin. The general depositional strike trends northeastwards direction and that the Tethyan geosyncline apparently bounded the shelf edge on the north and northeast. According to Kummel (1961) the southern boundary of the Tethyan Seaway extended eastward from eastern Egypt through Saudi Arabia and thence southward to Madagascar. Around the periphery of the Indian shelf, marine Triassic sediments (Wulgai Formation) are present from the Balochistan (Axial Belt of Pakistan) northward through Kashmir to Nepal. Thus, Kummel confirms, "we are reasonably certain that the Tethyan Sea opened southward between the Ethiopian and Indian Shields to the Indian Ocean". It is added here that the sediments of early Late Triassic in Pakistan have been encountered as for south as Nabiser-Badin area while further south in Kutch area, especially in the Indian Kutch area, continental arkosic sandstone lies over Indians Shield of Precambrian age.

## Himalayan Tectonostratigraphic Basin

### *Lesser Himalaya*

Mesozoic rocks of Lesser Himalaya are few and far between Peshawar Basin, is devoid of Triassic rocks but in lower Swat area, except for the Kashala formation which yielded late Triassic conodonts, no other fossiliferous Triassic sediments are reported throughout Lowe-Sur dome and Indus Syntaxis. However Nikanai and Saidu formation are doubtfully considered Triassic.

**Karapa greenschist:** Pogue et al. (1992) named and described Karapa greenschist sequence overlying the Jafar Kandao formation with sharp contact. The unit is well exposed near the Karapa Village, 30 km northeast of the Broach Village. The type section is designated along the south-facing slope of Gumbat Sar between the villages of Karapa and Sonigram.

Lithologically the Karapa formation is metamorphosed tholeiitic basalt as determined by geochemical analysis. According to Pougue et al. (1992) the Karapa greenschist extends from Late Carboniferous (Westphalian) to Late Triassic (Carnian) in age. The overlying Kashala formation yielded Late Triassic (Carnian) conodonts and the underlying Jafar Kandao extends from Devonian to Carboniferous in age. Due to its restricted exposures, Pogue et al. (1992) has brought the Karapa greenschist down to the level of a member stage of Kashala formation.

**Kashala formation:** About 1500 m of interbedded marble and phyllite to the north of Rustam has been named and described by Pogue et al. (1992) as Kashala formation. These rocks were earlier described by Martin et al. (1962) as marbles and calcareous schists of the "Lower Swat-Buner Schistose Group". Kazmi et al. (1984) included these beds in "Manglaur schist, Alpurai schist, and Saidu schist". According to Hussain et al. (1998) the Kashala formation is comprised of over 100 m of brownish grey marble and interbedded calcareous phyllite. The marble sampled from the middle part of the Kashala formation yielded *Neogondolella polygnathiformis angusta* conodonts of Late Triassic (Carnian) age.

**Nikanai formation:** Ahmad et al. (1987) used the name Nikanai Ghar to the massive dolomite and marble. The type section is designated in the Nikanai Ghar Mountain in southern Swat. Earlier the upper one-third of the marble and calcareous sequence was described by Martin et al. (1962) in their "Lower Swat-Buner Schistose Group."

DiPietro et al. (1999) described Nikanai Ghar formation as comprised of white to grey thick-bedded or massive, finely to coarsely crystalline marble and dolomitic marble. The sequence also includes thin beds of calcareous schist, schistose marble and calcareous quartzite. The age of the Nikanai Ghar formation, according to DiPietro et al. (1999) is Late Triassic based on the underlying Kashala formation, which is Late Triassic and also on the presence of palaeoniscoid fish teeth.

*Allai-Kohistan Area*

**Banna and Landai formations:** The Banna formation was named by Tahirkheli (1979a), to the upper division of his Besham group, exposed along the east side of the Indus syntaxis in the Allai-Kohistan area. DiPietro et al. (1999) used this name and defined it as follows: "The Banna formation is exposed in a small syncline with Indus melange is on the north side, Mansehra augen gneiss and Landai formation are on the west side, and a thin layer of garnet schist and feldspathic quartzite, mapped as the Tanawal Formation, is on the south side. They further added that the eastern extension of the formation is uncertain. According to DiPietro et al. (1999) the Banna formation consists entirely of graphitic schist and phyllite with interlayered calcite marble that is typically dark grey and varies from massive to well foliated.

**Landai formation:** DiPietro et al. (1999) named and described Landai formation for a small lens of rocks that is between the Mansehra augen granite gneiss, the Indus melange, and the Banna formation. Lithologically "the Landai formation consists of amphibolite, garnetiferous schistose marble, and white to light grey calcite marble, according to DiPietro et al. none of these beds are present in the Banna formation. Graphitic schist, which characterizes the Banna formation, is largely absent in the Landai formation.

The nature of the contacts surrounding the Banna and Landai formations is uncertain and calls for long discussion;" DiPietro et al. (1999) concluded "the map pattern is constant with the possibility that both formations are bounded by faults. The absence of brittle fabrics along the contacts suggests that the faults (if present) are synmetamorphic, imbricates associated with the obduction and thrusting of the Indus melange" and added that the "Banna formation is lithologically similar to the Karora formation and also to the Saidu formation. It has been correlated with the Salkhala Formation, implying a Precambrian age (Ashraf et al., 1980), and with the Alpurai group, implying a late Palaeozoic-Mesozoic age (Treloar et al., 1989c). The position of the Banna formation below the Indus melange as well as the absence of mafic intrusions in it favours a correlation with the Triassic or younger Saidu formation". The Landai formation is lithologically similar to the Kashala and "Duma formations", suggesting a late Palaeozoic-Triassic age.

## Hindukush-Karakoram Tectonostratigraphic Basin

### *Northern Sedimentary Province*

**Borom formation:** The Borom formation has been named and described by Gaetani et al. (1990) from the Chapursan Valley in Upper Hunza Valley. The formation is composed of well-bedded, platy, dark limestone with ribbons of black cherts. Graded fined grained carbonate sediments are interbedded in this anoxic sequence fed from reworked shallow water carbonate and accumulation along slopes of pelagic debris which includes bivalves, ostracods and radiolarian etc., the formation is fossiliferous. Some of the important among other fossils are *Neospathodus homeri* (Bender) an index for the Late Scythian, *Gondolella regale* (Mosher) of Early Anisian, *Metapolygnathus diebeli and G. foliata inclinata* and *Daonella indica* of Ladinian age. The age of Borom formation ranges from later Scythian to Ladinian.

**Chikchi-ri shale:** Desio (1963) renamed and described this formation after the range running along the north side of the upper Shaksgam Valley between Karakoram and Aghile Main ranges. Chikchi-ri shale consists of black brown, green and also red, sometimes more or less arenaceous shales, greenschists and with thin, grey or black limestone intercalations. The limestone is fossiliferous and contains *Heterastridium;* Chikchi-ri shale is overlain by Urdok conglomerate and is resting above the Kyagar formation of grey, cherty, thin bedded limestone of earliest Triassic or on Shaksgam brown limestone and shale of upper Permian age. The formation is two hundred to five hundred metres thick. The age of the formation according to Desio (1979) is Late Triassic.

**Urdok conglomerate:** Desio (1963) named and described Urdok conglomerate after the name of a glacier flowing down from the main Karakoram watershed to the Shaksgam Valley. The formation consists of polychromous conglomerate composed mainly of grey, white and black limestone pebbles cemented by marly more or less arenaceous red matrix. The clasts are mainly rounded with a few of angular shape. The conglomerate some times, may pass into a calcareous breccia, chert nodules are also present. The Urdok formation at places forms the base of Aghile formation in a lenticular shape. At other places it is associated with red shale. The Urdok formation lies over different formation, but more commonly on the rocks of Triassic age. The thickness of the formation ranges from a few meters to about five hundred metres. The age of the Urdok conglomerate is stated to be Late Triassic, Desio (1979).

Gaetani et al. (1990) noted some sandstone clasts in the conglomerate beds to be similar to Marpo formation and also some clasts of foliated gneisses of K2 as well as some of Sarpo lago formation of presumably Jurassic age and on the basis of this finding they considered the age of Urdok conglomerate as Cretaceous. Since at some places the Urdok conglomerate locally substitute the Chikchi-ri shale and thus on this stratigraphic basis the age of the Urdok conglomerate is considered by Desio (1936, 1979) as Late Triassic. The Urdok conglomerate is about 500 m thick at the most.

## JURASSIC

The Jurassic System in Pakistan is mainly represented by the limestone, shale and sandstone with subordinate dolomitic and ferruginous beds. The close of the Triassic is marked by emergence in the Salt Range, Trans-Indus ranges and Hazard areas while a continuity of sedimentation has been recognized in the Axial Belt (Hunting Survey Corporation 1961; Sokolov and Shah, 1965). Fatmi (1977) summarized the Jurassic set up of Indus basin, Axial Belt and according to him the Lower Jurassic rocks in the upper Indus Basin rest with a disconformity either on the Upper Triassic (Kingriali Formation) as in the Salt Range and Trans-Indus ranges, or on older rocks as seen in parts of Hazara. The lower part of the Lower Jurassic (Datta Formation) consists of arenaceous and argillaceous sediments of dominantly continental origin that grade upwards in the sequence of marine calcareous and argillaceous rocks with a lower Toarcian (Lower Jurassic) fauna i.e. (Shinawari Formation). Thus, the marine transgression in the Kohat-Potwar Province seems to have taken place in late Early Jurassic time as contrasted to the Axial Belt where there is no conclusive evidence of any break at the Triassic-Jurassic boundary and the sediments are mainly marine limestone and shale. The Axial Belt region, therefore, offers a more complete marine Early Jurassic sequence.

By Middle Jurassic, marine conditions were well-established in most of the areas and mainly carbonate rocks were deposited. The close of the Middle Jurassic is marked by regressive facies in the Kohat-Potwar Province, where Late Jurassic arenaceous, argillaceous and glauconitic sediments (lower part of Chichali Formation) rest with a disconformity either on the middle Callovian (Trans-Indus ranges) or on lower Callovian-upper Bathonian beds (Kohat, Kala Chitta and Hazara). The Jurassic in the Axial Belt and Lower Indus Basin is represented by a great thickness (several thousand metres) of marine limestone and shale with subordinate sandstone interbeds in the lower part. The Samana Suk Limestone is micritic oolitic, pisolitic, pelitic, shelly and reefoid. It is thin bedded in the lower and upper parts, but massive and thick bedded in the middle part. The colour varies from black and dark grey to light grey.

Cephalopods have been reported mainly from the upper and lower levels while other fossils such as radiolarians, foraminifers, corals, brachiopods, bivalves, gastropods, crinoids and algae are distributed in different parts of the Jurassic sequence. The rocks were deposited mainly in shallow marine environment, but towards the close of the Early Jurassic (Bajocian) the Axial Belt became tectonically active and temporary emergence during Middle Jurassic has been inferred. The close of the Callovian (the youngest being lower Callovian in the area) marked a widespread withdrawal of the sea from the whole of the Indus Basin. The area was submerged again in Late Jurassic to Early Cretaceous times. The evidence from the Lower Indus Basin of Late Jurassic faunas, from the disconformably overlying Sembar formation, Goru formation of mainly Early Cretaceous age, is scanty but it seems that a major transgression after the Callovian emergence took place probably during Tithonian times in the Lower Indus Basin and in upper Oxfordian in the Upper Indus Basin. Marine sedimentation continued during the Early Cretaceous and thus the Jurassic / Cretaceous boundary like that of the Kohat-Potwar Province, is regarded as transitional in parts of the Lower Indus Basin (Fatmi's view 1977).

In the Axial Belt this regressive phase is not well defined and studied, but there is evidence from some parts of a post-Callovian (Mazar-e-Dirk), pre-Callovian (Nakus) and post-Bajocian disconformities (Fatmi's view 1977). Thus in the Axial Belt region, the Upper Jurassic to Lower Cretaceous marine rocks (Sembar or Goru formations) rest with a disconformity on Early to Middle Jurassic sediments. Hunting Survey Corporation (1961) however, considers in some areas of Balochistan that no evidence of a break within the Jurassic or at the Jurassic Cretaceous boundary exists. The thickness of Jurassic sequences varies from 820 m in the Kohat-Potwar Province to over 3000 m in the Lower Indus Basin and the Axial Belt.

Jurassic rocks of Lower Indus Basin and Axial Belt are widely distributed in the Axial Belt, and Sulaiman and Kirthar Provinces of the Lower Indus Basin. Many prominent ranges and high peaks of (Chiltan, Takatu, etc.) are formed by Jurassic rocks. These prominent hills are located in the vicinity of Khuzdar, Karkh, Zahri Basin, Johan, Mazar Drik, Quetta, Ziarat, Mekhtar and Dhanasar, where they occupy the resistant cores of the anticlines. In contrast to the Kohat-Potwar Province, a more complete marine Jurassic sequence is developed in the Lower Indus Basin. The Triassic rocks, which are mainly exposed in the Axial Belt region transitionally underlie Jurassic strata and the change is so gradual that the boundary of the two systems has not been clearly defined. Williams (1959) and Hunting Survey Corporation (1961) have described a change from a dominant shale lithology of the Triassic System to thin bedded limestone and intercalated shale of the early part of the Jurassic System.

**Indus Basin**

*UPPER INDUS BASIN (KOHAT-POTWAR PROVINCE)*

The Jurassic System of the Upper Indus Basin is represented by Datta Formation (Early Jurassic), Shinawari Formation (Early to Middle Jurassic), Samana Suk Formation (Middle Jurassic) and the lower part or whole (in parts of Hazara) of the Chichali Formation. In northern Hazara, even the lower part of the mainly Lower Cretaceous Lumshiwal Formation is Late Jurassic in age. The Chichali and Lumshiwal Formations are dealt with under the Cretaceous System. An intra-Jurassic disconformity between the Samana Suk Formation and the overlying Chichali Formation is recognized in all these sections. The Late Jurassic and Early Cretaceous boundary is transitional in most of these sections (Fatmi, 1977)

**Surghar group:** The name Surghar Group was proposed by Shah (1980) for the Jurassic and Cretaceous formations exposed in the Surghar Range and Salt Range. A total of 5 formations were included in the group. They represent mixed environmental conditions starting from the continental deposits at the base, passing through marine environment and ending at the continental deposits at the top.

Thus, sedimentary rock sequence ranging from Liassic to Aptian was assembled together in a proposed Surghar Group. The sequence in the salt Range is comprised mostly of continental facies with shallow marine conditions in the middle of the group. Marine transgression invaded the Salt Range in Bajocian and continued through Valangenian. The group is well developed in the Surghar Range but gradually thins towards east. Consequently it is mostly absent in the Central Salt Range and completely missing in the Eastern Salt Range.

Most of the formations, included in this group have their type sections in the Surghar Range, giving justification for the proposed name as well as a place for the principal reference section. The formations assembled by Shah (1980) in the Surghar group are as follows (No.1 formation is the oldest).

5. Lumshiwal Formation
4. Chichali Formation
3. Samana Suk Formation
2. Shinawari Formation
1. Datta Formation.

Principal reference section is suggested at Datta Nala, (Lat. 33° 00' N: Long. 71° 10' E), District Mianwali, Punjab, Pakistan. The thickness of the group in Surghar Range ranges from 900 to 931 m and the age from Jurassic to Early Cretaceous (Shah, 1980).

Fatmi et al. (1986) divided Surghar group into lower Broach group and retained the upper part as Surghar group with type section of the Broach group in the Broach Nala, Surghar Range. The **Broach group** consists of three formations. Datta Formation is the oldest, which is predominantly a continental rock assemblage. It is composed of multi-coloured shale, sandstone, siltstone and minor dolomite. Shinawari Formation of Trans Indus ranges represent transitional beds between Datta Formation and Samana Suk Formation. It comprises sandstone, marble and limestone. The third formation is Samana Suk Formation of shallow marine origin. The top most surface of Samana Suk Formation is marked by small hollows or pits; they resemble features like animal boring and probably indicate a small break. Chichali Formation consists of ferruginous, glauconitic sandstone and shale and the Lumshiwal Formation is mostly a unit of continental facies. It is composed of sandstone and siltstone with carbonaceous material.

The Broach group starts with disconformity at the base of Datta Formation and at the top of Samana Suk Formation. As already pointed out, the top bed of the Samana Suk Formation indicates small cavities and pits, suggesting a probable small break in sedimentation. However, according to Shah (1980) both the Samana Suk and Chichali Formations broadly represent continuity in the marine deposition.

**Datta Formation:** The name Datta Formation was introduced by Danilchik (1961) and Danilchik and Shah, (1967) to replace the name "Variegated stage of Gee, (1945) and earlier workers. The formation is best developed in the Trans-Indus ranges and Salt Range. The name is adopted for similar rocks in parts of Kohat (the lower part of oldest "Samana beds" of Davies 91930) Kala Chitta and Hazara ("Red beds and part of Kioto Limestone" of Middlemiss 1896; lower part of "Maira formation" of Davies and Gardezi (1965). The type section is located in Datta Nala (lat. 33° 00' N: long. 71° 19' E) in the Surghar Range. According to Fatmi (1977) the formation is mainly of continental origin and consists of variegated red, maroon, grey, green and white sandstone, shale, siltstone and mudstone with irregularly distributed calcareous, dolomitic, carbonaceous, ferruginous glass sand and fireclay horizons. The fireclay is normally present in the lower part while the upper part includes a thick bed (4 to 7 m) of maroon shale easily recognizable in Salt Range and Trans-Indus ranges. Here it differs from type section (Surghar Range) in having much less shale or mudstone and more arenaceous beds. Excellent exposures of Datta Formation can be seen in Samana Range while going towards Samana Fort. (M. Mujtaba of HDIP, verbal communication, 2005). Here, according to him the Datta Formation is mostly quartzitic, it is thicker than that at Shamshuddin Village and sitting on Precambrian or Palaeozoic rocks.

According to Fatmi (1977), however, the formation extends as a tongue in Kala Chitta, Hazara and parts of Kohat area where it is represented by 7 to 10 m of mottled quartzose sandstone ferruginous (haematitic) sandstone and fireclay. In Hazara the basal beds are brownish calcareous grits. The Datta Formation is widely developed in, the western part of the Salt Range (west of Jhallar Lake) and in the Trans-Indus ranges (Surghar, Shinghar, Sheikh Badin Hill and western Khisor Range). The thickness in the type locality is 212 m but increases to 230 m in Punnu Nala to the west and over 400 m in the Sheikh Badin Hills. In the southwestern end of Khisor Range the thickness is reduced to 150 m. In the main Salt Range, it is 150 m in Nammal Gorge and decreases further east. In Hazara the thickness ranges from 0-10 m (10 m in the Bagnotar section). In Kala Chitta (Chak Dalla section) the thickness is 6 m. The Kala Chitta lithology persists in faulted outcrops further west in

Mazari Tang and parts of the eastern Kohat Tribal Belt. In western Samana Range it is 272 m near Shamshuddin Village.

The formation has disconformable lower contact throughout its distribution.It rests unconformably on the Kingriali Formation in the Salt Range, Trans-Indus ranges, Kala Chitta and eastern Kohat. In Hazara the formation unconformably overlies doubtful Precambrian (Hazara Formation), Palaeozoic and Triassic rock and is not developed in some parts of Hazara (e.g. Kalapani section). The upper contact with the Shinawari Formation is gradational. No diagnostic fossils have been reported from the formation except some carbonaceous remains. As the formation underlies the Shinawari Formation, which in its lower part has yielded lower Toarcian ammonites, age is inferred as Early Jurassic, mainly pre-Toarcian.

**Shinawari Formation:** The term Shinawari Formation was introduced by Stratigraphic Committee of Pakistan (1964), (on a verbal communication of Fatmi and Khan, 1966) after the village of this name in the western part of Samana Range, Kohat district. The name is adopted for the "Lowest Samana beds" of Davies (1930). "Lower part of Kioto Limestone" of Cotter (1933), part of "Red Clay Zone" of some oil company geologists (unpublished) upper part of "Maira formation" of Davies and Gardezi (1965) "upper transitional beds" of Datta Formation of Danilchik and Shah (1967) and upper part of Datta Formation of Fatmi (1968, 1972) "Wazirwal member" of Datta Formation of Fatmi and Cheema (1972).

Fatmi (1977) described the formation from the type locality as consists of thin to well bed limestone with nodular marl calcareous and non-calcareous shale and quartzose, ferruginous and calcareous sandstone. The limestone is grey, brownish grey fine to coarse texture and includes sandy, oolitic and ferruginous beds. The shale is grey, dark grey, brownish grey splintery, calcareous and non-calcareous. The sandstone is both quartzose and ferruginous and calcareous. It is white to light grey, brown, reddish brown and occurs in thin and thick beds. Sedimentary structures such as current bedding and ripple marks etc. are present in layers. In the principal reference section the lithology consists of a lower part of mainly limestone (with Bouleiceras) with a thick sandstone bed in the middle part of the-unit followed by maroon shale. The upper most part consists of variegated shale sandstone and siltstone.

According to Fatmi (1977), "In the areas Kala-Chitta, eastern Kohat and parts of Hazara a two fold division are recognizable. The lower part is limestone and marl (with Bouleiceras) with dolomitic beds locally developed as in Hazara. The upper part is red shale and clay with intercalated marl and shelly thin bedded limestone." Its presence in Hazara is questionable as per most recent work in this area (Mujtaba of H.D.I.P. verbal communication, 2005), he also said that this formation is a transitional zone between Datta and Samana Suk Formations and is absent in subsurface in most of Indus Basin drill holes. The formation is widely developed in the Kohat, Kala Chitta, Hazara, Trans-Indus ranges and the Salt Range. It is over 400 m thick (base faulted) in the type area, 80 m in the principal reference section of Sheikh Budin Hill, 35 m in Bhoje Nala and 30 m in Broach Nala sections of Surghar Range, 12 m in Chak Dalla section of Kala Chitta Range and 25 m in Bagnotar section of Hazara. The formation has a transitional contact with the underlying Datta Formation and overlying Samana Suk Formation.

From the lower part of the formation in Hazara (Bagnotar) and Kala Chitta (Chak Dalla) Bouleiceras is reported, in addition to Bouleiceras, Latif (1970) recorded *Terebratula, Montlivaltia, Pholadomya, Zeilleria and Eotrapezium.* In Kala Chitta *Spiriferina* sp., *Velata velata, Pecten* sp., *Lima (Plagiostoma)* gigantce, corals and gastropods are reported. In the Marwat Range (Sheikh Budin Hill) and Khisor Range Bouleiceras sp. bivalves, brachiopods, etc. have been recorded (Fatmi and Cheema, 1972) from the lower part. The fauna from lower part indicates an Early Jurassic (Toarcian) age, but the upper age may extend into Middle Jurassic. Fatmi et al. (1990) discovered Bouleiceras in the Surghar Range, which completes a picture of its distribution in all the marine sections of the Lower Toarcian in Pakistan (Indus Basin) right from Karachi (Gadani area) across the Axial Belt of Balochistan to the north. It further provides proof of a major marine transgression during Early Toarcian throughout Pakistan, though the sections in Axial Belt region of Balochistan, Waziristan and part of Kohat have a deeper marine Pre-Toarcian Jurassic sequence.

**Samana Suk Formation:** Davies (1930) introduced the name "Samana", "Suk" for the Jurassic limestone in Samana Range. The name is extended to include similar limestone sequence in the Salt Range and Trans-Indus ranges ("Broach limestone" of Gee, 1945), Kala Chitta (upper part of "Kioto limestone" of Cotter, 1933) and Hazara ("Kioto Limestone" of Middlemiss, 1896; "Daulatmar limestone" of Calkins and Matin, 1968; "Sikhar limestone" of Latif, 1970a). Davies did not indicate type locality. The name Samana Suk is derived from a mountain-peak of the same name in the Samana Range (Lat. 33° 33' 50" N: Long. 70° 50' 13" E). Fatmi (1968) designated a section northeast of Shinawari (Lat. 33° 31' 13" N: Long. 70° 48' 06" E) in the western part of the Samana Range as the type locality. Lithologically, as described by Fatmi (1977) in the type locality the formation consists of grey to dark grey, medium to thick-bedded limestone with subordinate marl and calcareous shale intercalations. The limestone is oolitic and has some shelly beds. In the Salt Range and Trans-Indus ranges (Surghar Range, Sheikh Budin Hill) the limestone is lighter in colour, medium to thin- bedded and is marly and shaly in the lower part.

In Hazara, Kala Chitta and eastern Kohat it is thin to thick-bedded and includes some dolomitic and ferruginous, sandy, oolitic beds. In parts of the Kohat Tribal Belt (Kohat Pass section) dolomite and dolomitic limestone with chert form the upper part of the formation where they constitute a distinct member. The formation is widely distributed in the western Salt Range, the Trans-Indus ranges, Kohat, Kala Chitta and Hazara. In the type locality the thickness is 186 m. It is 170 m further southeast in the Darsamand section but thickness eastward in eastern Kohat, Nizampur, Kala Chitta and Hazara where the thickness varies from 190 m (Chak Dalla section) to 366 m (Bagnotar section). It thins out in the eastern Surghar Range (66.5 m in Chichali Pass section) and western Salt Range and is absent from the eastern Salt Range. In Broach Nala of the Surghar Range the thickness is 129 to 136 m and from the Sheikh Budin Hill over 242 m of the limestone is recorded (Krishnan, 1960). The lower contact is transitional with the Shinawari Formation and is placed at the top of the last sandstone unit of the Shinawari Formation. The upper contact with the Chichali Formation is disconformable.

From the uppermost beds a middle Callovian fauna has been recorded in the Surghar Range (Fatmi, 1968, 1972). It consists of brachiopods, bivalves, gastropods, ammonoids and crinoids. The ammonoids include *Reineckeia (R).*, sp., *including R. (R), ancepts, Choffatia sp. (C. aff. cobra), Obtusicostites spp., Obuckmani, Hubertoceras* sp., indet and *Kinkeliniceras* sp. Among the brachiopods *Somalirhynchia nobelis* is quite abundant. The bivalves include *Homomya sp., Pecten sp., Arctostrea sp.* and *Tellurimya tellaris.* From the Samana Range *Belemnopsis grantana* is recorded (Fatmi 1968, 1972) from the upper part of the formation. In Kala Chitta (Jhallar and Chak Dalla sections) the uppermost beds have yielded bivalves including *Protocardia grandidieri, Eomiodon indicus* and *Corbula lyrata.* From northern Hazara the gastropod Cossmania sp. is reported (Calkins and Marin, 1968). Latif (1970a) recorded the following additional fauna from different parts of Hazara: *Stylina* sp., *Corbula* sp., *Eomiodon* sp., *Gervillea* sp. *Lima* sp., *Lucina* sp., *Nucula* sp., *Nerinen* sp., *Protocardia* sp, *pygurus* sp. This fauna indicates that the age in all areas is essentially Middle Jurassic. The upper age limit, however, is middle Callovian in, the Salt Range and Trans-Indus ranges, slightly older than Callovian in Kohat, upper Bathonian in Kala Chitta and possibly younger in Hazara (Latif, 1970a).

Vertebrate fossils have never been reported from Samana Suk Formation but in July 1987 news flashed in the "Hydrocarbon News" in a Quarterly House Journal of Hydrocarbon Development institute of Pakistan indicating "First Dinosaur Footprints Found in Pakistan". According to the news "a team of four geologists, namely, Muzzafar Kamran and Saleem Mahmood of Hydrocarbon Development Institute of Pakistan, Dr. H. Porth and Dr. W. Weiss of BGR, a West German research institute, in the course of their oil geological reconnaissance work in Surghar Range in April, 1986." It added "at least four different kinds, the footprints are partly in the form of long tracks on bedding planes in the topmost part of Samana Suk Formation which now lies exposed extensively in Baroch Nala near Kalabagh in Mianwali District. The Samana Suk Limestone is here fine grained, partly clayey or sandy. It was deposited in a very shallow marine coastal environment. The age of Samana Suk Formation is described as Middle Jurassic, 160-170 Ma years old. The dinosaurs which lived in the area probably belong to the groups of Saurischians and Ornithischians" The formation is correlated with the Takatu Limestone and Mazar Drik Member of Takatu Formation of Lower Indus Basin and Axial Belt.

## BALOCHISTAN BASIN

### *Southern Balochistan (Windar-Lasbela-Khuzdar-Anjira Areas)*

**Ferozabad Group:** The name Ferozabad Group was introduced by Fatmi et al. (1990). This name is derived after Ferozabad Village, 13 km west of Khuzdar. This group includes the following three formations in ascending order.

| | | |
|---|---|---|
| 3. | Anjira Formation | Early to Middle Jurassic |
| 2. | Malikhore Formation/Shirinab Formation | Early Jurassic |
| 1. | Kharrari Formation | Triassic to Early Jurassic |

**Kharrari Formation:** The name Kharrari Formation was introduced by Fatmi et al. (1990). It is composed of a mixed clastic carbonate facies which was included previously in "Windar group" and "Zidi formation" by Hunting Survey Corporation (1961). This name was derived from Kharrari Nai (Mor Range, 35K/16) in Windar area that drains Uthal Territory.

Anwar et al. (1991) studied the formation in detail. According to them the formation consists of limestone, dolomite, sandstone, siltstone and shale in the type locality. The sandstone is grey, light grey, purplish brown, weathering brownish grey, thin to medium bedded, fine to medium grained, well-sorted, quartzose, micaceous, gritty, cross-bedded, fragmentary and friable. The limestone is grey to brownish grey, weathering brown, laminated to thin bedded, flaggy, micritic and unfossiliferous. The siltstone is greenish grey to brownish grey and weathering brown. The shale is black to greenish grey, weathering brownish grey, sandy, soft flaky to hard fissile and platy. It is micaceous and silty at places.

Anwar et al. (1991) mapped the formation only in axial belt where northwards in the Khuzdar area the limestone with minor shale intercalations is common in the lower part; sandstone and limestone interbeds in middle part and limestone with sandstone and mart/shale intercalations in upper part. At places the limestone is palatal, silty, argillaceous, mottled, biosparitic and fragmentary in upper part. Coquina beds are common. In its contact relations, the base of the formation is not exposed. Its thickness in the type locality is more than 464 m, it is more than 248 m thick in the Ferozabad section and 824 m in the Lukh Rud Section. Its contact with the overlying Malikhore Formation is transitional. Based on the fossil content and stratigraphic position, the age of the Kharrari Formation is stated as mainly of Early Jurassic, but may extend into the Triassic.

**Malikhore Formation:** The name Malikhore Formation approved by the Stratigraphy Committee of Pakistan was introduced by Fatmi et al. (1990) to distinguish massive to thick-bedded middle carbonate unit of Windar group and "Zidi formation" of Hunting Survey Corporation (1961). This name is derived after the village of Malikhore (35 I/9), 27 km west-northwest of Khuzdar.

According to Anwar et al. (1991) the formation in the type locality is mainly composed of thick-bedded limestone with subordinate calcareous shale/marl as thin partings. The limestone is grey to greyish brown, weathering brown, thick bedded to massive, biomicritic, hard, palatal, oolitic, coquinoidal and shelly with frequent bioturbated mottled beds. The shale is dark grey to greenish grey and calcareous. In the Kharrari Nai and Lukh Rud sections, the shale is black, fissile and carbonaceous. The formation is highly resistant which forms steep slopes or cliffs. It is widely distributed throughout southern Balochistan and is 387 m thick in the type locality, 204 m in the Kharrari section and 136 m in the Lukh Rud section. Its contacts with the underlying Kharrari Formation and overlying Anjira Formation are transitional. The age is considered to be Early Jurassic. No cephalopods have been reported from the formation except abundant fragmentary gastropods, bivalves *(Pecten, Weyla, Gervillea)*, crinoids *(Isocrinus)*, brachiopods *(Spiriferina* sp.), corals, etc. from different levels. The age is considered to be Early Jurassic.

**Anjira Formation:** Earlier known Anjira Member of Shirinab Formation has recently been raised to the rank of formation by Fatmi et al. (1990). The name Anjira Formation as described here is the uppermost formation of the Ferozabad Group. Originally this name was introduced by Williams (1959) who derived it from the Anjira Village (34 L/7) with type locality, 12 km east of Anjira (Anwar et al., 1991).

According to Anwar et al. (op. cit.) the formation consists of thin to thick-bedded limestone interbedded locally with partings of marl and calcareous shale. The limestone is grey to dark grey, weathers brownish grey, and is lithographic and fossiliferous. It is marly, shelly, mottled and muddy at places. The marl is grey to greenish grey, weathers brownish grey, soft, flaggy and nodular; the shale is creamy grey and soft. The formation is extended to central Balochistan (Kalat-Quetta region) having almost same lithology except that the limestone is very thick bedded palatal, hard, fractured biosparitic and Shelley and contains cheat nodules and shall fragment at places. This lithology of Anjira Formation was earlier mapped as lower part of 'Chiltan limestone' by Hunting Survey Corporation (1961). It is now included in the Anjira Formation. In the southern exposures of Anjira Formation a mineralized zone occurs stratigraphically below the highest Early Jurassic (Upper Toarcian) and the lower part of Middle Jurassic (Lower Bajocian) strata in the Gunga section near Khuzdar, where the formation consists of marl and marly limestone with green shale intercalations and contains ammonites and other fossils.

The formation is distributed widely in the southern Balochistan. It is 110 m thick at the type locality, 168 m in the Goru section, 312 m in the Ferozabad section, 100 m in the Lukh Rud section and 352 m in the Kharrari section. The lower contact with the Malikhore Formation is transitional. The upper contact with the Sembar Formation is disconformable in all measured sections except in the type locality, where it is overlain disconformably by the Goru Formation. Laterite is developed at this contact. In the central Balochistan the formation is 135 m in Gurruk-Ziarat section and 225 m in Baleli section. Both the contacts lower and upper are conformable with Kharrari Formation and Chiltan Limestone respectively.

The fossils picked up from the Anjira section include *Trigonia sp., Spiriferina sp., Terebratula sp., gastropods, Polyplectus sp., Bouleiceras nitescens; Bouleiceras cf. arabicum, fuciniceras sp., Tachylytoceras sp., Grammoceras, protogrammoceras, Hammatoceras sp., Phylsiogrammoceras sp. Aff., Dispansum* (upper Toarcian) and *Dumorlieceras menaghini. Protogrammoceras sp.,* (lower Toarcian), *Hammatoceras sp.* (upper Toarcian) and *Nanolytoceras* (Bajocian) were collected from the Gunga section. The fauna found from the lower part of the formation from the Ferozabad section were brachiopods, *(Spiriferina, Terebratula),* corals (Montlivaltia sp.) and other molluscan including lower Toarcian ammonoids and nautiloids *(Bouleiceras, Protogrammoceras, Dactylioceratids, Cenoceras,* etc.) Anwar et al. (1991).

**Shirinab Formation:** The name Shirinab Formation was introduced by Hunting Survey Corporation (1961) for the oldest rocks in central Balochistan from Shirinab River that drains the Chapper, Mangochar and Shirinab valleys, and northwest of Kalat. The formation has been described by Fatmi et al. (1990) and Anwar et al. (1993) as follows:

"The formation consists of limestone with subordinate marl and shale. The limestone is light grey to dark grey, ash grey, weathers rusty brown to brownish grey, thin to thick bedded, mottled, sub lithographic, micritic to biomicritic with shelly, oolitic, pelitic and pisolitic interbeds. It is also crinoidal, platy, flaggy, dolomitised and argillaceous at places. Coquina beds are common. The marl is greenish grey and nodular. The shale dominate in the upper part, is buff, maroon, greenish grey to brown, calcareous and ranges from soft flaky to hard fissile".

The base of the formation is not exposed. Its thickness is more than 1000 m in the Kalat section, and 230 m was measured (base not exposed) in the Gurruk-Ziarat section. Its contact with the overlying Malikhore Formation is transitional. The age of the formation is Pre-Toarcian. Hunting Survey Corporation (1961) and Vredenburg (1909) reported the presence of Permian fossils in the Shirinab Formation, 11 km southwest of Sar Jangal and 3 km west of Shahr Haji in the Surab-Kalat areas, respectively, but later workers were unable to locate any Permian outcrops during their visit to the area. The present studies indicate that a dark grey, crinoidal, medium to thick bedded limestone is underlain by medium-bedded limestone with marl intercalations containing spiriferinids terebratulids and cephalopods including Harpoceratids of Early Jurassic age, 3km west of Shahr Haji. The fossils collected from the Gurruk-Ziarat section include Rhynchonella sp., *Terebratula* sp., *Spiriferina* sp. and bryozoans. From Sar Jangal area, middle Liassic ammonite *Oxynoticeras* has been collected. But keeping in view the enormous thickness of the formation, it is believed that it may extend into the Triassic. This has been the latest version of the Shirinab Formation by Fatmi et al. (op cit) and Anwar et al. (1993).

Earlier, in 1977, Fatmi had described the same Shirinab Formation with Loralai, Spingwar and Anjira as "Members". Now, in this current Memoir these 'Members' have been given the status of formations.

## NORTHERN BALOCHISTAN (GWAL-WULGAI-ALOZAI-MARA KILI AREAS)

**Alozai group:** The name Alozai group introduced by the Hunting Survey Corporation (1961) is reintroduced and modified the difination of the formation by Fatmi et al. (1990) in northern Balochistan. This name is derived from the village Alozai (29 B/10) in the Zhob Valley. The rocks belonging to this group are widely exposed in a long strip in the northern Balochistan between Loralai and Zhob Valley. This group is recognizable close to Quetta-Ziarat Road section. It is, however, proposed by Fatmi et al. (1990) that the undifferentiated Alozai Group should include the following formations:

| | |
|---|---|
| Loralai Formation | Early to Middle Jurassic |
| Spingwar Formation | Early Jurassic to Upper Triassic |

The stratigraphic studies of the Alozai group were carried out in four different sections, i. e. Gwal, Wulgai Nala, Zamari Tangi and Mara Tangi. A normal sequence of rocks from Early Jurassic to Early Cretaceous age is exposed in the Zamari Tangi and Mara Tangi sections.

**Spingwar Formation:** The name Spingwar Formation was introduced by Williams (1959).

It was included in the Shirinab Formation as member. Recently Fatmi et al. (1990) included it in the newly formed Alozai group. It consists of interbedded dark grey to black limestone and calcareous shales. The limestone is dark grey to black finely crystalline, but in some areas, oolitic and shelly beds occur in the upper part, while sandstone interbeds are present in the lower part.

The formation according to Anwar et al. (1991) can be divided in to lower and upper parts. The lower part mainly consists of micritic limestone with occasional dark shale and very pale orange marl beds. The upper part consists of greenish grey, soft-weathering marl and shale with subordinate limestone and calcareous sandstone. The limestone is dark grey, thin-bedded and marly. The thickness of the formation is more than 665 m in the Zamari Tangi section, 215 m in the Mara Tangi section and 140 m in the Tazi Kach section. It is underlain transitionally by the Wulgai Formation of Triassic age and is overlain by the Loralai Formation of Early to Middle Jurassic age. Its age is considered to be Early Jurassic on the basis of fossils and its stratigraphic position. The fossils include ammonites, brachiopods, bivalves, crinoids, corals and shell fragments.

**Loralai Formation:** The name Loralai Formation was introduced by Hunting Survey Corporation (1961) after the town of Loralai. Zamari Tangi, is proposed as type locality. Loralai Formation consists mainly of well-bedded limestone with shale and marl interbeds in the lower part. The limestone is dark grey to black, weathers brownish grey, thin-to thick-bedded, hard, argillaceous, fine grained, and sub-lithographic and breaks with conchoidal fracture. Chert lenses are developed along the bedding planes. In the upper part, it contains oolitic, pisolitic and palatal beds at places. The shale is black, grey, splintery, papery and calcareous. The marl is greenish grey and soft.

In many localities the formation can be divided into the lower and upper members. The lower member consists of dark grey, micritic and argillaceous limestone interbedded with shale and/or marl. Some beds are mottled and contain Toarcian ammonites. The shale is abundant in this part. The upper member is mainly thin to thick-bedded, micritic limestone with minor shale/marl as thin partings. The limestone is oolitic and pelitic at places. As the Loralai Formation is more resistant and harder than the Alozai group and Sembar formation, it forms prominent ridges in the area. The thickness of the formation is 250 m in the Zamari Tangi section, 360 m in the Mara Tangi section and 150 m in the Tazi Kach section (Khanozai area). Its lower contact with the Spingwar Formation is transitional and is placed at the base of the main limestone unit, above the uppermost thick beds of greenish grey marl/shale whereas its upper contact with the Sembar formation is sharp and disconformable.

The Loralai Formation is rich in radiolaria. The age assigned by Williams (1959) and Woodward (1959) is Early Jurassic but Hunting Survey Corporation (1961) and Japanese-Pakistani Research Group (1989) have recorded Toarcian fossils from the lower part of it. During present field investigations, some Toarcian ammonites were collected from this part in the Loralai area (*Nejdia* sp. and *Protogrammoceras* sp. from the Khulgai Ali Khel section and *Phymatoceras* sp. from the Mara Tangi section). Some poorly preserved ammonites were also found from the upper part of the Loralai Formation of the Zamari Tangi and Mara Tangi sections. The lower age limit is clearly late Liassic but the upper limit as considered by the authors may extend up to Bajocian (Middle Jurassic). Thin-bedded, radiolarian and micritic limestone suggests the low energy conditions. Its stratigraphic position is similar to that of the Anjira Formation in southern Balochistan (Anwar et al., 1991).

**Takatu Formation:** 'Takatu Limestone' was named by Williams (1959) for the youngest Jurassic formation in the Takatu Range near Quetta. The Stratigraphic Committee of Pakistan formalized this unit as the Takatu Formation with the Mazar Drik Member in its upper part. Earlier the Takatu Formation was called "Chiltan Limestone" of Hunting Survey Corporation (1961). Other names like 'Massive Limestone' of Vredenburg (1909), the 'Takatu Limestone' and uppermost formation of the 'Sulaiman Group' of Williams (1959) and Woodward (1959), have also been used. In Central Balochistan, the name Chiltan Formation is still in practice (Anwar et al., 1991). The type section is along Data Manda Nala, a small stream which passes throughout the entire formation in very deep narrow gorge and enters the plain about 3 km south of Bostan (Lat. 30° 20' N: Long. 67° 03' 39" E).

Lithologically, the Takatu Formation contains a wide variety of limestones; coarse-grained palatal, lumpy, skeletal and oolitic limestones comprise the bulk of the formation. Colour varies from dark to very light grey and brown to brownish grey. Beds are usually thick to very thick. Intraformational conglomerates have been found in the Takatu Range and in the vicinity of Morghi Nala. Although mappable as a single rock unit, and herein designated a formation, the Takatu Formation might be better described as a reef complex. The wide variety of lithologic types indicates deposition under diverse condition. Bioherms, which have been recognized, are located at Data Manda Nala, Spin Ghar, Gormai, Koh-I-Maran, Ailane Ghar and Ziarat Nala.

The bioherm of Dara Manda Nala is about 380 m thick, with an aerial extent of 12 km by 3 km. This massive mound shaped body, which forms the main mass of Takatu peak is devoid of bedding. This bioherm is composed largely of algal limestone with minor amounts of pellet skeletal limestone, which probably filled openings in the reef. The bioherms at Ziarat Nala are small, less than 65 m thick, and composed of algae, sponges and other unidentified skeletal material. Recrystallization of the limestone is common in these bioherms making recognition difficult.

**Mazar Drik Member:** Arkell (1956) introduced the name 'Mazar Drik limestone' for the “Polyphemus limestone” of Noetling (1895) and “Polyphemus beds” of Vredenburg (1909). The name is used here for a member, which includes interbedded shale and limestone lithology. In type area of Mazar Drik in the Mari hills, the member consists of interbedded grey limestone, dark shale and has an early Callovian fauna in the upper part. Late Bathonian ammonites have been recorded from the lower part by Arkell (1956). The upper contact of the Mazar Drik Member with the Sembar formation is disconformable. At Mazar Drik, its thickness is less than 30 m and thins to a few metres toward north in the Wam-Nakus area and to further north and northeast. The Mazar Drik Member is not developed in the Sulaiman Range. Vredenburg (1909) described it from the axis of the Moro Anticline, north of Narmuk in the Kirthar Province.

The Takatu Formation crops out in the northern fold belt near Quetta, forming high hills in the area and extends southwards up to the vicinity of Kalat. It is present in the Sulaiman Range and beneath the Mari-Bugti hills. The Takatu Formation is also encountered in the subsurface in Jandran well near Kohlu, Giandari well Jhatpat and Khairpur wells. The thickness of the Takatu Formation at the type section is 800 m and in between 600 and 980 m elsewhere. The massive, lithologically monotonous limestone present at Mughal Kot in the core of north-south running anticline is more than 1100 m thick. The Takatu Formation overlies the Shirinab Formation with a gradational contact. In some areas, the upper limestone is not developed and the Takatu Formation has a disconformable contact with the overlying Sembar formation.

With the exception of fossils from within the Mazar Drik Member, no identifiable fossils have been reported except poorly preserved fragmentary remains from the Takatu Formation. At Kasi Dera, fossils from this formation indicate an upper Toarcian to lower Bajocian age. They were collected from lower part, but because of faulting, the exact stratigraphic position is uncertain. Ammonites from Mazar Drik and also from parts of Moro area include *Macrocephalites, Dolikephalites, Indocephalites, Pleurocephalites, Indosphinctes* and *Choffatia.* Large *Indocephalites* were mistaken by Noetling (1895) for the similar *Epimayaites polyphemus* of late Oxfordian age which resulted in the misleading name "Polyphemus beds" for the unit. A similar fauna of *Macrocephalites* with *Paralcidia, Bomburites,* and *Choffatia* was described by Fatmi (1969) from the Wam Tangi-Nakus area, where these lower Callovian strata disconformably overlie the massive Takatu Formation. Arkell (1956) has recorded *Bullatimorphites bullatus* and *Clydoniceras* from a presumably lower level in the Mazar Drik Member, that indicate a late Bathonian age. The Mazar Drik Member, therefore, appears to be early Callovian to late Bathonian in age. Since the Mazar Drik Member contains late Bathonian fauna, the age of the Takatu Formation ranges from Toarcian to Bathonian. The Takatu Formation has not been found to underlay the rocks older than Cretaceous.

## AXIAL BELT

### *Kurram Agency area*

Jurassic rocks of Upper Indus Basin have their usual extension into the Axial Belt. This has been noted in the description of Datta, Shinawari and Samana Suk Formations. They are present in the western part of the Axial Belt. As for example in the area of the Axial Belt covering Kurram Agency, the same situation prevails but the change of facies is substantial and the units become little different from the Upper Indus and Balochistan basins. Following two units are described from this area, Sarobi and Isha formations.

**Sarobi formation:** The Sarobi formation is named and described by Ahmed et al. (2000). The formation comprising a sequence of alternating limestone and shale is exposed north of Sarobi Village where the type section is designated along Isha-Razmak road about 35 km southeast of Miran Shah Town. They stated that in the type locality, the lower part of the formation is predominately limestone, while the upper part is shale. The limestone is thin-bedded, in parts thick bedded, micritic and grey to dark grey weathering to brownish grey colour and yellowish brown colour respectively. The limestone is very hard and forms ridges. It is fine crystalline to fairly coarse-grained, with shelly, oolitic, pelitic, and pisolitic interbeds. The shale is flaky, slaty, splintery, papery and black on fresh surfaces and weathering to greenish grey, dark grey and brownish grey colours. The formation is 400 m thick at the type locality. The lower contact is terminated by thrust fault and the upper contact is gradational with Isha formation.

On the basis of lithology, stratigraphic position and fauna, it can be correlated with Spingwar and Loralai formations of the Early to Middle Jurassic age exposed in the axial Belt of Balochistan. The formation is fossiliferous and has yielded bivalves, crinoids, belemnites, gastropods, bryozoans and corals. Early to Middle Jurassic age is assigned to the formation by Ahmed et al. (2000).

**Isha formation:** Ahmed et al. (2000) introduced the name Isha formation for a limestone sequence well exposed at Isha Check Post, 8.5 km east of Miran Shah at the junction of Razmak-Miran Shah road along the Mirali-Miran Shah road. The type locality has been designated around Lat. 32° 58' 14" N: Long. 70° 06' 18" E.

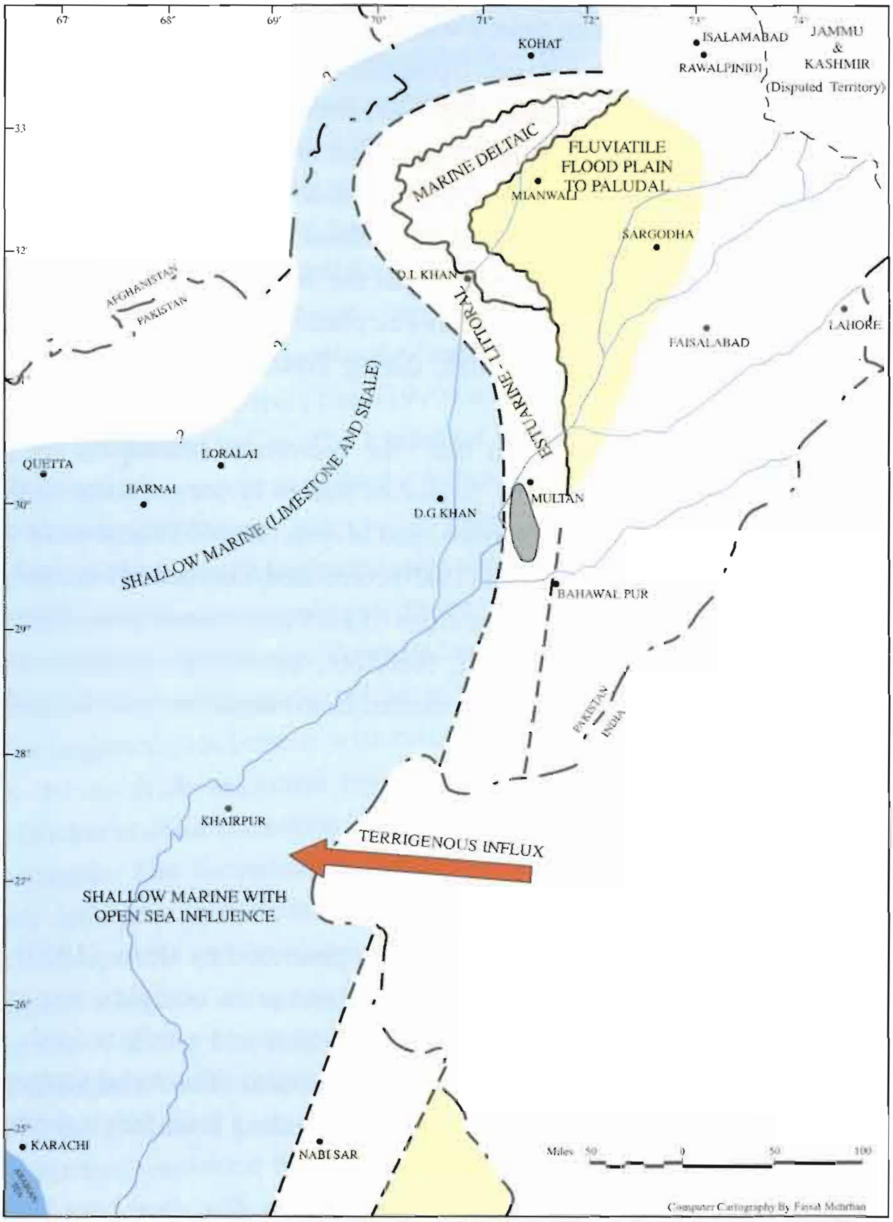
According to Ahmed et al. (op cit.) the formation typically consists of thick-bedded to massive limestone with minor shale intercalations. At the type section, it is mostly dark grey to blue and weather to light grey and to brownish colours. At places the limestone is thin to thick- bedded, hard and contains some secondary calcite veins. The limestone contains some chert nodules, ooids, pisolite and pellets. Its texture varies from fine-grained, sub-lithographic to oolitic, reefoid and shelly. The limestone forms high ridges throughout the area. In upper part the limestone is fairly jointed, fractured and numerous calcite veins are formed in these joints and fracture zones. The thickness of the formation at the type locality is 100 m. It has gradational contact with underlying Sarobi formation. While it's upper contact with Chashmai Karasai formation is disconformable.

Ahmed et al. (2000) correlated the Isha formation with the Takatu Formation of Axial Belt based on lithology and fauna. They also correlated it with the Samana Suk Formation of the Samana-Kohat area. The fossils found within the formation are mainly belemnite, algae, corals, bryozoans, brachiopods, crinoids and fragments of molluscs. On the basis of fauna Middle to Late Jurassic age has been assigned to the formation.

## LIASSIC PALEOGEOGRAPHY

Datta, Shinawari and Samana Suk Formations of Kohat Potwar Plateau, Shirinab and upper part of Loralai of Takatu Formation of the Axial Belt are the products of Liassic Sea.

According to Flynn (1972) during Liassic time Lower Jurassic, from Hettangian to Toarcian a shoreline existed along, or close to, the eastern border of Pakistan (Fig. 14). Seaward, to the north and west, a very shallow marine shelf extended into the area now occupied by the Kohat area and the Sulaiman Range. A delta lobe prograded westward, from the vicinity of the Salt Range, during early Liassic time, bringing terrigenous clastics onto the shelf at least as far as Zao River in the Sulaiman Mountains. Further to the south and west in the vicinity of Loralai, in the Mari-Bugti hills, terrigenous mud and thin lutaceous limestones were being deposited in an open marine environment. During late Liassic and Middle Jurassic (Bajocian-Bathonian) time the shoreline retreated further




LEGEND

- Shallow marine, the southern part with open sea influence
- Estuarine-littoral; estuarines grading into environment of marine tidal seaward and inlets of the sea into the land having morass or swamps with vegetable matter-coal etc.
- Marine deltaic with progradating shore line
- Fluviatile to Paludal environment (of fresh water deposits) grading to swamps or morass

Modified after Flynn (1972)

Fig. 14. Paleogeographic sketch map of Liassic (Lower Jurassic).

eastward onto the Indian Shield, and the area formerly occupied by the delta lobe became progressively more marine. By Bathonian time, a wide shallow marine continental shelf occupied most, if not all, of northern part of Indus Basin. Upon this shelf the oolitic, pisolitic, and palatal calcarenites of the Takatu and Samana Suk Formations were deposited.

According to Kummel (1961), the Jurassic shoreline around the ancient Ethiopian Shield was in general nearly coincident with the position of the Triassic shoreline except that a large island existed over an area comprising present day eastern Somaliland and south-eastern Aden. It may be mentioned here that Amoco geologists are of opinion that the Triassic and Jurassic shorelines were also nearly coincident along the western edge of Indo-Pak plate. Thus, the open seaway that existed between the Indian Shield and the Ethiopian Shield during Triassic time persisted on throughout most of Jurassic time.

Zardosht (in Flynn, 1972) pointed out that "the sediments containing the Orbitopsella biozone, which he recognized throughout the Sulaiman Range is very similar to the Lithiotis/ Megalodon limestone of the Lower Surmek (Surmeh) and Meyriz (Neyriz) Formations of the Zagros mountains in southern Iran". Shah and Quennell (1980) correlated Takatu and Shirinab Formations of Sulaiman range with Neyriz and Surmeh formations of Fars Province of Iran, where fossils and lithology of the units are almost the same. It would, therefore, appear that conditions similar to that which existed in Pakistan during Liassic time also existed in southern Iran and that a direct marine connection existed between the two areas.

## Hindukush-Karakoram Tectonostratigraphic Basin

### *Northern Sedimentary Province*

**Aghil limestone:** Aghil series of J. B. Auden was described by Desio (1963) in details, as Aghil limestone. According to Desio (1963), Aghil limestone is complex sequence of thick limestone and dolomitic limestone of white, grey and blackish and partly reddish. Usually this sequence alternate with thin lenticular beds of black and red shales. The Aghil formation is spread over the southern Aghil Range, main ridge of Karakoram, extending from the Gasherbrum Peaks to Apsarasas group.

Grey coloured dolomite containing *Megalodon* and *Dicerocardium* have been included in the Aghil limestone by Desio (1963). Gaetani et al. (1990) described the Aghil formation as consists of thick bedded or massive limestone and dolomite hundreds of metre thick forming a rugged topography. They recognized two basic facies: Black limestones (mostly mudstone and wackestone) and a whitish cyclothemic dolomite with large *megalodons* and *stromatolitic* layers. Locally *Multispira, Involutina, Glomospira,* and *Glomospirella* have been reported by Gaetani et al. (1990). These fossils indicate Liassic age for the formation. According to Desio (1979), the age of the Aghil formation is mostly Triassic and only the upper most part is Liassic. The thickness of the Aghil formation is in thousands of meters (Desio, 1963). The carbonate platform complex continues to the middle Liassic as testified by the abundance of lithiotis in the thick beds of limestones. The lower contact of Aghil formation is in fault contact with other Triassic formations. The upper contact is with lithiotis beds-slope facies of the sinking platform.

Evidently the central and southern part of the Sost area drowned again and the trough was filled by the sandstone sequence of orogenic provenance. This sequence is named by Gaetani et al. (1993) as **Astighar formation.** It is predominantly composed of terrigenous sequence of dark grey marl and shale intercalated with silt, clay and sandstone beds with a 5 m thick conglomerate bed at the top. The clasts of this conglomerate beds are derived from older formation especially Aghil formation. The Astighar formation is fossiliferous and contains brachiopods including *Zailleria sp. Spiriferina* and *Crinoids,* forams and Nannoflora include *Miteolithius jansae, and Lothaeingius.* The age of Astighar formation as indicated by the fauna and flora is considered Lower Jurassic.

**Yashkuk formation:** Gaetani et al. (1990) named and described the formation from the northern part of the Chapursan Valley. The formation is characterized by conspicuous arenaceous sequence. They described the sequence under the following depositional conditions.

Section near Reshit Village starts with fining upwards of red bed cycles; which was deposited in the lower reaches of a high-sinuosity alluvial system. They are followed by a mainly supratidal succession of green to red pelites with mud cracks or caliche nodules, interbedded at the top with dolostones and cherty limestone deposited in coastal sabkhas. The sandstone unit is overlain by dark blue-green algae (Porostromata), which indicates a restricted lagoonal environment. In the upper part of the sequence, wackestone with calcitized radiolaria pointing to open bay conditions, are capped by 10 m thick anhydrite layers interbedded with hemisphere stromatolites and porostromata. Thickness of the formation is 150 m in Reshit area and only 35 m at Yashkuk and thins out further eastwards. The formation is fossiliferous; Gaetani stated that "the hybrid arenites alternating with dark grey calcarenites contain benthonic foraminifera including *Haurania* sp., *Glomospira, Glomospirella* and *Involutina* with ostracods, echinoids, ostracods and brachiopods". This fauna suggests a Middle Liassic age. Giving further details of the depositional environmental conditions, Gaetani et al. (op. cit.) stated that the marine and non marine intertonguing and peritidal and inertial sediments in cyclic fashion are the important features of this formation. For example, "fossiliferous beds of Middle Liassic age are overlain by grey calcareous pelites and very fine grained ripple marked sandstone testify to the gradual progradation of mouth-bas deposits on a shallow marine carbonate shelf and then in turn it is overlain by fine-grained reddish sandstone, displaying scoured base and lateral accretion bedding, laid down by meandering channels". The section continues with sandstone showing tabular cross lamination truncated by ripple marks, to which they interpreted as late stage run off features diagnostic often in the intertidal sand-flat depositional environment. The overlying fine grained red and green sandstone showing rain drop prints ripples, broad scours and mud cracks which evidently testify to mostly sub aerial upper delta plain conditions. The sandstone unit is rapidly overlain by intertidal and subtidal cyclic carbonates. The formation is fossiliferous and contain following benthonic forums: *Trocholina, lenticulina,* Saecocoma, with fragments of brachiopods, corals and crinoids. The section continues with concoidal limestone deposited in an open lagoon environment containing benthonic foraminiferal genera which include *Trochammina, Ammodiscus, Frondicalaria Glomospira, Involutina, Ammobaculites* as well as *Valvulinidae* and other families. The age of Yashkuk formation has been described as Middle Liassic (Gaetani et al., 1990).

**Reshit formation:** Gaetani et al. (1990) named and described 300 m thick sequence of a rock unit as Reshit formation, exposed near the village of Reshit in Chapursan Valley northern Hunza area. According to them, in the south side of Reshit Village two tectonic slices are present, which constitute this formation. In the first tectonic slice, the formation consists of dark grey mudstone-wackestone with chert in layers of 10-30 cm thick, some times over a metre thick. In the upper part of this unit clay content dominate the sequence. The sequence contains *lenticulina spirillina, Trocholina, Protopeneroplis, Saccocoma, Valvulinidae, lagenidae.* The second slice of sedimentary sequence consists of bio-interclastics packstones interfingered with bio-interclastics calcarenites, lenticular beds alternate with dark grey thin bedded basin limestones having deformed ammonites, including *Hetromorph Parapathoceras* of Callovian age. The formation was deposited in shallow marine environment of Middle to Late Jurassic age.

**Bdongo-la formation:** Desio and Fantino (1960) named and described this formation from Shaksgam Valley. Mason (1928) and Dainelli (1933) described the sequence as marine "Callovian of Aghil and Karakoram pass". Searle (1991) described it as a sequence of yellow marly sandstone and dark colours limestones containing corals and ammonites. Searle (1991) noted that the previous workers ascribed an Upper Jurassic age, although there is little concrete biostratigraphic evidence, and added that Jurassic fossils are known from the Aghil Range north of the Rimo glacier and around the Karakoram Pass and uppermost reaches of the Yarkand River. Red marly limestones with sparse ammonite and lamellibranch faunas indicate a shallow water marine environment during the Late Jurassic.

Along the Baltoro glacier, the only possible traces of the Bdongo-la formation are samples of black laminated limestones with remnant belemnites and corals derived from the Gasherbrum Range (Desio and Zanettin, 1970). No detailed stratigraphy, palaeontology or thickness is known for the Jurassic rocks of the northern Karakoram.

## CRETACEOUS

Cretaceous system or part of it is present in almost all the basins of Pakistan. The Cretaceous Period was a time of great tectonic instability in various parts of Pakistan giving rise to the full development of important geanticlinal structures like the "Central and Lasbela anticlines" splitting up the Balochistan geosyncline into two main sedimentary basins, wide spread igneous activity and significant variation in rock types. Widespread withdrawal of the sea towards the close of the Middle Jurassic was followed by marine transgression in the Late Jurassic, which continued into the Early Cretaceous in many parts of Pakistan. The continuity of sedimentation from the Late Jurassic to Early Cretaceous has been established in the Kohat-Potwar Province (Fatmi, 1968, 1972), while from the Lower Indus Basin and Axial Belt regions, the evidence of such a continuity is not studied in detail, but for some areas it has been claimed that the Late Jurassic is transitional into the Early Cretaceous (Fatmi *verbal communication* 1979).

According to Fatmi (1977), in most areas the Upper Jurassic and Lower Cretaceous rocks are mainly arenaceous and argillaceous in the lower part, followed by marine carbonate and clastic sediments in the upper part of the Lower Cretaceous. The Lower Cretaceous is represented in Kohat-Potwar Province by a dominant carbonate lithology, but in the Lower Indus Basin, Axial Belt and the Balochistan Basin, in addition to the carbonate rocks, volcanics, shale, sandstone and conglomerate constitute a significant part of the section, as for example, from the Balochistan Basin (Eruptive Zone) the oldest strata are dated as Cretaceous and the lithology is mixed volcanics and sedimentary. In the region of the Axial Belt, a mixed sedimentary and igneous suite of rocks is present. These include shale, marl, limestone, basic lava flows of spilitic type, radiolarian chert, and other basic and ultrabasic intrusives, which are similar to the "Coloured Mêlange" of Iran and Turkey (Shah et al., 1980). In other parts of the Axial Belt and the adjoining regions of the Sulaiman and Kirthar Provinces of the Lower Indus Basin, the Cretaceous rocks are mostly of sedimentary origin and, except for local disconformities, constitute a continuous sequence from Early to Late Cretaceous. The overlying Tertiary sediments are transitional in parts of this area, while local disconformities between the Cretaceous and Tertiary have been recognized.

In the Upper Indus Basin (Kohat-Potwar Province), considerable variation, particularly in the Lower Cretaceous sediments is noted. The Neocomian sequence of this area is marine and represented by sandstone and shale, which are glauconitic, phosphatic and locally pyritic. The Aptian- Albian rocks in the Salt Range and Trans-Indus ranges show a change from marine to non-marine (deltaic) and indicate a possible emergence of this part of the Potwar area towards the close of the Early Cretaceous. No rocks of Late Cretaceous age are known from the Potwar area and Lower Cretaceous and older rocks disconformably underlie various Tertiary units. In Hazara, parts of Kala Chitta and Kohat, the Lower Cretaceous rocks (early to middle Albian in age) are disconformably overlain by Upper Cretaceous limestone and marl. The older stages of the Late Cretaceous have not been recognized from these areas. The emergence, therefore, near the close of the Early Cretaceous was in Kohat, Kala Chitta and Hazara, followed by marine transgression in the latter part of the Late Cretaceous, but this transgression does not appear to have reached the Salt Range and Trans-Indus ranges. In the Lower Indus Basin and adjoining areas of the Axial Belt, the Cretaceous rocks are many thousand metres thick. The thickness, however, decreases considerably in the Kohat-Potwar Province. In the northern Pakistan, large-scale tectonic activities with deposition of Early Cretaceous limestone, conglomerate and sandstone initiated along with the development of an island arc in the region. A separate chapter is devoted for this arc.

## INDUS BASIN

### *Upper Indus Basin (Kohat-Potwar-Province)*

The sequence of Cretaceous rocks in the Upper Indus Basin area is represented by the following formations (No.1 is the oldest):

3. Kawagarh Formation (Late Cretaceous)
2. Lumshiwal Formation (Late Jurassic to mainly Early Cretaceous)
1. Chichali Formation (Late Jurassic to Neocomian)

Although the lower age limit of the Chichali Formation and in some areas of the Lumshiwal Formation extend into the Late Jurassic. These formations are described in the Cretaceous Chapter because their contacts with Jurassic rocks are transitional. In the Kathwal Section of northern Hazara the basal part of the Lumshiwal Formation (thickness 10 m) is Tithonian, while the upper age limit is middle Albian. The underlying Chichali Formation in this area is Late Jurassic (late Oxfordian-Tithonian) in age. In the Trans-Indus ranges (Chichali and Datta Nala sections) the Lumshiwal Formation is doubtfully assigned an Aptian-Albian age as the underlying Chichali Formation has been found, on faunal evidence, to be Late Jurassic to Neocomian.

**Chichali Formation:** Chichali Formation was established by Danilchik (1961) and later refined by Danilchik and Shah (1967) for rocks previously described as "Belemnite beds" from the Salt Range and Trans-Indus ranges (Spath, 1939); (Gee, 1945). The name is extended to include rocks that disconformably overlie the Samana Suk Formation in Hazara, Kala Chitta ("Spiti shale" of Middlemiss 1896; Cotter 1933) and Kohat "Belemnite beds" of Davies (1930). The type section is in Chichali Pass, Surghar Range (Lat. 33° 01' N: Long. 70° 25' E).

Fatmi (1977) described the Chichali Formation from the Chichali Pass, the type locality, consists of dark green, greenish grey, weathering rusty brown glauconitic sandstone, with dark grey, bluish grey, greenish grey, sandy, silty, glauconitic shale in the lower part. In the western Salt Range, Trans-Indus ranges and parts of Kohat (Samana Range), the formation is divisible into three members. The lower member is sandy, glauconitic shale with some phosphatic nodules passing upward into dark green glauconitic sandstone with abundant belemnites, less commonly ammonoids and other fossils. The basal bed of the unit is a thin, nodular, calcareous, phosphatic, ferruginous sandstone or conglomerate. The middle member is greenish to rusty brown, fine- to medium-grained, calcareous sandstone, which stands out in topography and contains abundant belemnites and ammonoids. The upper member is glauconitic, chamositic, generally unfossiliferous sandstone (some bivalves and ammonoids occur locally). The upper member in Chichali Pass and adjoining outcrops and the middle member in the Makarwal section are sufficiently rich in iron to form a low grade iron ore.

The three-fold division loses its distinction in the Tribal Belt of eastern Kohat, Nizampur, Kala Chitta and southern Hazara, where the formation in the lower part consists of glauconitic sandstone with a nodular silty, calcareous, phosphatic base, followed by glauconitic, sandy shale or dark pyritic unfossiliferous shale in the upper part.

In sections of northern Hazara (north of the Haro River), the formation is dark grey to black, silty, pyritic shale ("Spiti", type) with some ferruginous calcareous and phosphatic nodules.
It is widely distributed in the Trans-Indus ranges, western Salt Range, northern Kohat ranges, Nizampur, Kala Chitta and southern Hazara. In northern Hazara (near Jabrian, Jhamiri, Kathwal and Kalapani) north of the Haro River the formation shows a facies change consisting of dark silty shale with nodules and is similar to "Spiti shale" of Himalayas (Kashmir). In the Chichali Pass area, the thickness varies from 55 to 70 m. From Sheikh Budin Hill 48 m thickness is reported. In western Kohat (Samana Range) thickness ranges 15 to 20 m. In eastern Kohat, Nizampur and Kala Chitta thickness varies from 12 to 27 m. In southern Hazara (north of Jabrian Rest House on the Haro River) it is 33 m, while further north the thickness is 34 m near Jhamiri to 64 m northwest of Kalapani

The lower contact with the Samana Suk Formation is disconformable. The upper contact with the Lumshiwal Formation though well defined, appears gradational. From the lower and middle members in the western Salt Range and Trans-Indus ranges late Oxfordian to Valanginian ammonoids are recorded (Spath, 1930; Fatmi, 1968, 1972). The age of the formation in this area is thus late Oxfordian to Neocomian. The fauna of the lower member consists of late Oxfordian forms (present in the basal nodular beds) like *Perisphinctes (Kranaosphinctes), P. (Dichotomosphinctes), Mayaites, Belemnopsis gerardi and Hibolithes.*

These are followed by Kimmeridgian ammonoids including *Aspidoceras (Aspidoceras). A (Pseudowaagenia), Physodoceras (Simaspidoceras)* sp., *Katroliceras* cf. *pottingeri, Pachysphinctea robustus, Hibolithes,* and *Belemnopsis gerardi.* In addition to cephalopods, the fauna consists of *Gryphaea* sp., rhynchonellid and Terebratulid brachiopods, foraminifers and some remains of vertebrate fossils were collected from Chichali Formation exposed in the Makarwal coal mines by Ibrahim Shah of GSP and Izhar-ul-Haque a mining engineer of PMDC, during the course of large scale mapping of the coal field by the former. These vertebrate remains contained a caudal vertebra of an extinct *Plesiosaur,* a dinosaur, of Cretaceous age. The sample was identified by Professor Taseer Hussain of Howard University (written communication 1974).

According to Fatmi (1977) the early Tithonian is represented by *Aulacosphinctoides* sp., *Virgatosphinctes, Hildoglochioceras, Proniceras indicum* and *Provalanginites.* The upper Tithonian fauna is found in the upper half of the lower member and consists *of Blanfordiceras, Pterolytoceras exoticum, Spiticeras multiforme* and *Protacanthodiscus.* The Jurassic/Cretaceous contact is gradational and lies in the upper one metre of the lower member of the Chichali Formation. The Cretaceous boundary is marked by the first appearance of *Subthurmannia* in the uppermost beds of the lower member. The middle member is Berriasian to Valanginian in age and includes ammonoid genera such as *Subthurmannia* (abundant), *Neocosmoceras, Neocomites, Kilianella, Neohoploceras, Olcostephanus (Olcostephanus...),O. (Rogersites), Distoloceras, Lyticoceras and Leopoldia.* No ammonoids occur in the upper member, but Gryphaea sp. is found in the Surghar

Range. From the Sheikh Budin Hill some late Neocomian ammonoids and gastropods have been recorded. The ammonoid fauna indicates a late Oxfordian to Valanginian age of the lower and middle parts of the Chichali Formation, while the upper member may represent the rest of the Neocomian. In western Kohat, the lower and middle parts of the Chichali Formation have yielded Tithonian, Berriasian and Valanginian fauna. The ammonoids include *Protacanthodiscus, Berriasella, Spiticeras, Neolissoceras, Neocomites, Kilianella, Olcostephanus (Olcostephanus)* and *Lyticoceras*. The upper part of the formation is devoid of fossils. The age is considered to be Tithonian to Neocomian.

In the eastern Kohat, Nizampur, Kala Chitta and southern Hazara, the basal beds contain a late Oxfordian fauna. The age of the formation is late Oxfordian to Neocomian. The ammonoids and belemnites include *Perisphinctes, Prososphinctes virguluiodes, P. (Arisphinctes) orientalis, Aulacosphinctes, Himalayites, Belemnopsis gerardi* and *Hibolithes*. The Late Jurassic is much condensed in these sections and there are indications in parts of the area of the absence of late Oxfordian. Kimmeridgian and early Tithonian ammonoids due to non-sequences. In the northern Hazara (Kalapani-Kathwal section) the formation is pre-Tithonian possibly late Oxfordian to Kimmeridgian in age. The lower part of the formation contains Belemnopsis sp. perisphinctid ammonoids and molluscs. The age of the formation is variable in different parts of the Kohat-Potwar Province. In general, it is Late Jurassic to Neocomian in age except in northern Hazara, where it is mainly Late Jurassic. The formation is correlated with the Sembar formation and parts of the Goru formation of the Axial Belt and the Sulaiman and Kirthar Provinces.

**Lumshiwal Formation:** Gee (1945) proposed the name "Lumshiwal sandstone" for usage in the Salt Range but due to variations in lithology in areas other than the type locality, the name has been amended by the Stratigraphic Committee of Pakistan as Lumshiwal Formation. The name is extended to Kohat, Kala Chitta and Hazara. It replaces the older names "Giumal sandstone" (Middlemiss 1896; Cotter 1933) and "Main sandstone series" (Davies 1930) in Hazara, Kala Chitta and Kohat.

Fatmi (1977) provided detailed lithology of Lumshiwal Formation covering all areas of Pakistan. According to him in Lumshiwal Nala (Lat. 32° 5' N: Long. 71° 09' E), the formation is not fully exposed. Danilchik and Shah (1967) designated type locality at a section one kilometre north of Lumshiwal Nala. Because of considerable variation in lithology and thickness, three principal reference sections have been designated (Fatmi, 1968, 1972) to appreciate the facies changes. The reference sections are the Fort Lockhart Road section in the Samana Range, Wuch Khwar section in the Nizampur area and Jhamiri Village section on Haripur-Jabrian Road in Hazara.

In the type locality and other sections of the Trans-Indus ranges, the lithology consists of thick-bedded to massive, light grey current-bedded sandstone with silty, sandy, glauconitic shale towards the base. The sandstone is feldspathic, ferruginous and contains carbonaceous material in the upper part. Except for the lower-most part, which contains glauconite and some poorly preserved specimens of *Gryphaea* sp, and *Hibolithes* sp, the formation in the Trans-Indus ranges is unfossiliferous and mostly of continental origin. Away from the Trans-Indus ranges, to the northeast and northwest, in the reference sections the formation is mostly marine and consists of sandstone and siltstone with argillaceous and shelly limestone in the upper part.

In the Samana Range, the lower part consists of fine- to medium-grained thin- to medium-bedded, light grey, brown, quartzose sandstone, with subordinate silty clay partings containing foraminifers. The middle part is massive, thick bedded, cliff forming, coarse- to medium-grained, light grey sandstone. The upper part is ferruginous and glauconitic sandstone with one to two metres thick hard, glauconitic, rusty brown sandy limestone, containing abundant fossil casts of bivalves, gastropods ammonoids, belemnites and echinoids.

In the Khadimak section to the southwest of the Samana Range, the formation is mainly dark green to greenish grey glauconitic sandstone and sandy and silty shale with hard calcareous fossiliferous sandstone near the top. In eastern Kohat, Nizampur, Kala Chitta Range and southern Hazara (south of Jabrian along the Haro River), the lithology consists of quartzose, glauconitic and calcareous sandstone in the lower part, followed by a sequence of greenish to greenish grey, silty, thin- to medium-bedded, slightly phosphatic sandstone (calcareous in the upper part), which is overlain by thin- to medium-bedded, argillaceous, shelly limestone and nodular marl having a nodular phosphatic, rubbly, hard, rusty brown top bed.

In northern Hazara (Jhamiri, Jabrian, Kathwal-Kalapani sections), the formation is a quartzose, ferruginous sandstone, weathering yellowish brown, rusty brown to light grey with locally calcareous, sandy beds and a hard, dark rusty brown, calcareous sandstone or sandy limestone top bed with abundant fossil casts. The formation is widely distributed in the adjacent ranges including Nizampur, Kala Chitta and Hazara ranges. The lithology of the type section is well seen in the Surghar Range and Sheikh Budin Hill. Towards the east, in the western Salt Range, the formation thins out and disappears. Thickness varies from 80 to 120 m in the Lumshiwal Nala and 38 m in the Chichali Pass section. In the western Kohat (Samana Range) the thickness is 194 m but the formation thins out further east in Nizampur (Wuch Khwar section) to 47 m. In the Kala Chitta Range, the thickness is 60 m (south of Shujanda) and 50 m (north of Jhallar). In southern Hazara (section near Jabrian Forest Rest House, north bank of the Haro River), the thickness is 50 m, while further north in northern Hazara, the thickness varies from 20 m (near Jhamiri village, road side section) to 10 m (near Kathwal).

From the lowermost beds in Makarwal and the Broach Nala sections *Gryphaea* sp. and *Hibolithes* sp. are recorded. From the Sheikh Budin Hill, some late Aptian fossils have been recorded (Spath, 1939). Generally in the Trans-Indus ranges, the formation is unfossiliferous. An Aptian-Albian age is doubtfully assigned in this area. The uppermost beds in the Samana Range contain abundant moulds of brachiopods, bivalves, gastropods, ammonoids, belemnites and echinoids. Among the ammonoids, *Douvilleiceras mammillatum* is the most common species. Other ammonoids include *Oxytropidoceras* spp., *Desmoceras* sp., *Cleoniceras* sp., *Brancoceras* sp. and *Lemunoceras* sp. (Spath, 1930; Fatmi, 1968). From the lower beds (in the middle part) in the Khadimak section *Ammonitoceras*, sp. and *Pseudosaynellid (Ailoceras)* and *Deshayesitids* ammonoids have been identified (Fatmi, 1968, 1972). The age in western Kohat is considered to be early Albian to Aptian. In the Nizampur and Kala Chitta sections, the lower beds (calcareous, glauconitic sandstone) contain Trigonia spp., including *Trigonia ventricosa,* followed higher up (the upper calcareous unit) by *Douvilleiceralid, Lyelliceras, Oxytropidoceras, nautiloids and Neithea attockensis.* A late Neocomian to middle Albian age is assigned to these beds.

In northern Hazara (Jhamiri, Jabrian, Kathwal and Kalapani sections to the north of the Haro River), the uppermost fossiliferous bed has abundant fossil casts of brachiopods, gastropods, ammonoids etc. The ammonoids include a rich Lyelliceras fauna, supported by Douvilleiceras, Oxytropidoceras and other ammonite genera (including uncoiled forms). In addition, from the Kathwal-Kalapani sections, the lowermost beds contain early Tithonian ammonoids like Aulacosphinctoides and Virgatosphinctes. The age of the beds in the Kathwal-Kalapani sections is Tithonian to middle Albian.

The age of the Lumshiwal Formation in western Kohat is Aptian to early Albian. In Nizampur, Kala Chitta and southern Hazara, the age is upper Neocomian to middle Albian and in northern Hazara Tithonian to middle Albian. In northern Hazara, the formation is condensed and is believed to include some non-sequences. The lower contact with the Chichali Formation appears transitional. In the Kohat and Hazara area the upper contact with the Upper Cretaceous Kawagarh Formation is disconformable. In southern Potwar and the Trans-Indus ranges, the Lumshiwal Formation is overlain by Tertiary formations and no Upper Cretaceous rocks are developed. The formation is correlated with the Goru formation of the Axial Belt and Lower Indus Basin.

**Kawagarh Formation:** Day, A. (in unpublished Attock Oil Company's report), introduced the name "Kawagarh marls" for the Upper Cretaceous rocks exposed in the Kawagarh hills, north of Kala Chitta Range. The name Kawagarh Formation was approved by the Stratigraphic Committee of Pakistan to incorporate Day's "Kawagarh marls" and its facies changes in Kohat and Hazara area. The name thus replaces "Sub lithographic limestone" of Davies (1930) in the Samana Range, "Darsamand limestone" of Fatmi and Khan (1966) in western Kohat, "Durban limestone" of Khan S. N, and W. Ahmed (1966), "Sattu limestone" of Calkins and Matin (1968) and "Chanali limestone" of Latif (1970) in Hazara area. In western Kohat, the formation is divisible into two members (Fatmi and Khan, 1966), and upper Tsukail Tsuk Limestone Member and a lower Chalor Silli Member. In parts of southern Hazara the upper part of the formation is dominantly arenaceous and is known as Nara Sandstone Member, after the "Nara sandstone" of Khan, S. N. and W. Ahmed (1966).

Kawagarh Formation is named after the Kawagarh hills, north of the main Kala Chitta Range in Attock District (Lat. 33° 45' 30" N: Long. 70° 28' 30" E). The two members in western Kohat are named after Tsukail Tsuk Peak, north of Darsamand (Lat. 33° 28' 33" N: Long. 70° 38' 9" E), and the Chalor Silli Village in the Samana Range (Lat. 33° 26' 25" N: Long. 70° 38' 16" E). The Nara Sandstone Member is named after the Nara village in southern Hazara (Lat. 35° 59' N: Long. 73° 13' 30" E).

Fatmi (1977) studied the formation in detail from different parts of the country and according to him the Kawagarh Formation in its type locality and adjoining areas of northern Kala Chitta, Nizampur and eastern Kohat consists of dark (when fresh) marl and cleaved calcareous shale, which weathers light grey, brownish grey, and nodular argillaceous limestone in its westerly extension in the Kohat area. In eastern Kohat (Kohat Pass section) dolomitic limestone beds occur in the lower part while further west in Samana Range, Darsamand and Khadimak sections. The formation is typically a lithographic to sub lithographic, grey, olive grey and light grey limestone with subordinate marl and shale (particularly in the lower part). The formation is divisible in western Kohat into two members; (1) *Upper: Tsukail Tsuk Limestone,* a grey sub lithographic thick bedded to massive, escarpment forming, limestone with common smaller foraminifers; *(2) Lower: Chalor Silli Member,* a light grey, olive grey, lithographic to sub lithographic, thin- to medium-bedded limestone with subordinate calcareous shale and marl intercalations in the lower part, with smaller foraminifers and rare ammonoids (in the lower part only).

In parts of the southern Hazara the formation is typically a thin- to thick-bedded, sub lithographic limestone, similar to western Kohat. The Nara Sandstone Member in the upper part is grey, brownish grey to dark grey, thick bedded, calcareous sandstone with some limestone interbeds. In northern Hazara (Kathwal-Kalapani section), the Nara Sandstone Member is not developed and the Kawagarh Formation consists of grey, olive grey, light grey sub lithographic limestone with subordinate marl and calcareous shale.

The calcareous shale and marl lithology is typically developed in parts of eastern Kohat, Nizampur (Mazari Tang-Wuch Khwar sections), northern Kala Chitta, including Kawagarh hills and part of southern Hazara. In western Kohat, the formation is typically a sub lithographic limestone, which is thick bedded in the upper part (Tsukail Tsuk Limestone Member) and thin bedded in the lower part (Chalor Silli Member). In Hazara the formation again shows a limestone lithology quite similar to that in western Kohat, excepting that in parts of southern Hazara calcareous sandstone is developed in the upper part (Nara Sandstone Member). The formation is not developed in southern Kala Chitta, the Salt Range and Trans-Indus ranges where the Tertiary rocks directly overlie Lumshiwal Formation or older rocks. In western Kohat, the thickness varies from 110 m (Samana Range) to 120 m (Darsamand Section). In eastern Kohat it varies from 70 m Taudi Mela Section to 90 m Mazari Tang section. In Kala Chitta, the thickness varies from 40 to 70 m (Kawagarh Section). In Hazara, the thickness varies from 45 m in the south (Changla Gali) to over 200 m in the middle of the area (Chanali Section). It is 70 m in the Kathwal Section.

The formation has disconformable contacts with the overlying Hangu Formation of Paleocene age and the underlying Lumshiwal Formation of mainly Early Cretaceous age. The formation is poor in mega-fossils, except in Darsamand area, where some collignoceratid ammonoids are recorded from the basal part of the formation (Fatmi, 1968, 1972). Smaller foraminifers including different species of Globotruncana are quite commonly distributed throughout the formation. From southern Hazara, Latif (1970) has reported Globotruncana lapparenti, G. fornicata, G. concavata carinata, G. elevata-calcarata, Heterohelix reussi, H. globocarinata, H. globulosa, Pseudotextularia elegans, Rugoglobigerina rugosa, Globorotalites multisepta, foraminifers. On the basis of this fauna, Latif has assigned a late Coniacian to Campanian age to the formation in the Changla Gali section of southern Hazara. The age of the formation, therefore, is Late Cretaceous. The formation is correlated with the Pab sandstone, Mughal Kot formation and Parh limestone of the Axial Belt and the Sulaiman and Kirthar Provinces.

***LOWER INDUS BASIN (SULAIMAN AND KIRTHAR PROVINCES)***

Away from the tectonically active region of the Axial Belt to the south and east in the adjoining Sulaiman and Kirthar Provinces, a dominantly sedimentary sequence of Cretaceous age is developed. Locally at some levels, particularly close to the tectonically active region of the Axial Belt, the sedimentary sequence shows inclusions of volcanic rocks. The sediments are marine and greatly variable in thickness in different areas. Generally, they are thick and some of the formations attain a considerable thickness in subsurface in the Lower Indus Basin. The following formations have been recognized from this area:

Sembar Formation
Goru Formation
Parh Fimestone
Mughal Kot Formation
Fort Munro Formation
Pab Fandstone
Moro Formation

Hunting Survey Corporation (1961) referred to units 1 to 4 as "Parh group undifferentiated" while the entire Cretaceous section mentioned above was referred to as the "Parh series". In the present descriptions the nomenclature of Williams (1959) with slight modification is being followed.

**Mona Jhal Group:** The name Mona Jhal Group was introduced by Fatmi et al. (1990) from the Mona Jhal anticline, 13 km north of Khuzdar. It is subdivided into the following four formations in ascending order:

1. Sembar Formation
2. Goru Formation
3. Parh Limestone
4. Mughal Kot Formation.

This group is developed throughout Balochistan and has the same characteristics in the southern, central and northern Balochistan. Hence, it is being proposed to replace Parh group or series of Hunting Survey Corporation (1961) in central and northern Balochistan.

**Sembar Formation:** The name Sembar Formation was introduced by Williams (1959), after Sembar Pass in the Mari hills, to include the lower part of the "Belemnite Beds" of Oldham (1892) and the "Belemnite Shales" of Vredenburg (1909). The "Belemnite Beds" of Oldham also included the overlying Goru Formation and the Parh Limestone as described below. Hunting Survey

Corporation (1961) did not recognize this formation as a separate unit but included it in the lower part of their "Parh Series" (implying undivided cretaceous) or "Parh group" (undifferentiated "Belemnite Shale" and Parh Limestone). The type section of the formation is about two kilometres southeast of Sembar Pass (Lat. 29° 55' 05" N: Long. 68° 34' 48" E) in the Mari-Bugti area of Sulaiman Province.

According to Fatmi (1977), the Sembar Formation consists of black, silty shale with interbeds of black siltstone and nodular rusty weathering argillaceous limestone beds or concretions. Glauconite is commonly present which gives the greenish hue to the weathering colour. In the basal part pyritic and phosphatic nodules and sandy shales are developed locally. The thickness in the type section is 133 m but the formation thickens to 262 m in the Moghal Kot section of the Sulaiman Range and has been reported to be much thicker in the subsurface (Williams, 1959). In some areas such as the vicinity of Quetta and Ziarat, the thickness of the formation is reduced to a few metre, and the formation is absent in parts of Axial Belt and the Kirthar Province, where the overlying Goru Formation directly overlies the Jurassic limestone. Its upper contact with various Jurassic formations such as Mazar Drik Member of Takatu Formation and Shirinab Formation is disconformable, while the upper contact is generally gradational with the Goru Formation.

The formation is reported to contain foraminifers, but the most common fossils are the belemnites *Hibolithes pistilliformis, H. subfusiformis* and *Duvalia* sp. From the Windar River in Lasbela, Nuttal (in Arkell, 1956) reported fragments of *Virgatosphinctes denseplicatus* and *V. cf. V. subquadratus,* but their stratigraphic position is not known. The *Hibolithes* spp though regarded as early Neocomian (Berriasian-Valanginian) may not be restricted to this age as comparable species from the Salt Range and Trans-Indus ranges have been found to be associated with Late Jurassic ammonites (Fatmi, 1968, 1972). The age of the formation though mainly Neocomian most likely extends into the Late Jurassic. The Sembar formation is correlated with the Chichali Formation of the Kohat-Potwar Province.

**Goru Formation:** The name Goru Formation was introduced by Williams (1959) for rocks included by Oldham (1892) in the upper part of his "Belemnite Beds" Hunting Survey Corporation (1961) included these strata in the "Parh group". The type section is located near Goru Village on the Nar River in the southern Kirthar Range (Lat. 27° 50' N: Long. 66° 54' E).

As described by Fatmi (1977), the Goru formation consists of inter bedded limestone, shale and siltstone. The limestone is fine grained, thin-bedded, light to medium-grey and olive grey. The interbedded shale and siltstone are grey, greenish grey and locally maroon in colour. The shale varies greatly in proportion and in places is the dominant rock type. Limestone is dominant in the lower and upper parts of the formation. The Goru Formation is widely distributed both in the Kirthar and Sulaiman provinces. It is 536 m thick in the type locality, but the thickness decreases to 60 m near Quetta. In the subsurface over 100 m has been recorded.

The lower contact with the Sembar Formation is conformable, though locally an unconformity has been reported by Williams (1959). In some parts of the Axial Belt, for example, east of Khuzdar, the Goru Formation directly overlies the Jurassic limestone and the Sembar lithology is not developed. The contact between Goru and Sembar Formations is placed at the appearance of frequent limestone inter beds. The upper contact with the Parh Limestone is transitional and is placed at the last shale interbed. The formation contains foraminifers and belemnites *(Hibolithes spp.)*. Fritz and Khan (1967) described the following foraminifers from Bangu Nala in Quetta region: *Globigerinelloides algeriana*, G. *breggiensis*, G. *caseyi*, *Ticinella roberti*, *Gavelinella lorneiana*, *Rotalipora ticinensis*, *R. appennenica*, *R. brotzeni*, *R. reicheli*, *Praeglobo- truncana stephani* and *Planomalina buxtorfi*. The age of the formation is assessed mainly as Early Cretaceous though the upper age limits in many areas extend into the Late Cretaceous and the lower age limit may extend down into the Late Jurassic, Fatmi (1977). The Goru formation may be correlated with the Lumshiwal Formation of the Kohat-Potwar Province.

**Parh Limestone:** The term "Parh" was introduced by Blanford (1879) for the rocks of Parh Range. The name was later applied by Vredenbrug (1909) to a prominent white limestone in his Cretaceous succession. Williams (1959) redefined it as a limestone formation between the Goru and Mughal Kot formations. The type area lies in the Parh Range in the upper reaches of the Gaj River (Lat. 26° 54' 45" N: Long. 67° 05' 45" E).

The Parh Limestone as described by Fatmi (1977) is lithologically very distinct unit. It is a hard, light grey, white, cream, olive green, thin-to-medium-bedded, litho-graphic to porcellaneous, argillaceous occasionally platy to slabby limestone, with subordinate calcareous shale and marl intercalations. The porcellaneous nature and the conchoidal fracture distinguish it from other limestone units. In the lower part an impersistent maroon coloured limestone bed is developed near the contact with the Goru Formation. The formation is widely distributed in parts of the Axial Belt and Lower Indus Basin. In the type area the thickness is 268 m but varies from 300 to 600 m in other areas. The formation is rich in foraminifers *(Globotruncana* spp.) and is dated as Late Cretaceous. The foraminifers include *Globotruncana ventricosa*, G. *lapparenti*, G. *sigali* and *Pseudotextularia elegans* (Gigon, 1962). The formation is correlated with Kawagarh Formation of the Kohat-Potwar Province.

**Moghal Kot Formation:** The term Mughal Kot Formation was applied by Williams (1959) to the strata between the Parh Fimestone and Pab Sandstone near Mughal Kot. J Williams distinguished the upper part as *"Fort Munro limestone member"* which is raised to formation rank in the present report because of its wider extent in areas where the rest of the Mughal Kot Formation is not developed. The Mughal Kot Formation of the present report thus represents the " Mughal Kot of Williams minus the *"Fort Munro member"*, the ...*Inoceramus* clays", "bedded clays" and lower part of the *("Orbitoides* limestones and shales" of Eames, 1952). Hunting Survey Corporation (1961) did not identify the formations as a distinct entity but included it in the lower part of their Pab sandstone.

A section (Lat. 31° 26' 52" N: Long. 70° 02' 58" E) exposed along the Fort Sandeman-Dera Ismail Khan Road, between two and five kilometres west of Mughal Kot Post and an adjacent stream, has been designated as the type section of the formation by William (1959).

Lithologically, as stated by Fatmi (1977) the formation comprises dark grey, calcareous mudstone and calcareous shale with intercalations of quartzose sandstone and light grey argillaceous limestone. The sandstone is well-developed in the northern part of the Sulaiman Province only.

Some yellow to greyish yellow marl and shale beds are present in the upper part of the formation in the southern Sulaiman Province, (northeast of Pui). In the Kirthar Province, grey, silty and calcareous shale is more abundant than the calcareous mudstone or marl. Locally in the Axial Belt region, a thick sequence of conglomerate ("Kahan conglomerate member" of Williams, 1959) occurs. The conglomerate represents a facies change of the Mughal Kot and is well-exposed along the Kach-Ziarat Road, near Kahan Village. The conglomerate is dark to grey-black and contains boulders cobbles and pebbles of basalt in a matrix of the same material.

The Mughal Kot Formation is best developed in the Sulaiman Province. It is 1170 m thick in the type section, 160 m in northeast of Pui and is absent at Duki. It is 360 m thick at Dabbo Creek in the subsurface and 150 to 300 m around Kach. The Kahan conglomerate member is 770 m at Kahan in the Ziarat area. The formation unconformably overlies the Parh Limestone throughout most of its extent. However, in the Karachi Embayment and the area around the type section, this contact is apparently conformable. The formation is conformably overlain by the Fort Munro Formation with a transitional contact in most of the areas. However, in part of the Ziarat-Loralai area, it is unconformably overlain by the Dungan Formation and the contact is marked by a laterite.

Williams (1959) reported *Omphalocyclus* sp. and *Orbitoides* sp. and assigned, a Maastrichtian age to the formation. Marks (1962) reported *Siderolites* cf. *calcitrapoides, Orbitoides tissoti minima* and *O. tissoti compressa* from Rakhi Nala (Sulaiman Province) and assigned a late to middle Campanian age to the upper part of the unit, which might extend up to early late Campanian. On the basis of this evidence, a Campanian to early Maastrichtian age is assigned to the formation. The formation is correlated with the upper part of the Kawagarh Formation of the Kohat- Potwar Province.

**Fort Munro Formation:** The *"Fort Munro limestone member"* of Williams (1959) is here elevated to the status of a formation because of its distinct lithology and wide extent. The formation represents the *"limestone with Hippurites"* of Blanford (1878), *"the Hemipneustes limestone"* of Vredenburg (1909a) and the upper part of the Orbitoides limestone and shales of Eames (1952). Hunting Survey Corporation (1961) included the unit in their "Pab sandstone" in the Sulaiman Province and Axial Belt but differentiated it as "Hemipneustes limestone" in the Kirthar Province.

Williams (1959) designated as the type section the western flank of the Fort Munro anticline, along the Fort Munro-D. G. Khan Road (Lat. 29° 57' 14" N: Long. 70° 10' 30" E). In the northern Sulaiman Province and Axial Belt the formation, as described by Fatmi (1977) typically consists of limestone. The limestone is dark grey to black, very hard, thick bedded, commonly sandy in the upper part and argillaceous in the lower part. In the southern part of the Sulaiman Province the formation is dominantly light grey to yellow grey, medium hard, argillaceous limestone which is slightly nodular in the lower part, where yellow to greyish yellow marl and calcareous shale are intercalated. In the area around Bara Nai (Kirthar Province), the formation consists dominantly of limestone which weathering in tones of bluish grey, light brown, cream and buff, thin bedded in the upper and thick-bedded massive and reefoidal in the lower part. The limestone is sandy in the upper part where some shale and brown weathering sandstone are intercalated in the Karachi Embayment area (subsurface at Dabbo Creek), light grey to chalky marl dominates the sequence with subordinate argillaceous limestone and calcareous shale.

The formation is widely exposed in the Sulaiman Province, parts of the Kirthar Province (Laki anticline) and the Axial Belt (Quetta region). The unit is 100 m thick at the type section, 53 m in north east of Pui, 44 m at Murree Brewery Gorge, 90 m at Bara Nai and 248 m in subsurface at Dabbo Creek. The formation conformably overlies the Mughal Kot Formation throughout its extent with a transitional contact. However, where the Mughal Kot Formation is not developed (Bolan Pass), it unconformably overlies the Parh Limestone. In the Sulaiman province, the formation is conformably overlain by the Pab Sandstone with a transitional contact, and by the Moro Formation with a sharp contact marked by resistant brown limestone that represents the basal bed of the Moro Formation. In parts of the Axial Belt it is unconformably overlain by the Dungan Formation and the contact is marked by a lateritic crust (Murree Brewery Gorge), while in other parts (Kirthar Province) it is conformably overlain by the Pab Sandstone. The unconformity recognized in the Murree Brewery Section is found to be widespread as is indicated by the "Ziarat laterite" that intervenes between the Parh Limestone and Dungan Formation in the Wani area (Sulaiman Province) and the Jacobabad well, where the Paleocene Dungan Formation overlies the Jurassic limestone.

Williams (1959) reported *Omphalocyclus macropora* and *Orbitoides* spp, and assigned Maastrichtian age to the formation. Hunting Survey Corporation (1961) reported Actinosiphon *punjabensis, Orbitoides media, Siderolites* sp. etc. and assigned a Maastrichtian age to the unit in Kirthar Province. Marks (1962) assigned middle or late Campanian age to the unit in Rakhi Nala on the basis of Orbitoides tissoti minima, found at its base and the upper part of the underlying unit. From the above it is reasonable to assign late Campanian to early Maastrichtian age to the Fort Munro Formation. Blanford (1879) correlated the formation with the "Hippuritic limestone" of Iran on the basis of a fragment of Hippurites from the scree at outcrops of the unit. Hunting Survey Corporation (1961) correlated the unit also with the Humai formation of Eruptive Zone on the basis of lithology and age. It is correlated with the upper part of the Kawagarh Formation of Kohat-Potwar Province.

**Pab Sandstone:** The term Pab Sandstone was introduced by Vredenburg (1908), the name being derived from the Pab Range in the Kirthar Province. Williams (1959) designated at its type section a section along the route, "Somalji trail", west of Wirahab Nai (Lat. 25° 31' 12" N: Long. 67° 00' 19" E), across the Pab Range.

The formation typically consists of quartzose sandstone which is white, cream or brown, weathering yellow brown, medium to coarse grained thick bedded to massive, and shows cross stratification. Some marl and argillaceous limestone, similar to that of the Parh Limestone are found intercalated. Subordinate shale is dark grey and calcareous in the Pab Range, brown and sandy in the Laki Range and pale grey, white, pale green and maroon in the Axial Belt (between Shinkai and Shingher). The formation is widely developed in the Sulaiman and Kirthar Provinces and Axial Belt. Its thickness varies considerably and is 490 m at type section and over 600 m to the south and west of Khuzdar but pinches out northward to complete absence in parts of Marri-Bugti hills. Further north, it thickens to 450 m in the Fort Munro anticline, but again further north it thins to about 240 m in west of Mughal Kot.

The sandstone conformably overlies the Fort Munro Formation in the Sulaiman and Kirthar Provinces and the Parh Limestone in the Axial Belt. In parts of the Sulaiman Province, Kirthar Province and Axial Belt, it is overlain conformably by Moro Formation, while in other parts unconformably by the Khadro Formation, "*Carditabeaumonti*" beds of Hunting Survey Corporation (1961) of the Ranikot Group. The presence of lateritic red nodules in the basal sandstone bed of the Ranikot Group is suggestive of a disconformity. In parts of the "Arenaceous Zone" of the Axial Belt, it is overlain conformably by the Rakhshani formation and by the Dungan Formation in parts of the Axial Belt and the Sulaiman Province.

According to Fatmi (1977), Vredenburg (1908) reported *Orbitoides (Lepidorbitoides)* minor of early Maastrichtian age from the lower part of the formation in Rakhi Nala. Williams (1959) recorded a mixed benthonic-pelagic assemblage of foraminifers of Maastrichtian age from the type locality. Hunting Survey Corporation (1961) reported two collections, one of them of "Sentonian-Maastrichtian" and the other of "probably Maastrichtian" ages. On the basis of these data, a Maastrichtian age is assigned to the unit. Recently, a large number of Dinosaurs fossils have been discovered by Malkani (2004). According to him, "Three new genus and species of *Titanosaurids/Pakisaurids,* and two new genus and species of Saltasaurids are identified. Three new taxon of Titanosaurids are *Pakisaurus balochistani, Sulmanisaurus gingerichi and Khetranisaurus barkhani;* two new taxon of *Saltasaurids* are *Marisaurus jeffi* and *Balochisaurus malkani.* All of them are diagnosed mostly on the basis of morphology of caudal vertebrae. One new genus and species of abelisaurids theropod dinosaur as diagnosed is Vitakridrinda sulaimani". The Pab Sandstone is correlated with the Moro formation and the upper sandy member of the Kawagarh Formation of Hazara.

**Moro Formation:** The "Limestone with Hemipneustes sp." of Vredenburg (1909) was named Moro Formation by Hunting Survey Corporation (1961), after the Moro River that flows between Johan and Bibi Nani. The Moro Formation as used in the present report also represents the lower part of the "Dungan and Jamburo groups "of Hunting Survey Corporation (1961). The shale and marl which have been included in the upper part of the Pab Sandstone by Hunting Survey Corporation (1961), in various parts of the area, are dealt with here under the Moro Formation.

Fatmi (1977) records the details of Moro Formation in which he stated that the formation consists of grey, medium to thick-bedded, argillaceous limestone, grey to dark grey marl, dark grey to grey green calcareous shale and minor "Pab like sandstone" and volcanic conglomerate of mottled appearance (only in the lower part). Limestone is the dominant lithology in the Sulaiman Province where it contains chert lenses while marl is dominant in the Sanjawi area (Sulaiman Province) and Axial Belt. In the Kirthar Province shale constitutes the main rock type.

In the Moro River and Bolan Pass sections Hunting Survey Corporation (1961) differentiated three units. The lower consists of limestone and marl with subordinate volcanic conglomerate and sandstone. The middle consists mainly of soft weathering marl and shale with locally developed sandstone beds, and the upper consists of dominant limestone, capped by the basal conglomerate of the overlying formation. These sub-divisions hold good in the area northwest of Pui, except for the absence of volcanic conglomerate and sandstone.

The Moro formation conformably overlies the Pab Sandstone with a gradational contact wherever the two units are in contact. However, where the Pab Sandstone is not developed the formation either conformably overlies the Fort Munro Formation (northeast of Pui) or disconformably the Parh Limestone (Moro River-Bolan Pass). The contact is marked by a conglomerate which is 10 to 90 cm thick and consists of small angular chips to rounded cobbles (up to 15 cm) of the underlying Parh Limestone embedded in greenish grey shale. The Moro Formation, in its type section, is overlain disconformably by the Khadro Formation (basal part of the "Karkh Group" of Hunting Survey Corporation, 1961) and the contact is marked by a basal algal conglomerate of the latter unit. However, where the formation is overlain by the Dungan Formation (northeast of Pui Siazgi. etc.) the contact is transitional and is placed at the base of the cliff-forming limestone of the Dungan Formation.

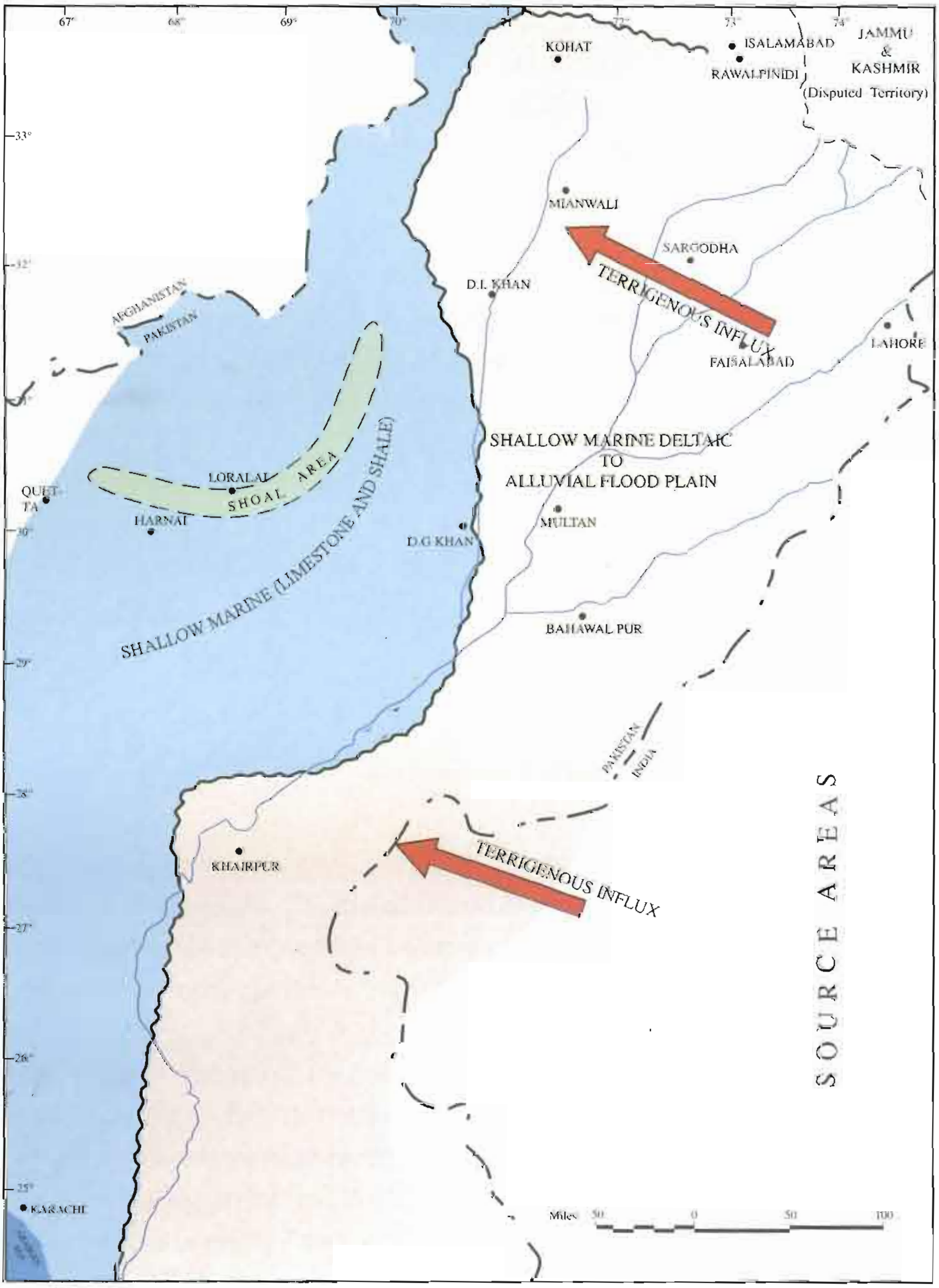
Hunting Survey Corporation (1961) reported *Globotruncana* aff. *G. linnei, Lituola* sp. *Omphalocyclus macropora, Orbitella media, Orbitoides* sp., *Siderolites* sp. and assigned a Maastrichtian age to the formation. The formation is a lateral facies equivalent of the Maastrichtian Pab Sandstone and at places overlies it (Fatmi, 1977). The Moro Formation is correlated with the Humai formation and the Pab Sandstone of Balochistan and the uppermost part of the Kawagarh Formation of the Kohat area.

## CRETACEOUS PALEOGEOGRAPHY

Depositional environment worked out for Sembar, Goru in the west, Chichali and Lumshiwal in the east, has been utilized in the reconstruction of Paleogeography of Cretaceous age. Other Cretaceous formations are also utilized but the basis of this map originates from Early Cretaceous formations. During Early Cretaceous time, the area of Sulaiman Range and the Upper Indus Basin and part of Axial Belt especially Quetta region in the west was a broad marine shelf opening westward, without restriction, into a southerly extension of the Tethyan Sea (Fig. 15). The shelf was bordered on the east by the Indian Shield which served as the source for the terrigenous clastics now present in the Lumshiwal, Chichali and Sembar formations. During the time in which the Lumshiwal Formation was deposited, a westward prograding delta was present in the area covering the "Sargodha High" and the Trans-Indus and Salt ranges. Rest of the area was occupied by a shallow marine sea throughout the remainder of the Early Cretaceous.

In other words, seaward advancement of the shoreline took place in the Early Cretaceous as a result near shore deposition of Lumshiwal Formation occurred. Thus, the Lumshiwal Formation is an excellent example of prograding delta.

Southwards, by Late Cretaceous time, broad elongate welts developed in the vicinity of the present day "Jacobabad High", Sanjawi Arc, and "Sargodha High". These structures apparently




LEGEND

Shallow marine (Limestone and shale), sablittoral, edge of continental shelf

Shallow marine, deltaic alluvial flood plain which may contain river swamps and delta

Shoal area, raised land but under water, not biogenic

Modified after Flynn (1972)

Fig. 15. Paleogeographic sketch map of Early Cretaceous.

controlled deposition to a certain extent, with the result that the intervening basin area received the greatest amount of clastic sediments, whereas the less rapidly subsiding arches were largely the sites for the deposition of limestones.

During Maastrichtian time, rate of deposition exceeded the rate of subsidence in the basin area, thereby causing a general retreat of the seas. The sandstones of the Pab sandstone were deposited in a very shallow littoral environment, indicating that the eastern shoreline had progressed westward. Thus, an elongate north south trending area developed, containing coastal flood plains, shallow marine embayment and linear coastline with beaches and offshore barrier bars throughout northern Kirthar and Sulaiman ranges and adjoining areas. It is important to record that the pinch out of Pab Sandstone towards the Sanjawi Arch, Jacobabad High and equivalent sand beds at Sargodha High indicates that these areas were emergent and probably subjected to erosion (Flynn, 1972).

## BALOCHISTAN BASIN

### Eruptive Zone of Balochistan Basin

Cretaceous strata are the oldest exposed rocks in this area and are divided into the following formations:

2. Humai formation
1. Sinjrani volcanic group

**Sinjrani volcanic group:** The name "Sinjrani" was introduced by Hunting Survey Corporation (1961) derived from the name of a tribal district in the Chagai area, for rocks referred to by Vredenburg (1901) as "Flysch". The name is extended to other parts of the Eruptive Zone such as the Raskoh Belt, where similar strata were referred to by Hunting Survey Corporation (1961) as "Kuchakki volcanic group".

Lithology of the Sinjrani volcanic group in the type locality, as described by Fatmi (1977), is mainly composed of "agglomerate, volcanic conglomerate, tuff and lava with subordinate shale sandstone and limestone. Agglomerate and volcanic conglomerate are the dominant rock types and are grey green or black in colour. Variegated fine ash and tuff are interlayered with the agglomerate. The lava flows are porphyritic andesite, but some are basalt and quartz andesite. Tuffaceous shale and gritty green sandstone are locally abundant. Some lenticular layers of limestone and calcareous shale are also found associated particularly in the upper part of the group south of Chagai hills. The limestone is either grey, argillaceous, crystalline or sub lithographic and porcellaneous similar to the Parh Limestone".

The Sinjrani volcanic group is widely distributed in the Chagai hills and Raskoh Belt of the Eruptive Zone, where it forms the oldest strata exposed. The exposed thickness is 900 to 1200 m. In the Raskoh Belt, however, limestone is frequently found in the upper part which may represent the Humai formation but was included by Hunting Survey Corporation (1961) in their "Kuchakki volcanic group". The upper contact with the Humai formation in the Chagai area is generally conformable and the lower contact is not exposed. In the Raskoh Belt, however, the Humai formation has not been recognized separately where the Sinjrani group ("Kuchakki volcanic group") is overlain transitionally by Rakhshani formation of Paleocene age.

The formation stratigraphically underlies the Upper Cretaceous Humai formation. It has yielded poorly preserved fossils including algae foraminifera and corals *(Mesophyllum)*. The group is dated as Cretaceous.

**Humai formation:** Hunting Survey Corporation (1961) introduced the term "Humai formation" from Koh-e-Humai Hill (of Koh-i-Sultan) in the Eruptive Zone for the Upper Cretaceous mixed lithology which included the "Hippuritic limestone" of Vredenburg (1901).

Fatmi (1977) stated that the formation shows great variation in lithology. In Koh-e-Humai, it consists of greenish-grey and purple shale. Calcareous sandstone, siltstone, thin bedded limestone and volcanic conglomerate in the lower part and massive, dense, reefoid limestone with abundant *Hippurites* in the upper part. This dense and reefoid limestone laterally passes into grey, thick bedded and arenaceous limestone in Mazenen Rud. On the eastern flank of the Kacha anticline in the westerly exposures the formation consists of conglomerate (boulders of limestone and volcanic rock) with gritty and tuffaceous beds and grey, thin bedded limestone. Massive limestone predominates at Kacha Rud, 6 km northeast of Kacha, while purplish-grey, some times white, thin- to thick-bedded limestone predominates at Siah Koh in the easterly exposures.

The Humai formation is restricted to part of the Eruptive Zone between the Kacha and Siah Koh areas in North Chagai division. Hunting Survey Corporation (1961) reported a thickness of at least 91 m from Koh-e-Humai and over 306 m from Mazenen Rud. The Humai formation overlies unconformably the Chagai intrusions or Sinjrani volcanic group along the southern margin of the Chagai hills but in other areas has a conformable contact with Sinjrani volcanic group though the presence of conglomerate at the base of the formation, may suggest a disconformity. It is overlain conformably by the Rakhshani formation and the contact is easily placed at the base of soft weathering shale of the later unit.

The Humai formation is fossiliferous and has yielded algae, foraminifers, coelenterates, gastropods and bivalves. The bivalves include *Hippurites* sp., *H. loftusi, Lapeirousia* sp. and *.Monopleuridea gen.*, nov., (Cox) etc. The foraminifers include *Lepidorbitoides socialis, Orbitella media, Orbitoides* sp., *Omphalocyclus* sp. and *Baculogypsinoides (=Siderolitis)* sp. These fossils indicate Maastrichtian age. The Humai formation has been correlated with the "Hippuritic limestone" of eastern Iran and south-western Afghanistan, the Fort Munro formation of western Sind and discontinuous beds of limestone in the upper part of the Sinjrani volcanic group of the Raskoh Belt.

## AXIAL BELT

In the southern part of the Axial Belt (Lasbela area) and it's northerly and north-easterly extension in the Zhob Valley and parts of Kurram and Waziristan territory, a heterogeneous assemblage of igneous and sedimentary rocks is present which is dated as Cretaceous. In the Lasbela region, these rocks have been referred to by Hunting Survey Corporation (1961) as "Bela volcanic group". The Zhob Valley and Waziristan outcrops seem to be an extension of this group. Many important mineral deposits such as chromite, manganese and others are associated with rocks of this group.

**Bela volcanic group:** The name was introduced by Hunting Survey Corporation (1961) derived from Bela town for rocks referred to by Vredenburg (1909) as a continuation of the Deccan Trap. The rocks of the group are quite distinctive and were laid down in marine environment as contrasted to the terrestrial (plateau type) volcanics of the Deccan Trap.

According to Fatmi (1977), the Bela volcanic group shows extreme variation in lithology and include volcanics, which are interlayered irregularly and in variable proportions with the sediments. The volcanic rocks are mainly basalt coarse agglomerate and bedded tuff. The lavas are commonly of pillow type and spilitic. Most of them weather reddish brown and green. The sedimentary rocks include shale, marl, limestone, conglomerate and radiolarian chert. The shale and marl weather maroon and dark green. The limestone is grey, white and is similar to the Parh Limestone. Radiolarian chert, jasper and silicified ferruginous shale are developed locally in considerable thickness.

The group is mainly developed in the southern part of the Axial Belt and rocks of similar nature are discontinuously found in Zhob Valley and Waziristan. In Lasbela, its thickess is 1515 to 3940 m. The group overlies the Shirinab Formation ("Windar group" of Hunting Survey Corporation. 1961) with a sharp contact, which Hunting Survey Corporation believes to be conformable (but it may represent a significant break). Northwest of Lasbela the group is overlain by *Nal limestone member* (Nari Formation) of Oligocene age. The Bela volcanic group is correlated with the Sinjrani volcanic group of the Eruptive Zone and with Sembar Formation, Goru Formation and Parh Limestone of adjoining areas of the Axial Belt and the Sulaiman and Kirthar Provinces (Fatmi, 1977).

**Chashmai Kharsai formation:** Ahmed et al. (2000) named Chashmai Kharsai formation to the belemnite-rich shaly horizon above the Isha formation, with type locality at Chashmai Kharsai (Lat. 32° 58' 36" N: Long. 70° 05' 30" E) along Mirali-Miran Shah road. Chashmai Kharsai formation is dominantly composed of shale of dark green colour weathering to rusty brown with purple tint. The formation at places, contains glauconitic sandy layers. The shale is highly fossiliferous and is full of the belemnites. The thickness measured at the type locality is 30 m. The formation has disconformable contact with the underlying Isha formation and the upper contact is gradational with the overlying Marsi Khel formation. Based on the belemnitic fauna and lithology, it can be correlated with the Chichali Formation in the Samana-Kohat area and Sembar formation of the Axial Belt. Early Cretaceous age is given to Chashmai Kharsai formation.

**Marsikhel formation:** Ahmed et al. (2000) named and described Marsikhel formation an alternate succession of belemnitic shale and limestone, best exposed near Marsikhel Village in North

Waziristan (Lat. 33° 02' 30" N: Long. 70° 10' 30" E). According to Ahmed et al. (2000) the Marsikhel formation consists of light grey to dark grey, thin to medium bedded limestone and greenish grey shale. In the lower portion the limestone is micritic and arenaceous at places. Ferruginous and calcareous sandstone is also present near the base. Within the limestone alternate layers of light green shale are present. The shale is rich in belemnites. The formation is found to be 250 m thick at the type locality. It has a conformable contact with the underlying Chashmai Kharsai formation and the overlying Zerghar formation in Kurram Agency area.

The formation is correlated with the Goru formation of Axial Belt, Sulaiman and Kirthar Provinces and with the Lumshiwal Formation of the Samana, Kohat area on the basis of its stratigraphic position; however there is considerable facies variation between the two formations. The Marsikhel formation has abundant belemnites and also contains forams. The age assigned to the formation is Early to Middle Cretaceous.

**Zerghar formation:** Ahmed et al. (2000) coined the term Zerghar formation limestone sequence exposed at about 5-6 km northeast of Miran Shah Town (Lat. 32° 59' 41" N: Long. 70° 08' 22" E). The lithology at the type locality is mainly limestone and varies in colour from brown to yellowish grey on fresh surface and on weathered surface it is dull brown. It is fine-grained and thin to thick-bedded. On broken surface the impurities of iron oxide are visible as cementing materials. The limestone is highly fossiliferous, worm burrows are also present; limestone is interbedded with shale. The shale is greenish grey to rusty brown in colour and contains belemnites. The formation has conformable contact with the underlying Marsikhel formation. Ahmed et al. (2000) correlated the formation with Fort Munro Formation of Kirthar and Sulaiman ranges and also with the Kawagarh Formation of the Samana-Kohat area. The formation is highly fossiliferous and contains fossils like corals, algae, foraminifera, bryozoans, belemnites, gastropods, brachiopods and fragments of molluscs. On the basis of the above mentioned fossils, Middle to Late Cretaceous age is assigned to the formation (Ahmed et al., 2000).

## KOHISTAN ISLAND ARC

In the Northern Tectonostratigraphic Basins and Ranges Terrenes, the Kohistan Terrene represents an intra-oceanic island arc. It is bound by Main Karakoram Thrust (MKT) in the north and the Main Mantle Thrust (MMT) in the south. The MMT is the north western extension of Indus-Tsangpo Suture into Pakistan and the MKT marks the closure of a back-arc basin. This back-arc basin and the Kohistan island arc were developed close to the Asian plate within the great Tethys Ocean. A general account of the Tethys Ocean is given below.

**Tethys Ocean:** It is generally believed that following the last vigorous phase of Hercynian orogeny, the Prototethys of Europe was closed and in the Upper Carboniferous, (the Stephanian), a new sea trough was formed above the Hercynian basement. This new sea trough is known as the Tethys. A very brief description or outline of the Tethys Ocean is given below:

Tethys was originally named by Eduard Suess (1883, 1904), having existed during Mesozoic time, surfing between the shores of Gondwanaland in the south and Angaraland to the north. He regarded marine sediments of Mesozoic extending from Sumatra and Timor through Tonking and Yunnan to the Himalaya and the Pamir, Karakoram, Hindukush, and Asia Minor as relict of the Tethys. On the other hand, in the later part of nineteenth century, the name Gondwanaland was introduced by a great geologist Eduard Suess (op. cit) for the lofty 'tableland' comprising southern and most central part of Africa, Madagascar and Peninsular India which are characterized by the Gondwana flora of essentially Carboniferous to Permian age.

Wegner (1915) conceived a great continent named Pangaea, a hypothetical super continent, which existed as a single land mass but defined together Laurasia in the north and Gondwana in the south.

Consequently, Alex Du Toit (1937), in forwarding the theory of continental drift recognized, during late Palaeozoic and lower Mesozoic, the existence of two super continents namely Gondwanaland to the south separated by Tethys from Laurasia to the north. Gondwana in its precise definition included South America, Africa, India, Australia and Antarctica as well as the smaller fragments of Arabia, Madagascar and New Zealand. Between 200 and 130 Ma, the fringe regions of Gondwana that bordered the northern edges of Australia, India and Arabia split from Gondwana into a number of small micro-continental fragments. These fragments drifted north and accreted to the southern margin of Laurasia. These accreted regions are now Iran, Afghanistan, northern Pakistan and southern Tibet (Molnar, 1986).

The total break up of Gondwanaland began with the flight of the continents from near the South Pole, movement among different plates initiated towards their destined course and the great Tethys started shrinking. Views of various workers are summarized below. The fragmentation of the Gondwanaland was probably initiated during Middle Jurassic. According to Powell (1979) India was separated from the rest of the Gondwana at about 130 Ma ago and moved northwards during 130 to 80 Ma with the speed of 3 to 5 cm/year, from 80 to 53 Ma at the speed of 15 to 20 cm per year and from 53 Ma to the present day at the speed of 4 to 6 cm/year. In a revised statement Powell et al. (1988) stated that the northward movement of India did not begin until about 96 Ma. He suggested that between 96 Ma and 49 Ma India moved northward for about 5600 km at a near constant speed of 12 cm/year, which is the minimum calculated pre-collision drift rate.

Actually, India then broke away from Gondwanaland at 132.5 Ma and began a counter clockwise rotation away from Antarctica (Powell et al., 1988; Treloar and Coward, 1991), at the same time northerly subduction of the Neo-Tethys was initiated (Johnson et al., 1976). On the other hand, Patriat and Achache (1984) estimated that, between 73 to 52 Ma, the drift rate was between 15 and 20 cm/year. According to Molnar and Tapponier (1975), from 65 to 50 million years ago, India moved with a rate of 15 to 20 cm/year; between 40 and 50 million years the movement decreased abruptly to a relatively constant rate of 5 cm/year. Molnar (1986) thought this abrupt slowdown was a consequence of the collision between Asia and India. This suggestion that collision occurred at this time based on the fact that the latest marine sediments found in the Indus-Tsangpo Suture Zone were about 55 Ma old (Powell and Conaghan, 1973) and that fossil mammals in the sedimentary rocks in

India are younger than 45 Ma., indicating land areas in place of sea.

The break-up of Gondwanaland during Middle Jurassic, rapid northward flight of India, northward intra oceanic subduction close to and south of the Asian plate, formation of intra oceanic island arc and subsequent collision between Indian and Asian plates have resulted in the sandwiching and preservation of the, now, world famous Kohistan island arc between Indian and Asian plates. These events have bestowed uniqueness to the geology of northern Pakistan.

Generally, the main Karakoram Thrust is taken as the separation line of Laurasia and Gondwana continents, but some Gondwanic similarities have also been reported from Chitral (Hindukush and Karakoram), making Chitral sediments (situated north of MKT) as part of Gondwanaland, thereby pushing the ultimate contact between Gondwanaland and Asian plate further north at Herat Fault. Nevertheless, arguments are still going on as to weather Chitral sediments have Gondwanic characteristics? To resolve this riddle, Fuchs (1982) and Bouline (1981) follow the ideas of Stocklin (1977) and assume that the Chitral-North Tibet fragment detached from Gondwana in the Early Devonian and crossed **Tethys 1.** In the Upper Devonian, it had the northern position and finally collided with Eurasia leading to the Hercynian Hindukush and Kun Lun Belt. In the Permian-Triassic, Central-Afghanistan and the South Tibet separated from Gondwanaland, crossed **Tethys 2** and collided with Asia (Neo-Kimmerian orogeny). Behind them **Tethys 3** opened, the ocean, which was closed in the CretaceousCainozoic, when India accreted to Asia.

**Research on island arc:** The work in this region remained a reconnaissance type prior to 1956, when Ivanac et al. (1956) initiated the work in the northern (adjoining) part of the Kohistan island arc. This was followed by the work by Martin et al. (1962) in the southern part of the Kohistan terrane in Swat, who named some of the rocks including the "Upper Swat Hornblendic Group".

Jan (1970), Jan and Mian (1971) and Jan and Kempe (1973) mapped much of the Swat Valley. In a preliminary petrological study, Jan and Kempe (1973) pointed out the similarities of the amphibolites and gabbronorites of the Swat area with those of the (calc-alkali) tholeiitic basalt-andesite series of orogenic belts. From additional geochemical data, Jan (1977) also concluded that the basic rocks from the southern parts of the Kohistan arc have chemical affinities of calc-alkaline magmatic rocks of orogenic belts and island arcs. Chaudhry et al. (1974, 1987) performed extensive geological work in Dir district and published several reports on Dir area. Chaudhry et al. (1974b) classified the amphibolites of the Kohistan into banded amphibolites, layered amphibolites, gneissic amphibolites and foliated amphibolites. Chaudhry et al. (1974c), for the first time in Dir, also proposed a northern amphibolite belt and a southern amphibolite belt. They regarded the northern amphibolite belt mainly as paraamphibolites and the southern amphibolite belt as orthoamphibolites. Later, they also carried out large scale mapping in the southeast and adjacent areas of the arc for detail work see Ghazanfar and Chaudhry, 1991 and Chaudhry and Ghazanfar, 1990. The earlier studies on the geology of this important unit of Kohistan was carried out by Jan (1968); Chaudhry et al. (1980, 1987); Hussain et al. (1989); Kazmi et al. (1984) and Spencer et al. (1988). Hussain et al. (1984) gave the name of Kot-Prang Ghar Mêlange Complex to an extensive mêlange zone exposed in the western part of Malakand Agency and southeastern Mohmand Agency.

In fact much of the Kohistan region remained unexplored till very recent times and as a result, this stretch of terrane was shown blank on the first geological map of Pakistan produced by the Geological Survey of Pakistan (Bakr and Jackson, 1964). However, in late seventies sufficient geological data had been collected to prepare a preliminary geological map that proposed some models for the evolution of the Kohistan terrane that would fit in the framework of plate tectonic theory (Tahirkheli and Jan, 1979). It was proposed that the Kohistan terrane represents an ancient fossil island arc trapped between Indian and Eurasian plates. Several studies have been conducted on various aspects of the lithologies of the terrane in terms of field relationships, mineralogy, petrology, metamorphism, structure and radiometric dating and tectonometamorphic events. To produce their work in a summarized form is beyond the scope of this volume and interested readers are referred to the publication cited here.

**Collision of the continents, Events and Times:** Three plates, Eurasian, Indian and intra Tethyan island arc, ultimately were joined together to form the present day south Asian subcontinent. Simplified version of the collision process of the plates, events and times as described by various workers is outlined below:

Originally it was proposed that the Kohistan island arc was welded to Indo-Pak plate first, in the early Tertiary and onwards an Andean-type cordilleran margin situation prevailed, before the final closure of the Tethys (Tahirkheli, 1979; Jan and Asif, 1983 and Chaudhry et al., 1994). According to Jan and Asif (1983), terminal collision took place between the combined terrane of Kohistan island arc and Indo-Pak plate with the Karakoram block of the Asian plate, which eventually whipped out the great Tethys Ocean. Chaudhry et al. (1994), on the basis of sedimentological record proposed that the Indian plate established its first contact with the Kohistan island arc at 67 Ma prior to the main collision between Indian and Asian plates, which completely sandwiched Kohistan island arc at 55 Ma. Reversely, another picture, based on radiometric dating of events came up subsequently, which confirmed the accretion of the arc with Eurasian continent first and then both Eurasian and the arc together, ultimately, collided with the Indo-Pak plate affecting the disappearance of the Tethys Ocean.

On the other hand, Spencer (1993) described a "head-on", north-south collision of India with Asia. This event is stated to have occurred in Eocene 55-40 Ma and very few workers span, this event earlier, up to 10-25 Ma. The terminal collision between the Indian and Asian plates is suggested to have occurred between 45-40 Ma. It is generally agreed; however, that much earlier than 55 Ma, the Kohistan island arc was already sutured to the Asian plate, probably since the Late Cretaceous. This

[1](Ahmad et al. 1987; Anczkiewicz et al. 2000; Bard et al, 1980; Based on different geochronological methods, the ages of the plutonic rocks very between 102 Ma and 29 Ma. Casnedi et al. (1979); Blasi et al. (1980); Jan et al. (1981) and Calkins et al. (1981) reported abundant occurrences of granitic rocks north of Gilgit and along the Indus, Giligt, Ghizar and Swat rivers, Burg et al., 1998; Coward et al., 1982, 1986, 1987; Ghazanfar et al., 1991; Jan and Asif (1983) presented geochemical data for calc-alkaline plutonic from Swat Kohistan; Jan and Howie, 1981; Jan and Jabeen, 1990; Jan and Windley, 1990; Jan et al. 1993; Khan 1988; Khan and Coward, 1990; Khan and Thirlwall, 1988; Khan T. 1994; Khan T. et al. 1993, 1994, 1996, 1997; Peterson et al., 1990, 1993; Pognante and Spencer, 1991; Petterson and Windley, 1985, 1991; Petterson and Windly, 1985, 1991; Petterson et al. 1993; Pudsey et al. 1985; Pudsey, 1986; Robertson and Collins, 1999; Rolland et al., 2000; Searle, 1991; Shah, M.T. et al., 2000; Takahashi Yuhei et al., 1996; Takahashi Yutaka et al., 2003; Treloar et al. 1989, 1990, 1996). The eastern and western parts of the Kohistan batholith have been extensively surveyed in the accessible valleys (Windley et al., 1985; Zeitlar, 1985).

is confirmed by the presence of 85-80 Ma thermal event at this time. According to Treloar et al. (1996), Kohistan arc sutured to Asia at 100 Ma and at about 85 Ma, intra-arc rifting permitted the emplacement into the arc of the voluminous gabbronorites of the Chilas complex, which intruded the Kamila amphibolites group. According to Spencer (1993), the collision between the Indian plate and the Kohistan island arc is recognized at a time when the Tethyan Ocean disappeared and the two continental masses docked. Schaltegger et al. (2002) also inferred a Late Cretaceous age of the docking of the Kohistan arc with the Asian margin before Paleocene-Mid Eocene collision with India.

Timing of these events is still in the process of finalization and so much discussion on the relative timing appears in the literature that it is hard to keep a track. However, a generalized view summed up by Searle (1991) and Spencer (1993) is summarized as follows:

The Indo-Pak plate broke away from the Gondwanaland in the Early Cretaceous but the northward movement began roughly at the early Late Cretaceous boundary. It then moved about 5000 - 6000 km north through over 70° latitude, relative to the Asian plate between 90 Ma and 50 to 45 Ma, until collision. This collision is associated with abrupt changes in the marine magnetic anomalies as either 23 (~ 55 Ma.) or 20 (~ 45 Ma.). After collision continued suturing occurred associated with a 35o anticlockwise rotation of the Indian plate relative to Eurasia.

Scenario in the Himalayan Tectonostratigraphic Terrane is altogether different. In the adjoining areas, south of Kohistan island arc, Chaudhry and Ghazanfar (1993) have located signs of taphrogeny and taphrogeosyncline. According to them in the northwest Himalaya, "Taphro orogenic" Hercynian earth movements are represented by well-marked tectono-thermal and tectonomagmatic events (Chaudhry et al., 1992; Chaudhry and Ghazanfar, 1993). A widespread "Permo-Carboniferous Alkaline Province" developed in northern Pakistan and adjoining Afghanistan (Jan and Kempe, 1970; Chaudhry et al., 1981; Baloch et al., 1997). While in the southern parts of Hazara and Kashmir, the deepening rifts changed to Panjal Sea, with the development of Hazara-Kashmir microcontinent and extensive submarine basaltic volcanism associated with siliceous turbidites (Chaudhry et al., 1992). Tethys was opening to the north of Hazara-Kashmir microcontinent (Butt et al., 1985). Due to the bpressure exerted by the rapid opening of the Tethys to the north on the Hazara Kashmir microcontinent, the Panjal Sea disappeared with accretion of Hazara-Kashmir microcontinent to the Indian Plate.

**Regional Tectonic setting of the Kohistan Terrane:** India drifted northward for a minimum of 5000 km with respect to Eurasia before the two collided during the Early Tertiary (Klootwijk et al., 1992; Le Fort, 1975; Molnar and Tapponnier, 1977; Powell, 1979). Its collisional boundary in southern Tibet is traceable along the Indus-Tsangpo Suture (ITS). The Northern suture or Shayok Suture or Main Karakoram Thrust (MKT) and the Southern suture or Indus Suture or Main Mantle Thrust (MMT), which are the westerly extension of the ITS, enclosed the Kohistan terrane (Tahirkheli and Jan, 1979). Both sutures are characterized by the association of ophiolitic mêlanges and, in the case of MMT, blueschist and high-pressure granulites (Jan, 1991), while in northern suture no blue schist is present, Muhammad Ayyub Khan of Geological Survey of Pakistan (verbal communication 2004). The MKT and MMT extend E-W in northerly convex arcs, terminated in eastern Afghanistan by the N-S trending Bela-Zhob-Waziristan suture (Khan, T. 1994)

Khan, T. (1994) stated that the MKT and MMT enclose an area of 36000 $km^2$, which is occupied by volcanic, plutonic, and subordinate sedimentary rocks variably deformed and metamorphosed. These were considered to represent an intra-oceanic island arc that developed in response to the northward subduction of Neotethyan oceanic lithosphere (Tahirkheli and Jan, 1979). The arc is split into Ladakh and Kohistan as its eastern and western parts by the N-S trending Nanga Parbat-Haramosh dome (Zeitler, 1985). Northern Pakistan, thus, comprises two continental blocks with a sandwich of the Kohistan terrane.The Karakoram block, bounded to the south by MKT, consists of Palaeozoic and subordinate Mesozoic sediments into which have been emplaced 1) the Khunjrab-Wakhan-Trichmir granitoids of the (?) Jurassic to Cretaceous ages to the north and 2) the Karakoram batholith of Cretaceous to Tertiary age to the south (Debon et al., 1987). The Indian plate is made up of Precambrian to Cambrian basement and Palaeozoic to Mesozoic and Tertiary cover. Several episodes of plutonic activity ranging from Precambrian to Permo-Triassic and even Himalayan age have been recorded in the Indian plate margin in northern Pakistan (Chamberlain et al., 1991; Jan and Karim, 1990; Shams, 1983).

The Himalayan mountain ranges are considered as a classical example of continent-continent (i.e. India-Eurasia) collision (Dewey and Bird, 1970). In the northwest Himalaya, sandwiched Kohistan-Ladakh island arcs separate the two continental blocks. Previous studies have shown that the Kohistan island arc in the northern Pakistan is tilted towards north. Uplift and erosion have revealed a remarkable complete cross section of the terrane in the middle Indus Valley (this arc according to the present investigations is a collage of island arc and back-arc basin (Khan et al., 1993). A north to south traverse between the Shayok (MKT) and Indus (MMT) sutures shows the following major lithologies, each stretching E-W for several hundred kilometres (Yoshida et al., 1996).

The Kohistan sequence represents a structurally coherent section of an island arc terrane, comprising of a 30-40 km thick section of metamorphosed, plutonic, volcanic and sedimentary rocks. This succession is interpreted as a whole as calc-alkaline plutons intrusive into an oceanic crust and overlain by the calc-alkaline lavas and associated sediments. Accordingly, the interpretation is an intra-oceanic arc that developed during the Cretaceous somewhere in Tethys, a situation reminiscent of, but more evolved than the calc-alkaline lavas found in the Oman ophiolites. The main rock assemblages from north to south, i.e. downward sequence are shown in Table 8.

Table 8. Kohistan island arc at a glance.

| Zones | Age | Lithology |
|---|---|---|
| Upper crust | Cretaceous (Aptian-Albian) | **Yasin Group (Thelichi formation):** Slates, turbidites, volcanoclastics, volcanic, limestone and basal conglomerate. (Ivanac et al., 1956; Pudsey, 1986; Khan, T. 1994). They grade upward into fine grained shales and tuffs and contain limestones with an Albian-Aptian fauna (Pudsey et al., 1985). |
| | Early Cretaceous and possible Late Jurassic | **Chalt volcanic group**: Pillow lavas, tuffs, pyroclastic, and minor calcareous rocks underlying the Yasin group. The volcanic are subduction-related high-Mg tholeiitic andesites, boninites, calc-alkaline andesites and rhyolites metamorphosed to greenschist facies (Ivanac et al., 1956; Petterson et al., 1990). Tholeiitic lavas that possibly represent part of an ophiolite assemblage obducted during the Kohistan-Asian collision. The size of this oceanic back-arc basin (with respect to the Kohistan) is conjectural. |
| | Eocene | To the southwest and within the Kohistan Complex, metasedimentary sequence of deep marine origin (Dir, Utror and Kalam Groups) yielded Eocene fossils in upper-level limestones. Depositional models point to rapid subsidence in Paleocene times in an extensional restricted basin. Associated volcanic and volcanoclastic series are calc-alkaline basalts, basaltic andesites and andesites, emphasizing an arc environment (Sullivan et al., 1993). |
| Plutonic Crust | Late Cretaceous-Tertiary | **Kohistan batholith:** Calc-alkaline (mafic to silicic) plutons intruding detrital and calcareous metasediments and metavolcanic (amphibolites). The Tertiary plutons are generally undeformed, whereas the older ones are metamorphosed and deformed (Jan et al., 1981; Jan and Asif, 1983; Peterson and Windley, 1985, 1991; Petterson et al., 1990).<br>**Chilas complex:** Generally separating the granitic belt from the southern amphibolite belt, this complex extends E-W for about 300 km and attains a breadth of up to 40 km. More than 85% of it is made up of meta-gabbronorites; other lithologies include hypersthene quartz diorites, troctolites, anorthosite, pyroxenites, chromite-layered dunites and peridotites, and retrograde amphibolites (Jan et al., 1984; Khan Asif et al., 1989). In the Chilas area the pyroxene quartz diorites, probably differentiate of the magma of gabbronorites affinity are the dominant rock-type and intrude amphibolitic rocks in the north and south of the complex. |
| | Cretaceous to Late Jurassic | **Southern (Kamila) amphibolite belt:** Metavolcanic with ultramafics, gabbros, diorites, tonalites, granites, trondhjemites and rare siliceous and calcareous metasediments (Bard et al., 1980; Jan, 1979, 1988; Khan et al., 1993; Treloar et al., 1990). |
| Mantle | Cretaceous (95 Ma minimum age) | **Jijal complex:** This complex is a tectonic wedge covering about 150 $km^2$ area to the north of MMT along the Indus river (Jan and Howie, 1981; Jan and Windley, 1990; Miller et al. 1991). This garnet granulite facies metamorphosed complex is made up of ultramafic base and gabbroic top, presumably representing cumulates in the roots of the Kohistan arc. The granulites, which have a Sm-Nd mineral isochron age of 103 ± 0.9 Ma (Coward et al., 1986) were equilibrated during high pressure metamorphism at a depth of about 34-40 km (Bard, 1983; Jan and Howie, 1981). Yamamoto (1993) has suggested even greater (~55 km) depth for the metamorphism of the complex.<br>**Sapat complex:** This complex also consists of ultramafic base and gabbroic top. Petrogenetically, the Sapat complex resembles the Jijal-Patan complex. Both form the basal part of the Kohistan terrane and are related to arc magmatism (Jan et al., 1993; Khan Asif et al., 1996; Kausar and Khan, 1996) |
| | Eocene-Oligocene | ( ? ) **Kalam-Dir volcanic:** Andesites, dacite, rhyolite, ignimbrite flows, tuffs and agglomerates, exposed in west-central Kohistan in Swat and Dir (Tahirkheli, 1979; Majid and Paracha, 1980). These overlie the Cretaceous detrital sediments of the Kalam group and older plutons of the Kohistan batholith, but are cut by younger granitic intrusions. |

**Arc splitting**

Gaetani et al. (2004) summarized some important information regarding the splitting arc obduction time, precollision events and collision related events, based on different views of workers as follows:

The Chilas noritic gabbros were first interpreted "to have been crystallized in the sub-arc magma chamber (Bard et al., 1980). "Later geochemical analyses suggested that it was generated by intra-arc rifting and subsequent mantle diapirism," Khan T. et al. (1993). The later interpretation is consistent with the gabbronorites having intruded volcanic and sedimentary components of the arc. Petro-structural observation supportively suggests that the ultramafic-mafic-anorthosite (UMA) associations occurring as a string of lenses over the >300 km length. According to the zircon U/Pb age of gabbronorites, rifting is about 85 Ma old (Schaltegger et al., 2002).

"The Chilas suite of mantle diapirs points to splitting of the Kohistan arc, with initial rifting taking place at the island arc like it is documented in modern island systems (e.g. Rocas Verdes). The UMA outcrops point to mantle diapirism as a key mechanism in opening back-arc basins between a volcanic and a remnant arc, the latter perhaps now seen as rocks screening the Kohistan batholith (Burg et al., 1998).

**When did arc obduction begin? What is the metamorphic record?**

The Kohistan island arc and the Indian plate were assembled during closure of Tethys, which produced thrusting along the Indus Suture. Within the suture, a discontinuous but up to 20 km wide zone of imbricated ophiolites, greenschist and blueschist is locally referred to as "mêlange unit". It is dominantly fore-arc related assemblage obducted onto the Indian plate (Anczkiewicz et al., 1998). In the footwall, the geology of the northern margin of the Indian plate is remarkably uniform. However, two high-pressure metamorphic events have accompanied the India-Kohistan convergence: blueschist facies metamorphism at ca. 80 Ma is linked to oceanic subduction and eclogite facies metamorphism at 50 Ma is linked to continual subduction.

Pre-collision events:

Blueschist imbricated within the suture between Indian plate and the Kohistan arc have yielded Ar40-Ar39 and Rb-Sr, phengite and Na-amphibole ages at 80 Ma and thus record a pre-collisional, Early/Late Cretaceous metamorphism during subduction of the Tethyan oceanic lithosphere (Anczkiewicz et al., 2000). Rapid exhumation and cooling of these high-pressure metamorphic rocks probably took place in an accretionary prism system dominated by corner flow processes.

**Collision-related events**

Collision of Asian plate and island arc with India plate developed Barrovian type metamorphism in the Indian sequence. U-Pb ages syn-metamorphic granites and Nd-Sm ages of ecologites indicate that at about 50 Ma the northern margin of Indian plate was deeply buried and being metamorphosed in high-pressure conditions (Spencer et al., 1995).

Metamorphosed sequences in the Indian plate give hornblende cooling ages of 38 Ma and muscovite cooling ages of 30 Ma (Treloar et al., 1989). The metamorphic and related structural fabrics in these rocks, therefore, record an important part of the collisions and the final emplacement of the Kohistan arc against this segment of the Indian plate. The post-Eocene thrust directions generated complex, refolded thrust patterns, large slab folding and rapid uplift with associated brittle faulting and seismic activity. No significant movement has taken place along the Indus suture since 20 Ma, as indicated by similar fission track ages on both sides of the suture (Zeitler, 1985).

**Existing Models for the Tectonic Evolution of the Kohistan Terrane**

A detailed fieldwork, supplemented by geochemical and geochmnological studies, has brought forth well-constrained models for the granitic plutons occupying most of the northern half of the Kohistan terrane. Petterson and Windley (1985, 1991) and Petterson et al. (1993) have recognized three stages of magmatism in the Kohistan batholith. The earlier phase granitic plutons yield an Rb/Sr whole-rock isochron age of 102 Ma emplacements, while the Kohistan island arc was still in the intraoceanic tectonic setting. The second stage of magmatism is most basic at 85-60 Ma, and acidic magmatism of 60-40 Ma, and is suggested to have formed and emplaced after the arc had accreted with the Karakoram plate, forming an Andean-type continental margin. The stage three magmatic activities comprises dense swarms of leucogranitic sheets at ca. 30 Ma., which are the possible melts of the Kohistan crust (Petterson et al., 1990).

Coward et al. (1982) considered the Jijal and Chilas complexes as the basal units of the Kohistan arc, overlain by the Kamila amphibolites and the Chalt volcanics. This configuration was thought of as a result of folding of the arc crust. This model, however, yields large dimensions of the arc (> 200 km in the N-S direction; not comparable to any present day intra-oceanic arc).

An alternative model was proposed by Coward et al. (1987), Khan and Thirlwall (1988) and Treloar et al. (1990), according to which the present Kohistan sequence formed due to accretion of two arcs; one represented by the Jijal complex and overlain by the Kamila amphibolites, and a northern arc comprising Chilas complex at the base and the Chalt volcanic rocks in the upper crustal levels. The two arcs were considered to have accreted along the Kamila-Jijal shear zone. This shear zone, indeed, represents the most intense deformation in southern Kohistan, comparable to that observed at MMT. However, the rocks bounding the shear zone are calc-alkaline in geochemistry, and there is a complete absence of rocks, which can be considered to represent remnants of a closed ocean.

A third model presented by Khan (1988) proposes the original Kohistan arc crust to be comprising the Jijal complex, tholeiitic amphibolites (exposed at Babusar pass) and tholeiitic to calc-alkaline arc volcanic now represented by those of Chalt. According to this model the Chilas complex (together with most of the Kamila amphibolites) was generated from a mantle diapiric rise and emplaced in an intra-arc rift set up or a back-arc basin Khan T. et al. (1993). The suggestion that the Chilas complex represent a separate magmatic entity within the Kohistan arc is supported by several attributes of the complex, such as a high liquid-cumulate ratio, and a calc-alkaline geochemistry characteristic of mature arcs (rather than early arc tholeiites). In fact, the Chilas complex shows a reversal to tholeiitic compositions in the younger dyke phase, (the amphibolite dykes of Jan et al. (1984) and Khan (1988), which is opposite to the evolutionary path in progressively maturing arcs. According to Khan et al. (1993) model, the earlier arc basement of the Kohistan island arc is represented by the metavolcanic of Kamila amphibolite belt.

Debon et al. (1987) discussed the geodynamic evolution of the NW part of the India-Eurasia suture zone. They proposed partly synchronous closures, by northward dipping subduction, of the two Tethys branches. The northern branch very likely closed before the southern one, and both are assumed to have encircled the Kohistan arc in Upper Mesozoic times and generated the Karakoram and Kohistan intrusives of Cretaceous and Paleogene ages.

Ghazanfar et al. (1991) considered the Chilas complex to have formed at an ocean ridge spreading centre, emplaced tectonically between two belts of island arcs. Their model is based mainly on field observations in certain accessible valleys. Virdi (1992) considered the Kohistan and Ladakh regions as western Pacific-type subduction zone with back-arc and fore-arc basins on the northern and southern sides, respectively, of a magmatic arc. According to him, the development and evolution of the back-arc is due to the northward movement and consumption of the oceanic crust of the Tethys along the Bennioff zone at the southern margin of Tibet, and during the build up of the island.

According to Yamomoto (1993), the Kohistan arc consists of amphibolites, granulites and ultramafics, forming at least a 55 km thick crust before and/or during closure of a back-arc basin. The gravitational collapse of this over-thickened crust by the collision between India and Asia-Kohistan caused the uplift of the high-pressure granulites. The tectonic evolution of Kohistan was still far from clearly understood. Khan T. (1994), together with petrological and geochemical data proposed a modified tectonic model for the Kohistan terrane. Details of this model are presented here. Khan T (written communication 2004) presented the following models.

"The tectonic scenario of the investigated area indicates a 120 Ma age for the separation and northward movement of Indian plate from Gondwana continent and 150 to 130 Ma age for drifting of the Karakoram plate ahead of the Indian plate. Khan and Jan (1991) proposed that the Karakoram plate was separated by the remnant paleo- or meso- Tethys from the Eurasian plate and by Neo-Tethys from the Indian plate. During this period an intra-oceanic Kohistan-Ladakh Island arc was formed due to the northward subduction of the Neo-Tethyan oceanic lithosphere. This arc was subsequently accreted to the Karakoram plate at the site of the Shayok (MKT) Suture.

Khan T (1994) and Khan T. et al. (1996) proposed a modified tectonic model for the Kohistan terrane. This model covers a span of 70 Ma from Early Cretaceous (120 Ma) to Eocene. According to this model, the Kamila amphibolite belt is considered to represent an arc magmatism related to the northward subduction of the Neo-Tethyan lithospheric plate. In the process, (as in other island arc occurrences: Hamilton (1989), a marginal or back-arc basin (Gilgit zone) developed between the Kamila arc zone and the Karakoram plate. In this basin, two stages of turbiditic deposition took place, together with volcanics derived from the subduction-modified mantle wedge (Chalt volcanics), and followed by MORB type (Majne volcanics and dykes). The Chilas complex formed from a magma that was probably derived from a metasomatised mantle diapir, and intruded the back-arc basin assemblages. All these lithologies are folded and imbricated due to the closure of the back-arc basin and, subsequently, collision of the Kohistan terrane with the Indian plate.

It is proposed, that the 3,6000 km$^2$ Kohistan can be divided into three tectonic zones: (i) the southern (Kamila arc zone = Kohistan island arc) comprises principally the Kamila volcanic (amphibolites), and is underplated by basal cumulates of the Sapat and Jijal complexes. These complexes, comprising ultramafic rocks at the base and gabbroic on top, occupying the hanging wall of the Indus suture (MMT), (ii) the central zone comprises gabbronorites, pyroxene diorites and ultramafic rocks, forming the 8,000 km$^2$ coherent Chilas complex and (iii) the northern (Gilgit) zone comprises the Gilgit formation at the base, followed by the Chalt volcanic group (commonly containing pillow lavas), and finally, the Thelichi formation (equivalent of the Yasin group).

The Gilgit zone was welded to the Karakoram plate 90 Ma ago along the Shayok Sture or Main Karakoram Thrust. This and the central zone are complexly folded and imbricated, with a persistent southward vergence. Much of the Kohistan batholith, principally formed in Paleocene-Eocene, cuts across the structures in the Gilgit zone.

Previous tectonic models for Kohistan considered the southern two zones as the basal crust and the northern zone as the upper crust of a Cretaceous island arc. Subsequently, it was suggested by Khan et al. (1989) that the Chilas complex was probably emplaced during an episode of back-arc rifting. The present research in the Gilgit zone has resulted in the recognition of two stages of turbidite deposition intervened by basaltic volcanisms, an assemblage formed very likely in a back-arc basin.

These findings have resulted in a completely new interpretation for the Kohistan terrane. It is further concluded that the southern or the Kamila zone represents an island arc crust, while the assemblage to the north of the Jal shear zone, including the Chilas complex and the overlying sequence of metamorphosed turbidites and basaltic volcanics, represent a folded and imbricated back-arc basin. Treloar et al. (1996); Burg et al. (1998) and Rolland et al. (2000) also supported the proposed back-arc basin model of Khan T. (1994). Based on this model, Treloar et al. (1996) re-evaluated their previous stratigraphic sequence of the Kohistan island arc. It has also been suggested that the Kohistan represents an intra-oceanic crust and that prior to collision with the Karakoram terrane, the Kohistan arc faced north, over a south-dipping subduction zone. The Kohistan intra-oceanic arc originated near the present location of the DUPAL isotopic anomaly, at near equatorial latitude. Burg et al. (1998) considered Kohistan batholith as remnant arc after the establishment of back-arc in this region. Rolland et al. (2000) reported Middle Cretaceous back-arc formation and arc volcanism along the Asian margin: the Shayok Suture Zone in northern Ladakh (NW Himalaya).

**Stratigraphic setup of the Kohistan island arc and adjoining area**

Bard (1983), made six major units of the entire Kohistan sequence (Fig. 16). Chaudhry and Ghazanfar (1990) and Ghazanfar et al. (1991) divided SE Kohistan into seven lithostratigraphic units, whereas Khan T. et al. (1994) provided details on the east central part of the Kohistan terrain with tectonic subdivision and Treloar et al. (1996) discussed the entire Kohistan terrane with a new stratigraphic order for the entire arc. Only the outline of the stratigraphic work is discussed here. A systematic large-scale mapping and interpretation of southeast Kohistan was carried out by

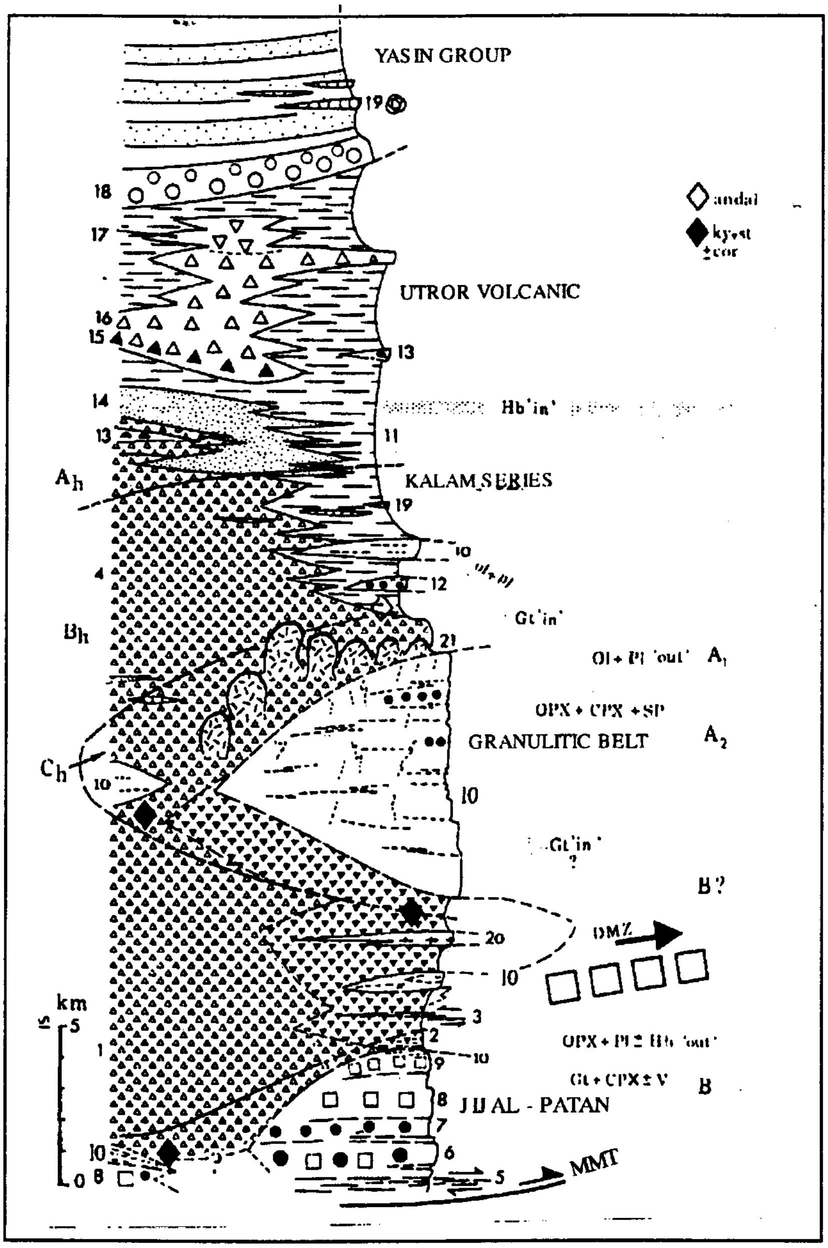



Fig. 16. Schematic section of the Kohistan island arc sequence.

After Bard, 1980-83

LEGEND

1. Southern striped amphibolite;
2. Coarse-grained metagabbro and amphibolite with blastomylonites in ductile (northwards) shear zones(3);
4. Northern striped amphibolite and amphibolitic schists;
5. Blastomylonites near the MMT paleosuture;
6. Ultramafic (metaharzburgites, websterites, dunites, pyroxenite);
7. Dunites and diopsidites;
8. Pyrigarnites (garnet-diopsidites and garnetities);
9. Plagiopyrigarnites;
10. Pyriclasites + amphiclasites+metatroctolites and meta dunites from the layered calc-alkaline lapolith;
11. Shales and metagreywackes;
12. Coarse grained metagabbros and associated layered dunite and pyroxenites;
13. Pillowed metabasalts;
14. Metacherts with alternating wackes and shales;
15. Andesitic agglomerates with granophyric pebbles;
16. Andesites;
17. Dacites with local ignimbritic aspects;
18. Unconformable massive heterogeneous conglomerates and breccias (mainly volcanics and dioritic blocks and pebbles);
19. Marbles calc-silicates bearing gneisses and skarns;
20. Dioritic-trondhjemitic deformed injections (Jalkot type);
21. Foliated heterogeneous late-anatectic diorites (late-to post-kinematic intrusives are not shown);

**DMZ**: ductile megashear zone; **Ah**: "chlorite + epidote" zone; **Bh**: "blue green Ca-amphibole + epidote" zone; **Ch**: "garnet + green/greenish brown hornblende ± clinozoisite" zone (including incipient anatexis of "wet" mafic rocks); $A_1$: low grade olivine + plagioclase bearing granulites; $A_2$: two pyroxene granulites: B: garnet - cpx (granulites; note the two "garnet -in isograd" i.e within the amphibolitic rocks and within the granulites).

Chaudhry and Ghazanfar (1990) and Ghazanfar et al. (1991). They subdivided the south-east Kohistan and adjoining areas into a number of lithostratigraphic units, with main lithology is given below:

**LITHOSTRATIGRAPHIC UNITS**

MAIDAN VOLCANO-PLUTONICS
INDUS SUTURE/MMT SEDIMENTS including
- Bachh limestone
- Richhpar graphitic pelites
- Keo phyllites

KOHISTAN GRANODIORITES including
- Babusar granodioritic gneiss
- Damyun tonalitics

MMT/INDUS SUTURE OPHIOLITES including
- Sumal greenstone
- Sangar Babusar greenstone
- Buto Gah Gali greenstone
- Ledi peridotites

DIAMIR DIORITES including
- Thor diorites
- Darel diorites

CHILAS NORITE COMPLEX Including
- Ultrabasics at Ronay,
- Bhashra damsite, Thurli, Khinner mouth
- Buto Gah mouth and Dossar

KAMILA AMPHIBOLITES including
- Thak striped amphibolites
- Babusar Sangar amphibolites
- Sumal amphibolites

The entire sequence is regarded as later Mesozoic to Tertiary. Khan T. (1994) and Khan T. et al. (1994, 1996) mapped the east central part of the Kohistan terrain and described some of the key position formations and tectonic subdivisions. They stressed that magmatic arc is made up principally of the Jaglot group, to which they attached much importance for its significant rule in the regional tectonic frame work of Kohistan. From bottom to top the Jaglot group consists of i) paragneisses and schists intercalated with amphibolites and calc-silicates (Gilgit formation), ii) Gashu-confluence volcanic (GCV) and iii) the Thelichi formation comprising a volcanic basal part Majne volcanics and dykes overlain by turbidites, marble, volcanoclastic sediments and lava flows.

Metamorphic grade varies up to the sillimanite zone.

The GCV are correlated with the Chalt volcanics and the Thelichi formation with the Yasin group. Other lithologies include the Chilas complex, the Kohistan batholith and part of the Kamila amphibolite. According to them Kohistan terrane can be divided into three tectonostratigraphic zones, i) the southern (Kamila) zone comprises amphibolitized basalts, mafic and ultramafic rocks, ii) the central Chilas complex and iii) the northern (Gilgit) zone i.e., the Jaglot group. They added that the previous tectonic models considered the Kohistan terrane as tilted island arc with a narrow marginal basin in the north, whilst their investigation concludes that only the southern zone represents a true island arc, the Jaglot group, which is in the Gilgit zone derives from back-arc basin assemblages and the Chilas complex is a magmatic diapir emplaced in the back-arc basin.

Treloar et al. (1996) in their re-evaluation of the stratigraphy and evaluation of the Kohistan arc sequence presented a host of data permitting the construction of a revised magmatic and tectono-stratigraphic history for the arc. The oldest units according to them are the transitional oceanic-type basalts, which form the basement to subduction related sequence. This sequence is intruded by arc-type gabbroic sheets and plutons; together these constitute the Kamila amphibolite belt. The Kamila amphibolite belt is overlain by Jaglot group of Khan T. et al. (1994) comprising of metasediments and basaltic lava. About metasediments and basaltic lavas, they opined, that they were deposited, within an extensional basin, which was formed over the Kamila amphibolite belt.

The Chalt volcanic group, according to them was originated in the following way. "Sediment charged turbidity currents transported material into the basin, whilst submarine eruptions contributed the basaltic component. This period of extension culminated in the eruption of high-Mg boninites of the Chalt volcanic group which overlie the rock of the Jaglot group and added that the earliest granitoids of the Kohistan batholith predate suturing and intrude the Jaglot and Chalt sequence". At 100 Ma, Kohistan sutured to Asia, suturing being accompanied by thickening of the arc with the development of major intra-arc shear zones and a penetrative, regionally developed steep cleavage. At 85 Ma, intra-arc rifting permitted the emplacement into the arc of the voluminous gabbronorites of the Chilas complex which clearly intrudes the Kamila amphibolite belt to the south and Jaglot group to the north. About the origin of the Chilas complex, Treloar et al. (1996) have hypothesized that the Chilas complex was emplaced after most of the Late Cretaceous suture-related deformation had taken place.

Explaining mechanism by using field data they stated "Heat advection associated with emplacement of the complex caused amphibolite facies regional metamorphism, melting of the lower arc and plutonism". They further added that "some of the resultant granitoid plutons were unroofed and eroded during a compressional phase at between 80 and 55 Ma, before emplacement of further plutons and extrusion of basaltic through to rhyolitic volcanic rocks" at between 55 and 40 Ma, this is Utror volcanic complex. On the evolution of the arc, the modality further inferred is as follows "at least three phases of extension and rifting, each separated by short lived phases of compression, characterized arc evolution. Much of the magmatism is controlled by extensional tectonics within the overriding plate of the kind commonly associated with a retreating subduction zone". As a result of this stratigraphic model, following stratigraphic succession has been presented by Treloar et al. (1996).

**Paleocene and Eocene**

Dir group
- Utror volcanics (552 Ma)
- Banda slates (Thanetian 55-60 Ma)
- Mankial volcanics

Shamran volcanic group
- Western volcanics, (ca.61 Ma)
- Shamran volcanics (ca.58 Ma)
- Drosh volcanics

**Suturing of Kohistan to Asia** (Between 102 and 85 Ma)

**Cretaceous**

- Yasin group (Albian-Aptian, ca. 114 Ma)
- Chalt volcanic group
- Jaglot schist group
- Peshmal schist, Jaglot volcanics,
- Thelichi formation, Gilgit paragneisses
- Kamila amphibolites

**Stratigraphic setup**

**Southern amphibolite unit:** It includes 6-8 km thick folded and refolded, fine- to coarse-grained, striped or homogeneous amphibolites, flaser-gabbros and blastomylonitic amphibolites (Bard, 1983). The striped-amphibolites are sometimes migmatitic in aspect with lit per lit quartzo-feldspathic injections. They are cut off by various folded and/or sheared leucocratic rocks that form a swarm of dioritic-trondhjemitic veins and dykes.

Lower part of the unit contains two large "patches" of mafic-ultramafic rocks mainly harzburgites, dunites, diopsidites and garnet-spinel diopsidites surrounded by more or less amphibolitized and / or garnetified metanoritic gneisses (two-pyroxene retrogranulites). They represent over all, the Jijal- Patan complex in the Indus Valley.

**Jijal complex:** Jan (1979, 1980) and Jan and Howie (1981) described the Jijal complex from the southern part of the Kohistan arc, according to them the Jijal complex is spread over 150 to 200 $km^2$ in a tectonic wedge exposed along the Indus and trends northwest. It is dominantly comprised of garnet granulites and with lesser amount of garnet free ultramafic rocks. The ultramafic rocks have Alpine type features but slightly differ in composition. The emplacement of both of these lithologies

(1) The metanoritic (granulitic) unit: This is a 1-12 km thick "belt" mainly composed of pyroclasts which is interpreted to be a grossly homogeneous stratiform calc-alkaline lopolith now transformed into granulites. The main rock types are mesocratic two-pyroxene ± hornblende granulites cut by coarse-grained poorly deformed (schistose) hornblende-plagioclase pegmatites (Bard, 1983).
(2) The Northern amphibolitic unit: This unit "overlies" the metanoritic unit. This is the same oldest unit of Bard (1983). According to him "the rocks of this unit are like those of southern amphibolitic unit and they are also heterogeneous striped-amphibolites, probably mainly from basaltic tuffaceous origin, locally interlayered with silico-aluminous, siliceous, calcareous and epidotic lenses". Bard (1983) stated that southeast of Timurgara, this amphibolite unit grades into the Southern amphibolite belt. In this area, the granulites seem to pinch out, a feature which may be related to the geometry of their parental rocks. (i.e., a wide stratiform noritic intrusive). Strongly migmatic aspect adjacent to granulitic units is striking characteristic feature of the northern and southern amphibolite units. More clearly, Bard (1983) added that at both the localities they are coarse-grained amphibolites injected by veinlets of diorite-leucodioritic, which may concentrate into weakly folded and foliated quartz-dioritic bodies. Stratigraphically younger to unit 3 is the fourth unit of Bard (1983). It is a complex unit of metasedimentary and metavolcanic rocks, which is exemplified by the Jaglot group and Kalam complex etc.
(3) The Volcano-sedimentary unit. This unit overlies conformably or with tectonic contact the northern amphibolite unit. It contains meso-to anchimetamorphic metagreywackes, chlorite-schists and phyllites with thick zones of fine-layered metacherts enclosing bands and lenses of finely calcareous metasediments. Some basic metatuffs and low-grade epidote-amphibolites occur locally together with pillow metabasalts. In Gilgit district this unit is very thick (at least 8-10 km) and much more greywacke-rich (with flyschoid pattern). The cherts are not massive but outcrop as centimetric black-grey level within greywacke containing some marbles. Mesometamorphic conditions transform these rocks into "quartzites", micaschist with or without andalusite and garnet, and calc-silicate gneisses and skarns (Bard,1983). The volcano-sedimentary rocks of Kohistan are extensively exposed throughout the length of Kohistan island arc. They range in age from Late Palaeozoic to Early Tertiary. They include Kalam, Jaglot, Chalt and Chilas groups and complexes, which are described as under.

**Kohistan batholith:** It comprises multiphase plutons of calc-alkaline composition, which intrude the Gilgit formation, Chalt volcanic group, the rocks of the Thelichi formation and the Chilas complex. According to the mode of occurrence, petrography, geochemistry and age data, the Kohistan batholith has been divided into three groups by Peterson and Windley (1985). Khan T. (1994), by analogy, divided east central part of the arc (i) basic to intermediate rocks consisting of gabbros, diorites, and tonalites (early stage-II plutons of the main batholith), (ii) acidic rocks containing granodiorites, granites, aplites and pegmatites (late stage-II plutons), and (iii) small bodies of granites, (?) tonalites, and acid sheets (stage-III plutons). The Sai Nala pluton is a deformed tonalite/trondhjemite, and may be equated with the stage-I plutons of Petterson and Windley (1985).

The Kohistan batholith records some 70 Ma of magmatism from about 102 to 29 Ma

(Petterson and Windley, 1991). These plutons show compatibility with normal calc-alkaline andesites and with rocks from New Britain-Solomon islands arc, the northern Caribbean arc, New Guinea mobile belt, and western American batholith. Petterson and Windley (1985) suggested that the batholith developed in two environments; the early plutons formed in an island arc set up, whereas much of the batholith was emplaced in an Andean-type continental margin when the arc was juxtaposed to the Karakoram plate after closure along the Shayok Suture or MKT (Khan T. 1994). It is to be noted that much of the Kohistan batholith appears to be a product of mantle wedge above the subduction zone, but some of the leucogranites and aplites seem to be derived by the partial melting of the crust of the Kohistan arc. Certain plutons are alkaline in nature and contain a higher amount of $K_2O$ over $Na_2O$. Blasi et al. (1980) proposed extensional environments for the evolution of such alkaline rocks of the batholith. These rocks may well be derived from crustal material, which may, either be related o the back-arc basin (Gilgit formation) or there a basement of the India plate crust underplating the arc.

The mafic dykes of the Chilas complex and Kohistan batholith are petrogenetically different. They are D-(depleted) and E-(enriched) types, respectively. The depleted dykes intruding the Chilas complex have major element characteristics between alkali olivine basalts and picrites (Khan T. et al., 1993), and may be related to magmatism during the back-arc rifting stage of the Kohistan terrane. This magmatism occurred before the closure of the northern suture (Khan T. et al., 1993). The dykes in the Kohistan batholith are tholeiitic and calc-alkaline, and derived from a heterogeneous mantle source. They are enriched in the incompatible elements and developed as a result of partial melting of a more metasomatised mantle source. The dykes of the Kohistan batholith were produced after the closure of the northern suture (Petterson and Windley, 1985; Treloar et al., 1989).

In the Gilgit and Chilas areas, the above succession shows two phases of isoclinal folding and metamorphism ranging from greenschist to garnet granulite facies before the intrusion of the Kohistan batholith. Coward et al. (1982, 1986, 1987) are regarding this succession as island arc sequence, to have formed due to northward subduction in Late Jurassic to Early Cretaceous, and the deformation and metamorphism to be related to the closure of the MKT. The continued subduction and crustal anatexis gave rise to the Kohistan batholith and Dir Kalam group (Petterson and Windley, 1985; Sullivan et al., 1993).

**Jaglot group:** Khan T. et al. (1994) named and described the Jaglot group exposed in the Thelichi-Gilgit sector of the KKH, which passes through a succession of metasediments and metavolcanics. Wadia (1932) recognised these metasediments and metavolcanic along with abundance of pelites and local presence of graphite, as the Precambrian Salkhala Formation. Tahirkheli (1979, 1982), after recognising the affinity of these metasediments with the Kohistan island arc assigned them a Jurassic-Cretaceous age and suggested a correlation with rock those of at Kalam. Coward et al. (1987) noted that these metasediments are stratigraphically lowest in the Kohistan sequence and occupy the core of a large antiformal fold.

The Jaglot group was mapped in detail by Khan T. et al. (1996) and according to them the group is exposed in two NW-SE trending belts between the Gilgit River and the Gor drainage divide, separated by the Shinghai plutonic belt of the Kohistan batholith. The SE extension of the group is truncated against faults associated with the Raikot fault/Main Mantle Thrust along the Indus River, while the NW extension is obliterated by the intrusion of the Kohistan batholith. The age of the Jaglot group as suggested by Khan T. et al. (1994) is Late Jurassic to Middle Cretaceous. Treloar et al. (1996) re-evaluated their previous work, while taking into account the Khan T. et al. (op cit.) tectonic model. They described that Jaglot group extends from east to west across the Kohistan arc and that they view it as "a major stratigraphic unit" best exposed between Gilgit and Chilas. According to Treloar et al. (1996), the Jaglot group also includes the Kalam group, exposed in Dir and Swat valleys, it also includes the Thelichi volcanic sequence exposed near Jaglot in the Indus Valley, and to the west and southwest of Gilgit as described by Khan T. (op. cit.), the Majne volcanic body SW of Gilgit of Khan T. (1994), and the Gilgit paragneisses of Khan T. et al. (1993). To the south, the Jaglot group is intruded by gabbronorites of the Chilas complex. To the north it is intruded by granitoid plutons of the Kohistan batholith and overlain by the Chalt volcanics. In Dir Valley, the sequence, intruded by plutons, is overlain by Eocene volcanic rocks.

According to Treloar et al. (1996), the Jaglot group comprises greenschist facies metabasalts, some pillow lava interbedded with volcaniclastic and schistose metasediments; evidently, they named it as "Jaglot schist group". The schists are dominated by quartz-rich semi-pelites with some psammitic and calc-silicate horizons. The Jaglot group exposed between Gilgit and Chilas, has been divided into three formations by Khan T. et al. (1994). The oldest formation in the group is Gilgit formation, followed by the Gashu-confluence volcanics and the top one is the Thelichi formation.

**Gilgit formation:** The Gilgit formation has been named and described by Khan T. et al. (1996) and according to them it is comprised mainly of paragneisses and schists of metasedimentary origin (Fig. 17). They include both metapelites as well as metapsammites, commonly interstratified at regular intervals having gradational relationship with each other at various places. Amphibolites and calc-silicates are subordinate lithologies. The amphibolites are frequent and form laterally continuous horizons. Although some of the amphibolites may be transposed dykes and sills, other are definitely derived from basic tuffs and volcanic flows. One such horizon is in the Sai Nala, midway between Jagot and Gashu confluence, where it is exposed as about 400 m thick sequence of stretched pillows. The calc-silicate horizons are common in the upper part of the formation, above the pillowed-amphibolite horizon.

The paragneisses and schists of Gilgit formation contain biotite, garnet, kyanite and sillimanite showing signs of regional metamorphism. The top-most unit in the Gilgit formation is biotite schist grading downward into garnetiferous schists, and kyanite and sillimanite gneisses. In the deeper levels the paragneisses have undergone anatexis, resulting in the development of migmatites. The principal belt of Gilgit formation (15 x 40 km) is located between Jaglot in the SE and Gilgit in the NW, in the core of a large antiform. The other two belts are relatively much narrower (<500 m each) and occupy the two limbs of the Jaglot syncline, enclosing the younger strata of Gashu-confluence volcanics and the Thelichi formation. The upper contact of the Gilgit formation is

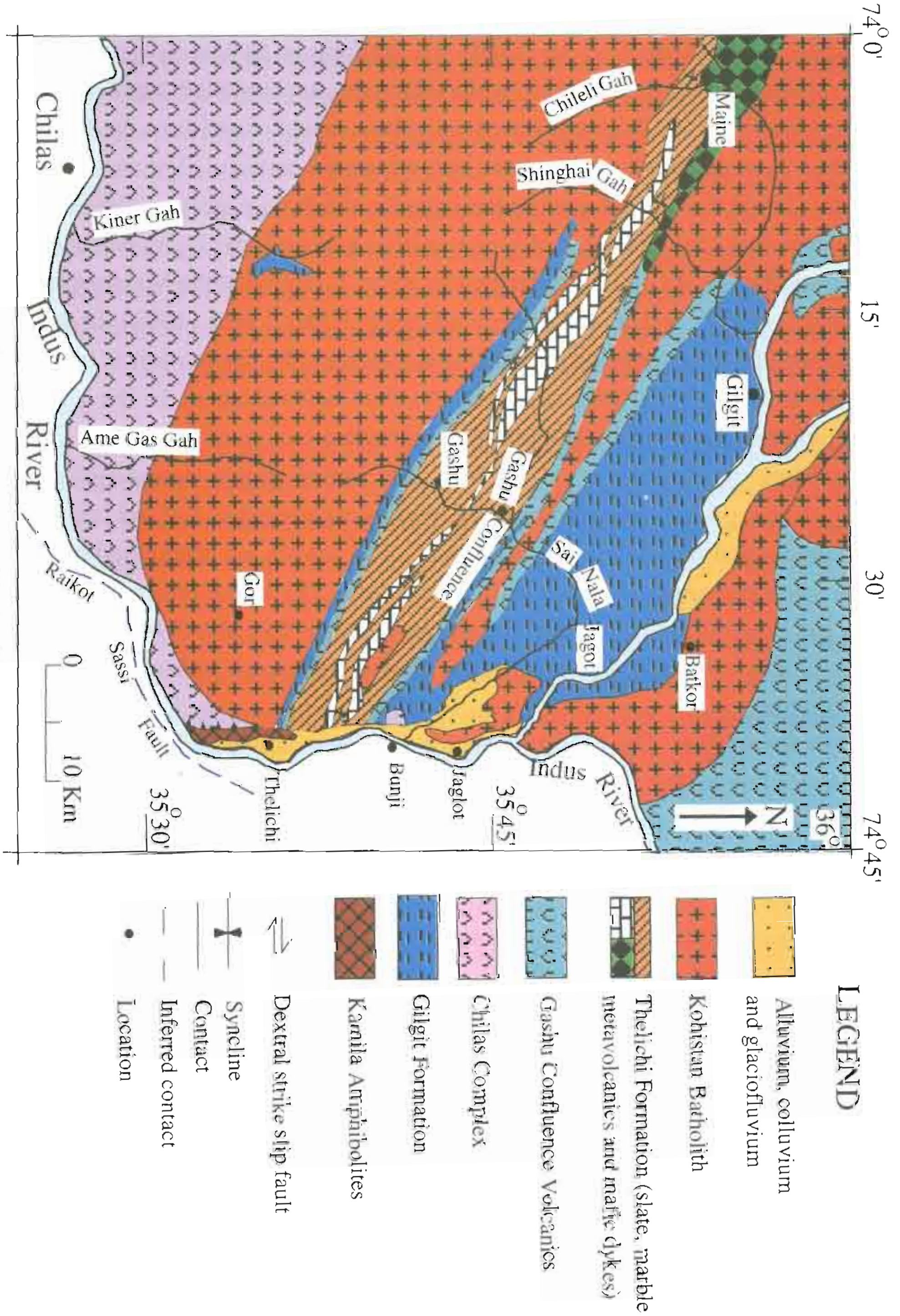



Fig. 17. Geological map of the area between Gilgit and Chilas, Northern Areas of Pakistan (after Khan T. et al., 1994)

transitional with over lying Gashu confluence volcanics, while the lower contact of the Gilgit formation is not exposed as seen in Sai nala. However, there is indication that the Gilgit formation is underplated by the Chilas complex. The age of the Gilgit formation has been considered as Jurassic.

**Gashu-confluence volcanics:** The presence of amphibolites, on the roadside between Thelichi and Jaglot villages have been named and described by Khan T. et al. (1994). Prior to this, the presence of amphibolites on the KKH between Thelichi and Jäglot have been examined by Ahmed et al. (1977); Tahirkheli and Jan (1979) and Bard et al. (1980) but no name was given. The type section of the formation is designated at the KKH between Thelichi and Jaglot villages. The Gashu-confluence volcanics comprise tuffs, volcaniclastic sediments, marbles and flows, a ~500 m thick section along the KKH, south of Jaglot, comprises pillowed basalts alternating with massive basalts and volcaniclastic sediments. The volcanic and associated rocks are metamorphosed to lower amphibolite facies of regional metamorphism.

The Gashu-confluence volcanics are about 500 m thick and have a transitional contact with the underlying schist and paragneisses of the Gilgit formation in Sai nala, however, in the Thelichi-Jaglot section, the contact appears to be a fault (Khan T. personal communication 2004). The upper contact with the Thelichi formation is sheared. However, persistence of the two formations along the contact suggests that originally the contact was stratigraphic. Khan T. et al. (1994), also considers the possibility of an unconformity at this contact. This inference is based in a clear break in the grade of regional metamorphism between the Gashu-confluence volcanics and the Thelichi formation, the former is at lower amphibolite / upper greenschist facies, while the Thelichi formation hardly approaches lower greenschist facies.

**Thelichi formation:** The Thelichi formation was previously described as Salkhala series Wadia, (1932) and Thelichi beds by Tahirkheli, (1982). Detailed mapping, carried out by Khan T. et al. (1994) shows that the Thelichi formation occurs in the core of the Jaglot syncline, and is therefore, younger than the Gashu-confluence volcanics and the Gilgit formation. The age of the formation as suggested by Khan T. et al. (1994) is Middle Cretaceous.

The Thelichi formation is composed of a sequence of slates, marbles and metavolcanics. The basal unit, which is localized only in the upper reaches of Kar Gah, comprises volcanics, which have been named as the Majne volcanics and dykes by Khan T. et al. (1994). The volcanic are fine grained and schistose to massive, presumably comprising volcaniclastic sediments and flows. The dykes are doleritic and basaltic, they occur as swarm of isolated doleritic and basaltic dykes in the Thelichi formation in Chelili Gah area. Elsewhere in the studied area, the Majne volcanic and dykes either do not continue laterally, or are difficult to be distinguished form the underlying Gashu-confluence volcanics. The rest of the formation comprises predominantly of interbedded slates and sandstones, probably derived from an assemblage of interbedded sand, silt, and mudstone of turbidite origin. A thick unit comprising thick-bedded marbles occur in the middle part of the formation. The unit is laterally persistent and serves as a useful marker horizon. The succession of slates above and below the marble unit is grossly identical. The lower contact of Thelichi formation with Gashu-confluence volcanic is sheared. The age of Thelichi formation is Middle Cretaceous, i.e. lower Late Cretaceous.

**Kalam group:** Matsushita (1965) named and described in brief a group of sedimentary rocks exposed near Kalam. The unit is composed of abundant micaceous quartzites, siliceous schists with phyllites at the base overlain by siltstone shale and limestone. The total thickness of Kalam group as stated by Tahirkheli (1979) is over 800 m, who divided the group into three formations, Shou quartzite (600 m), Deshan Banda limestone (35 m) and Karandoki slates (120 m). According to Jan et al. (1971), the schists and quartzites are more than 1000 m in thickness. They are bluish grey or dark, pink, light green and at places brown. Quartzite and schists are fine grained mostly thin bedded and banded, greenish bands are the most abundant with brown bands being more conspicuous. The rocks of Kalam group contain bands and thin beds of rare amphibolite which is composed of hornblende, plagioclase quartz, epidote ± chlorite. The quartzite and schist contain abundant quartz and lesser biotite sericite and epidote or rarely clinozoisite. These rocks also contain variable amount of ores and at some places graphite.

Siltstone, shale and limestone of red green colour overlie the quartzite and schist/ phyllites. Limestone is light grey and has calcite veins. They are fossiliferous and contain algae and coral. Limestone is thin bedded at places shaly, fossils found in the limestone are obliterated due to mild metamorphism. Doubtfully Carboniferous age has been assigned to these rocks, the under lying quartzite is also doubtfully assigned Silurian-Devonian age (Jan and Mian, 1971).

The calc-alkaline volcanic of Bard (1983) occur above the Kalam sequence, either with intraformational conglomerates, volcanic (andesitic) agglomerates or with andesitic flows. Near Utror village, the volcanic unit is 5-8 km thick and mainly composed of more or less schistose meta-andesitic agglomerates, metadacites and towards the top, by rhyodacites with iginibritic structures. The metamorphic and sedimentary rock of this unit is intruded by various type of plutonic rocks mainly quartz diorites (tonalitic) and granites (Jan and Mian, 1971). The calc-alkaline unit of Bard (1983) essentially constitutes ultra metavolcanic of Jan and Mian (1971). The unit is essentially composed of silicic to intermediate lavas, ignimbrites, tuffs and agglomerates.

Jan and Mian (1971) described the unit as grey, green, red and rarely white volcanic rocks, and may be fine-grained, homogeneous tuffaceous. The fragments are angular as well as rounded and up to 20 to 30 cm across. Due to some variation in colour, texture or mineralogy some pyroclastic rocks show banding. At places pyroclastic material and lavas are inter bedded. Lava dominates pyroclasts in the area between Gabral and Utror flows of rhyrolite having sodic plagioclase, quartz rarely potash feldspar phenocrysts dacite with tuffaceous agglomeratic some are strongly trachy oolitic and a few are banded and andesites make up substantial part of the unit and are thin bedded to massive. The presence of chlorite, epidote and the altered nature of feldspar point out to a conclusion that the rocks have suffered a mild type of metamorphism. Jan and Mian (1971) have noted that some breccia present in the unit exposed to the south west of Kalam, contain pebbles of the Kalam group sediments, thereby, making Utror volcanic younger than Kalam group.The age is probably Cretaceous to Paleocene.

**Chalt schist:** A group of rocks exposed southwest of Chalt extending as far as the village Tashot has been named Chalt schist by Stauffer (1968c). Ivanac et al. (1956) have described part of this formation as 'Darkot group'. Schneider (1957) introduced the name 'Chalt Schieferseries' for all metamorphics south of the Karakoram granodiorite, including the 'Chalt schist' and 'Greenstone complex' of Ivanac et al. (1956). The formation is dark-grey quartz biotite schist. Part of the formation is very fine-grained and may be called phyllite. Stauffer (1968c) studied thin section and recorded the presence of crystals of biotite, most of which show sieve structure, in a fine schistose groundmass of quartz, feldspar, ilmenite, magnetite, green biotite and actinolite. Calcite also occurs in the groundmass. At places the formation gives a smell of sulphurated hydrogen caused by weathering of pyrite cubes in the schist (Stauffer, 1968c).

The rock unit includes small portions of quartzite, marble and conglomerate. The quartzite beds are 65 m thick; the marble beds are as much as 30 m thick and are exposed along the Hunza River. This marble contains organic material. Conglomerate beds form a small portion of the unit and are composed mainly of crushed and sheared limestone pebbles. Ivanac et al. (1956) found some fossils in the upper part of the formation and assigned them Carboniferous to Permian age. In fact, they attributed this age to almost all the schistose rocks found in the Hunza Valley. Stauffer (1968c) disagreed with most of their correlations, as no fossils of any kind have yet been found in the Chalt area. He, however, accepted some of the fossil evidence, which was found in rocks identical to the Chalt schist at Sandhi in Yasin Valley, Gilgit. Dickins (in Stauffer, 1968c) identified some of the fossils as poorly preserved bryozoans, such as *Fenestella, Rhombopora* cf. *R. lepidodendroides,* a large crushed product and also a crushed coral. They are found in the limestone beds. The age of the Chalt schist is believed to be Carboniferous to Permian.

According to Treloar et al. (1996) the volcanic rocks, of what has been described above, outcrop to the north of the Jaglot group, along the northern margin of the arc over an area which extends from the Hunza Valley westward to Chitral (Tahirkheli, 1979; Coward et al., 1982, 1986; Pudsey et al., 1985; Pudsey, 1986). On the basis of geochemistry and facies analysis, Petterson et al. (1990) subdivided these rocks into the Hunza volcanic rocks in the Eastern and the Western volcanic rocks; they are strongly deformed with stretched pillows being common. There is a bimodal distribution from basaltic and andesitic to rhyolitic lavas, although the latter are volumetrically minor. The western volcanic rocks are calc-alkaline in type, with a bimodal distribution into basaltic andesites and rhyolites. Sullivan et al. (1993) correlated the latter with the Shamran volcanic rocks, which yield a Paleocene Ar-Ar hornblende age of 58±1 Ma (Treloar et al., 1989). They can thus be correlated with the Utror volcanic rocks in western Kohistan (Jan and Mian, 1971), and the Drosh volcanic rocks of NW Kohistan (Pudsey et al., 1985). On their revised map of Kohistan, Treloar et al. (1996) divided the volcanic rocks of northern Kohistan into two: the Cretaceous Chalt volcanic group, which outcrops in the Hunza and nearby valleys and passes downward into the Jaglot group, and the Eocene Shamran volcanic group which includes the Western volcanic.

**Chilas complex:** Jan et al. (1984) described the Chilas complex as the world's largest intrusion of basic magma and stressed that its understanding is of fundamental importance to the interpretation of the geology of Kohistan. It is 300 km long from Astor to western part of Dir and about 40 km wide in the centre extending eastwest.

It forms some continuous exposures as well as isolated outcrops. Khan T. et al. (1994) mapped the Gilgit and Chilas area including the rugged and high relief areas, and described the formation from the type section. Treloar et al. (1996) described the complex in their stratigraphy and evolution of the Kohistan sequence. According to them, the Chilas complex is a massive, calc-alkaline gabbronorite body, layered in places specially in Chilas-Gilgit area, although here it is predominantly composed of pyroxene diorites and gabbronorite yet contains all other major rocks types present elsewhere in the Chilas complex (Khan M. A, 1988 unpublished). They include gabbros, anorthosites, troctolites, peridotites, dunites and mafic dykes (Khan T. et al. 1993). Locally the pyroxene diorites and gabbronorites are sheared yielding amphibolites. In the eastern part of the mapped area, the Chilas complex has a direct northern contact with the granitic rocks of the Kohistan batholith. Khan T. et al. (1994) added that the contact is typically intrusive, as shown by the dykes and apophysis originating from the granitic body and cutting into the Chilas complex. This phenomenon can well be seen near the village of Drang situated southwest of Gor. Despite an intrusive nature, however, the contact is remarkably linear, which has been interpreted as either due to post-intrusion flattening or more likely, due to the linear nature of the magmatic axis for the Kohistan batholith. In the western side of the Chilas-Gilgit axis, there are screens and xenoliths of amphibolites, paragneisses and biotites schists contained in the pyroxene diorites of the Chilas complex. This feature is particularly well displayed in Kinar Gah. The paragneisses and schists contain quartz, plagioclase, biotite, garnet, kyanite and graphite. In the northern parts of Kinar Gah and Hudar Gah, the Chilas complex intrudes the amphibolites. The contact is sharp and shows chilling effects. Amphibolite xenoliths are found within the complex near the contact. Khan T. et al. (1996) finally concluded that i) "the Chilas complex was intruded into a sequence of country rocks comprising pelitic schist and paragneisses, which are commonly intercalated with amphibolites and ii) the Chilas complex was itself intruded by the Kohistan batholith".

Khan T. et al. (1994) stated that the Chilas complex has a tectonic contact with the Kamila amphibolite in southern Kohistan as well as in a small part of the Kamila amphibolite exposed to the eastern side of the Thelichi-Raikot section of the KKH. Again the Chilas complex is sheared and the two have a tectonic contact with, and at right angle to the trend of the metasedimentary succession of the Thelichi area. Treloar et al. (1996) stated that its contacts in the Indus, Swat and Dir valleys, are against intensely deformed metavolcanic and gabbros of the Kamila amphibolite belt to the south, and against schistose metasediments, intercalated with metavolcanic, to the north. Magmatic layers are locally folded; variable deformation is seen in the gabbronorites. The range is from undeformed to intensely deformed. The data presented by them implies that the Chilas complex was emplaced after most of Late Cretaceous suture-related deformation had taken place and added that this is consistent with zircon U-Pb ages from gabbronorites in upper Swat which fall on a Concordia of 84± 0.5 Ma.

Fifth unit of Bard (1983) overlies his unit 4 described above. He defined his unit 5 as the calc-alkaline volcanic unit and included the Utror volcanic as the prime example. According to him Utror volcanic occur above the Kalam sequence and specified the age of the Utror volcanic as Lower

Cretaceous, which makes it as one of the oldest units of the arc sequence. On the other hand, in his sixth unit named; by him as, "the Upper Detritus Sequence", comprising Yasin group, which according to him overlies Utror volcanic in his stratigraphic model. Tahirkheli (1979), on the basis of foraminifera, dated Baraul Banda slates, which are interbedded with the volcanic of Utror, as Middle to Upper Eocene. On the other hand Yasin group has been dated as the (Aptian) on the basis of fossils found in calcareous beds of Yasin group near Gilgit (Bard, 1983). Recently, Treloar et al. (1996) provided radioactive dating both on Utror and Yasin groups. According to them the age of Yasin group is 114 Ma i.e. Albian-Aptian and those of Utror volcanic 55±2 Ma i.e. Late Paleocene (upper Thanetian) or Early Eocene (lower Ypresian). The above-mentioned information evidently upset the stratigraphic sequence of Bard (1983).

Under the situation described above Bard's unit five and six need to be revised, both of those units have volcanic rocks along with detritus material. According to Ivanac et al. (1956) the rocks of Yasin group have been over folded and overturned, and are mixed up with older formations and at some places the Yasin group underlies the older groups (e.g. the Darkot group). To be more simplified, the rest of the Kohistan formation is described in radiometric chronological order, which is as under:

**Yasin group:** A heterogeneous collection of volcanics (tuff, lava etc), carbonate, conglomerates and shale was named as Yasin group by Ivanac et al. (1956). The group outcrops in the hills to the east and west of Yasin village. The group is divisible into two units, one volcanic and the other sedimentary. A part of greenstone complex and a few Yasin outcrop exposed around Shamran has now been included in the newly created Shamran volcanic group by Pudsey et al. (1985). The group is restricted to Yasin Valley and some east and some west of it.

At the type section near Yasin village, the thickness of the Yasin group has been estimated as more than 600 m but other exceeds more than 1000 m. The Yasin group has been traced up to about 5 km on either of the Yasin Valley by Ivanac et al. (1956). At the Garotian Shal, on the track to Chumar Khan Pass, the group is well exposed showing a sequence of tuff, agglomerates, quartzite, conglomerates and limestone. At the section west of Yasin Rest House the sequence of Yasin group is characteristically red and green and consist of massive and shaly limestone, slate, trachytic and rhyolitic tuffs, trachytic agglomerates and thin flows of trachyte and olivine basalt. Eastward in the south of the village of Ghojalti, the beds are overturned showing reversal of the sequence (Ivanac et al., 1956). The age of the group indicated by Ivanac et al. (1956) is Cretaceous, based on faunal occurrence. Recently the age of group based on radiometric dating supported this age of Ivanac et al. by Treloar et al. (1996).

**Shamran volcanic group:** Pudsey et al. (1985) named and described Shamran volcanic group from Shandur Pass, a sequence of generally low-grade, flat-lying or gently N-dipping metavolcanic rocks. According to them the group is dominantly composed of massive, commonly amygdaloidal, porphyritic andesite lavas and massive crystal-lithic material of similar composition. Less abundant are more finely bedded intermediate and acidic lavas and tuffs with intercalated shaly sediments. Locally there are pillow lavas with chert bands and also volcanic breccia and

**and sedimentary rocks of the NE succession"** exposed immediately south of the northern suture in the Harchin-Shandur Pass area. They are migmatitic amphibolitic gneisses, which were metamorphosed with a generally steeply-dipping foliation prior to the injection of tonalitic veins, muscovite pegmatite sheets and, lastly some undeformed basic dykes.

**Dir group:** The name Dir group was introduced by Tahirkheli (1979) for pelites and volcanic exposed in Swat and Dir areas. The rocks extend in east west direction from Ushu Valley to Dir and Bajaur area over to Afghanistan. Tahirkheli divided the group into the oldest Baraul Banda slates and younger Utror volcanic complex. The age of the group has been suggested as Eocene. The Baraul Banda formation was deposited as a marine fore arc sequence following collapse of the continental margin overlain by basaltic-andesite flows, dacitic ignimbrites and pyroclastic rocks known as the Utror volcanic formation. The age of the group is Eocene (Sullivan et al., 1993). Denominated formation is described below.

**Utror volcanic group:** Tahirkheli (1979) named and described the Utror volcanic group from Dir area. It is essentially composed of silicic to intermediate lavas, ignimbrites, tuffs and agglomerates. The Utror volcanic complex occurs above the Kalam sequence, either with intraformational conglomerates, volcanic (andesitic) agglomerates or with andesitic flows. Near Utror village, the unit is 5-8 km thick and grossly composed of more or less schistose, metaandesitic agglomerates or lavas, metadacites and, towards the top, by rhyodacites with ignimbritic structures and it is interbedded with some sedimentary rocks. The metamorphic and sedimentary rocks of this unit are intruded by various types of plutonic rocks mainly quartz diorites (tonalitic) and granites.

Jan and Mian (1971) described the Utror volcanic complex as grey, green, red and rarely white volcanic rocks, they may be fine grained, homogeneous tuffaceous, composed of larger fragments set in a tuffaceous or lava matrix. The fragments are angular as well as rounded and up to 20 to 30 cm across. Due to some variation in colour texture or mineralogy some pyroclastic rocks show banding. At places pyroclastic material and lavas are interbedded. Lava dominates pyroclasts in the area between Gabral and Utror villages. Phyllite has sodic plagioclase, quartz, along with chlorite, epidote and rarely biotite. Dacites have abundant tuffaceous or agglomeratic material. Some have trachytic texture and a few are banded. Andesites make up substantial part of the unit and are thin bedded to massive. The presence of chlorite, epidote and the altered nature of feldspar point out to a conclusion that the rocks have suffered a mild type of metamorphism. Jan and Mian (1971) have noted that some breccia present in the unit exposed to the south west of Kalam contain pebbles of the Kalam group sediments, thereby, making Utror volcanic younger than Kalam group. In Dir area the lower contact with Baraul slates is transitional. The age is Paleocene as indicated by Treloar et al. (1996). This age determination is based on Ar-Ar dating on hornblende technique in a sample of andesite near Kalam village. The age of Utror volcanic determined is 55±2 Ma.

**Baraul Banda slate:** The formation is named and described by Tahirkheli (1979) sequence contains shales, wakes, calcareous beds and some volcanic. Baraul Banda slates are light grey to greenish grey, thin-bedded, fine-textured and occasionally silty. Light grey, thin-bedded limestone occurs as thin bands in the slates, which are sparsely fossiliferous. The level of metamorphism in the slates ranges to chlorite and sericite grade.

The slates are isoclinally folded and have faulted contact with older formations. The Baraul Banda slates form the basal part of Dir group. The slates are interbedded with limestone containing fossils. These fossils are Actinocyclina, Discocyclina and Nummulities atacicus, which suggest Eocene age. Extensive lava flows are associated with these slates.

## HINDUKUSH-KARAKORAM TECTONOSTRATIGRAPHIC BASIN

### *Southern Metamorphic Province (west)*

**Koghuzi greenschist:** Desio (1975) named a complex of chloritic, actinolite schists exposed between "Koghozi" and Maroi as Koghozi schist. Pudsey et al. (1985), Khaliq et al. (1997) described the Koghozi greenschist 4 km wide lying between Chitral slates in the north and Gahiret limestone in the south and extend from Pakistan-Afghanistan border in southwest of Chitral district up to Reshun in the northeast, almost parallel with the Gahiret limestone and Chitral slates. The Koghozi greenschist consists of fine-grained pale green thinly laminated chlorite-epidote-quartz schists, generally intermediate in composition but with some thin acidic layer containing abundant quartz and varying amounts of sodic plagioclase and actinolite, Calkins et al. (1981) stated that it probably represents chloritic and somewhat calcareous sedimentary beds and some volcanic tuffs, they added that other rock types of this unit are quartzose sandstone, marble, calcareous phyllite and slate. Khan et al. (2000) has mapped greenschist and calcareous phyllite together (Fig. 11). Khan et al. (2000) stated that sulphide minerals include pyrite, chalcopyrite, chalcocite and galena, occurring disseminated and also in veins. A few non-laminated layers containing relict feldspar phenocrysts and accessory chalcopyrite indicate the presence of some volcanic flows. The greenschist unit may be equivalent to the volcanic greenstone unit of Shishi Valley, which is comprised of porphyritic lava flows, tuff, and volcanic conglomerate interbedded with calcareous red phyllite. Calkins et al. (1981) described the age of Koghozi greenschist as Cretaceous.

**Gahiret limestone:** Desio (1975) described this formation as follows: ".... and immediately afterwards one reaches a thick complex of ash grey and black veined and zoned saccharoid marble of the "cipolin" (crystalline limestone) type which Hayden called 'Gahiret limestone' which crosses the Chitral Valley obliquely". Pudsey et al. (1985) described this formation as massive light grey, coarsely crystalline marble. Metamorphism has destroyed the primary structures. The marble is banded and at places defines small steep synclinal folds. It is 3 km thick. The composition is almost pure calcite with chalcopyrite, graphite and traces of phlogophite. Khaliq et al. (1997) stated that Gahiret limestone extends northeastwards from the Pakistan-Afghanistan border near Mirkhani Fort, in the southwest of Chitral district, up to Barnis Gol and runs parallel to the greenschist unit. It is interbedded with dark phyllite and calcareous shale. Orbitolina are reported by Hayden (1915) and confirmed by Calkins et al. (1981). The reported fossils confirmed a Cretaceous age for this limestone.

**Southern Metamorphic Province (east)**

The area east of Haramosh spur centred around Chogo-Lugma glacier system. The area was mapped by (Desio 1963, 1964); Zanettin (1964), Searle (1989) and Le Fort et al. (1995), which include Paleo-island arc of Ladakh and all the rocks described by Searle (1989) in his "Karakoram Metamorphic Province." The area is considerably intruded by granitoids. The entire mass is thrust to the south.

According to Le Fort et al. (1995) this region is included in the Higher Himalaya, where ortho-and paragneisses are metamorphosed to granulite facies and are migmatized. The Ladakh arc is made up of two groups of formations. Greenstone complex occupy northeastern part of the area and Askore amphibolite in the southwest, they are separated by a screen or serpentinized ultramafics. Greenstone complex include limestone with post Valanginian fossils. The 'Karakoram Metamorphic Province' of Searle et al. (1989) includes orthogneiss domes of granitoids intruded into the surrounding metasedimentary formations. They are characteristic of 'Karakoram territory. Further south and east around Dassu-Shinghar Valley, numerous formations are named with lots of common characters among them and in quite a few cases one formation laterally pass into the other either by grade of metamorphism or change of lithofacies. Such cases are pointed out in the foregoing pages where and when described.

**Greenstone complex:** Ivanac et al. (1956) described an assemblage of lava, tuffs, agglomerates, metagneisses, quartzite, limestone, calc-silicate rocks, which cropout between Hanuchal and Hopar, and Roshan and Sor Laspur. The assemblage also includes the metamorphic succession south of Gilgit and many xenoliths in the Ladakh granodiorite. The word "Greenstone" indicates characteristic colour of the rock unit and complex indicate inconsistent volcanic or sedimentation activity. The name, however, does not fulfil the requirement of stratigraphic code as it lacks the geographic locality as well as a type section. One of the traverses made by Ivanac et al. (1956) includes Roshan-Sorlaspur, where in Sorlaspur-Shandur Pass area tuffs basalt lavas, agglomerate and gneisses are present. This area presents more representative section of the assemblage than other traverses. Another traverse they made is from Roshan through Gupis into the Yasin town. Yasin, Town is sitting on Yasin group, Gupis town is sitting on Ladakh granodiorite but little more than two km on way to Yasin Town, the complex can be seen which is exposed up to little short of Yasin Town.

The most representative section, according to Ivanac et al. (1956) is at the contact of the Darkot group, 1.6 km south of Haringal shale, to the Ladakh granodiorite, 1.6 km north of Galinga. The succession here consists of green and grey quartzite and slightly metamorphosed limestone with intercalated fine grained basalt, further south banded tuff, banded quartzite, chert is interlayered, lava flows increase in the vicinity of 'Babusar' where amygduloidal and vesicular fine grained and medium grained basalt, feldspathised basalt and andesite with a few beds of grossularite, calc-silicate rock are the main members. The succession is partly been altered by epidotization and serpentinization. Interbedded limestone contains fossils, they are obliterated and cannot be identified about 4 miles south of Shamran, the Greenstone complex is in contact with the Ladakh granodiorite, the Greenstone complex and is wide spread and covers very large area in Gilgit, Kashmir and Hazāra districts. At Chalt, lavas are found in the upper portion of Darkot group and Ivanac et al. (op. cit.) suggested that these volcanic rocks marked the introduction of a period of volcanism, which led to the formation of Greenstone complex. It is rather difficult, some times, to separate Greenstone complex from Yasin group and evidently many workers mapped it as Yasin group and named differently including Chalt volcanic group, Turmik formation, Rakaposhi volcanic group and Shamran volcanic group.

**Turmik formation:** The Turmik formation originally named by Desio (1963) after the name of a river. The formation is 1200 m thick and it is well exposed in Turmik Valley. The formation is composed of arenaceous phyllite and conglomeratic schist associated with the minute amphibole-schist and fine grained porphyritic with arenaceous shales and schistose conglomerate composed of very flattened pebbles of serpentine, amphibole. Turmik formation is very much similar rather synonymous with Askore formation of Zanettin, (1964), exposed in the adjoining Askore Valley. According to Le Fort et al. (1995) both of these formations constitute Greenstone complex. In Turmik and Askore valleys, the unit consists of a metasedimentary sequence tightly interbedded with basic metavolcanic and minor ultrabasic rocks. It is fruitless to describe Turmik, Askore units separately from Greenstone complex as they all are similar to one another only thick monolithic units can be isolated for different name.

Therefore, they describe the Greenstone complex in the Turmik Valley as consists of a metasedimentary sequence tightly interbedded with basic metavolcanic and minor ultrabasic rocks. North of Dassu, Village 'blastomylonitic arenaceous slates' complex mark the beginning of 'Greenstone complex volcanic-sedimentary series'. On the northern side of the Turmik Valley, the classic nature of the metasedimentary becomes more conspicuous as they include quartz-albite-epidote chlorite carbonate arenaceous slates, conglomerate schists with abundant micaceous matrix. The clasts of the conglomerate material up to 15 cm in length are of acid to intermediate volcanic rocks with marble, quartzite, amphibolites and minor serpentinite. Le Fort et al. (1995) noted that when the clasts are metavolcanic the matrix tends to be limy and reciprocately, when the clasts are made up of marble, the matrix contain much volcanic material. The formation also contains phyllite sheet of more than 100 m thick and numerous limestone horizons. The major one is Pakora limestone, which separates southern tuffaceous band from mafic material rich northern band. Pakora limestone is white and green, banded and is about 2000 m thick along the Pakora section southwest of the Gants-La. It is lenticular in shape and either is reefal limestone or exotic platform carbonate or both. It has yielded Post-Valanginian rudists in black limestone boulder from the left bank of the Pakora stream (Le Fort et al., 1995). They also collected belemnite remains and echinoderm from Tisar Valley side. As already described, the Askore formation is also included in this Greenstone complex. Askore formation (amphibolite) in the Greenstone complex is dominantly amphibolite interlayered with layers of pure saccharoidal marble and crossed by concordant and discordant dykes of porphyrics ,quartz diorite and granodiorite. The amphibolites of Askore formation are of volcano-sedimentary origin. Desio (1963) has described them in details from the

Askore Valley and Zanettin (1964) along the Indus River. In the Askobar Valley, the amphibolite is overlain by pink quartz and white marble, possibly a metasedimentary cover of the original basaltic sequence. The age of the Greenstone complex is Cretaceous (Le Fort et al., 1995).

**Askore amphibolite:** Askore amphibolite was named by Desio (1963) after the name of a valley, right confluent of the middle Indus Valley. According to Desio, the formation is amphibolite sometimes garnetiferous and epidotized, often associated with amphibole-gneiss amphibole-epidote-gneiss and amphibole biotite-gneiss. They sometimes contain thick beds of limestone. Thickness of the Askore amphibolite is more than 2500 m. The age of the formation is Late Cretaceous-Eocene.

From the Askore Valley as far as the Braldu Valley the amphibolites wide spread and according Zanettin (1964), they belong to the same formation. The Askore Valley prevail the garnetiferous amphibolite, whilst further east prevail the normal or epidotic amphibolite associated with amphibole-pyroxene-gneiss. Zanettin has associated in the same complex all the amphibolites cropping out between Askore and Braldu valleys.

**Tsordas gneiss:** Tsordas gneiss has been named by Desio (1936) after the village on the right bank of the middle Indus Valley. This formation or some other unit identical with Tsordas gneiss has earlier been described by Desio as "Askore Amphibolite series" and "amphibole schist of Askore Valley".

Lithologically the formation is defined as labradorite-biotite-garnetiferous gneiss, often sillimanite bearing, characterized by the presence of calcic plagioclase and large laminae of biotite irregularly scattered. The formation also shows alternations of very thin and irregular quartz lenses and cindergrey thicker bands; both are spotted with very numerous biotite laminae irregularly layered. The cinder-grey bands are composed of a minute aggregate of calcic plagioclase, quartz, muscovite, and biotite. Garnet is often present and sometimes abundant. The gneisses contain some discordant lenses of amphibolite. According to Desio, the Tsordas gneiss passes laterally into the Baumaharel schists of Upper Cretaceous-Eocene. Likewise the Tsordas gneiss is also upper Cretaceous-Eocene.

**Bauma Harel schist:** Desio (1963) named and described Bauma Harel schist after the name of a valley, left confluent of the Shigar Valley, this unit was earlier named as "Green Shales or Shigar Shales" by Lydekker (1883), it is a sequence of green slate; in some places, they are as coarse-grained as conglomerate; in this case the matrix cementing the elements of the volcanic rock is made up of chlorite and epidote with large quantities of calcite. According to Desio, the Bauma Harel schist represents a lateral facies of the Skoro slate, of the Hashupa limestone and the Tsordas labradorite-gneiss. This last unit at places seems to underlie the Bauma Harel schist. The formation is many hundreds of meters thick. The age of the formation is described as Upper Cretaceous-Eocene. The Bauma Harel schist has also been studied by Hanson (1989), who stated that it is a unit of volcaniclastic metasediments, having an outcrop width as much as 9 km, which occurs along the northeast side of the Katzarah formation. He differentiated Bauma Harel schist in having green colour as compared to dark, black cliffs former Katzarah formation.

According to Hanson (1989) the unit consists of volcaniclastic sediments that have been metamorphosed to chlorite-epidote greenschist. The greenschist are interbedded with slates, phyllites, and minor carbonate layers; multicoloured conglomerates containing clasts of red and black shales, white marble, and greenschist are exposed in the Bauma Harel and Skoro Lungma. The Bauma Harel schist is bound on the northeast by the northern suture, and it is correlated with the other volcanic and sediments occurring along the north side of the Ladakh-Kohistan arc, such as the Rakaposhi volcanic of Tahirkheli (1982) and the Gawuch formation of Pudsey et al. (1985). Some poorly preserved Torricelli fossils were found in the formation and have tentatively been dated as Cretaceous by Warren Allmon in Hanson (1988).

**Askole amphibolite unit:** Searle (1991) named and described an amphibolite unit which is mainly composed of bands of dark-coloured amphibolites, interbedded within marbles, pelites and gneisses. The amphibolites reach maximum thicknesses around Askole and west of Mango Gusar, but also occur around the Panah and Braldu river valleys. According to Searle (1991), the Askole amphibolites contain hornblende, biotite, plagioclase, quartz garnet clinophyroxen epidote. Garnets are Fe-rich almandines and have low Mn (spessartite) and Ca (grossularite) contents. The amphibolites form relatively thin bands interbedded with sillimanite or kyanite-garnet-biotite gneisses and high-grade marbles. They are interpreted to represent metamorphosed volcanic or intrusive rocks associated with a thick limestone and minor shale sedimentary succession. This metamorphosed volcanic rock, along the Braldu Valley show a typical garbenschiefer texture. These metavolcanic assemblages include amphibole garnet epidote.

**Hashupa limestone:** Marble quartzite formation of Zanettin (1964) and Hashupa section of Lydekker (1883) was named as Hashupa limestone by Desio (1963) after the name of a village on the left bank of the Shigar River. It is a complex of beds of limestone, dolomitic limestone and dolomite, sometimes shelly, locally passing into marble and calciphyre with repeated and remarkable intercalations of labradorite gneiss mica schist and slate. According to Desio (1963) the presence in these limestone, of a bed with articles of crinoids has been mentioned by Godwin-Austen (1964) and Lydekker (1883), but such a bed could not be found by anyone else, who covered the region after those authors.

The thickness of the formations 450 to 550 m, the age of Hashupa limestone has been ascribed to the Rhaetic by Lydekker to the Silurian, and perhaps Devonian by Dainelli. According to Zanettin's observations, the Hashupa limestone, being included in the Shigar group, belongs to the Upper Cretaceous and perhaps also the Eocene.

**Ganto-la group:** Desio (1963) named this group after a pass in the ridge, which divides the Turmik Valley from the Basha Valley. The group is composed of two thick layers of limestone separated by prasinitic amphibolite, amphibole-epidote-schist and chlorite schist. The calcareous layer which appears to be the lower one, is made up of whitish saccharoidal limestone followed by dark, slightly marly limestone, the limestone is interbedded with the schists as well as it forms a thick layer of about 300 m thick. The second layer is composed of grey-blue saccharoidal limestone and light-grey subcrystalline limestone with remains of poorly preserved fossils, and of calc-schist. The limestone layer is more than 1000 m thick; the group can be divided into two calcareous formations and one schistose formation.

Desio (1963) also named some of these units, as **Munbluk limestone (Saccharoidal and marly limestone); Blanzgo formation** (greenschist); **Matuntore limestone** (waxy limestone). The relationship between the two limestone layers is not clear; however, no correlation is possible between them the thickness of the group is about 1800 m. The age of the Gañtola group is Cretaceous.

**Skoro Lumba slate:** Desio (1963) named and described Skoro Lamba slate from Skoro Valley, left confluent of the Shigar Valley. The formation is light grey and dark-grey to black, carbonaceous, very laminated slate, composed of a sericite-quartziferous aggregate with chlorite and scanty sodic plagioclase, quartz lentils and graphite stripes. The unit grade laterally, into garnetiferous micaschists, sometimes remarkably graphitic, and upward into the arenaceous **Nang Brok quartzite.** The unit contain also thick beds of limestone. The thickness of the Skoro Lamba slate is 800 m to more than 2500 m as estimated by Desio (1963). The age of the formation is Upper Cretaceous-Eocene.

**Nang Brok quartzite:** Desio (1963) named this quartzite after the name of a locality in the high Skoro Lumba, a left confluent valley of the Shigar Valley. It is composed of greyish arenaceous quartzite composed of quartz, sodic plagioclase and, subordinate calcite, biotite and muscovite. Thin intercalations of paraschists, rich in micas with the aspect of micaschists are included. The Nang Brok quartzite passes into Skoro Lumba slate. The thickness of the formation is more than 1000 m with age of Upper Cretaceous-Eocene.

**Panah ultramafic unit:** Searle (1991) isolated a prominent belt of tectonic mêlange, which occurs immediately south of the Karakoram batholith, from within the Ganchen formation, and named it Panah ultramafic unit and described it as composed of mafic gabbros, intrabasalt chert, and ultramafic rocks within a shaly matrix. The belt extends from the Masherbrum glacier area in the east, and extends westwards across the upper Aling glacier, through lower Chingkang Valley to the Panah River area. Ultramafic assemblages present include harzburgites (serpentinized). Peridotites are strongly serpentinized with secondary talc, antigorite and magnesite. Widely spaced layers and pods of greenschist and amphibolite grade gabbro and basalt, together with minor conglomerate and limestone clasts, are also associated with the ultramafic blocks.

The tectonic ultramafic-mafic mélange zone occurs both in low regional metamorphic rocks as well as high-grade (kyanite-garnet-biotite-muscovite-quartz-plagioclase-pelites. Searle et al. (1989) stated that these pelites form a discontinuous band, south of the Karakoram batholith. The origin of these ultramafic rocks remains unknown, and stated that although it is possible that they could represent a Mesozoic suture zone, it remains highly speculative.

**Daltumbore (micaschist formation):** Named by Desio (1963) after the name of a valley, left confluent of the Shigar Valley. The Daltumbore formation is composed of normal micaschist and phyllitic micaschist, graphitic micaschist, albite-garnetiferous micaschist. The micaschists sometimes contain thick beds of limestone; the formation is more than 1200 m thick and represents a metamorphic facies of the Skoro Lumba slate. According to Desio the age of the Daltumbore micaschist formation is upper Cretaceous-Eocene.

Hanson (1989) studied the formation in little more detail; according to him the Daltumbore formation is a unit of interbedded clastic and carbonate metasediments that strips the mountains on the northeast side of the Shigar Valley. Metamorphic grade increases northwestward along strike. Shales, limestones, and conglomerates exposed in the Baumaharel Lungma become slates and marbles in the Skoro Lungma; farther northwest the slates are metamorphosed to garnet-biotite schists. According to Hanson the three different units along strike (the Skoro Lungma slates, the Daltumbore micaschists and the Askore amphibolites) described by Desio (1963) in the same general area are one and the same formation and that the difference occurs only in metamorphic grade.

As to its age the Daltumbore formation seems to span a fairly large time period in the Palaeozoic. No fossils were found by Hanson in the formation, but he recorded that Brookfield and Gupta (1984) reported Permian brachiopods, crinoids, and bryozoans in limestone beds in the upper Bauma Harel Lungma above the confluence with the Yaltsa Lungma and added that, "in a personal communication (1987), T. Tyrell, C. P. Chamberlain and T. Allen, have found some Carboniferous conodonts and coral respectively". Thus, their ages agree with Permo-Carboniferous age assigned by Ivanac and others (1956) to the Asian plate sediments in Chitral, and show that the northern suture in the Shigar Valley juxtaposes Palaeozoic rocks over Cretaceous rocks of the Bauma Harel formation

**Dassu gneiss:** Desio (1963) named Dassu gneiss after a village in the Braldu Valley, District Skardu. Desio, described the formation into two parts; "the lower part is predominantly granitoid gneiss, passing upwards into gneissic two-mica granite into garnetiferous granitite, into granitic kinzigitic gneiss, into garnetiferous two-mica gneiss." The upper part of the formation passes into plagioclase-quartz-amphibole-gneiss with inclusions of garnetiferous micaschists, and into biotitic-amphibole-epidote-gneiss with garnet and amphibole-epidote-biotite gneiss with garnet, and biotite-gneiss with calcite. According to Desio (op cit), the formation shows gradually lowering of thermal conditions upwards and exhibit vertical facies change in composition of the original sediments.

Searle (1991) located Dassu gneiss around Dassu and along the Biafo glacier and Panah Valley area. In his clear brief description he stated the Dassu felsic gneiss is composed of the assemblage of biotite-K-feldspar-plagioclase-quartz-sillimanite±garnet±muscovite, and formed at temperatures at or above the muscovite breakdown reaction. Partial melt pods and veins as well as dykes of garnet - biotite - muscovite ± tourmaline ± beryl leucogranite are present. Granodioritic and quartz dioritic gneisses are also present, and migmatites form a small but important part of the complex. Foliation in the surrounding pelites (including kyanite-biotite-garnet gneisses), marble and epidote-hornblende schists wraps around these domes, or doubly plunging culminations, the uplift of which is clearly late-stage and post-metamorphic. Metamorphic isogrades are also folded around these granite gneiss domes, suggesting either late diapiric intrusion of the Dassu gneisses or post-metamorphic folding of isogrades, or a combination of both of these processes.

**Skoyo gneiss:** Desio (1963) coined the term Skoyo gneiss for banded rock exposed in the middle valley of Indus River between Skoyo and Dassu villages. Lithologically, it is Plagioclase-gneiss of granitoid aspect, mostly with biotite and epidote, it is characterised by the presence of large feldspar grains developed in a predominantly light-coloured matrix with dark bands arranged in parallel planes. The bands are composed of a fine quartz-plagioclase aggregate with biotite, epidote, muscovite and sometimes also green hornblende. Zanettin (1964) has included Skoyo gneiss into his Dassu gneissic series. The age according to Desio (1963) extends from Cretaceous to Eocene.

**Katzarah formation:** The Katzarah formation was named and described by Desio (1964), lithologically it is a unit of metasediments (amphibolite facies or higher) occurring in the Indus Valley and in the lower Shigar Valley. From the same general area he also named Tsordas gneiss, the Skoyo gneiss, the Askore amphibolite, all of them have similar lithology but are exposed separately at different places. Hanson (1989) also visited the area and according to him all of these rocks belong to the same formation.

As described by Hanson the rocks of the Katzarah formation are dark brownish grey in colour, and are generally hard and resistant. The primary minerals are calcic plagioclase, quartz, and biotite; calc-silicate minerals such as epidote and grossular are common, and aluminous minerals such as muscovite and sillimanite are locally abundant. Beds of fairly clean marble occur toward the northeast side of the formation. The rocks were probably derived from argillaceous carbonates and calcareous shales. The formation is intruded in parts, by Ladakh batholith in the shape of small plutons. Igneous dikes of varying chemistry are also exposed in the formation. Regional metamorphic grade, in the formation reach generally, in the garnet and sillimanite grades, while sillimanite-K-feldspar rocks also occur in the Indus gorge below Kachura.

**Burjila formation:** Desio (1964) named and defined Burjila formation for a low-grade metasedimentary unit occurring along the southwest side of the Indus Valley, south-east of Skardu. The formation, according to him is composed of green shale, grey green arenaceous quartz-sericite slate grey and black calcareous graphitic shale with some beds of grey and white calc-schist, crystalline limestone and calcareous conglomerate, as well as amphibole-prophyrite and quartz porphyry. He found some fossils including Pseudomesalia regularis, Itruvia canaliculata from the limestone beds interbedded with the formation.

Hanson (1989) made a brief visit to the Satpara Canyon south of Skardu, from where he described several kilometres thick phyllites and chlorite-epidote green-schists, probably derived from volcanogenic sediments. According to him bedding in the unit strikes northwest and dips steeply northeast. The formation is also exposed farther up the Satpara Canyon and in Shigarthang Lungmas. Based on fossils found in a limestone bed in the Burjila Lungmas, the age of the formation is described as Upper Cretaceous.

***Northern Sedimentary Province***

**Reshun conglomerate:** McMahon and Huddleston (1902, p. 4), referred to Reshun conglomerate as "a bed of conglomerate below Reshun". The description of the conglomerate was reconnaissance type. The conglomerate later was mentioned by Hayden (1915, p. 283-286) in which he called it the Reshun conglomerate. Hayden did not designate any type area, but describes the formation in the vicinity of Reshun Village (Lat. 36° 9' N: Long. 72° 6' E) and the section in Reshun Gol. Stauffer (1971) described the details of the conglomerate formation and proposed that section in Reshun Gol may be formally designated as the type locality of the Reshun formation.

The Reshun formation is a massive, light brown, ridge-forming conglomerate and red coloured siltstone and shale. The conglomerate consists of pebbles of limestone, quartzite, and greenstone up to 15 cm is diameter in a matrix of medium to coarse-grained sandstone. The beds of conglomerate range from 3 m to more than 20 m in thickness. Conglomerate pebbles consist mostly of white or grey limestones and dolomite, some of which contain microfossils, including Orbitolina and fragments of macrofossils at the type locality. In some layers of the conglomerate, hard, white, quartzite pebbles are dominant. Also common among the pebbles are greenstones of various types, including epidiorites and metamorphosed andesites and dacites. Rare pebbles include slate and white quartz. It appears that the greenstone pebbles are dominant in the lower portion of the conglomerate and limestone and dolomite pebbles in the upper part. The pebbles are well rounded and range, generally from 3 cm to 8 cm in diameter some are up to 15 cm.

A medium to coarse-grained, calcareous sandstone forms the matrix between the conglomerate pebbles as well as sandstone beds that range from 5 cm to about 5 m in thickness. The hematite-red siltstones of the Reshun formation reach an apparent thickness of about 450 m along Reshun Gol. Within the tectonically distributed conglomerates of the Reshun formation are beds of siltstones ranging from 1 to 10 m in thickness. The siltstones consist largely of quartz, silt, partly calcareous, with a matrix of red hematite. Where carbonate dominates the rocks are a red, silty limestone. In palaces the rocks are so fine grained that they may be called red shale, elsewhere they grade into sandstones and conglomerates. Khan et al (2000) mapped a thick marble outcrops on the western side of the Chitral Valley, which forms a high un-scalable ridge which passes laterally into phyllite and conglomerate which continues eastwards to Yarkhun Valley. On the eastern side of the valley of Chitral, the outcrop makes two prominent bands of marble separated by calcareous phyllite/red siltstone and black phyllite and this sequence is capped by conglomerate.

The minimum unfaulted thickness, according to Stauffer (1971), is at least 150 m and may be as much as 750 m. The formation is thinner to the northeast and is only about 15 m thick at Kot Pass, 40 km northeast of Buni Village. Hayden (1915) stated that the Reshun formation was probably Cretaceous or Tertiary in age based on the crushed fragments containing Cretaceous foraminifera, Orbitolina. Stauffer (1971) quoted that Tipper confirmed the Cretaceous or Early Tertiary age of the Reshun formation. But plant fragments collected by him from a calcareous shale layer 5 m thick near the base of a waterfall in Korghulo Gol, a tributary of Reshun Gol about 2 km southeast of Reshun Village and examined by Curt Teichert, formerly with the U.S. Geological Survey, and R. A. Scott of U. S. Geological Survey. Both noted the 'Psilophytic appearance' of these plant fragments, which suggested to them that the shale might be Silurian or Devonian in age.

Talent et al. (1981) stated, "Plant remains collected in carbonaceous shaly siltstones within the Reshun conglomerate on the left flank of Reshun Gol 2 km above the Chitral-Mastuj road bridge are regarded (S. M. I. Shah and R. Gould, personal communication) as being morphologically suggestive of a Palaeogene age but confirmation from palynology is not possible presumably because of mild metamorphism having destroyed the spores and pollens (W. Harris, personal communication). We thus have no firm control on the age of the Reshun conglomerate apart from a range of age somewhere post-Aptian (indicated by the Orbitolina bearing pebbles) and perhaps some time in the Palaeogene" and that Talent et al (1981) further stated that an angular unconformity was observed between Chitral slate and Reshun formation in Reshun Gol by Hayden (1915) and also by Desio (1959) at Nol. These two places as well as at Awi on the right bank of the Masty River just down stream from purplish, were examined by Talent and his party. They observed that the surface on which the Reshun conglomerate was initially deposited was erosional surface, which was one of high relief and that this is strikingly brought out by the lenticular bodies of red quartzites and slate breccia present at the base of the Reshun formation which was deposited in depressions of the old surface. They also located "outcrops of Orbitolina bearing shale beds and argillaceous limestone teeming with Orbitolina in such abundance and find preservation that they have no doubt of their autochthonous nature. Studies and discussions so far done indicate the Reshun formation is of Aptian age.

**Tupop formation:** Gaetani et al. (1990) described Tupop formation from Hunza Valley mapped mostly by Zanchi around the Upper Hunza Valley along Chapursan and Shimshal side valleys. The formation is mainly composed of red cobble conglomerate beds as much as 2 m in size, interbedded with sandstones and unfossiliferous red and grey nodular limestone. Conglomerates are mainly poorly sorted and in many cases arranged in fining upwards cycle. Graded bedding is common. Imbricate, moderately sorted, and frame worksupported conglomerates are subordinate. According to Gaetani et al. (op cit.) rare megaripple, cross-lamination point to a southward transport direction. Sedimentary feature included, such as described above and occurrence of mud cracks and caliche nodules indicate semiarid climate a sub aerial alluvial-fan depositional environment. Conglomerates are totally composed of clasts of limestone, sandstone, siltstone and shale derived from older sedimentary rocks spanning in age from Permian to Triassic and Jurassic.

Gaetani et al. (1990) further added that prior to the deposition of Tupop formation, the older sequence had undergone through an early Tectonic episode. This was a very strong uplift, and was accompanied by deformation, "anchimetamorphism" (i.e. almost metamorphosed) and then was subjected to the erosion of the entire Permian to Jurassic succession, which is now composed of several tectonic slices arranged in a wide antiform, which apparently plunges to the south. This important event of early tectonic episode probably occurred during Early Cretaceous. The conglomerate of the Tupop formation seals in the Kundil and Tupop valleys, the stacked thrust-sheets, originated during this important tectonic event.

Gaetani et al. (1990) related this important event to the collision of the Kohistan arc with the southern margin of Eurasia, here represented by the Karakoram block, in other words the lower contact of the Tupop formation stands with spectacular 90 degree angular unconformity with older vertical standing sedimentary formation. According to Gaetani et al. (1990) the orogeny (early tectonic episode), which deformed the older rocks continued even during the deposition of Tupop formation. The upper contact of the Tupop formation with Darband formation is slightly unconformable. Thus Tupop formation is older than Companion Darband formation and younger than Early Cretaceous tectonic events, which caused the origin of Tupop formation.

**Darband formation:** Gaetani et al. (1993) coined the term Darband formation to describe a calcareous unit exposed in a limited area of Kundil Valley, upper Hunza district. According to them Darband formation is composed mainly of limestone inter-bedded with mudstone marl, sandstone and polymictic conglomerate towards the top of the formation limestone is pink in colour thick bedded and modular, mudstone and marl is grey and pink in colour.

The Darband formation overlies Tupop formation with a minor angular unconformity. The formation indicates short-lived ingression and is considered the youngest marine sediments detected in the north Karakoram region. The formation is fossiliferous but most of the fossils are crushed and fragmental, it contains Inoceramids and Globotruncanids. The formation is dated as Campanian and possibly Maastrichtian. This age assignment is based on the presence of Ceratolithoides verbekii and Calculites obscurus.

**Sarpo Lago slate:** Desio (1963) named the unit after the name of a valley to the north slope of Karakoram. Lithologically, the Sarpo Lago slate is argillaceous and arenaceous black slate with intercalations of foliated dark gneiss. The age of the formation, according to Desio is upper Palaeozoic. He further stated "Black slate are diffused also in the high Baltoro Valley and probably belong to the same Sarpo Lago formation".

**Savoia formation:** Desio (1963) named and described Savoia calc-schists, entitled after the name of a glacier, right tributary of the Godwin Austin glacier, Baltoro basin. According to him the formation is predominantly calc-schist, yellowish white and whitish limestone and schistose calcareous conglomerate. Searle (1991) described it as Savoia formation and repeated the definition of Desio and Zanettin (1970) as follows: "sequence of yellowish-grey limestones passing up to conglomerates and multicoloured breccias overlain by thin phyllitic calcschists. The formation is unfossiliferous and the true age remains unknown. Desio correlated it with Albian-Aptian orbitolina bearing limestone of the Yasin group which is far away and entirely a different basin and was far remote from the Northern Karakoram and added that no possible correlation can be made across the Karakoram batholith and metamorphic complex and their correlation must be rejected. The age, facies and thickness of these rocks are unknown. The Savoia limestone may, however, form some of the marbles exposed in the greenschist facies metamorphic rocks of the Doksam Ridge, north of concordia on the Baltoro glacier.

**Khalkhal formation:** Desio (1963) named and described Khalkhal formation as composed of green and red slaty calcareous sandstone and arenaceous phyllite with a few conglomerate intercalations. Searle (1990) described it as a sequence of "green fissile shales" sandstones and highly deformed conglomerates form the highest stratigraphic level of the Gasherbrum sedimentary sequence and have been studied along the southwestern flank of Broad Peak. According to Searle (1991) on Broad Peak the rocks of the Khalkhal formation are metamorphosed to greenschist facies and strongly deformed. Highly stretched conglomerates indicate a northwest southeast aligned shearing direction. On the southwest face of Broad Peak, the quartz diorites, lamprophyre dykes also intrude these sediments. The top of the formation is not seen as it crops out along the summit crest of Broad Peak and is mostly snow covered. The age of the Khalkhal formation according to Desio (1963) is Cretaceous.

**Hushe complex:** Hushe complex was named and defined by Searle et al. (1986, 1989), who restricted the formation to the area along the Hushe Valley and the mountains north of the Thalle Valley. It is closely associated with the older components of the Kande plutonic unit. North of the Thalle Valley, the lithology of the rocks comprises hornblendite and hornblende diorite, in places metamorphosed to amphibolites, biotite granodiorite to monzogranite, and occasional K-feldspar megacrystic granite. Most of these rocks are foliated and primary mineralogy is poorly preserved in the felsic gneisses. Based on intrusive relations, the mafic phases are inferred to be the oldest igneous components of the Hushe complex. He further added that thin bands of marble and psammitic metasediments are associated with the orthogneiss. Searle et al. (op. cit.) gave the age of 145-160 Ma. for a deformed hornblende biotite granodiorite of Hushe complex. From the same complex but separate diorite body near Tasser La and Meldi Peak gave age of 208±7 Ma.

**K2 gneiss:** K2 series of Desio (1936) has been re-named by Desio (1963) as K2 gneiss after the name of the highest peak in the Karakoram Range. Desio (1963) describes it as Porphyroblastic biotite-muscovite-gneiss with medium-sized plagioclase-gneiss striking out on a dark-grey and greenish-grey base, prevailing, associated with amphibolegneiss, augengneiss, dark, fine-grained gneiss. Earlier in 1957 Desio had included the crystalline limestone and other paraschists as lenses in this formation. The K2 gneiss is over 200 m thick and the age of it is unknown.

**Falchan Kangri gneiss:** Desio (1963) named and described this formation from the northern side of Falchan Kangri, or Broad Peak, in the Baltoro basin. Briefly, the lithology of the Falchan Kangri gneiss is composed of black to dark-grey phyllitic paragneiss alternated with light quartz-arenaceous gneiss. Its thickness is not less than 1000 m and the age is not known.

# CAINOZOIC

Cainozoic of Pakistan is the Era of Mountain building and the withdrawal of the sea, resulting in the accumulation of vast continental deposits with spectacular development of land life especially the mammalian population. The area suffered extremely complicated tectonic history having direct affect on the entire stratigraphic set up of Pakistan, especially in the northern and western half of the country. Without going much into the details of the tectonics, which is beyond the scope of this volume, it will be focused only on the stratigraphic set up of the Cainozoic rocks of Pakistan. To begin with a brief outline, of style, behaviour, vertical and lateral distribution of rocks is given below:

Regression of Mesozoic seas, in various parts of Pakistan; is marked by a period of emergence. As a result the Tertiary rocks have variable lower contact relationships with the older units. This contact varies from an angular unconformity between Paleocene and older unit (as old as Jurassic) in parts of the Sulaiman Province and Axial Belt to disconformable contact between various Tertiary and older units in the Kohat-Potwar Province. In some parts of the Lower Indus Basin, Axial Belt and Balochistan Basin, however, the contact between Cretaceous and Paleocene is reported to be transitional (Cheema et al., 1977).

This regression however continued even through the Paleogene times. In general the Cainozoic rocks were deposited in a broad sea, which gradually narrowed and retreated southward, with the passage of time, till it came to occupy its present position as the Arabian Sea. The rocks of the Cainozoic Era exhibit variation in thickness and lithology in different areas. Lithologically in the Paleocene and Eocene times the sediments are mainly limestone and calcareous shale, while in the younger ages the sediments are dominantly sandstone, silt, and mud. The Quaternary sediments are coarse clastics mainly conglomerate, as against fine clastics of the Late Tertiary. Various tectonic elements, especially the Axial Belt have played important role in controlling these variations. These elements have also affected numerous local unconformities in Pakistan.

Economically a number of important mineral deposits (coal, petroleum, natural gas, gypsum, rock salt, building stone, sulphur etc.) are associated with the Cainozoic rocks. Volcanic and Plutonic activities, also took place in a few areas of Pakistan, during the Cainozoic Era. Volcanism occurred sporadically in the Lower Indus Basin, Axial Belt and Balochistan Basin. The main area of volcanism, however, was the Eruptive Zone of the Balochistan Basin. The intrusions are associated with the geanticlines and welts of the ancient geosyncline. The intrusive rocks are in part basic to ultrabasic and in part granitic. Plutonic activities are mainly known from the northern half of Pakistan.

The Cainozoic stratigraphy of Pakistan has received much attention by various oil companies, Geological Survey of Pakistan and other agencies. This has resulted in the accumulation of a large volume of data on the Cainozoic rocks. To begin with the Tertiary sequence of Pakistan, it is stated that they are remarkably varied in lithology and thickness. The Central and Lasbela geanticlines (in the Axial Belt) played a very significant role in controlling these variations. The submarine Axial Belt partly prevented the eastward influx of clastic sediments from the Balochistan Basin into the Indus Basin, which was the realm of calcareous deposition during Early Tertiary times. Other structural elements that influenced the sedimentation in different Tertiary basins were the Muzaffarabad, Mianwali and Jacobabad highs, the Ras Koh geanticline and the Sanjawi, Hyderabad, and North Chagai arches. The pre-Pleistocene fundamental and orogenic structures produced local unconformities. The development of many of the structural elements in south-western Pakistan is considered to be genetically related to igneous activity (Hunting Survey Corporation, 1961).

As already described the close of the Mesozoic Era was marked by a widespread non-deposition. This resulted in an unconformable relationship between the Paleocene formations and various Mesozoic units in large areas of Sulaiman Province, Kohat-Potwar Province and the Balochistan Basin. At a few places, such as central Salt Range and Khisor-Marwat ranges, the Tertiary units (as young as Pliocene) lie unconformably on older units, as old as Cambrian. In parts of the Axial Belt, however, the sedimentation appears to have been continuous from Cretaceous into the Paleocene Epoch. In the early Tertiary Period, particularly the rocks of the Paleocene Epoch are mainly represented by limestone and marl with various proportions of shale, sandstone and conglomerate in different areas. The Paleocene sediments are almost entirely marine except for the mainly fluviatile Bara Formation and the basal laterite beds. Small-scale volcanism occurred in different parts of the Lower Indus Basin, Axial Belt and the Balochistan Basin.

This volcanism occupies large area in the Lower Indus Basin and is represented by large scale Khaskheli Basalt interbedded with clays and shale of Paleocene age. Partial emergence towards the end of the Paleocene was followed by submergence in Early Eocene when the sea, inundated a major part of Pakistan. Towards the close of Early Eocene a short-lived regression took place (Nagappa, 1960), which resulted in the formation of evaporites in the Kohat area, Sulaiman Province and parts of the Axial Belt. This regression was most effective in the Kohat-Potwar Province. In the Kirthar Province, at places, the regression is manifested by an unconformity between the Lower and Middle Eocene strata. The regression was followed by a widespread submergence which affected large areas including the western Kohat, Lower Indus Basin, Axial Belt and the Balochistan Basin. Pre-Pleistocene structural elements (pre-orogenic structures of Hunting Survey Corporation, 1961) influenced the sedimentation pattern of the area, especially in the Axial Belt. Volcanism is manifested by volcanic rocks of the Saindak formation and Chagai and Bunap intrusions of the Eruptive Zone.

The Eocene rocks are limestone and calcareous shale with subordinate sandstone and conglomerate. In some areas, however, the sandstone and conglomerate become important constituent of the sequence. Locally, red beds, gypsum, anhydrite, salt and coal also become significant in the Eocene sediments. Generally speaking, the limestone is dominant in the Indus Basin and the Axial Belt, while shale is dominant in the Balochistan Basin.

During Middle and Late Eocene times different parts of Pakistan became emergent resulting in unconformities of varying magnitude. The Kohat-Potwar Province and major parts of the Sulaiman Province completely emerged during the Oligocene as Eocene strata are disconformably overlain by Miocene rocks. In Kirthar Province and southern parts of Sulaiman Province, the Oligocene Epoch was characterized by deposition of deltaic and fluviatile sediments interfingering with marine sediments from north to south. Pre-Pleistocene orogenic structures continued to be the areas of tectonic influences and volcanism in the Eruptive Zone. These structures also influenced the sedimentary pattern, especially in the Axial Belt, where coarse clastic sediments were laid down following the emergence of the Central Geanticline. Igneous activity is manifested by the volcanic of the Saindak and Amalaf formations and intrusions of the Shore Koh and Ras Koh areas. Limestone was the dominant lithology deposited during Early Oligocene in the Kirthar Province and parts of the Axial Belt, while fine clastic dominated in the Balochistan Basin. After Early Oligocene, sandstone, silt and mud were deposited throughout the Lower Indus Basin, Axial Belt, and the Balochistan Basin. This change from carbonates to clastics was the result of the second Himalayan orogeny. Clastic sedimentation continued throughout the Oligocene and persisted into the Miocene.

In Miocene times the sea had regressed further west and south, which resulted in fluviatile sedimentation in Kohat-Potwar Province, Sulaiman Province and northern parts of the Axial Belt. Mixed deltaic and marine sedimentation was predominant in the southern Kirthar Province. The Balochistan Basin, however, witnessed the continuation of marine sedimentation through Miocene and Pliocene. The Pliocene Epoch was characterised by fluviatile sedimentation in the Indus Basin except in the area near the present coast, where it was deltaic to marine. Pliocene rocks are dominantly sandstone, silt shale and mudstone with locally derived conglomerate. Conglomerate is an important constituent of the rocks in Axial Belt and in Dalbandin trough of the Eruptive Zone which manifests the tectonic activity of the Central geanticline and the Ras Koh geanticline respectively Hunting Survey Corporation (1961).

Climax in the mountain building reached in the quaternary period, the rising mountains shed coarse clastics, which were deposited in the low-lying areas. In fact the Late Tertiary sedimentation of mainly fluviatile nature continued into the Quaternary Period. The Quaternary deposition was mainly influenced by the main phase of Himalayan orogeny, which began in the Early Pleistocene (Gill, 1952). This orogeny has been regarded as the strongest of all phases and resulted in folding, faulting and uplift of the Himalayas. The Quaternary sediments rest with an angular unconformity on various older units. In certain areas, however, the contact between the Tertiary and Quaternary units is apparently transitional. There is ample evidence that the tectonic activity is still going on, at places, in Pakistan.

Various workers have identified indications of glaciations and ice-rafting during Pleistocene Epoch in Upper Indus Basin and Northern Montane Area. No such observations have been recorded from other areas of Pakistan. Some small-scale volcanism occurred during the Pleistocene in the Eruptive Zone (Koh-i-Sultan volcanic group). The Pleistocene rocks are clastics, mainly conglomerate, which have been referred to as "molasses" in previous literature. These coarse clastics were deposited in isolated depressions that existed within the newly risen ranges. Most of the conglomerates were locally derived from the hills surrounding the depressions. All the sediments are continental, except near the present coast where they are littoral marine.

The folded Pleistocene rocks are followed by alluvial coarse clastics that are poorly consolidated and only slightly tilted if at all. These deposits are usually referred as "Sub recent deposits". The Sub recent deposits are followed by "Recent deposits" that are in an aggradation stage. These deposits include wind-blown sand, alluvial fans, recent floodplain deposits, mud deposits, present-day shingle beaches, lacustrine deposits, and others.

## PALEOCENE

### INDUS BASIN

In the Indus Basin, the Kohat Potwar Province and major part of the Kirthar Province was the site of deposition during Danian. Soon after the Danian, a dominantly sandstone facies at the base followed by shallow water foraminiferal limestone in most of the Indus Basin was deposited. The end of the Paleocene Epoch, in places, is marked by slight emergence but marine conditions returned soon after. Nothing much can be definitely said about the Paleocene occurrences in the Balochistan Basin. However, the Rakhshani formation in the Eruptive Zone and central part of Arenaceous Zone of the Axial Belt represents a marine sandstone-shale facies with common interbeds of andesitic and basaltic lava flows.

#### *Upper Indus Basin (Kohat-Potwar Province)*

Rocks of the Paleocene age constitute Makarwal group and are well developed throughout the Kohat-Potwar Province except in the Khisor-Marwat-Bhittani ranges in the south-western part of the Province. Coal, laterite, iron ore and bauxite occur within the sequence. Three formations, recognized in the Province, are as follows. No. 1 is the oldest.

1. Hangu Formation
2. Lockhart Limestone
3. Patala Formation

**Makarwal Group:** 'Ranikot' of Kirthar Range has sometimes been extended to denote Paleocene units of Upper Indus Basin in Kohat-Potwar Province. Although, the Paleocene of Kohat-Potwar Province has chronostratigraphic equivalence with that of Lower Indus Basin, yet both of them have considerable difference in terms of rock characters. This difference is probably due to the prominence of Sargodha High, which divided the Indus Basin during Paleocene. Obviously the extension of the name "Ranikot" to refer to the Paleocene of Kohat-Potwar Province is inappropriate. Alternatively, the name Makarwal Group as proposed by Shah (1980) is adopted here to assemble mixed deposits of continental and marine facies represented by Hangu, Lockhart and Patala Formations. However, Makarwal Group's comparison with Ranikot Group of Lower Indus Basin is shown in Fig. 18.

The group is well exposed at Makarwal, where all its components / formations are well

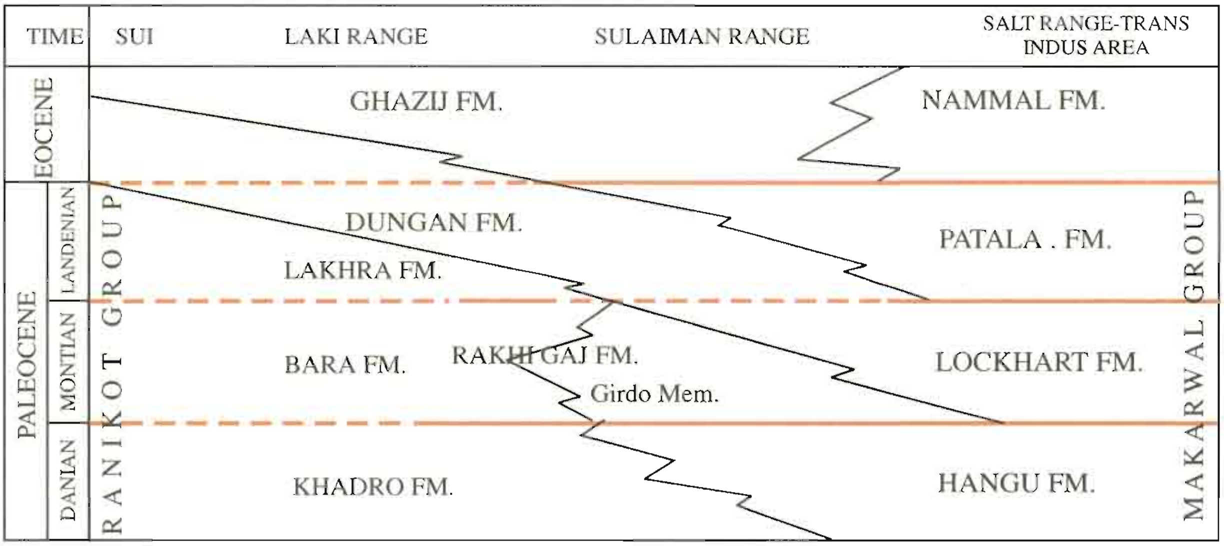



Fig. 18. Correlation of Ranikot - Makarwal groups.

developed and accessible. The type locality is suggested at Makarwal Kheji (Lat. 32° 51' N: Long. 71° 09' E) by Shah (1980) who named and described the group. Three formations are included in this group. The lowest is Hangu Formation, which is mainly composed of sandstone, siltstone, shale, claystone and limestone; average thickness of the formation is 50 m. Overlying Hangu Formation is Lockhart Limestone, which is composed of mostly nodular limestone with marl partings. It is about 66 m thick. The topmost is Patala Formation, which is composed predominantly of olive greyish green shale with thin bedded sandstone and limestone. Thickness of this formation at the type locality is about 150 m.

The Makarwal Group is well developed all over the Kohat-Potwar Province with gradual pinching of lower part of the group in the eastern Salt Range. The group unconformably overlies the Early Cretaceous in the western Salt Range and Trans-Indus ranges and oversteps different units of Palaeozoic in the central and eastern Salt Range. It conformably underlies the Chharat Group. The group is over 250 m thick in the Surghar Range. The age of the Makarwal Group, as determined from the fauna of its component formations, is Paleocene in the Salt and Surghar ranges. It is correlative with the Ranikot Group of Lower Indus Basin with which its wholesome continuity is yet to be established (Fig 18).

**Hangu Formation:** The "Hangu Shale" and "Hangu Sandstone" of Davies (1930a) from the Kohat area have been formalized by the Stratigraphic Committee of Pakistan (1973) as Hangu Formation and the name is extended to include the "Dhak Pass beds" of Davies and Pinfold (1937), the "Langrial Iron Ore horizon" of Khan and Ahmed (1966), the "Dhak Pass formation" of Danilchik and Shah (1967), and the basal "Mari Limestone" of Latif (1970a) in the Kohat-Potwar Province.

Type section of the formation has been designated at Fort Lockhart (Lat. 33° 33' 40" N: Long. 71° 03' E) and the Principal Reference section at Dhak Pass (Lat. 32° 40' N: Long. 71° 44' E) in the Salt Range. Lithologically, as described by Cheema et al. (1977), the Hangu Formation, in the Kohat area, consists of sandstone with grey shale intercalations in the upper part. The sandstone is white, light grey and reddish brown, weathering dark rusty brown, fine to coarse-grained, (in places conglomeratic) and medium to thick bedded. In the Salt Range and Trans-Indus ranges, the formation consists of dark grey, rarely variegated sandstone, shale, carbonaceous shale and some nodular, argillaceous limestone. The carbonaceous content increased locally and constitutes coal seems in parts of the Surghar Range (Makarwal area). A two to three meter thick bed of ferruginous, pisolitic sandstone occurs at the base of the unit. In western Kala Chitta, Nizampur and Hazara the unit is mainly represented by ferruginous, oolitic or pisolite sandstone, siltstone and clay and contains the "Langrial Iron Ore".

The Hangu Formation is widely exposed and also present in the subsurface in the Kohat-Potwar and Hazara areas. It is 90 m thick in the Fort Lockhart section, 50 m at Hangu, 75 m at Darsamand and 150 m in the Kohat Pass area. It is 45 m thick at Dhak Pass in the Salt Range and 30 m in the Surghar Range. It is less than 15 m thick in the Nizampur-Kala Chitta area and 35 m at Mandeha Banni in Hazara.

The formation disconformably overlies the Kawagarh Formation in the Kohat, Kala Chitta and Hazara areas and unconformably overlies various Palaeozoic and Mesozoic formations (the youngest being the Lumshiwal Formation of Cretaceous age in the Salt and Surghar ranges). It is conformably overlain by the Lockhart Limestone. Foraminifers with some corals, gastropods and bivalves have been reported by Cox (1930b); Davies and Pinfold (1937); Haque (1956) and Iqbal (1972). Davies et al. (1937) recorded the presence, in the Salt Range, of *Operculina*, cf. *O. candalifera, O. subsalsa, Miscellanea miscella, Lockhartia haimei, L. conditi and Lepidocycma (Polylepidina) punjabensis.* Haque (1956) recorded abundant Epistominella dubia from Nammal Gorge, Salt Range. The formation on the basis of the above mentioned foraminifers is assigned an Early Paleocene age. It is correlated with the lower parts of the Dungan, Bara and Rakhshani formations of the Lower Indus Basin, Axial Belt and Balochistan Basin.

**Lockhart Limestone:** Davies (1930a) introduced the term "Lockhart Limestone" for a Paleocene limestone unit in the Kohat area and this usage has been extended by the Stratigraphic Committee of Pakistan to similar units in other parts of the Kohat-Potwar and Hazara areas. This unit thus represents the "Nummulitic Series" of Middlemiss (1896), the lower part of "Hill Limestone" of Wynne (1873) and Cotter (1933), the "Khairabad Limestone" of Gee (1934) "Tarkhobi Limestone" of Eames (1952) and "Marl Limestone" of Latif (1970a). A section exposed near Fort Lockhart (Lat. 33° 26' N: Long. 70° 30' E) in the Samana Range has been designated as type locality of the unit.

Lockhart Limestone, in the Kohat area, is grey to medium grey, medium to thick-bedded, massive, rubbly and brecciated in places. The basal part is dark grey to bluish grey and flaggy. In the Salt Range and Trans-Indus ranges the limestone is grey to light grey, medium-bedded, nodular with minor amounts of grey marl and dark bluish grey, calcareous shale in the lower part. In the Hazara and Kala Chitta areas the limestone is dark grey and black in colour and contains intercalations of marl and shale. The limestone is generally bituminous and gives off fetid odour on a fresh surface.

The limestone is well developed throughout the Kohat-Potwar Province. It is 60 m thick in the type locality, 36 m at Darsamand and 40 m at Thal in the Kohat area. It is 70 m at Nammal Gorge in the Salt Range, 260 m thick in Kala Chitta and 90 to 242 m in Hazara. The formation conformably and transitionally overlies and underlies the Hangu Formation and the Patala Formation, respectively.

The Lockhart Limestone contains abundant foraminifers, corals, molluscs, echinoids and algae, Eames, Bhola and Nagappa (1951) have reported algae *corallina* grandis and foraminifera of which *Lockhartia conditi* var. *roeae, L. haimei. Miscellanea miscella* and *Operculina patalensis* are important. Raza (1967); Cheema (1968) and Latif (1970c) have reported a number of foraminifers from the Hazara area including *Lockhartia conditi. L., conica, L. haimei, Daviesina khatiyahi, Rotalia trochidiformis, R. perovalis, Globorotalia uncinata, globigerina tringularis, Textularia smithvillensis, Triloculina trigonula, Pseudogloborotalia khairabadensis, Miscellanea miscella,* and *Actinosiphon punjabensis.* From the Salt Range, Haque (1956) reported a rich foraminiferal assemblage including *Valvulinidae triangularis, V. nammalensis, Clavulina parisiensis, Planorbulinella khairabadensis, Pseudogloborotalia ranikotensis, P. paleocenica, P.*

*Khairabadensis, Ornatanomalina geei* and others. Larger foraminifers as reported by Davies and Pinfold (1937) from the Salt Range, include Operculina subsalsa, *O. patalensis, Miscellanea miscella, M. stampi, Lockhartia haimei, L. tipperi, L. newboldi, Discocyclina ranikotensis, Dictyoconoides flemengi, Fasciolites globosa, Assilina dandotica* and *Nummulites nuttali.* The above-mentioned fossils indicate a Paleocene age. The Lockhart Limestone is correlated with the Bara Formation, the lower parts of the Dungan and Rakhshani formations of the Lower Indus Basin, Axial Belt and Balochistan Basin, respectively.

**Patala Formation:** The term Patala Formation was formalized by the Stratigraphic Committee of Pakistan for the "Patala Shale" of Davies and Pinfold (1937) and its usage was extended to other parts of the Kohat-Potwar and Hazara areas. The formation includes the "Tarkhobi Shale" of Eames (1952), part of the "Hill Limestone" of Wynne (1873) and Cotter (1933), part of the "Nummulitic formation" of Waagen and Wynne (1879), part of the "Nummulitic Series of Middlemiss" (1896) and the "Kuzagali shale" of Latif (1970a).

The section exposed in Patala Nala (Lat. 32° 40' N: Long. 71° 49' E) in the Salt Range has been designated as type section. Cheema et al. (1977) stated that in the Salt Range the formation consists of shale and marl with subordinate limestone and sandstone. The shale is dark greenish grey selenite-bearing, in places carbonaceous and calcareous and also contains marcasite nodules. The limestone is white to light grey and nodular. It occurs as interbeds. Subordinate interbeds of yellowish brown and calcareous sandstone are present in the upper part. Coal seams of economic value are present locally (Dandot area). In the Kohat area, the formation is represented by dark grey shale, which, in places is carbonaceous and includes light grey argillaceous limestone beds. In Hazara, the shale is green and brown to buff in colour with interbeds of nodular limestone. In Kala Chitta Range, the formation is represented by light brown and grey marl with thin interbeds of limestone.

The formation is widely exposed in the Kohat-Potwar and Hazara areas and has been encountered in the subsurface of the Potwar area. It is 27 m thick at Khewra and 90 m at Patala Nala. The thickness varies between 30 to 75 m in the Surghar Range, 30 to 180 m in the Kohat area, 60 to 182 m in the Hazara area and is 20 m thick in the Kala Chitta Range. Throughout its extent the Patala Formation conformably overlies the Lockhart Limestone. The Patala Formation is conformably and transitionally overlain by the Nammal Formation in the Salt Range, the Panoba Shale in the Kohat area and the Margala Hill Limestone in the Hazara and Kala Chitta areas.

The formation is richly fossiliferous and contains abundant foraminifers, molluscs and ostracodes. From the Salt Range, Smout and Haque (1956) recorded larger foraminifera including *Actinosiphon tibetica, Assilina dandotica, Daviesina intermedia, Discocyclina ranikotensis, Kathina nammalensis, Lockhartia conditi, Nummulites globules, Operculina canalifera, O. patalensis* etc. The smaller foraminifera as reported by Haque (1956) include *Glandulina laevigata, Cincoriala cvoidea, C. patalensis, Cycloloculina glabra, Globigerina linaperta, Vavulineria patalensis* and others.

Latif (1970c) reported smaller foraminifera from Hazara which include *Globoratalia* *elongata, Globigerina primitiva, Triloculina trigonula, Rotalia trochidoformis* and *Miscellanea prehaimei.* The largest foraminifera recorded by Raza (1967) and Cheema (1968) include *Assilina dandotica, A. granulosa, A. spinosa, Daviesina danieli, D. khatiyahi, D. langhami, Lockhartia conditi, L. hunti, Operculina canalifera, O. patalensis, Rotalia dukhani* and *Sakesaria ornata.*

The Patala Formation has been assigned a Late Paleocene age throughout its extent, except for the Hazara area, where it extends into the Early Eocene. It is correlated with the Lakhra Formation, the upper part of the Dungan and Rakhshani formations and lower parts of the Ghazij Group and Laki Formation of Lower Indus Basin, Axial Belt and Balochistan Basin.

***LOWER INDUS BASIN AND CALCAREOUS ZONE OF AXIAL BELT***

Paleocene sequence of the Lower Indus Basin, particularly of Kirthar Province, has been well studied since the mid-nineteenth century due to its rich foraminiferal and molluscan fauna. The Paleocene formations of Kirthar Province have been loosely termed as "Ranikot" a name still in use as chronostratigraphic unit for the rest of the Indo-Pakistan subcontinent. Though limestone is the dominant lithology in most parts of the Lower Indus Basin, shale dominates in the Axial Belt and eastern Sulaiman Province. The following formations are recognized:

1. Khaskheli basalt (Lower Indus Basin and Axial Belt).
   Ranikot Group
2. Khadro Formation (Lower Indus Basin and Axial Belt)
3. Bara Formation (Lower Indus Basin and Axial Belt)
4. Lakhra Formation (Lower Indus Basin and Axial Belt)
5. Rakhi Gaj Formation (Sulaiman Province)
6. Dungan Formation (Sulaiman Province and parts of Kirthar Province and Calcareous Zone of Axial Belt)

**Ranikot Group:** Blanford (1876) was the first to use the name "Ranikot Group", named after Ranikot Fortress, in the northern part of the Laki Range, Sind. He used the name to designate strata lying between his "volcanic" and "Kirthar or Lower Nummulitic Group". Blanford also called Ranikot Group as "Infra-Nummulitic". From his description (op. cit; p. 11), it appears that he included strata, that he later (1879) named "Cardita beaumonti beds", as part of his Ranikot Group. He redefined the Ranikot Group in 1879 and excluded the "Cardita beaumonti beds" and "Trap group" from the unit. In the present report, however, Blanford's original description of the group is retained and the group is considered to represent strata that were identified by him in 1879 as "Cardita beaumonti beds", "Trap group" and "Ranikot Group". Blanford's redefined "Ranikot Group", was subdivided into "Lower Ranikot (sandstone)" and "Upper Ranikot (limestone)" by Vredenburg (1909a). This subdivision is held valid in the present report. Accordingly, the Ranikot Group is considered here to comprise three formations which in ascending stratigraphic order are Khadro Formation (Cardita beaumonti beds), Bara Formation (Lower Ranikot sandstone) and

Lakhra Formation (Upper Ranikot limestone). The group also represents a number of units of Hunting Survey Corporation (1961) to which reference is made in the description of the component formations.

The lower part of the group consists of olive, yellowish brown sandstone and shale with interbeds of limestone (Khadro Formation), followed by variegated sandstone and shale of mainly fluviatile origin (Bara Formation). The upper part consists of grey limestone, weathering brown, and some grey to brown sandstone and shale of estuarine origin (Lakhra Formation). Main areas of exposures are in the Kirthar Province. It is fairly well developed in the Axial Belt but only rare occurrences are recorded from the Sulaiman Province. The thickness ranges from 540 to 660 m. The group apparently unconformably overlies the Pab Sandstone and the Moro Formation. It is overlain conformably by different units in different areas.

A Paleocene age has been assigned to the group on the basis of fossils present in the Khadro and Lakhra Formations. The group is correlated with the Dungan Formation and Rakhshani formation of southern and western Pakistan. It is also correlated with the Hangu to Patala sequence of the Kohat-Potwar Province (see Fig.18). Paleocene series of Lower Indus Basin has always been correlated chronologically with Paleocene series of Upper Indus Basin. Details of this correlation are discussed below:

Fig. 18. is a diagrammatic sketch showing tentative correlations within the Paleocene Series. The correlations are based not only on the ages assigned to the several lithologic units but also on the stratigraphic position of these units, their lithologic character, and the interpreted history of their deposition. Some biostratigraphic observations commonly found among units are also indicated. The Hangu Formation of Makerwal group and the Khadro Formation of the Ranikot Group have been assigned a Danian age by earlier workers. The two units are also lithologically very similar. It is therefore assumed that they are lithologic as well as chronologic equivalents. Similarly, Bara and Lakhra Formations of Montian and Ladinian age respectively corresponds to Lockhart Limestone and Patala Formation, they are considered chronologic equivalents.

The Dungan and Lockhart formations are also very similar lithologically, but the Lockhart Limestone is considered Medial Paleocene (Montian) in age, whereas the Dungan Formation apparently ranges from Paleocene to Early Eocene in age. Because the Dungan Formation seems to become younger in a southerly direction (being largely Early Eocene at Sui). Flynn (1972) has interpreted the Lockhart and Dungan Formations as representing a single lithofacies, whose deposition commenced during Montian time in the Salt Range and Trans-Indus area and spread southward with time.

The upper part of the Rakhi Gaj Formation of the Ranikot Group of Sulaiman Range and the Patala Formation has been assigned a Late Paleocene (Ladenian) age, they are shown in Fig. 18 as chronostratigraphic equivalents. Owing to the interposition of the Dungan Formation, however, they apparently did not form laterally continuous lithofacies, although they have some lithologic similarity. Girdu Member of Rakhi Guj Formation is fluviatile and a product of delta, its exposures are restricted. In Early Eocene, the correlation of the formations of south with those of the north (Salt

Range area and Trans-Indus ranges) is as under:

Due to their similar lithologic character, age, and stratigraphic position, the Shaheed Ghat Formation and the Nammal Formation are considered to be lithostratigraphic as well as chronostratigraphic equivalents. Because the Drug limestone and the Sakesar Formation are lithologically similar, both of them contain the same robust molluscs and occupy alike position in the stratigraphic sequence, they are considered chronostratigraphic and lithostratigraphic equivalents.

Finally it is pointed out that it has also been observed that some formation tend to become younger in age (based on biostratigraphic zonation) as they continue southwards. As for example, Gaetani et al. (1980) demonstrated that Daviesina langhami zone is present in Hangu Formation of Danian (Early Paleocene) age. Incidentally, Daviesina langhami is considered as index fossil by Kureshi (1978).This formation also contains other fossils including Miscellanea miscella, Daviesina bramkampi, Actinosiphon tibetica; on the contrary, this entire set of fossils appear in the south as typical of Upper Ranikot/Upper Paleocene.

**Khaskheli Basalt:** The Khaskheli Basalt has been proposed by Nusrat Kamal Siddiqui of Pakistan Petroleum Ltd. (written communication 1987) to basically volcanic flows with interbedded mudstone and clay stone. These lava flows were originally included in the Khadro Formation and now in view of their great thickness (lateral extent and subsurface), they are separated as Khaskheli Basalt Formation.

Lithologically, these basalt flows are dark green to black in colour with abundant basic glass filling the vesicles and amygdules. The formation is generally interbedded with mudstone and clay stone. Top and base of the unit exhibits weathering effects showing reddish to brownish grey colour, which has been caused by abundant pyroxene, olivine and chlorite, filling the cavities. Unlike the Deccan Traps, which are generally free from olivine the basalts in Southern Indus Basin contain abundant olivine. These lava flows have been encountered in most of the wells e.g. Dasori-1 (PPL, 18m) Tallar-1, 30.5m drilled in the South Indus Basin including offshore. They are thickest in offshore areas where they are of the order of 333 m and in the north they thin to about 135 m near Badhra well of PPL-Hunt oil companies. The indicated thickness does not include the interbedded mudstones etc, which probably represent quiescent periods between volcanic eruptions. Eastern limit is probably marked by longitude 69° as the proposed formation was not encountered in Badin and Drigh wells of Stanvac Oil Company. In the west, it is exposed in Bara Nai Laki Range where a thin outcrop of about 27.5 m is seen at the Paleocene/Cretaceous contact.

Stratigraphically they overlie Cretaceous and are underlain by Paleocene rocks. On the basis of their stratigraphic position the lava flows can be assigned a post Cretaceous age but probably they range from Maastrichtian to Danian, which is to be confirmed by radiometric dating methods. Earlier, Kadri and Khan (1972) studied these traps and worked out their geological aspect. They compared these flows with Deccan traps and stated that they resemble with Daccan traps in many aspect but unlike the Daccan traps which are generally free from olivine, these basalts, in the offshore region contain olivine, where they are more than 300 m thick, whereas in its northern limit at Badhra, south of Dadu it is 13.5 m thick. In the offshore region Khaskheli basalt overlie Goru, Pab and

Khadro Formations ranging in age from upper Cretaceous to Paleocene.

**Khadro Formation:** "Cardita beaumonti beds" of Blanford (1878) and later workers were renamed Khadro Formation by Williams (1959). The Khadro Formation in the present report also includes the basal parts of the "Karkh", "Gidar Dhor", "Jakker" groups and the "Bad Kachu" and Thar formations of Hunting Survey Corporation (1961), and "Venericardia shales" of Eames (1952). Williams (1959) designated Bara Nai (Lat. 26° 07' 06" N:. Long. 67° 53' 12" E) in the northern Laki Range as the type section but named the unit after Khadro Nala, which is north of Bara Nai.

The Khadro Formation consists of sandstone and shale, with some limestone. The sandstone is olive, yellowish brown, grey and green, soft, medium grained, ferruginous and calcareous. The shale is olive, pale bluish grey, chocolate and reddish brown and gypsiferous and contains thin interbeds of grey to brown argillaceous, in places arenaceous limestone in the lower half of the unit. Both sandstone and limestone are fossiliferous. At the type locality the basal part of the unit consists of dark limestone bed with oysters and reptile bones. A number of basaltic flows (at least two) are present in the unit that are partly massive, partly amygdaloidal, brecciated and weather black. Top of the unit is usually marked by a volcanic flow. At Karkh and Jakker, the formation consists dominantly of interbedded soft, brown and olive shale and grey to green, well bedded sandstone. The Karkh occurrence contains fragments of greenish and rusty weathering vesicular rock and locally thin layers of dense, black basalt. Some marl beds are also present at Bad Kachu. Some conglomerate layers, consisting of pebbles and chips of red jasper, marl, limestone, red and green lava, diorite, black basalt and pink granite is present at Nagar Parkar.

The formation is widely distributed in the Kirthar Province and Calcareous Zone and parts of the Arenaceous Zone of the Axial Belt. It has been reported from one locality (Rakhi Nala) in the Sulaiman Province, where it is 170 m thick. Nusrat Kamal Siddiqui reported (written communication 1987) that the formation is present all along the eastern flank of Fort Monro anticlinal trend as observed at Drug (139 m), but further south at Kaha and Khalgari nallahs, it is comparatively thin. The formation probably pinches out north of Drug as Paleocene is represented by only Dungan Formation in Mughal Kot, Gat Tangi and Shapalai sections. The lithology of Khadro Formation at Khalgari Nallah is more or less same as observed at Rakhi Nallah. It is 67 m thick in the type section, (Bara Nai) 140 m in the subsurface at Lakhra, and 180 m in the subsurface at Dabbo Creek. The formation unconformably overlies the Moro Formation and Pab Sandstone. It is apparently overlain conformably by the Bara Formation.

Eames (1952) reported *Corbula (Varicorbula) harpa, Leionucula rakhiensis, Venericardia vredenburgi, Tibia (Tibiochilus)* rakhiensis and other fossils from the Rakhi Nala and assigned an Early Paleocene age to the unit. Abundant Cardita *(Venericardia) beaumonti* of Danian age have been reported from different areas by a number of workers. Besides these, Danian foraminifers like *Globigerina pseudobulloides* and *G. triloculinoides* have also been recorded by Nagappa (1959). Sohn (1959) recorded ostracodes such as *Howecythereis multispinosa, H. micromma* and *Paracypris rectoventra* from the Laki Range. A long list of foraminifera has been given by Hunting Survey Corporation (1961). Douville (1928) has also described a fauna from the formation. The age of the formation is regarded as Early Paleocene (Danian) which, in places, extends down into Late Cretaceous as indicated by the presence of *Globotruncana* (Hunting Survey Corporation, 1961). It may be correlated with the lower part of the Rakhshani formation in the Eruptive Zone of the Axial Belt.

**Bara Formation:** Ahmad and Ghani (written communication, 1971) have proposed the name Bara Formation for the "Lower Ranikot (sandstone)" of Vredenburg (1906) and "Lower Ranikot" of later workers. The formation is named after Bara Nai, Laki Range, in accordance with the stratigraphic Code of Pakistan (1967). The Bara Formation of the present report also represents the "Gorge Beds" of Eames (1952), the "Ranikot formation" of Williams (1959) and the "lower Ranikot formation" and lower parts of the "Jakker group", "Thar ", "Rat taro" and "Bad Kachu" formations of Hunting Survey Corporation (1961). Bara Nai (Lat. 26° 07' 06" N: Long. 67° 53' 12" E), northern Laki Range is herein designated as the type section while Ranikot (Lat. 25° 54' 24" N: Long. 67° 54' 38" E) is designated as the principal reference section of the formation.

Cheema et al. (1977) described the formation as consisting of dominant sandstone with lesser shale and minor volcanic debris. The sandstone is varicoloured, fine to coarse grained, soft and crumbly. Massive looking beds ranging in thickness from a few centimetres to 3 m are common. It is calcareous, ferruginous, ripple-marked and cross-stratified. The interbedded shale has dark shades of colour similar to that of sandstone and is soft, earthy and gypsiferous. At places, both shale and sandstone are carbonaceous, while the shale is sometimes highly carbonaceous and locally contains coal seams. Ferruginous nodules are usually present. Some volcanic debris, weathering greenish grey to black, has been reported from the lower part of the formation.

The formation is widely distributed in the Kirthar Province and Axial Belt. It is 450 m thick at the type locality, 600 m at Ranikot and 510 m in subsurface at Dabbo Creek. Williams (1959) has reported less than 60 m thickness from the northern part of the Sulaiman Range, while Eames (1952) reported 140 m of his "Gorge Beds" (see also Rakhi Gaj Formation), which represent the Bara Formation of the present report. Except for these two occurrences, the formation has not yet been identified in the Sulaiman Province. The formation conformably overlies the Khadro Formation and underlies the Lakhra Formation. At places where the overlying Lakhra Formation is absent (Ranikot area); it is unconformably overlain by the Laki Formation.

No fossils have been found in the formation except for some oysters, reptile remains and carbonized leaf impressions. Nagappa (1960) has mentioned the presence of rare arenaceous foraminifera. Since the formation conformably overlies the Khadro Formation of Danian age and underlies Upper Paleocene Lakhra Formation, it is regarded as Middle Paleocene in age. Vredenburg (1928) had given the Thanetian age to these beds on the basis of Ostraea talpur. The formation is correlated with the Hangu Formation of the Kohat-Potwar Province and with the lower part of the Rakhshani formation of the Balochistan Basin. The lower part of the Dungan Formation is also stratigraphically equivalent to Bara Formation in the Lower Indus Basin.

**Lakhra Formation:** Ahmad and Ghani (Shah, 1977) have proposed the name Lakhra Formation, after Lakhra, Laki Range, for the "Upper Ranikot (limestone)" of Vredenburg (1906) and

"Upper Ranikot" of later workers. The Lakhra Formation of the present report also represents the upper "Ranikot formation" and upper parts of the "Bad Kachu", "Rattaro" and "Thar" formations and lower part of the "Jakker group" of Hunting Survey Corporation (1961). The Lakhra-Bholari section on the southern flank of the Lakhra anticline, Laki Range is designated as the type section.

The formation consists of dominant limestone which is grey with yellowish staining and weathering brown and buff, at places orange brown and pinkish brown. It is thin to thick bedded, nodular, and has a brecciated texture. The limestone is sandy, in places argillaceous and fossiliferous. Some of the fossiliferous beds are coquina-like. Sandstone is present in the lower part while interbeds of sandstone and shale are present in the upper part. The sandstone is ferruginous, calcareous and in places grades into arenaceous limestone. It is grey and chocolate (weathering grey and brown), fine to coarse grained, ill-sorted, sparingly fossiliferous, thin to thick bedded and cross-stratified. The shale is grey, weathers yellow brown, and at places grades into clay stone. The formation is widely distributed in the Kirthar Province and the Axial Belt. It is 242 m thick at the type section, 135 m at the northern flank of the Lakhra anticline and 50 m at Bara Nai. The formation has been erroneously reported by Hunting Survey Corporation (1961) to be absent in the Laki Range. The formation conformably overlies the Bara Formation. In the Kirthar Province, it is unconformably overlain by the Laki Formation. In the Axial Belt, its upper contact is conformable and transitional with the overlying Nisai formation.

Khan, M. H. (in Lexique, 1956) has recorded presence of rich assemblages of foraminifers (Davies, 1927; Nuttall, 1931), corals (Duncan, 1880), molluscs (Vredenburg, 1909, 1928b), and echinoids (Duncan and Sladen, 1882). The foraminifers include *Nummulites nuttalli, N. thalicus, N. globulus, N. sindensis, Assilina ranikotensis, Miscellanea miscella, M. stampi, Lockhartia haimei, Lepidocyclina, (Polylepidina) punjabensis,* and *discocyclina ranikotensis.* Hunting Survey Corporation (1961) has also given a long list of fauna in which foraminifers predominate. On the basis of its fauna Late Paleocene age is assigned to the formation. Iqbal (1972, p. 24) also confirms Late Paleocene age to this formation. The formation is correlated with the upper parts of the Dungan and the Rakhshani formations. It is also correlated with the Lockhart Limestone and Patala Formation of the Kohat-Potwar Province (Cheema et al., 1977).

**Rakhi Gaj Formation:** The "Lower Rakhi Gaj Shales" and "Gorge beds" of Eames (1952) have been formalized by stratigraphic committee of Pakistan as the Rakhi Gaj Formation (Shah, 1999). Upon the suggestion of S. M. Hussain of American Oil Company, the Stratigraphic Committee has also adopted the name "Girdu Member" with the Rakhi Gaj Formation for the "Gorge beds" of Eames (1952), Lower Rakhi Gaj Shales and Zindapir shales of Eames (1952) are the synonyms. The Rakhi Nala section (Lat. 29° 27' 14" N: Long. 70° 01' 30" E) is designated as the type section.

The Rakhi Gaj Formation as defined by Shah (1999) consists dominantly of shale with subordinate amounts of sandstone and some bands of limestone. The shale is dark greenish grey and light olive grey. It is interbedded with thin bands or siltstone, quartzite and some bands of sandstone at the base which weather to moderate yel1owish orange. In Zindapir area, there are a few bands of grey, fossiliferous limestone and marl in the upper part. In the lower part, there are 4 to 5 m thick sandstone bands. The sandstone is rusty brown in colour and hard. The shale at places is sandy and contains iron concretions. In the Rakhi Nala, the shale contains common calcareous, carbonaceous and ferruginous concretions, and is highly bioturbated. In the middle part, clay stone nodules are common. Near the top, the limestone is interbedded with sandy, silty, calcareous and fossiliferous sandstone and shale.

The Girdu Member is mostly glauconitic, conglomeratic, micaceous, quartzose sandstone of red brown and yellow colour. Pyrite is abundant throughout the members. Simple cross bedding, alternating with laminated bedding is common in the upper half. The siltstone, limestone and shales are in subordinate amounts. The siltstone is thin bedded and is light grey in colour. The limestone is intraclastic and bioclastic and medium grey. The shale is carbonaceous and gypsiferous medium grey with mottled iron staining. In the middle part of the Rakhi Gaj Formation, the sandstone is greyish-red and medium to coarse grained, which becomes conglomeratic with common greyish red/quartzitic and oolitic hematite pebbles. Shale is present in very small amounts and is medium to dark grey. In the upper part, the quartzitic sandstone is interbedded with siltstone and shale. The quartzitic sandstone is fine-grained. Abundant small pebble sized. Ferruginous concretions weather out from the shale. The shale is medium to dark grey. In the uppermost part, the quartzite becomes pink to brownish grey, fine to medium grained and well-cemented. The shale present in the upper most part of the formation is olive grey, slightly silty and occasionally laminated.

The Rakhi Gaj Formation is primarily restricted to the eastern Sulaiman Range and the southern part of the Marri-Bugti hills. The thickness in the Rakhi Nala is 340 m whereas it is about 170 m thick on the eastern flank of the Zindapir anticline. The Girdu member is 140 m thick in the Rakhi Nala. The contact of Rakhi Gaj Formation with the overlying Dungan Formation is conformable, in fact; the decreasing abundance of sandstone towards the top of Rakhi Gaj Formation is probably the result of deposition in a transgressive sea. The Rakhi Gaj delta was submerged and at places it gave rise to transitional heads of the overlying formation. The lower contact with the Khadro Formation is also conformable. The shale and sandstone of the Rakhi Gaj Formation contain marine molluscs all over the formation. The diagnostic fossils, however, are rare and very little information is available concerning the age of the formation. On the basis of superposition and the position with respect to chronostratigraphic equivalent units of the region, a medial to late Paleocene age is assigned to the Rakhi Gaj Formation.

**Dungan Formation:** The name "Dungan Limestone" was introduced by Oldham (1890) to replace the "Alveolina limestone" of Griesbach (1881), which is a thick limestone sequence between Parh Limestone and Ghazij Group in the Dungan hills of the Sulaiman Province. Williams (1959) redefined, the terms as "Dungan Formation", and excluded the basal beds (his Fort Munro Limestone member), which were found to have unconformable relationship with the rest of the unit. The Dungan Formation of Williams (1959) is further redefined here to include the "Lower Rakhi Gaj Shales", "Zindapir Shales" and "Zindapir Limestone (lower part)" of Eames (1952) and "Dungan Group" (excluding Moro formation), "Dab formation" and "Karkh Group" of Hunting Survey

Corporation (1961). Williams (1959) designated Mirhab Tangi Gorge, (Lat. 30° 08' 38" N: Long. 67° 59' 33" E), 8 km northeast of Harnai, Loralai District as the type section.

The Dungan Formation dominantly consists of nodular to massive limestone with subordinate shale, marl, sandstone and limestone conglomerate. At its type locality and elsewhere, particularly throughout Marri-Bugti hills and Quetta region, the lithology is exclusively limestone that is dark grey to brown and creamy white weathering brown, grey and buff yellow. The dark blue grey, brown and olive shale, which weathers grey or green, becomes dominant in the southern Sulaiman Range. Appreciable amounts of varicoloured marl are also developed in the vicinity of the Kingri-Mekhtar and Bolan Pass (Mach) areas of the Sulaiman Province and the Karkh area of the Kirthar Province. In these parts of the Sulaiman and Kirthar Provinces (excluding the Kingri-Mekhtar area) thick beds of limestone conglomerate occur which grade into nodular and massive limestone. The conglomerate is usually composed of pebbles and cobbles of grey and brown limestone and marl embedded in a matrix of soft, ashy grey calcareous shale and hard ferruginous marl. Occasional brownish green, coarse grained, calcareous sandstone beds are interlayered with shale (Cheema et al., 1977).

The Dungan Formation is mainly developed in the Sulaiman Province and parts of the Calcareous Zone of the Axial Belt (e.g. in Quetta region,). It is also reported from the northern border of the Kirthar Province i.e., in the vicinity of Karkh. The formation is usually more than 300 m thick, though its thickness changes rapidly from place to place. It is reported to be 365 m in parts of the Quetta region. The lower contact of the Dungan Formation is unconformable in most of the localities and marks one of the major unconformities of the basin (Williams, 1959). It oversteps most of the Cretaceous and older rock units. In Quetta and Harnai regions including the type locality, it unconformably overlies the Fort Munro formation with a thick laterite bed ("Ziarat Laterite" of Shah, 1975) or conglomerate in between. In parts of the northeastern Sulaiman Province, it unconformably overlies the Pab sandstone. But in places, e.g. Siazgi and Sanjawi, in the Sulaiman Province and Karkh in the Kirthar Province, the contact is transitional with the underlying Pab sandstone and Moro formation. The upper contact with the Ghazij Group is conformable. A rich fossil assemblage including foraminifers, gastropods, bivalves and algae are recorded by Davies (1941), Khan and Haque (in Lexique 1956), Hunting Survey Corporation (1961), Latif (1964), Iqbal (1969a) and others. Foraminifers are generally abundant and most of them belong to *Fasciolites, Nummulites, Coskinolina, Dictyoconoides, Discocyclina, Linderina, Lockhartia, Operculina, Miscellanea, Globorotalia, Cibicides, etc.* Species like *miscellanea miscella, M. stampi, Nummulites nuttalli, N. thalicus, N. sindensis, Assilina dandotica, Kathina selveri,* and *Lockhartia tipperi* indicate a Paleocene to Early Eocene age. Some algae such as *Distichoplax* sp., *Lithothamnium* sp., *Mesophyllum* sp. reported from this formation confirm that age. The formation is correlated with the Ranikot Group and the Rakhshani formation of western Pakistan and the Hangu-Patala sequence of the Kohat-Potwar Province.

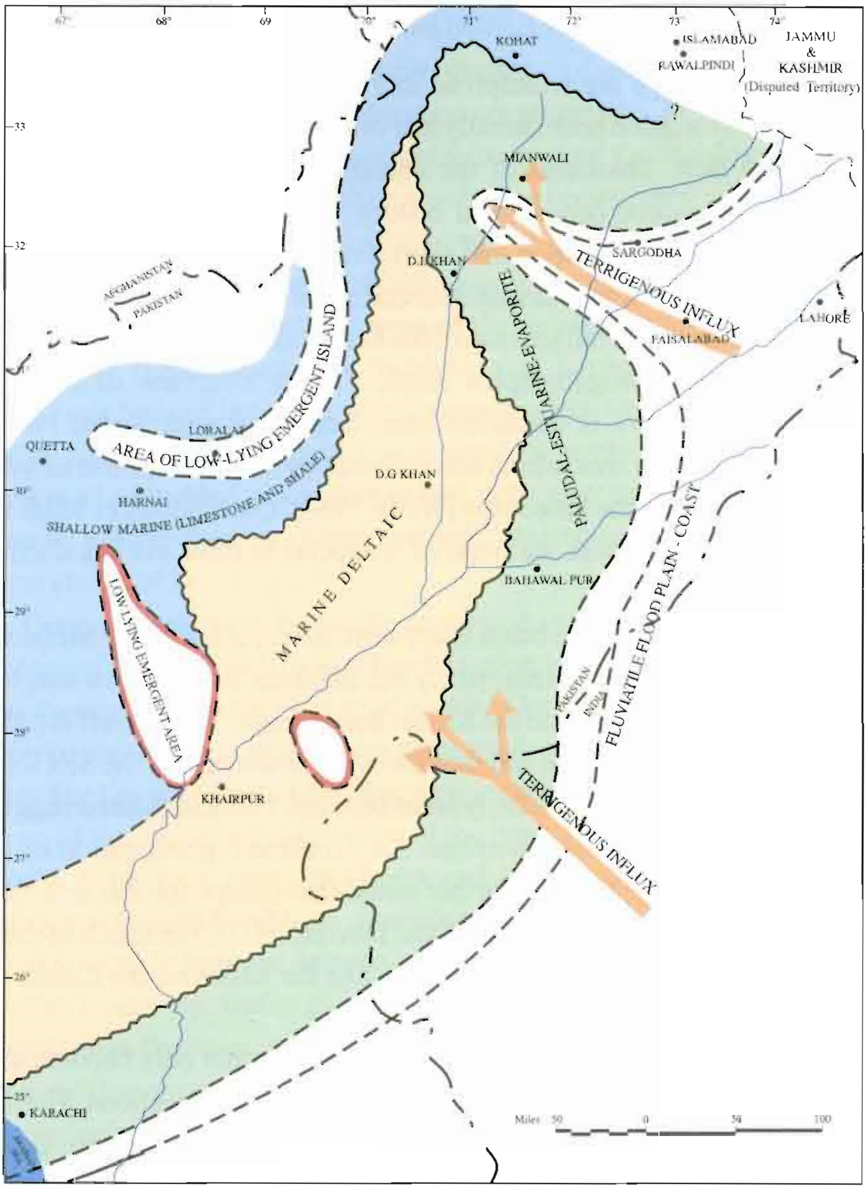
## PALEOCENE PALEOGEOGRAPHY

Rocks of Paleocene age are widespread in Pakistan. In the Upper Indus Basin they are characterized by frequent variation both laterally and vertically as compared to other areas like lower Indus Basin and Axial Belt. Thickness of the constituent formations also varies within short distances. This makes Paleocene depositional history very complicated in the sense that quick changes in the environment of deposition and short lived coastal lines throughout Kohat- Potwar Province and northern Sulaiman Range demand several maps to represent different attributes present at different times. Thus, only a generalized map of the Early Paleocene is reconstructed.

Before drawing the Paleogeographic maps, a quick overview of the events and their interpretation by various authors is discussed here. Beginning with Kohat Potwar Province a transgression is seen in the Kohat area, which was followed by the development of a depo-centre on a submerged open-marine shelf in the Paleocene (Wells, 1984). Quick changes south east of Kohat in the Kohat-Potwar Province and south and west of it appears to have made a distinct depositional basin from Paleocene times onwards.

The Paleocene geometry of the basin is apparent in isopach map by Meissner and Rahman (1973). It shows that the basin was at least partly cut off from the southern sea, by the opposing peninsulas formed by the Kirana hills and the Khisor Range High. This cut-off is probably reflected in the occurrence of Paleocene shoreline and shallow-water sediments in the Salt Range. The influx of submarine debris flows in the more northerly areas between Thal and Panoba suggests the location and orientation of the basin's northern shoreline. An excellent representation of this situation is shown by Flynn (1972) see Fig. 19. It is further noted that except for the lava flows, facies can generally be correlated across the basin (Pinfold and Davies, 1937). For much of the Paleocene, the basin may have been a submerged depo-centre, more like the basins on the California Shelf than a landlocked basin like the Persian Gulf (Wells, 1984).

From the Paleocene sequence it is evident that the facies not only become more marine in a vertical direction, but also more marine in the western and southern directions. These changes occur within short distances and for short period of time and because some units are time transgressive. The construction of a meaningful paleogeographic map necessitates some generalization. A generalized paleogeographic map showing the aerial distribution of the lithofacies present in the Kohat and Sulaiman sequences during Early to Middle Paleocene time is shown in Fig. 19. During Paleocene, the foreland shore was apparently located at a more westerly position than during the previous times, as evidenced by the carbonaceous, lignitic, and occasionally coaly beds within the Hangu Formation and the basal beds of the Ranikot Group. According to Flynn (1972) such sediments are present in wells drilled in the Jaisalmir area of India. They also outcrop in the Salt Range-Trans Indus area, and have been encountered in wells drilled in the Potwar Plateau. Thus, a long narrow zone, containing swamps, marshes, and meandering streams, probably existed along the eastern half of the Punjab. The area probably also contained shallow marine embayments, as evidenced by the presence of gypsum, oysters, and other bivalves.




LEGEND

- Shallow marine limestone and shale
- Marine Deltaic, Undifferentiated shallow marine and deltaic environment - the entire area shows mixed Paludal-estuarine-evaporite environment
- Mixed environment, showing indicators of swamps and marshes, swamps at places may be loaded with wood or covered with grasses as well as with aquatic vegetations
- Fluviatile Flood Plain in the coastal region
- Low-lying emergent areas

Modified after Flynn (1972)

Fig. 19. Paleogeographic sketch map of Middle Paleocene.

Another indication that the shoreline and source area lay not far to the east is found in the type of sediments comprising the Bara Formation of the Ranikot Group. Although the sandstones which constitute both the Pab Sandstone and Bara Formation of the Ranikot Group were apparently derived from the crystalline rocks of the Indian Shield, the Pab Sandstone is mineralogically mature and has good size sorting, whereas the sands of Bara Formation are mineralogically and texturally immature. Deltaic sandstones of the Bara Formation are present at Giandari, Rakhi Nala and Sore Nala in the southern Sulaiman Range but are apparently absent southward toward Sui Gas Field. Northward, towards the Zao River and Gumal River, and westward toward the Sanjawi Arch, the sandstones inter tongue with limestone and shale. With this situation in hand, Flynn (1972) hypothesized that "a delta transported sand across the paludal and estuarine zone and discharged it onto a shallow marine shelf."

As mentioned earlier that during Early and Middle Paleocene time no sediments were deposited on the Jacobabad "High", the Sanjawi Arch and the Sargodha "High". In these areas, Dungan Formation of mainly Late Paleocene lay directly upon beds of pre-Paleocene age, often separated from them by a laterite zone. This unconformity is considered one of the major break in sediments in this area where Dungan Formation is directly sitting on Cretaceous and older rocks. It is also noted, however, that deposition of the Dungan Formation apparently commenced in certain localized areas during Middle Paleocene time. Such is apparently the case, in the Quetta area, Sembar Pass area, and northward in the Gumal River and northern Potwar areas. Therefore, it seems that low lying emergent areas were present near Jacobabad and along the present day axis of the Sanjawi Arch. These areas probably formed a more or less continuous chain of islands. Along the east side, and possibly the west side, of the islands a narrow zone of open marine water existed in which deposition of the Dungan Formation commenced. On the east side, this marine shelf merged eastward into the area in which the deltaic sands were being deposited, but the area containing Dungan Formation was sufficiently far remote so as to have received no sand. Dungan Formation is exclusively composed of limestone at the type locality, throughout Marri-Bugti hills and the entire Quetta region. In southern Sulaiman and partly in northern Kirthar, conglomerate with clastics of limestone, some or negligible calcareous sand layers interbedded with shale is also present. During the same time of middle Paleocene, Wells (1984) reported partial emergent land, flanked by clastic shores and humid tropical deltas and euxinic conditions in the Kohat area. He also reported patch reefs in northwest.

During Late Paleocene time, throughout the northern part of Indus Basin a widespread shallow sea was established as indicated by the presence of Dungan Formation and Patala Formation spread all over the area. The establishment of this wide spread sea is also testified by the fact that even the Sanjawi and the Jacobabad High were also attached by sea and these elevated areas also became the sites of deposition for thick accumulation of foraminiferal calcarenites. Southwards, however, around Sui and Mari gas fields, shoaling (sand banks in the sea did occur and is apparently responsible for the good porosities encountered in their Paleocene to Early Eocene limestones (Flynn, 1972).

### BALOCHISTAN BASIN AND ARENACEOUS ZONE OF AXIAL BELT

The following Paleocene rocks are differentiated in the Balochistan Basin:

1. Rakhshani formation (Eruptive Zone and Arenaceous Zone of Axial Belt)
2. Ispikan conglomerate (Makran-North Zhob Region)

**Rakhshani formation:** The name "Rakhshani formation" was proposed by Hunting Survey Corporation (1961) for a heterogeneous sedimentary unit, which was variously designated in different localities as *"Cardita beaumonti beds"*, "Volcanic Flysch", "Ranikot", "Siwalik" etc. by Vredenburg (1901). In the present definition the Rakhshani formation also includes the "Juzzak formation", lower half of the "Gidar Dhor group", and basal part of "Pishi group" of Hunting Survey Corporation (1961), and "Bunap Formation" of Ahmed (1951). The formation has been named by Hunting Survey Corporation (1961) after the tribal belt of Rakhshani at the eastern end of Dalbandin Valley, Chagai District. However, no type section was designated. Cheema et al. (1977) described the formation as consisting of light to dark green and grey, medium to coarse-grained sandstone. Some grey to black, argillaceous and fine-grained limestone beds are also present, which are common in the lower part. Conglomerate, lava flows of basaltic and andesitic composition, tuff and volcanic agglomerate are essential ingredients of the formation.

The formation has a widespread distribution in the Eruptive Zone and is also developed in the Gidar Dhor Valley of the Arenaceous Zone of the Axial Belt. It has an extremely variable thickness, which generally ranges from about 150 m to more than 1,600 m. The thickest exposure is to the south of Rabat where it is more than 2,400 m thick. In the Chagai and Dalbandin areas, the formation is conformably underlain by the Humai formation whereas in the Raskoh Range by the Kuchakki volcanic group. In the Gidar Dhor Valley, however, the lower contact is transitional with the underlying Parh limestone. The upper contact with the Kharan and Saindak formations in the Eruptive Zone and formation of Ghazij Group exposed in the Gidar Dhor Valley is also transitional.

The formation has yielded fairly good assemblage of foraminifers, bivalves, gastropods, algae and rare coelenterates. The foraminifers *like Alveolina vredenburgi, Flosculina, globosa, Miscellanea miscella, Saudia labyrinthica,* etc., as reported by Hunting Survey Corporation (1961), indicate a Paleocene age. Some Danian fossils like those of *Venericardia sp. cf. V. (Cardita) beaumonti, Pyrazus sp. cf. P. Buddha, Pseudoglauconia lissoni,* etc., are reported from the lower beds of the formation (Cox, in Hunting Survey Corporation, 1961). The formation is correlated with the Dungan Formation and the Ranikot Group of the Lower Indus Basin. It is also equivalent to the Hangu-Lockhart-Patala sequence of the Kohat-Potwar Province.

**Ispikan conglomerate:** Hunting Survey Corporation (1961) named a single exposure of conglomerate, 3 km northeast of Ispikan, (20 km northeast of Mand in North Makran) as Ispikan conglomerate but has not chosen any type section.

The conglomerate comprises un-bedded and unsorted masses of boulders of grey limestone, igneous rocks and quartz pebbles in dark green, chloritic matrix. The igneous boulders resemble the Chagai intrusions and the Sinjrani volcanic group and consist of granitic and andesitic rocks. Some of them are of granitic gneiss. The limestone boulders resemble Jurassic limestone of the area.

The conglomerate has been mapped in only one area, on the north side of Kulbar Kaur, where a hill about 0.8 km long and 60 to 90 m high is mostly composed of this formation. The conglomerate is probably several hundred metres thick (Hunting Survey Corporation, 1961). The lower contact with the 'Cretaceous marl' is probably unconformable, while the upper contact is not exposed but blocks of the Nisai formation rest on the conglomerate suggesting that they are erosional remnants. Hunting Survey Corporation (1961) reported the following fossils: *Orbitolina sp. Discocyclina sp., Nummulites sp., Archaeolitho-thamnium sp.,* And *Distichoplax biserialis* from the pebbles of the formation. The stratigraphic position between Eocene and Cretaceous rocks suggests a Paleocene to Eocene age (Cheema et al., 1977). The Ispikan conglomerate cannot be correlated with any other unit of Pakistan, due to its localized occurrence and characteristic lithology.

## EOCENE

The transgression, which invaded the Kohat Potwar area in Paleocene, continued through Eocene and as a result, the Eocene represents a period of sedimentation throughout the Indus Basin where as the sedimentation occurs only in a small part of Balochistan Basins. In the southern part of Axial Belt, the Central and Las Bela provinces were sub-merged to the extent where identical marine sedimentation took place, on both the flanks, in various parts of the Axial Belt. Whereas shale-limestone facies dominated the sequence in the Indus Basin, rapid sedimentation of sandstone and shale (Khojak formation mostly Oligocene) started in major part of Balochistan Basin. However, localised basin in the southeastern part of the Eruptive Zone is the only site of deposition for the Eocene limestone in the Balochistan Basin.

### *UPPER INDUS BASIN (KOHAT-POTWAR PROVINCE)*

**Chharta Group:** The Chharat Series of Pinfold (1918) has been formalized by Stratigraphic Committed of Pakistan as Chharat Group after the Chharat Village in Attock District, Punjab Province. The group is comprised of the following formations in different parts of Kohat-Potwar Provience and Hazara area. In the Kohat area the group is represent by Kohat Formation, Kuldana Formation, Jatta Gypsum, Shekhan Formaiton, Panoba Shale and Bahadur Khel Salt. In Northern Potwar (Hazara, Kala Citta, and parts of eastern Kohat) the group includes Kohat Formation, Chorgali Formation and Margala Hill Limestone. In the areas of the Southern Potwar, Salt Range and Trans-Indus ranges, Kuldana Formation, Chorgali Formation, Sakesar Limestone and Nammal Formation, are included in the Chharat Group. Mixed marine and non-marine rocks with numerous elements of evaporitic nature, especially in Kohat area represent the lithology of the group, the whole sequence represents regressive phase, commencing earlier in the west than in the east.

The base of the group contains grey to bluish grey marl, limestone and shale (Nammal Formation) succeeded by nodular, massive and cherty limestone (Sakesar Limestone) in the south, these two units change, in the Kohat area, into olive green shale with few gypsum, limestone and shale intercalations (Panoba Shale), overlain by grey to yellowish green nodular limestone with gypsiferous shale in the upper part (Shekhan Formation) with local development of economic deposits of rock salt (Bahadur Khel Salt). In Kala Chitta and Hazara only a single stratigraphic unit, the Margala Hill Limestone, is recognizable which consists of grey, nodular limestone with subordinate shale. The Margala Hill Limestone is overlain by the Chorgali Formation, which shows a lateral facies change from limestone and gypsiferous shale in the north, to purple and grey shale and limestone in the south with the development of greenish white to grey gypsum (Jatta Gypsum). The next younger unit (Kuldana Formation) consists of varicoloured shale and marl with gypsum in the east changing laterally to the west into reddish clay with subordinate white sandstone near the top. The topmost unit of the group (Kohat Formation) that overlies the Kuldana Formation consists mostly of nodular, light grey to cream coloured limestone and olive green shale.

The group is widely distributed in the Kohat-Potwar-Hazara Province. Thicknesses of various formations are given in following chapters. The lower contact of the group with the Patala Formation is conformable. The Chharat Group is unconformably overlain by rocks of the Rawalpindi Group. Early to middle Eocene age is assigned to the group on the basis of the molluscan fauna and foraminiferal assemblage.

A total of eleven formations, recognized in different parts of Kohat-Potwar Province are listed as follows:

Panoba Shale
Gurguri sandstone
Shekhan Formation
Bahadur Khel Salt
Jatta Gypsum
Margala Hill Limestone
Chorgali Formation
Kuldana Formation
Kohat Formation
Nammal Formation
Sakesar Limestone

**Panoba Shale:** Eames (1952, p169) introduced the term "Panoba Shale" for a rock unit earlier represented by the "Green Clay" of Wynne (1879), it also includes the upper part of "group f-1" of Griesbach (1892), part of "group z (e2 b) and (3) ezc" of Pascoe (1920), the "Green Shales" of Parson (1926) and the "Green Clay and Sandstone" of Gee (1934), all in the Kohat area. The section exposed south of Panoba Village (Lat. 33° 37' N: Long. 71° 35' E) has been designated as the type section for the Panoba Shale, where the formation consists of shale with occasional bands of sandstone. The shale is greenish grey to light grey, slightly silty and is calcareous towards the base. In places, greenish grey alum shale, with ferruginous and calcareous partings and veins of gypsum are common. Flaggy limestone bands occur at different levels. The unit grades southward into rock salt (Bahadur Khel Salt).

The Panoba Shale is confined to the Kohat area and its thickness ranges from 40 m at Tarkhobi to 160 m at Uch Bazar it is 100 m thick at the Panoba section. The formation conformably overlies the Patala Formation and is, in different areas, conformably overlain by the Shekhan Formation or Jatta Gypsum or Bahadur Khel Salt. Only in few places is the Panoba Shale unconformably underlying the Kohat shale, e.g. in the Uch Bazar Section. Foraminifers including Globorotalia aequa, Assilina pustulosa, Orbitolites complanatus, Nummulites sp., and Eponides sp., have been reported by Meissner et al. (1968, 1969). The foraminiferal assemblage indicates Early Eocene age of the Panoba Shale.

The formation is correlated with the lower part of the Margala Hill Limestone, Nammal Formation and parts of the Jatta Gypsum and Bahadurkhel Salt of the Kohat-Potwar Province. It is also correlated with parts of the Ghazij, Laki, Kharan, Rakhshani, Saindak and Nisai formations in different parts of the Lower Indus Basin, Axial Belt and Balochistan Basin.

**Gurguri sandstone:** Shales of Panoba in the western part of Kohat are overlain by particularly interesting sandstone. Many people have called it an unconformity which caps the Panoba Shale. This sandstone unit is particularly important in the reconstruction of Paleogeography of the Paleocene. The unit is an indicator of an ancient coastal line, which drew detrital material, probably for the first time, from the west. The unit has been named as Gurguri sandstone by Wells (1984). The type section of the unit is designated at Gurguri, in the west-central part of Kohat area.

According to Wells (1984) at least 50 to 75 m of unfossiliferous, uniform, clay-grade, olive-grey Panoba Shale are capped by approximately 12 m of upward coarsening and brownish coloured Gurguri sandstone, which is in turn directly overlain by Kohat Formation. At Gurguri as an equivalent outcrops nearby, the sandstones contain abundant casts, including micrites, pelmicrites, other limestones, unfossiliferous silicified limestones, and radiolarian cherts.There are also fragments of clams, clasts of limestone with Laki foraminifera, and possibly Ranikot algae and bryozoans. Despite its less than perfect exposure, the sandstone is of considerable interest, and two good overlapping partial sections are described. The sections are exposed along the path up the ridge from the small Kohat limestone quarries NE of Gurguri police station. The exposures are located above a pond, which is not visible from below, where the path drops behind the low outer Kohat ridge. The first section covers the upper part of the sandstone and the second one covers the lower part.

Just below the Kohat Formation a bed of conglomerate with clasts mostly of about the size of 2 cm, well rounded comprising chert and quartz-arenite pebbles, coarsening upward, in a sand and clay matrix. Some of the topmost pebbles are oriented vertically and protrude into the overlying Kohat limestone. The pebbles and the matrix are stained, coated, and impregnated with iron gangue, mostly limonite and haematite. Below this bed is pebbly sandstone and dune-cross-bedded sandstone; medium to coarse-grained with low-angle planar cross-bedding. Wavy bedding at the top of many sandstone beds are burrowed with some nonparallel bedding.

Sandstone beds, in their upper part, show ripple marking and paleocurrents from east and southeast. Some sandstones are coarse grained, apparently massive and are capped by thick pebble layers, which are relatively planar with small pebbles. Sandstone also shows low-angle crossbeds from east or northeast. Sandstone is also plane-bedded, with very thin 0.5 to 1 cm laminae, dune-bedded, striking N 30° W. At places sandstone is medium to fine grained, massive and bioturbated.

In other sections, the sandstone is burrowed at base, contains pebbles and shells, trough-bedding at top (10 cm wide, 3 cm deep) showing paleocurrents direction of S30° E. Most of the lower part in other sections has alternating shale and sandstone.

**Shekhan Formation:** The term "Shekhan Limestone" of Davies (1926b) has been formalized by the Stratigraphic Committee of Pakistan as Shekhan Formation to represent the "Gypsiferous beds", "Upper Shekhan Limestone", "Middle Shekhan Limestone" and "Lower Shekhan Limestone" of Eames (1952) in the Kohat area. The section exposed in the Shekhan Nala (Lat. 33° 35' N: Long. 71° 30' E) of the Kohat area has been designated as the type section.

Cheema et al. (1977) stated that the Shekhan Formation consists of limestone and shale. In the Shekhan Nala, the limestone is yellowish grey to grey, thin bedded to massive and nodular. The shale is gypsiferous; limestone and shale occur as interbeds in the upper part. At Tarkhobi the limestone is the dominant lithology in the lower part. At Panoba limestone with shale partings occurs in the lower part followed by dusky yellow shale which is capped by argillaceous limestone with gypsum beds near the top. At Mami Khel, finely crystalline and light grey limestone occupies the lower part and is followed by shale in the upper part. The outcrops of the formation are restricted to the Kohat area and pinch out southwestward. It is 54 m thick at Shekhan Nala, 30 m at Mami Khel and 70 m at Panoba.

Both the lower and upper contacts of the Shekhan Formation with the Panoba Shale and Kuldana Formation, respectively, are conformable. The formation has yielded larger foraminifers, corals, molluscs and echinoids. The foraminifers, as reported by Nagappa (1959) and Pascoe (1963), include *Alveolina oblonga, Assilina daviesi, A. laminosa, Nummulites atacicus and Orbitolites complanatus,* these fossils indicate an Early Eocene age. The formation is correlated with the Sakesar Limestone and the upper part of the Margala Hill Limestone in parts of the Kohat-Potwar Province.

**Bahadur Khel Salt:** Meissner et al. (1968) introduced the term Bahadur Khel Salt for the "Kohat Saline Series" of Gee (1945) in the Kohat area. Bahadur Khel Salt quarry (Lat. 33° 09' 54" N: Long. 70° 59' 53" E) in Kohat District is designated as the type section for the unit. The salt formation black stringers, in places dark grey to black in the upper part, bedded to massive and contain some clear salt crystals. The upper dark coloured salt is bituminous with fetid odour and is slightly pyritic in places. The sodium content is 37% and the chlorine content 60%.

The rock salt, near Bahadurkhel, outcrops over a length of about 12 km with a width of about half kilometre. At Bahadur Khel Salt quarry, a thickness of 480 m of the salt has been penetrated, but true thickness is around 300 m with maximum exposed thickness is about 100 m. The Jatta Gypsum conformably overlies the Bahadur Khel Salt, while its lower contact, where exposed, is conformable with the Panoba Shale. Plant leaves fossils have been reported by Gee (1945) in certain bands of sandstone and clay, which are interstratified with the rock salt. Since it grades laterally into the Panoba Shale, an Early Eocene age is assigned to the Bahadur Khel Sält.

**Jatta Gypsum:** Meissner et al. (1968) introduced the term Jatta Gypsum for the upper part of the "Kohat Series" of Gee (1945) in the Kohat area. A section at Jatta Gypsum quarry (Lat. 33° 18' N: Long. 71° 17' E), in the Kohat area, has been designated as type section. The gypsum is greenish white in colour, massive to bedded and hard. Thin clay partings of red, purple and green colour occur at different intervals. The outcrops of the gypsum cover an area in the southern part of the Kohat, which is about 130 km long and 15 to 30 km wide trending west-southwest and extends into Parachinar. Its thickness ranges from 25 to 40 m.

The Jatta Gypsum conformably overlies the Bahadur Khel Salt, Panoba Shale and Shekhan Formation in different areas, but conformably underlies the Kuldana Formation (Cheema et al., 1977). No fossils have been reported from the unit. However, its conformable contacts with the Lower Eocene formations, above and below, indicate an Early Eocene age. The unit is equivalent to the Chorgali Formation of the Kohat-Potwar Province. It may also be correlated with the Baska shale.

**Margala Hill Limestone:** The term Margala Hill Limestone of Latif (1970 a) has been formally accepted by Stratigraphic Committee of Pakistan for the "Nummulitic formation" of Waagen and Wynne (1872), the upper part of the "Hill Limestone", of Wynne (1873) and Cotter (1933), and part of the "Nummulitic Series" of Middlemiss (1896). The name is derived from the Margala hills in Hazara.

The Shahdara section (Lat. 33° 48' N: Long. 73° 10' E) of southeastern Hazara is considered the type section of the formation. A section exposed to the south of Sur Burjianwala, northwest of Jhallar, Kala Chitta Range is the principal reference section of the formation. The formation consists of limestone with subordinate marl and shale. The limestone is grey, weathering pale grey, fine to medium grained, nodular, medium to thick bedded and rarely massive. The marl is grey to brownish grey while the shale is greenish brown to brown in colour. The unit is well-developed in the Hazara, Kala Chitta, eastern Kohat and in parts of Potwar areas. It is 100 m thick at Shahdara and 80 m at its reference locality. The lower and upper contacts with the Patala Formation and the Chorgali Formation, respectively, are conformable.

Foraminifers, molluscs and echinoids are common in the formation. Raza (1967); Cheema (1968) and Latif (1970c) recorded a number of foraminifers from the formation, including *Assilina granulosa, A. laminosa, A. papillata, A. spinosa, Discocyclina, ranikotensis, Fasciolites delicatissima, F. elliptica, Lepidocyclina (Polylepidina) punjabensis, Lockhartia conditi (L. hunti, L. tipperi, Nummulites atacicus, N. globulus, Operculina jiwani, O. patalensis* and *Rotalia trochidiformis*. These foraminifers indicate an Early Eocene age of the formation.

**Chorgali Formation:** The term "Chorgali beds" of Pascoe (1920) has been formalized as Chorgali Formation by the Stratigraphic Committee of Pakistan. The formation also represents the "Passage beds" of Pinfold (1918) in the Attock area "Badhrar beds" of Gee and Evans (in Davies and Pinfold 1937) in the Salt Range and "Lora Formation" of Latif (1970a) in the Hazara area.

The section exposed in the Chorgali Pass (Lat. 33° 26' 30" N: Long. 72° 41' E) in the Khair-e-Murat Range, has been chosen as the type section. According to Cheema et al. (1977), the formation is composed of shale and limestone. In the Khair-e-Murat Range, it is divisible into two distinct units. The lower unit comprises dolomitic limestone and shale. The dolomitic limestone is white to light grey and yellowish grey and medium-bedded while the shale is grey to greenish grey, calcareous and occurs as interbeds in the upper part of the unit. The upper part of the formation is composed predominantly of shale with one thick bed of dark grey limestone and a bed of nodular argillaceous limestone near the top. The shale is greenish grey, red, occasionally variegated and calcareous. Some grit beds are also intercalated.

In the Salt Range, the formation is also divisible into two parts. The lower part consists of shale and limestone, while the upper part is mainly limestone. The shale of the lower part is greenish grey or buff and calcareous, and the limestone is light grey and argillaceous. The most striking feature of the lower part is the appearance of a porcellaneous limestone band in the middle of the unit near Kalar Kahar, which gradually thickens westward, at the expense of the underlying and overlying shale, till the lithology of this unit becomes essentially limestone with subordinate calcareous shale near Tarki (Gill, 1953). In the upper part, the limestone is white or cream colour, porcellaneous and well-bedded. In the Hazara area, the formation is composed of thinly interbedded limestone and marl, which are light to pale grey and weather light yellow to cream. In the Kala Chitta, the formation consists of thin to medium-bedded, grey limestone with subordinate marl. The limestone is slightly nodular and contains chert lenses.

The formation is distributed in the eastern Salt Range, Kala Chitta Range, Khair-e-Murat Range and in the Hazara area. It is 150 m thick at Chorgali Pass, 30 m in Tarki, 15 m at Bahadurkhel and about 45 m in southeastern Hazara. In the Salt Range, the formation conformably overlies the Sakesar Limestone and at other places Margala Hill Limestone. In the Salt Range, it is unconformably overlain by the Murree Formation, while conformably in other areas by the Kuldana Formation.

A rich fossil assemblage including foraminifers, molluscs and ostracodes has been reported by Davies and Pinfold (1937), Eames (1952), Gill (1953) and Latif (1970c). The foraminifers include *Assilina spinosa, A. granulosa, A. daviesi, A. leymeriei, Flosculina globosa, Globorotalia reissi, G. wilcoxensis, Globigerina prolata, Lockhartia hunti, L. tipperi, L. conditi, Nummulites atacicus, N. mamilla, Orbitolites complanatus and Rotalia crookshankiana.* The fauna indicates an Early Eocene age.

**Kuldana Formation:** The term Kuldana Formation has been formally accepted by the Stratigraphic Committee of Pakistan, following Latif (1970a) for the "Kuldana Beds" of Wynne (1874), "Kuldana Series" of Middlemiss (1896), "Variegated Shales" of Pinfold (1918), "Lower

Cherat Series" of Eames (1952), and "Mami Khel clay" of Meissner et al. (1968).

The type section is located near the village of Kuldana (Lat. 33° 56' N: Long. 73° 27' E), north of Murree Hill station in the Hazara District. The formation is composed of shale and marl with occasional beds of sandstone, limestone, conglomerate and bleached dolomite. In the Hazara area, the unit predominantly comprises varicoloured shale and marl. The shale is crimson, purple, brown, buff, pale-grey and red, gypsiferous and arenaceous. The marl is brown and buff to pale grey with a few beds of fibrous gypsum. In the Kala Chitta Range and the northern Potwar area, the formation is composed mainly of shale, which is greenish grey to greenish yellow, brown to brownish yellow and mottled, silty and gypsiferous. In the Kohat area, the shale is dominant and is of brownish red to red colour, calcareous, silty and contains thin beds of sandstone, limestone and bleached dolomite (Cheema et al., 1977).

The formation is widely distributed in the southern Hazara, Kala Chitta, north-western Potwar and Kohat areas. It is about 150 m thick in Hazara, Kala Chitta and north-western Potwar areas whereas it ranges from 120 m (at Mami Khel) to 150 m (at Panoba) in the Kohat area. In the Hazara, Kala Chitta and part of Potwar, the formation has a conformable contact with the underlying Chorgali Formation, whereas in the Kohat area, it conformably overlies the Jatta Gypsum. The upper contact with the Kohat Formation is conformable everywhere, except in southern Hazara and parts of Kala Chitta where the Murree Formation overlies it disconformably.

Foraminifers, gastropods, bivalves and some vertebrates have been reported from different parts of the formation by Pinfold (1918); Dehm and Zu (1958); Meissner et al. (1968, 1969) and Latif (1970c). The foraminifers include *Assilina granulosa, A. spinosa, A. exponers, Gaudryina sp., Eponides sp., Lockhartia sp.* etc. The limestone bands near the top of the unit in Kohat area contain small oysters, while the fresh water gastropods *Planorbis* and *Pseudoceratodes* are reported from the middle part. The formation is of Early to early Middle Eocene in age.

Kuldana Formation attains prominence on the discovery, of earliest whales, made by Geological Survey of Pakistan in collaboration with University of Michigan, during late seventies. In eighties a paper was published by Gingerich et al. (1983), the authors describe Pakicetus inachus from the Early Eocene of Pakistan. They added that the origin of whales and their transition from land to sea is one of the most interesting problems of mammalian evolution. Middle Eocene whales have been known from much type of sediments, of many countries but fossil whales have not been reported from older marine rocks. Nevertheless diagnostic cranial remains of whales of Early Eocene age have been discovered from Pakistan. The specimens were recovered from fluvial red sediments of the Lower Kuldana Formation at Chor Lakki in Kohat district of Pakistan, where they were found in association with a terrestrial mammalian fauna. The post cranial skeleton of Early Eocene whales is not known, but a comparative study of cranial anatomy suggests that whales were probably not yet fully aquatic in Early Eocene. A total of three genera of primitive cetaceans are known from the Kuldana Formation of Pakistan: *Ganadakasia, Ichthyolestes,* and *Pakicetus*. Other Early Eocene mammalian fauna from red beds of the Lower Kuldana Formation include the orders of: Proteutheria, Lipotyphla, Chiroptera, Primates, Rodentia, Tillodontia, Creodonta, Artiodactyla, one species from Perissodactyla and some from Proboscidea.

**Kohat Formation:** The "Kohat Shales" of Eames (1952) with their three subdivisions "Nummulitic Shales", "Kohat Limestone", and "Sirki Shale" were formally accepted as Kohat Formation by the Stratigraphic Committee of Pakistan which has also approved its subdivisions into members following Meissner et al. (1968), namely (in ascending order) Kaladhand Member (Kohat Shales of Davies, 1926), and Sadkal Member (Nummulitic Shales of Pinfold, 1918). Earlier, Habib Rahi Formation and Sirki Shale were also included as members, which are now revised since the Habib Rahi Limestone Member was originally designated (Tainsh et al., 1959) as the lower member of the Kirthar Formation in the Sulaiman Province; it is proposed here to separate this member from the Kohat Formation and to describe it as separate formation. Further the "Sirki Shales" of Eames (1952) was also given a member status since it gradually thickens from 4 m near Sirki Paila to many more metres in the Sulaiman Province. But now in the present report, the Habib Rahi and Sirki members are separated from Kohat Formation and are dealt with under the name Habib Rahi Formation and the Kohat Formation is redefined here to represent the "Upper Cherat" of Eames (1952) and is divisible into a lower Kaladhand Member (Kohat Shales of Davies, 1926a) and an upper Sadkal member (Nummulitic Shales of Pinfold, 1918).

The section exposed along Kohat-Khushal Garh Highway (Lat. 33° 27' N: Long. 71° 35' E) is the type section. The Kohat Formation consists of interbedded limestone and shale. The lower Kaladhand Member is composed predominantly of limestone which is light grey, hard, compact and thin-bedded with shale intercalations, particularly in the lower part. The Sadkal Member, in the northern Kohat, Kala Chitta and northern Potwar areas is composed of greenish grey, calcareous shale with subordinate light grey limestone. The limestone interbeds become dominant in other parts of the Kohat area, where they are characterized by an abundance of Nummulites (Cheema et al., 1977). The formation is confined to the Kohat, northern Potwar, and Kala Chitta areas. It is 130 m thick at the Uch Bazar 50 m at Mami Khel, 170 m at Chilli Bagh, 90 m at Gumbat, 100 m at Sumari Payan and 70 m south of Lachi in the Kohat area.

The lower contact with the Kuldana Formation is conformable but sharp. The upper contact in the Kohat area, with the Habib Rahi Formation is conformable. Elsewhere, the formation is unconformably overlain by the Murree Formation and the contact is marked by a zone of derived fossils. The formation has yielded abundant foraminifers and few molluscs (Eames, 1952) and Meissner et al. (1968), which include *Assilina cancellata, Dictyoconoides vredenburgi, Fasciolites oblonga, Orbitolites complanatus* and various species of *Nummulites*. The fauna indicates a late Early Eocene to Middle Eocene age.

**Nammal Formation:** The term Nammal Formation has been formally accepted by the Stratigraphic Committee of Pakistan for the "Nammal Limestone and Shale" of Gee (in Fermor, 1935) and "Nammal Marl" of Danilchik and Shah (1967) occurring in the Salt and Trans-Indus ranges. The section exposed in the Nammal Gorge (Lat. 32° 40' N: Long. 71° 07' E) is the type section. The formation, throughout its extent, comprises shale, marl and limestone. In the Salt Range, these rocks occur as alternations. The shale is grey to olive green, while the limestone and marl are light grey to bluish grey. The limestone is argillaceous in places. In the Surghar Range, the lower part of the formation is composed of bluish grey marl with subordinate interbedded calcareous shale and minor limestone. The upper part consists of bluish grey to dark grey limestone with intercalations of marl and shale (Cheema et al., 1977).

The formation is well-developed in the Salt and Surghar ranges. It is 100 m thick in the Nammal Gorge and thins out westward to 60 m at Khairabad. It is 40 m thick in the Khewra-Choa Saidan Shah Road section in the eastern Salt Range. It is 130 m thick in the Chichali Pass and 35 m in Broach Nala of the Surghar Range. Its lower contact with the Patala Formation and upper contact with the Sakesar Limestone are transitional.

Abundant fossils, mainly foraminifers and molluscs, have been reported from the formation. The following larger foraminifers have been reported by Khan, M. H. (personal communication, 1969): *Nummulites atacicus, N. lahirii, N. irregularis, Assilina granulosa, A. laminosa, A. spinosa, Lockhartia tipperi, L. hunti, L. conditi, Operculina nummulitoides, Discocyclina ranikotensis,* and *Fasciolites oblonga.* Haque (1956) recorded abundant smaller foraminifers from the type section which includes Textularia *crookshanki, Quinqueloculina gapperi, Alabamina wilcoxensis, Loxostomum applinae, Dentalina plummerae, Gumbelina trinitatensis, Coleites reticulosus, Globorotalia velascoensis, Globigerina linaperta* and others. On the basis of the fauna, an Early Eocene age has been assigned to the formation.

**Sakesar Limestone:** The term Sakesar Limestone was introduced by Gee (in Fermor, 1935) for the most prominent Eocene limestone unit in the Salt and Trans-Indus Ranges. Sakesar Peak (Lat. 32° 31' N: Long. 71° 56' E) in the Salt Range has been designated the type locality. The unit consists dominantly of limestone with subordinate marl. The limestone, throughout its extent, is cream coloured to light grey, nodular, usually massive, with considerable development of chert in the upper part. The marl is cream coloured to light grey and forms a persistent horizon near the top. Near Daud Khel in the western Salt Range the limestone grades into white to grey and massive gypsum. In the Surghar Range, the chert lenses increase in number.

The formation is widely distributed in the Salt Range and the Surghar Range. In the Salt Range its thickness varies between 70 m and 150 m. It is 220 m at Chichali Pass and about 300 m in other parts of the Surghar Range. The lower contact with the Nammal Formation is conformable. In the eastern Salt Range, the upper contact with the Chorgali Formation is conformable, whereas in the central and western Salt Range and in the Surghar Range, the Rawalpindi or Siwalik Group unconformably overlie the formation.

The formation has yielded a rich assemblage of foraminifers, molluscs and echinoids. Some of the important foraminifers are *Assilina leymeriei, A. laminosa, Fasciolites oblonga, Flosculina globosa, Lockhartia conditi, L. hunti, Operculina nummulitoides, Orbitolites complanatus, Sakesaria cotteri* and *Rotalia trochidiformis.* The above listed foraminifers indicate an Early Eocene age of the unit. The formation is equivalent to the Shekhan Formation and the upper part of the Margala Hill Limestone in the Kohat, Kala Chitta and Hazara areas. It may also be correlated with parts of the Laki, Kharan, Rakhshani, Ghazij Group and Saindak formation in different parts of southern Pakistan (Cheema et al., 1977).

## LOWER INDUS BASIN AND ADJOINING AREAS OF AXIAL BELT

Limestone with prolific foraminifers, molluscs and algae is the characteristic of the Eocene sequence. The shale and marl in parts of the area are the major lithology in the Early Eocene times. As mentioned earlier the Eocene sequence of the Kirthar Province has long been used as yardstick for Eocene stratigraphy of Indo-Pakistan subcontinent. The following rock-units are recognized in this region:

| | |
|---|---|
| Ghazij Group | (Lower Indus Basin and Axial Belt) |
| Kirthar Formation | (Lower Indus Basin, northern calcareous zone of Axial Belt and Western Kohat) |
| Laki Formation | (Kirthar Province and southern Sulaiman Province) |

**Ghazij Group:** Oldham (1890) introduced the term 'Ghazij' for the shale beds between the Dungan Formation and Spintangi Limestone in areas southeast of Harnai (Ghazi Formation after Williams 1959). The Stratigraphic Committee of Pakistan formalized it and synonymised all other names like the "Shale with Alabaster, Rubbly limestone, Green and Nodular Shales, Ghazij Shales, Upper Rakhi Gaj Shales and Zindapir Limestone" of Eames (1952) and the Ghazij shales, Tiyon Formation and upper part of Gidar Dhor Group of the Hunting Survey Corporation (1961). The type section of Ghazij Group is designated after Williams (1959) at Spintangi Gorge (Lat. 20° 57' 02" N: Long. 68° 05' E), located about 8 km southeast of Harnai.

Shah (1999) described the Ghazij Group, to consist dominantly of shale with subordinate claystone, sandstone, limestone, conglomerate and also alabaster and coal which locally become abundant of commercial importance. The group consists of pale greenish grey or brown shale and white or light grey limestone. Sandstone is a subordinate component in some places but is highly calcareous and grades to sandy limestone. In the Axial Belt and parts of the Sulaiman Province, the Ghazij Group consists of olive, brown, maroon, purple and yellow shale, and green, grey or brown sandstone with interbeds of arenaceous limestone and some conglomerate. The sandstone is coarse grained to shelly, and carbonaceous. Conglomerate forming thin beds are associated with sandstone and shale. The pebbles in the conglomerate include chert and limestone derived from older formations of the Axial Belt.

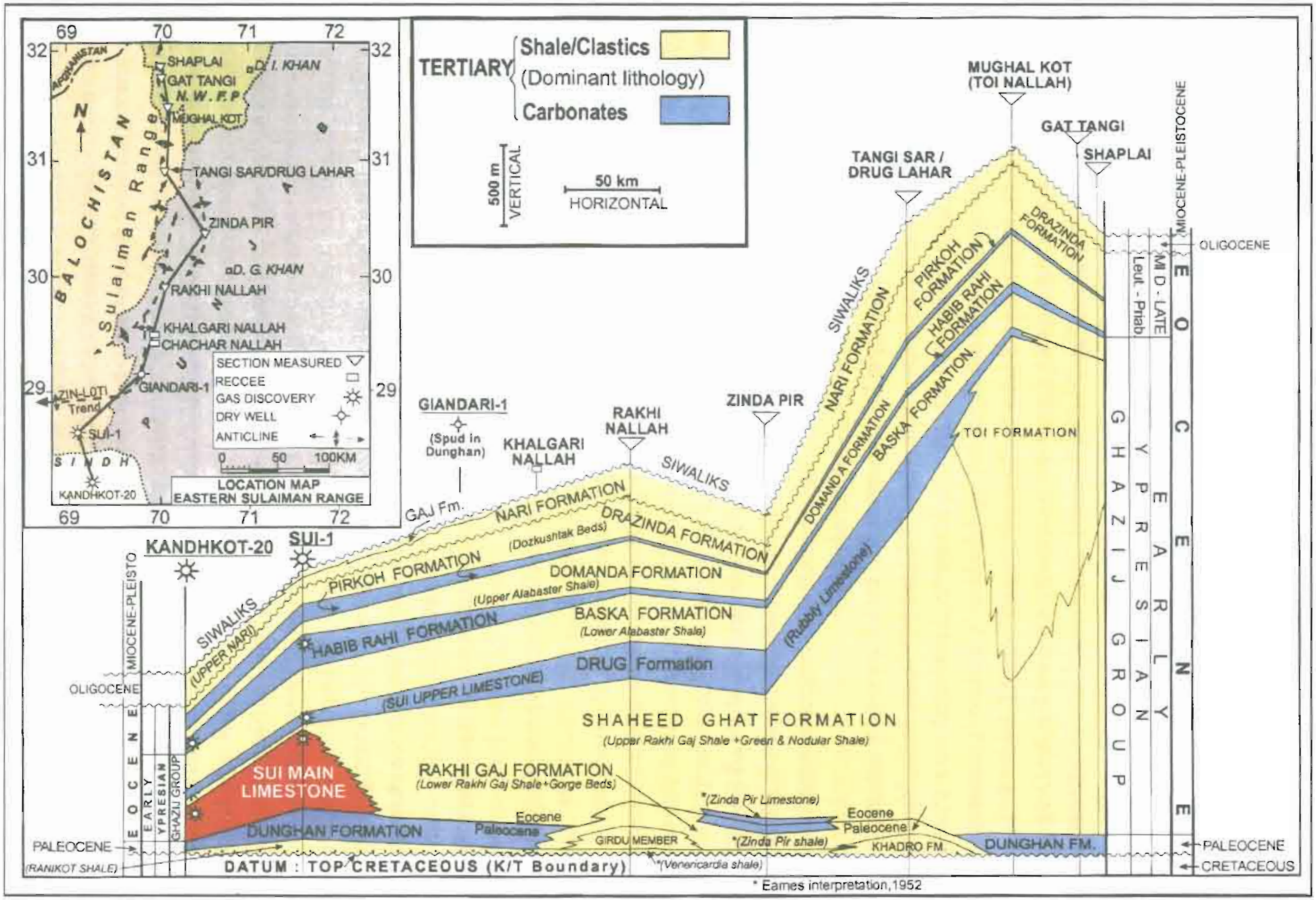
The Ghazij Group is widely developed in the Sulaiman Province, part of the Kirthar Province and the Axial Belt. It also extends into North Waziristan. The maximum thickness of 3300 m of the Ghazij Group has been recorded at Mughal Kot. It is about 1220 m thick at Zindapir and 160 m thick at Bar Nai and is 590 m thick in the type section. The Ghazij Group conformably overlies the Dungan Formation with some what sharp contact. The group overlies the Laki Formation and Ranikot Group in different areas. In the Sulaiman and Kirthar Provinces, and in the Axial Belt, it is conformably overlain by the Kirthar Formation. In some places within the Axial Belt, the Ghazij Group rests on older strata with angular unconformably. One of the best examples of the basal unconformity is west of Umai Village where the rocks of the Ghazij Group lie on an erosional surface that transects the older strata of the Takatu Formation (Shah, 1999). The subsurface behaviour of the formations of Ghazij Group is shown in Fig. 20.

Group is fossiliferous and yielded the following taxa: The foraminifers include *Lockhartia conditi, hunti, Alveolina globosa, and A. oblonga, Coskinolina, cf. C. balsilliei Assilina sublaminosa, flosculina globosa, and Dictyoconus indicus.* Among the bivalves *Cardita mutabilis, Corbula (Bicorbula) subexarata, Anomia sp. Parinomya* sp; Iqbal (1969a) recorded corals from the group near Quetta for the first time, *Trochoseris daviesi, Hydnophora insignis, Meandrina variabilis, Euphyllia flabellata* and *Placotrochus tipperi;* characteristic Ghazij gastropods recorded by Iqbal (1969a) are: *Pirena (pseudobellarala) delphinus, Amaurellina noetlingi Ampullella nuttalli* and *volutocorbis harnaiensis.* The age of the Ghazij Group is assigned as Early Eocene.

**Shaheed Ghat Formation:** A sequence of limited extension comprising mostly clays and minor shale of various colour, earlier called Green nodular shales by Eames (1952) has been formalized as such by the Stratigraphic Committee of Pakistan. Type section is designated at Shaheed Ghat, Zindapir, Dera Ghazi Khan District (Lat. 30° 24' N: Long 70° 28' E). Shah (1999) described that lithologically the Shaheed Ghat Formation is composed dominantly of clays, which range in colour from green, brown to chocolate shades. Subordinate beds of limestone, marl and marly clays with fossils, makes up a considerable part of the formation. Enclosed gypsum beds in the formation occasionally appear. At the type locality the clays are easily splintered. Numerous calcite veins occur covering large area in the middle part of the formation at Shaheed Ghat. The formation contains bands of limestone with Nummulites, gastropods and lamellibranchs in the upper part of the unit. In the Dera Ghazi Khan area, the formation consists mainly of greenish grey, light olive, grey, green and fissile claystone with argillaceous limestone bands.

In the central part of Zindapir, the unit consists of bluish grey; greenish grey to olive green shales, thinly laminated and fissile with a few 1-2 m thick marl interbeds. In the Mughal Kot section, the unit is comprised of shales with subordinate limestone. Associated with shales is a band of ferruginous, non-calcareous dark red claystone. Interbedded limestone is arenaceous, hard, olive grey to medium grey, brown and red brown. The thickness at Shaheed Ghat is 680 m and at Mughal Kot, it is 340 m. The Shaheed Ghat Formation is conformably overlain by Drug Formation and underlain by Dungan Formation Fig. 20. The Shaheed Ghat Formation is fossiliferous and contains foraminifera, gastropods and bivalves.The fossils among pelecypoda include *Venericardia pakistanica, Lucina yawensis, Corbula (Bicorbula) subexarata, C. (B) Paraexarata* and the gastropod species *Crommium polihathra, turritella, (stiracolpus) harnaiensis, Chondrocerithium pakistanicum, Gisortia cf. G. Murchisoni* have been collected from the formation (Iqbal, 1969b). Based on fossils the age of Shaheed Ghat Formation is considered as Early Eocene.

**Drug Formation:** Drug Formation has been formalized by Stratigraphic Committee of Pakistan, after this name was used by Jamil-ud-din, Kidwai and Sibghatullah (unpublished field




Courtesy Nusrat Siddiqui, 2004

Fig. 20. Tertiary stratigraphic correlation across eastern Sulaiman Range, showing depositional behaviour of Ghazij Group. Note the high sedimentation rate and increased clastic influx towards northern Sulaiman Range. The Sui Main is restricted only to Sui and areas further south.

notes 1968) and Iqbal (1969b) for Rubbly Limestone of Eames (1952). The type section has been designated in 'Drug-Tangi' located about 3 km southeast of Drug Village (Lat. 30° 49' 15" N: Long. 70° 12'30" E).

As defined by Shah (1999), the Drug Formation consists of limestone of pale orange to green colour and weathered white chalky, in the upper part and pale olive to green blue claystone and shale in the lower part, in the central part of Zindapir area. The Drug Formation consists of cream coloured limestone, which is grey on the freshly broken surface. It is pebbly and nodular in form. This limestone is interbedded with bluish grey shales. In the Rakhi Nala, the upper part consists of yellowish grey limestone, which is medium to very coarse grained, crystalline, nodular and has marly laminated partings. The shales are greenish grey to dark greenish grey, calcareous and slightly pyritic and become more clayey toward the top with common ferruginous concretions. In the middle of the Rakhi Nala section, the limestone is light olive green to pale green and on weathering, changes to olive green and dark green. The limestone is bioclastic, calcareous to calcirudite, argillaceous, hard and thin-bedded. At the base of the Rakhi Nala section, the light grey limestone is interbedded with shales.

The formation at Drug Tangi is 400 m in the Zindapir section, it is 340 m and in the Rakhi Nala section it is about 300 m thick. In the Mughal Kot section, it is absent, (Siddiqui N. K of PPL verbal comm. 2006). He also stated that Drug Formation is correlatable with 'Sui upper limestone' as encountered in gas well drilled in Sui gas field where it attains the thickness of 70 m (Fig. 20). The Drug Formation is overlain conformably by the Toi Formation and itself overlies the Shaheed Ghat Formation. In the Rakhi Nala Section; however, the Drug Formation is overlain by the Baska Formation (Shah, 1999). The formation is fossiliferous and has yielded the following fossils, Iqbal (1969b); Gastropod; *Euspirocrommium oveni, Cancelluria soriensis. Ringicuia pseudopunjabensis* and a pelecypod: *Lucina exquisica.* On the basis of these fossils, an Early Eocene age has been assigned to the Drug Formation.

**Toi Formation:** The Toi Formation has been formalized after S. M. Hussain of American Oil Company's briefing and verbal communication (1977), before the Stratigraphic Committee of Pakistan with type locality at Mughal Kot (Lat. 31° 26' 52" N: Long. 70° 20' 58" E). Detailed description of the Toi Formation as described by Shah (1999) is as follows: the Toi Formation comprises sandstone, siltstone, conglomerates, silty clay stones and shales with locally developed coal seams. The sandstone is mostly coarse grained, pebbly, poorly sorted and conspicuously cross-bedded. The siltstone is dark chocolate brown to red brown in colour, soft, block, argillaceous and sometimes calcareous. It commonly grades into sandstone or shale. The conglomerate is dark brown, and contains poorly sorted, sub angular, subrounded pebbles and boulders of sandstone and limestone cemented in ferruginous argillaceous sandstone matrix. In some places, it is also associated with shale and siltstone.

The shales are grey green to slightly micaceous dark grey, fissile and occasionally carbonaceous. In the Mughal Kot section, the formation consists of dark brown to red brown, olive green to light grey green sandstone. The sandstone in this area is medium to course grained, poorly sorted, laminated and cross bedded.It is interbedded with siltstone, claystone, shales and conglomerate. In this area the top of Toi Formation is composed of blocky sandstone interbedded with conglomerate calcirudite, which is grey, brown, hard, arenaceous, ferruginous, and well sorted with intercalates of calcilutite and calcisiltite in soft ferruginous sandstone. The siltstone in this part is blocky, soft, argillaceous, calcareous and slightly micaceous grading to shale, the siltstone is underlain by silty claystone. The Toi Formation is predominantly composed of fluviatile and estuarine sediments.

In the Sor Range near Quetta, the formation consists of calcareous sandstone, conglomerate calcareous claystone and carbonaceous shale with commercially exploitable coal seams. Towards the southeast, the sandstone and conglomerate grades into beds of limestone. The conglomerate beds in this area, are up to 6 m thick, which are remarkably continuous, the pebbles in the conglomerate include chert and limestone derived from older formations of the Axial Belt. The Toi Formation in the Mughal Kot Section is 2120 m thick in Toi Nala and that in the Rakhi Nala Zindapir (Sori Nala), it is missing. The Toi Formation is overlain by the Baska Formation of the Ghazij Group and conformably overlies the Drug Formation of the same group. In the Toi Formation, the bulk is characterized by paucity of fossils; found in the group indicate an Early Eocene age for the formation. Superpositionally, Toi Formation overlies Drug Formation of Early Eocene and is overlain by Baska Formation of the same age. It is assumed that the Toi Formation is Early Eocene in age.

**Baska Formation:** Hemphill and Kidwai (1973) named Baska Formation, which was earlier known as the Lower Kirthar Shales of Vredenburg (1909) "Shales with Alabaster" of Eames (1952). They designated the type section at the section exposed 2 km eastnorth of Baska Village (Lat. 31° 29' N: Long. 70° 08' E). A reference section suggested by Pakistan Petroleum Limited is at Dhurwali Chur (Rodho anticline) all along the black-top road (Lat. 30° 34' 45" N: Long. 70° 31'54" E) (Shah, 1999). According to Shah (1999), lithologically, the Baska Formation, in its type locality consists of green shales beds and clay-stones containing alabaster in nodules and veins. The claystone alternates with bedded alabaster, gypsiferous limestone and marl. The alabaster beds range from 10 cm to more than 10 m. The claystone is light red and purple towards the base. In the Zindapir area, the formation consists of olive green shale, thinly laminated and fissile. In the Rodho anticline Safed Koh Range, the formation is composed of shales with bands of gypsum in the upper part. The gypsum is white, massive and hard. The thickness of gypsum bands varies from one to three metres.

In the southern part of Sulaiman Range, the shales alternate with limestone bands. It is yellowish green, laminated, slightly calcareous and fissile. At the top near the contact with Kirthar Formation, gypsum beds occur throughout the area as marker horizon. In Bugti area the Baska Formation is comprised of yellowish grey gypsiferous shale and marl grading to limestone with milky white gypsum. The Baska Formation is 190 m at the type locality and 250 m in Zindapir area. The Baska Formation overlies the Toi Formation and is overlain by Habib Rahi Formation conformably. The age of the formation is Early Eocene as derived from the following fossils.

The marls of the Baska Formation contain larger foraminifera, bivalves and gastropods.

Foraminifera identified include: *Cuneoline* sp., *Lockhartia hunti,* and *Dictyoconoides vredenburgi.* Among pelecypoda: *Bulsella* sp. *A.* Eames and *Barbatia drougenis,* the later being restricted to Lower Eocene (Iqbal, 1969b), the gastropods include *Euspira* cf. *E. Punjabensis* and *Gosavia humberti.*

**Kirthar Formation:** Blanford (1876) used name "Kirthar" after the Kirthar Range to describe Eocene strata between his "Ranikot Group" and "Nari" in western Sindh. Later, Noetling (1903) separated the lower part as "Laki series" and retained the name "Kirthar" for the upper part only. This upper part is formalised here, as the Kirthar Formation; it is equivalent to the "Spintangi Limestone" of Oldham (1890). This formation also includes "Brahui Limestone" with "Kirthar Member" and "Gorag Member" of Hunting Survey Corporation (1961). Type section is designated at the Gaj River section (Lat. 26° 56' 10" N: Long. 67° 09' 06" E) in the Kirthar Range. The Spintangi Gorge in the western Sulaiman Province has been proposed as the principal reference section by Cheema et al. (1977).

Shah (1999) defined the Kirthar Formation as predominantly limestone with some shale and marl. The limestone is light grey, cream coloured or chalky white, and weathering in grey, brown or cream colours. It is thick-bedded to massive, in places nodular, and occasionally contains algal and coralline structures. The shale is olive, orange yellow, grey, calcareous, soft and earthy. However, in some parts of the Kirthar Province, the upper half of the unit is exclusively cliff-forming massive limestone ("Gorag member") of Hunting Survey Corporation (1961). In some parts of the Sulaiman Province, milky white gypsum beds, up to 6 m thick, are also present. The Kirthar Formation is distributed widely in the Kirthar Province, the Sulaiman Province and part of the adjoining Calcareous Zone of the Axial Belt. Near the Gaj River the formation is about 1270 m thick. It is only 5 m thick in the western Kirthar area, 300 m thick at the Spintangi Gorge in western Sulaiman Province. In most areas, the Kirthar Formation transitionally overlies the Ghazij Group or its chronostratigraphic equivalent the Laki Formation. However, in parts of the Axial Belt region, it is unconformably underlain by different Early Tertiary, Mesozoic and possibly Palaeozoic rocks where the contact is marked by a thin lateritic or pebbly conglomerate bed.

The upper contact of the formation is mostly unconformable with the Nari Formation. However, according to Hunting Survey Corporation (1961), it is apparently conformable with the Nari Formation in parts of the Uric Synclinorium, the mountain fringes of the Kachhi Plain and areas round the Gaj River. The Kirthar Formation is richly fossiliferous and represents different ages in various parts of its distribution. Both, its lower and upper, boundaries are time transgressive. The age of the formation in the Kirthar Province is middle Eocene to early Oligocene. In the Calcareous Zone of the northern Axial Belt and Sulaiman Province, the age is considered to be early to Middle Eocene. But in the Rakhi Nala-Zindapir areas of the eastern Sulaiman Province, it ranges from Middle to Late Eocene.

The Early Oligocene fauna from the Kirthar Range are reported by the Hunting Survey Corporation (1961) and includes *Lepidocyclina dilatata, Nummulites fichteli, N. intermedius etc.* and the Eocene fauna from different areas includes the following: Middle Eocene; *Acntinocylina* *alticostata, Assilina cancellata, A. rota, A. irregularis, Nummulites beaumonti, N. gizehensis, Dictyoconoides cooki,* and the fossils representing the age of Early Eocene include *Assilina laminosa, Coskinolina balsilliei, and Dictyoconoides vredenburgi.*

**Laki Formation:** The term "Laki Series" was proposed by Noetling (1903) for the lower part of Blanford's "Kirthar Series" (1876). Later Hunting Survey Corporation (1961) redefined the unit as "Laki group". In the present report, it is named as Laki Formation, which also represents the Sui Main Limestone of Tainsh et al. (1959) and the "Tiyon formation" of Hunting Survey Corporation (1961). In parts of the Kirthar Province two distinct members are identified in the lower part of the formation. The basal member is here named Sohnari Member, after Sohnari south of Meting (following Hunting Survey Corporation 1961), which represents the Basal Laki laterite of Nuttall (1925). The Sohnari Member, which overlies the Ranikot Group is itself overlain by the Chat Member. Both these members are now formalized by the stratigraphic Committee of Pakistan (Shah, 1977, 1999).

Mari Nai (Lat. 26° 06' N: Long 67° 51' E) southwest of Bara Nai, of the northern Laki Range, is herein designated as the type section of the formation. A section exposed about 5 km south-southwest of Meting (Lat 25° 12' N: Long. 68° 10' E) is designated herein as the type section of the Sohnari Member and Chat Member. The formation consists mainly of cream coloured to grey limestone, marl, calcareous shale, sandstone and lateritic clay may become significant constituents of the formation locally. In parts of the Kirthar Province, both the members are recognized in the lower part of the formation.

The **Sohnari Member** consists of varicoloured lateritic clay and shale with locally developed beds of yellow arenaceous limestone pockets of limestone or ochre and lignite seams. Lenticular beds of variegated, ferruginous sandstone and white, calcareous sandstone are common in the member. The member is the basal part of Laki Formation and directly overlies the Ranikot Group.

The **Chat Member** consists mainly of creamy white nodular limestone in the lower part and interbedded shale and limestone with subordinate sandstone in the upper part. The shale is grey, greenish yellow weathering dark rusty brown, ferruginous and gypsiferous. The limestone is thin-bedded and arenaceous whereas the sandstone is commonly ferruginous.

The Laki Formation is mainly developed in the southern part of the Kirthar Province and in the vicinity of the Marri-Bugti hills in the Sulaiman Province. It is about 240 m thick in the Bara Nai and the type locality (Mari Nai), but attains more than 600 m thickness at Tatti (Kirthar Province) and in Sui, where is the encountered subsurface and attains the thickness of 468 m. The Laki Formation is unconformably underlain by the Ranikot Group and the contact is marked by the base of the *Sohnari member.* Its upper contact with the Kirthar Formation in most areas of the Kirthar Province is conformable. In the northern parts of the Kirthar Province and throughout its development in the Marri-Bugti hills, the formation is overlain by the Ghazij Group. In many localities of Laki Range, the Nari Formation and the Siwalik Group unconformably overlie it.

Interesting and useful information has been provided by Outerbridge et al. (1990). They believed that the basal Sohnari Member of the Laki Formation is distinct from the underlying Lakhra

Formation and overlying Chat Member of the Laki Formation and that it deserves the status of a formation excluding it from the Laki Formation. In their concluding remarks they said: "the SohNari Formation is a wedge of clastic sedimentary rocks derived from the east and deposited between the marine Lakhra and Laki formations. The Lakhra Formation apparently pinches out eastward near Tando Muhammad Khan, and in that area the SohNari Formation/ Member and the Bara Formation may be in direct contact. The Sohnari Formation/Member pinches out to the west, and in that area the Lakhra Formation immediately underlies the Laki Formation. The Lakhra and Laki formation are lithologically distinct from each other, although both units represent mainly marine deposition: however, the Bara Formation and the SohNari Formation/Member lithologically are nearly identical.

The Sohnari, originally known as the Basal Laki laterite, represents a very slight marine regression, possibly a reduction in the rate of sinking of the continental shelf of the Indian plate, while clastic sediments and peat accumulated very close to sea level. The Sohnari does not represent an early Tertiary zone of weathering, as Nuttall (1925) and other authors have claimed, and so it should not be considered a basal member of the Laki Limestone/ Formation, because it is not related to that formation, except that it underlies the Laki Formation.

The Laki Formation contains rich fossil assemblages including foraminifers, gastropods bivalves, echinoids and algae, as reported by Noetling (1905); Nuttall (1925); Davies (1926); Haque and Khan (in Lexique, 1956); Haque (1962a); Hunting Survey Corporation (1961) and Iqbal (1973). The foraminifers include *Assilina granulose, A. pustulosa, Lockhartia hunti var. pustulosa, Flosculina globosa, Opertorbitolites douvillei, Fasciolites oblonga, Linderina brugesi and Dictyoconoides vredenburgi.* Important molluscs are *Gisortia murchisoni, Velates perversus, and Blagraveia sindensis.* Among the echinoids *Amblypygus subrotundus* and *Echinolampas nummulitica* are common. These fossils indicate an Early Eocene (Ypresian) age. The formation is correlated with the Kharan formation and lower parts of the Saindak and Nisai formations of the Balochistan Basin, and parts of the Chharat Group of the Kohat-Potwar Province.

**Habib Rahi Formation:** The Habib Rahi Formation is formalized by the Stratigraphic Committee from "Habib Rahi Limestone" of Tainsh et al. (1959) and "Habib Rahi Member" of Meissner et al. (1968) who recognized it in the Sulaiman Range and Kohat area, respectively. This formation was earlier called Platy Limestone of La Touché (1893), Assilina bed of Eames (1952) and upper part of Kohat Limestone of Davies (1940). Tainsh et al. (1959) did not propose any type locality but Hemphill and Kidwai (1973) proposed the Fort Sandeman-Dera Ismail Khan Road north of Zam Post as reference section (Lat. 39° 37' 50" N: Long. 70° 14' E).

Shah (1999) described Habib Rahi Formation as a greyish brown and buff, hard limestone that weathering white. It is fine-grained, thin-bedded, dominantly argillaceous, and in few places grades into marl. Thin cherty beds present in the formation are restricted to the upper part of the formation which contains marl with abundant Assilina. At Shinki Post (North Waziristan), the upper part of the Habib Rahi Formation is pebbly and massive; the middle part is thick bedded while the lower part is massive. At Sirki Paila in Kohat District, the upper five metres of the formation are composed of brownish and plum-coloured marl with alterations of pure limestone.

The Habib Rahi Formation is exposed along the east flank of the Sulaiman Range and as well as in the North and South Waziristan. The Habib Rahi Formation is also developed southwest of the Gumbat Village and Uch Bazar in Kohat District. The thickness of the formation ranges from 15 to 60 m. In the Sulaiman Province, the Habib Rahi Formation is conformably overlain by Domanda Formation and underlain by the Baska Formation. The lower contact of the Habib Rahi Formation with the Baska Formation, in Waziristan is transitional. Abundance of Assilina characterises the lower part of the formation. The age of the formation is Early to Middle Eocene. Hemphill and Kidwai (1973) have produced a list of foraminifera, collected by E. B Fritz from Habib Rahi and Domanda Formations in Toi Nala and suggested the above two formations may be as old as late Ypresian (Early Eocene). However, they also suggested Middle Eocene age based on mammals, crocodile and marine fish collected by Rahman and Dunkle (1966).

**Domanda Formation:** Hemphill and Kidwai (1973) named "Domanda Shale Member" to the "Lower Chocolate Clays" of Eames (1952). Domanda Formation has been formalized by the Stratigraphic Committee of Pakistan replacing both the above-mentioned shale and clays, this has been done on the verbal briefing and description by Shah (1977). The type locality is designated in the west of Domanda and adjacent to Fort Sandeman, Dera Ismail Khan Road (Lat. 31° 35' 30" N: Long. 70° 12' E). A reference section for Domanda Formation has been suggested by N. K. Siddiqui of PPL (written communication, 1987) at Dhurwali Chur (Lat. 30° 34' 45" N: Long 70° 31' 54" E).

Shah (1999) stated that at the type section the Domanda Formation consists mostly of dark brown and greenish grey claystone. Northeast of Nili Kach, subordinate amounts of grey and brown sandstone crop out in the upper 50 m of the formation. This sandstone is fine to medium grained, well-sorted, massive to thick bedded and calcareous near the top; each of the individual sandstone bed is about 3 m thick. In the Mughal Kot and the areas north of the Domanda Fort, the Domanda Formation is composed of chocolate, green to grey clays and contain some calcareous, gypsiferous marly layers and calcareous mudstone intercalations. In the Safed Koh Range, it is composed of shales with intercalations of limestone in the lower and middle part. The shales are brown and green laminated and often calcareous. The limestone in the lower part is whitish grey and highly argillaceous, whereas in the middle part, it is greyish, platy, hard, and contains common bivalves shells. In the Nili Kach area, a few thin siltstone beds occur in the lower part.

According to Shah (1999) the Domanda Formation is present in part of the Sulaiman Province and the Bugti Hill areas. It is also exposed, 300 m thick in Drug and Mughal Kot sections and thins out towards south. The formation is also present in Waziristan and perhaps in parts of the Kohat area. The Domanda Formation is 130 m thick near Domanda, 220 m north of Nili Kach and 150 m thick northwest of Jandola (Waziristan). The thickness of formation ranges between 180 to 330 m in Safed Koh Range. The formation is not present near Shinki Post in the northern Waziristan and pinches out along Spini Ghora in southern Waziristan. The contacts with the underlying Habib Rahi Formation and overlying Pirkoh Formation are transitional and conformable respectively.

The Domanda Formation is fossiliferous and contains foraminifera, gastropods, bivalves, echinoids, and rare vertebrate fossils. The foraminifera found in the type locality are *Nummulites beaumonti, N. subbeaumonti, Alveolina elliptica, and Dictyoconoides cooki.* In the vicinity of Nili Kach, thick beds of sandstone in the upper part contain about 20 cm long gastropods as well as abundant bivalves. Eames (1952) reported vertebrate remains from the middle part of the formation near Rakhi Nala. On the basis of fossil contents, a Middle Eocene age has been established.

**Pirkoh Formation:** The "Pirkoh limestone member" was introduced by Hemphill and Kidwai (1973) for the unit coeval with the "White marl band" of Eames (1952), "Pirkoh limestone and Marl Member" also of the later author. The Pirkoh anticline is provisionally designated as the type locality (Lat. 29° 7' N: Long. 69° 8' E). A reference section has been suggested at Dhurwali Chur (Lat. 30° 34' 45" N: Long. 70° 3' 54" E) by N. K. Siddiqui, PPL (written communication 1990).

Shah (1999) defined the formation as follows: Lithologically the Pirkoh Formation consists of limestone that is light grey to chalky white, buff to brown, fine-grained, mostly thin and regularly bedded, and often argillaceous. The formation commonly contains subordinate beds of soft, shay limestone and dark grey calcareous claystone. The Pirkoh Formation forms persistent continuous ridges throughout the foothills of the Sulaiman Range and in the Bugti hill area. The thickness varies between 10 to 175 m. The formation is 135 m thick in the Pirkoh area, 40 m in the Zin Range, 35 m in the South Waziristan as well as in the North Waziristan near the Shinki Post. The formation overlies the Domanda Formation and in turns overlain by the Drazinda Formation. Both the contacts are transitional. The Pirkoh Formation is highly fossiliferous, particularly in the middle and upper parts. The fossils include foraminifera, gastropods, bivalves, and echinoids. It is Middle Eocene in age. *Diplodonta Punjabensis,* a pelecypod restricted to Middle Eocene, and *Lydia cf. L. Punjabensis,* gastropods has also been reported by Iqbal (1969b).

**Drazinda Formation:** The term "Drazinda Shale member" of Hemphill and Kidwai (1973), and the upper chocolate clays of Eames (1952) has been formalized by Stratigraphic Committee of Pakistan as the Drazinda Formation after the village of Drazinda. The type locality, designated, near Drazinda (Lat. 31° 46' N: Long 70° 09' E) is by Hemphill and Kidwai (1973), with a reference section at Dhurwali Chur (Lat. 70° 31' 54" N: Long. 70° 31' 54" E) by N. K. Siddiqui, PPL (written communication).

The Drazinda Formation is described by Shah (1999) as consisting of dark brown to grey clay with subordinate fossiliferous marl interbeds. Marl intercalations increase upsection. The upper part is also gypsiferous. At places fossiliferous brownish limestone interbeds occur in the middle part. In the Gomal Pass area, a greenish-grey calcareous sandstone unit of about 10m thickness appears in the middle part. Celestite nodules and gypsum stringers are common in the northern part of Sulaiman foothills. The Drazinda Formation occurs as a recognisable unit from the Bugti hills to the foothills of the Sulaiman Range. This formation, along with the Pirkoh and Domanda Formations, wedges out in the Spin Ghora Range in South Waziristan. The maximum thickness estimated in the Drazinda area in 500 m. It is 400 m thick in the Domanda Post and only 15 m in Jandola (Southern Waziristan).

The Drazinda Formation is highly fossiliferous. Rich fauna comprising foraminifera, bivalve and echinoids are known from this formation. A late Middle Eocene age is assigned to this unit. Iqbal (1969b) collected pelecypod species restricted to Middle Eocene, which include *Nucula (lamellinucula) depressilunulata, N. (saccella) pakistanica Barbatia (plagiarca) pseudonavicula, Noetia magnifica, Chlamys cf. soriensis, C. cf. wynnei, Venericardia, soriensis, Chama Zindapiri, Diplodonta pakistanica,* and gastropod species also restricted to Middle Eocene which include Turritella soriensis, *T. (haustator) imbricataria and Motyris pseudoaralica.*

**BALOCHISTAN BASIN**

Eocene rocks are only known from the Eruptive Zone of Balochistan Basin. Though some doubtful occurrences are reported from Zhob and Siahan ranges of Makran-Zhob Region. The following rock units are differentiated:

Saindak formation (Western Eruptive Zone)
Kharan formation (Eruptive Zone)

**Saindak formation:** The name "Saindak formation" was proposed by Hunting Survey Corporation (1961) for a series of shale, sandstone, limestone and minor volcanic conglomerate in the western part of the Eruptive Zone, which Vredenburg (1901) had called "Kirthar Stage". The sequence mapped by Hunting Survey Corporation (1961) as "Washap formation" at Gwalishtap near the Pakistan-Iran border, and the "Amalaf formation" except its upper volcanic part are here regarded as synonyms of the Saindak formation. The exposures in the large syncline near Saindak Fort have been designated as the type locality.

The formation consists of interbedded shale, sandstone, limestone and volcanic rocks. The shale is green, yellowish-brown or maroon calcareous and/or sandy while the sandstone is fine to coarse-grained or gritty dark green, greenish grey brown and calcareous. The limestone is usually dark grey yellowish brown and weathering light grey. It is fossiliferous and in places sandy. Volcanic rocks occur as agglomerate and conglomerate, and include maroon, green, mottled andesitic or basaltic fragments and boulders. In places the red shale contains beds of white and fairly pure gypsum. The formation is developed in the western part of the Eruptive Zone. Its major exposures are along the axis of the Mirjawa synclinorium between the locality of Saindak and hills west of Alamereg. It is also exposed near Gwalishtap along the Pakistan-Iran border. The maximum thickness of the formation is not less than 1500 m. At Gwalishtap the formation is bevelled to only 60 m (Cheema et al., 1977). The Rakhshani formation conformably underlies the Saindak formation. At Saindak the Amalaf formation conformably overlies it. At Gwalishtap, the Saindak formation is unconformably overlain by the Bostan formation of Pleistocene age.

The fossils include foraminifera, coelenterates, gastropods, bivalves and echinoderms. The foraminifers are Assilina dandotica, *A. exponens, Fasciolites oblonga, Linderina brugesi, Opertorbitolites douvillei,* and others, while *Echinolampas nummulitica* (echinoid) and *Velates perversus* (gastropod) are important among other fossils. The fauna indicates an Eocene age.

Vredenburg (1901), however, found species of Cardita, Corbula, Natica and Turritella from the red gypsiferous shale of the formation. These fossils according to Noetling (in Vredenburg, 1901) were identical with those of the basal Nari Formation, has therefore, been assigned an Oligocene age. Though no fossils of Late Eocene age has been reported from the Saindak formation by Hunting Survey Corporation (1961), Eocene to Oligocene age has been assigned to the formation on the basic of above evidences. The formation is correlated with the Kharan formation of the Eruptive Zone and the Laki, Ghazij, Kirthar, Khojak and Nisai formations of the Lower Indus Basin, Axial Belt and other parts of the Balochistan Basin. It is also correlated with the Chharat Group of the Kohat-Potwar Province.

**Kharan formation:** The name "Kharan limestone" of Hunting Survey Corporation (1961) is here redefined as Kharan formation and is extended to other similar rock units, named by Hunting Survey corporation (1961) as "Robat limestone", lower part of "Pishi group" and "Washap formation" (except at Gwalishtap), and to include the "Eriklag Limestone" of Ahmad (in Bakr, 1963). The name originates from the district town of Kharan, the type section designated by Hunting Survey Corporation (1961) near Jalwar.

The formation, according to Cheema et al. (1977) consists of limestone, which is thin to thick-bedded fine-grained and argillaceous. The colour varies from medium to dark grey. At places the limestone is highly fossiliferous. It is reefoid and gives fetid odour on freshly broken surfaces. Thin calcareous shale intercalations of grey, green and brown colour are present as minor components but become dominant in lithology in the central part of the Ras Koh Range, particularly south of Dalbandin. Associated with the shale are common alternations of sandstone of light grey or greenish brown colour. The sandstone is fine to medium grained and calcareous. The formation is restricted to the Eruptive Zone. The thickness is highly variable and ranges from more than 600 m in the northwest corner of the Eruptive Zone to about 90 m near Sheikh Hussain at the southern edge of the Ras Koh Range. The formation is conformably underlain by the Rakhshani formation. In most of the localities the contact is gradational. It is conformably and transitionally overlain by the Khojak formation. At Robat however, the upper contact of the Kharan formation is not known.

Most of the fauna of the formation consists of foraminifers with some algae (Hunting Survey Corporation, 1961; Haque in Bakr, 1963). The foraminifers include *Assilina granulosa, A. exponens, Fasciolites oblonga, F. granulose, A. elliptica, F. cf. F. ovoilea, Discocyclina cf. D. ranikotensis, Flosculina globosa Lituonella douvillei, Opertorbitolites douvillei, Orbitolites complanatus* etc. The age of the formation is Early to Middle Eocene but might extend down into the Paleocene in some areas. It is correlated with the Saindak formation of the Eruptive Zone and the Ghazij, Laki and parts of Kirthar and Dungan Formations of the adjoining areas., It is also correlated with the Chharat Group of Upper Indus Basin.

## AXIAL BELT

A shallow-water, dominantly reefoid limestone facies with rich foraminiferal and algal fossils, referred herein as Nisai formation, represents the Eocene of the Axial Belt.

**Nisai formation:** Hunting Survey Corporation (1961) proposed the name "Nisai group" for the "black nummulitic limestone, conglomerates, etc. at the base of the Khojak shales" of Vredenburg (1906) and the "Ghazij shale and older Nummulitic beds" of Davies (1930 c). The unit is here redefined as Nisai formation, which includes the "Nisai group", "Nimargh limestone", "Wad limestone", "Wakabi limestone", "Wakai limestone", "Khude limestone", "Kasria group" and upper parts of the "Jakker" and "Jamburo groups" of Hunting Survey Corporation (1961) of similar lithology. Parts of the strata included in the Nisai formation of the present report have been previously referred to as "Eocene limestone" and "Lower Kirthar Shales" by Blanford (1879), "Black Nummulitic limestone" and "Ghazaband limestone" by Vredenburg (1904) and "Lower Kirthar Shales", "Upper Kirthar", "massive limestone", "Spintangi Limestone", "Nari" and "Khojak Series" by Vredenbrug (1909).

The section exposed 12 km north of the Nisai Railway Station and traversed by the road leading north from the railway station, was designated as type section by Hunting Survey Corporation (1961). Kasria Jhur, a main tributary of the Hab River flowing east from Pab Range is designated here as the principal reference section of the formation. Cheema et al. (1977) summarized the formation to consist of limestone, marl, shale with subordinate sandstone and conglomerate. Although various lithological components of the formation become significant in different areas, yet limestone of grey, greyish brown colour and variable texture constitutes the dominant lithology in many areas. The limestone is massive, brecciated, reefoid (at Wakai and Wakabi) and shelly. In places, some argillaceous, well-bedded limestone of grey to black colour is present. Some of the limestone beds in Wad area are oolitic and well bedded, similar to Jurassic limestone of the region (Hunting Survey Corporation, 1961). At Wakai, the limestone has a fetid smell. The marl that becomes a prominent constituent of the formation in the southern calcareous zone of the Axial Belt is usually clayey, commonly well bedded, soft and hard, invariably grading into hard fine grained limestone or soft calcareous shale, and rarely exhibits a breccia like structure (Jamburo area). The shale is grey, green, maroon, yellow and brown, usually calcareous, in places lateritic or carbonaceous, soft, earthy, flaky to fissile and hard. The sandstone is grey, green, brown and white, weathering dark grey, brown and rusty, fine to coarse grained and poorly sorted. Protoquartzitic to well sorted orthoquartzitic, usually thick bedded, in places cross-stratified and is commonly calcareous. The conglomerate is a jumbled mass of angular to rounded pebbles and boulders of limestone, marl, jasper, sandstone and various igneous rocks, which are present at different levels in different areas.

The main area of development of the Nisai formation is the Axial Belt. Small and isolated occurrences are reported from two regions, near the Iranian border (between Koh-i-Wakai and Shiraz Peak) and in the Siahan Range of Balochistan Basin. At the Shiraz Peak, thickness is about 30 m. The formation is about 1200 m thick in the type section, between 240 and 455 m in the area around its principal reference section and between 300 to 750 m in the Khude Range. It is about 600 m at Wad, but is only 3 to 10 m near Ghazaband Pass and west of Gidar Dhor River. In most areas of the

Calcareous Zone and some areas of the Arenaceous Zone of the Axial Belt, the formation overlies, conformably and transitionally, the Ranikot Group. In other areas of the Axial Belt, it overlies unconformably various Mesozoic and Permian strata. The lower contact of the formation with the Ghazij Group (of the present report) has been reported to be conformable at some places (such as Gidar Dhor. section) and unconformable at others, Hunting Survey Corporation (1961). The formation is conformably overlain by the Khojak formation or Nari Formation throughout its extent except in a small area west of Gaheto, where the Nisai formation has an unconformable upper contact with the Nari Formation.

The formation has yielded rich foraminiferal assemblages with some other fossils on the basis of which Eocene to Early Oligocene age has been assigned to it. No Late Eocene fossils have, however been reported from any areas other than the one between Sheikh Wasil and Gidar. An Early to Middle Eocene age has been assigned to the formation in the Wakai area. In some areas the age of the formation might extend down to the Paleocene as indicated by Miscellanea miscella from the Wakabi area. Some of the fossils recorded by Hunting Survey Corporation (1961) are:

EOCENE: *Assilina granulose, A. leymeriei, A. spinosa, A. subpapillata. Fasciolites globosa. F. lepidula, F. oblonga, Discocyclina sowerbyi, Dictyoconoides cooki, Lockhartia con'diti, L. newboldi, Lituonella brugesi, Nummulites atacicus, N. globosa, N. mamilla, Orbitolites complanatus, Globigerina linaperta, Rzehakina epigona, Bulimina pupoides, Velates perversus, Ampullella nuttalli Pyrazus indicus, Diplodonta hindu,* and others

LATE EOCENE: *Pellatispira madaraszi,*

OLIGOCENE: *Fasciolites elliptica, Lepidocyclina dilatata, L. blanfordi, Nummulites fichteli, N intermedius, Teredo (Kuphus) polythalamia*

The formation is correlated with the Ghazij Group, Laki, Kirthar and Nari (lower part) formations in the Axial Belt, and Sulaiman and Kirthar Provinces. In the Balochistan Basin, it is correlated with the Saindak, Kharan and Khojak formations. In the Kohat-Potwar Province, it may be correlated with the Chharat Group.

## EOCENE PALEOGEOGRAPHY

In the reconstruction of Paleogeography of Eocene all the available information is recorded here, however, the paleogeographic sketch map show only features particularly present in the Early Eocene times. Views of different authors are given; some of the views have ample scope for improvement for future research. In the Early Eocene, the old depocenter of the north western Kohat Basin was filled up with some more euxinic sediments and debris flow rudites (Patala Formation), followed upwards by a considerable thickness of green shale (Panoba Shale), and finally shallow-water carbonates that pass up through a dolomitised Sabkha sequence (Shekhan Formation) into laminated lagoonal gypsum (Jatta Gypsum). This was followed by red shale with thin channel form granule stones with terrestrial vertebrates (Kuldana Formation); the upper part of this formation contains oysters, marine and fresh water snails. These facies have been interpreted to be deposited as transitional marine, coastal wetland, lakes, saline evaporatic lagoons and marine oyster banks. Finally, the deposition of Kohat Formation took place, which is a product of productive shallow carbonate sea. It is also noted that shallow-water carbonates extended far to the east. The western half of the Kohat basin, predominantly shaly in the Paleocene, continued to be shaly in the Early Eocene. Wells (1984) considers the above package of lithology of more or less closed or partly opened basin and interpreted it as follows:

"Encirclement and constriction of shoreline facies and sediment sources were followed by quick filling of the central deep with halite and gypsum. Restriction of the basin and increased salinity appears to have caused the disappearance from Eocene sediments of reefs, pelagic foraminifera, nautiloids, nearly all corals and coralline algae, and most bryozoa. This stage was succeeded by very flat alluvial red bed plains with poorly developed drainage system. Subsidence of the basin continued which caused widespread development of coastal wetlands (marshes, lagoons, etc.) and eventually created a carbonate-floored sea around Kohat. The sea was rapidly drained before the end of the Middle Eocene and then the region lay more or less static until the first Himalayan molasses was deposited, probably in Late Oligocene or Early Miocene times". Wells (1984) further argued in favour of a creation of an epicontinental sea and added that because there are no marine deposits in northern Indo-Pakistan that are younger than the Middle Eocene strata of the Kohat Basin and because early and Middle Eocene deposition took place in a restricted sea with well-defined northern and western shorelines on what had previously been the outer shelf of the Indian subcontinent, Indo-Pakistan and Afghanistan are interpreted to have been touching in Early Eocene times. In fact, the occurrence in west-central Pakistan of Paleocene/ Early Eocene ophiolites, major east-facing post-Mid-Paleocene deltas, and Middle Eocene transgressive marine beds that extend into Afghanistan indicate that Pakistan began to collide with south-eastern Afghanistan early in the Paleocene. It follows that the Eocene seas around Kohat were not in the Neo-Tethys ocean basin, but were instead an epicontinental sea on the former ocean's southern shore". According to Wells (1984), this sea had specific characters, which are summarized below:

1). The sea was formed in a long enclosed basin, 2). It showed asymmetrical distribution of evaporates and clastics, 3) The sea lay about 10-15 south of its present position, 4). The life in sea indicate restricted fauna, 5). It had an extensive Sabkha shoreline, and finally, 6). It was an epicontinental remnant sea that did not lie on the parent ocean's suture line, "it strongly resembled the modern Persian Gulf, as described in Purser (1973)".

The situation in the lower Indus Basin and Axial Belt was little different to what has already been said for the Upper Indus Basin. In the southern part of Llower Indus Basin, Laki Formation and Lower part of Ghazij Group which in subsurface encloses gas productive Sui Main Limestone as well as Kirthar Formation represent shallow water carbonate shelf where the formations of Ghazij Group play an important roll in the reconstruction of paleogeographic map of the Eocene times.

The paleogeography of the lower Indus Basin and Axial Belt during deposition of the lower part of the Ghazij Group (earlier part of Early Eocene) was apparently little difference from that of Late Paleocene, except that water depths were generally somewhat deeper, as evidenced by the

Ghazij shales overstepping the limestones of the Paleocene Dungan Formation to Early Eocene (Sui Main Limestone). During the latter part of Early Eocene, however, a great change was brought in the depositional pattern which had persisted, with only minor changes, since Triassic time.

Flynn (1972) reconstructed a map (Fig. 21), which shows paleogeography during Early Eocene. The most striking feature of the map is that it shows terrigenous clastics entering the basin for the first time from the west.

Three subdivisions of the Ghazij Group in the Quetta and Mari-Bugti hills area by Hunting Survey Corporation (HSC) (1961) corresponds to three divisions formalized by Stratigraphic Committee of Pakistan Shah (2001). A lower zone of HSC consisting of grey calcareous shale that weathering olive green with subordinate thinly bedded intercalations of calcareous sandstone, this zone is now formalized as Shaheed Ghat Formation which intertongue with a large lense of limestone in upper part; and the upper two zones of HSC, are described as the middle zone consisting of interbedded green-grey sandstone having varied lithology, measures of coal, grey shale, chocolate-coloured, carbonaceous or sulphurous shale, calcareous siltstone and brown weathering shaly limestone and finally an upper zone as has been described by Hunting Survey Corporation (1961), as dominantly comprised of reddish-weathering claystone with intercalated claystone that weathers green, yellow, grey, and brown. The middle and upper zones of Hunting Survey Corporation has been formalized as Toi Formation by Statigraphic Committee of Pakistan on the recommendations of the attending members of Amoco Pakistan exploration company (Shah, 2000).

According to the Hunting Survey Corporation, the main geologic feature that explains the origin and distribution of the coal (in the middle zone) is the "Ghazij" delta (deltaic sediments comprising the middle and upper parts of the "Ghazij Formation" as defined by HSC, or the Toi Formation as defined by Shah, (1999). This river flowed southeast from the Hinterland terrain (Afghanistan and westernmost Pakistan) and emptied into the edge of the foreland basin between, present day, Quetta and Harnai, and coastal currents spread its deltaic debris south towards Johan and northeast beyond Bahlol. According to Flynn (1972), the conclusion of Hunting Survey Corporation is supported by field evidence gathered by Amoco geologists. Paleocurrents directions taken in the Toi Formation in the central and northern part of the Sulaiman Range indicate that the influx of terrigenious clastics was dominantly from the southwest. Evidently, the delta, which discharged sediments southeastward towards the Quetta-Harnai area, was also discharging terrigenous clastics north-eastward toward the central and northern parts of the Sulaiman Range.

The occurrence of coal deposits in Balochistan especially between Quetta-Duki, constitute commercial deposits over a large area roughly coincident with the eastern flank of the Sanjawi Arch, and a narrow elongate area between Quetta and Johan. Northward and westward the coal beds pinch-out against wholly fluviatile sediments, whereas in a southerly and easterly direction they inter-tongue with the wholly marine limestones and shales comprising Drug Formation (limestone) of the Ghazij Group. Thus the fluviatile, paludal, and shallow marine sediments are distributed aerially in a pattern, which can only be explained by a western or northern source for the terrigenous clastics (Flynn, 1972).

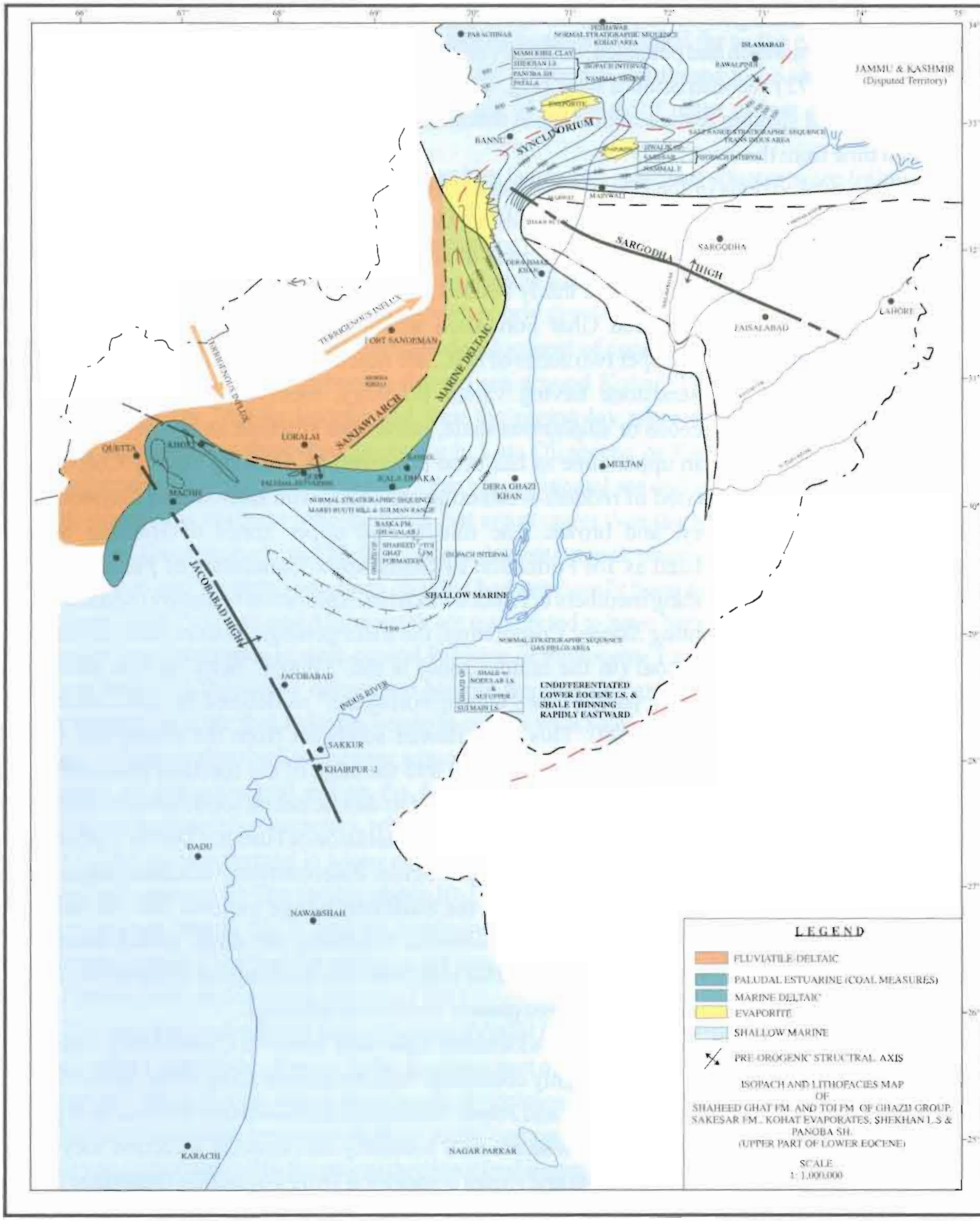



Fig. 21. Paleogeographic sketch map of lower Middle Eocene.

Meissner et al. (1974, p. 28) also found evidence of two shorelines on the east west line from Uch Bazaar to Pãnoba, traces of the shoreline are recorded between Uch Bazar and Chilli Bagh and thence to Shekhan Nala. The strike of the shoreline is described as northeast and the basin being towards the south. These shorelines existed during Early Eocene time. According to Meissner et al. (1974), two horizons of non deposition or erosion are present within the Early Eocene sequence near the western boundary of the Kohat quadrangle which is not present eastward or southward. On the other hand it is not known as to whether or not terrigenous clastics were also entering the basin from the east (Indian Shield) in any significant amount. Flynn (1972) further recorded that post-Eocene erosion has subsequently removed all evidence of a possible eastern source area. He also postulated that by Middle Eocene time the Indian Shield was largely covered by the basaltic lavas of the Deccan traps. Therefore, he believed very little sediments were derived from the shield after Paleocene time. The absence of post Eocene sediments on Sargodha High is considered as non depositional event. The "Sargodha High" was sub aerially exposed throughout most or all Eocene time (Flynn, 1972).

As to restriction of sea in Upper Indus Basin, Flynn described that "the paleogeography of the Eocene and Paleocene has one marked similarity in that it is apparent that the southern extension of the Tethyan Sea was much more restricted between the Asian and Indian plates than it was thought previously. This restriction is shown on Fig. 21 as an isthmus lying in an area bounded by the western end of the Marwat Range and the northern end of the Sulaiman Range. The known presence of salt and gypsum of Early Eocene age at Khairabad and near Kohat, and the interpreted presence of evaporate northeast of Gomal River; indicate that the restriction was due to the continuing movement of the Indian Plate toward the Asian Plate. The movement was mostly marked against the north-westward protuberance of the "Sargodha High", which acted either as a positive barrier (receiving no marine sedimentation) almost completely separating the Potwar Basin from the Sulaiman Basin, or as a very shallow marine sill (which may have received a thin cover of Eocene sediments) which have been removed from the top of the "high" in post-Eocene erosional event.

In the Lower Indus Basin shallow marine conditions continued in Late Eocene. Siddiqui (2004) described a good account of depositional environment of the Eocene of the Lower Indus Basin. According to him both Sui Main and its chronostratigraphic-equivalent Laki Formation represent shallow-water shelf carbonates, precipitated on a depositional platform that covered the entire lower Indus basin except for the present-day Sulaiman Range to the north of the Zin-Loti trend. At the start of the Eocene, there was a rapid drowning and transgression in areas north of the Zin-Loti trend and all along the Sulaiman Range, where thick shales with thin carbonate intervals (Habib Rahi and Pirkoh Formations) were deposited during the Middle to Late Eocene. This thick sequence of shales directly overlies the Paleocene Dungan Formation and its clastic facies (Fig. 20). South of Sui, toward the Kandhkot and Qadirpur areas, shallow-marine conditions prevailed where carbonates with increased clastic influx continued to be deposited as the Sui Main, but here, they were about half as thick compared to the Sui area. The basin configuration was such that the lower part of the Sui Main was deposited in shallow and more restricted (lagoonal) environments in the Sui area and represented a lowstand systems tract. The upper part was deposited in shallow-marine shoal carbonate environments, representing a highstand systems tract.

The Kirthar Range, however, represents a period of stability during the entire Eocene. Unlike the Sulaiman Range, where the stratigraphy is typically an alternation of limestone and shale sequences, the present-day Kirthar Range represents a carbonate-dominated basin throughout the Eocene, where even the cap rock for the Mazarani discovery in the Sui Main is provided by a thick and tight limestone bed (Chat beds). South of Sui is a Kirthar Range, during the entire Eocene, Kirthar area remained stable which gave rise to predominantly one kind of rock typethe limestone, and the sea remained shallow with clear warm water environment.

## OLIGOCENE

### INDUS BASIN

Rocks of Oligocene age are developed in the Lower Indus Basin, Axial Belt and the Balochistan Basin. These are not known from the Kohat-Potwar Province. In the Lower Indus Basin the following three formations are described:

Bugti Formation
Chitarwatta Formation
Guj Formation } Momani Group
Nari Formation

### Lower Indus Basin and Parts of Axial Belt

Nari Formation of the Momani Group is recognized in the Kirthar Province, in a few places of the Sulaiman Province and the Axial Belt; Chitarwatta and Bugti Formations are restricted to Sulaiman Range.

**Momani Group:** The term Momani Group was introduced by Cheema et al. (1977) to include the Nari Formation and the Gaj Formation of the present report. The group also represents the lower parts of the "Sibi group" and the "Urak group" of Hunting Survey Corporation (1961). Nari Formation is described in the Oligocene Chapter, whereas Gaj Formation is described under Miocene - Pliocene Chapter. The Momani River section in the Dadu District is designated as the type locality of the group.

The group according to Cheema et al. (1977) consists dominantly of marine sediments with some estuarine and fluviatile elements in the upper-most part. It consists of limestone near the base, followed by sandstone and shale (Nari Formation), which in turn is overlain by gypsiferous shale, calcareous sandstone and argillaceous limestone (Gaj Formation). In the area around Sibi and Urak, the section starts with the Nal member of the Nari Formation, followed by a sequence of red and green, friable, coarse-grained sandstone and olive green and khaki coloured shale of fluviatile or estuarine origin. It is difficult to place a boundary between the Nari Formation and the Gaj Formation in these areas.

The group is well distributed in the Sulaiman Province, Kirthar Province, and in parts of the Axial Belt. Its thickness in the type locality is about 660 m. It is 1700 m thick in the Gaj River Section, while in Mazarani-Miangun section the thickness ranges from 1200 to 2400 m. In the Sulaiman Province, its thickness ranges from 90 to 450 m. At Lukh Rud-Sor Dir Jhal Section in the Arenaceous Zone of the Axial Belt, the thickness of the group ranges from 300 to 600 m. At most of the places in the Sulaiman Province and the Axial Belt, only Nari Formation is developed. The group conformably overlies the Kirthar and Nisai formations in most of the areas. However, its lower contact with the Kirthar Formation in the eastern Sulaiman Province and in the Hyderabad area of the Kirthar Province and with the Nisai formation in parts of the Arenaceous Zone of the Axial Belt is unconformable. The group is conformably overlain by the Siwalik Group.

A number of foraminifers, coelenterates molluscs, echinoids, a few vertebrate remains and algae have been recorded by Hunting Survey Corporation (1961) and Pascoe (1963). The fauna indicates an Oligocene to Miocene age for the group. In parts of the Sulaiman Province and Axial Belt, the group is mostly Oligocene to Early Miocene. The group is correlated with parts of the Makran Group of the Balochistan Basin and the Axial Belt. It is also equivalent to the Rawalpindi Group and lower part of the Siwalik Group of the Kohat-Potwar Province.

**Nari Formation:** The name 'Nari series', derived from the Nari River in the Kirthar Range, was introduced by Blanford (1876) for a rock unit, which he later (1879) subdivided into Lower and Upper Nari. Following Williams (1959), the "Nari series" of Blanford is here referred to as Nari Formation. The Lower sub division of Blanford (1879) is here named as Nal Member, after the "Nal limestone" of Hunting Scurvies Corporation (1961). The formation constitutes the lower parts of the Sibi and Urak groups of Hunting Survey Corporation (1961). Williams (1959) proposed the Gaj River section (Lat. 26° 56' 12" N: Long. 67° 10' 10" E), in the Kirthar Range as the type section. Nal Village has been proposed as the type locality by Hunting Survey Corporation (1961) for the Nal Member.

Nari Formation consists of sandstone, shale and subordinate limestone. The lower part of the formation, the Nal Member is predominantly composed of crystalline limestone which is white to grey, brown or yellow shelly, nodular or rough surfaced, thin to thick bedded and even massive. Thin stringers of dark shale and of thin bedded and fine-grained brown sandstone are also present. The upper part of the Nari Formation consists predominantly of sandstone, which is greenish grey, grey brown and white coloured, fine to coarse grained often gritty and calcareous with subordinate shale, sandstone and varicoloured claystone. These subordinate rock types are commonly brown, yellow and dark red to brown or less commonly purple. Beds of conglomerate and ironstone are present either at the base or in the upper part. Generally there is no limestone in the upper part of Nari Formation but in the area around Karachi subordinate fossiliferous limestone interbeds are present which resemble those of the overlying Gaj Formation.

The formation has widespread distribution in the Kirthar and Sulaiman provinces and parts of the Axial Belt. The Nal Member is not developed in parts of the northern and eastern Sulaiman Province. But in the Kirthar Province, Sibi area of the Sulaiman Province and parts of the Quetta region of the Axial Belt, Nal Member represents the whole of the Nari Formation. The formation is 1400 m thick in the type locality and 1045 m in the Mazarani area of the Kirthar Province. The thickness ranges from 150 m (at Chitarwatta) to 300 m (at Moghal Kot) in the Sulaiman Province and 200 m (in Sor-Range near Quetta) to 600 m (in Nal) in the Axial Belt. However, a maximum of 1820 m has been reported from the Kirthar Province (Hunting Survey Corporation, 1961).

The lower contact of the formation is mostly conformable and gradational with the underlying Kirthar and Nisai formations. In the Hyderabad anticlinorium (Kirthar Province), it is unconformable with the Laki, Kirthar formations and Ghazij Group. The contact with the Kirthar Formation is placed below the lowest bed of shelly limestone of the Nal Member, while in case of the Nisai formation, it is drawn at the top of the highest bed of marl or limestone of light grey and white colour. In the Arenaceous Zone of the southern Axial Belt, however, the lower contact of the Nari with the Nisai formation ("Wad Limestone" of Hunting Survey Corporation, 1961) "Porali intrusions", and Bela volcanic group is invariably marked by an erosional unconformity. The Nari Formation is conformably overlain by the Gaj Formation in the Sulaiman and Kirthar Provinces and Quetta region, and or by the Hinglaj formation in the Arenaceous Zone of the southern Axial Belt. In the eastern Sulaiman Range, the contact with the Siwalik Group is unconformable because the intervening Gaj Formation is absent. The contact with the Gaj Formation is drawn above the last thick massive sandstone bed while the contact with the Hinglaj formation is placed at the top of the ridge-forming and pale weathering limestone.

Foraminifers, corals, molluscs, echinoid, algae, and other fossil groups have been recorded by Duncan and Sladen (1884, 1886); Vredenburg (1906b, 1909b); Nuttall (1925, 1926); Hunting Survey Corporation (1961); Pascoe (1963); Khan, M. H. (1968) and Iqbal (1969a). These include the following: Foraminifera ; *Nummulites intermedius, N. vascus, N. fichteli, N. clipeus, Lepidocyclina (Eulepidina) dilatata, etc. Bivalvia: Crassatella sulcata, Venus (Ventricola) multilamella, V. (Antigona) peepera:* Gastropoda; *Scaphander oligoturritus, Lyria anceps and Tritonsium (Saia) indicum.* Pascoe (1936) concluded that the formation, as a whole corresponds approximately to the Stampian of Europe and ranges from Rupelian to Chattian, Hunting Survey Corporation (1961) assigned an Oligocene age to the formation, with some upper strata being of Early Miocene age. Khan (1968) assigned a Rupelian to early Aquitanian age to the formation, basing his deductions on a comparative study of the larger foraminifers.

The formation is correlated with parts of the Khojak and Hinglaj formations of the Axial Belt and the Balochistan Basin. The upper part of the formation may also be correlative with the Murree Formation of the Kohat-Potwar Province.

**Chitarwatta Formation:** Hemphill and Kidwai (1973) introduced the name Chitarwatta for the Nari Formation of Eames (1952), in the Sulaiman Range, which has been formalized by Stratigraphic Committee of Pakistan. The formation is recognized only in the eastern and southern part of the Sulaiman Range. The type section is designated in the Vihowa Rud at the Chitarwatta Post (Lat. 31° 03' N: Long. 70° 14' E) in the Sulaiman Range.

Lithologically the formation consists of red, grey and green claystone and subordinate amounts of siltstone and sandstone. The siltstone is variegated, friable and ferruginous. The sandstone is white, brownish, yellow, calcareous in places and commonly ferruginous. In Litra and Kaura nallahs and in Vihowa Rud, hard ferruginous sandstone and conglomerate beds crop out at or near the top of the formation. In the lower 100 m section of Domanda Post area gypsiferous claystone, ferruginous beds of ripple marked variegated, and cross-bedded sandstone crop out. Further south, in the D. G. Khan quadrangle and adjoining areas, it is composed of variegated sandstone, siltstone and claystone. The sandstone is reddish brown, purple and khaki, fine- to medium-grained, sub-angular to sub rounded, thin to thick bedded, friable and calcareous in places. The siltstone and clay stone is moderate red to reddish brown, purple brown, friable, calcareous, argillaceous and ferruginous. The upper part is mainly sandstone. In the Bugti area, the formation comprises yellowish green, pinkish white sandstone alternating with maroon greenish grey siltstone and silty clay (Shah, 1999).

The Chitarwatta Formation is present in the foothills of the Sulaiman Range, the formation appears to be thin in the northern most parts of the Sulaiman Range and may wedge out along the western flank of the Sorai Ghar in Waziristan. The thickness is 400 m southwest of Domanda Post and 500 m in Chitarwatta and Kaura nallahs. Its thickness at Baghobandki is 250 m. The lower contact with the Kirthar Formation is disconformable with highly ferruginous beds marking the contact. The upper contact with the Siwalik Group rocks is also disconformable and is distinguished by a conglomerate unit containing rust coated sandstone and limestone pebbles. Thin carbonaceous beds near Domanda Post contain root fragments and plant species Croftiella escheri of Late Oligocene to Late Miocene. The age of this unit was determined as Oligocene by Iqbal (1969b), on the basis of fresh water gastropods and bivalves. Reported among the gastropods are Crommium sindiensis, Cirsotrema pseudodubiosa and Turritella cf. T. narica; the last species are considered to be restricted to Oligocene by Iqbal (1969b).

**Bugti Formation:** The formation underlying the Siwalik Group in the Bugti hills, is very rich in vertebrate fauna. It is usually referred to, as "Bugti Beds" and has been described here as the "Bugti Formation". Previously it has been referred to as upper part of "Upper Nari" Pilgrim (1908); "Upper Gaj" of Pilgrim (1912), "Bugti Bone deposits" of Cooper (1924), "Chur Lando beds" of Osborn (1936), "Bugti Member" of Raza and Meyer (1984), "Nari-Gaj beds" of oil companies.

The formation is restricted to Bugti area and the type locality is designated north of Gandoi (Lat. 69° 07' N: Long. 28° 48' E). The Bugti Formation is composed of bright and varicoloured sandstones with common interbeds of ferruginous conglomerates and yellow and red sandy silts. Some of the sandstones are pure white and soft with no apparent bedding pattern, while in the upper parts some sandstone beds are hard and resistant, and form conspicuous escarpments. Such beds increase in number and thickness progressively upwards. Lenticular beds of iron-coated ferruginous silty sandstone and thin beds of loosely cemented ferruginous grits are common in the lower part. These beds are composed of rounded to sub angular, completely iron-coated, grit sized quartz grains. Conglomerates occur lower in, the section and at few places, the basal 30-50 m are dominantly conglomerates with minor red brown sandstone (Raza and Meyer, 1984). The formation in the lower part contains tuff and ash beds. These beds are lenticular and are interbedded with thin sandstone and conglomerate. It is best developed on both flanks of the Zin anticline, and is not recognized in the Sulaiman foothills. The formation attains a maximum thickness of about 300 m in the central part of the Zin anticline and gradually wedges out in north east and west directions.

Rich in vertebrate fauna, the formation contains a unique blend of mammals of Asian affinity and of African origin. The vertebrate fauna is dominated by rhinoceratides and antharacotheriids with a few proboscideans, carnivores, chalicotheres, suids and crocodilians. The formation records the presence of the largest size land mammals, some of them were about 6 m high, belonging to hornless group of rhinocerotid family; most interesting and important among them are giant sized species of *Paraceratherium, Balochitherium* and *Bugtitherium.* Cooper (1911) found the bones of greatest of all the rhinos-the *Balochitherium bugtiensis.* His description of this remarkable discovery was based on some neck vertebrate, foot and limb bones. Later on, with the discovery of a skull and a part of mandible in Mongolia, the type was established as *Balochitherium grangeri.* Pilgrim (1908) found the genus *Bugtitherium* based on two fragments of two skulls which were identical and had portions of maxillaries and pre-maxillaries, he also attributed some isolated teeth to this genus. During 1985 and 1987, Geological Survey of Pakistan discovered 12 different faunal localities in the Bugti hills. No detailed excavation was carried out; only surface collection was made, with slight-excavation at a few places which provided enough material for study. Most of the material comprised of post cranial bones in fragmentary condition representing already described great rhinos. A partial skull with all the cheek teeth of *Bugtitherium grandicisivum* has been described by Shah and Arif (1992) and detailed first time comparative anatomy of the teeth of Paraceratherium Bugtiense has also been carried out (Antoine et al., 2000). They also revealed probable sexual diamorphism on the lower incisors.

Lenticular beds of volcanic ash contained in the formation were sampled from the lower part of the formation below the locality of Balochitherium in the Chur Lando Nala by the Geological Survey of Pakistan in 1985. The samples of tuff were processed by Tabbut et al. (1992) for absolute dating, on zircon grains, which yielded a concordant age of 22.6±2.9 Ma for the Bugti Formation. Based on faunal analysis and absolute dating, the age of the Bugti Formation is considered Late Oligocene to Early Miocene.

## BALOCHISTAN BASIN AND AXIAL BELT

Out of the three Oligocene formations, described here only the Amalaf formation is restricted to this age. The other two formations extend into the Miocene.
The following two formations are recognized in this region:

| | |
|---|---|
| Amalaf formation | (Eruptive Zone) |
| Khojak formation of Makran group | (Balochistan Basin and Axial Belt) |

**Amalaf formation:** The name "Amalaf formation" was introduced by Hunting Survey

Corporation (1961) for a sequence of sandstone, shale and volcanic rocks in the western Eruptive Zone, which was previously mapped by Vredenburg (1901) as part of "Cretaceous-Eocene Flysch". Since the lower part of the formation, as defined by Hunting Survey Corporation, consists of shale and sandstone and is similar to that of the Saindak formation of the present review, the name Amalaf formation is retained only for its upper part. A section northwest of Amalaf in Chagai District is chosen as the type section by Hunting Survey Corporation (1961).

The formation consists of volcanic rocks with occasional green and brown weathering shale and sandstone. The volcanics consist of coarse to fine ash and agglomerate in beds up to 9 m thick, which weather dark green and red. Lavas are also present but the flows are only a few metres thick and subordinate in amount. Most of the lava is green andesite mottled with white feldspar or black pyroxene phenocrysts. The formation has a restricted distribution and is developed only in the western part of Mirjawa-Dalbandin trough of the Eruptive Zone. The formation is estimated to be about 300 m thick. The lower contact with the Saindak formation is transitional. The upper contact is not exposed as the Amalaf formation is the youngest formation exposed in the region.

The formation is reported to be devoid of fossils Hunting Survey Corporation (1961). Since Vredenburg (1901) report all fossils of Oligocene age including species of Cardita, Corbula, Natica and Turritella from the underlying Saindak formation, the Amalaf formation is assigned an Oligocene age. No upper age limit can be assigned to the formation as it is the youngest pre-Pleistocene unit.

**Makran group:** Blanford (1872) gave the name Makran Series to a thick sequence of sandstone, shale, mudstone and minor conglomerate in the Makran coast area. Vredenburg (1906) redefined this as "Makran system", which he divided into three series the uppermost (dominantly sandstone) of which he named as "Hinglaj series". Later Vredenburg (1925) disowned his Makran system and instead renamed the Hinglaj series as "Makran series", dividing it an upper "Gwadar stage" and a lower "Talar stage". The Talar stage of Vredenburg (1925), with Flysch and Khojak shales of Griesbach (1880), and associated units from Geological Survey of India map (1931), are assembled here as Makran Group consisting of a lower Khojak formation representing "Flysch and Khojak shales" of earlier workers and an upper Hinglaj formation representing the Talar stage of Vredenburg (1921).

The group consists of clastic sediments, which were laid down in deltaic-estuarine to shallow-marine environments. The source area of the sediments was in the north. Lithologic variations in different areas are controlled by their distance from the source area. The group starts with a dominant shale sequence, followed by a dominant sandstone sequence, which together represents the Khojak formation which is transitionally overlain by the Hinglaj formation which comprises a dominant sandstone sequence with some shale, limestone and locally developed mudstone. Most of the Balochistan Basin and a greater part of the Axial Belt are occupied by the Makran group. It is 3,800 m thick at Jangal, 7,000 m in Jiwani-Gwadar area and more than 5,700 m in Diz. The group is overlain and underlain by various formations in different areas some of which have a conformable relation with it, while others have unconformable contacts. These relationships are described under individual formations of the group. The group has yielded rich fossil assemblages from different areas consisting mostly of foraminifers, gastropods and bivalves. The group is assigned different ages in different areas and extends from Eocene to Early Pleistocene (Cheema et al., 1977).

**Khojak formation:** The "Flysch and Khojak shales" of Vredenburg (1909b) are redefined here as Khojak formation. The name is derived from Khojak pass on the Quetta-Chaman Road. The formation represents the "Nauroz formation", "Turbat group" and "Pishi group" with its "Dalbandian assemblage " (except basal limestone and upper conglomeratic parts of Hunting Survey Corporation, 1961). In different parts of the Axial Belt and the Balochistan Basin, the succession representing the Khojak formation, in the present report has been subdivided by Hunting Survey Corporation (1961) into a lower predominantly shale sequence ("Murgha Faqirzai shale", "Siahan shale" and "Hoshab shale") and an upper predominately sandstone sequence ("Panjgur formation", "Shaigalu sandstone", "Binga formation" and "Multana formation"). As this two-fold subdivision is possible only in parts of the area of development of the Khojak formation, these units are here given member status. The lower predominantly shale sequence is named Murgha Faqirzai member, corresponding to the "Murgha Faqirzai shale" of Hunting Survey Corporation (1961) and the upper predominantly sandstone sequence is termed as Shaigalu member corresponding to the "Shaigalu sandstone" of Hunting Survey Corporation (1961).

Nauroz, about 30 km northeast of Kharan (Kalat) is designated as the type locality of the formation, following Hunting Survey Corporation (1961). The Pishi Rud, south of Dalbandin is designated as its principal reference section.The lower reaches of Murgha Faqirzai Rud are designated as type section of the, Murgha Faqirzai member, while Shaigalu, bout 50 km southwest of Fort Sandeman, is designated as type section of the Shaigalu member..

Cheema et al. (1977) defined the formation to consist of shale, sandstone and siltstone with subordinate limestone and conglomerate. Shale is the dominant lithology in the lower part. It is grey to green, in places brown or maroon, dominantly calcareous, in places arenaceous, fine textured fissile to flaky, but at places blocky in the upper part. Locally some beds are carbonaceous with lenses of lignite (e.g. at Multana). The sandstone is dominant in the upper part. It is grey to green or greenish brown, weathering grey, brown, rusty brown and maroon. The texture varies from fine to coarse grained in places gritty to pebbly, and usually thick bedded to massive. The sandstone is calcareous, micaceous rarely ferruginous or carbonaceous (e.g. at Amalaf) and shows cross-stratification and ripple marks. Conglomerate is present as subordinate component at different levels but predominates at Multana. The beds usually range within a metre thickness. The conglomerate includes sub angular to rounded pebbles, cobbles and boulders of up to a quarter metre diameter of sandstone, limestone, marl, red jasper and various igneous rocks, embedded in a sandy matrix. The limestone is dark grey to black, weathering light grey or brown, argillaceous, rarely sandy and is fossiliferous. In certain areas (Nushki, Khojak Pass etc.), the formation has been metamorphosed to slate and quartzite due to intense deformation.

The formation is widely exposed in the Axial Belt and the Balochistan Basin. Its thickness ranges from 900 to 1500 m in the area around type locality. The Murgha Faqirzai member is about 1200 m thick in its type section. The Shaigalu member has a maximum thickness of 600 m in the Kakar Khurasan Range (type locality) and about 1200 m in Diz. The formation conformably and transitionally overlies the Nisai and Kharan formations. In most of the areas of its development, various Pleistocene conglomeratic units (Bostan formation, Haro and Lei Conglomerates) uncomfortably overlie the formation. In parts of the Makran and north Zhob region of Balochistan Basin and the Arenaceous Zone of the Axial Belt, however, the Hinglaj formation conformably and transitionally overlies it and the contact is placed at the top of the highest hard sandstone bed.

Numerous Oligocene fossils like *Lepidocyclina dilatata, Nummulites fichteli, N. intermedius, N. vascus* and others have been reported by Eames (1939) and Hunting Survey Corporation (1961) from a number of areas, indicating the age of the main body of the formation to be Oligocene. However, from parts of the Balochistan Basin, the lowest beds have yielded a Middle Eocene assemblage (lower part of "Nauroz formation" of Hunting Survey Corporation, 1961) including *Nummulites atacicus., Assilina granulosa and Dictyoconoides cooki* and a Paleocene-Eocene assemblage (lower part of "Siahan shale" of Hunting Survey Corporation, 1961) including *Discocyclina* cf. *D. ranikoti, Nummulites globulus* and *N.* cf *N. irregularis* which indicate age of the formation from Eocene upwards. Two gastropods, *Telescopium charpentiert* and *Tympanotonos margaritaceus* of Oligocene to Early Miocene age and a bivalve, Ostrea gryphoides of Early Miocene to Recent age are mentioned by Hunting Survey Corporation (1961) from their Shaigalu sandstone indicating that in some areas the age of the formation does extend up into Early Miocene. In summary the age of the Khojak formation ranges from Eocene to Early Miocene.

## MIOCENE - PLIOCENE

Rocks of Miocene-Pliocene are more widespread than those of Oligocene. In some parts of the Makran-North Zhob Region, Kirthar Province and southern Axial Belt, the type of sedimentation which persisted into the Oligocene continued into the Miocene epoch. However, the continued southward withdrawal of the Tertiary sea, initiated by Middle Eocene times from Kohat-Potwar Province, resulted in wide-spread fluviatile sedimentation by Middle Miocene times in most parts of the Indus Basin and adjoining Axial Belt. It was during the Pliocene epoch that the sea probably occupied the present coast-line. Contrary to the Indus Basin and Axial Belt, rapid marine sedimentation was taking place in the central and coastal Makran areas of Balochistan Basin. Hinglaj formation represents the Miocene-Pliocene epochs in these areas (Cheema et al., (1977).

### INDUS BASIN AND CALCAREOUS ZONE OF AXIAL BELT

Southward regression of the Tertiary sea was very gradual, particularly in the southern parts of the Sulaiman Province, Urak Synclinorium of the Axial Belt and western part of the Kirthar Province. This resulted in contemporaneous sedimentation of marine, estuarine to fluviatile sedimentation in different parts of Indus Basin and in the Urak Synclinorium of the Axial Belt.

Following are the Mio-Pliocene rock units differentiated in the Indus Basin as well as Urak Synclinorium (i.e. Quetta region of the Axial Belt).

| | |
|---|---|
| Momani group | |
| Gaj Formation | (Kirthar Province, Marri Bugti and Quetta region) |
| Rawalpindi Group | |
| Murree Formation | (Kohat-Potwar Province) |
| Kamlial Formation | (Kohat-Potwar Province) |
| Siwalik Group | |
| Chinji Formation | (Kohat-Potwar Province and parts of Sulaiman Range) |
| Nagri Formation | (Indus Basin and Axial Belt, Quetta region) |
| Dhok Pathan Formation | (Indus Basin and Axial Belt, Quetta region) |
| Soan Formation | (Indus Basin and Axial Belt, Quetta region) |

**Rawalpindi Group:** The Stratigraphic Committee of Pakistan has approved the term Rawalpindi Group after the Rawalpindi District, as proposed by Pinfold (written communication, 1964), for the rocks comprising Murree Formation and Kamlial Formation in the Kohat-Potwar Province. The group consists of alternations of sandstone and shale of fresh water origin. The sandstone is light to dark red, purple and grey in colour, while the shale is purple and red. The sandstone in the Kamlial Formation is characterized by a flood of tourmaline and paucity of epidote while that of the Murree Formation by abundance of epidote. The rocks of the group are widely distributed in the Kohat - Potwar Province. In general, the thickness increases from southwest to north-west and reaches at least 3,330 m in the North. The lower contact of the group with various Eocene formations is disconformable, while the upper contact with the Siwalik Group is conformable.

Vertebrate and plant remains including silicified wood indicating Miocene age have been reported from the group. The group correlates with the Gaj Formation and the upper parts of the Nari Formation of the Lower Indus Basin and the Axial Belt. It also correlates with the upper part of the Khojak formation and lower part of the Hinglaj formation of the Balochistan Basin and the Arenaceous Zone of the Axial Belt.

**Murree Formation:** The "Mari Group" of Wynne (1874), "Murree Beds" of Lydekker (1876) and "Murree Series" of Pilgrim (1910) have been formally named Murree Formation by the Stratigraphic Committee of Pakistan. The name is derived from the Murree hills in the Rawalpindi District. A section exposed to the north of the Dhok Maiki (Lat. 33° 25' N: Long. 72° 35' E) in the Attock District has been designated the type section.

The formation is composed of a monotonous sequence of dark red and purple clay and purple grey and greenish grey sandstone with subordinate intraformational conglomerate. The basal strata of the formation consists of light greenish grey calcareous sandstone and conglomerate with abundant derived larger foraminifers of Eocene age. This horizon has been designated as Fatehjang

Member, after the "Fatehjang Zone" of Pilgrim (1918). In the Kohat area the formation has a higher percentage of sandstone which is brown, greenish grey in places purple and is medium to coarse grained. The interbeds of hard siltstone, lenses of conglomerate and purple to reddish brown shale are frequent.

The formation is widely developed in the Kohat-Potwar Province. It has also been recognized in Kashmir. It is up to 3,030 m thick in the northern Potwar but thins out to only 9 m at Banda Daud Shah in western Kohat. The formation ranges in thickness between 180 and 600 m in the northern Salt Range. Throughout its extent the formation unconformably overlies various formations of Eocene age. Its upper contact is broadly transitional with the Kamlial Formation. The main body of the formation is poorly fossiliferous and only few plant remains, silicified wood, fish remains, frog and mammalian bones have been recorded. However, the Fatehjang Member has yielded identifiable mammals indicating *Anthracotherium bugtiense, Brachyodus giganteus, B.* cf. *africanus, Palaeochoerus pascoei, Hemimeryx sp., Teleoceras fatehjangensis etc.* The fauna indicates an Early Miocene age for the Murree Formation.

**Kamlial Formation:** The "Kamlial beds" of Pinfold (1918) have been formally established as Kamlial Formation by the Stratigraphic Committee of Pakistan. The formation is equivalent to the "Kamlial Stage" of Pascoe (1963). A section southwest of Kamlial (Lat. 33° 15' N: Long. 72° 50' E), Attock District has been designated as the type section. The formation consists of purple-grey and dark brick-red sandstone which is medium to coarse grained and contains interbeds of hard purple shale and yellow and purple intraformational conglomerate. It is distinguished from the underlying Murree Formation by its usually spheroidal weathering and heavy minerals content in which tourmaline dominates over epidote.

The formation is widely distributed in the Kohat and Potwar areas and has also been recognized in the disputed territory of Jammu and Kashmir. It is 90 m thick at Kamlial, 580 m at Khaur, 650 m at Soan Gorge and 60 m at Ling River near Rawalpindi. In the subsurface, it is about 100 m at Balkasar, 150 m at Pamal Domeli and 180 m at Jhatla and varies between 120 and 300 m in the western Potwar, as drilled in oil wells. The formation overlies the Murree Formation conformably with a broadly transitional contact but in places it is unconformably overlying the Sakesar Limestone of Eocene age and the contact is marked by a basal conglomerate with derived fossils (e.g. in Musewali Khangah). The formation is conformably overlain by the Chinji Formation of the Siwalik Group. A number of fossil mammals have been recorded from the formation. Some of the important, as recorded include *Trilophodon cf. angustidens, Dinotherium indicum, Amphicyon cf. shahbazi, Hyaenaelurus lahirii, Anthracotherium sp., Hemimeryx blanfordi, Listriodon cf. guptai, L. pentapotamiae, Conohyus cf. sindiensis* and others. These fossils indicate Middle to Late Miocene age for the Kamlial Formation.

**Siwalik Group:** History of the nomenclature of Siwalik indicate that the term "Siwalik" was first used by Meddlicot (1864) for the upper part of the "Sub Himalayan system" of the Siwalik and Simla hills of India, later Oldham (1886) and Holland et al. (1913) used the terms "Siwalik Series" and "Siwalik System". Pilgrim (1913) proposed a three-fold division of the "Siwalik System" each of which was, in turn, divided into different faunal zones, viz. the "Lower Siwalik" into the "Kamlial" and "Chinji" zones, the "Middle Siwalik" into the "Nagri" and "Dhok Pathan" zones, and the "Upper Siwalik" into the "Tatrot", "Pinjor" and "Boulder Conglomerate" zones. Cotter (1933), following Wynne's (1878) classification, suggested that the "Kamlial Stage" should be grouped with the Murree Formation as the boundary between these two units is quite arbitrary. The suggestion has been accepted by the Stratigraphic Committee of Pakistan, which combined the Kamlial and the Murree in the Rawalpindi Group. The six faunal zones of Pilgrim were used as formal lithostratigraphic units by Lewis (1937). The Stratigraphic Committee of Pakistan following Danilchik and Shah (1967) established the Siwalik Group for the "Siwalik Series System", comprising the following formations, in descending order; Soan Formation (Tatrot and Pinjor), Dhok Pathan Formation, Nagri Formation and Chinji Formation. The name Siwalik Group is herein extended to similar suite of rocks in the Lower Indus Basin, including the "Manchhar or Siwalik Group" of Blanford (1867), the "Manchhar Series" of Blanford (1876), the "Manchhar" of Vredenburg (1906), the "Manchhar formation", and "Sibi" and "Urak" groups (excluding their lower parts) of Hunting Survey Corporation (1961).

No type locality has been designated for the group so far. Type localities of the component formations are, however, given in their respective descriptions. According to Denilchik and Shah (1967), the group is mainly composed of alternating beds of sandstone and argillaceous material. These were deposited in the belt between the Sub-Himalayan hills and the Arabian Sea, where a vast pile of fresh-water sediments had started accumulating since the Miocene epoch (Pascoe, 1963). The group, as a whole consists of sediments of clastic origin of molasses type. The lithology typically consists of red clay with subordinate sandstone (Chinji Formation) at the base, which is overlain by thick sandstone with minor clay (i.e. Nagri Formation). This is succeeded by a cyclic alternation of clay and sandstone (Dhok Pathan Formation), followed by a conglomerate sandstone clay sequence (Soan Formation) in the upper part.

The group is widely distributed in the Indus Basin, parts of the Calcareous Zone of the Northern Axial Belt and in the Waziristan Parachinar areas. This belt of Siwalik development continues (extends) in the east to Burma. The group is thousands of metres thick. The thickness of individual formations is highly variable and is given at relevant places. The lower contact of the group is conformable in most of the localities. However, in parts of the western Kirthar Province and Quetta region, the contact is unconformable with the Kirthar or Laki Formations; the upper contact with the Lei Conglomerate is usually unconformable. The group has yielded an abundant vertebrate fauna consisting of nearly all types of mammals together with varieties of reptile, fish and birds. The vertebrate fauna indicates Middle Miocene to Early Pleistocene age. The group is correlated with parts of the Hinglaj and Gwadar formations of the Balochistan Basin (Cheema et al., 1977).

**Chinji Formation:** Pilgrim (1913) proposed the name "Chinji Zone" to designate the upper faunal subdivision of his "Lower Siwalik". Lewis (1937) upgraded it to a formational level calling it "Chinji Formation and the name was accepted as such by the Stratigraphic Committee of Pakistan. The formation also represents the "Karghocha Formation" of Morris (1938) the red zone of Wynne

(1878) and the "Chinji" and "Alternation beds" of Eames (1952). The section south of Chinji (Kotchra) Village (Lat. 32° 41' N: Long. 72° 22' E) in the Attock District has been designated as type section.

According to Pilbeam (1977, 1979), the formation consists of red clay with subordinate ash grey or brownish grey sandstone. The sandstone is fine to medium grained, occasionally gritty, cross-bedded and soft. Scattered pebbles of quartzite and thin lenses of intraformational conglomerate are found at different horizons throughout the formation. The proportion of clay and sandstone in interbeds is variable from place to place e.g., in the Shinghar Range (in the Kohat-Potwar Province) the formation is mainly composed of reddish brown or reddish grey sandstone with subordinate clay interbeds. However, the formation essentially represents an argillaceous facies where the sandstone bands rarely attain 16 m thickness but clay bands may be as much as 60 m thick.

The formation is widely distributed in the Kohat-Potwar Province. It is only confined to the southern half of the eastern Sulaiman Range and is not developed in the rest of the Lower Indus Basin. The formation is 750 m thick in the type area and more than 1,800 m thick in the Shinghar Range. It is reported to be 400 m thick in Karkana, about 300 m in the Rakhi Gaj Nala and 150 m thick in the Zindapir area of the eastern Sulaiman Range. The formation is underlain by the Kamlial Formation in the Kohat-Potwar Province with a sharp and conformable contact. In the Sulaiman Range, it disconformably overlies the Nari Formation. It is conformably overlain by the Nagri Formation and the contact is usually drawn at the base of the first thick greenish grey sandstone bed.

The formation has yielded abundant vertebrate fossils, particularly from the Kohat-Pot-war Province (Pilgrim, 1913, 1926; Mathew, 1929; Colbert, 1933; Lewis, 1937) as listed by Pascoe (1963). The predominant groups in the Chinji fauna are innumerable crocodiles, turtles, monitor lizards, aquatic birds, dinotheres, primitive trilophodonts, forest dweling suidae, *Okapilike Giraffokeryx,* water deer, few hominoides, plethora of pythons and abundant *chelonian remains.* Some of the vertebrate species include *Sivapithecus indicus, Trilophodon macrognathus, Sivacanthion complicatus, Giraffokeryx punjabiensis, Chilotherium intermedium* and *Sivaelurus chinjiensis.* The age of the Chinji Formation is considered to be Late Miocene (Sarmatian) with some of the lower parts being of late Tortonian age.

**Nagri Formation:** The "Nagri Formation" of Lewis (1937) has been accepted as such by the Stratigraphic Committee of Pakistan. The formation represents the "Nagri Zone" or "Nagri Stage" of Pilgrim (1913, 1926), the "Dandot Sandstone" of Wynne (1877), the "Marwat formation" of Morris (1938), the "Lower Manchhar" of Blanford (1876), parts of the "Sibi group" and "Urak group" of Hunting Survey Corporation (1961) and "Uzhda Pusha formation" of Kazmi et al. (1970).

The village of Nagri (Lat. 32° 45' N: Long. 72° 14' E) in the Attock District has been designated as the type locality. The Gaj River section (Lat. 26° 51' N: Long. 67° 17' E) in the Dadu District is proposed here as the principal reference section. The Nagri Formation consists of sandstone with subordinate clay and conglomerate. The sandstone is greenish grey medium to coarse grained, cross-bedded and massive. In places, the sandstone is bluish grey dull red with "salt and pepper" pattern, calcareous, and moderately to poorly cemented. The clay is sandy or silty chocolate brown or reddish grey and pale orange, the proportion of which varies from section to section. The conglomerate beds have highly varied thickness and composition in different areas. They consist of pebbles of igneous rocks and Eocene limestone in the Kohat-Potwar Province and of Kirthar Formation in the Sibi area of Sulaiman Province, and nodules of clay and soft sandstone in the Kirthar Province.

The formation is widely distributed in the Indus Basin and the Quetta region of the Calcareous Zone of the Axial Belt. To the west of Dhulian and around Meyal-Jhammat area, a maximum thickness of 1,500 m has been recorded. The formation is 700 m thick at Litra Nala and 1100 m in the Sibi area of the Sulaiman Province, 600 m in the Urak area of the Calcareous Zone, and 940 m in the Gaj River area of the Kirthar Province. Generally speaking, its thickness ranges from 300 m to as much as 2,000 m. The formation conformably overlies the Chinji Formation in the Kohat-Potwar Province and parts of the eastern Sulaiman Range. In the Lower Indus Basin, it usually conformably overlies the Momani group. However, it unconformably overlies the Nari and older formations in the southern Laki Range, parts of the eastern Sulaiman Province and Quetta region. The upper contact with the Dhok Pathan Formation is always transitional. The contact can be easily placed as it is marked by colour change from greenish grey to bright red or gleaming white and also by regular interbedding of sandstone and clay of the overlying Dhok Pathan Formation.

The formation has yielded fairly rich assemblage of vertebrate remains as recorded by Pilgrim (1913, 1926); Anderson (1928); Colbert (1933); Lewis (1937); Gill (1952) and others. Pascoe (1963) listed numerous species including crocodiles, chelonians, proboscideans rhinoceratides and artiodactyles from the Kirthar Province and Marri-Bugti area of the Sulaiman Province. Some of the important mammals are *Trilophodon angustidens* var. *palaeoindicus. Pentalophodon falconeri, Dinotherium indicum* var. *pentapotamiae, Giraffokeryx chinjiensis* etc. The fauna indicates late Middle Miocene to Late Miocene age. No diagnostic fossils are reported by Hunting Survey Corporation (1961) from the outcrops in the Kirthar Province (Manchhar area), but they considered the age of the bulk of the strata in this region as of Pliocene age and believed that the lower beds may extend into Late Miocene. The Oil and Gas Development Corporation (1965 unpublished reports) assigned Middle to Late Miocene age to the formation in the Sibi-Quetta area. From the Potwar area, a rich assemblage of crocodilians, perissodactyles, artiodactyles, carnivors, proboscideans and primates have been reported by Pascoe (1963). Some of the important fossils are: *Hipparion* cf. *theobaldi, Giraffokeryx punjabiensis, Dorcabune nagrii,* and *Macrotherium salinum.* The fauna indicates an Early Pliocene (Pontian) age of the formation (Cheema et al., 1977). In the Lower Indus Basin and Quetta region (Calcareous Zone of Axial Belt), the Nagri Formation ranges from late Middle to Late Miocene in age, whereas in the Kohat-Potwar Province, it is Early Pliocene (Pontian).

**Dhok Pathan Formation:** The name "Dhok Pathan" was introduced by Pilgrim (1913) in a biostratigraphic sense for the upper subdivision of the Middle Siwalik in the northeast Punjab. Cotter (1933) redefined the unit as Dhok Pathan Formation, which was adopted as such by the Stratigraphic Committee of Pakistan for application in the Kohat-Potwar Province. The formation is herein extended to represent the "Upper Manchhar" (except its upper most part) of Blanford (1876); stages "e" "d" "c" of...Siwalik (of the Sibi-Pishin area) of Griesbach (1893), the "Sheri Ghasha Formation" of Morris (1938) parts of the "Sibi group" and "Urak group" of Hunting Survey Corporation (1961) and the "Shin Matai formation" of Kazmi et al. (1970), all of these units occur in the Indus Basin and the Calcareous Zone of the Axial Belt.

The village of Dhok Pathan (Lat. 33° 07' N: Long. 72° 14' E) Attock District, has been designated as the type section. The Gaud River section (Lat. 32° 55' N: Long. 71° 18' E), Mianwali District and Spintangi section (Lat. 29° 57' N: Long 68° 03' E), Quetta District, are proposed here as the principal reference sections. Cheema et al. (1977) described briefly that the formation is typically represented by monotonous cyclic alternations of sandstone and clay beds. The sandstone is commonly grey, light grey, gleaming white or reddish brown and occasionally brownish grey, greenish grey brown or buff coloured, thick-bedded, calcareous, moderately cemented, soft and cross-bedded. The clay is orange, brown, dull red or reddish brown and occasionally rusty orange, greenish yellow, yellowish grey, chocolate coloured, calcareous and sandy. Minor intercalations of yellowish brown siltstone are common. Conglomerate in the form of lenses and a layer is an essential character of the upper part. The thickness of one sandstone-clay cycle varies from 6 to 60 m.

The formation has a widespread distribution in the Indus Basin and Quetta region's Calcareous Zone (of the Axial Belt). It is 1330 m thick at the Gaud River and a maximum thickness of 1820 m has been recorded from southeast of the Khair-e-Murat Range in the Potwar area. It is about 1330 to 1500 m thick in the eastern Sulaiman Range, 1330 m to more than 2000 m in the Sibi-Kachhi area and about 120 to 300 m thick in the Marri-Bugti and Quetta regions. It is reported to be 1500 m thick in the Gaj River section of the Kirthar Province. The Dhok Pathan Formation has transitional contact with the underlying Nagri Formation. The upper contact with the Soan Formation is reported to be disconformable in the Kohat-Potwar Province but is gradational in the Lower Indus Basin and Quetta region. The conglomerate intercalations in these areas gradually increase upwards in number and are transitional to the overlying Soan Formation.

A very rich vertebrate fauna has been recorded from the Dhok Pathan Formation of the Kohat-Potwar Province (Pascoe, 1963). The formation is less fossiliferous in the Lower Indus Basin and the Quetta region. Some of the important fossils are: *Indarctos salmontanus, Arctamphicyon lydekkeri, Ictitherium indicum, Mastodon (Trilophodon) browni, Dicoryphochoerus titanoides, Pachyportax latidens* var. *dhokpathanensis, Hydaspitherium megacephalum.* From the Lower Indus Basin, Pascoe (1963) has listed: *Hipparion punjabiense Rhinoceros sivalensis* and Pachyportax latidens. The formation is remarkable for its rich Hipparion assemblage and numerous artiodactyles. The fauna indicates an Early to Middle Pliocene age. However, in the Kohat-Potwar Province, it is reported to be exclusively of Middle Pliocene (Astian) age.

**Soan Formation:** In the northwest Punjab the "Upper Siwalik" of Meddlicot (1864), which was later divided biostratigraphically into the "Tatrot" and "Pinjor" zones or stages by Pilgrim (1913) has been formally named "Soan Formation" by the Stratigraphic Committee of Pakistan, following Kravchenko (1964). The formation here also represents the upper part of the "Upper

Manchhar" of Blanford (1876). In the Lower Indus Basin and the Axial Belt the formation Includes the upper division of the "Siwaliks" of Nuttall (1926), the upper division of the "Sibi Group" and "Urak Group" of Hunting Survey Corporation (1961) and the "Urak formation" of Kazmi (1970).

The section along the road from Gali Jagir to Sihal near Mujahad Village north of the Soan River (Lat. 32° 22' N: Long. 72° 47' E), Attock District, has been designated as type locality. The section near Urak villages (Lat. 30° 15' N: Long. 67° 11' E), Quetta District, is here proposed as the principal reference section. The formation consists essentially of compact massive conglomerate with subordinate interbeds of varicoloured sandstone siltstone and or clay. The proportion of different rock type varies within short distances. The conglomerate consists of a variety of pebbles and boulders of different sizes. The conglomerate of the Kohat-Potwar Province is massive and consists mainly of pebbles and boulders of "Margala Hill" type grey limestone, quartzite, porphyritic rocks, sandstone, gneiss, schist, diabasic, etc. The pebbles and boulders range in size from 5 to 30 cm commonly claystone and sandstone are intercalated. The claystone is orange, brown, pale pinkish or red and soft, the sandstone is grey, greenish grey, coarse grained and soft (Cheema et al., 1977).

In the Lower Indus Basin and Quetta region, the conglomerate is composed of ill sorted well-rounded to sub-angular boulders and pebbles of limestone (being most abundant and are mainly derived from the Kirthar Formation), sandstone, chert, quartzite and igneous rocks embedded in a clayey or sandy matrix. The intercalations are usually of dull yellowish clay and light brown, occasionally grey sandstone. The formation has widespread distribution in the Indus Basin and the Quetta region of the Calcareous Zone of the Axial Belt. Its thickness varies from 120 to 450 m in the Kohat-Potwar Province, from 300 m to more than 1500 m in the Sulaiman Province, from 1500 to 3000 m in the Quetta region and is usually less than 300 m in the Kirthar Province.

The formation is underlain by the Dhok Pathan Formation with an apparent disconformity, which is marked by sharp coarsening of clastics and by the appearance of massive, densely packed conglomerate. In the Lower Indus Basin and Quetta region, the lower contact is gradational. The upper contact with the Lei Conglomerate is marked by an angular unconformity. However in parts of the Lower Indus Basin and Quetta region, the contact has been reported to be transitional by Hunting Survey Corporation (1961).

The Soan Formation is poorly fossiliferous, Pascoe (1963) has reported vertebrates from the Potwar area, which includes *Mastodon sivalensis, Stegodon clifti, Elephas (Archidiscodon)* cf. *planifrons, Sivatherium giganteum, Proamphibos lachrymans, Dicoryphochoerus durandi* and *Sivafelis potens.* The fauna indicates Late Pliocene to Early Pleistocene (Astian to Villafranchian) age for the formation. Kravchenko (1964) assigned an Early Pleistocene (Villafranchian) age, extending in places into very late Astian. In conclusion, the age of the Soan Formation is late Astian to Villafranchian). East of Potwar Plateau, across the Jehlum River Mirpur area, numerous localities of vertebrate fossils are present. Stratigraphically, these localities lie in similar beds as those of Soan and Lei Conglomerate. They are rather considered as the extension of the above two formations. Arif (1985) described three formations namely, Samwal, Kakra and Mirpur formations and correlated them with Lei and Soan Formations (Table 9). Description of these three formations is given below:

**Samwal formation:** The "Samwal Section" (Lat. 33° 6' 11" N: Long. 73° 45' 40" E), has been provisionally designated as the type locality of Samwal formation where it is measured to be 750 m thick by Johnson et al. (1979). The formation in this area forms core of the Mangla-Samwal anticline.

Arif (1985) described it as interbedded sequence of mudstone and sandstone. The mudstone is dominantly yellowish coloured with some brownish shade and is valley and slope forming. The proportion of mudstone increases up-section. The sandstone is fine to medium grained, sub-rounded to sub-angular thin to medium bedded and often show cross-bedding. The colour of sandstone is generally light grey to grey. It is slightly micaceous and forms ridges. The vertebrate fossils occur mainly in the sandstone. The lower contact of the formation is not exposed in the type area. The upper contact with the Kakra formation is placed at the base of the first conglomerate unit.

**Kakra formation:** The type locality of the Kakra formation has been proposed near Tarappa village (Lat. 33° 07' 15" N: Long. 67° 47' 30" E), about 8 km southwest of the new Kakra Town. According to Arif (1985), the formation consists of conglomerate, sandstone and mudstone. The conglomerate is composed of heterogeneous material, like gravels and pebbles of limestone, quartz, sandstone, metamorphic and igneous fragments. The clast size of the conglomerate is compact as compared to the upper conglomerate. The cementing material in the lower conglomerate is arenaceous while it is argillaceous in the upper part. The sandstone is medium grained, but occasionally coarser, moderately sorted, grey to dark grey and often contains conglomeratic lenses. The mudstone is yellow to pale yellow and silty with occasional sandstone lenses. The lower contact is placed at the base of first conglomerate bed. The upper contact with the Mirpur formation is transitional and conformable.

**Mirpur formation:** Mirpur formation is mainly a conglomerate unit with some mudstone and sandstone. A section near the town of New Mirpur (Lat. 33° 8' 45" N: Long. 73° 45' 30" E) has been designated as the type section of the formation. Arif (1985) described the formation as dominantly composed of conglomerate and mudstone. The conglomerate consists of well rounded pebbles and boulders of limestone, sandstone, quartzite and volcanic material, which range in size from 5 to 200 mm in diameter.The conglomerate is loosely set in mudstone mostly of silt composition. The formation contains frequent sandstone lenses. Age and Correlation of the above three formations are shown in Table 9.

Table 9. Plio-Pleistocene Stratigraphic Section, Mirpur, Azad Kashmir.

| Paleomagnetic, Stratigraphic Age, Johnson et al. (1979) | Pilgrim (1913) | Shah (1977) | Arif (1985) |
|---|---|---|---|
| Brunhes | BoulderConglomerate | Lei Conglomerate | Mirpur formation |
| Late Matuyama | Pinjor zone | Soan Formation | Kakra formation |
| Late Gilbert to Early Matuyama | Tatrot zone | -- | Samwal formation |

## *LOWER INDUS BASIN AND AXIAL BELT*

**Gaj Formation:** Blanford (1876) introduced the term "Gaj series" for a sequence of shale and sandstone with subordinate limestone. The series is referred here to as Gaj Formation following Williams (1959), and represents the "Lower Gaj", "Upper Gaj" and the "Estuarine Passage beds" of earlier workers (described in Pascoe, 1963) and the upper horizons of the lower part of the "Sibi group" and "Urak group" of Hunting Survey Corporation (1961). The section along the lower part of the Gaj River (Lat. 26° 51' 40" N: Long. 67° 17' 18" E) has been chosen the type locality.

The formation consists of shale with subordinate sandstone and limestone. The shale is variegated greenish grey and gypsiferous. The sandstone is brown greenish grey calcareous ferruginous and cross-bedded. The limestone is brown or yellowish white argillaceous and fossiliferous. At some places minor conglomerate beds containing pebbles, separately derived from the Nari Formation are also present. In the Karachi region, the formation consists predominantly of white or yellowish brown soft, crumbly to hard sandstone and cream coloured or pinkish white argillaceous limestone.

The formation is confined principally to the Kirthar Province although it has also been reported from parts of the Sulaiman Province (Sibi and Marri-Bugti areas) and Quetta region (particularly in Urak and the Sor Range). The Calcareous Zone of northern Axial Belt is the area where it is not easily distinguishable from the Nari Formation. At the type locality the formation is 650 m thick and usually ranges between 600 and 750 m in other areas of the Kirthar Province. It is bevelled to only 65 m at Patina Creek and 50 m at Korangi Creek of Karachi region in the subsurface. In the Sor Range (of the Quetta region) the Gaj Formation has been reported by Williams (1959) to be 90 m thick.

The formation conformably and transitionally succeeds the Nari Formation and the contact is usually drawn below the thick sequence of multicoloured shale and dark, ferruginous, sandy limestone. The upper contact with the Siwalik Group is also transitional and is placed above the uppermost bed of the limestone. However, near Manchhar Lake, the contact is unconformable with a slight angular discordance. The formation has yielded abundant foraminifers, molluscs and echinoids with some bryozoans, corals and other groups (Duncan and Sladen, 1882; Nuttall, 1926; Vredenburg, 1928; Hunting Survey Corporation, 1961; Pascoe, 1963; Khan, 1968). Hunting Survey Corporation (1961) has concluded that most of the fauna is of Miocene age.

Khan (1968) described the larger foraminifera of the formation which includes. *Miogypsina* *globulina, M. intermedia, M. cushmani, M. tani, M. gunteri, Miogypsinoides deharti, Austrotrillina howchini, Tabertina malabarica and Eulepidina dilatata etc.* and suggested late Aquitanian to Burdigalian age (Early Miocene) for the formation. Pascoe (1963) has also assigned an Early Miocene (Aquitanian-Burdigalian) age to the formation basing his conclusions on the following:

| | |
|---|---|
| Foraminifers : | Lepidocyclina marginata, L. blanfordi etc. |
| Bivalves: | Arca submultiformis Glycimeris (Pectunculus) sindiensis, Ostrea vestita Venus (Clementon) papyracea etc. |
| Gastropods: | Melongena lainei, Turbinella affinis, Potamides (Pyrazus) protebeninus; etc. |
| Echinoids: | Caelopleurus forbesi, Temnechinus affinis, Clypeaster depressus, Breynia carinata, etc. |

To conclude, the age of the formation is mainly late Aquitanian to Burdigalian, but in some places, the upper part of the formation may extend into Middle Miocene (Cheema et al., 1977). The formation is correlated with the Murree Formation in the Kohat-Potwar Province and the lower part of the Hinglaj formation in the Balochistan Basin.

## BALOCHISTAN BASIN AND ARENACEOUS ZONE OF AXIAL BELT

The Eruptive Zone of the Balochistan Basin does not record any Mio-Pliocene rocks. These rocks are restricted to southern half of the Makran-North Zhob Region and its adjoining part of the Arenaceous Zone of the Axial Belt. Hinglaj formation of Makran group is the only rock unit recognized in this region.

**Hinglaj formation:** The "Hinglaj series" of Vredenburg (1906) is described here as Hinglaj formation, with the exclusion of its uppermost conglomeratic part, which is given a separate formation status (Haro conglomerate), following Hunting Survey corporation (1961). The Hinglaj formation of the present report also represents the "Sandstone stage" of Asrarullah (1954) and the "Hinglaj group", "Diz formation", "Talar sandstone" and "Greshak group" (except its lower limestone part) of Hunting Survey Corporation (1961). The "Parkini mudstone" of Hunting Survey Corporation (1961) which also represents the "Lower Mudstone stage" of Asrarullah (1954), and the "Chatti mudstone" of Hunting Survey Corporation (1961), which represents the "shales weathering to clays" of Vredenburg (1909) and the "Upper Mudstone stage" of Asrarullah (1954) are adopted here as lower and upper members of Hinglaj formation.

No type section of the strata, presently included in the Hinglaj formation, has been given, though the Hinglaj mountains, have been considered to be the type locality. The Talar Gorge and Jiwani are designated here as two principal reference sections of the formation. Parkini Kaur, a tributary of the Hinglaj River, is designated here as the type section of the Parkini mudstone member; Chatti, from where Hunting Survey Corporation (1961) reported the best exposures, is designated as the type locality of the Chatti mudstone member.

... Cheema et al. (1977) recorded the formation as consisting of dominant sandstone with shale, subordinate shelly limestone and minor conglomerate. The sandstone is grey, greenish grey, pale yellowish brown to brown, weathering in various shades of brown (from yellow brown to rusty brown), grey, maroon and at places black. It is fine to coarse grained, gritty to pebbly in places, mostly soft and crumbly, but at places hard in the upper part. The thickness of individual beds varies from a few centimetres to 6 m. The sandstone is cross-stratified ripple marked, usually calcareous and Protoquartzitic. Shale is commonly present in the lower and upper part and is pale greenish grey, brown, hard and soft, flaky and grades into mudstone and siltstone. The limestone is usually present in the lower part and is typically shelly to coquinoid, argillaceous, sandy and dark grey in colour. Mudstone of the (Parkini mudstone) member is nodular, dark grey in colour (light greyish green on weathered surface) with abundant small mud cracks. The mudstone of the (Chatti mudstone) member is similar to that of the Parkini mudstone member but in places it is harder due to greater lime content, which qualifies it to be called marl. Subordinate siltstone and fine gained sandstone are also interbedded.

The formation is restricted to other Arenaceous Zone of the Axial Belt and Makran-North Zhob regions of the Balochistan Basin. The Parkini mudstone member is developed along the westerly coastal region of southern Makran and in the Haro area of the Axial Belt while the Chatti mudstone member is exposed in the westernmost coastal areas of southern Makran. The formation is about 4545 m thick in the Talar area, 3030 m in Jiwani and about 4000 m in the Hinglaj Mountains. The thickness of the individual members varies from 450 to 1200 m.

The formation is conformably and transitionally underlain by the Khojak formation except in the area north of Bela, where the Nari Formation conformably underlies it. In the area to the south and southeast of Greshak, various older units (such as Nisai formation, "Parh group" and Porali intrusion) unconformably underlie the formation and the contact is marked by a thin pebbly conglomerate. In the areas where Chatti mudstone member is present, the formation is unconformably overlain by the Gwadar formation. Where the Chatti member is not developed, the Haro conglomerate unconformably overlies the formation, though locally the contact between the two is reported to be transitional (Hunting Survey Corporation, 1961). Upper contact of the Parkini mudstone member and lower contact of Chatti mudstone member is placed at the base of the first and top of the last significant sandstone bed, respectively.

Cheema et al. (1977) continued that, in the Arenaceous Zone of the Axial Belt, the formation has yielded Oligocene and Late Oligocene-Miocene foraminiferal assemblages. The fossils include among others, *Assilina mamilla, Fasciolites borealis, Discocyclina undulate, Lepidocyclina bionfordi, L. dilatata, Nephrolepidina sp., Nummulites atacicus, N. fichteli, N. intermedius, Spiroclypeus* sp. In areas other than the Axial Belt, the Parkini mudstone member has yielded abundant smaller foraminifers of Miocene age while the lower shelly limestone of the formation contains gastropods and bivalves of Miocene age. The upper part of the formation, including the Chatti mudstone member has yielded abundant foraminifers, gastropods and bivalves that indicate

Pliocene age. Some of these fossils as recorded by Hunting Survey Corporation (1961) and Haque (1966) are: Bivalves; Anadara *inflata, A. clathrata, Paphia deshayessi, placeneta inanica, Ostrea rholfsi, Mactrinula plicataria; and others., Gastropods; Cymia carinifera, Clavilithes verbekii, Ficus gracilis, Telescopium pakistanicum, Tonna arabica, Turritella angulata, T. harrisoni, Volema ponderosa, Volutospina mekranica. Foraminifers: Bolivina dilatata, B. mekranensis, Bulimina marginata, B. elongata lappa, Cassidulinoides mekranense, Globigerina bulloides, Globorotalia menardii, Globigerinoides triloba triloba, Haplophragmoides carinatum, Rotaliabeccari, Uvigerina graciliformis* and others. According to Hunting Survey Corporation, the age of the uppermost strata of the formation in some areas may extend up into Pleistocene. To sum up, the age of the formation ranges from middle Late Oligocene to Pleistocene in the Axial Belt and Miocene to Pliocene in the Balochistan Basin.

# QUATERNARY

## PLEISTOCENE

Quaternary sediments of Pakistan include the rocks of Pleistocene age, which occur in isolated areas of Pakistan and serves mostly as blanket for the earlier folded structures:

**INDUS BASIN AND AXIAL BELT** (QUETTA REGION)

Detrital rocks comprising mostly of conglomerate facies, for example, Lei Conglomerate is recognized throughout the region.

**Lei Conglomerate:** The name "Lei Conglomerate" was introduced by Gill (1952) for the post-Siwalik conglomerates of the Soan area, earlier named "Boulder Conglomerate" by Pilgrim (1910), constituting the uppermost subdivision of his "Upper Siwalik". The formation here defined also includes the "Kalabagh beds" of Waagen (1891), "Kalabagh Conglomerate" of Gee and "Kalabagh Hill Conglomerate" of Danilchik and Shah (1967) of the Upper Indus Basin and the "Dada conglomerate" of Hunting Survey Corporation (1961) of the Lower Indus Basin and the Quetta region.

Gill (1952) designated the Lei River Section, southeast of Rawalpindi as the type section. The Dada River section, south of Spintangi Railway Station, Balochistan is proposed as the principal reference section by Cheema et al. (1977). According to them the Lei Conglomerate is essentially regarded as a valley fill, laid down as fluviatile, lacustrine and piedmont outwash deposits in the lower parts of the structural depressions. The formation is composed of coarse boulder and pebble conglomerates, with minor coarse and cross-bedded sandstone. In the Soan Valley (Kohat-Potwar Province), the conglomerate consists of poorly sorted pebbles and boulders of mostly Eocene rocks, with a small proportion of older sedimentary rocks, quartzites and igneous rocks. The conglomerate is intercalated with beds of soft sandstone and siltstone of pale brown to ochre colour. The conglomerate in other parts of the Kohat-Potwar Province comprises pebbles of various igneous and metamorphic rocks with a small percentage of Eocene limestone pebbles ranging up to half a metre in diameter has intercalations of soft, grey sandstone and orange claystone. In the Lower Indus Basin, the conglomerate is composed of poorly sorted pebbles, cobbles and boulders with a calcareous sandy matrix. It is thick bedded and usually stained ochre red or yellow. Most of the boulders are of limestone, marl and sandstone derived from Tertiary and older rocks of the neighbouring areas. Subordinate sandstone beds are intercalated with the conglomerate. This sandstone is green grey and brown, cross-bedded, crumbly and pebbly. The conglomerate usually forms steep or vertical walls and cliffs.

The Lei Conglomerate has widespread distribution in the Indus Basin and Quetta region. The formation varies from 150 to more than 900 m in the Kohat-Potwar Province. It is 300 to 600 m thick in Jalalapur-Chambal Ridge section, about 600 m in Makhad, 600 to 900 m in the eastern otwar and is only 150 m in the Kalabagh area. The maximum thickness of about 900 m is reported from the Urak synclinorium (Quetta region). It ranges from 150 to 455 m in the Lower Indus Basin. The Lei Conglomerate is unconformably underlain by the Soan Formation in most localities. However, in some places the contact is transitional. The unconformable relationship is well discernable along the western edges of the Kachhi Plain in the Sulaiman Province and south of Rawalpindi near Golra where the formation overlies the Soan Formation and older units with a sharp angular unconformity. The upper contact is commonly gradational with Subrecent deposits and is difficult to define. It is an unconformity in places where the Lei Conglomerate is steeply inclined, as seen in a railway cutting just west of Mach (in the Sulaiman Province).

The conglomerate has not yielded any fossils except few fragments of Elephas, Equus, and Bos etc. from the eastern Salt Range and some pre-Soan artefacts from the Soan Valley as reported by Pilgrim (1913), Wadia (1928), Cotter (1933), Gill (1952), Pascoe (1963) and others. The fauna reported from the formation including *Elephas hysudricus. Sivatherium giganteum, Dicerorhinus platyrhinus, Equus sp., E. namadiscus Bos sp.*, and *Camelus* sp. Pascoe (1963) considers the formation to be of Middle Pleistocene age. Hunting Survey Corporation (1961) inferred the age to be Pleistocene on the basis of the origin of the Lei Conglomerate of the Lower Indus Basin ("Dada conglomerate" of Hunting Survey Corporation, 1961), which is considered to be related to the main Himalayan orogeny that began to phase out in the Early Pleistocene.

**BALOCHISTAN BASIN AND AXEL BELT**

The Pleistocene formations of Balochistan Basin are few. Some of these formations extend into the Arenaceous Zone of Axial Belt. The formations differentiated in these areas are as follows:

| | |
|---|---|
| Gwadar formation | (Makran coast and Astola Island) |
| Jiwani formation | (Makran coast and Astola Island) |
| Haro conglomerate | (Arenaceous Zone of the southern Axial Belt and parts of North Makran) |
| Bostan formation | (Northern Axial Belt, Eruptive Zone and northern margin of Makran, North Zhob region) |

**Gwadar formation:** The "Gwadar stage" of Vredenburg (1921) is here redefined as Gwadar formation, the name being derived from Gwadar Peninsula. The formation also includes the "Ormara formation" of Hunting Survey Corporation (1961). The name "Gwadar" is preferred over "Ormara" in observance of the rule of priority in nomenclature and because of the fact that the Gwadar Peninsula is now under Pakistan jurisdiction and is no longer under the jurisdiction of Oman authorities as was the case when Hunting Survey Corporation (1961) coined the term "Ormara formation".

The type section lies in Gwadar Peninsula, while the Ormara is designated as the principal reference section of the formation. Cheema et al. (1977) described the formation as composed of sandy clay of dark buff colour that weathers to light buff. It is soft, poorly consolidated and poorly bedded or massive. In the type locality and, elsewhere, subordinate sandstone is interbedded. The sandstone is light brown, weathering buff or dark brown and is medium to coarse grained, poorly consolidated and thick bedded (up to 3 m). Thin beds of conglomerate consisting of well-rounded pebbles and cobbles mainly of sandstone embedded in a sandy calcareous matrix are also present. The sandstone interbeds contain fossil shells near the top of the formation. At Astola Island, thinner beds of calcareous sandstone containing rounded and elongated hard concretions or doggers are present in the lower part and are similar to those found in the upper part of the underlying Hinglaj formation. The formation is developed in the area between Jiwani and the Hinglaj River along the Makran coast. Most rocks on Astola Island belong to the Gwadar formation. The formation is about 450 m thick in Ormara and Ras Malan, 60 m at Ras Jiwani and about 900 m on Astola Island. Everywhere the formation unconformably overlies the Hinglaj formation. The upper contact of the formation with the Jiwani formation is unconformable on Astola Island and transitionally conformable at the Ormara and Jiwani headlands, where it lies below the lowest thick bed of shelly limestone or shelly conglomerate of the Jiwani formation.

Haque (in Hunting Survey Corporation, 1961) has identified a number of smaller foraminifers which indicate Pliocene to Pleistocene age. Some of the foraminifers are *Bolivina* cf. *B. acerosa, Bulimina* aff. *B. elongata, B.* cf. *B. marginata, Cibicides lobatulus, Clavulina* cf. *C. humilis, Globigerina inflata, G.* cf. *G. bulloides, Globigerinoides trilocularis, Lagena perlucida,* and *Rotalia* cf. *R. beccari.* Cox (in Hunting Survey Corporation, 1961) identified number of bivalves and gastropods, most of which range from Early Miocene to Recent. Nevertheless, two of them *Chlamys (Aequipecten) hashnizensis* and *C. kenti* have been reported to occur in the Pliocene of Iran. Hunting Survey Corporation (1961) have assigned Late Pliocene to Pleistocene age to the formation.

**Jiwani formation:** The term "Jiwani formation" was introduced by Hunting Survey Corporation (1961), derived from the coastal village of Jiwani, Makran for the Subrecent "Shelly limestone" unit of Crookshank and Heron (1955). The formation is restricted to the south Makran division of the Arenaceous Zone where a section east of Jiwani as far as Gaug is proposed as the type locality by Cheema et al. (1977). The formation consists of shelly limestone sandstone and conglomerate which characteristically weather greyish brown or dark ferruginous brown. The limestone is composed of shell fragments set in a sandy calcareous matrix and is usually porous, hard, and pebbly and medium to thick bedded. The conglomerate contains rounded cobbles and pebbles of sandstone, some blue grey Fasciolites bearing limestone and red jasper. The sandstone is well sorted, medium- to coarse-grained, mostly pebbly, cross bedded and forms beds up to 3 m thick. The formation exhibits great variations in terms of degree of cementation, relative proportion of clastic components and rock types.

As already stated, the formation has a restricted development along the Makran coast as far east of Ras Malan in the Makran-North Zhob Region of the Balochistan Basin. It also forms the surface formation on Astola Island. The formation has a maximum thickness of 30m at the type locality. The lower contact of the formation is angularly unconformable or disconformable or broadly transitional with the Gwadar formation. In some areas, the formation lies with an angular unconformity on the Hinglaj formation. The upper contact of the formation is not known, since it is the youngest formation along the coast except for recent deposits.

The fauna of the formation are more or less similar to the present sea life. As the formation is a littoral deposit, the fossils are considerably eroded, broken and partly destroyed by solution. Cox (in Hunting Survey Corporation, 1961) identified the following bivalves: *Fossularca (Noetia) pectunculiformis, Timoclea arakanensis, Martesia striata, Ostrea pseudocrassissima Anadara cf. A. cistula*, etc. On the basis of this fauna, Hunting Survey Corporation (1961) assigned Pleistocene age to the formation with some parts ranging to even subrecent times. The formation is correlated with the Haro conglomerate of the Balochistan Basin and parts of the Arenaceous Zone of the southern Axial Belt, the Bostan formation of the Eruptive Zone and northern Axial Belt and the Lei Conglomerate of the Indus Basin.

**Haro conglomerate:** Hunting Survey Corporation (1961) introduced the name "Haro conglomerate" after the Haro Range, for a conglomerate unit, which has not been previously described. Hunting Survey Corporation's "Kech conglomerate" is also included here in the formation (Hunting Survey Corporation's "Kech conglomerate" is also included in the Haro conglomerate). Kech Valley near Gish Kaur of the Kharan District has been designated the type locality.

The conglomerate consists of conglomerate with subordinate sandstone, claystone and siltstone. It is typically weathering dark ferruginous brown. The conglomerate consists of sub-rounded to angular pebbles and boulders (up to 30 cm in diameter) of sandstone, siltstone, and shelly limestone, derived from rocks of the Makran group, embedded in a calcareous, sandy matrix. Near Bela, the conglomerate contains pebbles and boulders of volcanic rocks in addition to those of limestone and sandstone. It mostly forms beds up to 15 m thick and is occasionally loosely consolidated. Towards the top, some places the conglomerate includes a considerable proportion of shelly material and resembles typical beach deposit. The sandstone is greenish brown, cross bedded, coarse grained and in many places, pebbly and poorly cemented. The claystone and siltstone are greyish brown, weather light buff to brown, well bedded and occasionally gypsiferous.

It is confined to the Arenaceous Zone of the southern Axial Belt and the central part of the North Zhob-Makran Region of the Balochistan Basin. The thickness ranges from an average of 600 m to as much as 1500 m in some areas. The lower contact of the Haro conglomerate with the Hinglaj formation is usually marked by an angular unconformity. However in some places, the Haro is probably transitional with the Hinglaj formation. The formation is overlain by subrecent deposits with a distinct unconformity (Cheema et al., 1977). In the southern part of Arenaceous Zone of Axial Belt, the conglomerate has yielded fragments of oysters and large gastropods, which are similar to those, recorded from the upper part of the Hinglaj formation and are mostly representatives of living forms. However, the stratigraphic position of the Haro conglomerate between the Hinglaj formation and the subrecent deposits led Hunting Survey Corporation (1961) to assign Pleistocene age to the formation.

**Bostan formation:** Hunting Survey Corporation (1961) introduced the name "Bostan formation", derived after Bostan Village near Quetta, for a unit of clay, conglomerate and sandstone, which had not been previously named. The concept of the formation is herein extended to include the "Cameron formation" and upper part of the Pishi group of Hunting Survey Corporation (1961).

The valley in Pishi Lora, Pishin District, is designated as type section. The village Kamerod on the north margin of the Siahan Range is proposed as the principal reference section, Cheema et al. (1977).The formation consists of lacustrine clay, silt, conglomerate and sandstone that were deposited in tectonic depressions between the newly arisen ranges. Conglomerate and sandstone, predominate and are coarser near hills of older rocks whereas clay and silt are dominant in areas far from the hills near the centre of the present tectonic depressions. The clay is white light grey brick red maroon or apple green, soft poorly consolidated and gypsiferous. The silt and sandstone are brown, reddish brown, grey with salt and pepper texture, soft and thin bedded. The conglomerate consists of subrounded pebbles and boulders of limestone sandstone and volcanic rocks, depending upon the composition of surrounding older rocks.

The formation occurs all over the northern part of the southern sector of Axial Belt, Eruptive Zone, Chagai-Raskoh (magmatic) Province and along the northern margin of the Makran-North Zhob Region of the Balochistan Basin. The formation is more than 750 m thick in the Pishin Valley of the northern part of southern sector of Axial Belt and about 600 m thick north of the Siahan Range in the Makran-North Zhob Region. The formation rests with an angular unconformity on older folded strata such as the Shirinab, Loralai, Nisai and Khojak formations. However, in the Dalbandin Valley of the Eruptive Zone, the lower contact with the Khojak formation has been reported to be broadly transitional Hunting Survey Corporation (1961). The upper contact with the subrecent deposits represents an angular unconformity and at places it is transitional depending on the intensity of folding of the Bostan formation. The formation seems to be barren of fossils. Its relationship with the Himalayan orogeny and homotaxis with the Lei and Haro conglomerates suggests Pleistocene age.

# MINERAL DEPOSITS

To every student of stratigraphy, the subject has two main values, the immense practical value and a broad philosophical interest. From the broader philosophical point of view, the stratigraphy provides basis for understanding the past history of a given region and the earth as a whole. In other words, beginning with the classification of rocks, in terms of physical, biological, chronological or ecological parameters, which is exploited to its far reaching affect and ultimately appear in the development of economy and the society by discoveries and aid in the development of natural resources. The stratified rocks contain vast fuel deposits in the earth crust, all the coal, petroleum and water, stratified iron ores and numerous metalliferous deposits, phosphate deposits, all the industrial minerals, potash, sodium and other salts of gypsum, limestone and various clays and above all much of the fissionable atomic fuel. Even where metalliferous deposits occur in the intrusive igneous rocks, the study of surrounding set up of sedimentary rock sequence is extremely useful which ultimately will workout the regional history and will permit an understanding of ore genesis and localization. In other words, if mineral deposits are viewed in correct stratigraphic perspective, their exploration becomes canalized in the scientific direction and proves more fruitful. Thus the wonders of the studies of stratigraphic genesis cannot be denied. Following points are cited as few examples from Pakistan:

(a) The formation and accumulation of petroleum in sediments formed prior to Himalayan orogeny (Eocene and older).

(b) Association of coal with the Paleocene and Eocene deltaic complex of Ghazij, Ranikot and Makarwal groups including the Thar coal field, which is one of the largest coal deposit in the world.

(c) Presence of iron silicate ore in near shore, marine, late Oxfordian to Neocomian onlap of Chichali Formation in Kohat-Potwar Province.

(d) Development of rock salt and gypsum in the transgressive Precambrian sequence (Salt Range Formation) of Salt Range and the regressive Lower Eocene complex (Bahadur Khel Salt and Jatta Gypsum) of Kohat area in the Kohat-Potwar Province.

Mineral potential of Pakistan is generally recognized to be very good, however, its exploitation and further exploration are very slow as compared to other countries of the world. Several factors combined with lack of finances are responsible for this state of affairs. The net result is that its contribution to the Gross National Produce (GNP) remained between 0.3 to 0.5%, which is insignificant. In fact low contributory figures are nothing but a retributive affect of what is spent on mineral sector. It is evident from the reality that mineral sector has been allocated very scarcely from the public sector expenditure, which ranged from 0.45 to 2.46% throughout the past many decades.

However, this does not warránt pessimism since more and more recent exploration techniques are today contributing to the discovery of hitherto unexpected mineral occurrences throughout the world.

For practical purposes in this chapter the term ' mineral deposits is used to include all naturally occurring materials in the earth's crust, which can be exploited economically. They have been categorised under three groups, viz., Energy, Mineral Resources, Metallic Ores and Industrial Minerals and Rocks. Only the more economically important deposits-known up to November, 2004 are being described here. A comprehensive discourse of mineral deposits of Pakistan may be found in the book on Mineral and Rocks for industry compiled by Ahmad and Siddiqi (1993) and published in three volumes by the Geological Survey of Pakistan, which lists more than 40 commodities. Various symposia held by CENTO at different times also contain useful information on mineral deposits of Pakistan. Most of the original information is, however, contained in and is derived from the serials of the Geological Survey of Pakistan, viz., Memoirs, Records, Pre-Publication Issues and Information Releases etc:

**Energy situation**

Energy in a large part is obtained from the energy mineral resources. Energy minerals that are directly utilized for the generation of energy, include, petroleum (oil and gas), coal and radioactive minerals. The importance of energy minerals is directly proportional to the number of industries and increase in the production, which has raised the recent energy crisis in Pakistan.

According to Energy Year Book 2003, primary commercial energy supplies have now reached at 47.1 million tones of oil equivalent (MTOE). During the year 2003, the oil supplies dropped due to lesser import of furnace oil and high speed diesel oil. It has also been noted that the import of coal for energy usage has been increased in the country. The cement industry has started using coal, both local as well as imported to replace natural gas and furnace oil. This trend has been seen for the last few years. As a result, a sharp decrease in consumption of gas by cement industry is seen during the last 5 years, which has dropped from 33 to about 9 million cubic feet per day. Similarly, oil consumption in cement industry has also dropped from 739,488 in 1998-99 to 367,898 tonnes in 2002-03. Consequently, both of these fuels are being replaced by coal in the cement industries.

In other words, the share of various primary energy sources in energy supply mix during 2002-03 was: gas: 43.8%, oil: 38.3%, LPG: 0.4%, coal 5.4%, hydroelectricity: 11.3%, and nuclear electricity: 0.9%.

Brisk activities in oil and gas exploration are distinctly obvious so as to achieve the target of self-sufficiency. As for example 32 exploratory wells for oil and gas were drilled and ten discoveries were made. In addition, 45 development wells were drilled during the year 2002-03. Average oil production was 64,268 barrels per day, while natural gas production reached an average of 2,719 million cubic feet per day. To sum up the oil and gas exploration activities, it may be recorded that the position up to June 30, 2003 was as follows:

**Oil and Gas Exploration as on July 1, 2003**

| | |
|---|---|
| Exploratory Wells | 572 |
| Development Wells | 754 |
| Sedimentary Area | 827,268 km2 (approximately) |
| Expl. Drilling Density | One well per 1446 km2 |
| Discoveries | 154 |
| - Oil | 59 |
| - Gas | 95 |
| Overall Success Rate: | 1:3.7 |

In the power sector, information on 30.4 MW Jagran hydropower projects of Azad Jammu and Kashmir Hydro Electric Board (AJKHEB) has been included in the Yearbook as the electricity generated from this power project is purchased and supplied by WAPDA. AJKHEB is operating three more hydro projects: Kathai 1.6 MW, Leepa 1.6 MW and Kundal 2.0 MW but their production so far is being distributed by the Board itself and does not involve WAPDA's network, hence not included here.

During 2002 - 03, 75,682 GWh electricity was produced as compared to 72,405 GWh in 2001-02, showing an increase of 4.0%. This increase is attributed to hydel generation which was up by 18% as compared to last year. The power generation included 68.2% thermal, 29.5% hydel and 2.3% nuclear. Electricity consumption also increased by 4.0% from 50,622 to 52,655 GWh during 2002-03. Major increases in consumption were in the commercial sector (9.1%) followed by agriculture sector (7.3%), industrial (6.9), and domestic (1.8%).

Energy situation is described in brief in the foregoing paragraphs: by way of conclusion it is clear that ease in energy situation depends on the availability of energy mineral resources. The most important among them are water, petroleum (oil and gas), coal and radioactive minerals. Pakistan, fortunately, has enough scope of these minerals and there is no room of pessimism since more and more recent exploration techniques are today contributing to hither to unexpected mineral occurrences throughout the world. Water is a miraculous mineral and its wonderful power needs no explanation. Other minerals are described as under:

**Petroleum:** Oil and gas is usually derived from marine sedimentary rocks. There is no dearth of marine sedimentary rocks of Palaeozoic, Mesozoic and Tertiary age in Pakistan. Basin set up is ideal for petroleum to have been formed. Shelf facies are dominant. The shelf gives way to deeper troughs and has been divided into subsidiary basins by fundamental highs. Tectonism in the shelf areas has been modest. Indeed up to Tertiary times, all the earth movements were of non-orogenic type. Main orogenic movements had been post marine sedimentation leading to formation of favourable structural traps. The source-reservoir-cap rock combinations are present. The region is nearby to the oil producing areas of Persian Gulf. In spite of all these favourable factors, the scale of petroleum discoveries to-date has not been a substantial one. The reason, above all, may be that more drilling has to be done. The salient features of petroleum occurrence in the region are described hereunder (Raza et al., 1977):

The Indus Basin, where most of the exploration activity has taken place is more prospective than other areas. To date many small oil fields have been discovered in the Upper Indus Basin (Kohat-Potwar Province) and numerous gas fields in the Lower Indus Basin (Sulaiman and Kirthar Provinces). In Balochistan Basin, lesser efforts on oil exploration have been made so far and no note worthy discovery has been reported. Most petroleum prospects of the Indus Basin are in the Tertiary and Mesozoic rocks. They form traps in drillable depth and possess the combinations of source-reservoir-cap rock. All petroleum fields have been discovered in structural traps. Exploration has not yet reached a stage, where search for stratigraphic traps can effectively be made.

The oil occurrences which are confined to small fields in Pakistan are estimated to have a reserve of 777.518 million barrels and cumulative production up to 2003 is 488.845, leaving behind 288.673 million barrels as recoverable balance. Total production from Punjab oil fields, mostly Potwar Plateau is 8112620 barrels and from Sindh 15,345,224, barrels by the year 2003 (Pakistan Energy Year Book-2003). Oil fields of Punjab are older than the Sindh field. The fields in the Potwar Plateau are very well studied as compared to other oil fields. The largest field- are Pindori and Adhi, where 2,071,398, and 116,311 barrels in 2002-03 were produced respectively. Total oil production from all the 24 fields of Punjab has been more than 8 million tones. Potwar oil fields are all anticlinal or domel structures situated on two parallel E-W lines of folding on the northern and southern limbs of Soan syncline, which is bounded in the south by the Salt Range and in the north by Kala Chitta Range. The northern group of oil fields includes Khaur Dhulian, Tut and Meyal, and the southern group comprises Joyamair, Balkassar and Karsal. The quality of the oil is highly variable with densities ranging between 16° API to 50° API. Along with the oil, a substantial amount of gas is also produced. The production is obtained from those reservoirs which are emplaced in Datta Formation (Early Jurassic), Lockhart Limestone (Middle Paleocene), Sakesar Limestone (middle Early Eocene) Chorgali Formation (late Early Eocene) and Murree Formation (Early Miocene). The Jurassic and Eocene reservoirs are the most important producers. Jurassic and Miocene production is mainly due to granular porosity whereas the Paleocene and Eocene production from the limestone is due to fracture porosity. Sealing cap has invariably been provided by the shales. The source of oil in Datta Formation is considered as Jurassic shales; the Lockhart, Sakesar and Chorgali formation's oil is thought to be indigenous whereas that in the Murree Formation is assumed to have migrated vertically from underlying Eocene rocks (Rahman, 1963). The possibility, however, exists of other sources too, viz., Mianwali Formation (Early Triassic), Patala Formation (Late Paleocene) and Nammal Formation of Early Eocene (Raza et al., 1977).

In Sind, there are more oil fields than the Punjab and all of them are small, except Kunnar, Pasakhi, Thora, Buzdar, Dabi, Ghungro, Mazari, Sonro, Tangri and Zaur. Total oil fields are as many as 72 and their total production of oil during 2002-2003 are stated to be more than 15 million barrels. Most of the oil comes from Cretaceous rocks (Pakistan Energy Year Book-2003).

Most of the gas fields of Pakistan are situated in the Lower Indus Basin especially Sindh.

The majority occur in the central part, in an area surrounding the Jacobabad High, hereafter, informally referred to as the Sui Gas Province. There are eight gas fields in the province, namely Zin, Sui, Uch, Jacobabad Khandkot, Mari, Mazarani and Khairpur. Besides that, there are three small fields in the southern part near Karachi at Sari Sang, Hundi and Kothar. The recoverable reserves of all the fields 'are estimated to be more than 42.7 TCF. Sui and Mari fields are on production since long. Sui gas is used as a fuel throughout the country whereas Mari gas is utilized in fertilizer manufacturing, Sari Sang and Hundi fields have also been commissioned for production. Sui is the largest field having original reserve over 10.78 TCF, followed by Mari (6.8 TCF), Qadirpur (5.1 TCF), Uch (3.1 TCF), Zamzama (2 TCF) and Khandkot (1.3 TCF) Pirkoh (2.1 TCF). Total reserve including all the small fields of Pakistan are more than 42.7 TCF, with large cumulative production, the balance recoverable reserve as on 30th June, 2003 is stated to be more than 15.9 TCF.

The gas in the Sui Gas Province is a mixture of hydrocarbon gases, with carbon dioxide, nitrogen, traces of helium and sulphur. The proportion of different components in the gas is highly variable. Noteworthy are the high proportions of carbon dioxide at Khairpur (70%), of nitrogen at Jacobabad (38%), Uch (25%) and at Mari (20%), and of helium at Uch (0.5%). Percentage of methane varies from 90% at Sui, 79% at Khandkot, and 73% at Mari, to 47% at Zin, 27% at Uch, and 25% at Jacobabad. The variation in composition demands special attention as to ascertain the reasons of difference and to find out if at all any oil could have been formed with these gases. Presence of oil seepages in nearby areas, traces of oil and bitumen in the limestone cores and small scale production of condensate along with the gases (about 2.3 litres per thousand cubic metres) are factors, which merit consideration (Raza et al., 1977).

Reservoir in the Sui Gas Province in all cases (except Mari) is the Sui Main Limestone of Early Eocene age; at Mari field the reservoir is Habib Rahi Limestone member of Middle Eocene age. All traps have been provided by anticlines or domes. The gas column rests directly on water. The Sui Main Limestone is composed largely of foraminifers and is considered to have originated in a reef shoal. Sealing cap in all the reservoirs has been provided by shales. The variation in the composition of gases contained in otherwise closely situated traps have led to confusion about the possible sources. Tainsh et al. (1959) have suggested the Lower Eocene and Cretaceous shales as the possible sources of much of the methane and some carbon dioxide, whereas Paleocene sandstone and Upper Cretaceous and Jurassic limestones are considered to have produced carbon dioxide and some methane. They also consider that much nitrogen and carbon dioxide may have migrated from contact with igneous rocks in or below Jurassic.

**Exploration strategy**

In Pakistan, the early exploration approach of merely searching for favourable locations within sedimentary basins has been replaced in recent years by a comprehensive and scientific basin analysis aimed at understanding why, when and how petroleum occurs in a basin. Raza et al (1989) introduced sedimentary basins and delineate 24 possible petroleum zones within seven main tectonic features of these basins (Fig. 22).

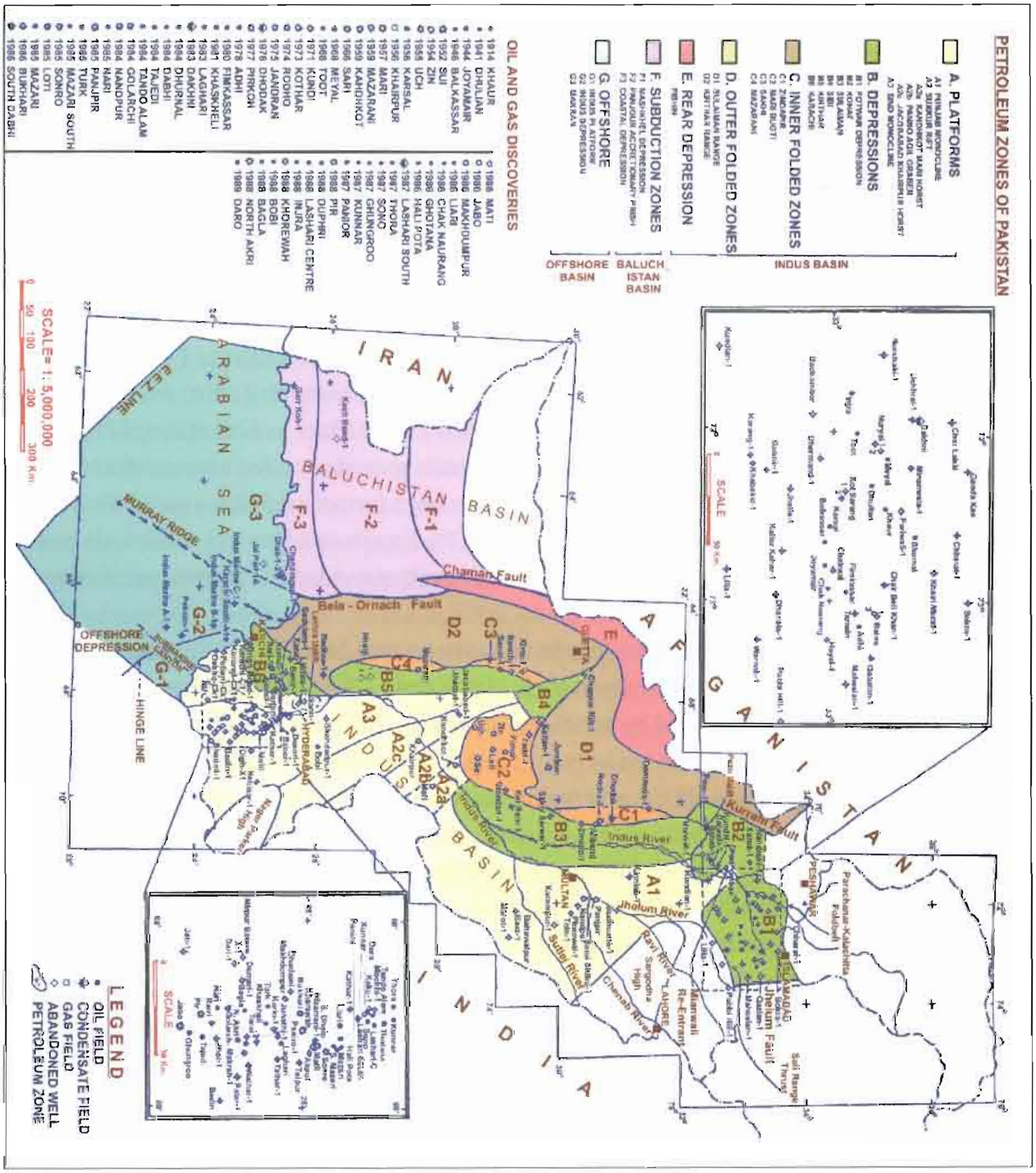



Fig. 22. Map showing Petroleum Zones of Pakistan.

After Raza et al., 1989

**Indus Basin:** According to Raza et al. (1989), the Indus Basin has an area of 533, 540 $km^2$ with an average of 4.8 km thick sedimentary section. The sedimentary rocks in the basin range in age from Late Precambrian to Recent and are predominantly of marine origin. A large number of oil and gas seepages/shows occur in exposed sections and wells. Sixty three oil and gas fields have been discovered as of January 1989, which include two giant gas fields. The producing horizons are sandstones of Cambrian, Permian, Jurassic, Cretaceous and Miocene ages and limestones of the Paleocene and Eocene. As already stated, the proven recoverable reserves are nearly 777 million barrels of oil and 43 TCF of gas of which about 488 million barrels of oil and 15 TCF of gas have been consumed as of 2003. They divided the basin into large longitudinally oriented parallel tectonic features which are as follows:

**Platforms:** (Tectonic Feature A). It is stable area founded on the Indian shield. Sedimentary rocks of Palaeozoic, Mesozoic and Cainozoic ages as well as recent alluvium are present here. Marine transgressions, regressions, overlaps and unconformities in the stratigraphic section provide evidence of sea-level fluctuation in response to local as well as world wide tectonic events.

Platform is subdivided into several sub zones such as follows:

| | |
|---|---|
| $A_1$ | Punjab Monocline |
| $A_2$ | Sukkhar Rift |
| $A_{2a.}$ | Kandhkot Mari Horst |
| $A_{2b.}$ | Panno Aqil Graben |
| $A_{2c.}$ | Jacobabad Khairpur Horst |
| $A_3$ | Sindh Monocline |

**Punjab Monocline** ($A_1$): It is a generally westward sloping monocline with its northern edge down warped to the north. The subsurface prolongation of the Sargodha High has shaped the Mianwali re-entrant. The part of the monocline north of Sargodha High contains a thin section of marine Palaeozoic and Tertiary strata, covered by Neogene fluviatile sediments. This part of the zone seems to have poor petroleum prospects. On the other hand southwest of Sargodha High, a vast gently dipping monocline contains considerably thick sediments of Palaeozoic, Mesozoic capped by Neogene flysch. This area contains salt pushed gentle anticlines. It has good prospects of oil, gas and evidently, Nandipur and Panjpir gas fields have so far been discovered. Thus, Mesozoic sandstone plays appears to offer exploration potential.

**Sukkhar Rift** ($A_2$): On the basis of satellite imagery interpretation (Chaudhry, 1979), the central Sukkhar area of the platform is considered a faulted rift structure comprising a graben ($A_{2b}$: Panno Aqil graben) and two horsts ($A_{2a}$ Kandhkot-Mari and $A_{2c}$: Jacobabad-Khairpur horsts). The Panno Aqil graben ($A_{2b}$) is a continuation of the Cambay graben of India, which contains several oil and gas fields (Cambay, Anklesvar, Kalol, Navagan etc).The producing horizons are of Eocene, Oligocene and Miocene ages.

**The Kandhkot-Mari horst** ($A_{2a}$): consists of Mesozoic, Tertiary and Quaternary sediments. This horst structure has produced gas in the Eocene carbonate with 4 TCF reservoirs. Mari gas field is considered a giant gas field. It is equated with Jasalmer Basin of India where same horizon of gas has been hit at few places in India. Another structure called Sindh structure east of Mari also extends into India but its main crest is in Pakistan.

**The Jacobabad-Khairpur Horst** ($A_{2c}$): started becoming a positive area in Late Jurassic. It consists of Mesozoic, Tertiary and Quaternary sediments with the Cretaceous and Jurassic truncated and reduced in thickness over the horst. Mesozoic and Tertiary plays are significant targets for exploration in the Jacobabad - Khairpur horst, because Eocene carbonate produced low methane natural gas at Khairpur and in Jacobabad structure.

In between the Kandhkot-Mari and Jacobabad Khairpur horsts lies graben area called *Panno Aqil graben* ($A_{2b}$). This graben area also offers better chances for generation and accumulation of hydrocarbons. Oligocene/Miocene and Eocene reservoirs are within reasonable drilling depths if suitable traps (probably fault traps) are seismically delineated.

**Sindh Monocline** ($A_{2b}$): The Sindh monocline is a gently sloping monocline of Mesozoic and Cainozoic sediments deposited on a shelf. The zone is delineated by the Lakhra uplift in the west and Nagar Parkar high in the east. Within this zone west of the Nagar Parkar high, a number of fields in the Badin area are producing oil and gas from the Cretaceous sands. The structures producing oil and gas in Badin area are mainly fault traps related to Late Mesozoic rift phase.

Depressions (Tectonic Feature-B): Platform described above is followed to the west by a belt of depressions. As a consequence of coalescence of Indian and Eurasian plates, along with rotational movement of Indian Plate, a sever deformation of sediments has resulted near the plate boundaries and a fold belt was raised with simultaneous creation of a belt of depressions on the flank. The deformation front is progressing from west to east and north to south. The western flanks of the depressions are deformed and from east to west and south to north the structures become more complicated. The depressions are covered with thick Quaternary deposits characterized by the occurrence of multiple unconformities.

The belt of depressions comprises six petroleum zones, they are: Potwar ($B_1$), Kohat ($B_2$), Sulaiman($B_3$), Sibi($B_4$), Kirthar($B_5$) and Karachi($B_6$) depressions.

**Kohat-Potwar Province** termed here Petroleum Zone $B_1$ and $B_2$ comprises the two depressions. Potwar and Kohat respectively. The province is bounded in the north by Parachinar-Kala Chitta fold belt through a system of faults. The Salt Range thrust marks its southern limit. South-westward, it is separated from the Sulaiman depression by the Pezu uplift. Its western and eastern limits are marked by the Kurram and Jehlum faults respectively. The main sediments supply during Tertiary appears to be derived from the rising Himalayas with uplift ending during the Late Pleistocene. However, in past, especially in Eocene the source of sediments was also from the west (see paleogeography section).

**Potwar Depression:** The zone $B_1$ is a major oil producing province of the country with production from Jurassic, Paleocene and Eocene rocks. Some discoveries have also been made in Cambrian and Permian. Whereas Kohat depression, the zone $B_2$, still remains an under explored area and holds good prospects for oil and gas. Recent discoveries in this area confirm the occurrence of hydrocarbons. Palaeozoic, Mesozoic and Tertiary hydrocarbon plays merit investigation and estimation in both the depressions.

**Sulaiman Depression:** This depression corresponds to Petroleum Zone $B_3$ of Raza et al. (1989). This is a large down warp and is contemporary with the Potwar-Kohat depression. The sediment fill is of Palaeozoic, Mesozoic and Cainozoic age and covered by Quaternary alluvium and Neogene molasses. Decrease in the thickness of various rock units towards east is noted from subsurface data. Simple structure like antiform with pinch-outs and unconformities in the eastern side, offer good prospects for petroleum.

**Sibi Depression:** Forms Petroleum Zone $B_4$: The Sibi Depression is a narrow, triangular depression sandwiched between the Sulaiman and Kirthar ranges. Continental molasses with huge thickness serves as cover on the Paleogene rocks. According to Raza et al. (1989), the fold on the flanks have some prospects in Eocene carbonates and Cretaceous sands. Ahmed et al. (1992) made detailed study of Sibi Forland basin, then presented few concepts and hypothesises based on structural interpretation, surface geological expression and world analog. According to them two regimes are present. They are: (1) Wrench associated and (2) up thrust fault bounded regimes. The structural traps within these together with source and reservoir rocks indicate good prospects for oil and gas. They added that these types of structural traps have often produced oil and gas in several sedimentary basins of the world.

**Kirthar Depression** conforms to Petroleum Zone $B_5$: This zone is a north-south trending down warp south of Sibi Depression. Its western limit is marked by Sanni and Mazarani folded zones. It has faulted eastern boundary with the Sindh Monocline. The molasse here is quite thick as in other depressions. Apparently, the area seems nearly flat, but the possibility of some structural traps developed due to basement flexures can not be ruled out. There are various possibilities of development of stratigraphic traps in Paleogene sediments.

**Karachi Depression** named as Petroleum Zone $B_6$: The Karachi depression is an embayment opening up into Arabian Sea. The northern part of the depression is raised while the southern part is submerged under the sea. Mesozoic rocks overlain by thick marine sediments of Paleogene and Neogene are present. Few gas fields have been encountered in Paleogene carbonate reservoirs and prospects of oil and gas in other rocks are there, in other words Cretaceous and Tertiary plays need to be investigated.

**Inner Folded Zones** (Tectonic Feature $C_1$): According to Raza et al. (1989), the western flanks of the Sulaiman and Kirthar depressions are bounded by uplifted and folded zones comprising Zindapir, Mari-Bugti, Sanni and Mazarani zones. Parachinar-Kala Chitta fault-fold zone bounding Kohat-Potwar depression in the north is for the time being excluded because of our poor knowledge of the subsurface picture beneath this complex zone. These zones also represent deformation. Here the uplift has brought prospective reservoirs higher in trap conditions, thus enhancing oil and gas prospects. The anticlines are in the form of box-like folded zones forming pronounced ridges passing into wide synclines. There is large number of gas fields in these zones. At least four petroleum zones can be delineated, and are as follows:

**Zindapir Folded Zone** (Petroleum Zone $C_1$): This zone is a north-south elongated narrow region flanking the Sulaiman depression in the east and is comprised of the Zindapir, Afiband, Rodho, Dhodak and Domanda anticlines all of which have steep eastern limbs and gentle western flanks. This chain of ridge-forming anticlines turns westwards in the south and seems to merge with the Mari-Bugti folded zone. Condensate from Dhodak and gas from Rodho structures have been discovered in Cretaceous sandstone reservoir.

**Mari-Bugti Folded Zone** (Petroleum Zone $C_2$): The Mari-Bugti area comprises three chains of anticlines with intervening synclines. The folds are sub-latitude arranged and increase in amplitude and deformation northwards. The chains are: (1) Sui-Uch, (2) Giandari-Loti-Zin and (3) Shamkalik-Pirkoh-Bambor. Neogene molasses cover the Sui-Uch sub zone, whereas various horizons of Paleogene form the central parts of the Giandari-Loti-Zin and Shamkalik-Pirkoh-Bambor sub-zones. The area is mainly gas prone and contains many gas fields including the giant Sui field, but some oil shows are present in its northwestern edge. The Cretaceous and Eocene plays need to be further evaluated.

**Sanni Folded Zone** (Petroleum Zones $C_3$): The Sanni is a narrow folded zone flanking the Kirthar depression in the east. The zone is longitudinally oriented and comprises Sanni and Bannh anticlinal sub-zones, which expose marine Eocene and continental Oligocene sediments in the central parts of the anticlines. The zone is down warping northeastwards. Oil seepages are present in the zone.

**Mazarani Folded Zone** (Petroleum Zone $C_4$): The Mazarani zone is the southern extension of zone C3 west of the Kirthar depression. Like Sanni Zone ($C_3$), it also has a longitudinal orientation. The zone comprises a northern anticlinal uplift (Mazarani anticline, which contains gas condensate in Lower Eocene carbonates) and a southern up dip sloping towards the Kirthar depression. Eocene and Cretaceous play merit investigation.

Outer Folded Zones (Tectonic Feature - D): The depressions are succeeded in the north and west by a mountain belt comprising Parachinar-Kala-Chitta, Sulaiman and Kirthar ranges. These ranges were produced during the Tertiary by collision and coalescence of the Indian and Eurasian plates. Here only Sulaiman and Kirthar ranges are discussed because the Parachinar-Kala Chitta ranges, according to our present level of information, hold some hydrocarbon potential in the sub thrust zones, where trap delineation can only be done through intensive seismic survey.

**Sulaiman and Kirthar Ranges** (Petroleum zones $D_1$ and $D_2$): As discussed earlier, these zones represent the deformed and uplifted areas of the Indus basin because of their position near the collision front.

The Sulaiman range swings from northsouth to eastwest forming an arcuate chain. Western part of the chain is formed of Fort Sandeman-Loralai sub zone. Older rocks (mainly Mesozoic) are exposed in sharp folds often complicated by faults. The part close to Zindapir and Mari-Bugti folded zones contains some interesting anticlinal folds, which can be considered as potential exploration targets. A gas field (Jandran) in the Cretaceous reservoir and a number of oil seepages in the eastern part of the zone prompt investigation and evaluation of the Cretaceous.

The Kirthar Range is a north-south oriented tectonic feature. The inner or western Fort Sandeman-Loralai sub zones extend southward into Kirthar Range and are represented by Quetta and Mor sub zones. The eastern or outer part of the Kirthar Range containing Bolan and Gaj anticlinal sub zones having Mesozoic-Neogene sediments. This part may have potential for hydrocarbon in Jurassic and Paleogene plays as indicated by the occurrence of oil seepages at Hernia, Bambina, and Gourd.

**Rear Depression** (Tectonic Feature - E): It occurs in between the Chaman Fault and the obducted ophiolitic margin of the Indian plate. The boundary of the rear depression follows the patterns of Sulaiman and Kirthar ranges, although sediments infill and tectonics are not identical. Turbiditic sequences ranging in age from Oligocene-Miocene pile up in the basin with sporadic exposures of Eocene carbonates. Tight anticlines, broad synclines and northwardly dipping thrusts are characteristic features. Dark shales associated with turbidites are considered as potential source rock. There is no dearth of structures with large closures.

**Pishin Depression** (Petroleum Zone - E): This depression is filled with fine clastics of Cainozoic age underlain by Eocene carbonates. The sediments have been strongly deformed, sheared, folded, faulted and refolded. The synclines have occupied high relief position and anticlines have slipped in depression. The complicated structural geology demands careful evaluation of the zone. Ahmed et al. (1991) stated that the thickness and lithology of the sedimentary fill and reporting of an oil seepage indicate some potential for the occurrence of hydrocarbon in the basin. However, considering the tectonic setting and sedimentary pattern, it is more gas prone than oil.

**Balochistan Basin**

The hydrocarbon prospects of Balochistan basin of Pakistan situated in the west of the country between longitude 61° to 66° 30' E and latitude 23° to 30° N are assessed on the basis of a new concept related to the structural and tectonic behaviour of the basin. So far this basin is known as a fore-arc subduction basin. According to the interpretation of the geological, geophysical and other relevant data by Raza et al. (1991), the Balochistan is an extra continental subduction basin, which has been subjected to plate convergence to such an extent that the arc has been destroyed by subduction and transform movements, reducing it to a non-arc basin. Thus, oil and gas pools associated with normal faults, positive structures, structural anticlines and stratigraphic traps may form the targets for hydrocarbon exploration in the basin.

Projection of the surface geological data in the subsurface in combination with seismic, aeromagnetic and gravity information fits well in our model of non-arc subduction basin containing a wrench zone modification of the originally fore-arc basin. Non-arc subduction basins have the reputation of containing giant field and their yield per sediment volume is the highest among all the categories of sedimentary basins. Kharan depression with pools associated with normal fault blocks and Panjgur wrench zone with pools brought up due to the flower pattern of faulting are the two most prospective areas of the basin where exploration is recommended first. According to the model presented above by Raza et al. (1991), the maturation, migration and trapping factors are highly favourable and in conclusion, they expect that systematic exploration may result in the discovery of substantial amount of hydrocarbons.

**Subduction Zones** (Tectonic Feature - F): The feature is situated between the northern magmatic arc region and the Arabian Sea. Its structural trends start from the Chaman-Bela-Ornach transform fault zone in the east and extend westward beyond the border of Pakistan. The feature exhibits progressively southward shifting tectonism and sedimentation. Three parallel petroleum zones based on the evolution of accretionary complex are recognized from north to south.

**Mashkhel Depression** (Petroleum Zone $F_1$): Renamed as Kharan fore-arc depression by Raza et al. (1991), the Mashkhel depression represents a flat area of Hamuni-Mashkhel and Kharan desert, covered by Quaternary sands. Aeromagnetic surveys have confirmed the presence of depressions containing huge thickness of sedimentary rocks of possible Paleogene age. Seismic survey is required to delineate subsurface structures.

**Panjgur Accretionary Prism** (Petroleum Zone $F_2$): It is a prism formed by thrusting up of accretionary sediments in front of the fore-arc region. The name Panjgur wrench zone has been proposed for this region by Raza et al. (1991). According to their interpertation the zone is developed as a result of wrench faulting caused by the pressure of the subduction from the south and deforming northern region, in combination with transform movement both in the east and west of the basin squeezing up the sediments in the form of positive flower structures. Eocene Limestone and Miocene sandstone may form potential targets.

**Coastal Depression** (Petroleum Zone $F_3$): The zone represents the coastal Makran region, which includes part of Makran subduction complex of Raza et al. (1991). The tectonic style in the zone is characterized by huge synclines flanked by small anticlines. Reverse faults are less common in this zone as compared to the accretionary prism. A large number of mud volcanoes emit gaseous discharge along the coastline expressing the ongoing subduction. Additional stratigraphic traps towards the southern flanks of the synclines are produced due to facies changes in Pliocene shelf sandstone. Kapper dome striking north-south and dipping into the sea represents another departure from the regional trend and is speculated to be effected by some mud diaperism. Miocene-Pliocene shelf sandstones are the target plays in addition to Miocene turbidites.

**Offshore** (Tectonic Feature - G):A vast offshore area of Pakistan measuring approximately 240000 km$^2$ is situated in the south of the country between longitude 61° 45' and 68° 10'. Tectonically, it is divisible into (1) Offshore Indus with a continental crust and (2) offshore Makran having an oceanic crust. The Murray ridge and Owen fracture zone form a transition plate boundary between the two.

**Indus Platform** (Petroleum Zone $G_1$): It is a platform area, which is the prolongation of the onshore Sindh Monocline. The zone is cut in the southeastern corner by a submarine canyon of the Indus River. The region is dominated by intricate drainage pattern of many mouths of the Indus River. The stratigraphy in the areas is similar to the onshore Sindh Monocline. The structures are oriented in northwest-southeast direction. Cretaceous, Eocene and Oligo-Miocene are objective plays in the zone.

**Indus Depression** (Petroleum Zone $G_2$): The zone represents a deep depression, which appears to be direct prolongation of the onshore Karachi Depression. The area is severely faulted by sinuous and gravity growth faults. The southwestern margin of this depression is bounded by a gentle uplift running parallel to the axis of the deep Eocene and Oligo-Miocene plays are the objectives of investigation.

**Makran** (Petroleum Zone $G_3$): The zone covers the region in between the coastal depression zone and east-west oriented trench, where the Arabian plate is being subducted beneath the Eurasian plate. This zone has been renamed as makran subduction complex by Raza et al. (1991). Accreted sediment pile at the prism front is succeeded by slope mantling mud facies and southward prograding shelf wedge. The intensity of tectonic deformation is relatively mild. The resulting simple fold closures in abyssal plain and slope sediments as well as stratigraphic traps due to facies changes may be targets for exploration.

## COAL

Pakistan contains large deposits of low quality (lignitic to sub-bituminous) coal of Tertiary age. The reserves excluding Thar Coal, field are estimated to be 447 million tonnes and a yearly production is over two million tones (some times 2-3 million tonnes). The main coalfields are situated in Indus Basin in three general areas, termed here as Coal Provinces, which are Salt Range, Quetta and Hyderabad.

***Salt Range Coal Province***: This is situated on the southern limit of Kohat-Potwar Province of the Upper Indus Basin. Two different coal horizons occur, one at the base of Paleocene in the western part of the area (i.e. Makarwal coal field in Trans-Indus Salt Range) and the other in Late Paleocene in the eastern part of the -area (i.e. Khushab-Dandot coal fields in the central and eastern Salt Range). The basal Paleocene Makerwal coal is the result of earliest Cainozoic transgression. The coal has perhaps been transformed from the vegetation, which flourished in the area following the Cretaceous regression and prior to Paleocene transgression which caused deposition of sandy strand plain type sediments called as Hangu Formation. The Hangu Formation exhibits rapid onlap eastwards, which possibly is the reason of non-development of this coal horizon in eastern part of the Salt Range Coal Province. Generally there are one or two coal beds ranging in thickness from less than 20 cm to 3 m. Permian coal is reported from Borikhel, but it is in insignificant quantities (Bhatti, 1983).

The Late Paleocene Salt Range coal is found in the Patala Formation. Although the formation is found all over the Salt Range but the coal of economic value is located in the central and eastern Salt Range only. In the central Salt Range there are more than two coal seams ranging in thickness between 10 cm to 1.5 m. Coal seams are generally thickest in the south towards anticlinal core and thinnest in the north towards Synclinal axis of the Potwar synclinorium (Shah, 1971, 1980).

Reserves of Makerwal coal are estimated at about 19 million tonnes (Danilchik and Shah, 1967), those of the central Salt Range are 23 million tonnes (Shah, 1971 unpublished and 1980) and eastern Salt Range 65 million tonnes (Khan, 1950).

***Quetta Coal Province*:** This province is situated around Urak trough in the Lower-Middle Indus Basin and comprises three major coal fields, namely Khost-Harnai, Sor Range, Degari. and Mach and several small fields at Bahlol, Duki, Johan, etc. The coal horizon occurs as thin lenticular seams in the middle zone of Ghazij Group of Eocene age. The coal has developed as a result of an Eocene delta formed by a river flowing southeast and entering the Indus Basin near Quetta in a pre-orogenic structural depression known as Urak trough. Thus, around Quetta, there is a maximum development of coal deposits. The minor development in localities south (Johan) and northeast (Duki, Bahlol) of Quetta is due to the spreading of deltaic debris by the coastal currents (Hunting Survey Corporation, 1961).

***Hyderabad Coal Province*:** This province is situated near the crest of a pre-orogenic positive structure called Hyderabad arch or high in the southern Kirthar Province of Lower Indus Basin. Two coal fields are known, one at Lakhra and the other at Meting-Jhimpir. There are two coal horizons one in the Bara Formation of Paleocene age (at Lakhra) and the other in Sohnari member of Laki Formation of Early Eocene age (at Meting-Jhimpir). The Paleocene and Eocene sequences are separated by an unconformity. The Bara Formation is of fluviatile origin, which favoured accumulation of vegetation to give rise to coal. It is overlain by Lakhra Formation (Paleocene) of estuarine origin whose deposition was followed by emergence of the Hyderabad arch thereby marking an unconformity on top of Paleocene. Later the Eocene transgression resulted in the development of coastal swamps on the flanks of the arch in which swamp vegetation grew and was the source of the coal in the Sohnari Member (Hunting Survey Corporation, 1961).

Largest of all the coal deposits, is a recently discovered Thar Coal Field within the Hyderabad Coal Province. Separate and special treatment is given here to this coal field with all about its coal geology and its stratigraphy. The information on the Thar Coal resources has been provided by Abbas Ali Shah, (Director General, Sindh Coal Authority) in a written communication (2005).

**Coal Resources:** Coal resources of the Thar Coalfield constitute around 98% of total coal deposits of the country. Thar Coalfield contains a minimum of five coal bearing areas, these coalfields spread over an area extending from Thatta to Lakhra. The sizes of the coal fields can be well imagined from following reserve figures:

| | | (Billion Tonnes) |
|---|---|---|
| a) | Lakhra, (District Dadu) Coalfield | 1.328 |
| b) | Sonda, (District Thatta) Coalfield | 7.112 |
| c) | Metting-Jhimpir, (District Thatta) Coalfield | 0.161 |
| d) | Badin Coalfield | 0.016 |
| e) | Thatta Coalfield | 175.506 |
| | | 184.125 |

Thar Coalfield, one of the biggest lignite deposits in the world, spread over an area of about 9100 km$^2$ with dimensions of 140 km (north-south) and 65 km (east-west). Main coal deposition is located in district Thar Parkar in eastern part of Sindh province of Pakistan. It was discovered in the late 1980's. During the period (1992-93) regular exploration was initiated over four blocks covering an area of 356.5 km$^2$. Based on 167 drill hoses, coal reserves of 9.715 billion tonnes, were established. Drilling continued and up to date 217 holes have been drilled. Revised reserves of entire coal-field (9100 km$^2$) are estimated around 175.506 billion tonnes; the work is still in progress. Based on the reconnaissance programme, preliminary evaluation of resources showed extremely high in-situ tonnage of coal (coal ASTM type B) in seams of extractable thickness up to 22.85 m. Depth of coal is 114 m minimum and 203 m maximum. The cumulative coal seam thickness is 36 m. The block-wise deposits are as under:

| Chemical Analysis of coal is as follows: | |
|---|---|
| Coal Quality | Lignite A-B |
| Moisture (AR) | 46.77% |
| Ash (AR) | 6.24% |
| Volatile Matter (AR) | 23.42% |
| Fixed Carbon (AR) | 16.66% |
| Sulphur (AR) | 1.16% |
| Heating Value (AR) | 5774 Btu/lb |
| As received | 5780 to 9398 |
| Dry | 10723 to 11353 |
| DAF | 11605 to 12613 |
| MMM Free | 6101 to 6841 |

**Coal Stratigraphy:** The area is mostly covered by sand dunes. The nearest exposed out crop is of granite basement rock. The basement rocks also contain sub-ordinate rhyolite and metamorphic rocks. Thar Coalfield rests upon a structural platform, which is underlain by relatively shallow granite basement rock. It is also interpreted that the geological formations follow the normal depositional sequence. They dip very gently towards northwest without major tectonic deformations. The generalized stratigraphic sequence in the Thar Coalfield is as under:

| **Formation** | **Age** | **Thickness** | **Lithology** |
|---|---|---|---|
| Dune Sand | Recent | 14 m to 93 m | Sand, silt and clay |
| --------------unconformity-------------- | | | |
| Alluvial deposits | Subrecent | 11 m to 209 m (variable) | Sandstone, silt, clay mottled |
| --------------unconformity-------------- | | | |
| Bara Formation | Paleocene to Early Eocene | + 52 m (variable) | Claystone, shale, siltstone, sandstone, coal, carbonaceous claystone/shale |
| --------------unconformity-------------- | | | |
| Basement complex | Precambrian | | Granite (grey, pink) and quartz diorite |

Rock formations are described in brief as follows:

**Basement Complex:** The basement rocks are mainly granite with minor amount of rhyolite and metamorphic. The granites of Nagar Parkar area are of two types i.e., pink and grey.

**Bara Formation:** The unit at the type locality is composed pre-dominantly of sandstone and subordinate amount of claystone, shale, siltstone, coal, and carbonaceous claystone/shale. In the Thar Coalfield area, Bara Formation has unconformable contact with overlying Quaternary deposits as well as with the underlying basement rock. The lithological sequence is as follows:

**Claystone:** It is medium grey to dark grey and silty at places and contains pockets of very fine sand. Generally forms the floor, as well as, the roof rock.

**Carby claystone:** It is dark-grey and brownish-black in colour. Carbonaceous and coal fragments are present throughout.

**Sandstone:** It is very fine to coarse grained with subangular to subrounded grains. Sandstone is friable and consists of dominantly quartz and minor amount of ferromagnesian grains.

**Coal:** It is brownish black, black and greyish black in colour, poorly solidified to well solidified and compact, contains scattered resin globules throughout. The resins are two types, brown and greenish yellow. The rank of the coal is lignite "B" with less ash and sulphur percentage.

**Shale:** It is medium grey to light grey in colour and medium hard and compact. At some places, it is sandy and silty containing coal laminations and wood fragments.

**Carbonaceous shale:** It is greyish black to black in colour. It is fissile semi compact with leaf impressions.

**Siltstone:** Light brownish grey, compact with coaly streaks and has sandy partings.

**Underclay:** It is present under or in between the coal beds the layers are 0.20 to 1 m thick. It is olive-grey in colour.

Subrecent Deposits: Unconformably underlie the dune sand and its lower contact with coal bearing Bara Formation is sharp and unconformable. The lithology of the Subrecent deposits is composed of sandstone, siltstone, claystone and a kaolin/granite wash. They are described as follows:

Sandstone is pale orange to pale yellowish orange. It is silty or clayey fine grain mostly well sorted, at few places also poorly sorted. Sandstone is moderately to highly oxidized with yellow brown, dark brown and red iron oxide patches, which impart it a mottled appearance. It also contains dark brown and black ironstone concretions. Siltstone is light grey to dark yellowish orange in colour. It is compact and very fine grained that contains black ironstone concretions and highly oxidized. Claystone is yellowish brown and pinkish grey in colour. It is mottled due to yellow, brown, dark brown and red iron oxide patches. It is usually silty and sandy. Usually kaolin/granite wash is white or bluish grey and contains fine to very coarse quartz grains in a white clayey matrix. It was probably formed from the alteration of feldspars in the granite. Granite wash also contains a few black, very fine-to fine ferromagnesian grains. Granite wash is noticed above the coal bearing formations.

**Recent:** The unit dominantly consists of sand and also contains a few meters thick bands of silt and clay. Sand is pale yellowish brown, yellowish brown and pinkish grey in colour. It mostly consists of quartz and ferromagnesian grains. Grains are mostly subangular to subrounded and moderately to well sorted.

**Hydrologeology:** The hydrological studies show three possible aquifer zones at varying depths.

- **Aquifer above the coal zone:**
  There are numbers of aquifers present above the coal zone between depths of 41.38 m ASML to 40 m below the mean sea level. The water bearing horizons are medium to coarse sand horizons. The first perched aquifers somewhat persistent throughout the Thar Coalfield are at a depth of 50 to 90 m.

  The water quality is mostly brackish and saline. Water column varies between 0.61 to 7.62 m. Rainwater directly recharges this aquifer.The local people dug their wells through low-lying inter dune flats and utilize this water for all purposes.
- **Aquifer within the coal zone:**
  This coal zone has two or three aquifer of sand horizon, which varies in thickness from 2.24 to 68.74 m between 43 to 150 m below the mean sea level. All aquifers under pressure consist of quartzitic sand that is medium- to coarse-grained and gritty. The quality of water is brackish to saline.
- **Aquifer below the coal zone:**
  A deep aquifer below the coal zone is present throughout the area. It ranges in thickness from 54 to 64 m. It mainly consists of coarse, gritty quartzitic sand/sandstone. The quality of water is saline. Thar Coal with huge reserves is expected to be used in the generation of power and water from these aquifers. Especially from "Aquifer below the coal mine" will be utilized in the power generation process. Most of the tube-wells are now installed in this horizon.

***Other Occurrences of Coal*:** Besides, the above mentioned three coal provinces, there are minor occurrences of coal deposits at a few other places also, e.g., Chhoi in Kala Chitta Range and Cherat hills near Peshawar. These coals are contained in shales of Eocene age (Ahmad. 1969). A commercially insignificant but of much geological interest is the discovery of Permian coal in the Warchha Sandstone at Burikhel in Salt Range. However, no major coal deposits have yet been found in this horizon. Coal is also found in Hangu, Azad Jammu and Kashmir and costal Makran Region of Balochistan Basin.

It can thus be seen from the foregoing discussions that except the one non-commercial Permian coal occurrence, all the known coal deposits of Pakistan were formed during Early Tertiary times. Indeed that was the time of widespread marine transgression on the fringes of which conditions of continental deposition existed, which led to the formation of coal. Since the coals are comparatively younger, they have not yet been substantially metamorphosed to become mature: most of them are still of the grade of lignite. However, possibility of a commercial discovery of good quality Permian coal exists; more so in view of a recent discovery of thick beds of subvitreous

Permian coal in the subsurface in oil wildcat in Indus Plains near Multan at a depth of about 2700 m.

**Radioactive Minerals**

Indications of uranium mineralization have been reported from various places in Indus Basin, Balochistan Basin as well as from Northern Montane Area. However the most well explored occurrence is that located at Baghalchur in Dera Ghazi Khan District (Middle Indus Basin) which will be described here.

A belt of uranium bearing rocks belonging to Middle Siwaliks (Nagri Formation) is exposed along the foothills of Sulaiman Range in D. I. Khan and D. G. Khan districts. Seven strong radioactive anomalies have been located along this belt of which the one at Baghalchur has been explored in detail, where the work is still in progress. In an area of 2250 $m^2$, 1250 tonnes of ore with an average grade 0.138% $U_3O_8$ has been established (Moghal, 1974).

The mineral is a hydrated vanadate of calcium and uranium called tyuyamunite and occurs as greenish yellow coatings on sand grains and in the interstices of grey coloured medium to coarse grained sandstone. The mineralization is confined to small pockets and lenses (15 to 60 cm thick) and is seldom banded. There is no regularity of pattern of size or grade of individual bodies either along the strike or along the dip. Generally, the mineralization is confined to the cross-beds but it does not seem to indicate any preference for any particular kind of rock. It has, however, been noted that the uraniferous zone is restricted between a bed of greenish shale below and a bed of reddish brown shale above. Significant relationships of mineralization that can be established, is that all the mineralized lenses yet located occur either above the water table or just below it (Moghal, 1974).

**Metallic Ores**

The metallic ore group includes those ores from which metals can be economically extracted. About 13 metallic ores are known from Pakistan. Out of these many are found as showing and traces. Only a few have been exploited on a substantial scale. Metallic mineral deposits consist of chromite, iron, aluminium, copper, antimony, lead zinc, manganese, gold, silver, platinum, strontium, arsenic and many others, only the important deposits are discussed below.

**Chromite:** Chromite is the ore of chromium. Its occurrence in Pakistan is mainly spotted in ultramafic rocks of the ophiolite complex and mêlange. Although chromite occurrences have been reported from many areas, but the one which has commercially been exploited on a large scale lies in the Zhob Valley around the town of Muslimbagh, which is 120 km NE of Quetta. The reserves have been estimated to be fairly large (Hundal and Gauhar, 1975). Exact reserve estimates are difficult to make due to irregular and unpredictable shape of deposits. Production in 1974 was about 9,000 tonnes, which in fact is not a representative figure. In past the production has reached a peak of about 40,000 tonnes. The variation in the production has chiefly been due to various factors relating to mineral economics.

The chromite of Axial Belt and adjacent areas is associated with an ophiolitic suite of ultramafic rocks, which are principally saxonite peridotite and serpentinite of Late Cretaceous to Early Tertiary age. They have intruded the sedimentary rocks of Triassic to Late Cretaceous age. Besides the intrusive ultramafics there is an assemblage of basaltic and andesitic pillow lava and agglomerate within the sedimentary complex. The latest phase of igneous intrusion is represented by a swarm of dolerite dykes. Neither the volcanic nor the dolerite intrusions have any apparent connection with chromite bodies. Chromite concentrations are generally within or adjacent to, serpentine is an environment of saxonite (Hunting Survey Corporation, 1961). The chromite deposits are conventionally classified into the Alpine type and are generally considered to have been the product of liquid magmatic injection (Ahmed, 1966a). However, Ahmad (1974) has recently shown that at least part of the chromite has crystallized later than the country rock (peridotite) and is not introduced at excessively high temperature. It is partly associated with minerals of hydrothermal rather than pyrogenic origin. Thus he concludes that possibly at least a part of the chromite is of hydrothermal origin.

Extensions of Muslimbagh chromite deposits have been reported from areas to the north (Zhob, Waziristan, etc.) and south (Lasbela) along the Axial Belt. Detailed work on these deposits has been done on the Bela ophiolite near Khuzdar, where the rocks contain disseminated chromite as well as massive bodies of high-Cr chromite. Some of the commercially explorable chromite bodies are being mined at several places. These deposits collectively produced 7,698 tonnes of chromite during 1996-97 (Ahsan and Quraishi, 1997).

A small deposit of chromite is present along the flanks of Raskoh Range in Balochistan Basin. Chromite occurs in the form of scattered pockets in ultramafic rocks of Late Paleocene to Early Eocene age, which have intruded the Paleocene Rakhshani formation. Evidently, these are younger than the Muslimbagh intrusives; all are small in size (Hunting Survey Corporation, 1961).

Similar situation occurs in the northern areas of Pakistan, where in Bucha, Mohmand Agency, Hussain et al (1984) reported "Lenses, pockets and disseminations of chromite, occuring in ultramafic rocks, near village Parai, Yousaf Baba, Auro Khawar, Balola, Bucha and Mamanai Gudar in lower Mohmand Agency and at Hero Shah, Ospan Khare and Qila in Malakand Agency. The lenses are, generally, from 30 cm to 1 m in length but some are longer. A few lenses of chromite having similar size have also been discovered from Khanori, Malakand Agency.

Further east in Dargai area people have been mining from small pockets intermittently. The deposits may be called workable showing on a very small scale. Recently workable deposits of chromite have been reported from Jijal-Basham area where it is found in several small lenticular shapes pods (Millar et al., 1991; Ashraf et al., 1982).

Raza et al. (1977) noted that the "ophiolitic suites show clear tectonic affiliation and are developed along the pre-orogenic geanticlines. There is enough evidence to postulate that the ophiolitic trend corresponds with former destructive plate boundaries and the ultramafics may well be the result of plate subduction". However, it has not been possible to determine any structural relationship of the chromite concentrations within this tectonic framework except that most of the chromite concentrations have their long axes parallel with the length of the ultramafic host (Hunting

Survey Corporation, 1961). All chromite has been discovered by random prospecting and is being exploited by "follow the outcrop" method.

**Iron Ores:** Both poor and rich iron ores are wide spread in Pakistan, which include endogenetic as well as exogenetic deposits. Reserves of all types of iron ores have been calculated to be about 430 million tonnes (Asrarullah, 1976). However, no commercial exploitation has been made to date. Endogenic iron ores occur in Balochistan Basin, Axial Belt and Northern Montane Area, whereas exogenic iron ores are confined to the Indus Basin in formations of various ages. The larger deposits are described below.

**Endogenic iron ore deposits of Balochistan Basin:** A good potential of iron mineralization exists in North Chagai arc and Ras Koh Range in the Eruptive Zone of Balochistan Basin. The deposits are scattered and small but are fairly rich. Most of them are the result of contact metasomatism or hydrothermal replacement of calcareous rocks. The principal ore minerals are hematite and magnetite.

Major iron concentrations in the North Chagai arc are the result of contact metasomatism between Cretaceous Sinjrani volcanic group and the granitic rocks of Late Cretaceous and younger ages. They occur in areas around towns of Dalbandin (Bolochap-Kundi and Chilghazi deposits), and Nokundi (Mashki Chah, Durban Chah and Lufto deposits). The largest of these deposits is at Chilghazi where there are three magnetite bearing horizons (Faruque and Rahman, 1970). Magnetite is banded or disseminated. The top-most magnetite horizon contains three magnetite bands (1 to 2 m thick) separated from each other by epidote-andesite rocks. Percentage of magnetite varies from 60 to 80 in solid bands and total iron content from 32% to 55%, averaging about 45%. There are also a few lenses of disseminated low grade magnetite ore. The other two magnetite bearing horizons are 100 m and 500 m below the topmost horizon. The middle horizon is not of economic importance. The lower horizon is 30 m thick zone of disseminated magnetite. The reserves at Chilghazi have been established only in the topmost horizon described above and are calculated at 5.8 million tonnes. Total reserves of Chilghazi have been stated to be 23 million tonnes (Kazmi et al., 1991).

Ahmed et al. (1981) carried out detailed magnetic, gravity and susceptibility analysis of Pachin Koh iron ore deposits. Seventy lenticular ore bodies of varying sizes are reported from Pachinkoh, 80 km north of Nokundi Town, Chagai district, Balochistan. The main iron mineralization has taken place in andesitic rocks of Sinjrani Volcanic of Cretaceous age. Chemical and mineralogical analyses indicate that the ore is mostly magnetite with an average iron content of 49 percent which can be beneficiated to 67 percent. Proved iron ore reserves are 45 million metric tonnes.

Other deposits in the area are small but with high iron contents ranging between 42% to 64% (Asrarullah, 1976). In Ras Koh Range, Eocene and younger diorites and syenites have intruded Cretaceous volcanic and sedimentary rocks giving rise to hematite and magnetite at the contacts. Reserves are small, estimated at over 20,000 tonnes (Hunting Survey Corporation, 1961).

***Endogenic iron ore deposits of Axial Belt:*** At Shekhan near Khuzdar a sizeable iron ore deposit is described by Hunting Survey Corporation (1961) to occur in the limestone of Zidi formation of Jurassic age. The chief ore mineral is siderite, which has altered to hematite and limonitic hematite near the surface. The ore bodies are irregular veins considered to have been developed by selective hydrothermal replacement of the limestones due to solutions issuing from Late Paleocene to Early Eocene Porali intrusions. Conservative rough reserve estimates are of the order of 10 million tonnes of ore containing 40% iron.

***Endogenic iron ore deposits of Northern Pakistan*:** High quality iron ore deposits occur in the remote terrain of Hindukush Range in Chitral area. In southern Chitral, at a place called Dammel Nisar near Lowari Pass, magnetite lenses of varying dimensions (6 to 130 m long and 1.5 to 23 m wide) are found in crystalline Ashret limestone. The mineralization is due to contact metasomatism associated with granitic intrusions of Mirkhani granite. Stratigraphy of the area is complex and ages uncertain. The ore bodies consist of fine-grained magnetite crystals which are partly pseudomorphs after hematite. Concentration of magnetite crystals decreases outwards in the ore body grading into garnet-epidote rock (Asrarullah, 1976). Iron content in the ore ranges between 45% to 65% and the reserves are 6.5 million tones.

High grade iron ore has also been discovered in northern Chitral at altitudes of 4000 to 5000 m above sea level in Chakuli Bakht area of Zarimuro Mountain, 70 km north east of Chitral town. This again is a contact metasomatic deposit developed due to Phargan granitic intrusion into the marble beds of Reshun formation of Cretaceous age. The mineralized zone is 5 m thick of which 2 m is massive magnetite (Asrarullah,1976).

***Exogenic iron ore deposits of Upper Indus Basin*:** Iron ore deposits of sedimentary origin are known to occur in Upper Indus Basin in Marwat Range, Surghar Range, Salt Range, Kohat and Hazara. The largest deposit of iron ore, though of low quality, is a marine deposit associated with glauconitic sandstone and shale of Chichali Formation of Cretaceous age, exposed in a discontinuous belt from Makarwal to Kalabagh in Surghar Range and Sakesar in the Salt Range. The ore contains silicates of complex mineralogy and chemistry, which make its metallurgy problematic. Two types of ore have been recognized; (i) Chichali type (glauconite-siderite) and (ii) Kuch type (chamosite-siderite). Transitional varieties are also present. Iron content varies between 32% to 36%; silica is in abundance, varying between 20% to 26% (Klinger et al., 1963). Reserves of all types of ore have been given as 295 million tonnes by Klinger et al. (1963) and 385 million tonnes by Ahmad (1969). Chichali type ore constitutes nearly 65% of the total reserves. East of Sakesar Peak, the exposures of the formation do not extend.

Shah (1973), reported hematite in the form of lenses in quartzite and slate beds in the Kirana group, which are distributed all over the area. Alam (1987) carried out more detailed work in the area. The same general area was taken up by Ahmed et al. (1989), who reported the discovery of a large iron ore deposit by geophysical exploration in the buried Precambrian shield rocks of Punjab plains, near Chiniot, Jhang district Punjab. Hassan et al. (1997) presented detailed analysis of rock samples from the drilling core and developed a deposit of hematite and magnetite mineralization that exists in the Precambrian basement rocks in the Punjab plains near Chiniot at a minimum depth of 91.56 m under alluvium. According to them the iron mineralization occurs as massive zones alternating with lean disseminated zones. The anomalous value of copper in DH-3 and the presence of chalcopyrite and its alteration to chalcocite suggest that it may be an iron-copper-gold deposit. The magnetite and the hematite ore bodies are of hypogene origin, although the solutions are of magmatic or other origin is a problem. Geological reserves of 27.46 million tones of iron ore have been estimated on the basis of four drill holes. Much more reserves of good quality iron ore are likely to be present in the area as the geophysical anomaly is spread over 2.5 $km^2$.

In Marwat Range, at the western edge of Sheikh Budin Hills, near Pezu, four ferruginous horizons occur in Cretaceous succession (Asrarullah, 1976). Of the four horizons, two are in Chichali Formation and two in Lumshiwal Formation. The lower horizon of Lumshiwal Formation is considered as a potential iron ore bed. It is 6 to 8 m thick and is exposed for about 3 km. There are several thin ore layers in the bed, which have been grouped into a lower and an upper zone separated by carbonaceous silty shale. The ore is oolitic consisting of limonite and siderite in proportions of about 7: 3. Average iron content is 31% with total reserves of 12 million tonnes. Raza et al. (1994) stated that detailed mineralogical report on Pezu Iron Ore has been discussed by Farooqi M. A. A. (1973). According to him detailed mineralogical analysis of the Pezu iron ore belonging to two different groups of marine sedimentary origin are reported. One group of brown colour and less oolitic to clastic texture belongs to the oxidizing zone. They dominantly contain glauconite, hydro hematite, limonite and detrital primary quartz. Hydrohematite is the oxidation product of siderite and varies from 2% to 15%. The second group is of grey colour and has oolitic to nodular texture, dominantly contains chamosite, limonite, siderite, calcite, and chamosite clay, mixed with even grained detrital primary quartz of about 0.02 mm in size. The clay content in the specimen of this group varies from 10% to 40%. The microscopic analysis gives the following percentages, limonite 30%, siderite 20%, quartz 10%, calcite 15% and chamosite clay 20%.

In Kohat area two ferruginous horizons are known. At Mazari Tang, hematite deposits have been located within the Jurassic Samana Suk Formation of Jurassic age (Rashid et al., 1965). Hematite is present in two beds, each one metre thick. One chemical analysis shows 45% iron and 5% silica. Second ferruginous horizon has been reported from sandstone of Lumshiwal Formation of Cretaceous age at Marai Bala (Rashid, op. cit.) and at Samana Range (Fatmi, 1966), containing about 40% iron. These are small deposits and the reserves of these deposits are only in thousands of tones.

Two sedimentary iron-bearing horizons are present in Hazara area. A red shale and sandstone succession of possibly Jurassic age (referred to as "Galdanian formation" by Calkins et al. (1969); Latif (1970); and as " Kihal formation " by Butt (1972) contains iron rich beds at Kakul, Galdanian and Chur Gali. The ferruginous beds are hematitic claystone and siltstone and a few layers and lenses of black massive hematite (Ali et al., 1964). The iron beds are not persistent and laterally change into red shale. On an average the ore contains are 20% iron and 9% silica. Reserves of all categories of ore are calculated at 60 million tonnes by Klinger et al. (1963) and 100 million tonnes by Ahmad (1969).

Another hematitic horizon lies at the base of the Hangu Formation of Paleocene age which disconformably overlying the Kawagarh Formation of Cretaceous age at Langrial that extends for about 25 km in the northeastern direction. The ore is mainly oolitic hematite mixed with chamosite, limonite and hydrohematite. Its complex mineralogy would require special smelting process to be evolved. Iron content is between 9% to 30% percent and silica 9% to 60% percent (Khan and Ahmed, 1966). Reserves of all the categories of ore have been estimated at about 28 million tonnes (Ahmad, 1969).

***Exogenic iron ore deposits of Middle Indus Basin***: In Sulaiman Range at Rakhimunh in Dera Ghazi Khan Area, a thick bed of iron occurs at the base of Nari Formation of Oligocene age. The bed is 30 c to 2 m thick and is exposed for 27 km strike length (Asrarullah, 1976). The ore consists of limonite and siderite in 7: 2 portions with subordinate iron silicate. Average iron content is 37%. The ore bed is thickest in the central portion of exposure of 7 km in which the reserves have been estimated at 14 million tonnes.

***Residual iron ore deposits of Indus Basin***: In addition to the sedimentary deposits of iron ore several occurrences of residual lateritic deposits are also reported from Indus Basin (Ahmad, 1969). Presently they are not considered as of much economic significance as ores of iron but they hold a promise for the future. These deposits are mainly associated with the omni-present unconformity between Cretaceous (or older) and Tertiary systems in the Indus Basin. The laterite mostly occurs along with bauxite which is the main source material for aluminium and is described under that heading. Major occurrences of laterite are reported (Ali, 1963) from Ziarat near Quetta (15 million tonnes, 29% iron), Surg near Attock (250,000 tonnes. 12%-17% iron), Chappar near Sargodha (125,000 tonnes, 13%-25% iron) and the most important and rich deposit of Dilband area, Kalat district, Balochistan Basin.

Ironstone bed earlier described as laterite zone marking Jurassic-Cretaceous unconformity, has been for the first time recognized as sedimentary depositional iron ore of economic significance occurring in Dilband area of Kalat District, Balochistan (Abbas et al., 2000)

According to Abbas et al. (2000) the deposits are already connected with RCD Highway as well as with railway track through truckable roads and are only 650 km away from the port city of Karachi. Ironstone bed is at an average 2 m thick having wide spread exposures, forms generally very low dipping folded structure and is traversed by normal faults of minor throw. The ore consists of hematite, while quartz, calcite and chlorite occur as gangue minerals. Chemically it contains 54% to 63.6% iron oxides, 12.6% to 21.5% $SiO_2$, 6.7% to 9% CaO, 0.8% to 4.8% $Al_2O_3$ and traces of undesired elements (Abbas et al., 1998).

This deposit is large with favourable location, open cast mineability, having simple mineralogy and medium grade. According to Abbas et al. (1998), this ore is better than any other iron ore known to occur in Pakistan and compares very well with ironstone type ores being commercially exploited on a very large scale in Europe, America, Russia and other pats of the world.

The ironstone is exposed forming a blanket on top of the Chiltan Limestone in Dilband plateau area. The Chiltan Limestone forming the footwall of the ironstone is the oldest rock exposed in the area.

**Copper Ores:** Deposits of copper ore are described area wise and as such they are grouped into four generalized areas, viz., Eruptive Zone of Balochistan Basin. Axial Belt, Indus Basin and northern areas. None of the deposits in any area has to date been proved economical. Only recently, detailed exploitation work has been started on one of the deposits in the Eruptive Zone at Saindak. Except for the Saindak copper deposits, the available information on rest of the deposits is sketchy.

***Copper deposits of Eruptive Zone of Balochistan Basin*:** Besides Saindak, several indications of copper mineralization have been reported from the Eruptive Zone at Kirtaka, Robat, Amuri, Amir Chah, Mashki Chah, Durban Chah, Patkok, Dalbandin, Bandgan, Kimri and Jadino etc. (Ahmed, 1964; Ahmad Z, 1969; Khan A. L, 1975). Copper mineralization in all these areas is associated with siliceous to intermediate magma intrusions of Cretaceous to Tertiary age and occurs as veins or disseminations. The copper minerals are malachite, chrysocolla, bornite and chalcopyrite, etc. Economic mineralization is not very evident on the surface, but in as much as the Saindak deposit has been proved to be of porphyry type (Khan A. M, 1974), there is much hope of similar discoveries in other areas too.

***Saindak Copper deposit*:** Saindak copper deposit is located in the extreme west of Pakistan near the Pak-Iran border, about 650 km by road from Quetta. Mineralization is confined to an area over 5 $km^2$, referred to as "Sulphide Valley", 5 km southeast of Saindak Fort (Khan S. N. 1974). The sulphide mineralization is associated with quartz diorite intrusive in the volcano-sedimentary suite of Amalaf formation of Oligocene (?) age. The intrusions are considered by Khan S. N (1974) to have been emplaced during the times of active compression in Pleistocene epoch. The intrusions have occurred in a narrow structural zone which is traversed by parallel closely spaced fractures. This has increased the potential for mineralization (op. cit.). Summarising the field observations, Khan (op. cit.) expects to find the following types of ore bodies other than disseminated ones in the area:

(i) Massive sulphide bodies at the contact of the intrusive diorite and volcanic rocks.
(ii) Sulphide mineralization along bedding planes in volcano-sedimentary suite of rocks.
(iii) Disseminated replacement type deposits within volcano-sedimentary and intrusive rocks.
(iv) Deposits along joint planes and fissures.
(v) Vein type deposits in contact zone.
(vi) Vein type deposits in propylitized areas.

The Resource Development Corporation in a" Brief on Saindak Porphyry Copper Deposits, Balochistan, Pakistan " has stated to nave blocked a total of over 300 million tonnes of copper ore reserves (with proved reserves of over 250 million tonnes) at a cut-off grade of 0.3% copper in three ore bodies in the " Sulphide Valley ". Significant gold and molybdenum values are also associated with the ore bodies. A large scale mining and production has already been started and the present status of the Saindak deposit is as follows:

Bizenjo et al. (2000) of Saindak Metals Ltd. (SML) stated that detailed study of Saindak by a large number of professionals at national and international level, has "proved over 412 million tones" of poly-metallic ore containing copper, gold, silver, iron and molybdenum etc. at Saindak, Chagai District, Balochistan. Based on these proven deposits, SML planned and established a project under the name of Saindak Copper Gold Project (SCGP). This project envisages mining, milling of the multi-metallic ore and producing blister copper containing gold and silver as associated metals in phase-I to be followed by production of mild steel billets and sulphuric acid in phase-II. The capital cost of the project is Rs. 14.5 billion.

They added that the project, in its present form, "envisages to produce for 19 years an average annual production of 15810 tonnes of blister copper containing 1.47 tonnes of gold and 2.76 tonnes of silver. The project is estimated to generate revenue of Rs. 2 billion per year from sale of copper, gold and silver. The major components of the project include, open pit mine, concentrator, smelter, analytical laboratories, automobile workshops etc. and the infrastructure facilities including 50 megawatt power plant, bulk water supply system (30,000 tonnes per day) and rail track from Taftan to Saindak (38 km)".

Khan (1975) has described three zones of porphyry type sulphide: mineralization in areas of Durban Chah and Mashki Chah about 96 km, ESE of Saindak. In this area, rocks of Cretaceous Sinjrani volcanic group have been intruded by four phases of igneous intrusions. Porphyritic rhyolites, which belong to the second phase of igneous activity, are the centre of mineralization, where surface studies have revealed the presence of pyrite, chalcopyrite, malachite and chrysocolla. Well developed prophylitic and potash alteration zones have been noticed. This along with extensive sulphide mineralization is indicative of considerable hydrothermal reactions in the area making it promising.

***Copper indications in other areas***: Indications of copper mineralization have been reported from various localities associated with magmatism in Chitral, Gilgit, Dir and Kohistan of northern areas (Ahmad 1969; Hussain, 1974; Sillitoe, 1979), Lasbela, Zhob and Waziristan in Axial Belt (Hunting Survey Corporation, 1961; Ahmad, 1969) and from Salt Range in Upper Indus Basin. Except for the Salt Range indications, the rest are associated with igneous intrusions, ophiolites and related hydrothermal emanations of different ages (Cretaceous and younger). In the central and western Salt Range, malachite and cuprite are in Nilawhan Katha, Warchha and Musakhel, where they are reported to occur in Warchha Sandstone of Early Permian age (Ahmad, 1969). It is interesting to note that in Waziristan, detailed survey indicated estimated reserves of 50 million tonnes, with an average of 0.61 copper content. (Verbal communication by Iftikhar Malik of Pakistan Mineral Development Corporation (2005). However, no published report is available.

**Bauxite:** Mostly alumina clay or high aluminous rocks including clays and laterite as with occasional process of bauxitic composition have been found in different parts of Pakistan. Only a few commercial bauxite deposits have been established in Pakistan. Therefore, they may, at best be termed as aluminous rocks. Since in most cases, bauxite is invariably associated with laterite (with increase in iron content) and with high alumina clay (with increase in clay mineral) it is difficult to make reasonable estimates of reserves and grade unless very detailed work is carried out which is yet lacking. Laterite deposits have been briefly described under the heading of Iron Ores. The aluminous rock horizons are developed mostly in the Upper Indus Basin, at the basal Tertiary unconformity which is recognized all over Pakistan and are supposedly the result of in situ weathering of Mesozoic rocks. About a dozen occurrences have been reported from Muzaffarabad and Kotli in Azad Kashmir with an estimated reserve of about 3 million tonnes of bauxite material (Ahmed, 1969). Quality of the rock differs greatly and the grade has not yet been established. The deposits occur as small pockets and irregular lenses of pisolitic to massive ferruginous bauxite material overlying the Permo-Carboniferous limestone and underlying the Eocene (op. cit.).

Bauxite-high alumina clay deposits in a somewhat similar stratigraphic position overlying Permian Zaluch Group and underlying Hangu Formation of Paleocene age have been identified in central Salt Range. In Khushab area a total of 70 randomly distributed zones were recorded along the outcrop (Gauhar, 1976).Chemical composition of the rock is highly variable. Major minerals constituting the rock are dickite and boehmite. Geological reserves are 5 million tonnes, whereas the projected reserves are much larger. The aluminous horizon however, extends to other adjoining areas in the central Salt Range and the reserves are expected to increase with further detailed work in the area. In a small segment of Khushab area measuring 640,000 $m^2$ near Katha, some detailed work has been carried out (Cheema, 1974), where 0.7 million tonnes of ore with bauxite nodules (Alumina:Silica) and more than 5.56 million tonnes have been established with an average grade of Alumina 48%, Silica 13% and Ferric Oxide 15%. Ashraf. et al. (1976) reported Sedimentary reworked bauxite and kaolinite deposits found in the Kala Chitta area. These deposits are of Jurassic age and they occur on an erosional unconformity at the top of Triassic rocks. Due to reworking of bauxite and kaolinite from the same source area, the physical appearance is almost identical. The bauxitic zones are occasionally more compact than the kaolinite zones. The basal beds always consist of kaolinite. The alterations of bauxite and kaolinite continue upward. This cyclic deposition is conceived due to alternate deposition of kaolinite and bauxite. Moreover, the occurrences of bauxitic nodules in the kaolinite zone at places show that the whole deposit is of reworked nature and cyclic. The occurrence of irregular and patches of ferruginous material shows that the formation of laterite was not regular in all the zones, because the source rocks must have been rich in aluminium than iron and might be locally rich in iron. The bauxite and kaolinite zones have been evaluated in detail by chemical, X-ray and D.T.A. methods (Ashraf M. et al., 1972).

The chemical composition of different samples is very variable, in which it is observed that the basal zones in almost all the cases is rich in $Al_2O_3$ (around 41% to 44%), and $SiO_2$ (about 36% to 40%). On the basis of mineral calculation from chemical analyses it is also observed that kaolinite contents in the basal zones are 77% to 81% and diaspore is about 10% to 15%. Only in one case basal zone has been found to consist of kaolinite and hematite (R-3R) as chemically this zone has $Al_2O_3$ 32%, $SiO_2$ 37.6 % and $Fe_2O_3$ 12 %.

In the succeeding zones in different profiles a bauxite zone has definitely been recognized having composition in the range of 68% to 76 % $Al_2O_3$ and 2.5% to 11.6% $SiO_2$.The important mineral contents of this zone are kaolinite 4% to 23 % and diaspore from 68.8% to 87.9%. In the other zones either the composition is highly aluminous or kaolinitic. This is quite evident from the chemical analyses of the different zones. Even at places in kaolinite rich zone high aluminous nodules have been found. This shows the formation of the zone due to cyclic deposition of the material.

Other oxides like $Fe_2O_3$, $TiO_2$, CaO, MgO, $SiO_2$, $Na_2O$, $K_2O$ and $P_2O_5$ are more or less uniformly distributed in almost all the zones. The only contrasting variation found is due to high concentration of lateritic lenses at places in the profiles studied.

Preliminary studies on the economic geology of bauxite-laterite deposits, Katha area, Salt Range indicated the discovery of a bauxite/laterite zone, which crops out intermittently over a distance of more than 16 km in the Salt Range, north of Katha. The zone ranges from less than 0.3 m to over 7 m in thickness. At places, bauxite is white but joints are incrusted with red iron compounds, probably goethite, and hematite. Samples analysed indicate an average of 50% $Al_2O_3$. It has also been suggested that the bauxite clay is Jurassic-Cretaceous in age and has resulted due to insitu weathering and leaching of rocks of Triassic and partly Late Permian age of the Salt Range.

Shah (1975) recorded a laterite band at Ziarat, which lies between Parh and Dungan Formations. It is Late Cretaceous to Paleocene in age and has developed along a regional disconformity. Lithologically the laterite shows frequent facies change sometime gradually and sometimes rapidly. The mineralogical composition of the laterite is: $Fe_2O_3$ 29%, $Al_2O_3$ 27%, $SiO_2$ 11.82% and $TiO_2$ 5%. The iron is in the form of hematite and chamosite while the alumina is in the form of diaspore and boehmite. The internal structure of the band shows variations from place to place.

According to Shah (1975) the source of the bulk of the laterite was the basic volcanic rocks occurring in the nearby area of Kach and Chinjan. The mode of the formation of the laterite is of classical type, i.e., subaerial weathering under tropical or subtropical condition that has acted long enough to change source rocks into laterite.

Cheema (1974) in its report said "Mesozoic rocks of Chhoi-Jabbiwala Kas area of northern Kala Chitta area mapped on 1: 250,000 scale have eight Mesozoic stratigraphic units which are repeated through imbricate structure". High alumina clay/bauxite (kaolinite to diaspore) is present as rapidly pinching and swelling lenses in the overstepping lower member of Early Jurassic representing Datta Formation, unconformably overlying the Kingriali Formation of Late Triassic age. Associated lithosomes are hematitic ironstone, ferruginous sandstone to claystone and quartzose sandstone. The member represents "unconformity sand" and "Still stand sand" association of quartz arenite group, deposited in beach milieu of littoral environments of a rather stable shelf. Possible source of the deposits are the Precambrian basement rocks of Kirana-Sangla hills, which emerged during Late Triassic time. A very conservative reserve estimate of 1.35 million tones of good quality clay bauxite is calculated for a depth of 30.5 m in more than 19 $Km^2$ area.

**Other Metallic Ores**

Deposits of manganese, antimony, lead and gold are known to occur at several places. Their commercial value has, however not been proved neither they have been fully explored. Due to their insignificant economic nature they have been grouped here together and only a brief remark is made. For details, see Ahmad et al. (1993).

Reserves of all types of manganese deposits (mostly of uneconomic grade) are reported to be 0.5 million tonnes (Gauhar, 1969). They occur in Lasbela in the Axial Belt region associated with intrusive in Mesozoic rocks, in Hazara, in the Upper Indus Basin associated with Mesozoic iron mineralization, and in Chagai District of the Eruptive Zone.

Antimony deposits are described from Chitral in the Northern Sedimentary Province, from Kalat in the Axial Belt and from Pishin in the northern Balochistan. Total reserves are estimated at 21,000 tonnes (Hundal and Gauhar, 1975). Deposits of lead are reported from various localities in Chitral and Swat in the Northern Sedimentary Basin, from Chagai in the Eruptive Zone of Balochistan Basin, from Khuzdar and Lasbela in the Axial Belt and from Hazara region (Ahmad, 1969).

Siddiqui et al. (1976) have described lead-zinc and silver mineralization in dolomite and limestone of Abbottabad Formation (Cambrian) near Kotli, Azad Kashmir. The mineralization occurs as replacement of the host rock more commonly in shear zones. One square Kilometre zone of gossan has been discovered, where detailed geochemical prospecting is needed. Gold extracted by panning, from the sands of Indus, Gilgit, Hunza and Chitral rivers, is known from ancient times. Recent studies have revealed the presence of gold ranging from 0.01 to 0.3 gram per ton in these rivers (Ahmed et al., 1975). An exceptionally high value of 1.4 gram per tonne was recorded at a locality from high terrace. But picture gold panning over all is uneconomical.

Shah (1962) unpublished and (1973) reported the occurrence of gold in the basic dykes of Kirana group. The gold contents in the rock range from traces to 0.6 grams per tonne.

Commercially insignificant nature of all these deposits at present may not be considered absolutely discouraging while they are by no means of lesser geologic importance. A case history may be cited of the Saindak copper deposit which a few years ago was regarded as small and incidental (Hunting Survey Corporation, 1961) has now proved to be comparable in size and shape to the Sar Chashmeh deposit of Iran (Khan, 1974) through exploration by modern techniques. The presence of small mineral occurrences described above especially in areas of the Eruptive Zone, Northern areas and Axial Belt is at least indicative of the mineral potential of the areas and of the fact that geologic processes that operated in the area have led to formation of minerals. It is only that economic deposits have to be located by using more refined techniques in which stratigraphy does play its significant role in working out the economics of units.

Malik (2004) published the occurrences of gold and hypothesized the expectation of the occurrences of gold and other associated minerals in an area, that he called mineralization along the Arc of Hope.

According to him collisional zone developed in between the Karakoram Block and the

Kohistan island arc commonly known as Main Karakoram Thrust (MKT) spreading over a distance of more than 700 km has been so for conceived as a dotted line confirmed only at four accessible sites in the Northern areas. Geochemical mapping involving gold, copper, nickel, lead and cobalt has delineated this zone as an established zone in between these two blocks. Geochemical maps prepared after determining statistical parameters for spatial distribution of these elements has in fact yielded several anomalies well spread along the MKT, which has been renamed as the Arc of Hope. Gold, copper and cobalt appears to be concentrated at several places on both side of the Arc while lead has shown a variable distribution in the entire Karakoram Block besides its concentration along the Arc thus confirming very high lead contents in the continental block against nearly barren Kohistan island arc. Analysis of 80 mesh samples have shown that these hold gold values range from 0.5 to 2 ppm; copper from 50 to 500 ppm; lead from 50 to 250 ppm; zinc from 50 to 2,000 ppm; cobalt from 30 to 300 ppm and nickel from 30 to 1500 ppm. Maximum concentration for pan concentrate samples has yielded 330 ppm for gold, 7600 ppm for copper, 6900 ppm for lead, 3300 ppm for zinc, 500 ppm for cobalt and 3380 ppm for nickel.

**Industrial Minerals and Rocks**

This group includes minerals and rocks, which can be utilized as such or after some processing and beneficiation in various industries. Pakistan has bountiful reserves of large varieties of industrial minerals and rocks such as gypsum, clay, rock salt etc. Since most of the industrial minerals are associated with sedimentary rocks, stratigraphy bears a more direct relationship with their discovery and development.

**Limestone:** Limestone is by far the most abundant mineral commodity in Pakistan. With its unlimited reserves, limestone forms many ranges and is exposed in the Indus Basin, Axial Belt right from Karachi in the south to Khyber in the north and further north at several places in the Northern Montane Area. Balochistan Basin is deficient in limestone since surface outcrops are mostly of Late Tertiary clastics. Limestones of the Indus Basin and Axial Belt are Late Palaeozoic to Tertiary in age, while in the Northern Areas, Early Palaeozoic limestones are also found. Due to the widespread development of limestone deposits, it is not possible here to list the individual occurrences, but a glance over the geological map of Pakistan and through the description of stratigraphy would reveal that the formations listed below, where exposed, are good resources of limestone.

| **Formation** | **Area of outcrop** |
|---|---|
| Tertiary | |
| Gaj, Kirthar, Laki, Dungan | Lower Indus Basin |
| Kohat, Chorgali, Margala | Upper Indus Basin |
| Hill, Sakesar, Nammal, Lockhart. | |
| Cretaceous | |
| Fort Munro, Mohall Kit, | Lower Indus Basin, |

| | |
|---|---|
| Parh, Goru. | Axial Belt |
| Kawagarh, Lumshiwal (in parts) | Upper Indus Basin |
| **Jurassic** | |
| Jakatu, Loralai | Lower Indus Basin, |
| Axial Belt | |
| Samana Suk, Shinawari | Upper Indus Basin |
| **Triassic** | |
| Shirinab | Axial Belt |
| Chak Jabbi | Upper Indus Basin |
| Mianwali (in part) | Upper Indus Basin |
| **Permian** | |
| Wulgai | Axial Belt |
| Wargal | Upper Indus Basin |
| Khyber | Peshawar Basin |
| **Devonian** | |
| Shagai | |
| Nowshera | |
| Various units in Chitral-Baroghil valleys, Northern Sedimentary Province | |
| **Precambrian** | |
| Shah Kit Bala Formation | Attock Cherat Range |
| Khattak limestone | |

Chemical composition of the limestone varies from bed to bed and place to place. Geochemical evaluation has to be made before putting them to use in a specific industry. Details may be seen in Master (1963) and Ahmad and Siddiqi (1993).

**Dolomite:** Dolomite deposits are mostly associated with limestone and are of diagenetic origin. In fact the process of dolomitization is so common in the rocks that most of the limestones of the country are observed to have been dolomitised to a lesser or greater degree. In the Upper Indus Basin, the major dolomite bearing formations are in Salt Range (Precambrian), Jutana (Cambrian), Khisor (Cambrian), Kingriali (Triassic), and Samana Suk (Jurassic). Some detailed work has been done on Kingriali Dolomite in the Surghar Range, where four deposits of dolomite have been located. About 900 million tonnes of reserves have been established in beds averaging 80 metres in thickness. Dolomite is of good grade, close to the theoretical value of dolomite. Datta Formation especially of Trans Indus ranges contains one of the best dolomite deposits. Details on other dolomite horizons are not available but, generally the dolomite is of good quality and large reserves are available. In southern part of Lower Indus Basin, near Jhimpir, about 0. 5 million tonnes of dolomite reserves are established in two beds measuring 2.5 m and 7 m in the Laki Formation (Eocene), MgO content is 17% and CaO 36%, as determined in two samples (Khan and Gauhar, 1966).

Good quality of dolomite has been discovered in the Axial Belt near Quetta (Ahmad, 1974). Dolomite is present in beds up to 80 m thick at the base of Jurassic Takatu Formation in the Chiltan Range. The dolomite is saccharoidal in texture and of good quality. Representative chemical analyses have given an average of about 20% MgO and 32% CaO with negligible insoluble (S. H. Gauhar personal communication). Reserves for a strike extension of 5 km are estimated at 250 million tonnes. These reserves are conservative estimates, however, it may be much more than indicated.

In the northern areas near Sherwan, about 16 km west of Abbottabad and within the Abbottabad Formation (Cambrian), here it is bedded, but the dolomite is associated with soap stone at some localities near the villages of Khanda Khir and Chalethar. It is small but fine quality deposit.

In the Northern part of Axial Belt, large dolomite deposits are described from Khyber Agency. The dolomite occurs in Shagai limestone and Khyber limestone, both of probable Precambrian age. Larger and better grade deposits are found in the upper part of Khyber limestone. The dolomite has saccharoidal texture. It is present in the defiles of Khyber Pas area. Further north in the Northern Sedimentary Province, numerous dolomite deposits of Devonian age are present in the Chitral district, where massive dolomite in lower part of the Shogram formation and bedded dolomite in the middle part of Shogram formation is present. Further northeast in the northern Karakoram Guhjal formation is mostly dolomite. Other formations, which contain dolomite within are Chilmarabad formation, Kilik formation, Aghil limestone formation and many others.

**Gypsum and Anhydrite:** The gypsum deposits range from Precambrian to Miocene-Pliocene in age. Mostly they are small deposits. Only gypsum deposits of Sargodha and Kohat division are larger (3 to 15 m) deposits of widely distributed in the Upper Indus Basin, which have practically inexhaustible reserves. Precambrian gypsum and anhydrite deposits are confined to the Salt Range Formation exposed along the southern escarpment of the Salt Range. Cambrian gypsum and anhydrite deposits are locally developed in Khisor Range in the Khisor Formation; they are more than 200 m thick. Eocene gypsum-anhydrite deposits occur in Ghazij Group in Middle Indus Basin all along the Sulaiman Range and in Kirthar formation in Marri-Bugti hills, in Jatta Gypsum in Kohat area of Upper Indus Basin and in Sakesar Limestone (facies change) near Deduce in the Salt Range. Studies of representative sections of gypsum-Anhydrite deposits by (H. A. Raza, 1977) at Cheri (Salt Range), Saiyiduwali (Khisor Range), Jatta (Kohat) and Rakhimunh (Sulaiman Range) have shown that the gypsum is associated with dolomite and organic laminite in acyclic sequence and possesses characteristics which point to its formation in sabkha type supratidal flat environment (Shearman, 1963, 1966; Kinsmall, 1969). The available generalized composition of gypsum from various localities is given as under (Ahmad, 1969).

| | Lime% | Silica% | Water% |
|---|---|---|---|
| Salt Range | 31-43 | 41-57 | 0.01-21 |
| Kohat Ranges | 30-33 | 38-46 | 17-20 |
| Marri Hills | 31-32 | 46-47 | 19-20 |

Besides, the above-mentioned gypsum occurrences, small layers of gypsum up to one metre thick have been reported from several places in hallows amongst the sand dunes in the Thar Desert (Ahmad, 1969).

**Rock Salt:** Inexhaustible reserves of rock salt from numerous localities are available in Pakistan. Extensive deposits of rock salt occur in the Salt Range Formation (Precambrian) and in Early Eocene Bahadur Khel Salt (Early Eocene). Besides these, the sea salt is also produced in coastal areas and lake salt deposits in Thar area. Production of rock salt in 1974 was 350,000 tonnes as compared to that of sea salt, which was 125,000 tonnes (Hundal and Gauhar, 1975). Since, sea salt is not a commodity related truly with geology, only rock salt deposits will be described here. The main Precambrian salt production comes from Billianwala Salt Marl Member (the lower member of Salt Range Formation). It is exposed along the southern escarpment of the Salt Range where salt mines are established at Kalabagh, Warchha and Khewra. There are several salt seams, some of them as much as 20 to 25 m or exceptionally up to 90 m thick. The seams are generally separated by beds of red marl. Thinner salt seams are also present in the upper member, viz., Sahiwal Marl member. Salt is white to pink in colour. Total reserves of salt present at the three localities are 85 million tonnes of which only Khewra deposits carry 82 million tonnes (Asrarullah, 1962).

Malik, 2001, carried out detailed exploration of the mines of Khewra area and indicated the reserves as follows:

"Resource calculation has been based on the available survey data and geological information. It is the first time that salt resources of the entire leased area have been calculated. Total resources are summarized here:

| Mine | Measured (mt) | Indicated(mt) | Inferred(mt) | Total(mt) |
|---|---|---|---|---|
| Main Mine | 264.482 | 128.137 | 3,144.920 | 3,537.485 |
| Sohal Mine | 1.443 | 5.155 | 3,143.108 | 3,149.706 |
| Total | 265.871 | 133.292 | 6,288.028 | 6,687.191 |

or say 6,687.20 Million Tonnes

Eocene salt production is obtained from Bahadur Khel Salt quarried at Jatta, Bahadurkhel and Karak in Kohat area of the Upper Indus Basin. The formation exposes massive salt bed, which is up to 100 m thick and is overlain by gypsum, dolomite and clay of Jatta Gypsum. Base of the salt is nowhere exposed, at Bahadurkhel about 500 m of salt was penetrated by drilling without reaching the base (Rashid et el., 1965). Reserve estimates have not been made but undoubtedly the deposits are very large.

**Potash:** Potassium salts deposits are few and found only in the Indus Basin especially in the Kohat-Potwar Province. There are three known potential sources of potash in Pakistan. They are the potash beds associated with rock salt in the Salt Range Formation, subsurface brines encountered in a drill hole in the Salt Range and the green sand of Chichali Formation in the Surghar Range. Potash minerals occur interbedded in the Salt Range Formation and have been described from the Khewra salt mines (Alam and Asrarullah, 1973). The potash occurs as specks thin streaks, thin seams and lenticels of limited extent in the rock salt and the salt-marl separating the salt seams. Seven potash bearing salt-marl beds have been recognised of which two contain thicker seams varying between 1 to 5 m in thickness and 250 to 400 m in their lateral extent. Chemical and mineralogical variations are significant. The ore is either clay bearing or clay free. In addition to halite, it is mostly composed of sulphate minerals like kainite, langbeinite, kieserite and polyhalite. Presence of sylvite has only been noticed in one instance. The proved reserves of ore containing 7.83% potassium oxide are estimated at 12,500 tonnes.

Another source of potassium is subsurface brines. In an exploratory drill hole by an oil company at Dhariala, 15 km, NW of Khewra. Saturated artesian hot brines were encountered at a depth of about 2600 m. The brine contained chlorides of potassium, magnesium, sodium and calcium, and bromine and boron in small quantity. The flow of brines at a high pressure was found to be 4,500 litres per minute (Richards, 1963).

Chichali Formation of Jurassic-Cretaceous age contain yet another potential source of potash in which the glauconitic sandstone (or green sand) is exposed in the Surghar Range from north of Kalabagh to Makerwal for a distance of 45 km. Beds of green sand are 3 to 20 m thick and at places, make up a cumulative thickness up to 30 m. Total reserves of about 23 million tonnes of green sand are available (Kidwai, 1963). Experiments have been made to utilize the green sand as water softener and potasic fertilizer (Bakhsh et al., 1963). The results obtained indicated that the potash contents are rather low ($K_2O$ 1.28% to 4.28%) and all the potassium is not readily available for nutrition to plants as only a small fraction of it is in exchangeable form. For this reason and because of high transportation cost, the green sand is not presently considered useful for direct application as a fertilizer. It may become of economic significance if a method for extraction of potassium from the green sand is successfully evolved. However, Bakhsh and others (op. cit.) have recommended its use as an effective water softener; they have calculated that one tonne of green sand with exchange capacity of 16 m. eq. per 100 gm. will completely remove the hardness of 35,500 litres of water with a hardness of 250 ppm calculated as calcium carbonate. It may be further added that the potash content of green sand are low to consider its use as fertilizer, however, it is very effective as a water softener.

**Rock Phosphate:** Horizons presenting rock phosphate are those of Precambrian-Cambrian-Late Jurassic-Early Cretaceous, Paleocene, Eocene and Oligocene. Most of the rock phosphate deposits of Pakistan are confined to the Indus Basin and Axial Belt out of which only the Precambrian-Cambrian phosphate of Hazara is meritorious. Hazara phosphorite occurs along with dolomite and cherty dolomite in the upper part of Abbottabad Formation of Cambrian age. The exposures are widely scattered and are also traceable into Kashmir. Phosphorite occurs in thin (about one metre) discontinuous lentils scattered within the wide range of horizons of thick dolomitic rocks. Structural disturbance is also common, thus rendering reserve estimates difficult. The deposits are spread over area of 155 km$^2$. Major localities are located in Kakul, Mirpur, Lagaran, Baghla Gali, Kalu-De Bandi, Dhola and Sirban (Bhatti, 1972). At one locality, Kakul-Mirpur, more than 1.5 million tonnes of grade 18% - 40% $P_2O_5$ have been established. Phosphorite is usually palatal, hard, compact, siliceous, grey to black in colour with bluish phosphoratic bloom. At a locality near Dhola, 15 m thick phosphorite horizon has been recently discovered which holds a good promise in the area. Generally, more precise and optimum range of phosphate content is 10% to 30%. The reserve of phosphate rock is estimated to be 22.9 million tones (Hassan et al., 1986).

Parts of Chichali Formation (Late Jurassic-Early Cretaceous) exposed in Kohat area of Upper Indus Basin contain phosphatic nodules within the dark glauconitic shale. $P_2O_5$ percentage is, however, low (5% to 15%). The nodules develop around a nucleus, which in certain cases may be an ammonite. Several localities of phosphatic nodule localization have been reported out of which the one extending between Khwari and Gandab Khwar is perhaps the most promising.

In Kala Chitta Range, near Chhoi, 20 m thick phosphatic limestone has been noticed in the Kawagarh Formation (Late Cretaceous). The extent and grade of this phosphorite horizon is not available.

Low grade (5% to 20%) phosphatic nodules are also known from the Patala Formation of Paleocene age from various places in eastern and central Salt Range. The occurrences are sporadic and are not commercially exploitable. Phosphatic rocks are also reported from various Cainozoic formations along the length of Sulaiman Range in Middle Indus Basin. Investigations have been made in the Rakhi gorge, where indications of phosphate have been noted in Khadro Formation (Paleocene), Ghazij Group of Eocene age (basal part) and Nari Formation (Oligocene). The Nari portion is important since it has a bed of about 30 cm thick with 20% $P_2O_5$ content. Ghazij horizon contains nodules with 5%-20% $P_2O_5$.

In other areas e.g., Marri-Bugti hills of Middle Indus Basin, Moro formation of Late Cretaceous to Paleocene age is reported to contain phosphatic nodules and pebbles in a heterogeneous lithology of clastics, limestone and chert. One sample gave 11% $P_2O_5$. Phosphatic nodules in the shales of lower part of Khadro Formation (Paleocene) are reported from Pabni Chawki and Naka Pabni in Pab Range in the southern part of Lower Indus Basin. The nodules are scattered or as lenticular layers. All the nodules are not phosphatic and it is sometimes difficult to recognize the phosphatic nodules by appearance only. $P_2O_5$ content is low, between 5%-15%. These deposits are at present uneconomical.

**Marble:** Marble is defined here to include recrystallised limestone, which can take polish and is used as building and decorative stone. Pakistan has fairly large deposits of marble, they are located in the Northern areas, as well as in Chagai, Balochistan; evidently due to the fact that being near to the centres of stress and temperature during orogeny, rocks in the area suffered metamorphism, changing limestone to high quality marble as well as recrystallisation in the limestone beds producing low quality marble.

Important marble deposits are located in small hillocks in the Peshawar basin at Nowshera, Pir Sabak, Gohati and Swabi. Marble occurs in rocks of Devonian age. In the Gilgit-Skardu, large reserves of marble are present. Similarly Reshun marble in Chitral, also in Swat and Malakand (Ahmad, 1965). Among them the noteworthy is that of Bampokha group deposits. From where marble comes to the Punjab a market with a trade name of "Pampakhan Marble". According to Calkins et al. (1981) marble along with dolomite and limestone is widespread in the Chitral District.

Important among these deposits is the Reshun marble, which occurs almost along the full length of the Chitral district area. While fine-grained marble is also available in large quantities in Gahirat, just near the main road between Drosh and Chitral Towns. The other marble localities are in the Bumboret, Rumbur and Biriw valleys of Kafristan. Marble dolomite interbedded with the limestone and shale suitable for Portland cement, is available in the Reshun area. The reserves have not been calculated but seams to the order of millions of tonnes.

Marble of Khyber Agency is in Mullagori territory at two places viz., Shahid Mena and Kambela Khwar. It is developed in the Khyber limestone of probable Precambrian age. The deposits are long known and have been exploited on limited scale since decades. The Shahid Mena marble is generally white, medium to fine grained saccharoidal, calcitic and free from impurities; it is comparable to world famous marble of Carrara, Italy and Makrana, India. Most of the marble is covered with scree from which boulders provide al l easy means of extraction. Only 33 m of bed rock section is exposed in a cliff where more than 65,000 $m^3$ of marble has been estimated by Asrarullah (1963), and The actual reserves must be much more. At Kambela Khwar, about 600 m thick succession of marble of variable quality is exposed over an area of 1.5 km x 0.8 km (Asrarullah, 1963). Exact reserve estimates have not been made but judging from the extent of the rocks, the reserves should be immense. The Kambela Khwar marble varies in colour and quality. It is generally fine grained but some layers are saccharoidal. In upper part of the succession, banded marbles and beds of grey green, yellow and brown marble are present whereas the lower part consists of beds of grey and white marble. Some of the white saccharoidal marble is comparable to that of Shahid Mena.

Marble in the hillocks of Peshawar plain belongs to the reefal development of Siluro-Devonian age (Teichert and Stauffer, 1965). The deposits of Nowshera hills are of poor quality. It is generally argillaceous, ferruginous, and pink to reddish brown with joints, cracks and veinlets of calcite. Large uniform coloured blocks are difficult to obtain. Although reserves are of the order of millions of tonnes but poor quality renders it unsuitable as decorative building stone. The hillock of Ghundai Tarako near Gohati contains white saccharoidal marble of good quality (comparable to Shahid Mena marble) in its northwestern part, restricted to the lower 15 m of the exposed succession. The upper 50 m of the succession contains poor quality marble (Ahmad, 1965). Reserves of good quality marble are estimated at 300,000 $m^3$ (Asrarullah, 1963). Another occurrence of marble is in a hill just north of Manari near Swabi. The hill is composed of grey crystalline limestone and some dark grey siltstone and slate. Most of the marble is of low quality and grey colour white, green and yellow varieties are also found. White marble often containing grey patches, occurs in the western part of the hill in two beds totalling 10 m in thickness. It is medium to fine grained, comparable to Shahid Mena marble chemically. However, numerous joints and fractures and the grey patches degrade its quality. About 35,000 $m^3$ of workable reserves of white marble have been calculated at Manari (Asrarullah, 1963).

**Travertine:** In the southwestern Pakistan, the deposits of travertine referred to as onyx marble are widely distributed in the Eruptive Zone of Balochistan Basin. Travertine is of excellent quality, highly priced and has been a major export mineral commodity in the past. Travertine deposits occur in the area of Chagai between Longitude 62°-65° east. Recent sand dunes in the desert, west of low hillocks often covered by overburden of travertine are interbedded with volcanic rocks of Pleistocene age. The main deposits are located at Zeh, Tozghi, Mashki Chah, Butak, Patkok, Juhli, Anar Malmal and Zard Khan (Ahmed, 1965). Marketable reserves of travertine at all localities (except Zeh) are one million cubic metres plus an additional 0.5 million cubic metres of estimated reserves at Zeh, which have been calculated by using aerial photographs and with out ground check.

Genetically, travertine is considered to be the result of hot-spring deposition related to the latest phase of volcanic activity in the long series of volcanic episodes that characterise the Eruptive Zone. Travertine appears to have been deposited in spring pools on an irregular topography and after subsequent erosion is now found as flat or gently dipping remnants situated as terrace deposits at many levels (Hunting Survey Corporation, 1961). The mineral forming travertine is calcite (Ahmad, 1965) banded in layers of various shades of green, yellow, red and white. Blocks of large size can be obtained. However, the bedding planes and interlayering of tuffs limit the thickness of the blocks (Ahmed, 1965).

Poor quality small occurrences of travertine have recently been located in Laki Formation of Eocene age in Thano Bula Khan area of southern Lower Indus Basin. Travertine occurs in caverns and cavities in the limestone formations.

**Building Materials**

One of the factors in the development of a civilization is strongly protected shelter/home. Today we know the important ancient civilization by remnants of their homes and other buildings, e.g., ancient Egypt, Babylon and Persia. Although we have entirely different raw material from the ancient civilization yet it is as strong as those of ancient raw material and much cheaper too. Natural building material has truly quickened the establishment of long lasting civilizations. Rocks, gravels and sands are widespread in the country and are conveniently used for construction purposes. Gravels are generally obtained from stream beds in the foothill zone of the Indus Basin. The predominant rock type in the area being limestone serve as an excellent parent material to yield good quality gravel which can not be transported far from parent rock and is dumped in the stream beds and piedmonts. The finer sand particles are however carried to the plains, where they are generally deposited as point bars of rivers of the Indus drainage system. Sand deposits are also present along the coastline beaches. Eolian sand deposits are widespread in the Thar and Balochistan deserts. Easy availability of unconsolidated sand from these sources renders it cheaper.

Construction material represented by a large variety of rocks is available in the stratigraphic columns present near populated areas. To name a few better ones, examples, may be given of Parh Limestone, Pab Sandstone, Kirthar Limestone, Nari Sandstone etc., in Lower Indus Basin; Khewra Sandstone Jutana Dolomite, Sakesar Limestone. etc., in Upper Indus Basin; granites of Nagar Parkar Indian Shield remnants; and slates, quartzites and granites of Northern Area can also be made available close to population.

**Clays:** Various earths, compound of silica and alumina having properties of stiffness, viscid and ductile when moistened, having various uses in arts, pipes, porcelain industry. The term clay is used here includes natural earthy fine-grained (grain diameter less than 4 microns) material largely composed of hydrous aluminium silicates which are plastic when wet. Deposits of clay are widespread in time and space in Pakistan. The clays are classified here on the basis of their physical properties and variable uses into four different categories viz, china clay, fire clay, fuller's earth, and bentonite. Clays other than these are grouped as' miscellaneous clays':

***China Clay***: Kaolin also called China clay is located at two general areas of Pakistan deposits of which are found mainly in Swat area near Shah Dheri and Ah1 in Hazara and at Didwa, Parodhra and Dhedvero in the Nagar Parkar area.

In Swat area, Shah Dheri China clay deposits are located 23 km northwest of Saidu Sharif in Swat District. The area is underlain by igneous and metamorphic rocks mainly amphibolites and metamorphosed diorite (Moosvi et al., 1974). The leucocratic quartz diorite occurs as patches, pods, sills and elongate bodies in the country rock. Feldspar in the diorite has been kaolinized forming China clay deposits, which are present as large lenses in two prominent areas at Shah Dheri and Taghma. Small occurrences are also present. Moosvi et al. (1974) have inferred that these deposits are residual resulting from the weathering of leucocratic quartz diorite under humid conditions. Concentration of diorite itself is ascribed to metamorphic differentiation and subsequent accumulation of the felsic material along zones of least stress. The clay is categorised into two categories on the basis of chemical and physical properties. The content of clay in the deposits varies between 16.5% to 31%. The reserves of total raw clay are estimated at about 2.8 million tonnes after allowing for mining loss of 5% and taking the average available clay grade material in the raw clay as 16.5%, the reserves of marketable clay in the deposits are calculated to be 0.5 million tonnes (Moosvi et al., 1974).

The other deposit of China clay is at Ahl, which is smaller, carrying a reserve of only 50,000 tonnes. The clay does not appear to be of commercial grade. It is a product of partial decomposition of feldspar in place during weathering of foliated granite (Cretaceous), which has intruded the schistose country rock (Ali et al., 1964).

In Nagar Parkar area variable quality of China clay is reported, where it is covered with laterite. The deposit extend over a large area, some of them is in lenticular shape. The clay is violet to greyish white. The chemical composition is as under.

At Parodhra it contains 12.14% to 40.9% $Al_2O_3$, 35.2% to 72.3% $SiO_2$ having total reserves at 297,000 tonnes and at other place near Didwa and Dhedhvero, the chemical content are 13.20% to 40.55% $Al_2O_3$ and 26.7% to 59.08% $SiO_2$. Raza et al. (1994) quoting Kela (1980) stated that the total reserves of both of the above mentioned localities are estimated at 616,200 tonnes.

***Fire Clay***: Fire clay deposits are reported from various places and are worked extensively in the Salt Range and Trans Indus ranges. The clay beds occur mainly in Datta Formation (Jurassic) and Hangu and Patala Formations (Paleocene). In the eastern Salt Range, fire clay is found at Manhiala, Wehali and Nali in the basal part of Patala Formation underlying the carbonaceous shales of the formation. Another horizon is in the basal part of Hangu Formation, which is exposed at Dalwal and Karuli

(Ahmad, 1969).

In the western Salt Range, Datta Formation is reported to contain two or three beds of fire clay at several localities viz., Dhak Pass, Manza Bazar, Dama and Gole Wali (Ahmad, 1969). The clay is generally of better quality than that of the eastern Salt Range. Thickness of individual clay beds varies between one and four metres. The Jurassic clay horizons are known to be present westward in the Trans-Indus ranges at Chapri, in Surghar Range and Paniala in Khisor Range (op. cit). Some of these beds are now revised and few more localities are added e.g., fire clay deposits of Doya, Kutki Kachura, Barbara areas of Surghar Range, where lenticular beds ranging from few cm to 10.7 m thick with as much as 47 m long seams are present. Chemical analysis shows $Al_2O_3$ content from 16.4% to 35.59%. Total estimated reserves are 569,700 tonnes.

The following reserve figures for the generalized areas are consolidated from details given by Ahmad (1969) and Hussain et al. (1973).

| Area | Horizon | Approximate reserves in million tonnes |
|---|---|---|
| Eastern Salt Range | Patala | 2.0 |
| Eastern Salt Range | Hangu | 3.5 |
| Western Salt Range | Datta | 5.0 |
| Trans-Indus ranges | Datta | 0.02 |

Thus the total reserves of all categories of fire clay in the Salt and Trans-Indus ranges exceed well over 10 million tonnes.

Raza et al. (1994) quoting Abbasi and Razaque (1977), reported investigation of clays of Sindh covering an area of 9795.45 km2 between Indus River and East Shago-Thero hills in the west, Schwam in the north and Ghoroin in the south. These clays range in age from Paleocene to Oligocene. In Lakhra area, 2 to 5 clay horizons of variable thickness lie above such coal seam. Total reserves of clays in Lakhra coal field are 5.28 million tonnes.

It can be noted from the foregoing description that all the fire clays are associated with formations which have an affinity with carbonaceous accumulation. Patala, Hangu and Laki Formations have well developed coal resources whereas, although Datta Formation does not have economic development of coal but it is carbonaceous everywhere. Indeed, association of fire clays with carbonaceous occurrences is a good indicator for their exploration (Raza et al., 1977).

***Fuller's Earth:*** Fuller's earth has been found mainly in Sind and Punjab and to a lesser extent in NWFP and Balochistan. It is usually used in oil and Ghee Industry, foundries of steel as well as in the insecticide preparations. The main deposits of Fuller's earth are known from Lower Indus Basin. Thick beds of Fuller's earth up to 30 m thick have been observed by Hilal A. Raza (verbal communication) in the Rakhi and Sebdi nallahs in the southern Sulaiman Range, in Domanda member of Kirthar Formation (Middle Eocene) and Baska member of Ghazij Formation (Early Eocene) Presumably these beds extend over wide area along the strike and may form immense reserves of Fuller's earth. Huge reserves of Fuller's earth are also present in area around Thano Bula

Khan in Laki Rage, here it occurs in the Ghazij Group (Tiyon formation of Hunting Survey Corporation, 1961). Since the formation is widespread in the area, the deposits are also supposed to be fairly persistent (Ahmad, 1969). A thick bed of Fuller's earth is found in the Khairpur District at the base of Eocene limestone of Laki Formation. Main deposits of the Punjab are found in the D. G. Khan. Yearly production of the Fuller's earth during 2000-2001 has been 17,579 tonnes from Punjab, Sindh and minor production from NWFP and no production from Balochistan (Nazar-ul-Islam et al., 2003).

***Bentonite*:** Thin beds of bentonite are known to occur at several places in the rocks of Siwalik Group in Upper Indus Basin, associated with beds of volcanic ash. Economically workable bentonite deposits are reported from Qadirpur-Bhilmor and Badhrar in central Salt Range, from Rohtas-Dariala in the eastern most part of the Salt Range, and from Bhimber-Mawa Kaneli and Samwal-Pothi-Kharota in the foothills of Azad Kashmir. Generally, the bentonite beds are not more than a few centimetres thick (Ali and Shah, 1963). The bentonites are white, grey or brown and have a high calcium percentage; they are of non-swelling type. To convert them to swelling type they should be converted into sodium bentonites by base exchange process (P.C.S.I.R., 1963). Origin of bentonites is attributed by Bhola (1947) to re-deposition of devitrified and decomposed volcanic ashes, tuffs and lavas derived from Permo-Carboniferous volcanic rocks in Kashmir, whereas Ali and Shah (1962) considered that volcanic ash was derived from Tertiary volcanism. Cumulative reserves of bentonites at localities are given as 12,000 tonnes per metre of depth by Ali and Shah (1962).

***Miscellaneous Clays*:** Clays, which are used in earthenware works, brick making, mud houses, etc., occur throughout the country, especially in Recent and Subrecent deposits of Indus plains in the valleys of various large and small rivers. It is a common sight to notice such deposits. Details of these deposits are beyond the cope of this report.

**Silica Sand:** Silica Sand deposit are available in all the Provinces of Pakistan. In Punjab large deposits of silica sand are found in the basal part of Datta Formation (Jurassic) of the Khisor and Marwat ranges in Upper Indus Basin. The bed of silica sand is about 20 m thick and is exposed for a length of 16 km from Paniala to Pezu (Siddiqui, 1973). Two analyses have shown that the sand size is medium to fine grained suitable for glass making. Silica content varies between 76% to 97% and ferric oxide between 0.67% to 4.5%. The sand is friable thus easy to mine. Total reserves are estimated by Siddiqui (1973), to be 20 million tonnes up to a workable dip depth of 30 metres. Ahmed and Siddiqui (1993) calculated total reserves of Pezu deposits as 17 million tonnes with the length of the deposits as 6,653 m, average thickness 15 m, assumed depth 60 m, Specific gravity 2.50 and a tonnage factor of 12.8.

Silica sand deposits in Datta Formation are also known from Salt Range near Mianwali (Ahmad, 1969). The deposits are extensive but the details are not known.

Large deposits of silica sand are found in Hazara area near Manda Kuchha village, which is 50 km from Mansehra (Ali et al., 1964). The sand is contained in a 150 m thick succession of metamorphosed calcareous sandstoné resting on biotite-quartz schist. Due to its high carbonate content the sand is not suitable for commercial use in raw form but in view of the large tonnage available it may be worthwhile to evolve a process for upgrading the material. Recently some pockets of good quality silica sand have been discovered in the area. Total reserves of this area are about 155 million tonnes, which has been described under four types of deposits (Ahmed et al., 1993).

Ahmad et al. (1993) have also reported deposits of silica sand from southern part of Lower Indus Basin of which the largest is a 5 to 10 m thick bed carrying reserves of 3 million tonnes located near Unt Palan in Dadu district. Other deposits are at Thano Shah Beg (50 km WNW of Thano Bula Khan) in Oligocene rocks, between Meting and Jhimpir in Eocene rocks and at Jungshahi. There are three separate deposits in this area, Ahmed et al. (1993) calculated separately good and bad deposits, good deposits are 65,000 tonnes and bad quality is 170,000 tonnes. In Balochistan, silica sand is associated with carbonate rocks and occurs in Loralai, Quetta and Zhob districts. The deposits range in thickness from 1.2 m to 4.5 m with all kinds of varieties, length of these deposits is from 1.5 km to as much as 6 km (Ahmed et al., 1993).

**Sulphur:** Balochistan is the only sulphur producing Province in Pakistan. There are two major sulphur deposits one is located around Koh-i-Sultan volcano in the western part of Eruptive Zone. Lenses veins and encrustations of sulphur are found at shallow depth in the southern half of the extinct Koh-i-Sultan volcano about 500 km west of Quetta. Thickness of lenticular bodies varies between 1 to 10 m and is generally 100 m or so in length. The deposits are essentially volcanic in origin and associated with altered porphyritic andesitic lavas, which have undergone a protracted fumarolic or solfataric action during Pleistocene to Recent. Sulphurous exhalations may still be seen from fissures and surface outcrops of sulphur bodies (Muslim, 1971). Reserves as given by Muslim are 738,000 tonnes of 50% grade.

The other deposit is called the Sanni sulphur deposit, where the sulphur is present as veins, encrustations and partial replacement of a sandstone bed in the lower part of Nari Formation (Oligocene) near Sanni, about 125 km SSE of Quetta. The mineralized clayey sandstone bed is 2 m thick underlying an 80 cm thick marker foraminiferal limestone bed (Muslim et al., 1971). Reserves are calculated at 59,000 tonnes of 45% grade. Sulphur mineralization is attributed to ascending hydrogen sulphide, which was perhaps liberated due to action of sulphate reducing bacteria upon the organic matter present in the underlying rocks. Absence of any evidence of volcanic activity and extinct or active thermal springs in the area is taken to rule out the possibility of fumarolic or solfataric origin (op. cit.).

Other than the above-mentioned two main deposits, several small occurrences have also been described by Ahmad (1969). Potential sources for obtaining sulphur have also been indicated which include desulphurization of coal, natural gas containing hydrogen sulphide and anhydrite deposits.

**Barite:** Barite mineralization occurs in Balochistan and NWFP provinces. Commercially, explorable deposits are in the Lasbela-Khuzdar area of the Balochistan Province, where appreciable deposits of barite carrying a reserves of about 14 million tonnes. The deposits can be classified into three categories on the basis of their mode of occurrence (Klinger and Abbas, 1963).

(i) ***Vein deposits***: They are found in shear zones, faults, or tension fractures in Hazara and Lasbela areas and Axial Belt region. Mineable deposits are pod-shaped, often not more than 30 m long.

(ii) ***Replacement deposits***: They occur as replacement bodies in carbonate rocks in Lasbela-Khuzdar area in the southern part of Axial Belt. They exhibit stratigraphic control and are larger and regular than the vein deposits.

(iii) ***Sedimentary deposits***: They are generally present over large areas but have low concentration. They occur as nodules in Jurassic-Cretaceous shales in Lasbela-Khuzdar area. Minor occurrences are also reported from Warchha Sandstone (as detrital grains) and from Sardhai Formation (as nodules) in the Salt Range. These deposits have little economic significance and will not be dealt with here in detail.

Raza and Khan, (1994) state that more than 30 occurrences with zinc lead barite are found in Jurassic carbonates of Lasbela district. Azam et al. (1992) recorded the Duddar deposit being the promising and the best studied one. The Duddar deposit, spread over an area of about 4 km$^2$, is located about 110 km on the unpaved Khurkara-Kanrach Road, which branches off from the RCD highway at 84 km from Karachi. Duddar deposit is composed of two distinct parts, named as North and South Duddar bodies and the Kharrari North and South bodies. The Duddar North body is 250 m long of an average 10 m thickness and consists of siliceous gossans and three barite beds, with each being 2.8 m thick and are separated by hydro thermally altered siliceous rocks. The Duddar South body is 289 m long of an average 10 m thickness and is composed of lensoid beds of barite, siliceous gossans with barite beds, and a zone of siliceous sinter. The Kharrari prospects have relatively complex structure and barite mineralization occurs as fissure/fracture filled veinlets with some galena, and siderite hosted in the west-dipping limestone of the Spingwar Member of the Shirinab Formation. Duddar north-body is of sedimentary exhalative (Sedex) type whereas the Kharrari South prospects are stratiform replacement of limestone beds with mineralization in veins/fracture fillings and in brecciated beds.

The data obtained from the 8 drill holes in the Duddar North body shows that mineralized zone (sulphide and barite together) ranges from 3 m to 79 m in thickness. The ore reserve estimates based upon the drill hole data and their exploration in the surrounding areas suggest total reserve of 1.08 million tonnes (including proven reserve of 272,124 tonnes and indicated reserves of 816,734 tonnes) with about 6% combined zinc-lead concentration. The barite reserves (about 45% concentration) are calculated to be 1.27 million tonnes, including proven reserves of 527,920 tonnes and indicated reserve of 736,824 tonnes.

The other barite deposit at Gunga southwest of Khuzdar, gives estimated reserve of more than 1.4 million tonnes (Klinger et al. 1963). The barite is found as a series of elongate lenses stratified and interbedded with Jurassic limestone and shale in a mineralized zone extending for 1,500 m. The age of mineralization is considered Pre-Oligocene by Shcheglov (1969). There are four principal beds ranging from 90 to 400 m in length and 3 to 25 m in thickness. Bedding within the lenses is parallel with that of the enclosing rocks, which are marked by extensive leaching, oxidation and silicification. The ore is relatively uniform in composition, having an average specific gravity of 4.15 and an estimated barite content of 80% to 90%. Mineral impurities are chiefly calcite and iron oxide. The Gunga deposits have been commissioned for production and a grinding plant has been set up at Khuzdar. Smaller deposit of replacement type barite, occurs at Kundi, about 65 km northeast of Bela in a somewhat similar stratigraphic position. The reserve estimates are given as 13,000 tonnes by Klinger et al. (1963).

Several small vein type deposits are located near Bankhri, 16 km east of Bela Serodhero and Kundi mostly in Winder Limestone where ore occurs as veins in folded thin-bedded sandstone of Jurassic age. The principal deposit is a fissure vein following a shear zone. Thickness of barite varies between a few centimetres to 2 m exposed for about 200 m along the strike and 65 m down dip. The ore is clear dense and of high quality. The workable reserves are small, estimated at 2,000 tonnes. Balochistan is comparatively rich in zinc-lead-barite mineralization that occurs in a narrow metallogenic belt, which extends more than 600 km from Lasbela to Kurram Agency. At present about 30 occurrences have been reported with large and small size. Reserves mentioned above are conservative. Further detailed work in this belt will certainly increase the barite reserve many fold.

In the northern Pakistan, vein type deposit is present in Hazara area, 5 km to the southwest of Kohala, carrying a reserve of about 150,000 tonnes (Klinger et al., 1963). The barite is found with quartz in lenticular veins cutting the slate of Hazara Formation (Precambrian). There are several veins exposed on steep mountain slopes of which the largest is about 300 m long and 5 m thick. Barite in the ore is estimated to be 30% to 95%. Smaller vein type deposits are present in the southern Hazara. One is near the village Kachhi, 20 km northwest of Haripur, present as discontinuous pod-like bodies, 30 cm to 1 m thick and up to 30 m long cutting across the quartzite of Tanol Formation (Palaeozoic). Another locality is near the village Faquir Mohammad, 20 km east of Haripur. Here the veins occur in the Eocene limestone, parallel to the bedding. There are two principal veins, 15 cm to 1 m thick and 12 to 65 m long. The ore contains traces of copper and galena along with quartz. Reserves at the two localities are of the order of 1,500 tonnes (Klinger et al., 1963). Several localities in Khyber agency contain vein and pod shape deposits of barite (Shah and Siddiqui unpublished report). Detailed work could not be done due to restricted movement of the workers in the area.

**Celestite:** Celestite has been reported from Indus Basin only. Major celestite deposits of Pakistan are present in the southern part of Lower Indus Basin located in the north, east and south of the town of Thano Bula Khan. Celestite occurs as veins in fracture zones in the limestones of Laki and Ghazij formations (Eocene). Celestite probably replaced the limestone as evidenced by the presence of remnants of limestone pieces enclosed by Celestite mass (Hunting Survey Corporation, 1961) and by banded character of the deposit (Ahmad, 1963). However replacement of the limestone wall rock has not taken place at all and the finely brecciated limestone has been more extensively replaced than the larger fragments of limestone (Ahmad, 1963). Shcheglov (1969) has argued that the deposits are of infiltration type having originated from descending solutions.

On all average, the celestite ore contains 25 % un-replaced limestone. The ore bodies are lenticular measuring 10 to 50 m, in length and 1 to 2 m in thickness. However, the existence of celestite mineralization can be traced for a distance of more than 30 km (Ahmad, 1969). Content of strontium sulphate in representative samples is between 84% and 89%, whereas selected specimen has given a figure of as much as 99%. Reserves of all categories in the entire celestite bearing area of Thano Bula Khan are estimated at 300,000 tonnes (Ahmad, 1969).

In the Upper Indus Basin small deposits of celestite are reported to occur near Daudkhel, western Salt Range as irregular veins up to a metre thick and, as nodules up to 10 cm in diameter in brecciated limestone. The celestite contains on an average 83% strontium sulphate. The reserves are estimated at about 10,000 tonnes.

**Fluorite:** Fluorite occurrences have been reported from Chitral district in the Northern Sedimentary Province and at several places in the Balochistan Province. In Chitral the source of fluorite mineralization is known in metamorphic rocks. The deposits are small and are located in Yarkhun Valley and Migrant Gol. Fluorite deposits in Chitral are found in small quartz veinlets and are uneconomic.

The Axial Belt fluorite deposits have been worked in some detail, (Bakr, 1962, 1965; Mohsin et al., 1974). They are located mainly in two areas near Johan (80 km south of Quetta) viz., Koh-i-Maran and Koh-i-Dilband forming southwest plunging anticlines, 32 km apart. Small occurrences have been reported from Neghrani, Degari and Mach. Mohsin et al. (1974) have designated this entire area of fluorite mineralization covering 38,000 $km^2$ as "Dilband Fluorite District". More than 25 calcite-fluorite veins, ranging in width from a few cm to more than 2 m and are found in fracture zones of Takatu Formation of Jurassic age. Although calcite veins are present in all the bedrock formations, fluorite has been found only in those veins that are in Takatu Formation (Bakr, 1965). Replacement of wall rock adjacent to veins has taken place and disseminated fluorite grains are found in limestone. Several fluorite and calcite filled solutions cavities have been observed by Moshin et al. (1974), one of which is 2 to 4 m in surface exposure. Fluorite is invariably associated with calcite.

From Maran 94.5% $CaF_2$ grade is reported by Mohsin et al. (1974), have recognized three types of ore from Dilband :

(i) Transparent, colourless, pink or violet, crystalline.
$CaF_2$ more than 97% "acid grade ".

(ii) Translucent, white, yellow, reddish crystalline aggregate.
$CaF_2$ more than 97%" acid grade".

(iii) Opaque brown coloured massive.
$CaF_2$, 80% to 90%. "metallurgical grade".

The second variety is most prevalent in the area.

The origin of fluorite mineralization is the result of replacement by hydrothermal solution accompanied by cavity filling as a minor process. Faults, fractures and bedding planes are considered as the channels for moving solution (Mohsin et al., 1974). They added that the mineralization is restricted only to the upper part of Takatu Formation is explained by the sealing mechanism of the overlying impervious shale of Parh Limestone. Shcheglov (1969) also considered fluorite as of epithermal type. He dated them post-Oligocene (post-orogenic) since they are developed in fracture zones cutting the fold structures.

Mohsin et al. (1974) have calculated the reserves of the deposits at Dilband as 95,500 tonnes ore containing 50% fluorite. Ahmed et al. (1993) gave the reserves at Maran as 1,500 tonnes.

**Magnesite:** Magnesite is one of the few magnesium bearing minerals from which magnesium metal is commercially extracted, other being dolomite and brucite with theoretical magnesia content of 46.6%, 22% and 69% respectively. Olivine is also important magnesium mineral but it is generally used as foundry sand. The magnesite deposits of Pakistan occur in the Axial Belt region and most are of cryptocrystalline variety associated with ultramafic intrusive complex, especially where these rocks have been serpentinized (Van Volten, 1963). Cryptocrystalline magnesite forms as enrichment and fissure filling deposits of hydrothermal origin whereas the crystalline magnesite deposits are the product of replacement reaction between carbonate rocks and ascending solutions associated with magnesium rich igneous rocks. Several cryptocrystalline magnesite deposits are known all along the Axial Belt from Lasbela in the south up to Malakand in the north (op. cit.) Except the Spin Kan deposits near Nisai, 35 km east of Muslimbagh, all deposits are very small or of unknown magnitude. The Spin Kan deposit carries a reserve of 15,000 tonnes. It is a lenticular body 80 metres long and 5 m wide surrounded by serpentinized dunite containing sparsely disseminated grains of chromite. MgO content in the ore is about 45.38 %, silica 0.38% and lime 1.72% in the same general area. Small deposit is present at about 15 km west of Spin Kan deposit Shasi Ghundi. In the southern part in Kalat District near Baran Lak, further 18 km south of Wad village, at Loya impure magnesite is present. Some small deposits are also present in north of Lasbela and in Sindh near Hyderabad. All of these deposits are very small and at present they are commercially uneconomical.

In the vicinity of Sra Salawat, near Muslimbagh, a deposit of crystalline magnesite occurs. The deposit is bedded and folded and grades into Eocene dolomite that unconformably overlies the ultramafic intrusive complex. Rough conservative estimate of reserve is about 10,000 tonnes (Van Volten, 1963).

Karim et al. (2000, 2002) made detailed investigation of magnesite deposits of Hazara and according to them, the largest of all the magnesite deposits is situated in Sherwan area, Hazara. This deposit is known as Kumhar magnesite ore deposits. The deposit has 14 lenticular bodies; among them 2 are the biggest. Total reserves are calculated at 4 million tonnes. The MgO content of the magnesite is 45%.

**Soapstone:** In a simplest term, the talc is generally known as magnesium laminated mineral with a characteristic of being greasy to touch. It is hydrous silicate of magnesium with increased impurities in the talcose material, the product is known as soapstone. In Pakistan one of the largest soapstone deposits of the country is located near Sherwan in Hazara. Soapstone forms irregular bedding-replacement bodies along bedding shears, as well as veins along a set of nearly vertical shear zones, in the dolomite of Abbottabad Formation. Dolomite is the main impurity in soapstone making up 10% to 50% of the material mined. The Sherwan soapstone deposits have been mined fairly well, the reserves are given as nearly 200,000 tonnes.

Deposits of soapstone are found mainly in the Axial Belt carrying a reserve of 600,000 tonnes (Hundal and Gauhar, 1975). Small soapstone deposits are present in Zhob area and occur as hydrothermal replacement veins in ultramafic rocks. Further north in Safed Koh mountain, near Parachinar north of the Kurram Agency, veins replacement layers and pockets of soapstone are present in a sequence of limestone and quartzite of Jurassic to Cretaceous age (Ahmad, 1969).

A few more small deposits of soapstone are mentioned from northern part of Axial Belt and Northern Montane Area at localities Landikotal, Jamrud, Kund, Nauseri and Chalt but the details are not available.

**Other Industrial Minerals**

Small deposits or indications of quartz, feldspar, mica, graphite, asbestos, vermiculite, alum, cinnabar, pyrite and ochres are reported from different parts of country. The details may be seen (Ahmad, 1969). Huge deposits of biotite mica are present in Loe Shilman area in the northern Khyber Agency. If this biotite can be put to any use, it may prove to be an economic deposit.

## GEMSTONES

Most of the gemstone occurrences are reported from the Northern Areas of Pakistan. Although a variety of gemstone occur, but only emerald of Swat is being exploited on a substantial commercial scale at present. The Swat emerald mines are situated near the town of Mingora. The emerald bearing area is composed of low-grade metamorphic rocks of greenschist facies particularly chlorite-mica schist, talc schist, graphite-quartz-mica schist and dolomite-quartz schist which are traversed by quartz veins (Ahmed, 1969). Emerald is found in the soft talc schists, which outcrop for about 1.5 km with an average thickness of 200 m. Emerald crystals occur in irregular clusters or in pockets, which do not have any orderly distribution with in the schist. Occasional emerald crystals are also found to occur in the quartz veins.

Other places where, emerald mineralization is known include Nawe Dand in Mohmand Agency (Ahmad, 1969) and the Tora Tigga (Khattak et al., 1974). At Nawe Dand the country rock is talc schist. Emerald is associated with quartz veins cutting the talc schist. The veins generally follow the foliation planes of the host rock. At Tora Tigga, the country rocks may be divided into a lower unit of grey micaceous schists inter bedded with lenses of limestone and an upper unit of green grey and black schists. A dolomite about 130 m thick occurs between these two rock units and is exposed in two outcrops, about 300 m apart. One of the dolomite outcrops has been yielding emerald from the quartz veins, which traverse the rock. The emerald bearing outcrop is 1,300 m long and 600 m across. Most of the veins are a few millimetres thick but some range in thickness from 10 to 30 cm. The emerald crystals occur in the veins less than 3 cm thick.

Except for the emerald, economic potential of other known gemstones is not yet clear, however, a list of the reported gemstone occurrences is given below:

1. Sapphire-Illaga Khorming, Baltistan Gilgit (Ahmad, 1969)
   Mochel, Padror, Kashmir (Ahmad, 1969)

2. Ruby-Bashe-Highar and Strakin Rondu, Baltistan, Gilgit (Ahmad, 1969). Host rock for ruby is marble.
3. Corundum-Timurgara, Dir (Arbab et al., 1973)
   Shah Dheri and Kalam, Swat (Ali, 1967)
4. Topaz-Katlang, Mardan (Arbab et al. 1972)
   Lutkho Valley, Chitral (Ahmad, 1969)
   Haramosh Range, Iskere Valley, Gilgit (Ali, 1967)
5. Aquamarine-Lutkho Valley, Chitral (Ali, 1967)
   Talash, Dir (Ahmad, 1969)
   Dassu and Khaplu, Baltistan, Gilgit (Ahmad, 1969)
   Indus Kohistan and Kaghan Valley, Hazara (Ali, 1967)
   Kel, Neelum Valley, Azad Kashmir (Ali, 1967)
6. Spinel-Baltit, Hunza Valley, Gilgit (Alam and Cheema, 1973)
7. Tourmaline-Khaplu, Baltistan, Gilgit (Ahmad, 1969)
   Haramosh Range, Gilgit (Ali, 1967)
   Lutkho Valley, Chitral (Ali, 1967)
   Swat area (Ali, (1967)
8. Garnet-Bash-Shigar and Khaplu, Baltistan, Gilgit (Ahmed, 1969)
   Hazara area (Ali, 1967)
   Lutkho Valley, Chitral (Ali, 1967)
   Haramosh Range, Gilgit (Ali, 1967)
9. Vesuvianite-Muslimbagh, Zhob (Ahmad, 1969)
   Several showings of black tourmaline, green garnet, serpentine and actinolite in Malakand Agency and actinolite in lower Mohmand Agency have been noticed. All these mineral showings and occurrences indicate that the environment for the mineralization of gemstones are favourable in the mélange complex or shear zones along sutures.
10. Kyanite-Oghi Fort Hazara (Ali, 1967)
    Landakai, Swat (Tahirkheli, 1959)

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