

GEOLOGY OF HETTANGIAN TO MIDDLE EOCENE ROCKS OF HAZARA AND KASHMIR BASINS, NORTHWEST LESSER HIMALAYAS, PAKISTAN

BY

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ABSTRACT:-The Mesozoic to Eocene sedimentary succession of Hazara Basin dominated by carbonates is characterized by a distinct package of sediments punctuated by a number of diastems, hiatus and unconformities. The Hazara Basin evolved in Hettangian with the development of lagoonal to upper shoreface conditions on the northern margin of northward flying India. It was followed by a thick pile of middle Jurassic to upper Cretaceous sediments representing deposition in supratidal to outer ramp settings. During late Cretaceous the basin was exposed subaerially when the Indian Plate established its first contact at 67 ± 2 Ma with the Kohistan Island Arc. During this time the Kashmir Basin remained exposed.

Sedimentation resumed in Hazara and Kashmir basins with the development of transgressive shoreline and Hangu Formation was formed in Danian. The Hazara and Kashmir basins and adjacent areas experienced the last marine incursion at the close of Danian in which a sequence of carbonates and siliciclastics represented by Lockhart Formation, Patala Formation, Margala Hill Formation and Chorgali Formation were deposited. This was followed by main collision between India and Asia sandwiching the Kohistan Island Arc at 40 to 50 Ma. This collision was followed by retreat of sea, uplift of Himalayas, development of a foredeep and deposition of a fluvial package, by meandering river system, from Himalayan provenance namely Murree Formation.

INTRODUCTION

Fragmentation of the super-continent, Pangaea (e.g. Scotese et al., 1979; Condie, 1984), initiated in Carboniferous to Early Permian (300-250 Ma) resulted into the formation of several plates microplates and a new ocean, Neo Tethys (e.g. Angiolini et al. 2003). The Indian Plate, began its rapid northwards drift across the Indian Ocean from the Southern Hemisphere (Mattaue et al. 1977, 1978, 1986a, b; Farah and DeJong, 1979; Tapponnier, et al. 1986; Searle, 1991) and the Neo-Thethys that stretched from the Pacific to the Mediterranean started to shrink (Mattaue et al. 1977, 1978, 1986a, b; Farah and DeJong, 1979; Tapponnier, et al. 1986; Jaeger et al. 1988; Searle, 1991; Chaudhry et al. 1994b; Valdiya, 2002; Burlini et al. 55-45 Ma (in Eocene). However according to Chaudhry et al. (1994b) the Kohistan Island Arc sandwiched between

2005). A series of volcanic arcs (e.g. Kohistan Island Arc) were generated due to intra-oceanic subduction of the Indian Plate in Cretaceous (Chaudhry et al. 1974a, b; Searle, 1991; Ghazanfar; 1993; Burg et al., 1996, 1997, 2005a, b, 2006, Ahsan, 2008). During Turonian the Kohistan Island Arc accreted to Eurasia. The suturing event is constrained at 102 Ma (Searle et al., 1991). The Indian Plate established its first contact with the Kohistan Island Arc at 67 ± 2 Ma (Bard et al., 1980; Jaeger et al. 1988; Spencer, 1993; Valdiya, 2002; Burlini et al. 2005). This conclusion is further substantiated by Chaudhry et al., (1994b) on the basis of biostratigraphic and sedimentological studies. Many workers (e.g. Dewey et al., 1988; Klootwijk, et al., 1979; Powell, 1979; Searle et al., 1987; Searle, 1991) have accepted that collision occurred at India and Eurasia at 55 Ma. The terminal collision between Indian and Asian Plates according to Spencer (1994)

occurred between 45-40 Ma. The collision between Indian Plate and Kohistan Island Arc is recognized when the Neo-Tethys disappeared and the two continental masses tied up (Spencer, 1994).

The flight of India and its collision with the Asian continent has been studied from many different aspects, such as sea-floor spreading, paleomagnetism, seismicity, structure, stratigraphy, paleontology and sedimentology (e.g. Ahsan, 2008; Ahsan et al., 2001a; Chaudhry et al., 1998a; Chaudhry and Ahsan, 1999a,b; Klootwijk et al., 1985; Latif et al., 1995; Powell, 1979; Patriat and Achaie, 1984, etc). A series of benchmark papers published by Latif (e.g. 1970a and b, 1976, 1980, 1990, and 1995), Marks and Ali (1961), Gardezi and Ghazanfar (1965), Calkins et al. (1975), Latif (1980), Ghazanfar et al. (1987, 1990), Butt (1986, 1987, 1988, 1989), Baig and Lawrence (1987), Baig (1999), Chaudhry et al. (1992; 1994a and b; 1995; 1996a and b; 1998a, b and c; 2000) and Baloch et al., (2002) have contributed to the understanding of lithostratigraphy, tectonics and structure of the Hazara area and partly the Kashmir Basin.

Sedimentary rocks are believed to keep the record of relative sea level changes and provenance of sediments in relation to plate movement and reflect on the tectonic evolution of sedimentary basins (e.g. Pettijohn, 1957; Krumbein and Sloss, 1963; Tucker and Wright, 1990; Reading, 1996; Tucker, 1988). Sedimentological studies of the Hazara Basin with emphasis on microfacies investigations of numerous Mesozoic and Tertiary formations were carried out by Chaudhry et al. (1992, 1994a and b, 1996a and b, 1997a, 1998a, b and c, and 2000), Ahsan et al. (1993, 1994, 1998a and b, 1999a and b, 2000a and b, 2001b, c and d) and Ahsan and Chaudhry (1998 and 1999). Microfacies and palynological studies of Tertiary rocks in the adjoining Kashmir Basin permitted correlation with the Hazara Basin (Ahsan et al. 1998a and b, 1999a and b, 2001b, 2001a, b, c and d). Recently, Ahsan (2008) established microfacies, worked out environments of deposition and diagenesis and interpreted the inferred pathways of geochemical changes in the Kawagarh Formation of Hazara Basin.

This paper documents the geology of Hazara and Kashmir Basins in relation to tectonics of the India and Asia, timing of collision, provenance of the sediments and finally the development of foreland basin. In addition to this, in the last section of this paper, an over view of the tectonic has been presented to understand and constrain sedimentological variations in the area.

REGIONAL SETTING

The Northwest Himalaya is the meeting point of a number of tectonic elements and lines (Fig. 1). From north to south they can be enumerated (Ghazanfar, 1993) as the Asian plate (Desio, 1963, 1964, 1979; Tahirkheli et al. 1979; Bard et al. 1980; Ghazanfar, 1993;), the Shyok Suture Zone (Main Karakoram Thrust, MKT; Tahirkheli, et al. 1979; Ghazanfar, 1993; Heuberger et al. 2007), the

Kohistan Island Arc Complex (Tahirkheli et al. 1979; Bard et al. 1980; Chaudhry et al. 1984; Treloar et al. 1989a, b, 1991; Ghazanfar et al. 1991; Anckiewicz et al. 1998 a,b; et al. 1996, 1998, 2005a,b; Arbaret et al. 2000; Zeilinger et al. 2000; Llana-Fúnez et al. 2005; Garrido et al. 2006, 2007), the Indus Suture (Tahirkheli et al. 1979; Ashraf et al. 1991; Zeilinger et al. 2000) and the Indian Plate margin (Chaudhry and Ghazanfar, 1987, Ghazanfar, 1993) with its cover sequence as the major tectonic elements of northern Pakistan.

The Northwest Himalayas in Pakistan (Bard et al. 1980; Ghazanfar et al. 1991; Ghazanfar, 1993) extends from Main Frontal Thrust (MFT) to Main Mantle Thrust (MMT). Internally they are divided into Outer, Lesser, Higher and Tethyan Himalayas. Each unit is demarcated by a major boundary thrust. The existence of Tethyan Himalaya is being debated (Bard et al. 1980; Tahirkheli et al. 1979; Chaudhry et al. 1983; Fletcher et al. 1986 and Ghazanfar, 1993). Two major rock sequences of the Indian plate comprise the Proterozoic basement and the Phanerozoic cover rocks (Chaudhry and Ghazanfar, 1987, 1993; Ghazanfar, 1993; Spencer, 1994; Chaudhry et al. 1974a, b and c; 1976; 1980; 1983a and b; 1984, 1986; 1987; 1993a, b and c, 1997b and c, 1999, Burg et al., (1996, 1997, 1998, 2005a, b, 2006). The Precambrian basement is subdivided into Salkhalas, Hazara slates and Tanols. The Main Central Thrust (MCT) demarcates two main tectonostratigraphic areas (Ghazanfar, 1993; Spencer, 1994; Chaudhry et al. 1997b and c). In Kaghan the High Himalaya basement composed of metaturbidites, migmatites, pelites, psammites, calc pelites, minor marbles and granitoids is designated as Purbi Nar Group. The Higher Himalayan cover is composed of marbles, dolomitic marbles, pelites, garnetiferous calc pelites, amphibolites and eclogites. Their equivalents in Swat are Manglaur Group (basement) and Alpura Group (cover to basement). In the southern part the Precambrian rocks of the Lesser Himalaya are overlain by Palaeozoic to Neogene cover sequences in various basins like Kashmir, Muzaffarabad, Attock, Hazara, Peshawar and the Salt Range. Molassic sediments fill a wide trough in the extreme south. The Indian platform exposures, for the most covered by alluvium, can be recognized near Sargodha, Chiniot and Sangla Hill and again far to the south at Thar and Nagar Parker in southern Pakistan. These four zones namely Tethys Himalaya, High Himalaya, Lesser Himalaya and Sub-Himalaya in Northwestern and Western Himalayas represent an essential continuity of the geology of Central and Eastern Himalayas.

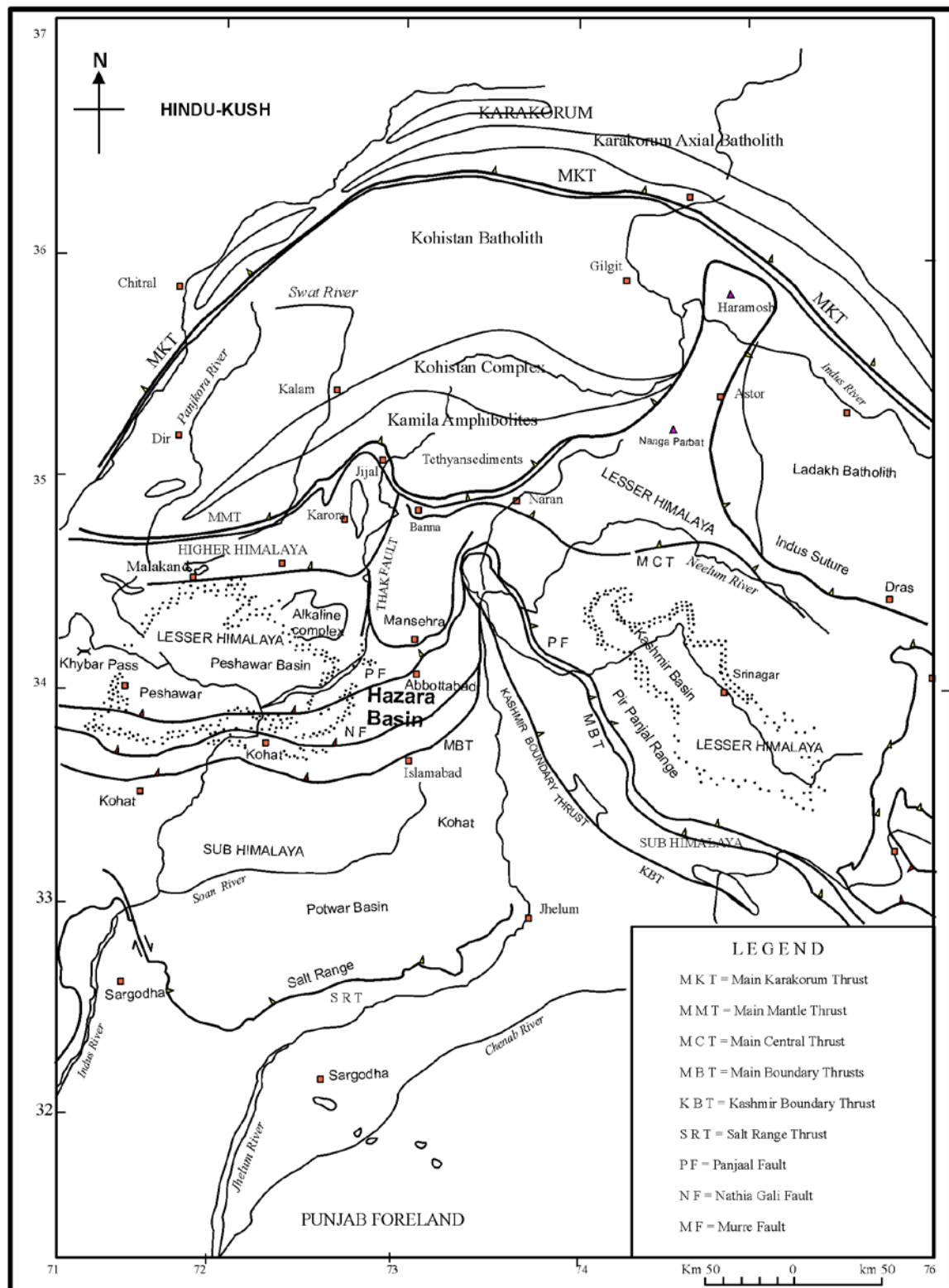


Fig.1. Tectonic map of Pakistan.

After the demarcation of the Main Central Thrust throughout the Northwest and Western Himalaya of Pakistan and Azad Kashmir (Ghazanfar and Chaudhry, 1987; Chaudhry Ghazanfar, 1990; Chaudhry et al. 1997b) it is possible to define and differentiate the major tectonic zones of Higher Himalaya and Lesser Himalaya separated by MCT (Fig. 1). The southern boundary of Lesser Himalaya with Sub-Himalaya is the Main Boundary Thrust (MBT) delineated by the distinctive nature of the red Neogene molasses considered to lie south of the MBT.

The Sub-Himalaya mainly comprises red molassic foredeep deposits of Murree Formation and Siwalik Group which have been disrupted at places to reveal upthrust structures like Balakot - Muzaffarabad and Salt Range. The more tightly folded northern part includes the Poonch, Patehka areas of Azad Kashmir, Kwai (area of Kaghan Valley) and the Rawalpindi Zone of Potwar (Ghazanfar, 1993). The southern less compressed areas have been called the Sialkot Zone in Azad Kashmir and Soan Zone in Potwar (Sokolove and Shah, 1966). The two zones are separated by the Muzaffarabad and Jammu/Riasi zones of uplift in Kashmir and the Khairi Murat anticlinal zone in Potwar. Salt Range is the limiting structure (Lillie et al. 1987) on the southern fringe where the Precambrian rocks have been thrust over Pleistocene fanglomerates along the Himalayan Frontal Thrust, HFT (Yeats and Lawrence, 1984; Lillie et al. 1987). The Sub-Himalaya is generally unmetamorphosed.

Delimited to the north by MCT and to the south by MBT the Lesser Himalaya in northern Pakistan extends in the form of a thick slab covering the areas of Kashmir, Kaghan, Hazara and Swat. The width is attenuated north of Hazara-Kashmir Syntaxis (Bossart et al. 1984, 1988, 1992; Ghazanfar, 1993). The Precambrian and Palaeozoic sediments have in general suffered low grade metamorphism and are overlain by younger sediments in large basins (e.g., Peshawar Basin, Hazara Basin and Kashmir Basin) and by high grade Precambrian metasediments and gneisses occurring as nappes eastwards in Shimla and Gharwal Himalaya. There is a general tectonic inversion, from north to south of metamorphic grades. The mainly brittle deformation is characterized by tight to overturned folds and imbricate faulting. The Lesser Himalaya is broadly subdivided into two zones (Ghazanfar, 1993).

The northern metamorphic zone includes the terrain between Luat and Nauseri in Neelum Valley, between Batal and Tutan in Kaghan Valley, between Banna sequence and Panjal fault in Northern Hazara, and the whole of Peshawar

Basin including the terrain between Malakand and Attock-Cherat (Ghazanfar, 1993).

The southern sedimentary zone extends around Nauseri in Neelum Valley (Autochthonous Fold Belt), between Tutan and Paras in Kaghan Valley, between Abbottabad and Murree in Hazara area and the Cherat Kalachitta and Kohat Ranges (Attock Hazara Fold and Thrust Belt, AHFTB). This zone of Precambrian to Eocene rocks is broadly correlatable with the Tibetan Tethys sediments which occur between the Higher Himalaya Crystalline and the Indus Tsangpo Suture Zone (e.g. Burg et al. 1987; Ghazanfar, 1993; Kazmi and Jan, 1997; Anczkiewicz et al. 1995, 1998a, b).

Geologically, the area of Northern Hazara lies between the Panjal Fault in the south, MMT in the north and between the Panjal Fault/MBT in the east and the Indus River on the west. This is the area where the Tanol sequence and Mansehra Granite outcrop. It is tectonically characterized by E-W faults that bend northwards on the sides to merge into the N-S Panjal and Thakot Fault. The arcuate trends of the Tanol region of Northern Hazara have been noted and some faults marked since the work of Calkins et al. (1975). More recently Coward et al. (1988) and Treloar et al. (1989a, b) have interpreted the Northern Hazara as an imbricate thrust pile.

The sedimentary zone of Southern Hazara comprising of a thick foreland sedimentary sequence is exposed as a wide belt to the south of the metamorphosed hinterland. The wide belt may be subdivided into a northern Cambrian to Eocene sequence between the Panjal Fault and the MBT and further to the south a Miocene and younger foredeep molasses sequence between MBT and MFT. This shelf sequence is part of the Lesser Himalaya and will be discussed here.

The Lesser Himalaya shelf sequence covers the areas of Galiat, Margala Hills, Kalachitta, Attock-Cherat, Kohat and Parachinar in the form of a wide E-W trending belt which turns northeastwards to converge and close into the western limb of Hazara-Kashmir Syntaxis at Garhi Habibullah, in the east. This is the Attock Hazara Fold-and-Thrust Belt (AHFTB; Ghazanfar et al. 1987, 1990) of which the Hazara Basin constitutes a northeastern part. The Precambrian to Eocene rocks of this synclinorium have been folded into tight to overturned folds and imbricated by numerous high-angle thrusts and normal faults. This basin was studied along the Abbottabad-Murree road between Abbottabad and Kuza Gali. Detailed mapping at 1:9500 was carried out along 3 to 8 km wide sections between Abbottabad and Nathia Gali and in the Langrial area, the structure was unravelled and stratigraphic sections

measured (Ghazanfar et al. 1987, 1990; Ghazanfar, 1993; Baloch et al. 2002).

The stratigraphy of the southern Hazara i.e., Galiat including the Margala Hills to the south has been summarized by Wadia (1975) and Shah (1977). It was worked out by Waagen and Wynne (1872), Middlemiss (1896), Latif (1970a, b), Calkins et al. (1975), Ghazanfar et al. (1990) and Ghazanfar (1993). Ghazanfar (1993) carried out large-scale mapping including section measurement and worked out the structure and tectonics of the area. Ghazanfar et al. (1987) correlated the stratigraphy of southern Hazara with Muzaffarabad and Pir Panjal areas of Kashmir to the north.

HETTANGIAN TO MIDDLE EOCENE GEOLOGY

Rocks of the study area belong to Paleozoic to Eocene strata (Table 1) exposed in Attock Hazara Fold and Thrust Belt and Azad Kashmir that itself is a part of Northwest Lesser Himalaya (Fig. 1). Many workers (e.g. Waggen, 1872; Waagen and Wyne, 1872, Wadia, 1931; Gardezi and Ghazanfar, 1965; Fatmi, 1973; Latif, 1970a, b, 1980; Shah, 1977; Butt, 1986, 1987, 1988, 1989; Ghazanfar et al., 1986, 1987, 1990; Baig and Lawrence, 1987; Kadri, 1995; Chaudhry et al., 1998a; Baig, 1999; Ahsan et al., 2001d; Ahsan, 2008, etc) have discussed the geology of the area. Their work shows that internal, lateral and vertical thickness and facies variations are common in these sediments. A comprehensive description and comparison of lithostratigraphic units of Hazara, Khanpur Dam area, Fauji Cement Factory located near Brahama Bhater and Neelum Valley in Azad Kashmir is given below. The measured section representing Tertiary formations exposed in Neelum valley, Azad Kashmir (Lat 34° 23' 25"N; Long 73° 28' 25" E) have been presented whereas references for the lithostratigraphic units that belong to Hazara Basin have been cited in the text.

Datta Formation

During upper Hettangian, after a break (Cambrian to Early Jurassic) in deposition, the Hazara landmass again changed into a marine basin (Chaudhry et. al., 1998a; Chaudhry and Ahsan, 1999a; Ahsan, 2008) with the development of a transgressive shoreline marked by the deposition of the siliciclastic Datta Formation. It overlies either Upper Proterozoic Hazara Formation or the Cambrian Hazira Formation (Chaudhry et. al., 1996a; Manzoor et al., 1996) or Sanghar Gali Formation of Ghazanfar (1993). In the northern part of the Hazara Basin the Datta Formation rests directly on the Cambrian sequence of the Hazira Formation but southwards the Datta Formation rests successively on older Formations until south-east of Thandiani it onlaps directly on the

Precambrian Hazara Formation. In the Salt Range the Datta Formation (e.g. Shah, 1977) is of much thickness (about 150m thick) and of continental origin containing plant remains and carbonaceous matter and giving a variegated color. In the Hazara area, today 100 km, to the north of the Salt Range the thickness of the Datta Formation is greatly reduced (2.6m near Thai) and it changes to a marine facies. It is not exposed in Khanpur Dam section.

In the southeast Hazara the best-developed outcrop (18.40m thick) of the formation is exposed at Jaster Gali (Chauhan et. al. 1992) on the Abbottabad Nathiagali Road. It generally represents all the lithological variations in the Datta Formation in Hazara Basin. According to Chaudhry and Ahsan (1999a), at Thai further north the Datta Formation is poorly developed and only 2.6m thick. Thus from south in the Salt Range to north at Thai, the Datta Formation progressively thins.

The Datta Formation in the south-east Hazara is composed (Chaudhry and Ahsan, 1999) of gritty sublithic arenites, gritty arenites, arenaceous limestones, bioclastic wackestone, oolitic and pelletoidal wackestones – packstones with occasional dolomitic, marly and shaly horizons. The sandstones are cross-bedded at places. Microconglomerate occurs in the basal portion and contains slate clasts derived from the underlying Hazara Formation. Laterite bands and coaly layers occur at places. Fireclay is also intercalated at places.

Chaudhry and Ahsan (1999a) grouped the above mentioned microfacies of Datta Formation under four standardized lithofacies that include carbonate facies, argillaceous facies, arenaceous facies and ferruginous hardground facies. In all, this predominantly clastic shoreface lithostratigraphic unit is intercalated with the lagoonal shale beds, carbonate shoals, lagoonal pelletoidal limestone horizons, glauconitic subtidal sandstone, minor shallow tidal channels and barriers which indicate cyclic deposition. The study of heavy mineral suits, their quantities, and shapes suggest a recycled origin of the clastic part of the Datta Formation from metamorphic sialic part of the Indian continental Plate (Chaudhry et al. 1998a). The average lithified rates of sedimentation were 2mm/1000 years. The very low rates of sedimentation are due mainly to frequent breaks in sedimentation.

Contrary to the description of Shah (1977) the Shinawari Formation can hardly be identified as a distinct lithostratigraphic unit in Hazara. In Bagnotar section, Shah (1977) reports 25 m thick Shinawari Formation, whereas study by Chaudhry and Ahsan (1999a) does not support this observation. Moreover, the formation does not outcrop in Khanpur and Fauji Cement Factory area.

Table 1
Stratigraphic Table of Hazara Basin, Margala Pass, Fauji Cement Factory and Nelum Valley

Age	Hazara Basin		Margala Pass	Fauji Cement Factory, Brahama Bhater	Neelum Valley Azad Kashmir	
	Galiat	Khanpur Dam Area				
Middle Eocene to Miocene	Not Exposed	Not Exposed	Not Exposed (?)		Murree Formation	
Early to Middle Eocene	Kuldana Formation	Kuldana Formation			Kuldana Formation	
Early Eocene	Chor Gali Formation	Chor Gali Formation			Chor Gali Formation	
Early Eocene	Margala Hill Formation	Margala Hill Formation	Margala Hill Formation	Margala Hill Formation	Margala Hill Formation	
Late Paleocene	Patala Formation	Patala Formation	Patala Formation	Patala Formation	Patala Formation	
Middle Paleocene	Lockhart Formation	Lockhart Formation	Lockhart Formation	Lockhart Formation	Lockhart Formation	
Early Paleocene	Hangu Formation	Hangu Formation	Hangu Formation	Hangu Formation	Hangu Formation	
Late Cretaceous	UNCONFORMITY					
	Kawagarh (Jabri) Formation	Kawagarh (Jabri) Formation	Lumshiwal Formation	Lumshiwal Formation	UNCONFORMITY	
	Early Cretaceous to Middle Cretaceous	Lumshiwal Formation				
	Late Jurassic to Early Cretaceous	Chichali Formation	Lumshiwal Formation	Chichali Formation		Chichali Formation
	Middle Jurassic	Samana Suk Formation	Samana Suk Formation	Samana Suk Formation		Samana Suk Formation
	Early Jurassic	Datta Formation	Datta Formation	Datta Formation		Not Exposed (?)
	UNCONFORMITY					

Samana Suk Formation

The Samana Suk Formation (Shah, 1977) generally represents an epicontinental intertidal environment. The formation is generally medium grey on fresh surface. However, fine-grained horizons give darker shades of medium grey. At places, the limestone shows a brownish tinge on weathered surface. It is well bedded and the individual beds being generally 40 cm to 60 cm in thickness. Some parts show thick intercalations of thinly bedded marl or shale between massive beds. The bedding planes of some massive beds in south at Kundla are particularly irregular with pits and protuberances. The limestone is medium grained but fine-grained horizons towards top break with conchoidal fracture. The occasional fine-grained texture and lighter grey weathering may be confused with Kawagarh limestone. Yellow dolomitic patches, streaks, and bands are present especially towards the lower and middle parts. Oolites, pellets and intraclasts are common alongwith or without bioclasts. They are generally difficult to recognize in the Ayubia area. Oolites are well developed near the base and top.

At places, medium grained quartz bearing beds are exposed. A 30 cm thick bed composed of flat pebble conglomerate occurs near Thai. The pebbles are generally 4 cm to 5 cm long. The matrix contains sub-rounded to subangular detrital quartz grains. Gastropods and pelecypods oyster-bearing beds occur frequently. Horizontal, inclined, vertical and U-shaped burrows are common. Burrow infill has been dolomitized and shows positive relief. Other sedimentary structures such as ripple marks and cross bedding are common. Laterite encrustations are dark brown to blackish brown and occur at most places. Scours are now filled with dolomite and are augen shaped. Towards the top, near Neil Gadri, Khanpur Dam area, Margala Pass section and Fauji cement factory belemnites are pricked in the beds. Flat pebble conglomerate beds occur in Thai and Khanpur Dam areas. Some carbonaceous layers also occur at places. The formation is highly folded. Its estimated thickness is about 160m near Biran Gali.

As described earlier the formation contains oolites, pellets, intraclasts and bioclasts. These allochems occur in many combinations in the formation. Thus, this limestone, of all the limestones exposed in the Hazara Basin, contains maximum number of microfacies (Chaudhry et al. 1998a). Besides this, angular to subrounded detrital quartz occurs in association with pellets, oolites and intraclasts in some cases in the in the Samana Suk Formation. The oyster topped beds and hard grounds represent slow rates of deposition and subareal exposures (Latif, 1970a). The average lithified rates of sedimentation according to Chaudhry et al., (1998a) were about 6mm/1000 years. The

low rates of sedimentation may be due to frequent breaks in deposition. On the basis of fauna it ranges in age from Toarcian to Collovian. The lower contact of the Samana Suk Formation with Datta Formation is sharp but normal. The upper contact with Chichali Formation shows minor disconformity and lateritization. One such horizon is exposed around Thandiani.

In the Kashmir Basin the Samana Suk Formation is absent.

Chichali Formation

It is separated by Callovian disconformity (Shah, 1977) in the Hazara Basin from the underlying Samana Suk Formation. The unit is exposed at a number of places in the studied area as thin bands. However, near Kundla the exposure is fairly wide. The formation is composed of blackish grey to grey splintery shale. It weathers to brownish black to rusty grey shades. However, khaki colored shale belonging to this formation is exposed near Harno. Ferruginous concretions, silver yellow pyrite nodules with rusty brown to rusty black weathering are also present. At places, shale contains rounded or elliptical variegated clayey nodules with concentric layers. At places, subordinate beds of sandstone are present. Petrographically, sandstone is composed of arenites that are cemented with quartz, calcite, clay or glauconite. Quartz is fine to coarse grained. Glauconitic horizons are also present at places. Parts of Chichali Formation are fossiliferous (Iqbal and Shah, 1980) and in Hazara Basin it hardly contains fossils. However, near Margalla Pass and Brahama Bhater it contains belemnites. Because of its incompetent nature, the shale is commonly squeezed and forms topographic depressions. Its thickness may vary from 33 m to 64 m (Shah, 1977; Iqbal and Shah, 1980).

The formation was deposited in a restricted anoxic environment during Oxfordian to Kimmeridgian time (Shah, 1977). The lithified sedimentation rates are 2.3mm/1000 year (Chaudhry et al., 1998a).

The Chichali Formation has not developed in the Kashmir Basin and Khanpur Dam area. In Khanpur Dam area, Lumshiwai Formation rests unconformably over Samana Suk Formation.

Lumshiwai Formation

Being absent in the Kashmir basin, the Lumshiwai Formation comprises four principal lithologies that include sandstone/quartzite, marl/shale, arenaceous limestones and arenaceous dolomite in the Hazara basin. Some impure glauconitic sandstone, brownish grey on fresh surface and yellowish brown on weathered surface alongwith some shales occur also. Towards the base, where the formation has gradational contact with the underlying formation (at

Borian and Kundla) belemnite, ammonite and brachiopod rich horizons occur at places. The shaly/marly horizons are rusty brown to maroon purplish and black in colour. At places, intraformational breccias and conglomerate with angular monocrystalline and polycrystalline quartz clasts occur that range in size from a few millimeters to 20 cm or even more in size. One such horizon is exposed in Toot Gran village on Abbottabad Nathia Gali Road. The conglomeratic zone is followed towards the top by siltstones and shales. The siltstones and shales are dark grey on fresh surface and yellowish brown on weathered surface. The shales are splintery while the siltstones occur as relatively massive beds, some of which are lenticular and grade into shale.

In the Khanpur Dam area, the formation is about 1m thick and is composed of coarse grained ferruginous quartz arenites. It contains paleo-channels at the base and elsewhere elongated clasts of Samana Suk Formation are embedded in coarse grained sandy matrix. Here, this unit appears to show time transgression. In Margalla Pass area the formation contains a number of hard grounds marked by intact and abraded pelecypod shell lags that occur at the top of every bed. The formation here is composed of medium to coarse grained quartz arenites cemented with silica and iron oxides. The beds vary in thickness from 30cm to more than 1m. Minor shaly horizons also occur at places.

Chaudhry et al. (1998b) and Ali et al. (2000) described twelve lithofacies from Kundla that include lower grey sandstone facies, fossiliferous limestone facies, phosphatic glauconitic sandstone facies, sandy shale/carbonaceous sandstone facies, lower grey sandstone facies, silty sandstone facies, green sandstone facies, light grey sandstone facies, carbonaceous sandstone facies, hard-ground facies, upper grey sandstone facies and grey arenaceous carbonate facies. Ahsan et al., (1999a) described fourteen microfacies from Jhameri Village section. They grouped these microfacies into three facies on the basis of grain size. According to Chaudhry et al. (2000), the Lumshiwal Formation is composed mainly of quartz arenites at Karlan Bazar. Fine-grained quartz arenites are represented by 57% of samples. Fine to medium grained quartz arenites were minor and represented by 14% of the samples. Remaining samples were medium grained.

Ahsan and Chaudhry (1999) presented a comprehensive study of the Lumshiwal Formation of Hazara Basin. According to them the formation is composed of glauconitic arenite, quartz wackes, arenaceous limestone, arenaceous dolomites and oolitic limestones. Shales/marls are minor. Diastems at places are marked by submarine hard-grounds. These horizons are cemented with iron oxides and may occasionally contain colophonite or

dahalite. Heavy mineral suit indicates derivation from a low relief area on the Indian Shield to the south.

Strongly reducing conditions changed to mildly reducing environment with better circulation in the Thithonian to deposit the Lumshiwal Formation (Ahsan et al. 2001c). The ubiquitous glauconite indicates slow rates of deposition. The average lithified rates of deposition were about 0.96mm/1000 years (Chaudhry et al. 1998a). Frequent breaks in deposition are responsible for low rates of sedimentation. The age of the formation is Thithonian to Lower Turonian. In Khanpur Dam area it can be recognized as a time transgressive unit.

Kawagarh (Jabri) Formation

One of the tectonically significant formations of the Hazara Basin, the Kawagarh Formation, shows two distinct facies (Ahsan and Chaudhry, 1998) north and south of the Nathiagali Fault. The northern facies are exposed near Giah (Chaudhry et al., 1992a), Borian (Ahsan et al., 1993a) and Kala Pani (Ahsan et al., 2001a) whereas the southern facies outcrop at Changla Gali (Ahsan et al., 1994) Jabri (Ahsan et al., 1993b) and Khanpur Dam area. In Kashmir basin and Margalla Pass (Ahsan et al. 2000) section and Fauji Cement factory setion at Brahama Bhat the formation has not developed.

The Kawagarh Formation in the sections north of the Nathiagali Fault is mainly thick bedded, fine grained and medium to dark grey limestone. The basal part is relatively coarse grained on fresh surface. It is whitish grey or yellowish grey on weathered surface. The middle part is medium to thick bedded, medium to dark grey and breaks generally with conchoidal fracture. The basal portion at Kala Pani is nodular. The upper part of the Kawagarh Formation at Giah is generally coarse grained and somewhat arenaceous. A few yellow dolomitic bands are also present within Kawagarh Formation. In the Khanpur Dam area the formation contains centimeter sized solution holes that indicate the effects of subareal weathering at Cretaceous Paleocene boundary. In this area the top portion of the formation is dolomitized and shows sugary texture with distinctive brownish to blackish weathering colours whereas base is marly.

South of the Nathia Gali Thrust the upper part of Kawagarh Formation is marly and intercalations of marl are also present. This part is especially well developed on the Dunga Gali pipeline road and at Changla Gali. The marly part is dark grey to yellowish grey on fresh surface and relatively more yellowish on the weathered surface. The marly part has a dark grey colour on the fresh surface. Near Kundla the base of the Kawagarh Formation has a slightly

irregular surface with some pebbles and few inches to about one foot long worm tracks.

In the Khanpur area the formation contain cleaved marls at the base. The topmost beds of the formation that underlie the Cretaceous Tertiary unconformity contain iron stained solution holes. These holes are 5 to 6cm in radius and penetrate downwards in the underlying beds. The Kawagarh limestones contain millimeter sized burrows that can easily be recognized on the outcrop. It contains dolomite beds at the base and at places top beds are also dolomitized.

Plankton foraminifera, shelly fauna and calcispheres are the major skeletal components of the Kawagarh Formation. Filaments, echinoids, ostracods, bryozoans and textularia constitute the shelly fauna that occur as skeletal debris. Three genera, *Pithonella sphaerica*, *Pithonella ovalis* and *Pithonella perlonga*, of calcispheres are recognized (Ahsan, 2008).

The study of the Kawagarh Formation in the Hazara Basin shows that it is generally composed of seven microfacies (Ahsan, 2008) that include Planktonic foraminiferal-calcispheres wackestone (and packstone), Planktonic foraminiferal-shelly faunal wackestone (and packstone), Shelly faunal mudstone and wackestone (and packstone), Calcispheres-planktonic foraminiferal wackestone (and packstone), Dolostone, Planktonic foraminiferal wackestone (mudstone and packstone) and Marl.

The Kawagarh Formation, according to Ahsan (2008) needs a new nomenclature as existing type locality and division into two members (Shah, 1977) is indistinct. By itself, the designated type section is structurally disturbed and the two members indicated by Shah (1977) could not be recognized in Hazara Basin. Two lithologies, carbonates and marls occur in parts of the study area. The Jabri section (73° 10' 1.5" E; 33° 5' N, 43G/1) with good lithological contacts may be preferred as type section in Hazara Basin with a new nomenclature as Jabri Formation (Paper in preparation by Ahsan and Chaudhry) instead of Kawagarh Formation. Moreover all the 7 established microfacies outcrop at Jabri.

The petrographic analyses indicate that the Kawagarh Formation carbonates have undergone a complex diagenetic history encompassing compaction, minor cementation and dolomitization (Ahsan, 2008). Depletion in $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ as well as Sr and Na and elevated Fe and Mn content confer a meteoric diagenetic environment with minor contribution from an outside source (Ahsan, 2008). Ambient sea surface temperature of about 27°C to 33°C is estimated for warm tropical waters in which Kawagarh

Formation was deposited. Trace elemental variations and stable isotopes compositions are interpreted to reflect meteoric and burial diagenetic processes for the precipitation of dolomite at 38°C to 54°C temperature (Ahsan, 2008).

According to Ahsan (2008) the base of the Kawagarh (Jabri) Formation is marked by the occurrence of *Globotruncana helvetica* followed by *Globotruncana sigali* at Turonian, at Giah, Borian and Kala Pani sections. Lower Coniacian is recognised by the presence of *Globotruncana sigali* in Jabri and Changla Gali sections. Last zone of the Kawagarh (Jabri) Formation is *Globotruncana gansseri* in the Lower Maastrichtian. On the basis of paleoecological information rendered by planktons, shelly fauna (especially filaments) and calcispheres the formation was deposited on a homoclinal ramp, (middle to outer ramp settings) at about 23°S (Ahsan, 2008). The average lithified rates of sedimentation were about 9mm/1000 years that compares favorably with the American and European chalks (Chaudhry et al. 1998a).

Hangu Formation

Laterite and fireclay are predominant lithologies of the Hangu Formation. However, subordinate carbonaceous shales and sandstones are also present at places. The laterite is reddish brown to reddish black or reddish grey or even grayish on fresh surface and reddish brown, dark grey and rusty brown on weathered surface. The fire clay is pale white and earthy grey on fresh surface and yellowish brown to rusty brown on weathered surface. Horizons of ball clay are present near Khaira Gali. Well-developed pisolites also occur in laterites. Carbonaceous shales are dark grey to black. Quartzites are dominantly white but variegated coloured quartzite may occur also.

In the Kashmir area the basal microfacies, black shale, marks the on set of a transgression that deposited 227 cm thick black shale. The formation consists of coarse to fine grained clay/iron oxides cemented quartz arenites at the base which grades to silty coal to the top. The top of the Hangu Formation contains bauxitic clays that vary in color from off-white to black and weathers to rusty grey to orange.

In Khanpur Dam area, the Hangu Formation is maroonish to red coloured laterites and khaki to grey coloured shales. Poorly developed pisolites can be recognized associated with laterites. At places, it contains about 35cm thick coarse grained sandstone beds. The laterites are mined for use in nearby cement factories.

The upper and lower contacts of the formation are unconformable. It does not contain fossils however some plants remains are present. The Lockhart Formation unconformably overlies the Hangu Formation. The lithified

rates of sedimentation were 1.77mm/1000years (Chaudhry et al., 1998a).

Lockhart Formation

The formation is light grey, pale grey, bluish grey and blackish grey on fresh surface while the weathering colours are generally dirty grey with dark patches but pale grey and rusty grey patches are also seen. On the outcrop it is fine to medium grained and gives foetid smell on freshly broken surface. The limestone has a fair amount of marly intercalations. These marly intercalations are generally upto 8 cm thick and weather pale grey. Southeast of the Nathiagali Fault, in the section between Kuza Gali and Changla Gali, the limestone is found frequently intercalated with marls. Shales have not developed.

In the areas northwest of the Nathiagali Fault, the limestone is dark grey and weathers to bluish grey. At the base the limestone is massive (upto 2m thick), coarse grained and does not contain marly intercalations. The middle part is medium bedded and marly horizons are absent. However, towards the top the formation is highly nodular and contains marls around the nodules. Limestones are composed of foraminiferal mudstones, wackestones and packstones. The lithified rates of sedimentation were 30mm/1000years (Chaudhry et al., 1998a). Ahsan et al. (2000a) have described one such outcrop near Ghumawan.

Lockhart Formation, according to Ahsan et al., (2001e), near Chahla Bandi, in Neelum Valley Azad Kashmir, is light grey, pale grey to khaki grey, bluish grey and blackish grey on weathered surface and dark grey on fresh surface. It is about 72.80 m thick nodular limestone with intercalations of marl/shale. Nodules vary in size and are poorly developed. These nodules are smaller than that of Margala Hill Limestone. At places the intercalations of grey colored carbonaceous material occur within the limestone. Lithologically, the formation can be divided into two parts: i) Nodular limestone that contains marl and shale intercalations. The nodules vary in size. The calcite veins occur in the marl between the poorly developed nodules; and ii) Massive to thick-bedded limestone having no intercalations of shale or marl. In this part the nodules are not clearly visible. At the contact with the Hangu Formation the formation is splintery and contains orange patches, and upward it grades into thin-bedded limestone.

Patala Formation

In the Hazara and Kashmir Basins the conditions changed from carbonate shelf to siliciclastic depositional environment that deposited Patala Formation. The formation is composed of shale and occasional limestone bands with abundant larger benthic foraminifera of upper Paleocene to lower Eocene age. The shales are khaki, yellowish brown to yellowish grey on weathered surface

and on the fresh surface they are khaki to grey. At other places, the shales are greenish brown or greenish grey on fresh surface and brown to dark brown on the weathered surface. They have been called khaki shales after their colour (Latif, 1970). Pyrite nodules 1 to 2 cm across are present at some horizons. The shales are splintery and some marly bands near the contact with the Lockhart limestone are present. Some times splinters take on the shape of small brittle flakes. Within the body of the shales subordinate lithologies, both arenaceous and calcareous, occur in the form of thin bands. In the Khanpur area it contains various hard grounds. The lithified rates of sedimentation were 30mm/1000years (Chaudhry et al., 1998a).

Margala Hill Limestone

During Ypresian the siliciclastic basin developed into a carbonate platform and deposition of the Margala Hill Formation took place. The formation (Shah, 1977) is mainly a fossiliferous, medium grained to fine grained nodular limestone with marly horizons. It is bluish grey and yellowish grey on the weathered surface and on the fresh surface is generally dark to blackish grey. The lower part may contain frequent marly horizons. The nodularity of Margala Hill Limestone is more prominent as compared to the Lockhart limestone. Generally the limestone is medium grained but fine-grained horizons occur which may break with sub-conchoidal fracture. Some pyritic nodules are observed which contain weathered limonitic powder. Sometimes they show hollow cavities. Ahsan et al. (1998a, 200b) described the Margala Hill Limestone from Khaira Gali that contains twelve lithofacies units, separated by eleven marly horizons. These lithofacies contain 45% foraminiferal wackestone facies, foraminiferal mudstone and foraminiferal packstone facies (19% each) and 17% marly facies. The entire formation is free of oolites and pellets. Sedimentary structures like ripple marks and cross bedding are absent. Basal beds are bioturbated. The lithified rates of sedimentation were 62.5mm/1000years (Chaudhry et al., 1998a).

The Margala Hill Limestone at Chahla Bandi, Azad Kashmir (Chaudhry et al., 2001) is composed of light grey to dark grey limestone. The formation at the base is thinly bedded. It is overlain by calcirudite that contains abundant pelecypode shells. Some shells are reworked. Highly fissile dark grey shale overlies the shelly beds and contains marcasite nodules. The shale is followed by highly nodular limestone. The nodules are upto 30 cm x 50 cm x 13 cm and contain very thin shale partings. This zone is 29m thick. It is very dark grey in color and gives very strong fetid smell. An argillaceous marly limestone that is 28 meters thick overlies the dark grey limestone. It is overlain by medium bedded to highly nodular limestone towards the top of the formation. This zone is grey and weathers to light

grey. On the basis of petrographic and field observations the formation is divided into six facies.

Chorgali Formation

The Margala Hill formation passes upwards with a gradual change of facies into the Chorgali Formation. The formation outcrops near Khaira Gali and Rati Gali, south of the Nathiagali Fault in the Hazara Basin. The formation comprises of limestone, marls and shales. The shale is khaki to off-whitish grey. The limestones are light grey on fresh surface, weather to pale grey and are nodular. The size of the nodules is smaller than that of Lockhart limestone or Margala Hill formations. They generally contain marl around the nodules. The nodule size is generally 2 cm x 4 cm at places. The limestone is rarely massive and generally shows a flaggy habit. The beds are usually less than 8 cm in thickness. The flaggy habit is due to the increasing marly intercalations. At places, the limestones are fine grained and break with conchoidal fracture. Occasionally, these limestones weather to a chalky appearance. The marls are generally cream to off-white in color and sometimes give light shades of grey. The argillaceous content increases upwards, which may range from argillaceous limestone to calcareous mudstone.

The Chorgali Formation in Neelum valley, Azad Jammu and Kashmir (Ahsan et al., 1998b) is 60.75m thick. It is mainly composed of medium grey shale and silty shale, light grey to dark grey foraminiferal mudstone to packstone, dolomitic limestone and dolomite. No grainstone was observed. The limestone is thin to thick bedded and contains occasional nodules.

According to Ahsan et al. (1998b) this formation can be divided into 3 facies. The lower unit is composed of intercalated limestone and shale. This unit is 31.04 m thick. The shale of this unit is medium grey to grey splintery and fissile. The limestone is thin to thick bedded and nodular. Nodules are poorly to well develop. The middle unit is composed entirely of thin to very thin-bedded limestone. Limestone is grey poorly nodular and the nodules are generally small and elongated. The upper unit is composed of intercalated dolomite, calcareous shale and shale. The dolomite horizons are fine grained and greenish in color. The shale and calcareous shale are light grey to greenish grey and splintery. This unit is 19.51 m thick. The lithified rates of sedimentation were 83.3mm/1000years (Chaudhry et al., 1998a).

Kuldana Formation

The formation (Shah, 1977) is exposed in the southeast of Hazara Basin from Kalabagh Cantonment to Islamabad. The formation consists of crimson, brown,

purple, chocolate, green, grey and khaki shales interbedded at places with khaki to pale grey marl and marly limestone bands and lenses. The clays are gypsiferous near Bansara Gali and Kalabagh (Latif, 1976). The formation is generally calcareous at the base and arenaceous towards the top.

Chaudhry et al. (1998a) measured the Kuldana Formation at Ratri Gali on Murree Ayubia Road and reported 17 lithofacies. According to them it is composed of splintery marl, calcareous shale, sandstone, sandy shale, sandy marl, clayey sandstone, oolitic grainstone, pisolitic limestone, bioclastic wackestone to grainstone and intraclasts bearing wackestone. Some lithic arenites contain clasts of limestone and abundant haematitic specks. Clayey siltstones contain stylolites.

In the Khanpur area the formation is composed of maroonish red to greenish grey shales. Here, the formation contains grey to white gypsum bands that are being mined for use in cement industry. At places, the formation contains maroonish red to greenish beds of coarse grained sandstone that are about 30cm to 90cm in thickness. At Jab, these beds contain mm to cm sized angular limestone clasts. Generally, in the Khanpur area, the Kuldana Formation outcrops along the Nathia Gali Thrust (in contact with the Pre-Cambrian Hazara Formation).

The Kuldana Formation in Neelum Valley is composed of greenish to maroonish coloured shales with occasional limestone and calcirudite facies.

According to Chaudhry et al. (1998a) the upper contact of Kuldana Formation with Murree Formation is transitional and they place the contact between the Kuldana Formation and the Murree Formation at the base of a sandstone bed, which has a Himalayan (northern) rather than Indian Shield (southern) provenance in the Murree area. As a whole the contact is either transitional or slightly disconformable but the break, if present, is likely to be minor. The formation contains macrofossil and microfossils. Latif (1976) on the basis of fossils assigned middle Eocene age to the formation. The lithified rates of sedimentation were 71.1mm/1000years (Chaudhry et al., 1998a).

Murree Formation

The Murree Formation consists (Chaudhry et al., 1998c) of a monotonous sequence of dark red, purple and maroon coloured shales and purple grey and greenish grey sandstone with subordinate intraformational conglomerate. The shales are characterized by a splintery nature, presence of fracture cleavage and tension gashes. The sandstones are maroon and show green tinge.

Sandstones, though very abundant, are nevertheless subordinate to shales. Sandstones are cross-bedded or have epsilon cross bedding. The predominant type are lithic arenites, and wackes are rare and when they do occur it is not certain whether the matrix is primary or diagenetic in origin. The sandstones are predominantly medium to fine grained, coarse grained and gritty sandstones are minor. The grains in general are sub-angular to sub-rounded. Distinctly angular and rounded grains are minor. The stable minerals/rock fragments are subangular to subrounded and include quartz and chert. Feldspar is generally less than 5%. The unstable rock fragments are represented by limestone, argillite/meta-argillite that includes slate, phyllite and shale.

Shales and claystones are the most common lithologies of the Murree Formation. These rocks are massive to moderately well laminated. They represent over bank or abandoned channel fill deposits. In some cases they represent the complete soil profile. These rocks are composed predominantly of clay minerals with subordinate silt sized and fine sand sized quartz and some carbonates. The clay is composed predominantly of illite. However, some kaolinitic and mixed layered clay with smectitic components are also present. Other ordered phyllosilicates like muscovite, biotite and chlorite generally occur as accessories. Silt to fine sand sized quartz grains constitute essential components of these rocks. Chaudhry et al., (1998c) have measured section from base of the Murree Formation from Murree area and Neelum valley.

Conglomerates/breccias occur repeatedly along the paleo-channels. The fragments are generally subangular. The conglomerates may be either clast supported or matrix supported. They have a limited number of lithologies represented in them. The matrix is often grit or coarse gritty sand. The fragments include argillites, sandstone, carbonate fragments, re-worked calcareous concretions, calcareous fossils mainly larger foraminifera. The fragments are mainly of granule or pebble size. Quartzite and volcanic rock fragments are rare.

According to Shah (1977) the basal strata of the formation consists of sandstone and conglomerate and it has been designated as Fatehjang Member after "Fatehjang Zone". *Fatehjang Member* present in other areas at the base of Murree Formation is absent in Galiat Area.

Chaudhry et al. (1998a) reported a couple of limestone and shale horizons at the base of the Murree Formation near Ratri Gali. These horizons are fossiliferous and contain foraminifera (e.g. *Nummulites striatus*). On this basis and palynoflora recovered they assigned an upper Eocene to Oligocene age to Murree Formation.

It is doubtful that Swaliks were deposited in the Hazara Basin.

TECTONO-SEDIMENTARY EVOLUTION OF HAZARA AND KASHMIR BASINS

In the following a brief account of evolution of Hazara Basin and Kashmir Basin is presented to explain the relationship between tectonic activity and sedimentation.

Paleozoic

The Tethys (e.g. Angiolini et al. 2003) stretched from the Pacific to the Mediterranean encompassing India and the northern borders of Arabia and Africa and formed through the process of rifting and successive fragmentation of Gondwanaland (Kazmi and Jan, 1997). The process started in Middle to late Paleozoic while the assembly of Pangaea was still in progress (Sengor et al., 1988; Tikku, 2002). In middle Carboniferous, the ocean between Laurasia and Gondwanaland has been universally known as Paleo-Tethys. From early Permian to late Triassic the northern passive continental margin of Gondwana was covered by a thick pile of sediments, most of which comprised thick carbonate platform deposits (Shah, 1977; Spencer, 1993). In late Permian, rifting along northern margins of the Gondwanaland formed a Cimmerian microcontinent (Sengor et al., 1988) and several back arc basins of Paleo-Tethys had evolved followed by the opening of Neo-Tethys (Patriat and Achache, 1984; Scotese et al. 1988; Van der Voo et al. 1999). By the late Triassic, most of the Cimmeride blocks had collided with Laurasia and the Paleo-Tethys closed by the early Jurassic times. During this complex interplay of opening and closing of oceans Paleozoic sequence in Hazara and Kashmir was deposited followed by a period of uplift and metamorphism during Pan African Orogeny (Baig and Lawrence, 1987).

Mesozoic

Throughout much of the Mesozoic, the Hazara Basin (Chaudhry et al. 1998a) was an important depocenter at the Northern margin of the Neo-Tethys resulting in the deposition of Mesozoic pile of sediments upto 1000m thick (Latif, 1970a; Shah, 1977). However Kashmir was a positive area throughout the Mesozoic. With the development of a transgressive shoreline of Neo-Tethys during upper Hettangian, the Datta Formation was deposited (Chaudhry and Ahsan, 1999a) that overlies either upper Proterozoic Hazara Formation or Cambrian Hazira Formation (Table 1). The Datta Formation represents open marine, lower to upper shore face, lagoonal to subareal regimes of deposition (Chaudhry et al., 1995, 1996a, 1997, 1998a;). The sediments were derived from metamorphic sialic Indian Plate to the south.

The Neo-Tethys shoreline changed to a shallow carbonate platform containing oolitic - pelletal shoals in Toarcian all over the Indus Basin (Shah, 1977) and Hazara (Chaudhry et al., 1998a) and to deposit several hundred metres thick carbonates of Samana Suk Formation from Toarcian to Callovian (Shah, 1977; Jadoul et al. 1989; Kemal et al., 1992). Many workers (e.g. Bernoulli and Jenkyns, 1974; Bosellini, 1989) have reported such platforms along the other Neo-Thethyan margins. The Hazara carbonate platform was stable until Bathonian (Shah, 1977, Chaudhry et al., 1998a; Ahsan, 2008) after which it remained exposed till Callovian with the separation of the Indo-Pakistan continent from Gondwanaland and then started to collapse (Garzanti, 1993). This separation started with the late Mid-Jurassic (Callovian) opening of the Somali and Mozambique basins (Scotese et al., 1988).

After the deposition of Samana Suk Formation a restricted anoxic environment (Chaudhry et al. 1998a) prevailed and a condensed, pyrite rich and belemnite bearing black shale siltstone sequence represented by Chichali Formation was deposited on mid-outer shelf. Similar conditions may have prevailed at the time of deposition of the Chichali Formation as in the Black Sea (Demaison and Moore, 1980). The base of the time equivalent Spiti Shale in the Zaskar is late middle Jurassic (Gaetani, et. al. 1986), while that of Chichali Formation in the upper Indus Basin is early late Jurassic, whereas in lower Indus Basin it is late upper Jurassic to basal Early Cretaceous (Shah, 1977; Dolan, 1990). Therefore the middle Jurassic carbonate platform lasted longer in the southern Pakistan. Latif et al. (1995) have correlated this event with the break up of Indo-Pakistan from Gondwanaland. The Chichali Formation pinches out towards the Kashmir Basin that was a positive area.

According to Katz (1979) and Norton and Sclater (1979) by the basal early Cretaceous, the subcontinent had separated from Madagascar and the West Coast Fault was formed and probably the Sargodha horst also started to rise (Latif et al., 1995). In early Cretaceous the Indo-Pakistan passed over the Ninety East-Kerguelen hotspot, the Rajmahal Traps of northeast India erupted (Mahoney et. al., 1983; Baksi et. al., 1987) while the Bela volcanism was active in the Axial Belt (Shah, 1977). In Valanginian, the seafloor spreading began in the Indian Ocean and the subduction of the Neo-Tethys oceanic crust started in Aptian to Albion towards end of Early Cretaceous (Garzanti, 1993). According to Latif et al., (1995), South Asia experienced a domal uplift in the early Cretaceous and due to craton erosion, sands were wide spread in all the Indo-Pakistan sedimentary basins from Berriasian to Aptian stages (Sastri et al., 1981; Garzanti, 1993). In Tithonian the Lumshiwal Formation composed mainly of glauconitic

quartz arenite (Ahsan and Chaudhry 1999; Ahsan et al. 2001c; Chaudhry, et al. 1994a, Chaudhry, et al. 2000) with submarine hardgrounds was deposited. The formation contains pelecypods, brachiopods, ammonites and belemnites (Shah, 1977). They indicate improved circulation conditions compared to Chichali Formation for the deposition of the Lumshiwal Formation at a depth of less than 80m (Ahsan and Chaudhry; 1999). Slightly reducing conditions, at least below water – sediment interface, were indicated by the ubiquitous presence of organic matter, glauconite and pyrite. According to Ahsan and Chaudhry (1999) plagioclase, microcline, schrol, indicolite, zircon, epidote and sphene are the accessory minerals that indicate sialic basement with minor basic component as the ultimate source from a low relief area on the Indian shield to the south.

However, to the southwest of Hazara Basin the Lumshiwal Formation in the Surghar Range was deposited under terrestrial conditions (Danilchick and Shah, 1987). Warwick et al. (1995) considered the basal part of the Formation in the Surghar Range a shallow marine deposit in the lower part and deltaic in the upper part. However, Frederiksen (1992) suggested a brackish to marine environment of deposition for the upper part of the formation. Gradational contact of the Lumshiwal Formation with Hangu Formation led Danilchick and Shah (1987) to suggest a late Cretaceous age for the upper part of the formation.

In Cenomanian due to rapid northwards flight of India from near Madagascar, the Hazara Basin started to sink gradually to deposit Kawagarh Formation (Ahsan and Chaudhry, 1998). The formation is composed of pelagic limestones and marls. The Kawagarh Formation, of upper Cretaceous age, in the Hazara Basin (Ahsan and Chaudhry, 1998; Ahsan et al., 1993a, b, 1994, 2001a, c,) overlying the Lumshiwal Formation was deposited in a homoclinal ramp settings (Ahsan, 2008). This setting is further substantiated by the presence of effects of abrasion in the grains, sharp crested wave ripple cross-lamination and cross-lamination and waviness, tubular tempestites and alternations of micrite and skeletal grains laminae (Ahsan, 2008). Moreover, contrary to previous interpretations (e.g. Ahsan et al, 1998) these features indicate a water depth of not more than 100m for the deposition of Kawagarh Formation. In the Kashmir Basin Cambrian to Cretaceous strata is absent (Table 1).

The top of the Kawagarh Formation exposed sub-aerially when the Indian Plate established its first contact with the Kohistan Island Arc at about 67 ± 2 Ma. This reworked the Maastrichtian (top of Kawagarh Formation)

sediments into pisolitic laterites, bauxites and fireclays now represented by Hangu Formation of Danian age (Ahsan et al., 2001a; Chaudhry, et al., 1994b, 1998a).

Tertiary

There is a large gap of about 505 million years after the deposition of Precambrian Abbottabad Formation in Azad Kashmir Area (Ahsan et al., 2001b, d). At the advent of early Paleocene the Kashmir and Hazara Basins changed into a transgressive shoreline with the deposition of sub-aerial / lagoonal / supratidal (marshy) / middle shoreface sediments represented by the Hangu Formation (Ahsan et al., 1999b, 2001b, d). The beds underlying the Danian Hangu Formation (Ahsan et al., 1999b) belong to Abbottabad Formation (Shah, 1977)/Sirban Formation (Ashraf et al., 1983) of Cambrian age. The Hangu Formation unconformably overlies the upper Cretaceous Kawagarh Formation in the Hazara Basin. Whereas in the areas around Rawalpindi, the Hangu Formation lies over Lumshiwal Formation (Ahsan et al., 2000a, Williams, 1994) or reduced Kawagarh Formation. The rocks belonging to middle Paleocene-Eocene strata are represented by Lockhart Formation, Patala Formation, Margala Hill Limestone and Chorgali Formation. These units were deposited in lagoonal to inner ramp settings in Hazara-Kashmir Basin (Chaudhry et al., 1998a, Ahsan et al., 2001d).

At about 45-50Ma (upper Eocene), the main collision between India and Kohistan Island Arc took place due to which during Lutetian the sea retreated. Continental conditions prevailed in the Salt Range while marginal

marine and evaporitic environment occurred in the Hazara area under which Kuldana Formation was deposited followed immediately by the deposition of Murree Formation. On the basis of micropalaeontological and palynological studies the Murree Formation started deposition in the upper most Eocene (Chaudhry et al., 1998a). This age is contrary to the general thinking that Murree Formation was deposited in Miocene in the area. In addition to this the Murree Formation represents fluvial deposition by meandering river system.

Quantitative XRD analysis (Ahsan et al., 1998b) has been used in the determination of clay minerals of Chorgali Formation while tourmaline, zircon, hematite and pyrite were determined petrographically. The clay mineral assemblages in the Chorgali Formation consist of illite, chlorite and kaolinite. Illite (38%) is the chief clay mineral and its relative abundance through out is persistent. It is detrital in origin and is due to the abundant supply from the source area. Illite remains stable during burial (Abassi, 1994). The chlorite (24%) and kaolinite (29%) are subordinate to illite. However a minor contribution from the south cannot be ruled out. This conclusion is further substantiated by the findings of Chaudhry et al. (1998c) in the case of Kuldana Formation and molasse sediments of the Murree Formation (Chaudhry and Ashraf, 1978) of NW Himalayas that were derived from the north. Earlier, Calkins et al. (1975) have suggested that rising Himalayas went under intense chemical weathering and the Murree sediments of Hazara Kashmir Syntaxis were derived. Moreover, Latif (1970a), Fatmi (1973) and Tahirkheli (1982) consider these sediments of continental origin.

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