THE
GEOLOGICAL BULLETIN
of the
PUNJAB UNIVERSITY

Number 40-41 *December 2006*

CONTENTS

Geol. Bull. Punjab Univ. Vol. 40-41, 2005-6, pp 1-19

LITHOFACIES ANALYSIS OF THE LOWER CRETACEOUS LUMSHIWAL FORMATION, KALA CHITTA RANGE, NORTHERN PAKISTAN

BY

MUHAMMAD KALEEM AKHTER QURESHI
Geological Survey of Pakistan, Trade Centre Johar Town Phase-II, Lahore, Pakistan
Email: mkaleemakhter@yahoo.com

KHAN RASS MASOOD
Botany Department, Quaid-e-Azam Campus, University of the Punjab, Lahore-54590, Pakistan

AND

SHAHID GHAZI, AFTAB AHMAD BUTT
Institute of Geology, Quaid-e-Azam Campus, University of the Punjab, Lahore-54590, Pakistan

Abstract: *Detailed lithological studies and microfacies analysis of the Lower Cretaceous Lumshiwal Formation from the Kala Chitta Range, northern Pakistan have been carried out from a number of sections. Eight micofacies including glauconitic sandstone, mudstone, bioclastic wackestone-packstone, bioclastic grainstone and bioclastic floatstone have been identified. These studies have contributed towards the interpretation of its diagenetic components combined with the environment of deposit. It can to introduction describe briefly interpretation with respect to environments.*

INTRODUCTION

The name Lumshiwal Sandstone proposed by Gee (1945) has been formalized as the Lumshiwal Formation by the Stratigraphic Committee of Pakistan (Fatmi, 1973). The name replaces the Giumal Sandstone of Cotter (1933) from the Kala Chitta Range (Fig. 1), where the formation has been measured and sampled at Choi, Chapra, Surg, Dherikot, Burjianwala Laman, Togowala and Dourdad (Fig.1).

The Kala Chitta Range is a longitudinal trough which is bounded on the east by the Islamabad – Peshawar Highway and by the Indus River on the western side. It forms the northern border of the adjoining hydrocarbon bearing Potwar Basin. Structurally, the Kala Chitta represents foreland fold and thrust belt.

In the Kala Chitta Range, the Lumshiwal Formation and the Chichali Formation form a wedge-on-wedge relationship, the Chichali Formation thinning to the east, whereas the Lumshiwal Formation is thinning towards the west. Thus a paleoenvironmental shift in time and space has been envisaged during the deposition of the tow formations. The reduced thicknesses are mainly considered to be starved deposition resulting into condensed sections. According to Fatmi (1972), the Lower Cretaceous age of the Lumshiwal Formation in the Kala Chitta Range has been assigned on the basis of faunal name fauna composition.

The Mesozoic succession of the Kala Chitta Range as formalized by the Stratigaphic Committee of Pakistan (Fatmi, 1973) is as follows:

Upper Cretaceous Kawagarh Formation (Kawagar Shales of Cotter, 1933)

Lower Cretaceous Lumshiwal Formation (Giumal Sandstone of Cotter, 1933)

Upper Jurassic – Lower Cretaceous Chichali Formation (Spiti Shales of Cotter, 1933)

Middle Jurassic Samana Suk Formation (Kioto Limestone of Cotter, 1933)

Lower Jurassic Datta Forma;tion (Ferruginous beds in the Kiotos of Cotter, 1933)

Upper Triassic Kingriali Formation (Kioto Limestone of Cotter, 1933)

Lower Triassic Chak Jabbi Limestone (Kioto Limestone of Cotter, 1933)

Lower Triassic Mianwali Formation (kioto Limestone of Cotter, 1933)

The present study is the first of its kind. Although its Lower Cretaceous age was already established on the basis of faunal composition (*Oxytropiceras* sp., *Caspionites* sp., *Neocosmoceras* sp., and *Trigonia ventricosa*) by Fatmi (1972), the recently studied paly nological data further substantiated its age assignment. The following species were encountered.

Aequitriradites triangulates, Densoisporites nejburji, Leiotriletes sp., *Leptolepidites eparcornatus, Leptodineum eumorphum, Faveosporites subtriangularis,* Valiasaccites validus, *Laevigatosporites, Succinctisporites grandior, Inaperturopollenites* sp., *Ovalipolis ovalis, Crybelosporites pannuceus, Afropollis jardinus, Pododocarpites ellipticus, Gordodinium alberti, Enzonalasporites vigens, Punctatisporites* sp., *Frangospora* sp. and *Endogone* sp.

The Upper Triassic to Liassic Kioto Limestone of Cotter (1933) has been differentiated into the Mianwali Formation, the Chak Jabbi Limestone, the Kingriali Formation, the Datta Formation and the Samana Suk Formation. (Fig. 2)

LITHOLOGY

The lithostratigraphic sections have been measured and studied from a number of places within the Kala Chitta Range (Fig.3). The formation is thickest towards the east about 61.50 m at the Daurdad Section and thinnest towards the west about 8 m at Chapra. Fatmi (1972) has, however, reported increased thicknesses further west in the Nizampur Hills (47 m).

At Dourdad Section the upper part of the formation comprises predominantly massively bedded and jointed shelly limestone (Plate 1, Fig.3) underlain by soft quartzose sandstone and glauconitic sandy silty shales having gradational contact with the underlying Chichali Formation.

In the southwest at Togowala Section, the formation is 38 m thick. A more terrigenous input in the lower part has been recorded, whereas the limestone zone in the upper part in only 6 m thick. The prominent 3 m thick massive and hard quartzose sandstone is a conspicuous lithology (Plate-1, Fig.1) in the lower middle part of the formation. The overlying Kawagarh Formation is very thin at this locality and thickness is about 2-3 m mainly marls and clays. Towards further west, south of Dherikot, the formation is 40 m thick and comprises a lighology comparable with Togowala Section, with the exception of hard massive sandstone horizon.

At Burjianwala Laman section in the southern Kala Chitta, the Lumshiwal Formation comprises calcareous and sandy shale over lain by prominent shelly limestone. The Lumshiwal Formation at this locality is overlain by the Paleocene Lockhart Limestone with an intervening lenticular sandy laterite and decomposed clay horizon that represents the unconformity. The intervening residual zone ranges between 0.50 m to 1 m in thickness. At Surg, the Chichali Formation is 16 m thick with two fold lithology of calcareous marls and glauconitic shales in the lower part with medium to thick bedded limestone in the upper part. Soft sediment slumpingl intraformational folding and escaping ichnofossils have been observed at this locality, indicating unstable slope environments. West of Surg in Chapra and Choi sections, the thickness of the Lumshiwal Formation further decreases. It is only 8 m thick at Chapra and 11 m thick at Choi with slight variation in lithology, having very thin glauconitic sandstone/sandy shale at the base and hard coquinoidal limestone in the upper part.

The lower contact with the Chichali Formation is gradational, whereas the upper contact with the Kawagarh Formation in the northern Kala Chitta and with the Lockhart Formation in the southern Kala Chitta is unconformable. After the deposition of the Lumshiwal Formation, the Late Cretaceous represents break in the deposition in the southern Kala Chitta Range.

MICROFACIES

The Lumshiwal Formation exhibits limited variations in the carbonate depositional environment with relatively calm water depositional conditions resulting in the deposition of carbonate mudstone/wackestone/ packstone with significant algal and coralline and reef dwellers association. The following microfacies have been identified:

Glauconitic sandstone (Plate 2, Fig. 1)

The facies is commonly present at the base of the Lumshiwal Formation. The quartz grains are subangular to subrounded with good sorting. Glauconite is present both as cement and in pellet form. Oxidized clay and silica cements are present. The glauconite cement and pellet are considered to be early diagenetic and were formed mostly during deposition and very shallow burial under mildly reducing conditions. The silica cement followed clay cementation when the silica rich fluids moved through the pores.

Mudstone (Plate 4, Fig. 1)

The lime mudstone is unlaminated and at places is associated with quartz grains (5%), fragmented bioclasts (2-5%) and peloid (2-5%) are the minor associations. Unlaminated, carbonate mudstone is deposited in a somewhat saline to cut off tidal ponds to supra tidal environments, with calm water conditions, essentially below wave base. The scarcity to complete absence of marine life is attributed to high or variable salinity conditions. The quartz crystals could have been wind blown.

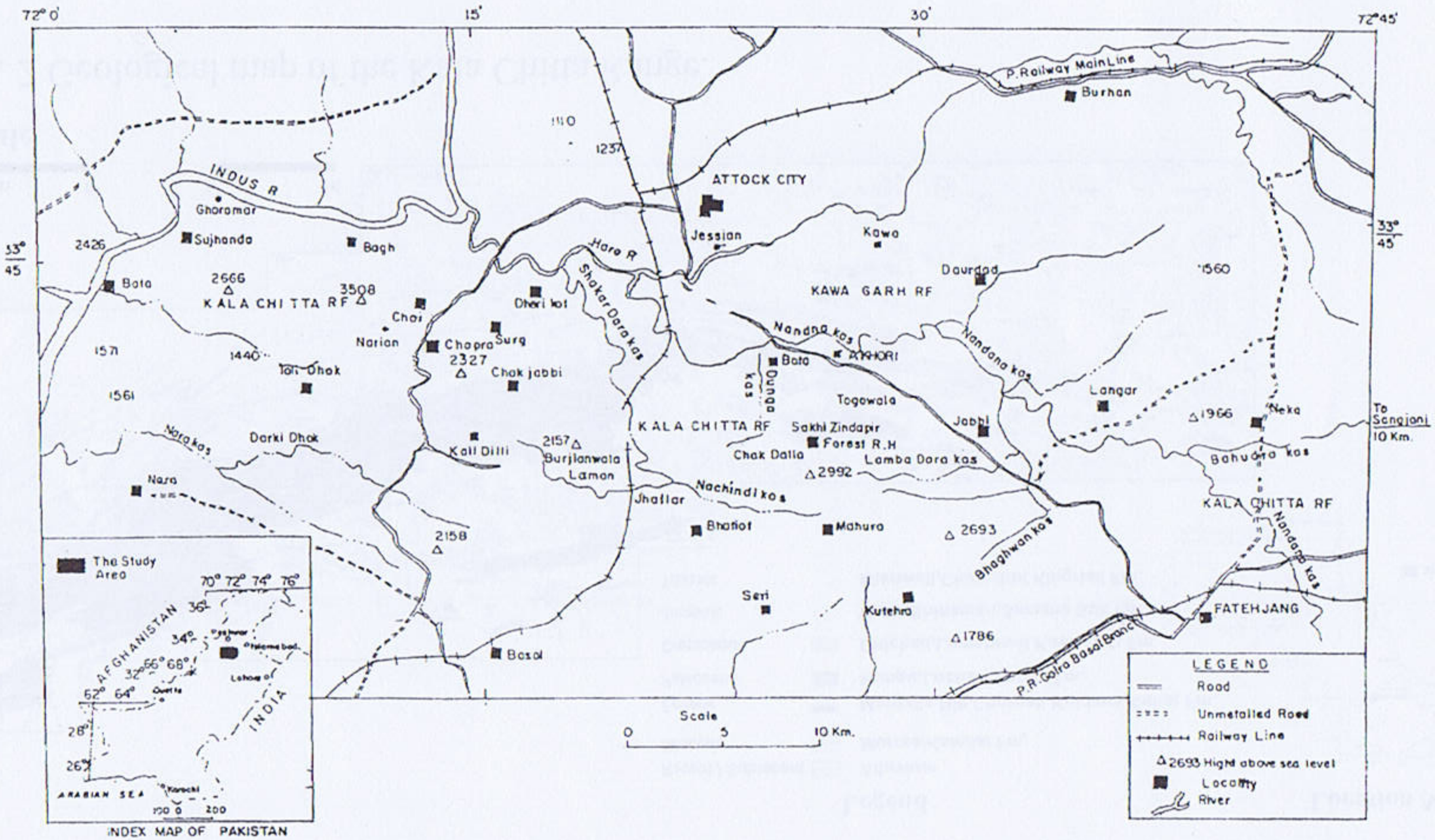


Fig.1: Location map of the study area. Kala Chitta Range.

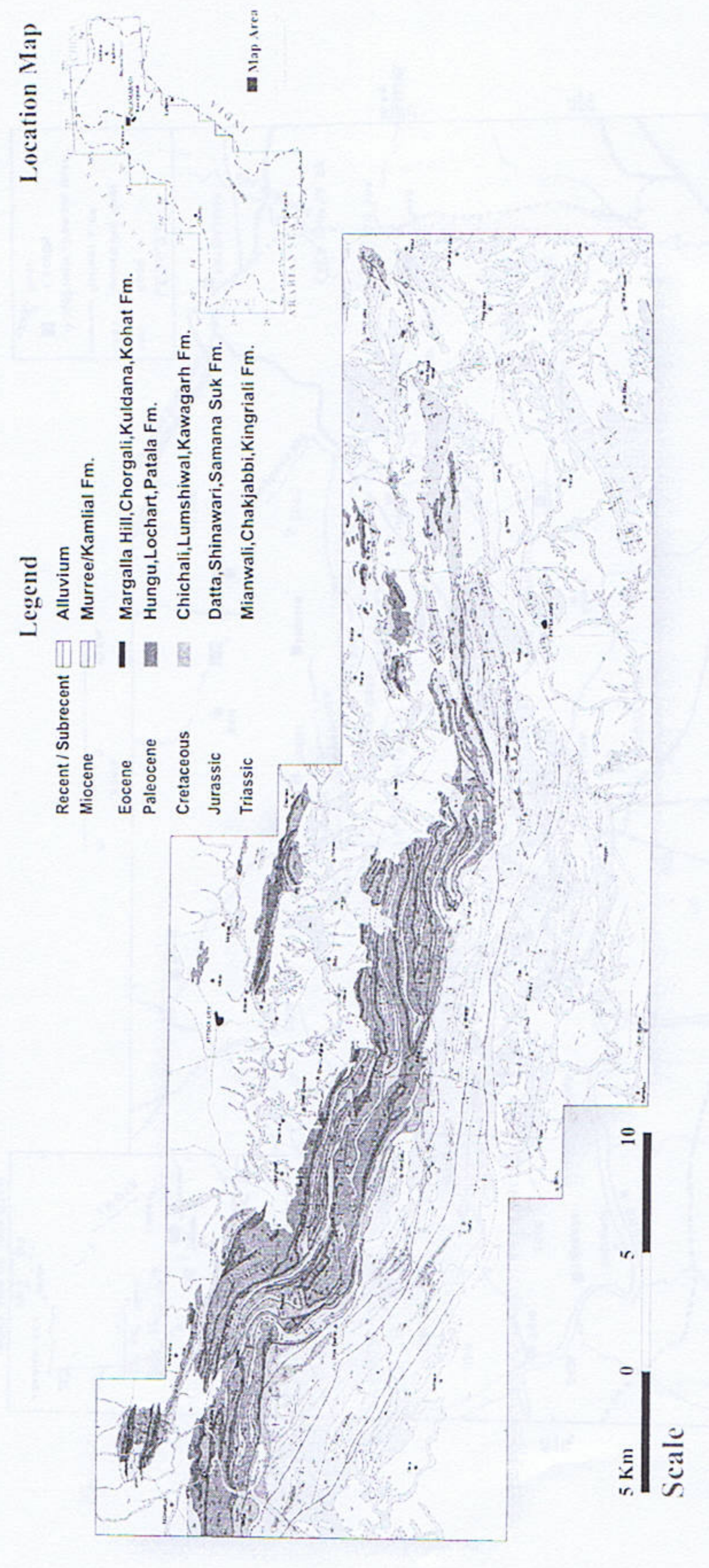


Fig. 2 Geological map of the Kala Chitta Range.

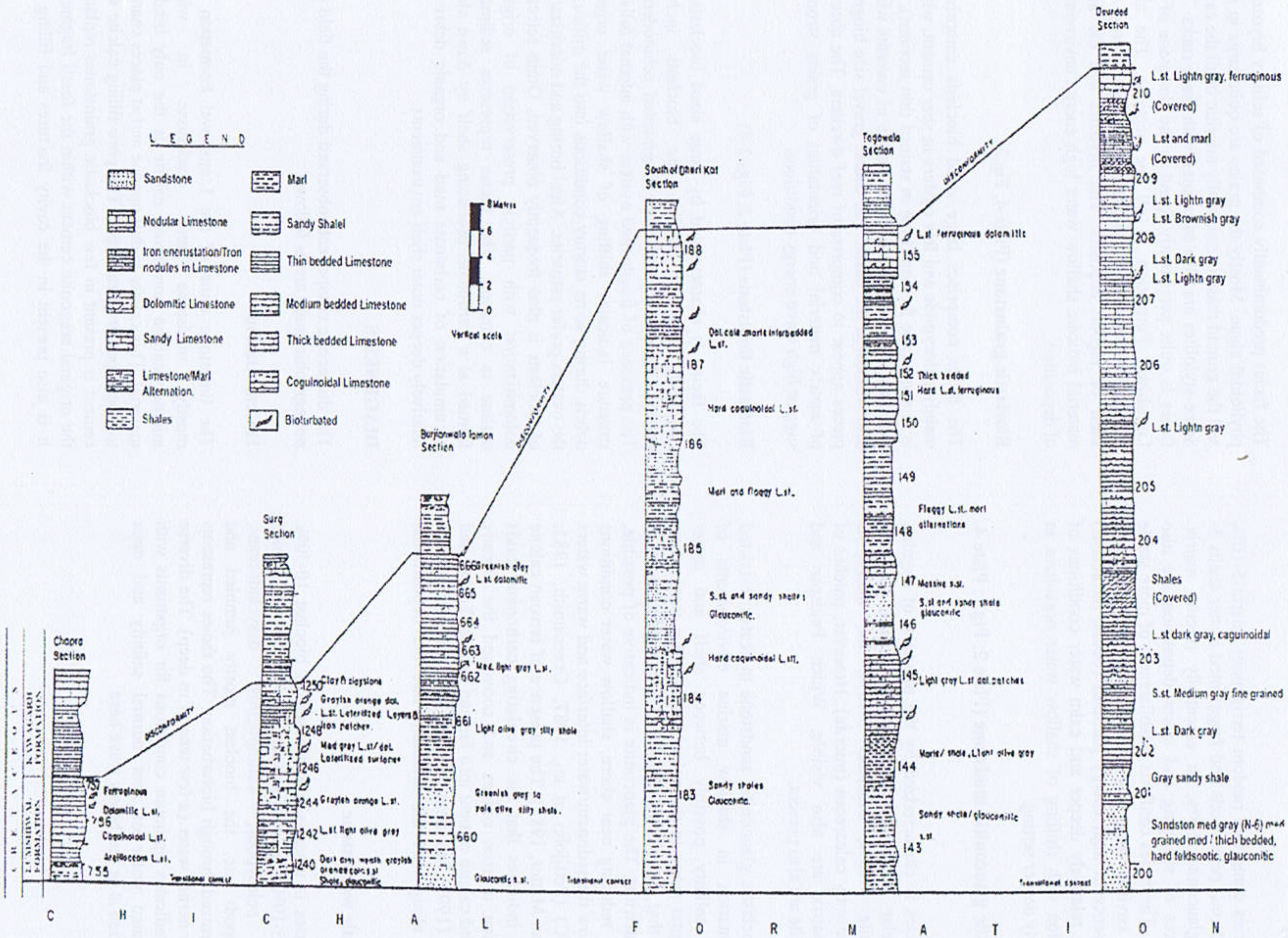


Fig.3: Lithostratigraphic Section of the Lumshiwal Formation, Kala Chitta Range, Northern Pakistan.

Bioclastic mudstone – wackestone (Plate 2, Fig.1; Plate 4, Fig.4)

The facies comprises random terrigenous quartz 5-10%, echinoderms, pelecypods and fragmented oyster shells 5-10%, glauconite 2-5%, in essentially micrite matrix. Evidences of slumping and storm deposition are also present. The facies confirms establishment of more stable marine environments. The presence of calcareous mud and absence of high energy particles (ooids, intraclasts) suggest relatively deeper and calm water conditions of deposition with shifting of shallow water organisms in relatively deeper setting.

Bioclastic glauconitic sandstone (Plate 2, Fig.1; Plate 4, Fig.3)

The facies is characterized by the presence of angular, subangular to subrounded quartz grains, 30-35% glauconite 5-15%, bioclasts 5-10%; the matrix is predominantly calcareous (micrite). However, patches of clay matrix are also visible. Which Feldspar and muscovite are also present.

The bioclastic glauconitic sandstone indicates restricted sedimentation in shallow marine environments of normal salinity possibly between shelf and upper continental slope in the neighborhood of a very active massif that periodically supplied the high amount of quartz detritus. The glauconite is indicative of possible, slightly reducing near shore, shallow water conditions just below the sediment/water interface and warm waters (15-20°C) (Pettijohn et at., 1987; Greensmith, 1981; Odin and Matter, 1981). The presence of ferroan calcite cement indicates that the circulating carbonate fluids were rich in iron oxides and converted the already deposited calcite cement into ferroan calcite. Tucker and Wright (1992) has mentioned the transportation of iron oxides along with the sediment into the depositional basin.

Bioclastic wackestone

The facies is essentially composed of bioclast 10-30%, peloid 5-10%. The matrix is micrite. The bioclast include oyster pelecypods, echinoderms, dasycladaceans, brachiopods etc. the bioclast mostly jumbled and homogenized through bioturbation. The facies represents shallow neritic water (a few tens of m deep). The diverse fauna indicates optimum conditions for organisms with oxygenated water of near normal salinity and open circulation at or just below wave base.

Bioclastic wackestone – packstone (Plate 3, Figs.1-3)

The facies predominantly composed of solitary bryozoan, phylloidal algae. Mostly the grains are quite large in size and the ground mass is essentially micritic in all the cases. Some stylolites are also associated with these rocks. The facies is quite persistently found in the limestone of the Lumshiwal Formation in all the sections. The algal associations indicate shallow water, moderate energy, and shelf or lagoon deposits. The bryozoa and the algal material indicate shallow water high energy environment of deposition.

Bioclastic grainstone (Plate 4, Fig.2)

The facies comprises large sized bioclasts comprising mainly pelecypods and few oysters in spar cement, which is in some case ferroan (blue in stained thin sections), the bioclasts are oriented due to the action of currents which also winnowed the basin. The coarse gravel size biogenic pieces appear to comprise of reef dwellers. The absence of matrix material and orientation of grains strongly suggest high wave energy conditions.

Bioclastic floatstone (Plate 2, Figs.3-4)

The facies is characterized by large sized bioclasts in essentially micritic matrix. The bioclasts include pelecypods, oysters and some fragmented echinoderms. The presence of fragmented oysters with internal foliated structure indicates shifting of shallow water organic debris during some stormy conditions into the milieu, as the oysters prefer estuaries. Algal boring and micritization of bioclasts is also frequently observed. Grain selective dolomitization with particle preservation of original outline is common. The facies represents sediments formed at a carbonate producing shelf by down slope accumulation of carbonate mud and organic debris in relatively deeper outer shelf environments.

DIAGENESIS

The diagenetic components observed during the field and petrographic study are as follows:

1) Cementation

The limestone units of the Lumshiwal Formation are mostly mudstone and wackstone in which microcrystalline non-ferron calcite is the only binding material. This calcite is dull opaque and at places changes to microspar or pseudospar. The pore filling calcite spar cement is present in few bioclastic grainstones replacing the original aragonite cement within the fossil fragments. It is also present in the cavity fractures and filling the intergranular porosity. Glauconite, clay and quartz cements have been observed in sandy facies. The clay and glauconite cementation is early diagenetic and followed by quartz cementation. The solubility of the silica increases with pH, and the silica cements occur where acid fluids have moved through the pores (Selley, 1985).

2) Compaction

a. Mechanical compaction

Evidences of the mechanical compaction before cementation are represented by interfering, sutured and corroded grains margins (Plate-3, Fig.2). Fractured and dislocated grains are also seen. However, in most of the cases the grain are floating or having planer contacts indicating early lighification. The mechanical compaction and stylolitization has also brought the grains much closer.

b. Chemical compaction

The chemical compaction and pressure dissolution of grains and sediments is a significant source of $CaCo_3$ for burial cementation. The pressure solution structure in the Lumshiwal Formation includes the following:

i) Fitted fabric

In the Lumshuwal Formation the surfaces between the grains vary from having point and planer, interfering to sutured and corroded grain margins, depending upon the degree of dissolution and compaction.

ii) Stylolitization

The stylolite represents serrated interface between two grains or rock masses with sutured appearance in cross section. The stylolite transect the grains, rock fabric, cement and matrix indiscriminately. Two phases of stylolitization with respect to dolomitization are identified. Dolomite crystals superpose the stylolite formed prior to dolmitization where as those formed later cut through the dolomite rhombohedron.

The dissolution seams, as observed in the Lumshiwal Formation, lack the distinctive sutures of stylolite and mostly pass around and between the grains than cutting them and usually are anatomizing. These sometimes wrap over nodules, grains and lead to the development of falser structure.

iii) Dissolution and Replacement

Dissolution of aragonite in some bioclasts and replacement by calcite spar as intragranular cement and replacement of calcite by dolomite are important diagenetic features.

iv) Dolomitization

Dolomitization is commonly the late phase in the diagenetic history. The upper part of the Lumshiwal Formation beneath the unconformity has been partially dolomitize. Such dolomites are developed beneath an unconformity are best explained by the mixed meteoric sea water, where the unconformity surface represents the area of subaerial recharge for a fresh water aquifer (Collins, 1975).

DISCUSSION

Environmental Interpretation

The Lumshiwal Formation exhibits an interesting paleogeographic setting that has changed during space and time. At the base, the transitional contact with the underlying Chichali Formation is indication of continuation of the depositional setting. The presence of calcareous shale and laminated glauconitic sandstone at the base of the Lumshiwal Formation, in which shelly founa and bioturbation is lacking suggests continuation of abnormal physicochemical conditions restricting the flourishing of organic life.

The presence of quartzose sandstone in the eastern sections of Daurdad and Togowala indicates a close proximity of source area or a local rise of the provenance. The general reduction of the formation thickness from East to West in contrast to the underlying Chichali Formation is explained as being manifestation of paleoenvironmental shift in space and time and the two formations represents a wedge on wedge relationship.

The reduced thickness is also attributed to the result of condensed section and depositional breaks which are also obvious by the presence of oxidized surfaces and ferruginous films. The lower flauconite bearing beds of the Lumshiwal Formation might have been deposited in some what reducing shallow to moderately deeper water with low sedimentation rate, at or just below sediment water interface where the glauconite is formed by the alternation of other minerals in the presence of organic matter.

The upper limestone horizons in the Lumshiwal Formation are essentially shallower water. The presence of abundant oyster bearing packstones / wackestone and variety of fauna, including Trigonia, echinoderms, ammonoids, nautiloids, gastropods and vast variety of algae and coal is indicative of establishment of well oxygenated marine conditions, with water of normal salinity. The limestone has been deposited in shallow protected marine to shallow open marine shelf, or mound slope environments with intermittent submarine lithification.

The palynological studies reflect a strong regressive phase associated with wide climatic variations as depicted by the heterogeneity and diverse assemblage in the Lumshiwal Formation. This indicates a close by (few kilometers) land or mound surface from where these palynological fossils had been derived and preserved.

CONCLUSIONS

1. The Lumshiwal Formation is mainly composed of glauconitic sandstone, limestone and shale. Eight microfacies have been identified.

2. The sedimentological studies and the faunal composition have highlighted the shallow marine environment of the Lumshiwal Formation.

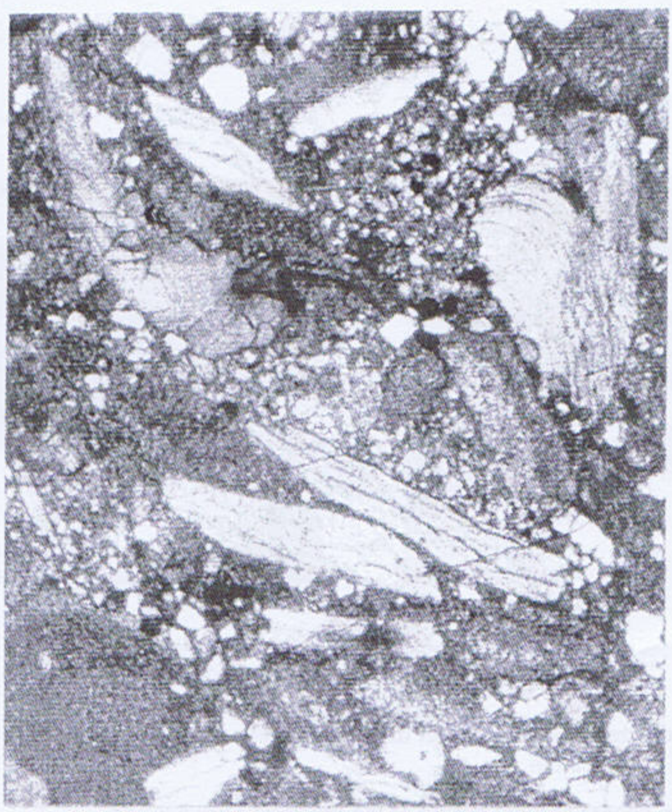
Plate 1

Fig.1 Hammer is the scale

Fig.2 Hammer is the scale

Fig.1: A localized massive (3 meters. thick) quartzose sandstone bed in the Lumshiwal Formation at Togowala Section.

Fig. 2: Calcareous facies of the Lumshiwal Formation showing massive and jointed beds at Daurdad Section.



500 μm

Fig.3: Bioclastic Wackestone-Packstone, Oysters are the prominent bioclasts. Umbrella effect and subsequent infiltration of finer sediments is prominent Chapra Section

Plate 2

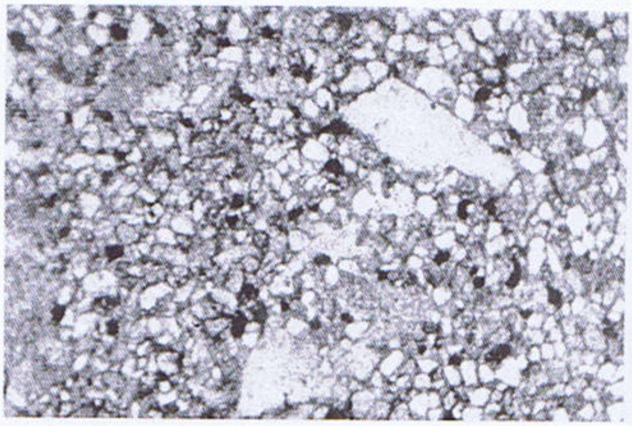


Fig.1 550 µm

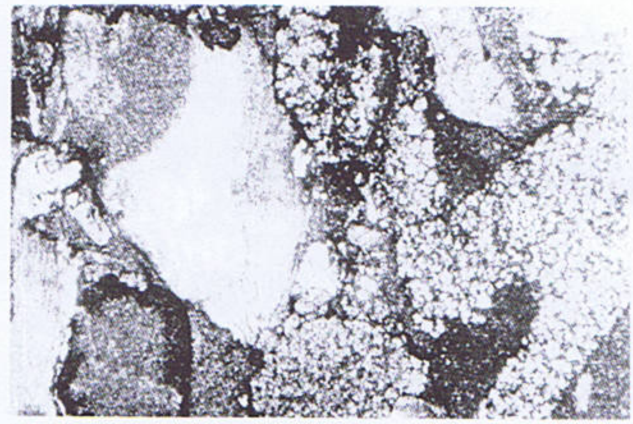
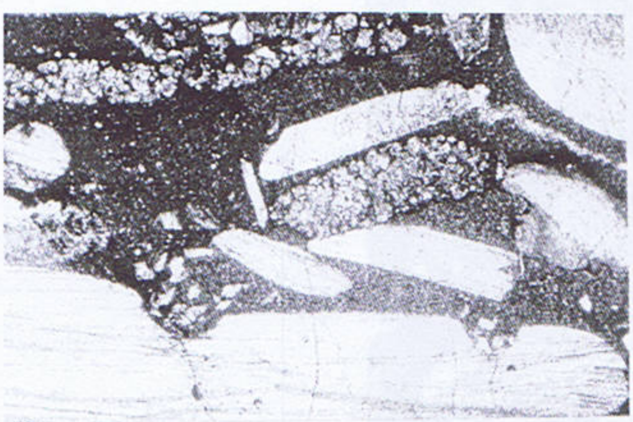


Fig.2 550 µm

Fig. 1: GlauconiticSandstone in micritic matrix Chapra Section.

Fig. 2: Bioclastic Wackestone Packstone Oysters are the prominent bioclasts with corroded grain margins. Some bioclastic grains have retained their shape and outline during grain selective dolomitization Surg Section.



250 µm

Fig.3

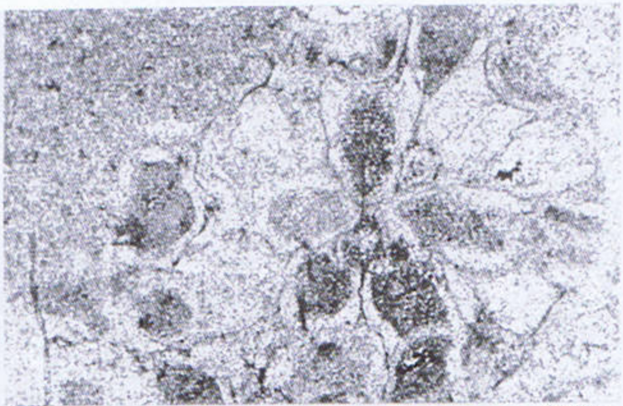
250 µm

Fig.4

Fig.3: Bioclastic Floatstone. Gravel sized bioclasts in finer matrix. Umbrella effect and geopetal filling due to infiltration of finer sediments are conspicuous Surg Section.

Fig.4: Bioclastic Floatstone. High degree of algal boring of the bioclasts Surg Section.

Plate 3



250 µm

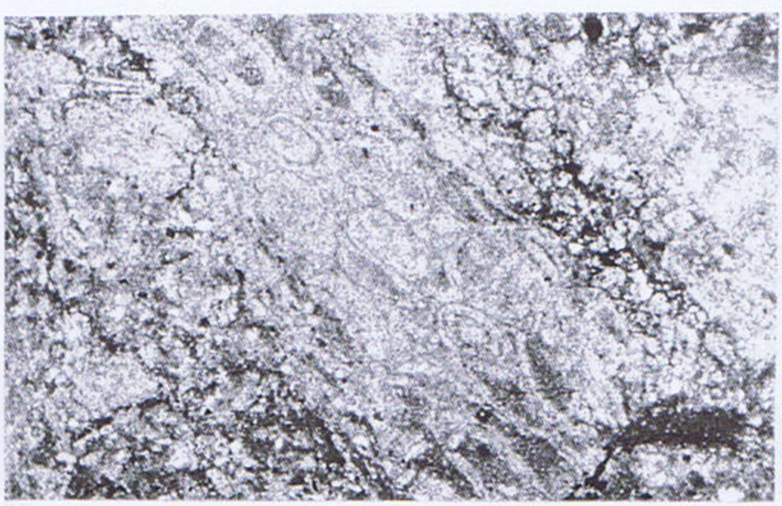
Fig.1

250 µm

Fig.2

Fig. 1: Bioclastic Wackestone -Packstone. Bryozoan colony is the prominent Bioclast Burjianwala Laman Section.

Fig.2: Bioclastic Wackestone-Algal Limestone. The algae are slightly displaced.



550 µm

Fig.3: Bioclastic Wackestone. Bryozoa prominent bioclast. Stylolites stylocumulate on either side of the bryozoan bioclast Togowala Section.

Plate 4

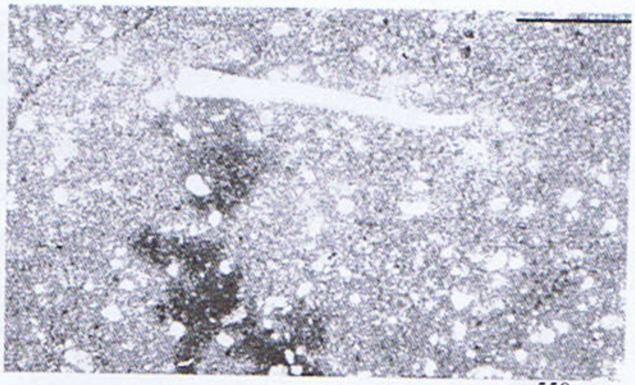


Fig.1 550 µm

Fig.2 550 µm

Fig . :1 Carbonate Mudstone with quartz grains. Burjianwala Laman Section.

Fig. 2: Bioclastic Grainstone showing current deposited bioclasts which are pelecypods Daurdad Section.

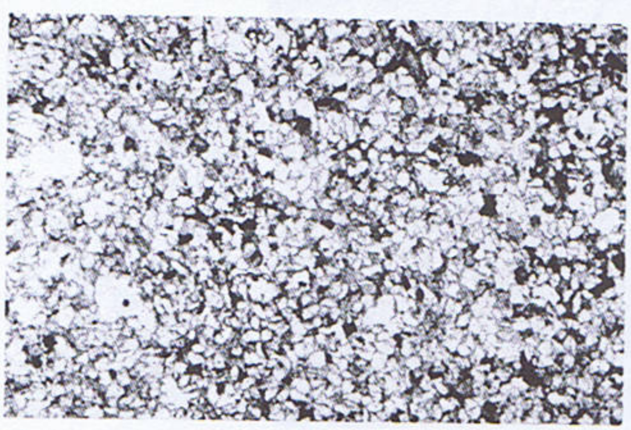


Fig. 3 550 µm

Fig. 4 550 µm

Fig,3: Glauconitic Sandstone Dherikot Section.

Fig.4: Glauconitic Sandstone. A large size crinoid and abundant quartz grains are common Burjianwala Laman Section.

Plate 5

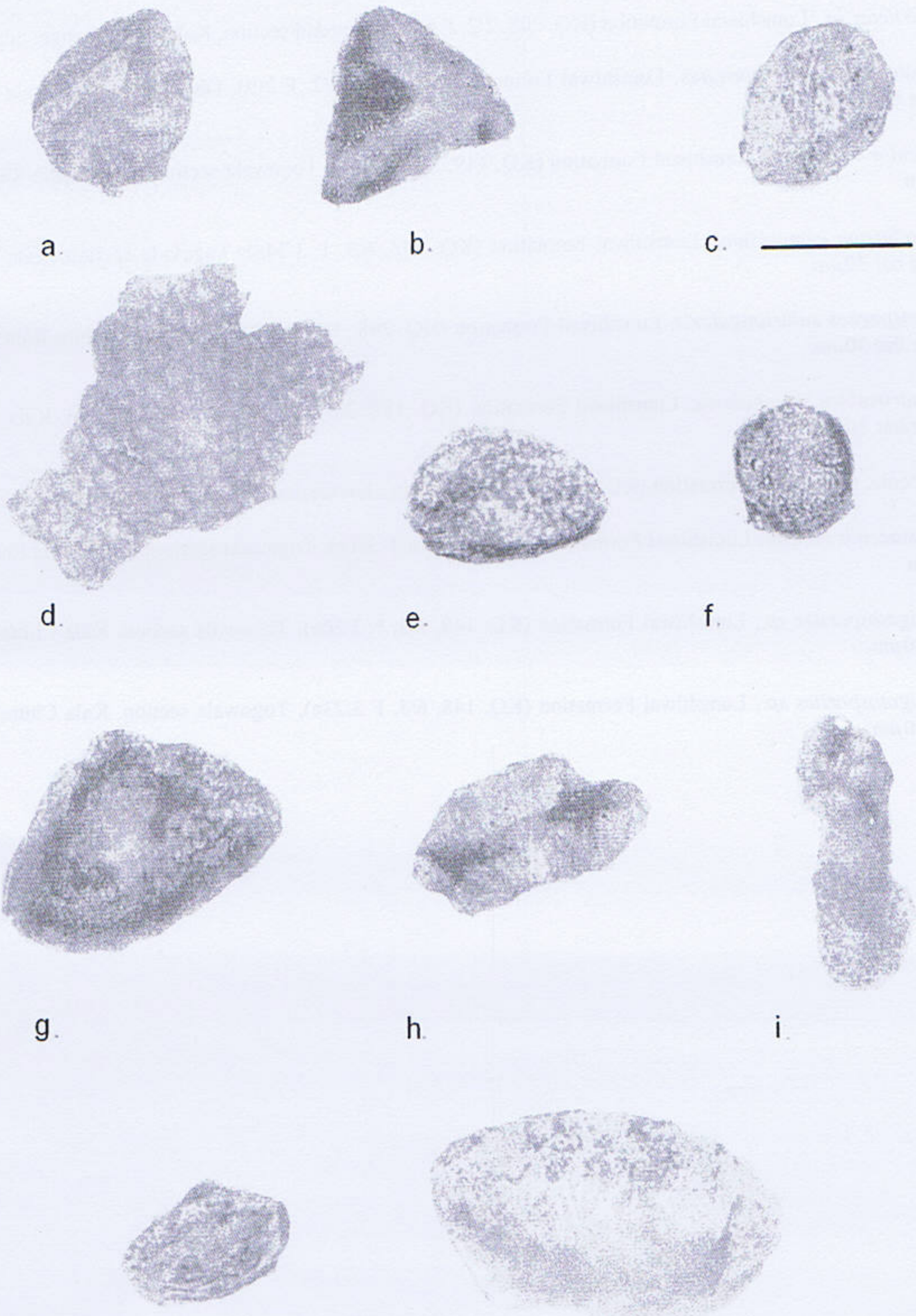


Plate 5

Fig. a: *Densoisporites nejburji*, Lumshiwal Formation (KQ. 665, 1/7, F 1/31), Burjianwala Laman section, Kala Chitta Range. Scale bar 30μm.

Fig. b: *Leiotriletes sp.*, Lumshiwal Formation (KQ. 208, 2/2, F 1/32), Daurdad section, Kala Chitta Range. Scale bar 30μm.

Fib. c: *Leptolephidites eparcornatus*, Lumshiwal Formation (KQ. 187, 4/2, F 2/9), Dherikot section, Kala Chitta Range. Scale bar 30μm.

Fig. d: *Cuticular Fragment*, Lumshiwal Formation (KQ. 149, ½, F 3/30a), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fig. e: *Leptodineum eumorphum*, Lumshiwal Formation (KQ. 148, 6/3, F 3/24a), Togovida section, Kala Chitta Range. Scale bar 30μm.

Fig. f: *Foveosporites subtriangularis*, Lumshiwal Formation (KQ. 208, 1/1, F 1/35), Daurdad section, Kala Chitta Range. Scale bar 30μm.

Fig. g: *Aequitriradites triangulares*, Lumshiwal Formation (KQ. 188, 3/3, F 2/11), Dherikot section, Kala Chitta Range. Scale bar 30μm.

Fig. h: *Bisaccate*, Lumshiwal Formation (KQ. 188, 2/1, F 2/10), Dherikot section, Kala Chitta Range. Scale bar 30μm.

Fig. i: *Valiasaccites validus*, Lumshiwal Formation (KQ. 147, 1/1, F 3/14), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fig. j: *Laevigatosporites sp.*, Lumshiwal Formation (KQ. 148, 3/3, F 3/20a), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fig. k: *Laevigatosporites sp.*, Lumshiwal Formation (KQ. 148, 6/3, F 3/23a), Togowala section, Kala Chitta Range. Scale bar 30μm.

Plate 6

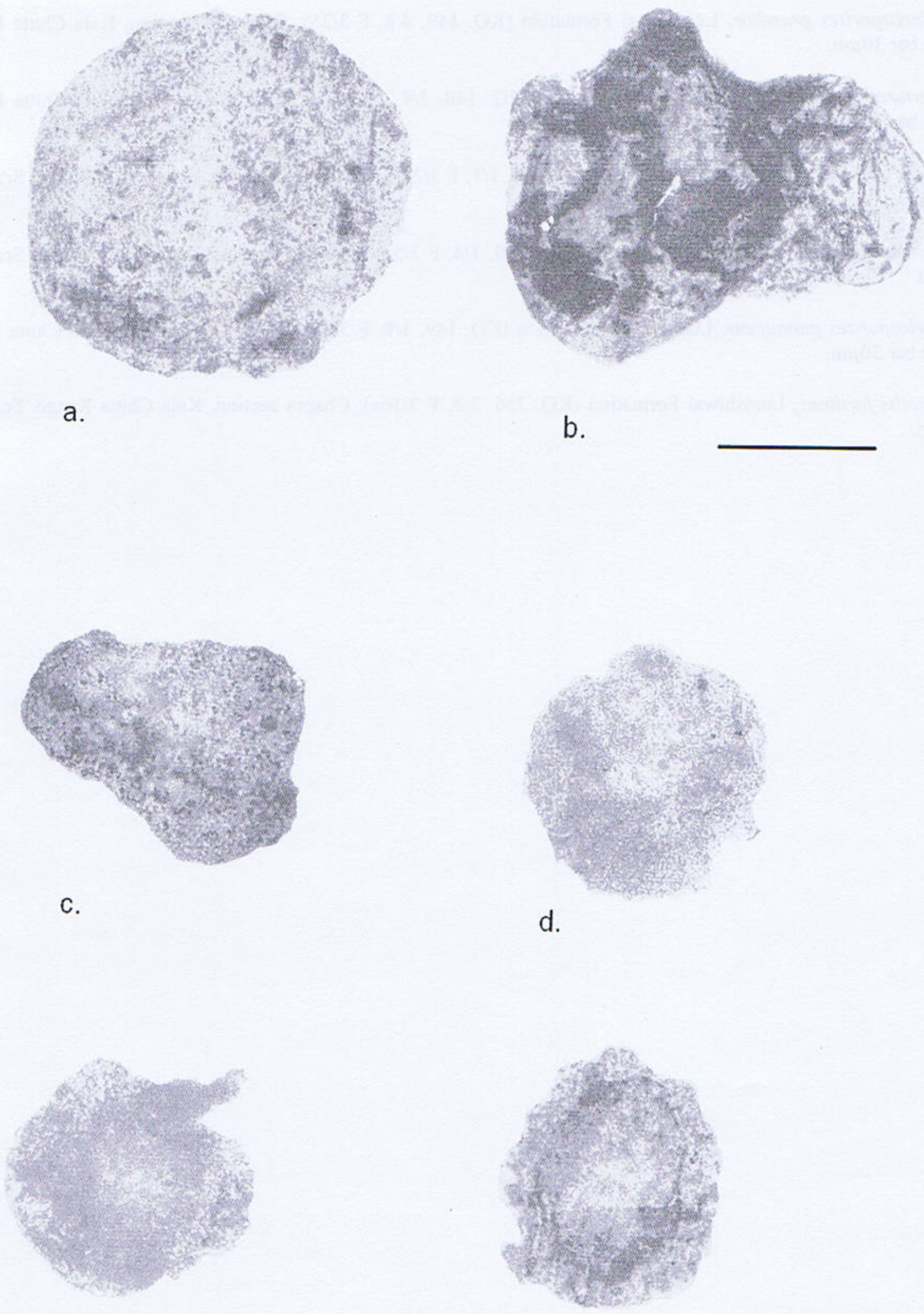


Plate 6

Fig. a: *Succinctisporites grandior*, Lumshiwal Formation (KQ. 149, 4/8, F 3/35), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fig. b: *Inaperturopollenites sp.*, Lumshiwal Formation (KQ. 148, 3/4, F 3/21a), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fib. c: *Ovalipolis Ovalis*, Lumshiwal Formation (KQ. 149, 1/1, F 3/29a), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fig. d: *Crybelosporites sp.*, Lumshiwal Formation (KQ. 209, 1/4, F 3/5a), Daurdad section, Kala Chitta Range. Scale bar 30μm.

Fig. e: *Crybelosporites pannuceus*, Lumshiwal Formation (KQ. 149, 1/9, F 3/25a), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fig. f: *Afropollis jardinus*, Lumshiwal Formation (KQ. 756, 2/2, F 3/16a), Chapra section, Kala Chitta Range. Scale bar 30μm.

Plate 7

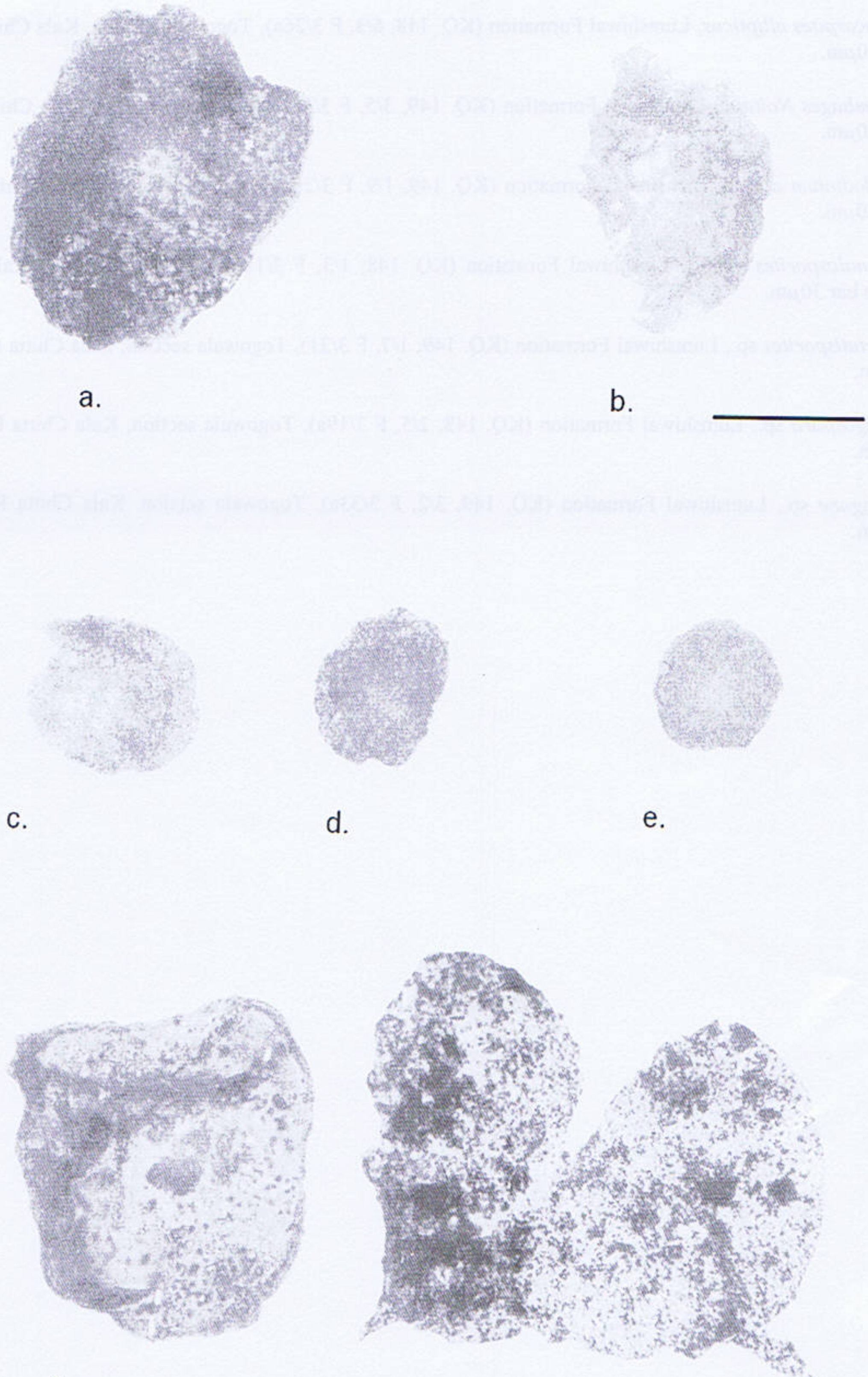


Plate 7

Fig. a: *Podocarpites ellipticus*, Lumshiwal Formation (KQ. 148, 6/3, F 3/26a), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fig. b: *Palambages Noitalic*, Lumshiwal Formation (KQ. 149, 3/5, F 3/32a), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fib. c: *Gordodinium alberti*, Lumshiwal Formation (KQ. 149, 1/9, F 3/28a), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fig. d: *Enzonalasporites vigens*, Lumshiwal Formation (KQ. 148, 1/3, F 3/18a), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fig. e: *Punctatisporites* sp., Lumshiwal Formation (KQ. 149, 1/7, F 3/31), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fig. f: *Frangospora* sp., Lumshiwal Formation (KQ. 148, 2/5, F 3/19a), Togowala section, Kala Chitta Range. Scale bar 30μm.

Fig. g: *Endogone* sp., Lumshiwal Formation (KQ. 149, 3/2, F 3/33a), Togowala section, Kala Chitta Range. Scale bar 50μm.

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DISCOVERY OF A *BRAMATHERIUM* (GIRAFFID) HORN CORE FROM THE DHOK PATHAN FORMATION (MIDDLE SIWALIKS) OF HASNOT, POTWAR PLATEAU, PAKISTAN

MUHAMMAD AKBAR KHAN, MUHAMMAD AKHTAR
Department of Zoology, Quid-e-Azam Campus, University of the Punjab, Lahore (54590), Pakistan
Email: akbaar111@yahoo.ca

AND

MUHAMMAD ANWAR QURESHI
Institute of Geology, University of Azad Jammu & Kashmir, Muzaffrabad, Pakistan

Abstract: *The recent collection from Hasnot has brought about the discovery of a horn core belongs to a gigantic Upper Tertiary giraffe. The giraffids are abundant in the Upper Tertiary rocks of the Siwaliks and mostly diverse in the Tertiary rocks of Hasnot and Dhok Pathan. The studied specimen is found from the locality H 7 situated at 4 kilo meters west of the Hasnot village.*

INTRODUCTION

The Late Miocene to early Pleistocene deposited in the elongated foreland basin of the Himalayas are well known and have been studied intensively for many years (Biswas, 1994; Behrensmeyer et al., 1997). Although Tertiary Vertebrate remains have been known from the Siwaliks for more than a century however there had been mostly foreigners who collected the remains (Falconer and Cautley, 1836; Lydekker, 1876, 1878, 1880, 1883a and b, 1884; Pilgrim, 1937, 1939; Barry, 1989, 1995, 2002, 2005). As a result, few assemblages of the large mammal remains are available for research in Pakistan. The Siwaliks of Pakistan especially the area of districts Gujrat, Jhelum and Chakwal is very famous for the Tertiary vertebrate groups and a great variety of giraffid is found in the Tertiary rocks of the Siwaliks (Table 1) (Khan and Farooq, 2006). The succession in Hasnot village is represented by numbers of vertebrate fauna in which ruminants are a prominent diverse group.

In the late Miocene two giraffid subfamilies, Giraffinae and Sivatheriinae were present in Eurasia. The Sivatheriinae are large giraffes with two pairs of horns. This character is not always absent in other late Miocene giraffids (Bohlin, 1926) and has already been noted in Middle Miocene ones (Gentry et al., 1999). The Hasnot village (Lat. 32° 49′ N: Long. 73° 18′ E) is situated at about 70 km west of the Jhelum city in the Potwar Plateau of the northern Pakistan (Fig. 1). The village is surrounded by extensive Neogene freshwater sedimentary rocks. The region of the Hasnot exposes the most complete sequence of the Siwalik Group and yields a diversified assemblage of the Middle Siwalik Formation.

MATERIAL AND METHOD

The Tertiary hills of the Hasnot were investigated thoroughly. As a result, a worth identifying specimen of giraffid horn core was discovered along with other ruminant species. The specimen is found lying completely exposed on the surface. In the laboratory, the horn core was carefully washed, cleaned and prepared for the study. The specimen catalogued numbe· consists of series i.e., yearly catalogued number and serial catalogued number, so figures on the specimen represents the collection year and serial number of that year. The measurements of the specimen in millimeters were taken with the help of metric Vernier Calipers. The identification and the terminology are according to Gentry (1999).

Table-1
Stratigraphic sections of the Siwalik group showing Formations and Zones.
*** the studied area. (Boundary dates are set from Barry et al., 2002).**

0 – 2 – 4 – 6 – 8 – 10 – 12 – 14 – 16 – 18 – 20 –

Soan Fm.	Upper Siwalik	Boulder Conglomerate Zones
		Pinjor Zone
		Tatrot Zone
*Dhok Pathan Fm.	*Middle Siwalik	*Dhok Pathan Zone
Nagri Fm.		Nagri Zone
Chinji Fm.	Lower Siwalik	Chinji Zone
Kamlial Fm.		Kamlial Zone

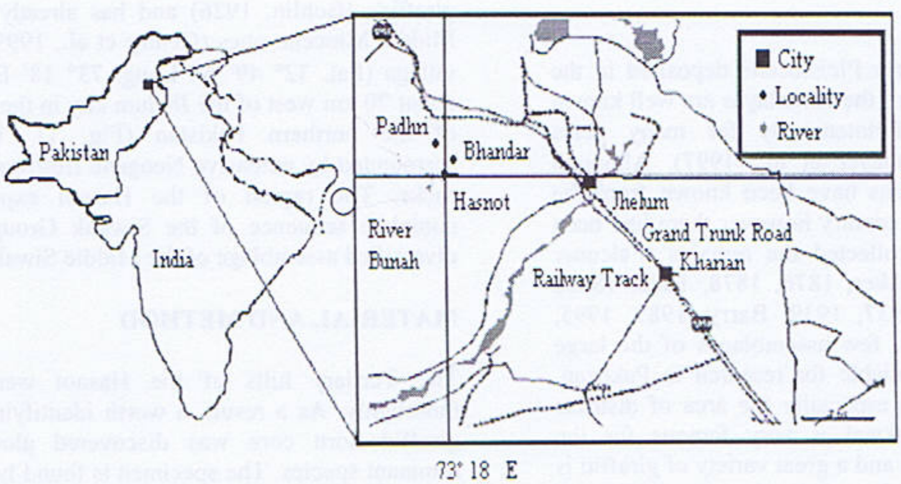

Fig. 1: Location of the study section; Hasnot and the surrounding localities of the study section.

SYSTEMATIC PALEONTOLOGY

Family Giraffidae Gray

Subfamily SIVATHERIINAE Zittel

Genus *Bramatherium* Falconer, 1845

Type Species: *Bramatherium perimense* Falconer, 1845.

Included species: *Bramatherium perimense* Falconer, 1845; *Hydaspitherium megacephalum* Lydekker, 1876; *Hydaspitherium magnum* Pilgrim, 1910; *Hydaspitherium birmanicum* Pilgrim, 1910; *Hydaspitherium grande* Mathew, 1929.

***Bramatherium Perimense* Falconer, 1845**

Type Specimen: A maxilla with left P^4-M^3 (BMNH 48933).

NeoType Specimen: A skull (Royal College of Surgeons-1436).

Material: PUPC 2004/22, a horn core (Fig. 2A, B).

Locality: Hasnot (H 7) Jhelum district, the Punjab province, Pakistan.

Stratigraphic Level: Middle Siwaliks.

Diagnosis: The small posterior lateral horns are of parietal origin.

Distribution: The species has been found in various localities of the Potwar Plateau (Dhok Pathan Formation) of Pakistan, Perim Island (India) and Abu Dhabi (Pilgrim, 1910; Gentry, 1999).

DESCRIPTION

The horn is flattened, somewhat curved and tapering rapidly to the tip. The cortical bone is compact compared with the more cancellous medulla within, and the horn is smaller comparatively. PUPC 2004/22, measures 40.8mm along its convex edge, 22.9mm maximum width at its base and 23mm thickness or minimum basal width. The horn is round in cross section and conical in shape.

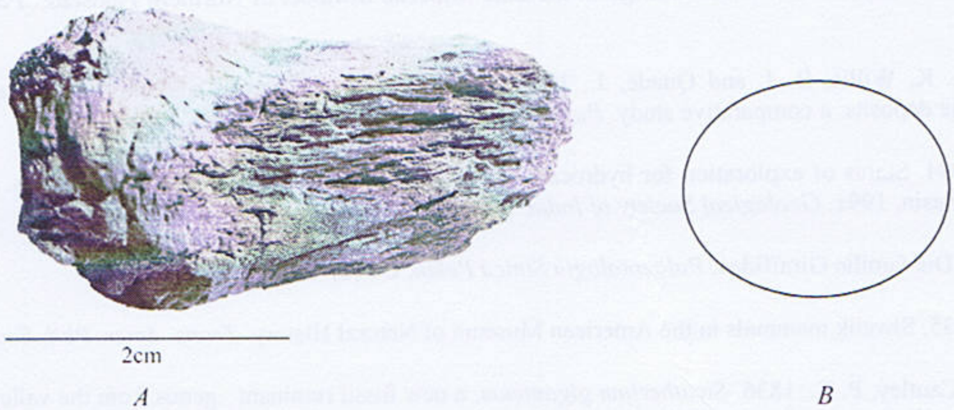

Fig. 2: *Bramatherium perimense* Falconer (PUPC 2004/22): **A)** a horn core **B)** Outline of the horn core just above its base.

DISCUSSION

The horns are the most striking feature of the Siwalik giraffoids. In giraffes a permanent bony horn-core covered with skin is present. In *Giraffokeryx* the horns are well behind the orbit (Colbert, 1935). In *Bramatherium* horns are four in number, a large anterior pair and a much smaller posterior pair. The anterior horns are placed anteriorly on the frontal and the posterior horns are placed laterally on the parietals and they project out at right angles to the median axis of the skull (Colbert, 1935). They are much smaller and whereas the front horns are roughly rectangular in cross section, these parietal protuberances are round in cross section and conical in shape.

The cortical bone of the specimen is compact compared with the more cancellous medulla within, as is characteristics of giraffids (Gentry, 1999). The horn core is too small to belong to anterior horns. The flattening fails to match known sivathere horns but the irregular knobbiness of the surface suggests a sivathriine rather than a giraffine giraffid. *Samotherium* horns are longer although also slightly curved backwards. Portions of horns of a Siwaliks *Giraffokeryx*, BMNH M15722, are smoother surfaced. The studied specimen is small and round in cross section which agrees with the *Bramatherium perimense*. The Siwalik Miocene sivatheriines *Bramatherium* and *Hydaspitherium* were probably similar to the European *Decennatherium* in showing an enlarged anterior pair of ossicones (or one single fused anterior ossicone) and a less prominent posterior pair. *Bergerbohlinia* of the Spanish Turolian, on the other hand, had a large posterior pair of ossicones and a smaller anterior pair, a pattern more reminiscent of later *Sivatherium* (Gentry and Heizmann, 1996).

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Geol. Bull. Punjab Univ. Vol. 40-41, 2005-6, pp 27-44

GEOLOGY OF THE LOWER JURASSIC DATTA FORMATION, KALA CHITTA RANGE, PAKISTAN

BY

MUHAMMAD KALEEM AKHTER QURESHI
Geological Survey of Pakistan, Trade Centre Lohar Town Phase II, Lahore, Pakistan.
Email: mkaleemakhter@yahoo.com

AND

SHAHID GHAZI, AFTAB AHMAD BUTT
Institute of Geology, Quaid-e-Azam Campus, University of the Punjab, Lahore-54590, Pakistan.

Abstract: Detailed *geological mapping contributed towards the tectonic framework of the Kala Chitta Range for the purpose of a compressive knowledge of the mode of occurrence of the Fire Clay horizons in the Datta Formation .Furthermore, detailed analytical work was carried out to elucidate the mineralogy of the Fire Clays. Lithological details and the depositional style have been highlighted comparative data of the Datta Formation with the adjoining areas has also been presented.*

INTRODUCTION

The name Datta Formation was introduced by Danilchik and Shah (1967) after the Datta Nala section in the Trans Indus Salt Range, to replace the Variegated Series of Gee (1945). This name has also been extended to the Kala Chitta Range and adjoining areas by the Stratigraphic Committee of Pakistan (Fatmi 1973). In the Kala Chitta Range, the Datta Formation represents low-stand deposits formed during a complete sea level withdrawal over a gentle undulating relief provided by the unconformable surface of the Upper Triassic Kingriali Formation. Due to the economic significance of the fireclay deposits in the Datta Formation, Ashraf et al. (1976) carried out investigation on some of the isolated exposures of the fireclay horizons of the Datta Formation, while Baluch (1986) gave an account of Bauxitic clays of Nawa area.

The present investigation is based on the comprehensive knowledge of the tectonic behaviour and mode of occurrence of the fireclays in the Datta Formation throughout the Kala Chitta Range after the detailed geological mapping and systematic sampling of the properly located and well distributed lithosomes in the formation particularly in the Surge, Chak Jabbi, Sakhi Zindapir area of the Kala Chitta Range (Fig.l).

METHODOLOGY

Considering the economic importance of the fireclays in the Lower Jurassic Datta Formation, a detailed study was planned to be carried out in Surg- Chak Jabbi- Sakhi Zindapir, in the central Kala Chitta Range due to their excellent exposures and easy access.

Precisely, well located samples were taken from different well developed fireclay horizons of the Datta Formation. These horizon are mapped in detail (Fig. 2). The location of the samples, the lithological composition and the thicknesses of the various lithozones are given.

The detailed laboratory studies including geochemical analysis (Table Nos.I-2) differential thermal analysis Crable No.3) and XRD testing Crable NO'iA-5) were carried out in order to know the mineral composition of the fireclays which is largely kaolinite and diaspore, quartz being present invariably. The significant of these clays as compared with those of other areas is discussed.

Geochemical Behaviour

The geochemical analysis were carried out with the help of Scanning Electron Microscope (SEM, Table No. 1) and by wet geochemical methods Table No. 2.

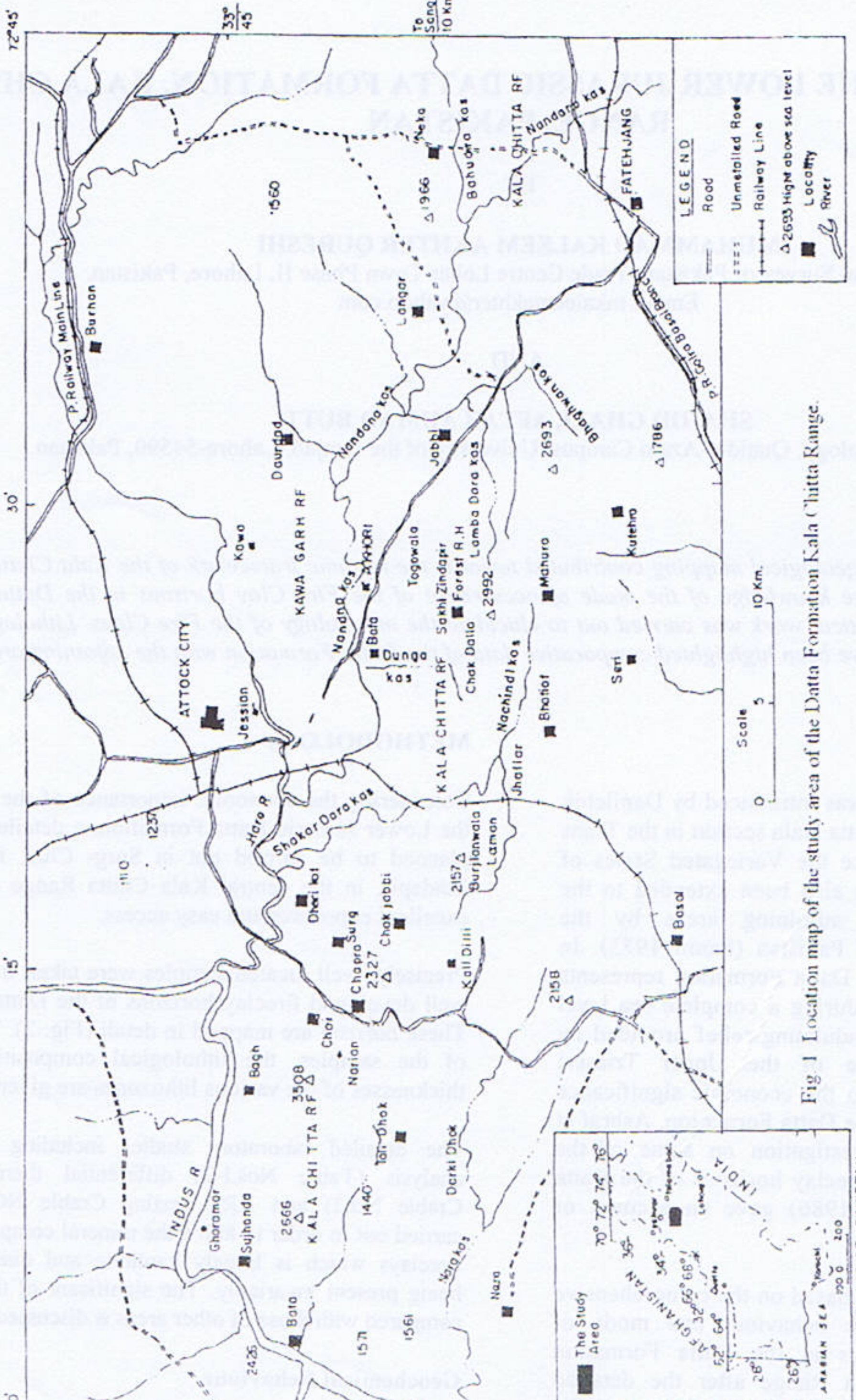


Fig. 1. Location map of the study area of the Datta Formation Kala Chitta Range.

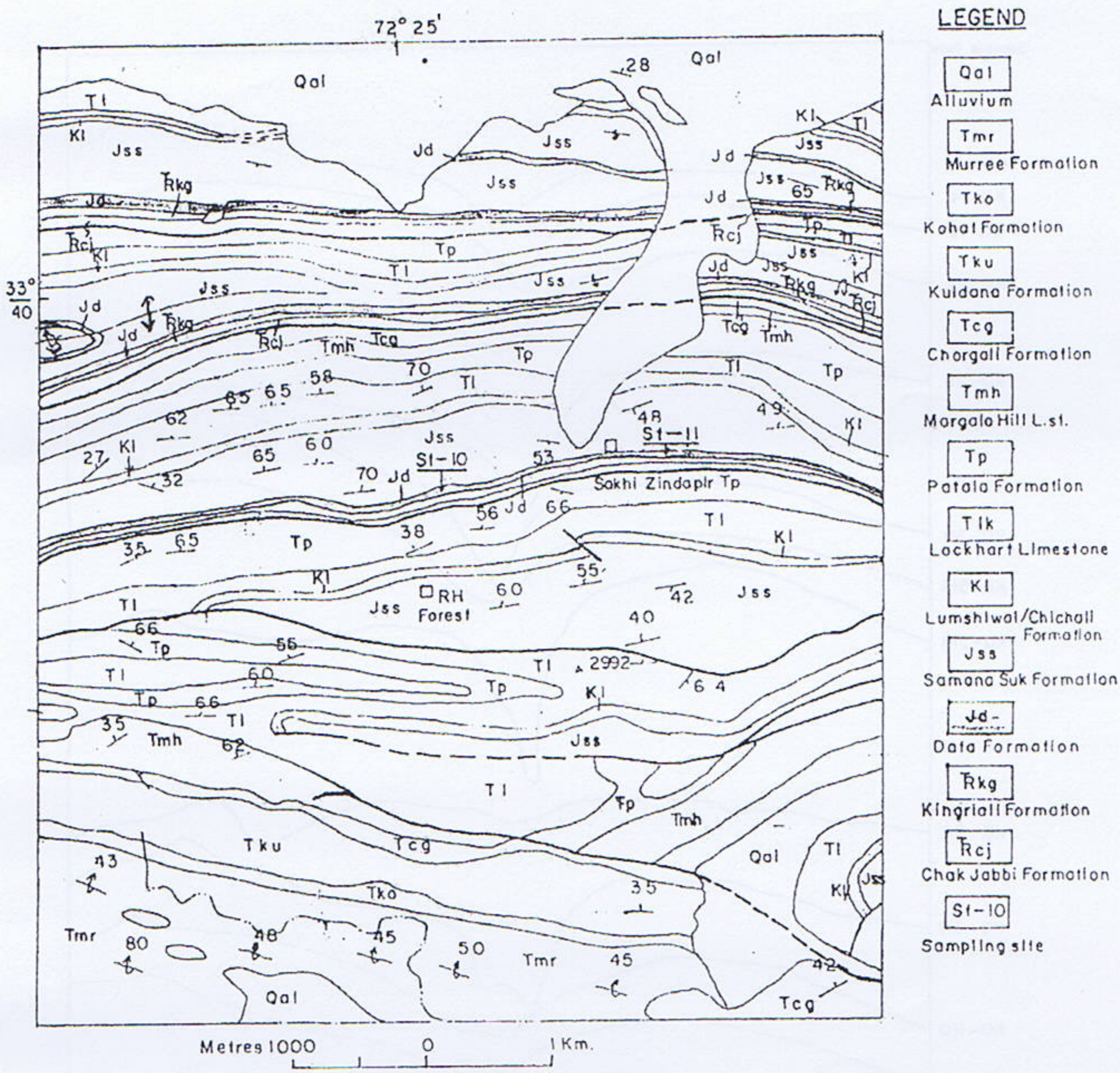


Fig 2 Geological map of Sakhi Zindapir area showing distribution of Fireclay-bauxite bearing Datta Formation.

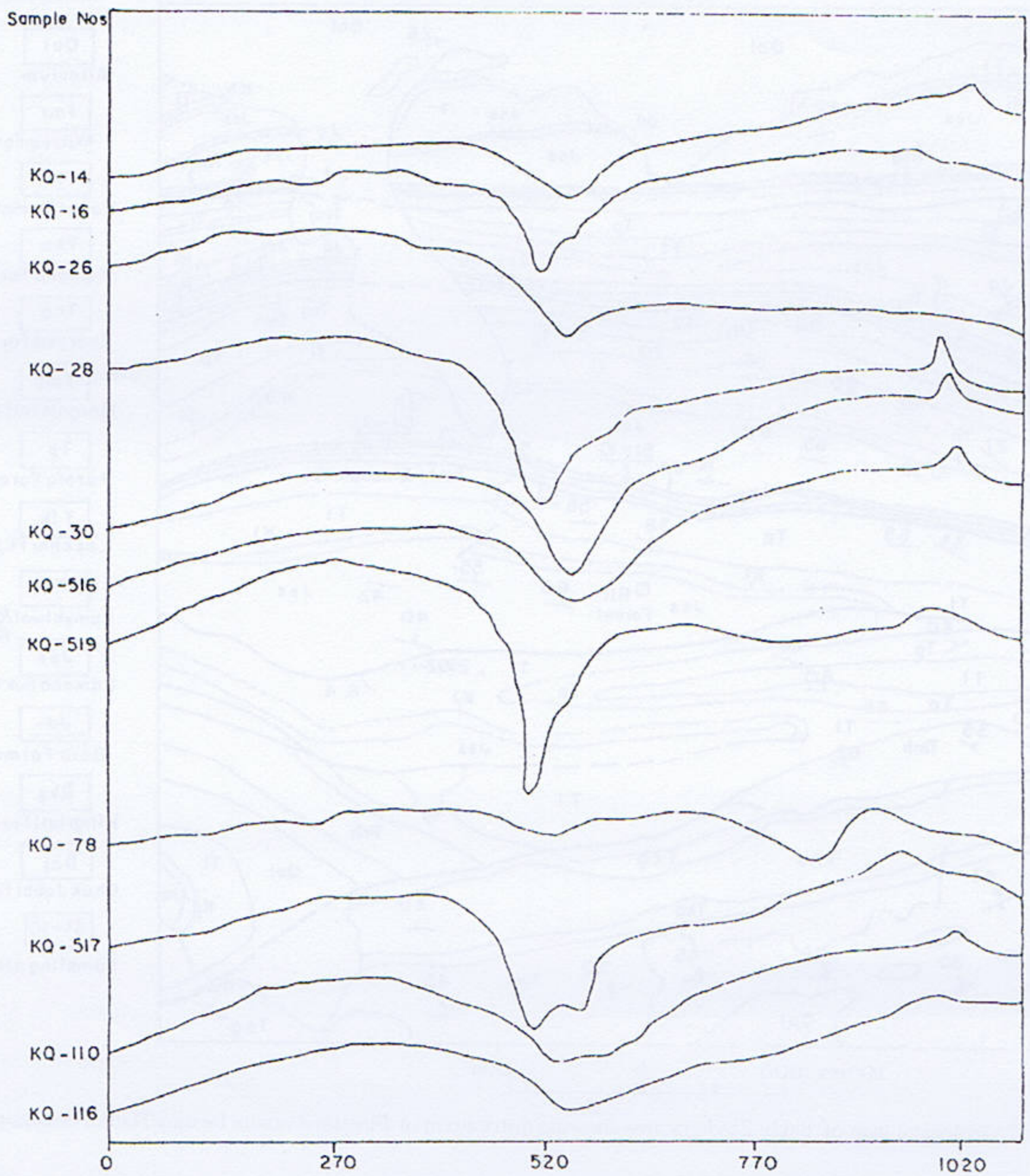


Fig. 3 DTA Curves of fireclay samples from surg-chak Jabbi-zindapir area Kala Chitta Range
(for explanation see Table No. 3)

The chemical composition of the samples show a remarkable difference in A 1203 taken from the upper part of the Datta Formation, ranging from 39 .61 % to the over 78 % (samples Nos. 15,17,78,516,517,519; Table No.2) with an overall low value at Sakhi Zindapir Section where the A 1203 does not exceed more than 26.09 % with high silica of the order of 69 .26% (samples Nos. 110.11; Table No.1). The clays from middle part show an average composition of A 1203 ranging from 36.21 % to 44.19 % (sample Nos. 16.26.28.30.517; Table No.2).

Lithology

The Datta Formation in the central and parts of the western Kala Chitta Range, comprises a complex facies of (1) clays, claystone with subordinate bauxitic lenses in the upper part and (2) quartzose sandstone, hematitic sandstone and ironstone in the lower part with (3) laterite commonly present at the base. Fireclay is present in the upper part of the Datta Formation, that comprise these lithosomes (red ironstone to hematitic sandstone, white quartzise sandstone, white to grey and purple clay and bauxite) in a lateral pinch-out relationship. Vertically, the lithosomes have distinctly gradational to abrupt relationship. The lithosomes pinch and swell rapidly, without definite trend. Isolated areas with predominance of anyone or more of the lithozones, can be identified. In the eastern Kala Chitta, the fireclay part is not present and the formation comprises only the quartzose ferruginous sandstone or sandy laterite, limiting the scope of mining activity in the area. The formation unconformably overlies the Kingraili Formation and is composed of red ferruginous or lateritized sandstone grading up into medium to fine grained white quartzose sandstone. The quartzose sandstone is overlain by white to cream clay with sand to silt sized quartz grains in the lower part. Instances of occasional quartzose sand over clay or of red sandstone with clay are not uncommon. Ironstone to ferruginous sandstone is the most common association in the subject area. In some parts the Datta Formation unconformably overlies the Chak Jabbi Limestone and the Kingriali Formation had been completely eroded due to the Upper Triassic denudation.

LITHOSTRATIGRAPHY

The following lithological units have been identified in the Datta Formation from the Kala Chitta Range.

Ironstone/laterite

It represents the basal most lithosome being usually developed over the irregular top surface of the Kingraili Formation. It dominantly consists of red ferruginous claystone with dark red, hematitic nodules (up to 7.0 cm), which are irregular to near oval shape.

Ferruginous sandstone

It consists of ill sorted medium to coarse grained red to maroon sandstone, well bedded to poorly bedded and ferruginous. At places it has hematitic intraclasts. Commonly, it overlies either the Kingraili Formation (unconformably) or the ironstone (gradationally). Rare instances of cross-stratification are also present wherein fine and coarse grained sets are repeated.

Quartzose sandstone

It is quite immature white sand, slightly calcareous in parts, medium to coarse grained and up to 6 meters thick. At places it has angular-subangular quartz grains in clay matrix. Lenses of quartzose sandstone usually overly the ferruginous sandstone. Sometimes these are found within the clay zone. It becomes more compact in the eastern most occurrences that can be used as silica sand. South of Narian Village (Fig. No. 1) in the northern most strip of the Datta Formation, a basal zone of greenish grey to brownish grey, hard quartzitic sandstone that weathers to dull maroon colour is developed.

Bauxite

It is rarely found and is present in the form of irregular lenses in massive clay. At places, however, a thin blanket of bauxite is also found. Bauxite is distinguishable from clay on the basis of its hard nature, subconchoidal fracture, high specific gravity and mostly concentrically layered oolites to pisolites.

Clay

A variety of clay is found. It is white cream, yellow, light grey, pink and purple. It is mostly massive and stratification is imparted by bands of different colour or other lithologies. It is brittle, splintery, or soil like, and non-oolitic, or pisolitic. Occurrence of medium grey, slightly compact and oval intra clasts in massive white to light grey clay is quite common, which are sometime bauxitic.The fire clays occur in the form of lenses that pinch and swell rapidly. An interesting feature common to almost all the big or small lenses is that the clay occupies pouches formed in the top part of the Kingraili Formation due to the erosion subsequent to the regional, Late Triassic-Early Jurassic uplift.

CHEMICAL ANALYSIS

The chemical composition of the sample show a remarkable difference in Ah03 taken from the upper part of the Datta Formation, ranging from 39.61% to over 78% (sample Nos. 15, 17,78,516,517,519; Table

No.2) with an overall low value at Sakhi Zindapir Section where the Al203 does not exceed more than 26.09% with high silica of the order of 69.26% (sample nos. 110, 117; Table No.1). The clays form middle part show an average composition of Ah03 ranging from 36.21 % to 44.19% (sample Nos. 16,26, 28, 30, 517; Table No.2).

Table-1
Chemical analysis of Fireclay Samples from Surg-Chak Jabbi Area, Kala Chitta Range (Determined by SEM)

Sample No.	KQ-16	KQ-28	KQ-78	KQ-110	KQ-117	KQ-517
SiO_2	37.28	51.76	29.15	66.58	69.26	43.03
AhO_3	51.60	45.04	25.13	22.29	26.09	51.73
Fe_2O_3	5.59	0.67	7.22	8.37	0.48	0.87
CaO	0.00	0.00	34.37	0.64	0.40	0.21
MgO	0.37	0.00	1.15	0.00	0.34	0.00
Na_2O	0.95	0.68	1.11	0.00	1.01	1.34
K_2O	0.32	0.19	0.52	0.21	0.39	0.70
TiO_2	3.90	1.66	1.35	1.90	2.03	2.12
Total	100.01	99.99	100.00	99.99	100.00	100.00

The upper part of the formation shows less silica values ranging from 49% to 26.37% (very rarely high values up to 44.88% sample No. 78, Table No.2) and % age of iron ranging from 0.18% to 2.0% as compared with the lower part of the formation. Alkalies, (0.02% to 2.82%) Magnesium (0.00% to 0.75%) and Ti02 (0.20% to 3.37%) do not show any remarkable variation. The Ti02 composition ratio is directly proportionate to Fe203 and it increases or decreases along with iron. An increased value of CaO (22.64) has been found (Sample No. 77: Table No.2) in rare cases which may be due to the contamination by calcite solutions from overlying limestone beds of the Samana Suk Formation. The loss on ignition shows a similar trend (10.30% 14.60%) in almost all samples.

Table-2: Chemical Analysis of the Fireclay Samples from Surg-Chak Jabbi- Zindapir area, Kala Chitta Range.

Sample No.	I/L	SiO^2	Al^2O^3	Fe^2O^3	CaO	MgO	Na_2O	K_2O	TiO_2	Total
KQ-14	13.42	45.60	36.21	2.30	0.14	0.03	0.49	0.38	1.21	99.78
KQ-15	13.92	3.49	78.95	2.00	0.22	0.05	0.39	0.07	0.87	99.96
KQ-16	13.66	31.29	43.05	4.83	0.00	0.32	0.82	2.82	3.37	99.96
KQ-17	14.16	7.39	73.68	2.50	0.21	0.10	0.30	0.06	1.32	99.72
KQ-26	14.06	44.50	38.00	1.00	0.35	0.19	0.51	0.37	0.20	99.18
KQ-28	14.18	44.42	38.65	0.57	0.00	0.00	0.58	0.16	1.41	99.97
KQ-30	14.60	44.40	37.39	1.52	0.32	0.44	0.15	0.20	0.79	99.81
KQ-77	34.12	19.20	16.55	4.75	22.64	0.75	0.73	0.34	0.89	99.95
KQ-78	12.72	44.88	39.61	1.10	0.14	0.05	0.48	0.32	0.39	99.69
KQ-516	14.34	43.20	40.1 0	0.84	0.29	0.40	0.21	0.30	0.21	99.89
KQ-517	14.58	36.76	44.19	0.74	0.18	0.00	1.14	0.60	1.81	100.00
KQ-518	10.30	27.84	30.81	25.02	3.21	0.23	0.00	0.00	2.47	99.88
KQ-519	14.35	26.37	56.50	0.18	0.25	0.35	0.02	0.02	1.80	99.84

MINERAL COMPOSITION

As the fireclays from the Datta Formation are very fine grained it is not possible to determine the mineralogical composition through ordinary polarizing microscope therefore, X-ray diffraction (XRD) analysis, and Differential Thermal Analysis (DTA) techniques were employed to determine the mineral composition of the fireclays.

a. Differential Thermal Analysis (DTA): The samples showing almost the same chemical composition were selected for DTA and XRD analysis. The DTA curves of the fireclay samples are shown in Fig. No.3 and the values are given in the table No.3. it is revealed from the DTA analysis that almost all the fireclays show the mineral composition of Kaolinite and diaspore with the exception of sample No. 78 (Table No.3) in which the Al203 is represented by gibbsite. The sample Nos. 14,28,30,516, and 519 (Fig. No.3; table No. 3) show the exothermic peaks of Kaolinite at about 988°C, whereas the sample Nos. 16,26,78 and 517 (Fig. No.3; Table No.3) show peaks at different temperature which corresponds to the variation in the alumina composition. A shift in endothermic peaks of diaspore is noted in the samples which are also due to the variation in Al_2O_3) composition.

b. **XRD Analysis** The XRD analysis also proves that the main mineralogical composition of fireclays in the investigated area is Kaolinite, diaspore and gibbsite. The results are given in table Nos. 3,5 and the relevant peaks are shown in (Fig. Nos. 4-10). The minerals identified with the help of DTA are comparable with those of XRD results. The XRD results in some cases, however, show slight difference in the peaks and in their "d" values, which is attributed to the variation in their chemical composition.

Table-3

Minerals identified by Differential Thermal Analysis of Fireclays from Surg, Chak Jabbi and Zindapir areas, Kala Chitta Range. (Data refers to Fig. 3)

Station No.	Sample No.	Temperature	Peak	Minerals
1.	KQ-14	534°C 988°C	Endo Exo	Diaspore Kaolinite
2.	KQ-16	504°C 935°C 955°C	Endo Endo Exo	Diaspore Kaolinite
3.	KQ-26	537°C	Endo	Diaspore
4.	KQ-28	536°C 522°C 988°C	Endo Endo Exo	Diaspore Kaolinite Kaolinite
5.	KQ-30	539°C 987°C	Endo Exo	Diaspore Kaolinite
6.	KQ-516	545°C 989°C	Endo Exo	Diaspore Kaolinite
7.	KQ-519	510°C 533°C 988°C	Endo Endo Exo	Diaspore Kaolinite
8.	KQ-78	260°C 522°C 822°C	Endo Endo Exo	Gibbsite Kaolinite Calcite
9.	KQ-517	504°C 550°C 950°C	Endo Endo Exo	Kaolinite Diaspore Kaolinite
10.	KQ-llO	522°C 550°C 992°C	Endo Endo Exo	Kaolinite Diaspore Kaolinite
11.	KQ-117	537°C 989°C	Endo Exo	Diaspore Kaolinite

Table-4

Minerals identified by X-ray diffraction data of fireclay from Surg, Chak Jabbi, and Zindapir areas, Kala Chitta Range. (Analysis carried out at PCSIR Laboratories, Lahore)

Sample No.	Minerals identified
KQ-14	Kaolinite, Quartz
KQ-16	Kaolinite, Diaspore
KQ-26	Kaolinite, Quartz
KQ-28	Kaolinite, Quartz
KQ-519	Kaolinite, Diaspore
KQ-llO	Kaolinite, Quartz
KQ-117	Kaolinite, Quartz

Table-5

Minerals identified by X-ray diffraction data of Fireclays from Surg, Chak Jabbi, and Zindapir areas, Kala Chitta Range. (Analysis carried out at Geosciences Laboratories, GSP, Islamabad)

Sample No.	Minerals identified
KQ-77	Hematite, Geothite, Quartz, Kaolinite
KQ-78	Quartz, Kaolinite, Calcite, Gibbsite
KQ-106	Quartz, Kaolinite, Haematite, Maghemite, Muscovite
KQ-117	Haematite, Geothite, Quartz, Kaolinite, Calcite
KQ-515	Haematite, Geothite
KQ-516	Kaolinite, Quartz
KQ-517	Kaolinite, Quartz
KQ-518	Kaolinite, Quartz

COMPARISON WITH OTHER AREAS

Salt Range: In the western Salt Range (Nammal Gorge section) the formation is of continental origin and consists of variegated sandstone and shale with carbonaceous, ferruginous, glass sand, and fireclay horizons. The fireclay is present in the lower part. Fatmi et al. (1987) described an onlap relationship of the Datta Formation over the Triassic from the western Salt Range (Lalumi-Chidru section).

Whitney et al. (1990) reported the predominance of boehmite and gibbsite in the samples from the Salt Range. On the other hand kaolinite and diaspore are the dominant minerals in the Kala Chitta Range. The iron rich laterites comprise foliated hematite (particularly in the Sakhi Zindapir) in the Kala Chitta Range with respect to the reported massive goethite in the Salt Range.

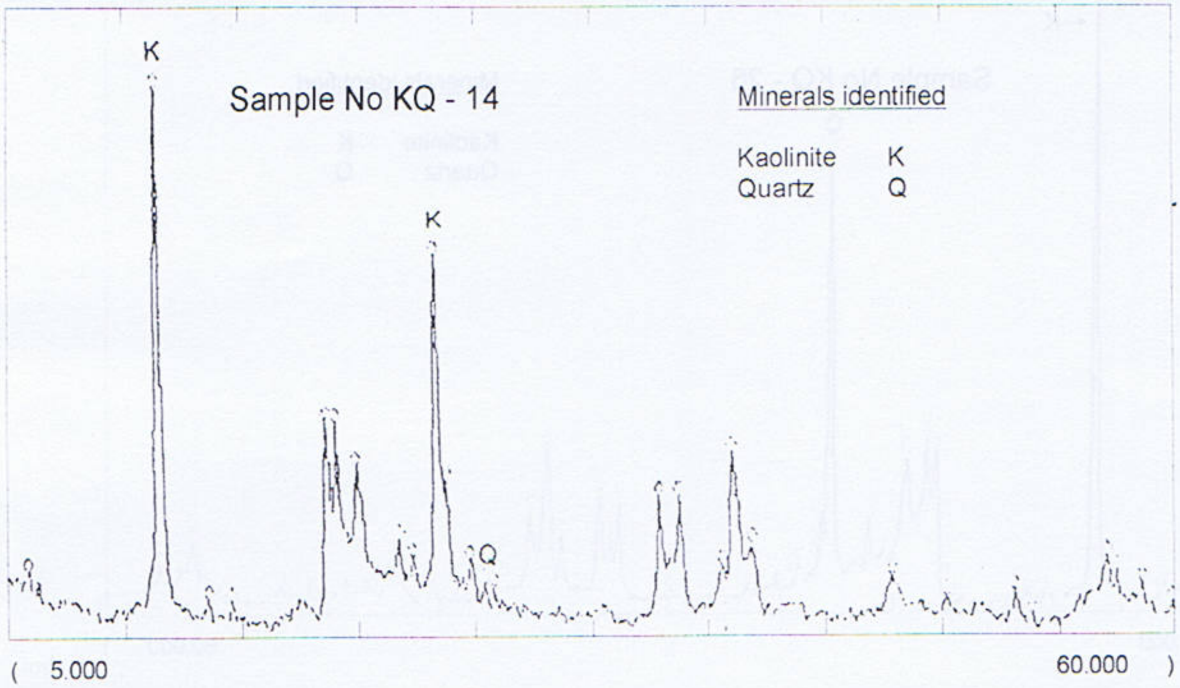
According to Veletone (1972), the thermal alteration of fireclays and bauxite causes gibbsite and boehmite to react to diaspore. The reaction of gibbsite to boehmite occurs near 120°C and the reaction of boehmite to diaspore normally occurs between 200°C - 300°C. Furthermore, the transition from goethite to hematite occurs at near 100°C.

All these reactions are too complex to use as simple or precise geothermometers. However, the presence of high temperature minerals i.e. diaspore and micaceous hematite in the Kala Chitta Range is a clear evidence of burial metamorphism in the laterite and fire clays deposits when compared to the equivalent rocks (e.g. Jurassic Datta Fire Clays in the Salt Range) having low temperature minerals such as gibbsite, boehmite and goethite. The dynamic metamorphism caused by the extensive tectonism in the Kala Chitta Range can also be responsible for this mineralogical change.

Trans Indus Ranges: Mensink et al. (1991) have described Lower Jurassic facies from localities in the Trans-Indus Range (Lat 32° 55' Long. 71° 10'). The Datta Formation in these areas comprises cross bedded sandstone, siltstone, sandy marls and clays with mud cracks, skolithos burrows horizons, drifted wood and paleosols. A transitional change from the dolomite facies (the Kingriali Formation) to the sandstone facies (the Datta Formation) is reported. Thus, the succession from the Kingriali Formation to the Datta Formation does not appear to be separated by a discontinuity. Although the bedding planes are locally covered with Fe-crusts but their primary Jurassic origin is considered to be doubtful.

Table-6
Lithological section of the Datta Formation from Bara Oater Area Hazara (Chaudhry et al. 1994)

Bed	Facies	Environment of Deposition
I	Arenaceous dolomite with streaks and layers of grit.	Low to moderate energy marine, with worm tacks. Shallow intertidal/tidal mud flat.
II	Mudstone.	Marine, very low energy.
III	Fine to very fine grained, carbonate and quartz cemented quartz arenite.	Marine, very low energy.
IV	Very fine grained arenaceous limestone.	Marine, low energy.
V	Fine grained, quartz and carbonate cemented quartz arenite.	Marine, very low energy.
VI	Coarse grained carbonate cemented quartz arenite.	Marine, high energy.
VII	Medium grained, ferruginous quartz arenite.	Marine, low to medium energy.
VIII	Alternation bands of carbonate cemented quartz arenite and oolitic, pellectoidal limestone.	Marine, high energy.
IX	Medium to fine grained quartz and kaolinite-illite cemented quartz arenite.	Marine, bimidal, lag sand deposit.
X	Fine grained glauconitic sandstone.	Low rate of sedimentation, low energy, reducing condition, marine transgression.
XI	Medium grained quartz cemented quartz arenite.	Medium energy continental environment.



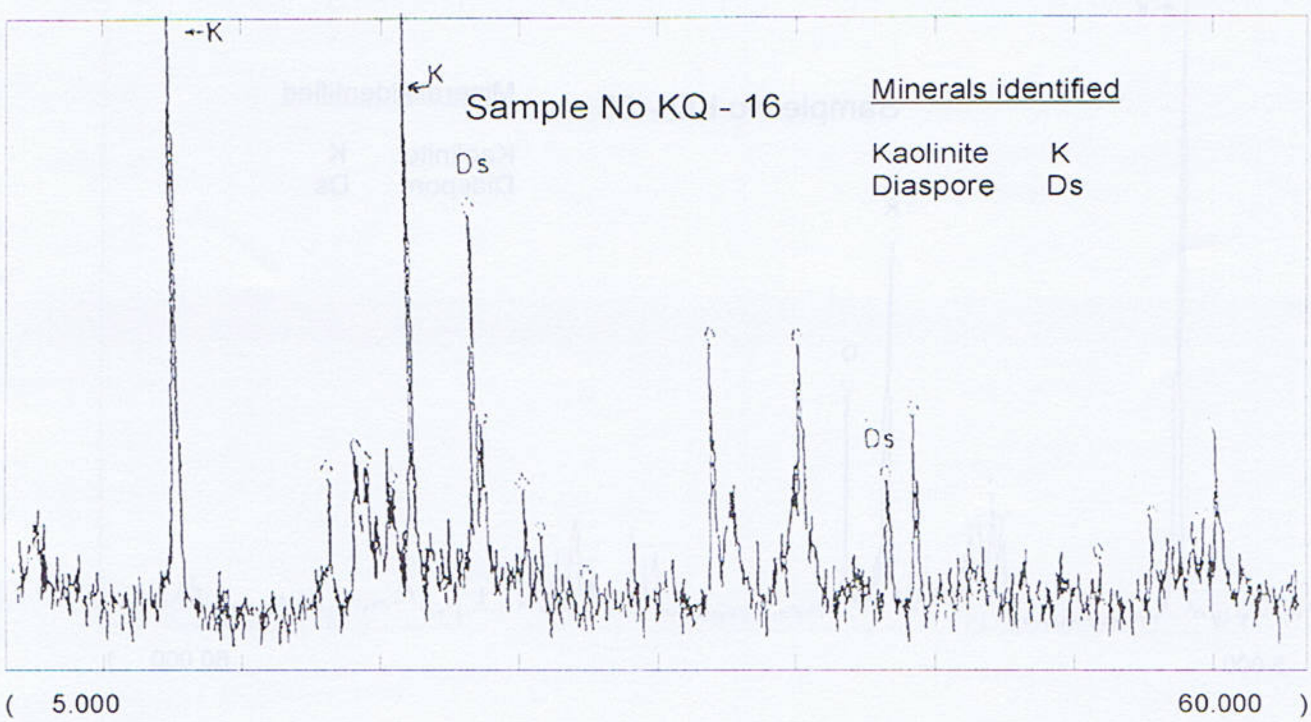
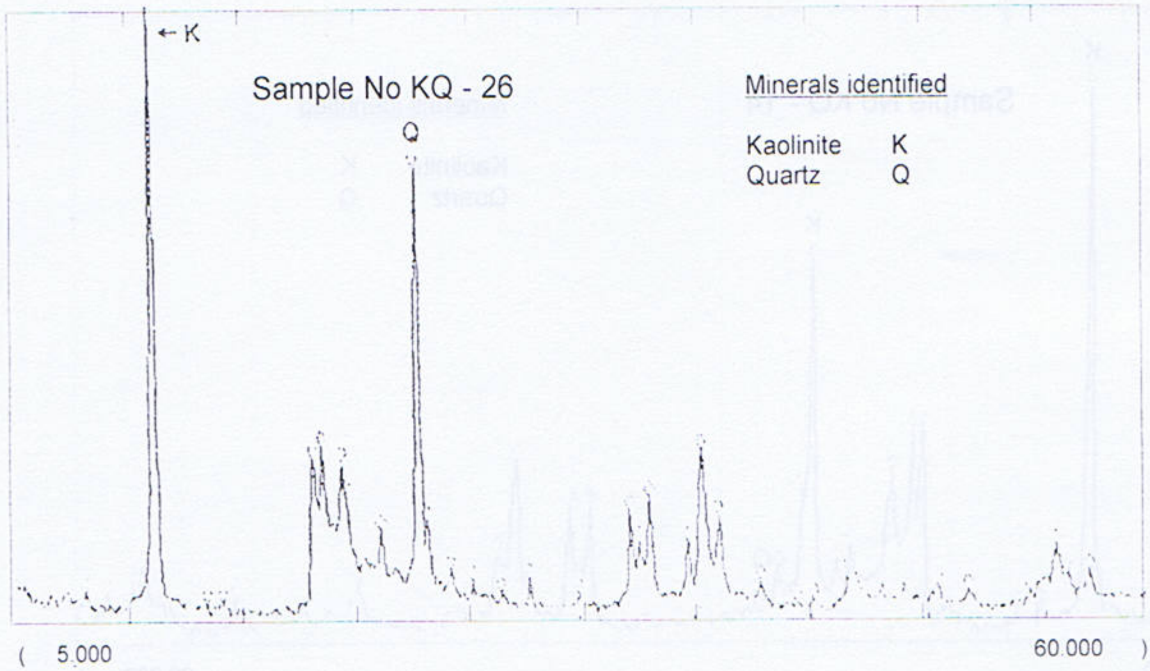


Fig 4 X-ray diffraction analyses of clays of the Datta Formation (sample no KQ-14. KQ-16) Kala Chitta Range



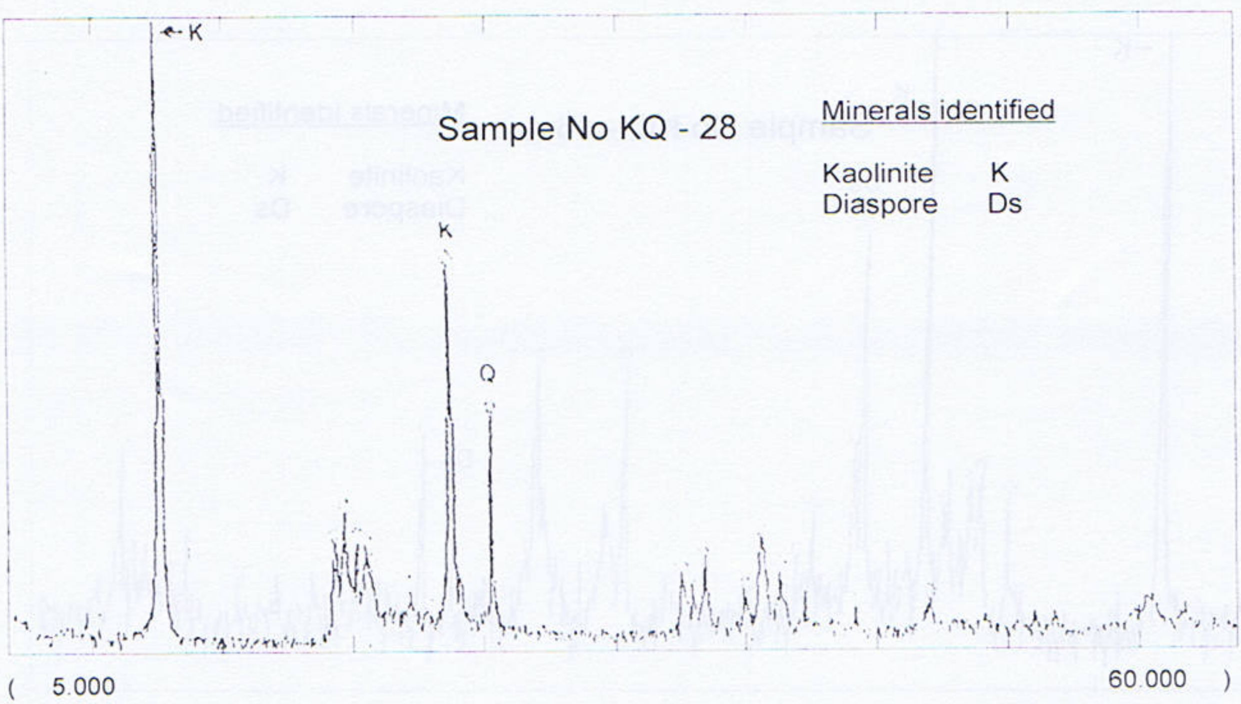
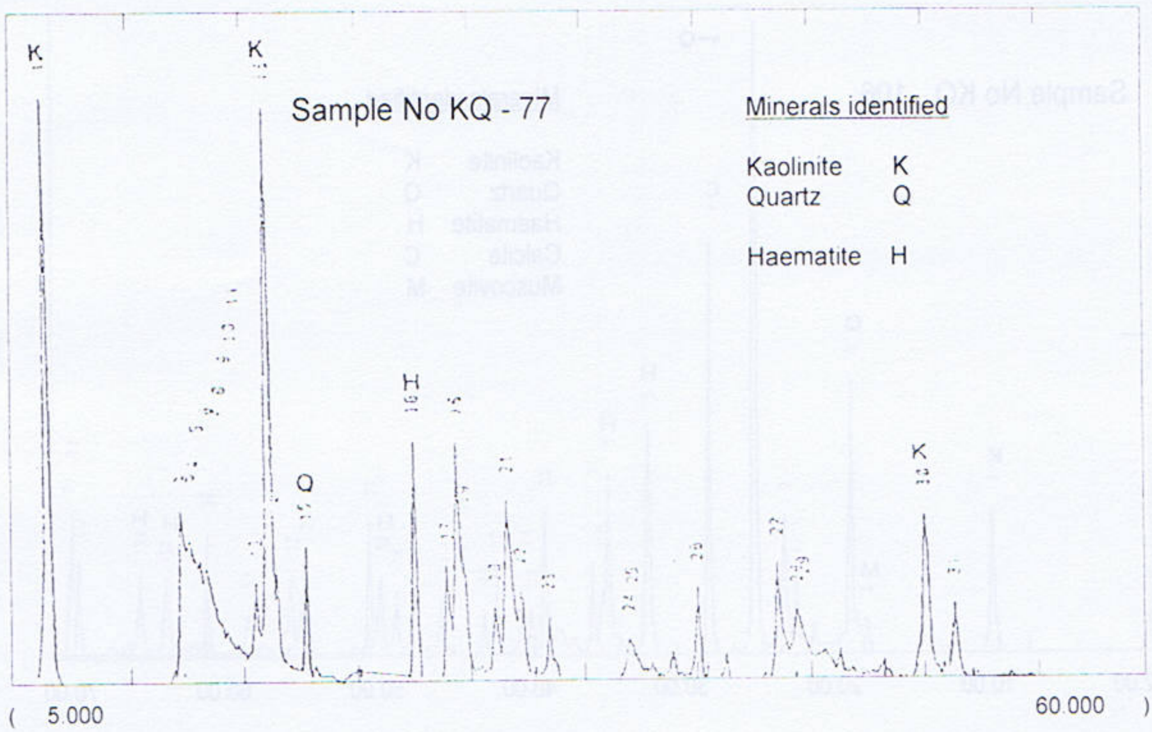


Fig 5 X-ray diffraction analyses of clays of the Datta Formation (sample no KQ-26. KQ-28) Kala Chitta Range



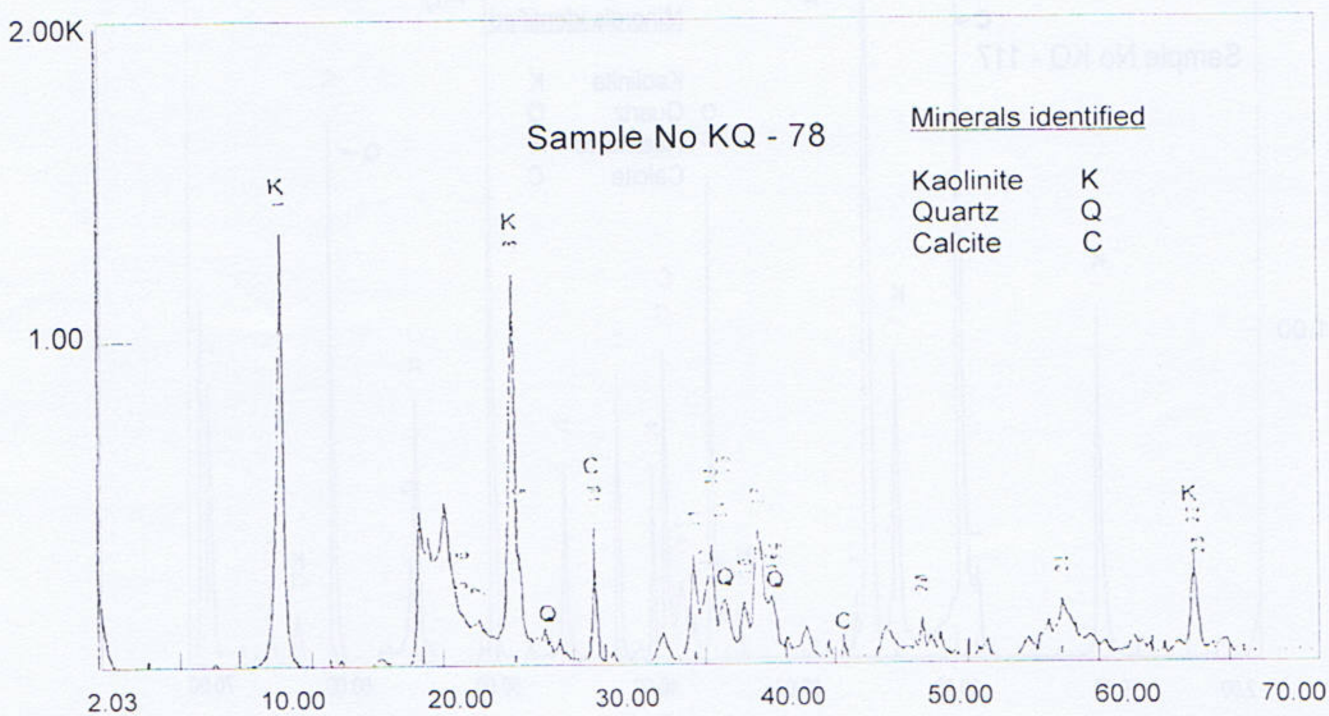
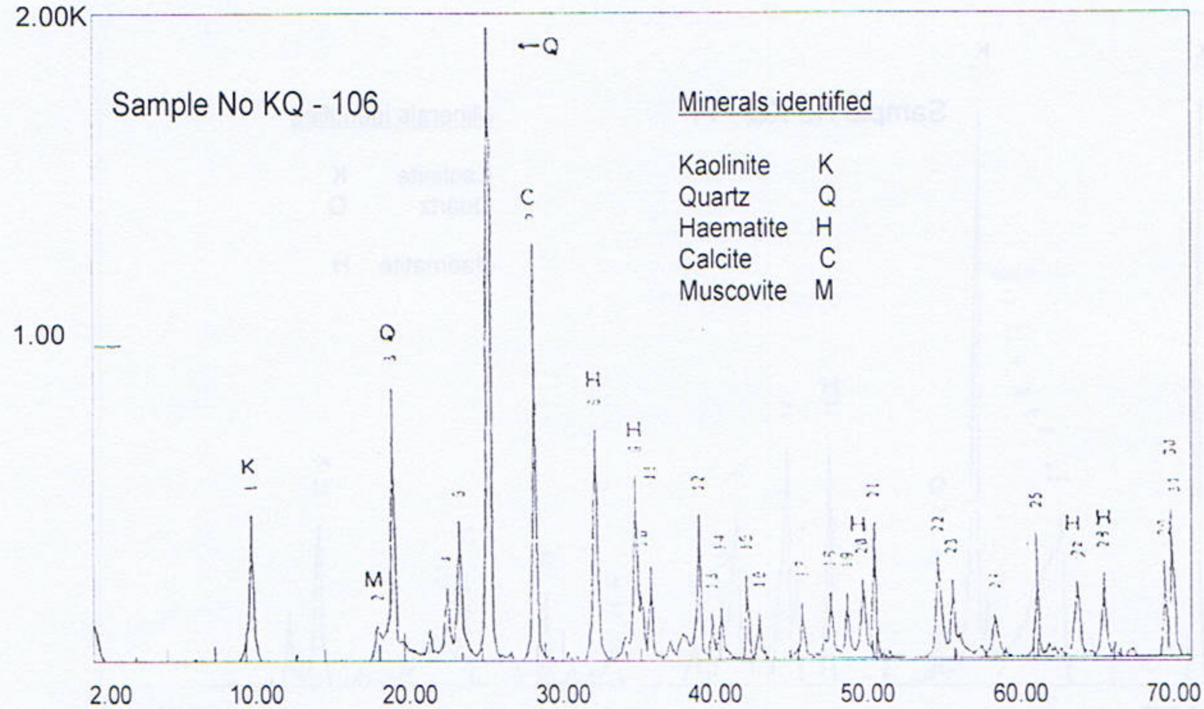


Fig 6 X-ray diffraction analyses of clays of the Datta Formation (sample no KQ-77, KQ-78) Kala Chitta Range



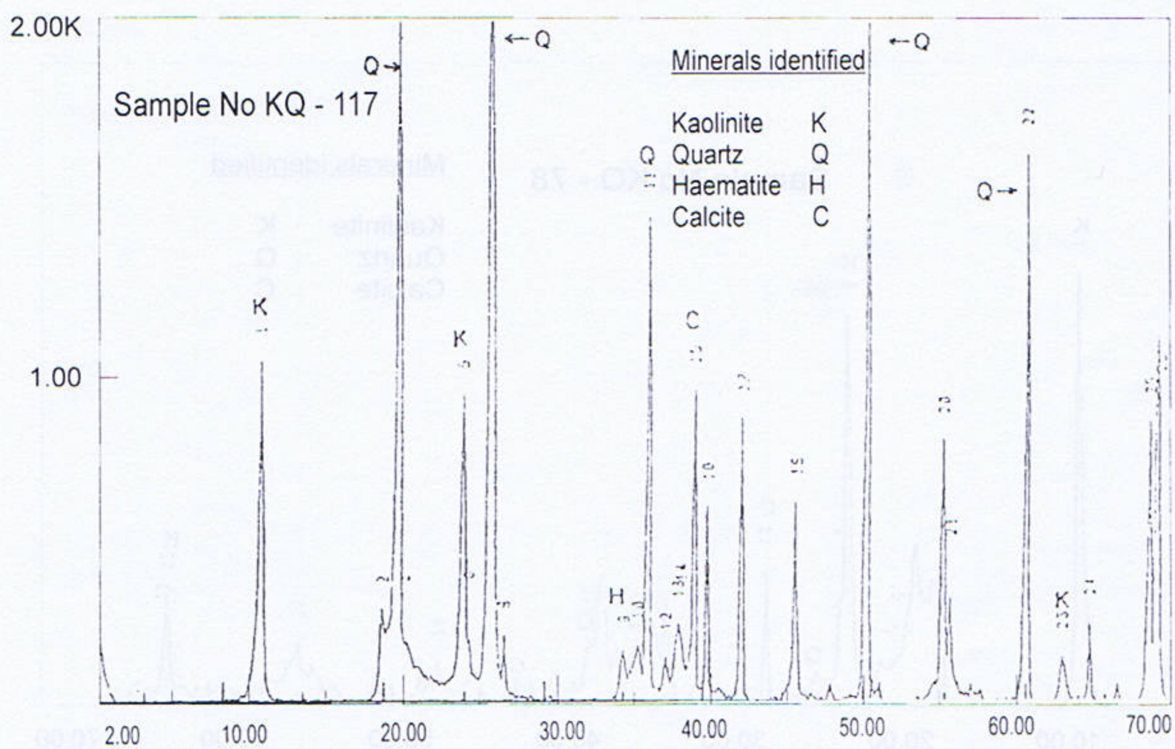


Fig 7 X-ray diffraction analyses of clays of the Datta Formation (sample no KQ-106. KQ-117) Kala Chitta Range

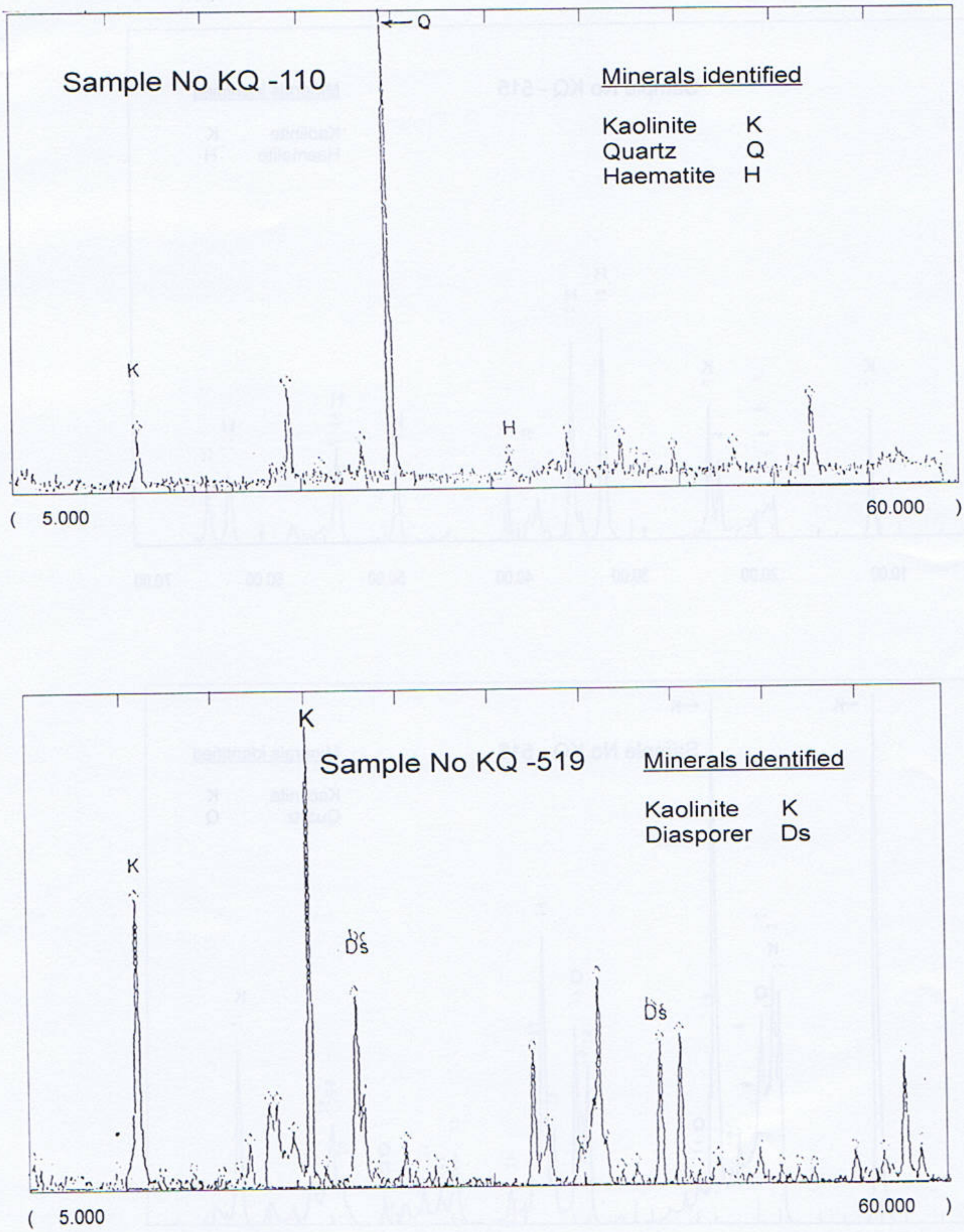


Fig 8 X-ray diffraction analyses of clays of the Datta Formation (sample no KQ-110. KQ-519) Kala Chitta Range

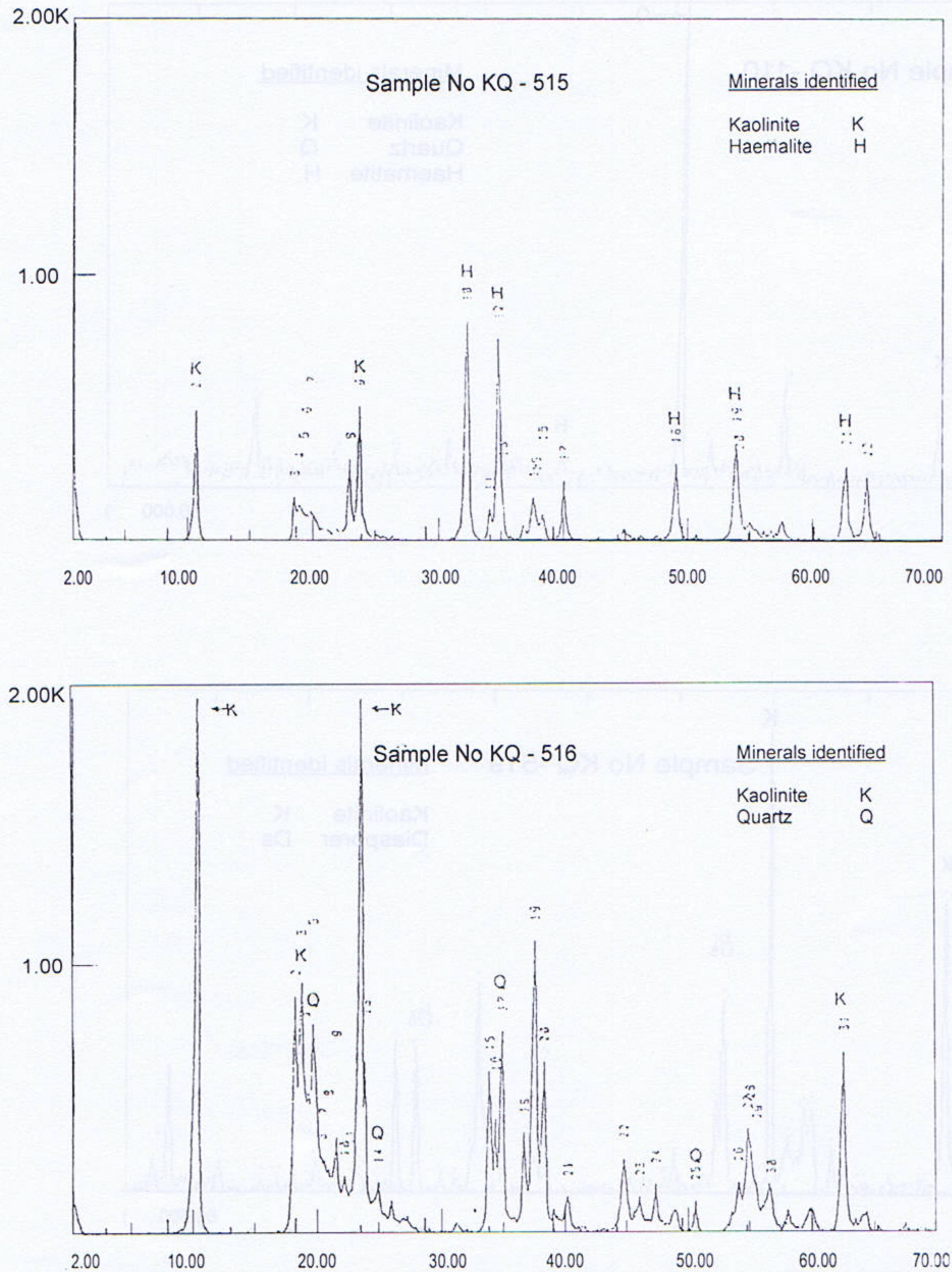


Fig 9 X-ray diffraction analyses of clays of the Datta Formation (sample no KQ-515. KQ-516) Kala Chitta Range

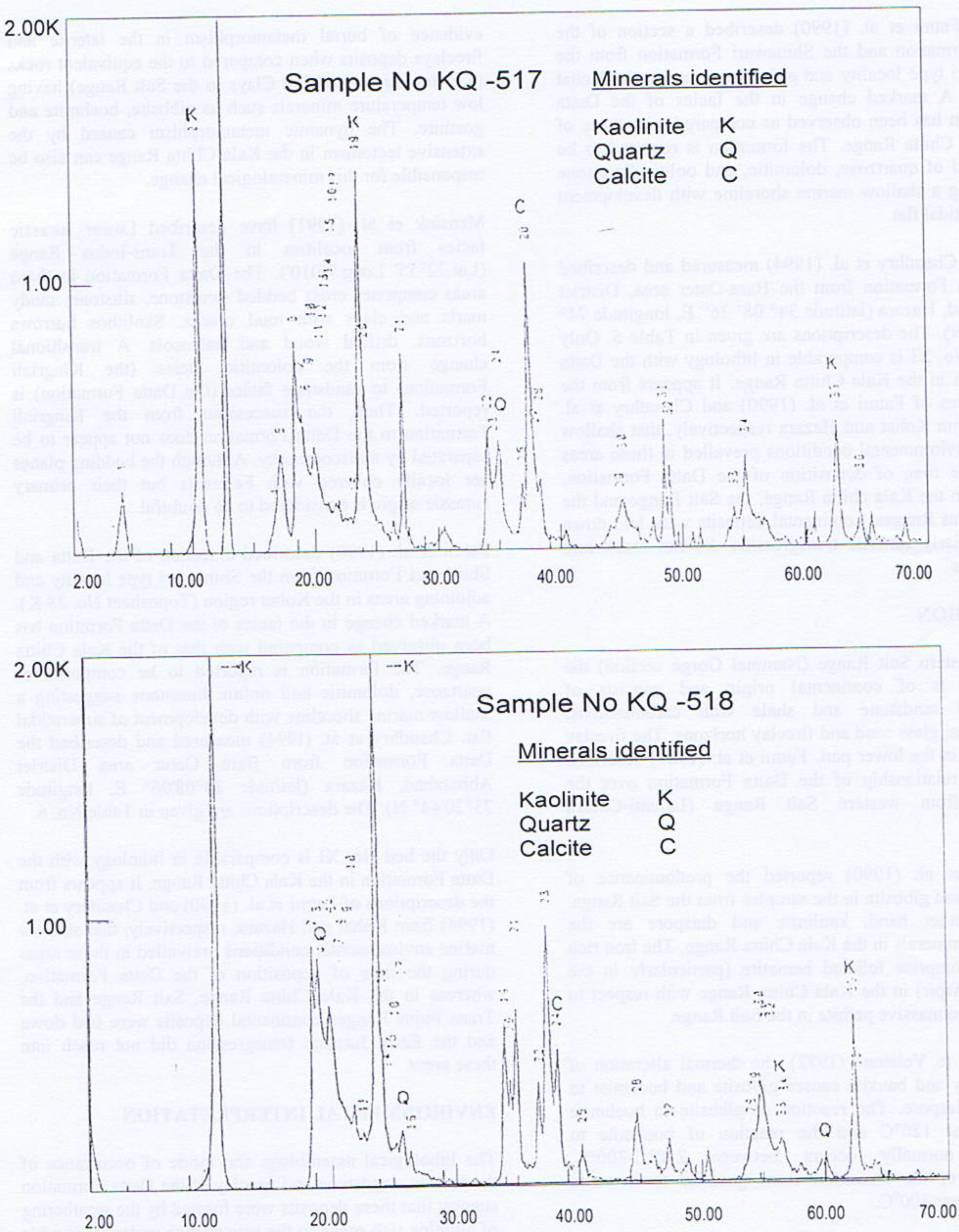


Fig 10 X-ray diffraction analyses of clays of the Datta Formation (sample no KQ-517. KQ-518) Kala Chitta Range

Kohat: Fatmi et al. (1990) described a section of the Datta Formation and the Shinawari Formation from the Shinawari type locality and adjoining areas in the Kohat region. A marked change in the facies of the Datta Formation has been observed as compared with those of the Kala Chitta Range. The formation is reported to be composed of quartzose, dolomitic, and oolitic limestone suggesting a shallow marine shoreline with development of superatidal flat.

Hazara: Chaudhry et al. (1994) measured and described the Datta Formation from the Bara-Oater area, District Abbotabad, Hazara (latitude 34° 08' 36" E, longitude 74° 20' 44" N). The descriptions are given in Table 6. Only the bed No. XI is comparable in lithology with the Datta Formation in the Kala Chitta Range. It appears from the descriptions of Fatmi et al. (1990) and Chaudhry et al. (1994) from Kohat and Hazara respectively, that shallow marine environmental conditions prevailed in those areas during the time of deposition of the Datta Formation, whereas in the Kala chitta Range, the Salt Range and the Trans Indus Ranges, continental deposits were laid down and the Early Jurassic transgression did not reach into these areas.

DISCUSSION

In the western Salt Range (Nammal Gorge section) the formation is of continental origin and consists of variegated sandstone and shale with carbonaceous, ferruginous, glass sand and fireclay horizons. The fireclay is present in the lower part. Fatmi et at. (1987) described an onlap relationship of the Datta Formation over the Triassic from western Salt Range (Lalumi-Chidru Section).

Whitney et at. (1990) reported the predominance of boehmite and gibbsite in the samples from the Salt Range. On the other hand, kaolinite and diaspore are the dominant minerals in the Kala Chitta Range. The iron rich laterites comprise foliated hematite (particularly in the Sakhi Zindapir) in the Kala Chitta Range with respect to the reported massive pethite in the Salt Range.

According to Veletone (1972), the thermal alteration of the fireclay and bauxite causes gibbsite and boehmite to react to diaspore. The reaction of gibbsite to boehmite occurs near 120°C and the reaction of boehmite to diaspore normally occurs between 200°C-300°C. Furthermore, the transition from goethite to hematite occurs at near 100°C.

All these reactions are too complex to use as simple or precise geothermometers. However, the presence of high temperature minerals such as the diaspore and the micaceous hematite in the Kala Chitta Range is a clear evidence of burial metamorphism in the laterite and fireclays deposits when compared to the equivalent rocks (e.g. Jurassic Datta Fire Clays in the Salt Range) having low temperature minerals such as gibbsite, boehmite and goethite. The dynamic metamorphism caused by the extensive tectonism in the Kala Chitta Range can also be responsible for this mineralogical change.

Mensink et al. (1991) have described Lower Jurassic facies from localities in the Trans-Indus Range (Lat.32°55' Long.71010'). The Datta Formation in these areas comprises cross bedded sandstone, siltstone, sandy marls and clays with mud cracks, Skolithos burrows horizons, drifted wood and paleosols. A transitional change from the dolomitic facies (the Kingriali Formation) to sandstone facies (the Datta Formation) is reported. Thus, the succession from the Kingriali Formation to the Datta Formation does not appear to be separated by a discontinuity. Although the bedding planes are locally covered with Fe-crusts but their primary Jurassic origin is considered to be doubtful.

Fatmi et al. (1990) described a section of the Datta and Shinawari Formtion from the Shinawari type locality and adjoining areas in the Kohat region (Toposheet No. 38 K). A marked change in the facies of the Datta Formtion has been observed as compared with that of the Kala Chitta Range. The formation is reported to be composed of quartzose, dolomitic and oolitic limestone suggesting a shallow marine shoreline with development of superatidal flat. Chaudhry et at. (I994) measured and described the Datta Formation from Bara Oater area District Abbotabad, Hazara (latitude 34°08'06" E, longitude 73°20'44" N). The descriptions are given in Table No. 6.

Only the bed No. XI is comparable in lithology with the Datta Formation in the Kala Chitta Range. It appears from the descriptions of Fatmi et al. (1990) and Chaudhry et at. (1994) from Kohat and Hazara, respectively, that shallow marine environmental conditions prelvailed in those areas during the time of deposition of the Datta Formation, whereas in the Kala Chitta Range, Salt Range and the Trans Indus Ranges continental deposits were laid down and the Early Jurassic transgression did not reach into these areas.

ENVIRONMENTAL INTERPRETATION

The lithological assemblage and mode of occurrence of the laterite, sandstone and fireclay of the Datta Formation suggest that these deposits were formed by the weathering of alumina rich rocks in the provenance under favourable conditions and later were transported to the present site of deposition. The conditions that favour the formation of such deposits have been studied by Dorokhin et at. (I969) and Valeton (1981) from different parts of the world and are summarized as under:

1. Presence of rocks with readily soluble minerals whose insoluble residue was rich in alumina.

2. A tropical climate with abundant rainfall alternating with dry periods.

3. High rock porosity

4. A flat or gently undulating relief.

5. Prolonged periods of rest in the earth's development in a given region.

6. Presence of bacterial or vegetable life.

It is quite likely that the conditions outlined above were approaching the ideal ones in the provenance, where the subaerial weathering of the Pre-Cambrian quartzite, rhyolite, andesite, ash, tuff and low grade metamorphics of Indian Shield - the provenance (presently exposed around Sarghoda) produced laterites and aluminous clay/bauxites, which were reworked and deposited during Early Jurassic times, in the low lying Kala Chitta area (Ashraf et al., 1976).

Localizing effect of the irregularities of the top of Kingraili Formation is responsible for restriction of clay in the pouches and deposition of sand along the crest of protrusion. Various stages of formation of these deposits from the bed rock and transportation to the present site are given below:

1. In the first stage the weathering and alteration of bed rock in the provenance produced clays with free silica. The most of the iron, calcium, magnesium and other elements were removed.

2. The alumino-silicates were dissolved by weathering to form a aluminium hydroxide and iron hydroxide in the tropical to subtropical humid environments.

3. Favourable chemical and physical conditions also led to desilication or bauxitisation of the clay, at a certain stage. This desilication/ bauxitisation might have taken place in colloidal state around numerous favourable centers or nuclei. As silica leached out, alumina concentrated around these nuclei in the form of pisolites and nodules forming patches/lenses of bauxite depending upon the intensity of bauxitisation around these nuclei.

4. The deposition of kaolinite and bauxite occurred in definite and distinct zones. However, it is postulated that the weathering conditions have been subordinately persisting and repeatedly quick change from dry to humid conditions prevailed. These climatic fluctuations muddled up the sediments, resulting in mixing up of kaolinite and bauxite.

5. The laterite was formed on top during more tropical conditions, when iron bearing solutions were brought up from weathering bed rock by capillary action and ironstone was deposited on top of claylbauxite. The iron bearing solution during their upward journey impregnated the clays giving rise to lateritized clays/bauxite. The occurrence of irregular patches of ferruginous material indicates that in the provenance the lateritisation process was not regular. It might be due to the source rock being richer in aluminium than iron.

6. The rocks thus formed were transported to their present site over lateritized and weathered surface of the Kingriali Formation during the lower Jurassic with ironstone being eroded and redeposited first, forming the base of the Datta Formation.

FAUNA AND AGE

The formation is unfossiliferous in the Kala Chitta Range. However, as it underlies the *Bouleiceras* bearing beds (Fatmi, 1977) an Early Jurassic age has been assigned to the formation. In the Salt Range, Jain and Shah (1968) and Masood and Bhutta. (1985) reported a rich variety of palynomorphs belonging to the Early Jurassic age.

CONCLUSIONS

- Detailed geological mapping and the sampling of the Datta Formation have led to establish the mode of occurrence of economically important Fire Clay horizons.

- The analytical data has contributed towards determining the mineralogy of the Fire Clay horizons.

- Lithological details have highlighted the depositional pattern of the Datta Formation in comparison to its environmental style in the type area of the Salt Range as well as the Hazara Mountains.

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Geol. Bull. Punjab Univ. Vol. 40-41, 2005-6, pp 45-52

NEOTECTONICS IN UPPER CHAJ DOAB PUNJAB PAKISTAN

BY

MUHAMMAD MUNAWAR IQBAL GONDAL
Road Research & Material Testing Institute Research Campus Lahore, Pakistan

AND

CHAUDHRY MASOOD AHMAD
Regional Laboratory Highway Circle Lahore, Pakistan

Abstract: *The upper Chaj Doab is a part of Punjab Plain and borders Sub Himalayas that had undergone faulting and folding. The area is dominantly composed of alluvial sediments. It is drained by the River Jhelum and the River Chenab. There are two prominent scarps/upland in the area. Gondal bar Scrap runs over 40 km from Charund to Rerka and beyond. Bahlulpur Scrap upto* 18 *km from Kotali Baidan to Sheikh Chogahi in District Gujrat. Gondal bar scarp exposes fluvial quartzose sand capped by flood plain silt and clay with profuse quantity of calcareous nodules. Bahlulpur Scarp exposes alternating beds of laterally accreted (point bar) quartzose sand and vertically accreted (flood plain facie) clayey silts to silty clays. The top member (clayey silt and silty clays) of both the scraps contains cultural debris suggesting Quaternary age of these deposits. Field study and regional context suggest that Bahlulpur and Gondal Bar Uplands vis-à-vis Dinga Basin are neotectonic features developed under south ward propagating compressional stresses which have accommodated themselves in this area. The neotectonic study has direct implications in combating with ground water, water logging and soil salinity, flood hazards and foundation problems encountered during execution of development projects.*

INTRODUCTION

Upper Chaj Doab is the north central part of the Punjab plains and lies on the northeastern rim of this basin where it joins Himalayan foothill zone. It is bounded in east south west by River Chenab and in north west by River Jhelum. It is located between 73°30'-74° 28. East and 32°-7' to 33° 0 North [Fig. I] Punjab plain is a geomorphic name and these plains are called Punjab foreland basin because they possess thick alluvium overlying Tertiary and older sedimentary deposits (Kidwai, 1962). Northern rim of this basin where it joins foothill zone i.e. Salt Range in northwest, Pabbi hills in north, Jammu hills in northeast is under considerable structural strain (Wadia 1992). The northern margin of Punjab basin is marked by major fault scarps that separate the basin from Himalayan foreland fold and thrust belt [HFFTB]. Indo Pak shield (basement) protrude the Quaternary alluvium in Central Chaj Doab in Sargodha Chiniot area. Sargodha ridge is a neotectonic feature (Gee, 1983) and it may have formed by late Cenozoic faulting. The Salt Range in the north of upper Chaj Doab is marked by southward moving Sa]t Range thrust which is still active (Yeats and Lawerence 1984). The deformation in Salt Range and Pabbi area is thin skin type, which involves the sediments over Cambrian and does not stop at Salt Range and Pabbi area but continues further south in upper Chaj Doab. The convergence of basement under Salt Range formation is merely 12 mm/year (Lillie et al., 1987) which suggests that basement of Punjab is still active. Punjab Seismic zone has been marked by Yeats and Lawerence (1984), which is parallel to Indian Himalayas. The seismic instability of the area is well known with earthquake of magnitude level m.a.4 (Quitmeyer et al., 1979).

A number of lineaments have been reported in the Punjab basin (Upper Chaj Doab), that may be active faults (Kazmi 1979, Kazmi and Rana 1982). One of these lineaments has been studied on ground by Yasin et al. (1993) and they have shown the possibility of quaternary faulting whereas other features had not been properly appraised. It has been tried to present here all neotectonic features controlling geomorphology, ground water and surface water regime and most importantly hierarchy of fluvial sedimentation in upper Chaj Doab.

OUT LINE GEOLOGY OF UPPER CHAJ DOAB

Upper Chaj Doab contains more than 500m thick Quaternary deposits (Kidwai, 1962). Below this alluvial cover older sedimentary deposits either consolidated or unconsolidated overlies igneous/metamorphic rocks of Indo Pak shield/basement. Kidwai (1962), Kazmi and

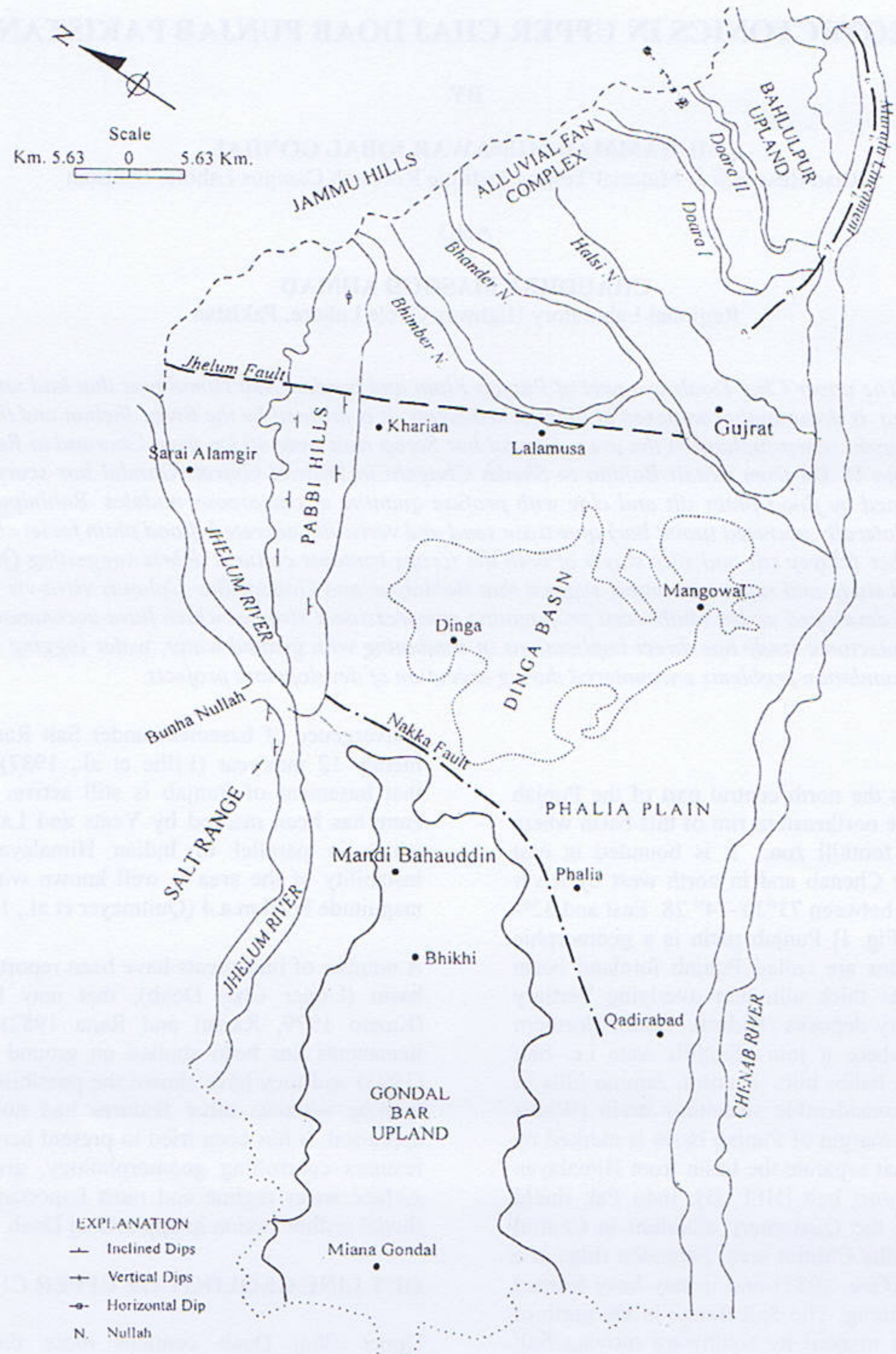

Fig. 1 Neo- Tectonic Features in upper Chaj Doab.

Rana (1982) have delineated a buried ridge and a monocline in the basin. Whereas Farah et al. (1977) considered Kirana hills as part of east-southeast trending Sargodha ridge of raised continental crust, which extends from Indus river at least as far as Indian border at Sutlaj river. This ridge is expressed by positive gravity anomaly and is a horst like block of continental crust. Conventionally it is believed that Kirana hills are old remnants of Palaeozoic geomorphic feature of Indian shield where as by recent research, it has been considered to be a neotectonic feature (Gee, 1983) where as sharp topographic break between Sargodha high and surrounding plains is suggestive of its relative youth (Yeats and Lawerence 1984). It is part of seismically active Punjab Seismic Zone (Seeber and Armbuster, 1979), which extends as far as Dehli (Menke and Jacob 1976). Sargodha ridge is parallel to Indian Himalayas therefore; Lefort (I975) suggested the possibility of a new thrust fault in front of Himalayas "a new MCT". The strike slip fault plain solution may indicate that the seismicity is actually controlled by transverse faults (Validya, 1976) which themselves localize position of re-entrants in [HFFTB] Himalayan foreland fold and thrust belt of Pakistan.

Yeats and Lawerence (1984) had suggested the possible mechanism of Sargodha ridge emplacement. It may had formed by loading of the shield by Himalayan thrusts producing bending moment stresses resulting in an outer swell that is Sargodha ridge. Alternatively they suggested that buoyancy prevent further subduction at Himalayas and a new seismically active subduction zone had formed within basement at Sargodha ridge.

The rock units making up Sargodha ridge has been named as Kirana group (Shah 1977, Alam et al. 1962). These rocks consist of metasediments, andesites, rhyolite, tuff beds etc. Lillie et al. (1987) have suggested that low strength of evaporites under sub Himalayas i.e. Salt Range and Pabbi hills have allowed the decollement to extend far out over the Punjab foreland. Gee (I 983) suggested that this southward movement of decollment have developed folding in the strata underlying Quaternary alluvium. Lillie et al. (I987) have suggested that active foreland thrusting is occurring on continental scale as basement is over ridden by its own northern margin in a series of south ward migrating thrust sheets from Himalayas, which shed their erosion products onto active fore deep of Jhelum plain & Upper Chaj Doab which itself is migrating south ward (Acharyya and Ray, 1982, Johnson et al. 1979). In the northern part of Jhelum plain (Upper Chaj Doab) river flows west south west of Salt Range along the axis of fore deep (site of topographic minimum). Lillie et al. (1987) have shown that most of the deformation in Salt Range is late Quaternary. The Siwaliks and older strata are thrusted southward over river Jhelum plain and are strongly deformed. These beds are overlain by an angular unconformity by undated fan gravels and alluvium (Lillie et al., 1987) of Salt Range provenance. These younger sediments themselves are folded and over ridden by Salt Range thrust/suggesting that deformation is still active. Lillie et al. (1987) have shown that river Jhelum had removed the southern flank of Lilla anticline as it formed. This appear to be a blind sledrunner thrust extending south from the Salt Range implying that a portion of relative motion between Paleozoic sediments and basement took place south of Salt Range. This thrust front has recently been propagating further over the foreland as a giant sledruner (Baker et al., 1988). It is suggested that Salt Range thrust has been moving over the foreland as a coherent mass for the last 2 m.y.

Burbank et al. (1986), suggested that Plio Pleistocene structural disruption in the north western part of Indo-Gangatic foredeep appear strongly dependent on the distribution of incompetent (Particularly evaporite) horizons in the Paleozoic succession. Kazmi and Rana (1982), Khan et al. (1986), suggested that there exists a thin cover of Palaeozoic and Tertiary rocks over the basement. Kidwai (1962) and Yeats et al. (I986) suggested the presence of Miocene (Rawalpindi group) under lain by Siwaliks and Quaternary sediments. Kidwai (1962) had given detailed geology of Upper Chaj Doab with cross sections. He had described that quaternary alluvium consist of unconsolidated sand, silt and clay whereas gravels occur in depth close to hilly areas which had been deposited in a subsiding trough by present and ancestral streams of river Indus. The clayey silt mounds (Tibbas) present in Punjab basin documents wide spread aeoline phenomena in Punjab basin (Wadia 1992).

The presence and exposure of lacustrine sediments along the northern peripheral regions suggested wide spread occurrence of lakes during last glacial period, such as in south western Afghanistan (Smith 1974) Yasin et at. (1993) pointed out the possibility of Quaternary faulting in Punjab basin.

THE SCARPS IN UPPER CHAJ DOAB

River Jhelum and Chenab are two main trunk streams draining the area, which flowed southwest to join each other at Trimu head. The area lying between these rivers is termed as Chaj Doab. Basement rocks are exposed in the central part of Doab close to Sargodha and Chiniot. River Chenab passes through a narrow valley cut in these rocks at Chiniot. In Upper Chaj Doab a number of lineaments have been mapped from aerial photographs and speculated to be active faults in Quaternary alluvium by Kazmi (1979) Kazmi and Rana (1982). The scarps examined in the field have been mapped and marked is Fig-1. There are two main scarps exposed along Gondal Bar and Bahlulpur uplands.

1- GONDAL BAR UPLAND SCARP

The lineament along Gondal Bar scarp is well exposed at Channi Rahim Shah on Kuthiala- Phalia road, from here scarp has north east south west trend and best exposures are at Pandowal Jand and Rerka zarin in south west where as in north east at Bohat and Charund. The trend at Charund is almost north south. In this area Kazmi (1979) had marked a lineament named as Mangla fault, which extends northeast and passes close to western margin of Mangla Lake and had a left lateral movement. This lineament on ground had been studied by Yasin et al. (1993) who showed the possibility of Quaternary faulting along Gondal Bar scarp with north south and north east south west trending two faults. Near Channi Rahim Shah the low ground rises gradually for about 400 meter as a ramp and then it rises abruptly in a scarp, which is about 5- I 0 meter high. Quartzose sand is exposed at the base of scarp that fines up to silt and clay showing abundant calcareous Kankers (Gondal and Ahmed 1994). The sediments on top of this scarp can not be older than Holocene as these shows red earthen pottery fragments and cooked animal bones which suggested them younger than the earliest human settlements in the area. The fluvial faceis exposed in the scarp vary from place to place and appear to be cut by the scarp along their depositional strike. At Bohat the sand facies cut laminated silt and clay facies with some marsh plant rootlets and leaf imprints. This facies appear to be deposited in a shallow lake, which extends to Mangat. Detailed study is needed to establish depositional hierarchy. The up and down sides of scarp are different regarding ground water regime and gradational processes. On down side of scarp, swamps are common with a number of small-scale alluvial fans parallel to the scarp. Especially in Pindi Lala, Bohat and Charund area north of Phalia Town. Vegetation on the both sides is different. Gondal bar upland slope is drained to the north west whereas central part of this feature is slightly depressed which is ponded during moon soon e.g. Bhikhi, Khai, Ajowal, Rukan and Wariat area. Gondal bar posses a mature soil profile i.e. Kanker horizon is available through out the bar upland at 3-4 feet depth. The Kanker horizon is 2.5 to 4 feet thick bed underlain by alluvial, cross-bedded sand where as such a horizon close to Phalia Town is available at 400 feet depth (Wasid 2-1980).

2- BAHLULPUR UPLAND SCARP

The second scarp exposed close to Murala Head works where river Chenab enters Punjab plain is a piedmont scarp some times called scarp lets (Thornbury 1972) which runs from Kotali Baidan and beyond to Sheikh Chogahi with a curvilinear trend of north west to south west in district Gujrat. Near Bahlulpur, old flood plain of river Chenab gradually rises for about one km laterally then it rises abruptly in a vertical bluff. The relative height difference across vertical bluff and Chenab flood plain is nearly 25m. This scarp is well exposed at Kotali Baidan, Kuri Bahlulpur, Shampur and Sheikh Chogahi, Beyond Sheikh Chogahi, the bluff suddenly diminished in height till the confluence area of Doara I and river Chenab is approached.

It possesses alternating beds of laterally accreted (point bar) deposits of light grey to buff coloured, fine to medium grained parallel to cross bedded quatzose sand bodies. It is 0.5m to 2m thick interbedded with vertically accreted over bank fine deposit (flood plain facies). Its colour varied from reddish brown to yellowish brown clayey silts to silty clays with 2-3 m thick massive beds. Silts O.75m thick cap the top of these deposits with profuse quantity of Kankers/Calcareous concretions from fine to coarse grained in texture. This Kanker bearing silt sharply changes upwards to sandy soil (thin veneer), which at present is erosional surface. These sediments appear to be deposited by fluvial processes of river Chenab in middle late Pleistocene times (Rafique, 1967). Share of aeolin sedimentation in these deposits cannot be rolled out.

The up and down side of the scarp are different regarding vegetation, ground water regime and gradational processes. Abnormally small scale alluvial fans are common along the base of bluff developing ramps which have been incised by transverse steep ephemeral streams draining ponded drainages up valley with well developed three pair of level terraces in the vertical bluff. In contrast this upland is poorly cultivated with rolling topography and representing bad land area/geomorphology of the scarp area. The human settlements are mainly located on the upside of the scarp where as major cultivation is on down thrown side.

3- DINGA BASIN

The central part of upper Chaj Doab is bounded in north east by Jhelum fault with north south trend having a left lateral movement cutting across Pabbi hills parallel to G.T. Road propagated Upper Chaj Doab (Kazmi 1979), It had been concealed by small scale alluvial fans prograding basin ward from Bahlulpur uplift/old piedmont. Northwestern boundary of central upper Chaj Doab is marked by Nakka fault (Yasin et al. 1993). Which is a continuation of Mangla right lateral wrench fault (Kazmi (1979). The northern north eastern boundary is marked by Pabbi anticlinal flexure which has got surface expression since 0.4m.y. before present (B.P) (Johnson et.al. 1979) where tectonic compressional stresses originating in HFTB [Himalayan Frontal Thrust belt] are being accommodated in this area developing thin skin fault controlled folding i.e. Pabbi decollment. In front of this Pabbi anticlinal flexure site of subsidence is developing due to localized rifting along northern margin of Punjab basin. This subsiding area is known as piedmont basin (Fraser 1958, Rafique 967) and Dinga basin (Gondal and Ahmed 1994). Along southern flank of Pabbi decollement dipping 35° south alluvial fans have been developing due to mass wasting and stream activity, which coalesced laterally overlooking ox-bow lakes along Gondal Bar scarp at Charund and Keerbawa in north west of Dinga basin. Along the northern northeastern flank of this basin where thrusting is actually taking place with an uplift rate of 1.3m3m/l000y (Johnson et al. 1979). There are a number of small scale to medium scale laterally coalesced alluvial fans prograding over this basin and documenting a series of intra-formation discontinuities. Localized deposition occurs along the fans causing a new fan segment to prograde basin ward. The southern southwestern boundary of this basin is marked by a few alluvial fans, which represents its passive margin. This basin consists of a number of sag basins with poor seasonal drainage representing an open shallow ephemeral alluvial lake. The sedimentary strata' exposed in the bluffs of seepage drain and auger holes consist of severely shrinking/swelling silty clays upto a depth of 5 meters.

DISCUSSION

The origin of bars/uplands in Punjab basin has been suspected by Khan (1991) to be geomorphic or structural in nature. The area under study is comprised of fluvial sediments vis-à-vis aeoline deposits of clayey silty mounds with effusive salts locally known as Tibbas. Simple fluvial terraces are commonly parallel to the streams responsible for their formation (Selby, 1985) but Mial (1981) has described that rivers. tends to run either parallel or perpendicular to structural strike. Gondal bar scarp is not parallel to any major stream instead there are a number of oxbow lakes, marsh lands lying opposite of this scarp. The coalesced alluvial fans originating from Pabbi hills to Charund and Keer Bawa north west of Dinga basin over looked Ox bow lakes. Rafique (1967) described it as an old levee remnants whereas Fraser (1958) called it as an old spillway rout of river Jhelum which was flowing south ward and later on switched over to present route due to uplift of Pabbi on left bank of river Jhelum. Bahlulpur scarp parallels river Chenab on right bank with steep bluff where as such a feature is not available on left bank side. Alexander et al. (1987) suggested that intrabasinal faulting may act as floodwater dams and produced raised topography where more rapid pedogenesis and localized erosion will occur. It was further suggested that river tends to flow toward topographic minimum. In a simple half graben the area of maximum subsidence will be adjacent to main fault, which had been rapidly occupied by alluvial fans prograding from footwall i.e. southern limb of Pabbi decollement, which pushed the axial river path *further from* the locus of maximum subsidence. The neo-molasic alluvium presently lying against Siwaliks foot hills will be involved in future upheaval as exhibited by Siwaliks to the old rocks. The inner boundary of Siwaliks is a faulted one as for as Chenab in the east, southeast and south (Wadia 1992) beyond which west ward the fault is gradually concealed and replaced by anticlinal flexure/decollement. This fault cuts obliquely Jhelum fault/lineament close to Lala Musa and passes over Gujrat to Sheikh Chogahi defining the southwestern boundary of Bahlulpur upland where lineament had been concealed by alluvial fans. This Hneament had been mapped by Kazmi (1979) under Kalar Kahar fault with a WNW trend and right lateral movement. As a consequence of the past and continuing collision of Indo-Pak with Eurasia, propagating faults and folds had disrupted proximal margins of Punjab alluvial basin and this deformation along northern margin of Punjab foredeep had disrupted molasic deposition in this basin (Burbank et al. 1986). The studied scarps are situated very close to the active Himalayan foreland fold and thrust belt [HFFTB]. The uplifted seismically active Salt Range thrust is very close to the Gondal bar upland in the north west where as northern tip of Gondal bar is near Pabbi hill which is still active with an uplift rate of l.3m-3m/lOOO years and surface expression of Pabbi began to develop sine 0.4 M.Y ago (Jhanson et al. 1979). Bahlulpur upland is close to Jammu hills in the north -north east and Pabbi hills where localized deposition occurred along the fans, carrying a new fan segment to prograde basin wards. The portion of fans in fault footwall suffers uplift, incision nick, point retreat, terrace formation and surface soil development (Leeder et al. 1987).

The alluvial terraces on the foot wall of Pabbi decollement (Southern limb) developed in alluvial fans had now uplifted above a general level of Punjab plain developing angular unconformity between upper Siwaliks/Pinjor stage and alluvial fan deposits, traceable up to 34 km in transverse stream emanating from Pabbi hills. This angular unconformity is also present along the southern margin of Slat Range where it is overlain by undated gravels of Salt Range provenance, which had also folded along southern margin of Salt Range, (Lillie et al., 1987). These gravels are present in sub surface at a depth of 160-194 feet along the northern margin of Gondal bar upland between Malikwal and Bahowal (Wasid-2,1980).

The fore land basins are characterized by sedimentation sourced from rising mountains and synsedimentary deformation of deposited strata (Tankard, 1986). Thrusting and thrust relate the deformation folding of sedimentary strata which result in foreland fold and thrust belts [FFTB]. Fault propagation and fault bend folds are common with blind thrust folds and strike slip faults in foreland fold and thrust belts, as FFTB advances toward the craton (Marshak and Woodward, 1988). Himalayan foreland fold and thrust belt [HFFTB] is still active (Yeats and Lawerence 1984). So Punjab foreland basin may be called active as it borders the HFFTB. The area under study falls on northern peripheral region of Punjab basin which has been propagated by faults (Kazmi, 1979) and blind thrust folds. (Gee, 1983). Upper Chaj Doab/Jhelum plain has a faulted contact with Salt Range where basement is converging underneath Salt Range at a rate of 12mm/year (Lillie, et al.; 1987). Salt Range decollement is sliding over salt/evaporite bed developing strain in adjacent neo-molasses deposits/Quaternary deposits composing upper Chaj Doab and is pushing them southward. Rise in Pabbi hill has been calculated to be 1.3m-3.0m.m/1 000 years and its surface expression took place during 0.4 M. Y (Johnson et al. 1979). So in this context the studied scarps are more likely active faults rather then the bluffs of simple geomorphic terraces. Gondal bar scarp takes turn at Mekan and become north south so the scarp possibly represent two faults with north south and northeast southwest trend (Yasin et al. 1993). The lineament passing close to Gondal bar scarp had been named as Nakka fault. The Bahlulpur scarp is more a piedmont scarp, a definite evidence of active fault (Thornbury, 1972), an expression of the faulted inner boundary of upper Siwaliks as far as Chenab River in east south east (Wadia 1992). This lineament is named as Murala fault. The fault line in both these cases is away from the exposed scarps as these have retreated to their present position/ locations due to toppling, rotational and cantilever sliding of the scarp fronts. The area described previously as Dinga basin represents an open shallow ephemeral lake, which is subsiding relative to Pabbi hills, Gondal bar upland and Piedmont basin whose northern northwestern margin is still active.

The implication of possible faulting and folding in upper Chaj Doab are important. Faulting control the facies architecture in alluvial basin. Upper Chaj Doab has been divided into different blocks with a sense of movement vertical as well as lateral movement. Gondal bar and Bahlulpur uplands had been not over run by floodwater in recent past. Instead these act as dams to flood water where as low lying areas are prone to floods, water logging, salinity and marshland development. The low lying area/areas of maximum subsidence are favorite sites for river avulsion e.g. river Jhelum is flowing along the axis of actively subsiding foreland basin (Lillie et al. 1987) and similarly river Chenab is also flowing in such a low lying area. Big salt deposits capped by marine sedimentary rocks (Cambrian to Tertiary) lies in the north of Punjab basin, which extends southward as far as Sargodha ridge in the southwest (Shah, 1977 Kidwai, 1962, Yeats et al., 1986, Lillie et al., 1987). These rocks in subsurface may contain trapped marine water which may up well along the paths provided by the intrabasinal faulting. So soil salinity may also be related to this flow of marine water. Upper Chaj Doab fell in Punjab seismic zone with earthquake magnitude ma>4 (Quittmaer et al., 1979). So far the planning and designing of industrial complexes and urban settlement is concerned, proper consideration to neo-tectonic activity should be given for their safety and durability. In the water logged, saline and flood prone areas road/highway designing should be done with respect to related neotectonic element and sedimentary suite.

ACKNOWLEDGEMENTS

The authors are highly thankful to Mr. Akbar Ali for typing this manuscript and Mr. Mahmood Mukhtar Chishty for drawing the figures thanks also goes to the anonymous referee for his critics. Last but not least the author are thankful to anonymous referee for is critical review of the article.

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Geol. Bull. Punjab Univ. Vol. 40-41, 2005-6, pp 53-55

FOSSIL MOLARS OF *SELENOPORTAX VEXILLARIUS*

BY

MUHAMMAD AKBAR KHAN, MUHAMMAD AKHTAR , MEHBOOB IQBAL
Department of Zoology, Quid-e-Azam Campus, University of the Punjab, Lahore 54590, Pakistan
Email: akbaar111@yahoo.ca

MUHAMMAD ANWAR QURESHI
Geology Department, University of Azad Jammu & Kashmir, Muzaffrabad, Pakistan

AND

UMAR FAROOQ
Executive District Officer Education, Khushab (Johrabad) University, Pakistan

Abstract: *Two upper second and third molars of Selenoportax vexillarius are collected from Hasnot and described in this paper. The molars are ever-preserved fossil specimens of S. vexillarius found from the Middle Siwaliks of Pakistan. All the morphological characters of the fossilized cheek teeth are excellently preserved and not any part of the specimens is damaged.*

INTRODUCTION

The earliest known boselaphines if *Eotragus* be excluded may be in Pakistan in the middle Miocene (17.6 million years ago; Solounias et al., 1995; Gentry, 1999). In Africa *Kipsigicerus* is of middle Miocene age (Thomas, 1984). In Europe boselaphines do not appear until later in the middle Miocene, and in China they appear only in the late Miocene. The Eurasian ones, surprisingly, have lower crowned teeth and longer premolars row than *Kipsigicerus* (Gentry, 2000).

Boselaphines are known abundantly from the Middle Siwaliks but found scarcely from the Lower and Upper Siwaliks of Pakistan. Most of the boselaphine specimens are collected from the Dhok Pathan village, a type locality of the Middle Siwaliks and from the Hasnot, a late Miocene locality of the Siwaliks. The studied specimen is collected from the Hasnot, 5-7 million years old in age and situated at 70 km west of the Jhelum, a city of the Punjab in the Potwar Plateau of northern Pakistan.

SYSTEMATIC PALEONTOLOGY

Tribe Boselaphini Simpson, 1945

Genus *Selenoportax* Pilgrim, 1937

Type Species: *Selenoportax vexillarius* Pilgrim, 1937.

Included Species: *Selenoportax vexillarius* Pilgrim, 1937; *Selenoportax lydekkeri* Pilgrim, 1937; *Selenoportax tatrotensis* Akhtar, 1992; *Selenoportax dhokpathanensis* Akhtar, 1992.

Distribution: Middle to Upper Siwaliks.

***Selenoportax vexillarius* Pilgrim, 1937**

Type Specimen: A skull lacking maxilla and dentition and most of the basicranium (AMNH 19748).

Referred Specimen: A broken maxilla having second and third molars (PUPC 06/14).

Locality: Hasnot, Jhelum district, the Punjab province, Pakistan.

Stratigraphic Level: Middle Siwaliks.

Diagnosis: Cheek teeth large and strongly hypsodont, enamel very rugose. Upper molars quadrate with strong and divergent styles near the neck of crown, ribs quite large, entostyle strongly developed. Fossettes without indentations and simple in outline, transverse anterior goat folds poorly developed at front of lower molars.

DESCRIPTION

Two cheek teeth belonging to upper dentition are described here. PUPC 06/14 (Fig. 1a, b and c) is extremely hypsodont and narrow crowned. The right upper second molar (M^2) is a well preserved molar and all the principal cones are preserved up to the apex. The paracone and protocone are well developed anteriorly and pointed in the middle with two running cristae. The metacone and hypocone are present posteriorly with their well developed styles. The anterior and posterior median ribs are prominent in the molar. The enamel is moderately thick and rugose. The rugosity is more distinct on the buccal side than on the lingual side of the tooth. The entostyle is present in the transverse valley between the protocone and the hypocone and oval in shape owing to the early wear. The parastyle is very strong and prominent. The mesostyle and the metastyle are moderately developed and the anterior median rib is more prominent than the posterior rib. The fossettes are well defined and wide. The third right upper molar of PUPC 06/14 is in an excellent state of preservation and in an early stage of wear. The enamel is finely rugose and the rugosity is more evident on the lingual side than the buccal side. The entostyle is strongly developed and looks like a pillar present in the transverse valley of the molar. The principal cones are well developed and the buccal cusps are higher than the lingual ones, which at this stage of wear are not attached to each other at the transverse valley. The protocone is V-shaped and praeprotocrista is slightly longer than postprotocrista. The prae-and postparacristae are equal in length. The prae- and posthypocristae are more crescentic than the prae- and postmetacristae of the molars. The styles and median ribs are well developed. The fossettes are wide and no spur of the enamel seems to project into these fossettes.

Fig.-1: *S. vexillarius* (PUPC 06/14): A) Crown view, B) Lingual view C) Buccal view.

Table-1
Comparative measurements of the cheek teeth of *Selenoportax vexillarius* in mm (millimeters). * The studied specimens.

Number	Nature	Position	Length	Width	W/L ratio
PUPC 06/14*	right molar	M^2	27.0	23.0	0.85
	right molar	M^3	32.0	26.0	0.81
PUPC 00/53	right molar	M^2	27.5	18.5	0.67
PUPC 96/39	right molar	M^2	26.0	19.0	0.73
PUPC 01/23	left molar	M^2	23.5	19.5	0.82
PUPC 87/199	left molar	M^3	25.0	21.2	0.84
AMNH 19844	right molar	M^2	25.7	24.0	0.93
PMNH 87/19	a maxillary part of the	P^3	19.5	16.5	0.84
	skull having right P^3-M^3	P^4	19	17	0.89
	and left P^4-M^3	M^1	24.2	21.5	0.88
		M^2	29	21	0.72
		M^3	28.7	18	0.62

DISCUSSION

Selenoportax and *Pachyportax* are known from the late Miocene of the Siwaliks (Khan et al., 2006). The *Selenoportax* is a moderate to large sized Boselaphini, whereas *Pachyportax* is a gigantic sized form. The PUPC 06/14 is large enough to exclude it to the small Siwalik bovids. The general contour of the studied specimen, the rugosity of the enamel, the strong entostyles, the prominent median ribs, the strong and divergent styles evidently prove the specimen inclusion in the genus *Selenoportax* (Akhtar, 1992, 1995, 1996). Pilgrim (1937) based this genus on a collection from the various Siwalik localities of Pakistan and India. Pilgrim referred all the collected specimens to the genus *Selenoportax* and added two species in it, *S. vexillarius* and *S. lydekkeri*. The dimensions (Table 1) and the morphology of the studied material reveal all the features of the species *S. vexillarius* cited by Pilgrim in 1937. PUPC 06/14 present the same morphological features of the type specimen AMNH 19844 (Pilgrim, 1937). The specimen is an extremely hypsodont and narrow crowned tooth as indicated by its measurements. The molars show fine enamel corrugacy, which is relatively more prominent on the lingual side than on the buccal side. However, the wrinkles are more conspicuous on the buccal side than on the lingual side.

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BIOSTRATIGRAPHY OF THE MIDDLE EOCENE KOHAT FORMATION, SHEKHAN NALA KOHAT BASIN, NORTHERN PAKISTAN

BY

KAMRAN MIRZA, SHAHID JAMIL SAMEENI
Institute of Geology, Quaid-e-Azam Campus, University of the Punjab, Lahore 54590, Pakistan.
Email: thesuccessful@yahoo.com

MUNIR-UL-HASSAN MUNIR
Institute of Geology, University of Azad Jammu & Kashmir, Muzaffarabad, Pakistan.

AND

AAMIR YASIN
Natural History Museum, Shakar Parian, Islamabad, Pakistan.

Abstract: *The Kohat Formation from Shekhan Nala, Kohat Basin, northern Pakistan has been measured and closely sampled to undertake detailed stratigraphical and micropalaeontological studies to determine the age and environmental style of the formation. Ninty seven (97) samples were collected to cover all the lithological and facies variations from bottom to top. More than one hundred thin sections were made. A number of foraminiferal species belonging to the genera Nummulites, Assilina, Operculina, Discocyclina, Alveolina and Dictyoconoides have been recorded. These foraminiferal species are age diagnostic and are excellent indicators of the paleoenvironments prevailing during the deposition of the Kohat Formation.*

INTRODUCTION

The Kohat Basin is an important geological entity of the Northern Pakistan. The importance of area lies in its enormous hydrocarbon potential, which is a burning topic in today's oil industry. A number of successful discoveries of oil and gas have increased its importance manifold.

The Eocene sequence of the Kohat Basin shows a variety of environments during this period in the Kohat Basin. The stratigraphical nomenclature according to the Stratigraphic Committee of Pakistan (Fatmi, 1973) is as follows (Fig. 1)

The Kohat formation is an integral part of the Eocene sequence of the Kohat Basin and is quite well exposed throughout the Basin. In fact the Kohat Formation marks the end of Eocene period in the area followed by an unconformity. This unconformity which is marked by the Fateh Jang member of the overlying Murree Formation represents the absence of upper Eocene time throughout the Kohat Basin. The Kohat Basin can be divided into two parts on the basis of its structural and depositional systems. The northern part of the basin represents imbricate structures and normal marine shallow shelf environments of deposition (Panoba Shale and Shekhan Formaiton). Whereas, the southern part of the basin represents normal marine to restricted lagoonal environments during the Eocene period (Bahadur Khel Salt and Jatta Gypsum Fig. 1).

The Kohat Formation is one of the most widely exposed stratigraphic units present in the entire Kohat Basin. The formation is only exposed in the Kohat, Northern Potwar and Kala Chitta areas. The formation is traditionally divided into three members. These members in the order of superposition are:

- Habib Rahi Limestone Member (Kohat Limestone and Sirki Shales of Eames 1952)
- Sadkal Shale Member (Nummulitic Shales of Pinfold 1918)
- Kaladhand Member (Kohat Shales of Davies 1926)

This threefold division of the Kohat Formation is well represented in the Shekhan Nala. At this locality the lower Kaladhand member is composed of well developed, hard, thin to medium bedded, sometimes massive light to medium grey limestone. The limestone also contains some thin beds of shale in the lower part. This member is consistent in lithology and appearance throughout its extension in the Kohat Basin. The middle and upper parts of the member are richly fossiliferous. The Sadkal member is mainly composed of khaki to light brown color shale. The member is so richly fossiliferous that the rock appears to be almost entirely composed of fossils. The member also has fine layers of marl and limestone which are also full of fossils. This part of the formation is so rich in micro fauna that it can be called biolithite. In other parts of the basin the percentage of limestone becomes more dominant and the member appears to be a part of the lower Kaladhand member. That's why at most of the places in Kohat Basin it is difficult to mark the boundary between the Kaladhand and Sadkal members and these units appear to be mixed with each other.

The Habib Rahi Limestone Member marks the upper part of the formation and contains well bedded to slightly nodular cream colored limestone. This unit is also richly fossiliferous. But the abundance of fossils and their size decrease in the upper part of the member. The upper most part of the member i.e about 5-10 m is shattered, fractured and nodular with scarcity of fossils. The solution holes and the karren structure also dominant in the upper most part of the member. The Habib Rahi Limestone Member has quite uniform appearance and lithology throughout its extent (Fig. 2).

The lower contact of the Kohat Formation is conformable and sharp with the Mami Khel Clay (Kuldana Formation), whereas the upper contact with the Murree Formation is unconformable throughout the area, which is marked by Fatehjang member (of Murree Formation) containing foraminifera from underlying units.

The Kohat Formation is almost entirely composed of larger benthic foraminifera belonging to the genera Nummulites, Assilina and Alveolina. The forams are age diagnostic and some excellent age diagnostic larger foraminiferal species of Nummulitids, Assilinids and Alveolinids have been found namely *Nummulites mamillatus, N. atacicus, N.globulus, N. subirregularis, Operculina patalensis, Operculina sp., Assilina exponens, A. granulosa, A. spinosa, A. subspinosa, A. laminosa, A. dandotica, Assilina sp., Discocyclina dispansa, Dictyoconoides sp., Alveolina elliptica* and *Alveolina stercusmuris.*

On the basis of this faunal assemblage a late early Eocene to early Middle Eocene age of the formation has been confirmed.

Bioclastic wackestone, packstone and grainstone microfacies have been identified (Fig.2). The bioclasts are mainly larger forams. On the basis of observed fauna and lithologic assemblage it has been established that the formation was deposited under shallowshelf open marine environments representing both inner neritic facies and bank bed facies.

Systematic Paleontology
Genus: Nummulites Lamarck, 1801
Nummulites mammillatus (Fichtel & Moll)
(Plate 1, Figs. 1, 2)

Nautilus mammilla, sp.nov. ; Fichtel and Moll, 1798. 'Testacea Microscopia', pp. 53-54; Pl. 6, figs. a-d.

Remarks:

This species is very common and abundant throughout the formation. It is characterized by having a biconvex shell with thick umbilical pillars in the middle part. Marginal cord is present. but comparatively thin as compared to the other species of Nummulites.

Nummulites atacicus, Leymerie
(Plate 1, Figs. 3, 4)

Nummulites atacicus Leymerie, A., (1846), Mem. Sur le Terrain a Nummulites des Corbieres, etc., Mem. Soc. Geol. France, (2), V. I: 337-373.

Remarks:

This species is not so common in the Kohat Formation. Only found in the middle part of the formation. Mostly the megalospheric forms are present with larger proloculus. The pillars are not so well developed. The marginal cord is well preserved and quite prominent.

Nummulites globulus, Leymerie
(Plate 1, Figs. 5, 6)

Nummulites globulus Leymerie, A., (1846), Mem. Sur le Terrain a Nummulites des Corbieres, etc., Mem. Soc. Geol. France, (2), V. I: 337-373.

Remarks:

This species has few representatives in the Kohat Formation. It is characterized by having a strongly biconvex shell which is more globular in appearance. The umbilical pillars are well developed and very prominent. The wall of the shell is usually very thick.

AGE			NORTHERN KOHAT		SOUTHERN KOHAT	
MIOCENE			MURREE FORMATION FATEH JANG MEMBER		KAMLIAL FORMATION	
OLIGOCENE						
EOCENE	UPPER	PRIABONIAN				
EOCENE	MIDDLE	LUTETIAN	KOHAT FORMATION	Habib Rahi Limstone Member	KOHAT FORMATION	Habib Rahi Limstone Member
				Sadkal Member		
				Kaladhand Member		Kaladhand Member
EOCENE	LOWER	YPRESIAN	KULDANA FORMATION (MAMI KHEL CLAY)		MAMI KHEL CLAY	
			SHEKHAN FORMATION		JATTA GYPSUM	
			PANOBA SHALE		BAHADUR KHEL SALT	
PALEOCENE	UPPER	THANETIAN	PATALA FORMATION		PATALA FORMATION	
			LOCKHART LIMESTONE		LOCKHART LIMESTONE	
PALEOCENE	LOWER	DANIAN	HANGU FORMATION		HANGU FORMATION	

Fig. 1: Stratigraphic Succession of the Paleocene-Eocene rocks of the Kohat Basin, Northern Pakistan

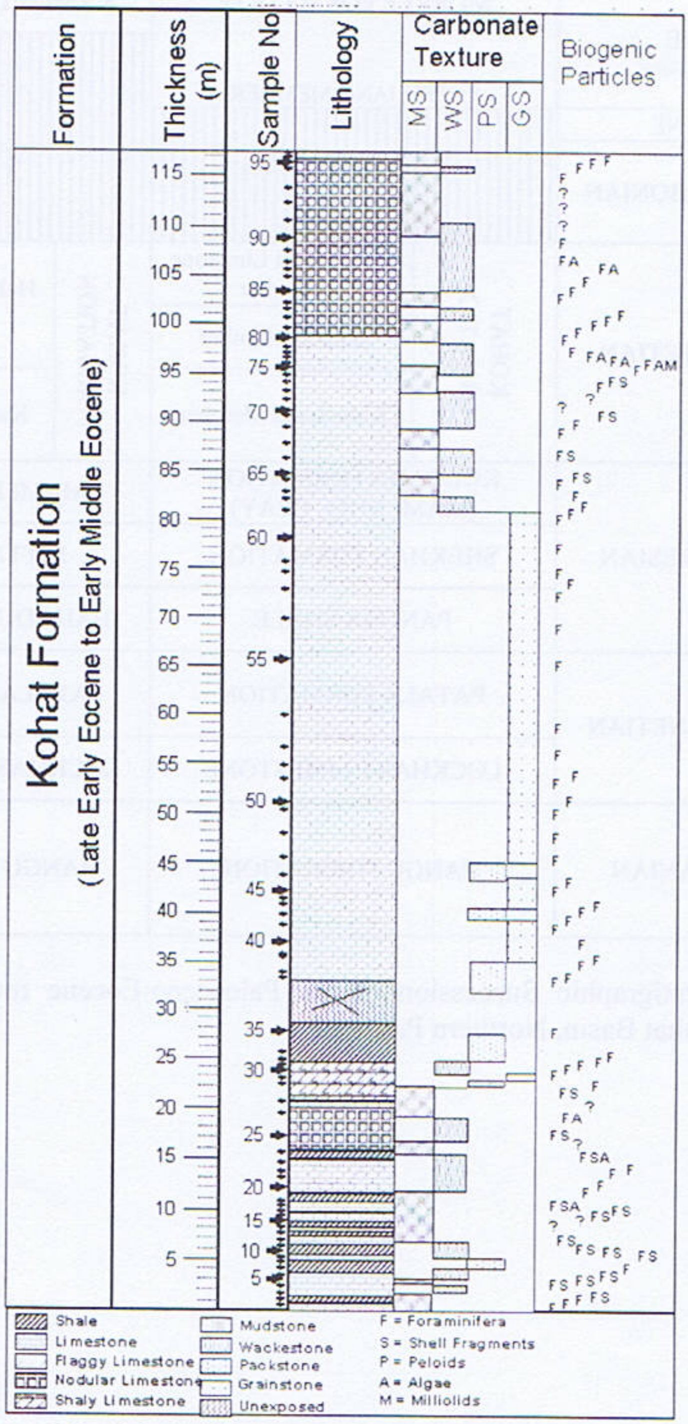


Fig. II Depositional Log of the Kohat Formation, Shekhan Nala

Fig. 2: Depositional Log of the Kohat Formation, Shekhan Nala.

Nummulites subirregularis De la Harpe
(Plate 2, Fig. 1)

Nummulites subirregularis Harpe, De la (1883) Mem.Soc. pal. suisse, Vol. X, pp. 158-159; Pl. V, figs. 3-14a.

Remarks:

There are only few specimens of this species found in the Kohat Formation. It is first time being reported from this formation in northern Pakistan. It is characterized by having comparatively thin shell with thin walls.

Genus: Operculina, d'Orbigny 1826.

Operculina patalensis Davies and Pinfold

(Plate 2, Figs. 2, 3)

Operculina patalensis Davies, L. M. and Pinfold, E. S., (1937), The Eocene beds of the Punjab Salt Range. Geol. Surv. Mem., Paleont. Indica, New series, V. 24 (1), p. 79.

Remarks:

There are few specimens of this species recorded from the middle part of the formation. It is found in association with different species of Assilina. But it is differentiated by having a rapid loosening of the spire (operculinoidal growth). The shell is elongated with thin walls and smooth surface in the longitudinal section.

Operculina sp.
(Plate 2, Figs. 4, 5)

Remarks:

This species is also found in association with *Operculina patalensis* in the middle part of the formation. It is differentiated from above on the basis of having very prominent pustules throughout its extent on both sides of the shell.

Genus Assilina, d'Orbigny 1826.

Assilina exponens, Sowerby
(Plate 2 Fig. 6; Plate 3, Fig. 1)

Assilina exponens Sowerby, J. De C., (1840), Systematic description of organic remains of Cutch., Trans. Geol. Soc. London, (2), V. V,: 327-329.

Remarks:

This species is quite abundant in the middle part of the formation. This species is distinguished on the basis of its rounded shape and very thin structure. It also has thick ribs throughout its extent.

Assilina granulosa, d'Archiac

(Plate 3, Figs. 2, 3)

Assilina granulosa Archiac, E.J.A.D (1847) Mem.sur les Fossiles des couches a Nummulites des environs de Bayonne et de Dax, Bull. Soc. geol. France, (2), Vol. IV, pp. 1006-1010.

Remarks:

This species is quite frequent in the Kohat Formation and is found mainly in the middle part of the formation which is shale bearing (Sadkal Member). The shell is generally flat with sharp margins. There are frequent granules on the surface of the shell. These granules are sometimes very clear.

Assilina spinosa Davies and Pinfold
(Plate 3, Fig. 4)

Assilina spinosa Davies, L. M. and Pinfold, E. S., (1937), The Eocene beds of the Punjab Salt Range. Geol. Surv. Mem., Paleont. Indica, New series, V. 24 (1), p. 79.

Remarks:

There are few representatives found in the middle shaly part of the formation. This species is relatively stouter than the *Assilina granulosa*. The wall is relatively thick and the granules or spines are more strong and prominent throughout the shell. There is always a central depression which separates it from *Assilina subspinosa*.

Assilina subspinosa Davies and Pinfold
(Plate 3, Fig. 5)

Assilina subspinosa Davies, L. M. and Pinfold, E. S., (1937), The Eocene beds of the Punjab Salt Range. Geol. Surv. Mem., Paleont. Indica, New series, V. 24 (1), p. 79.

Remarks:

Few specimens of this species are also found in the middle part of the formation. The species is characterized by having large and very prominent spines closely distributed on the surface of the shell. These spines are relatively more concenterated in the middle part of the shell. Unlike *Assilina spinosa* there is no central depression in the middle part of the shell.

Assilina laminosa Gill
(Plate 3, Fig. 6)

Assilina laminosa Gill, W. D., (1953), the genus Assilna in Laki Series (Lower Eocene) of the Kohat Potowar basin, north-west Pakistan. Contr. Cushman Found. Foram. Res. V. 4: 76-84.

Remarks:

There are few specimens of this species found in the middle part of the formation. The species is characterized by having thick wall and thick margins, in cross section the walls showing quite prominent laminations.

Assilina dandotica Davies and Pinfold
(Plate 4, Fig. 1)

Assilina dandotica Davies, L. M. and Pinfold, E. S., (1937), The Eocene beds of the Punjab Salt Range. Geol. Surv. Mem., Paleont. Indica, New series, V. 24 (1), p. 79.

Remarks:

There are only very few specimens of this species found in the Kohat Formation. The form is discoid, thick from the centre, with sharp periphery. The surface of the shell is sometimes covered with granules which are not so prominent as in the other forms of Assilina. The shell is stouter than the *Assilina granulosa* or *Assilina subspinosa*.

Assilina sp.
(Plate 4, Fig. 4)

Remarks:

There are only few specimens of this species found in the middle part of the formation. The form has a unique appearance especially in the middle part where it is strongly biconvex. The margins are sharp. The author has not found any species comparable to this in the available literature.

Genus: Discocyclina, Gumbel, 1868.
Discocyclina dispansa Sowerby
(Plate 4, Fig. 2)

Discocyclina dispansa Sowerby, J. De C., (1840), Systematic description of organic remains of Cutch. Trans. Geol. Soc. London, (2), V. V,: 327-329.

Remarks:

Only two specimens of this form are found in the middle part of the formation in association with rich assemblage of Assilina. It is characteristically a biconvex form with thin edges. Numerous chamberlets which are a characteristic of this form are also visible in the cross section.

Discocyclina ranikotensis Davies
(Plate 4, Fig. 5)

Discocyclina ranikotensis Davies, L. M. (1927) The Ranikot Beds at Thal. Quart. Journ. Geol. Soc. Lond., Vol. LXXXIII, pp. 260-290; Pls. XVIII- XXII.

Remarks:

There are only few specimens of this form present in the middle shaly part of the formation. This species is characterized by having a thin and elongated shell unlike *Discocyclina dispansa* which is strongly biconvex. Numerous chamberlets are also visible and prominent.

Genus: Dictyoconoides, Nuttal
Dictyoconoides sp.
(Plate 4, Fig. 3)

Dictyoconoides Nuttal, W. L. F., (1925). The Stratigraphy of Laki Series, Quart. J. Deol. Soc. London, V. LXXXI: 417-453.

Remarks:

This species is also rare in the section. There are only few specimens observed in association with Assilinids in the middle part of the formation. It is differentiated by having a trochospiral shell. The dorsal side is more convex than the ventral side.

Genus: Alveolina, d'Orbigny 1826.
Alveolina elliptica Sowerby
(Plate 4, Fig. 6)

Alveolina elliptica Sowerby, J. De C., (1840), Systematic description of organic remains of Cutch., Trans. Geol. Soc. London, (2), V. V,: 327-329.

Remarks:

This species is characterized by having flosculinization in its early stage then regular whorls.

Alveolina stercusmeris Mayer-Eymar,
(Plate 4, Fig. 7)

Alveolina stercusmeris Mayer-Eymar K., 1886, table 1.

Alveolina stercusmeris Mayer-Eymar, Hottinger L., 1960, p.147, (no figure)

Remarks:

The flosculinization in the early stage which is a characteristic of *Alveolina elliptica* is lacking in this form and the whorls are quite closely spaced.

PLATE 1

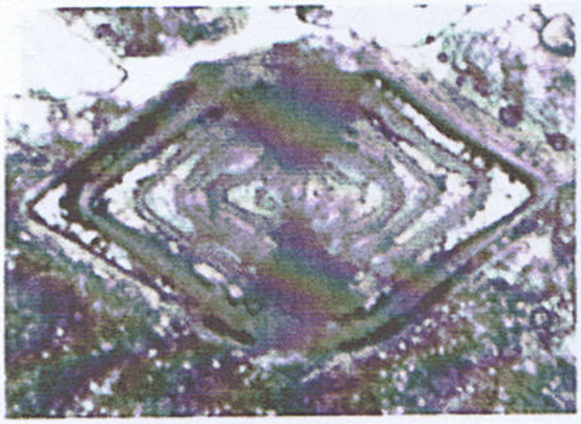


Fig. 1

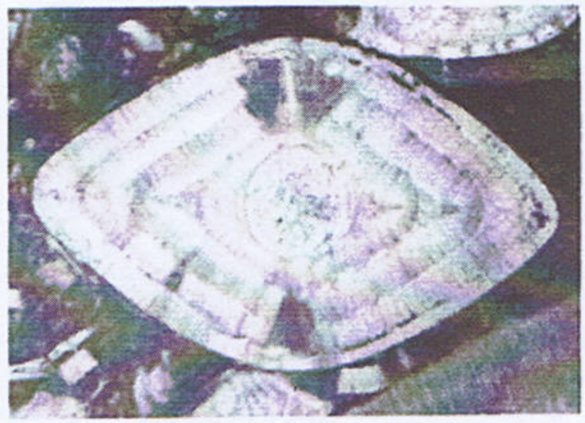


Fig. 2

Figs. 1-2 *Nummulites mamillatus* (Fichtel & Moll)


Fig. 3

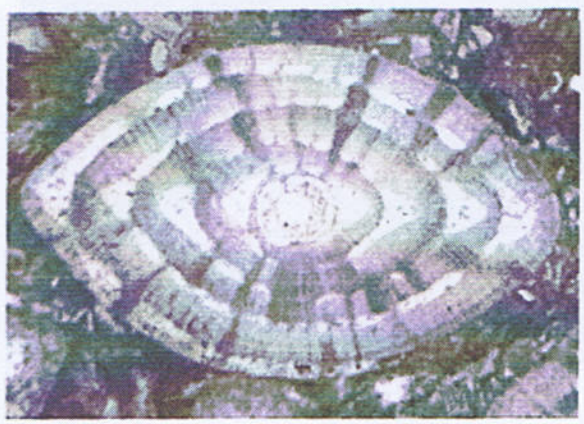


Fig. 4

Figs. 3-4 *Nummulites atacicus* Leymerie

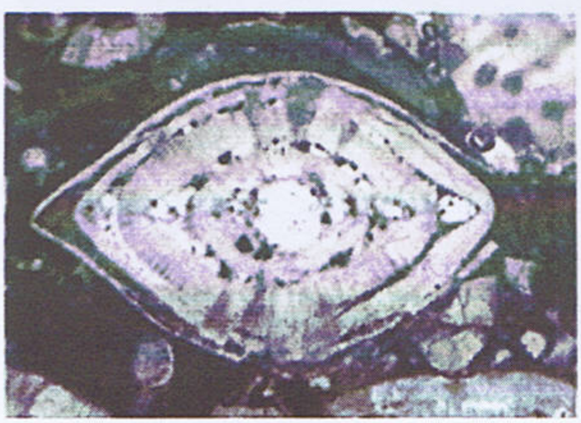


Fig. 5

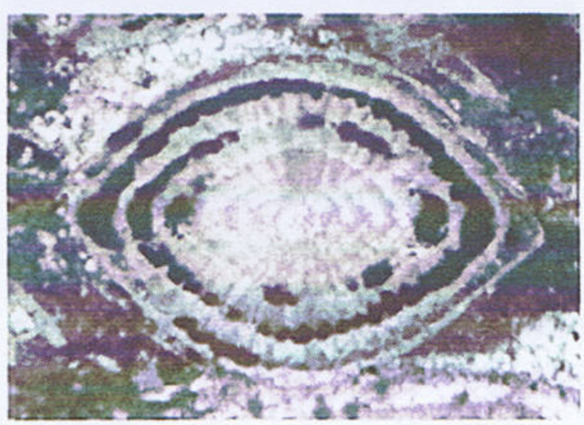


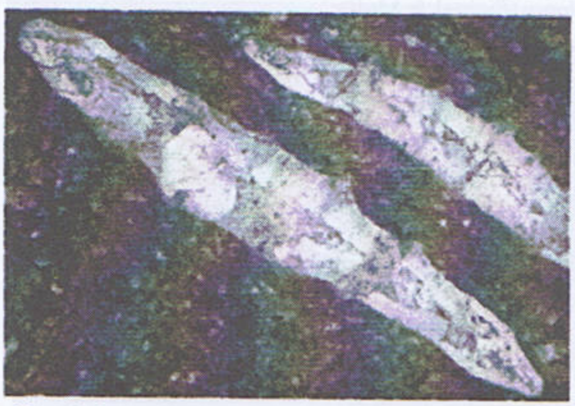
Fig. 6

Figs. 5 - 6 *Nummulites globulus* Leymerie

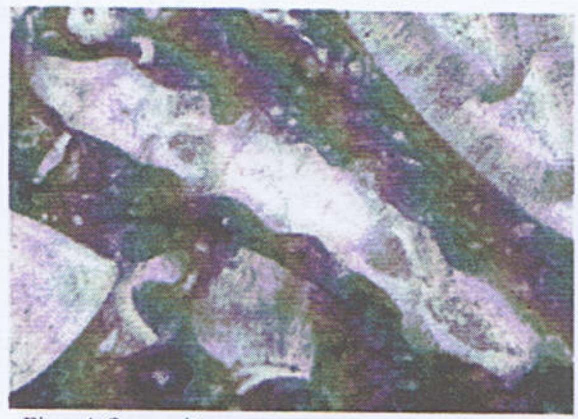
PLATE 2

Fig. 1 *Nummulites subirregularis* De la Harpe

Figs. 2 *Operculina patalensis* Davies and Pinfold



Figs. 3 *Operculina patalensis* Davies and Pinfold



Figs. 4 *Operculina sp.*

Figs. 5 *Operculina sp.*

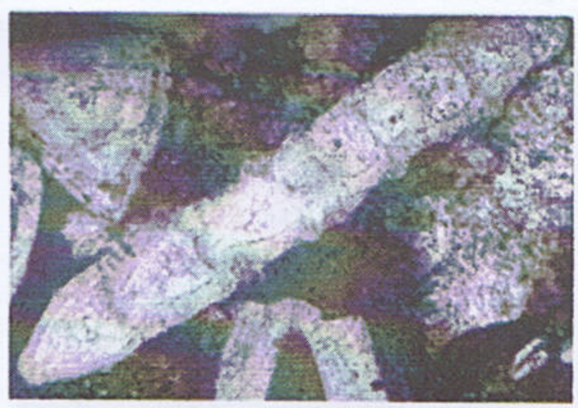


Fig. 6 *Assilina exponens* Sowerby

PLATE 3

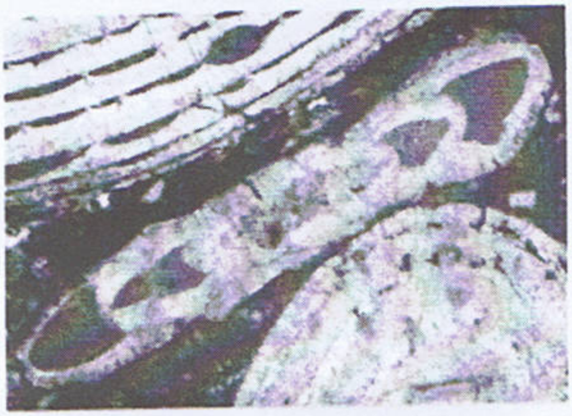
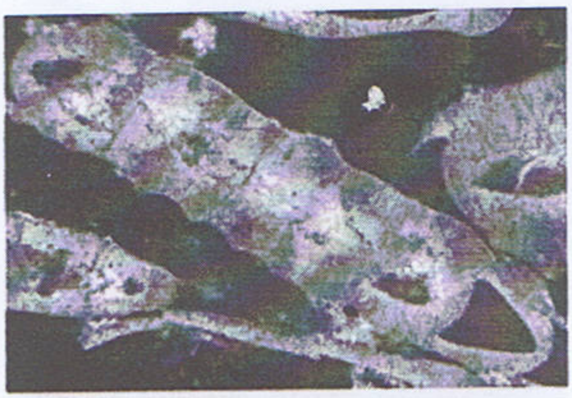


Fig. 1 *Assilina exponens* Sowerby

Figs.2 *Assilina granulosa* d'Archiac



Figs. 3 *Assilina granulosa* d'Archiac

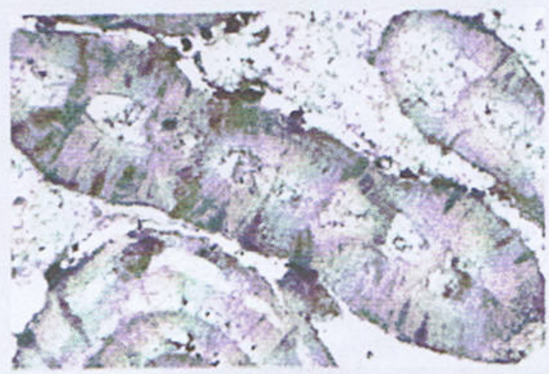


Fig. 4 *Assilina spinosa* Davies and Pinfold

Fig. 5 *Assilina subspinosa* Davies and Pinfold

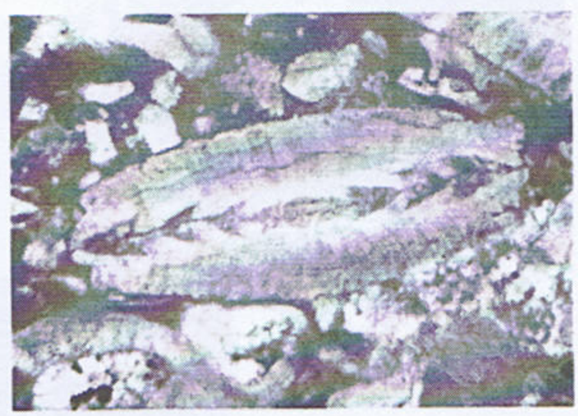


Fig. 6 *Assilina laminosa* Gill

PLATE 4

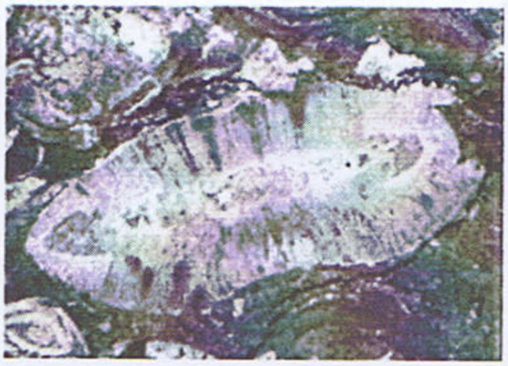


Fig. 1 *Assilina dandotica*, Davies and Pinfold

Fig. 2 *Discocyclina dispansa* Sowerby

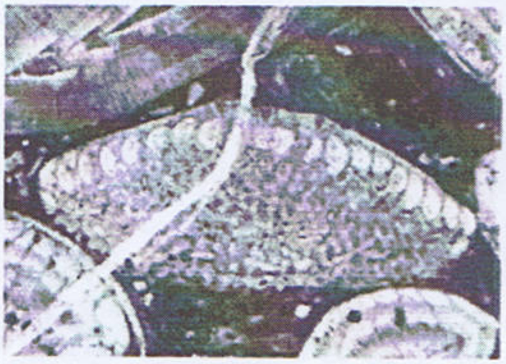


Fig. 3 *Dictyoconoides sp.*

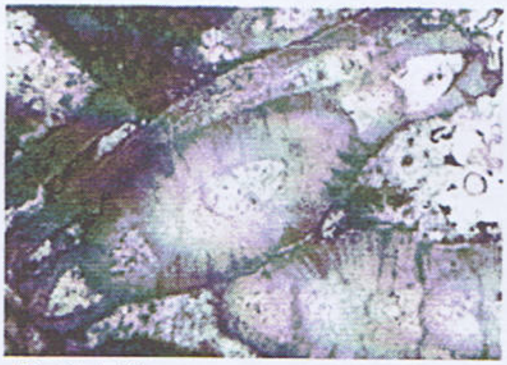


Fig. 4 *Assilina sp.*

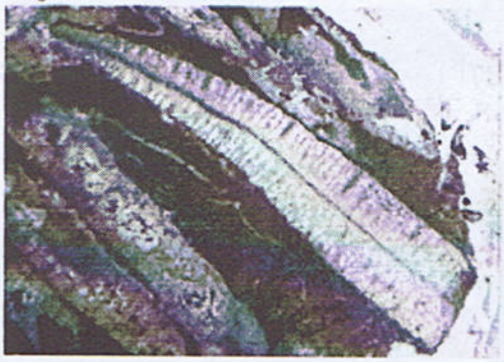


Fig. 5 *Discocyclina ranikotensis* Davies

Fig. 6 *Alveolina elliptica* (Sowerby)

Fig. 7 *Alveolina stercusmeris* Mayer-Eymar

Conclusion:

The middle Eocene period is characterized by having abundant fauna and making bank bed deposits throughout the world. The Kohat Formation being an integral part of the Eocene Biostratigraphy of the Northern Pakistan is also characterized by having bank bed facies. This type of facies is more common in the middle part of the formation which is shale bearing (Sadkal Member).

On the basis of observed fauna in the formation it can be concluded that the formation was deposited in open marine, shallow shelf environments. The observed fauna also confirms the middle Eocene age of the formation.

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UPPER CRETACEOUS OF HAZARA AND PALEOGENE BIOSTRATIGRAPHY OF AZAD KASHMIR, NORTH WEST HIMALAYAS, PAKISTAN

MUNIR-UL-HASSAN MUNIR, MIRZA SHAHID BAIG
Institute of Geology, University of Azad Jammu & Kashmir, Muzaffarabad, Pakistan.

AND

KAMRAN MIRZA
Institute of Geology, Quaid-e-Azam Campus, University of the Punjab, Lahore 54590, Pakistan.

Abstract: *The Hazara-Azad Kashmir area lies in the northwest Himalayas of Pakistan. The Upper Cretaceous to Paleogene rocks are exposed in the fossiliferous sedimentary cover sequence of the Indian plate. The Upper Cretaceous-Paleogene rock sequence of the Kawagarh Formation, Hangu Formation, Lockhart Limestone, Patala Formation, Margala Hill Limestone, Chorgali Formation and Kuldana Formation has been investigated for micropalaeontological studies. In Hazara area, the Cenomanian to Campanian marine transgressive cycle deposited the micritic limestones of Kawagarh Formation on the north subducting shelf of the Neotethys Ocean below the Kohistan Island arc. The presence of foraminiferal genera such as Globotruncana, Dicarinella, Rugoglobigerina, Heterohelix, Planularia, Lenticulina, Globorotalites, Buliminella and Vaginulina in Kawagarh Formation suggests that the formation deposited in shelf outer neritic conditions. This transgressive cycle ended before the Maastrichtian as a result the regressive to partially transgressive facies of Early Paleocene Hangu Formation deposited unconformably on the Kawagarh Formation. This regressive cycle occurred between the Maastrichtian to Lower Danian. This regressive gap is marked by the aerial, tropical and sub tropical brecciated quartzite, laterite and bauxite facies of the Lower Danian basal part of the Hangu Formation. However, the upper part of the Hangu Formation deposited partially transgressive restricted shallow marine to lagoonal facies as carbonaceous shale, coal seam, sandstone and siltstone in Upper Danian. The Cretaceous-Tertiary Boundary on the basis of fossils can not be marked in Hazara and Azad Kashmir, as there is no record of Maastrichtian and Danian fauna. However, the K-T Boundary can be placed at the basal residual part of the Hangu Formation. The second transgressive cycle deposited the Upper Paleocene-Early Eocene shallow marine limestone and shale sequence that includes the Lockhart Limestone, Patala Formation, Margala Hill Limestone and Chorgali Formation. The Middle Eocene Kuldana Formation records the transitional environments and marks the closing of the Neotethys Ocean and initiation of Middle Eocene to Miocene continental molasse of the Murree Formation.In these study 23 sections were measured from Hazara and Azad Kashmir. More than 1000 outcrop samples were analyzed for microfossils and microfacies of the Upper Cretaceous to Paleogene sequence. The Paleogene of Hazara and Kashmir includes the genera of larger and smaller benthic foraminifers such as Lockhartia, Operculina, Miscellanea, Ranikothalia, Assilina, Nummulites, Alveolina, Clavulina, Quinqueloculina, Spiroloculina and Thalmannita. The microfacies and faunal analyses represent warm shallow marine inner shelf or inner neritic environments during Paleogene transgression cycle. The Paleocene-Eocene Boundary is marked on the basis of disappearance of Lockhartia haimeis and Miscellanea miscella and the appearance of Nummulites atacicus and Nummulites mammillatus in the upper part of the Patala Formation and basal part of the Margala Hill Limestone.*

Introduction

The Upper Cretaceous Kawagarh Formation of Hazara and the Paleocene-Eocene succession of Azad Kashmir were studied for foraminiferal Biostratigraphy. The age assignment of the Kawagarh Formation (Coniacian-Campanian) ascertained on the basis of planktonic foraminifera. On the basis of faunal assemblage it was determined that the formation was deposited in outer neritic, open marine environments. The Paleocene-Eocene succession of the Azad Kashmir consists of the Paleocene Hangu Formation, Lockhart Limestone and the Patala Formation while the Eocene contributes Margalla Hill Limestone, Chorgali Formation and the Kuldana Formation. Age diagnostic benthic larger foraminifera belonging to the genera Operculina, Assilina, Nummulites, Lockhartia, Miscellanea, Ranikothalia, Discocyclina and Actinosiphon were encountered. The presence of the larger foraminifera was indicative of shallow shelf (inner neritic) marine environments.

The present work is partially sponsored by the Pakistan Science Foundation and Higher Education Commission and an attempt to study the Upper Cretaceous of Hazara and the Paleogene succession of Azad Kashmir with particular emphasis on the foraminiferal biostatigraphy for age evaluation and environmental interpretation. Twenty three (23) stratigraphic sections were measured at Dana Nuranlan, Lassan, Jabri, Sangjani, Sohaba, Mandiabani, Chanali, Hothla, Jhan, Kalsan, Jhansa, Khairagali, Changlagali, Chumbi, Kuzagali, Kundla, Mochidhara, Kalas, Reechmari, Yadgar, Tandabotha, Tattapani and Kamroti areas (Fig. 1). More than 1000 samples were collected at suitable interval covering lithological variations of all the rock units (Fig. 2). The samples were properly numbered. Thin sections of the carbonate sequence were prepared in the laboratory for micropalaeontological studies. Softer rocks like shale and marl having foraminiferal assemblages were processed for picking of micro fossils. This fauna was preserved in the micropalaeontological slides for study. The Paleogene rock sequence is rich in microfossil assemblages especially, foraminifera (Fig. 3). The regional species distribution and time boundaries of the Upper Cretaceous and Paleogene rock units tells more about the geological history and environments of deposition of the area. These also throw light on the timing of transgression and regression of the Neotethys Ocean .Closing of Neotethys Ocean and the Himalayan collision between the Indo-Pak Plate and the Eurasian Plate.

BIOSTRATIGRAPHY OF THE UPPER CREATACEOUS SEQUENCE OF HAZARA

Kawagarh Formation

The Kawagarh Formation comprises of light grey to grey limestone, sandy limestone and minor dolomitic layers (Fig. 2). The lower and upper parts of the formation are fine to medium grained limestone. The fine grained limestone alternates with fine to medium grained dolomite. The fine grained limestone shows conchoidal fractures. However, at places in the middle part of the formation sandy limestone is present. The sandy limestone is grey to dirty grey and medium to coarse grained. It has a number of colour shades like light to dark grey, light yellowish grey to creamish grey, brownish grey to rusty grey, whitish maroon to maroonish grey, red maroon to pale maroon and very pale maroon. The formation is generally medium to thick bedded and beds range in thickness from 0.4 to 2 meters Calcite veins is abundant and some of them are dolomitized. The fractures at places contain gypsum crystals. A joint set perpendicular to bedding, where closely spaced, imparts shattered appearance to the formation. It is tough to hammer and breaks with conchoidal fracture. Some horizons especially dolomitic break with irregular fractures. The yellowish horizons are dolomitic relatively coarse grained, show chopboard weathering, small solution depressions and micro ridges at places. The maroonish horizons are dolomitized limestones and contain holes due to solutioning. The palaeontologoical study shows that the Upper Cretaceous diagnostic species are as follows, which confirms the Coniacian- Campanian age of the formation.

Dicarinella carinata, Globotruncana linneiana, Globotruncana elevata-calcarata, Globotruncana fornicata, Globotruncana fornicate-caliciformis, Globotruncana concavata concavata, Globotruncana cf. *concavata carinata, Globotruncana* cf. *thalmanni, Rugoglobigerina rugosa ordinaria, Rugoglobigerina rugosa subrugosa, Heterohelix reussi, Heterohelix glubolosa, Heterohelix globulosa, Buliminella cushmani, Plannlaria liebusi, Lenticulina navarroensis extrauatus, Lenticulina muensteri, Globorotalites multisepta* and *Vaginulina subcomarginata* (Plate 2).

BIOSTRATIGRAPHY OF THE PALEOGENE SEQUENCE OF AZAD KASHMIR

Hangu Formation

The Hangu Formation in the study area is divided into the lower and upper parts. The lower part consists of brecciated sandstone/cherty quartzite, pebbly layers, laterite, bauxite and fire clay. However, the lithology generally varies at places in the lower part of the formation. The upper part includes siltstone, sandstone, carbonaceous shale and coal seams the basal part of the formation marks the disconformity.

In Hazara, the lower part is mostly marked by laterite, oolitic haematite and bauxite. However, at places the siltstone, sandstone, carbonaceous shale and local coal seams are present in the upper part of the formation .The thickness of the unit varies from 1 to 22 meters.

The Hangu Formation occurs in Reechmari, Balakot and Muzaffarabad area of Azad Kashmir. The lower and upper parts of the Hangu Formation are present in Balakot and Azad Kashmir areas. Near Reechmari, Balakot the formation consists of brecciated quartzite, ferruginous pisolitic bauxite, fire clay, carbonaceous shale and sandstone. The formation occurs between the Cambrian Abbottabad Formation and the Early Eocene Margala Hill Limestone. The thickness of the Hangu Formation is 9 meters. The Hangu Formation near Yadgar and Tandabotha includes brecciated quartzite, bauxite, limonite, fire clay, carbonaceous shale, ferruginous sandstone and coal seams. The basal brecciated zone is composed of aluminous to calcareous clays with abundant quartz and chert pebbles. The thickness of the unit at Yadgar and Tandabotha is 26 and 14 meters respectively. In Tattapani area the Hangu Formation consists of brecciated quartzite, bauxite, fire clay, carbonaceous shales and local coal seams. The thickness of the unit is 3 meters. The Hangu Formation near Kamroti includes aluminous to calcareous clays, quartz and chert pebbles, bauxite fire clay, carbonaceous shales and coal seams. The fire clay zone is grey to dark grey with cream to light grey clays. The bauxite is pisolitic and occasionally oolitic, compact and splintery in nature. Pisolitic bauxite is the top most zones, consisting of pisolits and oolites. It is reddish brown to cream coloured and partly lateritized. The laterite and bauxite consists mainly of the oxides of iron and alumina respectively. These are the ideal conditions for decomposition of the clay minerals to laterite. Similar environments must have prevailed in Hazara, Balakot and Azad Kashmir areas during the formation of laterites/bauxites. Formation of oolites in the laterite has taken place because of the transportation of iron content in colloidal form to shallower conditions where it transformed into oolitic/pisolitic form. Beyond the oolitic environment, the sandstone, sandy shale and shale were deposited under an oscillating shallow sea as characterized in the deposits of Hazara, Balakot and Azad Kashmir areas. Whereas, the carbonaceous shale with coal seams deposited under lagoonal conditions. The presence of pebbles and brecciated sandstone and quartzite in the basal part of the formation, shows the reworking of the underlying rocks during regression of the Neotethys Ocean before the formation of laterite, bauxite and fire clay in the lower part of the formation. The sandstone, siltstone, carbonaceous shale and coal seams of the upper part of the formation in Hazara, Balakot and Azad Kashmir, represent the shallow marine to lagoonal environments. In Hazara area, the Early Paleocene Hangu Formation overlies unconformably the upper Cretaceous Kawagarh Formation in Samana Suk Range it overlies unconformably the Kawagarh Formation. It is overlain by the Late Paleocene Lockhart Limestone in Hazara. The stratigraphic relationship in Hazara and Azad Kashmir suggests the Lower Paleocene age for the formation.

Lockhart Limestone

There is transgression of the sea during the deposition of the Lockhart limestone. It is mainly a calcareous, nodular limestone with subordinate shales in the lower and upper parts The limestone is grey, medium to thick bedded, medium grained and hard. The weathered surfaces indicate solution weathering, very prominent flazzer bedding and bluish to light grey in colour. On fresh surface generally dark grey and gives a foetid smell by hammering. There is a marked decrease of nodules towards the middle part of the unit. Nodularity increases towards its contact with the overlying shale of the Patala Formation. In the middle part of the unit calcite veins are common. Microfossils of foraminifer can be seen on the weathered surfaces in the form of tiny speaks less than one millimeter.

The nodular habit of the limestone appears to be of sedimentational origin. This origin is supported by the fact that the nodules are more frequent where shale and marls are interbedded with limestone. Topographically the formation forms ridges and cliffs. In Yadgar and Tandabotha areas of Muzaffarabad, the Lockhart Limestone is present between the Hangu Formation and the Patala Formation. The Lockhart Limestone is dominantly nodular and massive with subordinate shale intercalations. The massive portions of limestone show diffused nodularity. Nodules are generally 2 – 6 centimeters in length and 1-5 centimeter in width. The limestone is dirty grey to light grey on weathered surfaces and grey to dark grey on fresh surfaces. The limestone contains secondary calcite veins. It is highly fossiliferous and fossil size from 0.5-1.5 mm

The foraminifers like *Lockhartia, Assilina, Discocyclina* and *Ranikothalia* are present in the Lockhart Limestone (Plate 1, Fig. 3).

The larger foraminifera are known to characterize the shallow shelf carbonate environments. The Lockhart Limestone represents a shallow shelf carbonate platform as is evidenced by the occurrence of a number of larger foraminifera and dasycladacean algae in the formation. It is inferred that relatively constant water depth was maintained during accumulation of entire sequence. This is an indication of shallow shelf deposits.

In this study the following age diagnostic species of foraminifera are identified:

Operculina salsa, Operculina subsalsa, Lockhartia haimei, Lockhartia tipperi, Lockhartia conditii, Miscellanea miscella Daviesina langhami, Ranikothlia sindensis, Ranikothalia sp., *Kathina delseota, Sakesaria ornata, Quinqneloculina* sp., *Actiosiphon tibetica, Nodosaria* sp., *Textularia punjabensis, Textularia* sp., *Clavulina parisiensis, Pseudogloborotalia membranacea, Globorotalia* sp., *Bigenerina* sp. and *Triloculina* sp.

The other fossils identified in this study from various thin sections of Khaira Gali, Mandedabani, Jabri, Dana Nuranlan, Yadgar and Tandabotha areas include dasycladacean (green algae), red algae, pieces of corals, bryozoans, echinoderm spines and sponge spicules and forams.

Patala Formation

The formation at the type locality mainly consists of dark grey shale, which is sometimes carbonaceous and include workable coal seams. The shaly unit is intercalated with limestone and sandstone. The shale contains selenite and marcasite nodules at places in different levels. Slightly ferruginous beds also occur in higher part of the section. The shale contains foraminifers and Ostracods.

The formation is separated by underlying Lockhart Limestone and overlying Margala Hill Limestone by its significance nature in the area. Shale is the predominant component of the unit though thin limestone and marl band intercalations are frequent towards the base and the top of the formation. The shale represents a prominent olive green colour. The limestone is grayish yellow, mainly nodular with marl intercalation, medium to thick bedded and massive. In Hazara the Patala Formation is mainly a unit with intercalations of marl and limestone towards the base and the top of the formation. The shale varies in colour from khaki to pale grey and greenish grey to occasionally dark grey. It has a permeable nature in general so do not produce mud in the rainy season. These are much cleaved and have a tendency to splinter rather than split. The Hazara Formation on the other hand relatively arenaceous and slightly metamorphosed, with a habit of splitting into plates and devoid of fossils. The shale bands within Margala Hill Limestone of khaki colour differ from shale of Patala Formation by having forams of much larger size (4-8 mm). The khaki coloured shale of the Kuldana Formation is generally associated with purple and grey coloured gypceous shale. In the Changla Gali area, the intercalation of thin-bedded limestone is very common. Shale unit is observed in the Kuza Gali area.

Lithologically, the formation consists of alternating beds of limestone and shale, however, influence of little interbeds of marl and siltstone is also observed. The interbedded limestone is generally nodular.

The shale was deposited in quite water out of suspension while the thin intervening siltstone beds were deposited as distal deposits by occasional strong currents, which were possibly storm related. It is also possible that the shale in parts may have been deposited in the last phase of waning storm currents Swift, D. J. P., HAN, G. and C.E Vincent, (1986).the limestone beds suggest local fluctuation between clastic and non clastic environment of deposition. It is possible that the calcium carbonate was being deposited in the vicinity of the site of deposition of shale and siltstone, the currents during high energy conditions would have transported the calcareous material from its site of origin and deposited in its present position where predominant clastic material was being accumulated. This assumption is supported by the fact that some of the limestone beds are laterally lenticular uneven in the thickness and exhibits lower erosional bedding planes. The deposition of these limestone beds took place during wanning stage of the high-energy condition.

The Patala Formation display a remarkable succession of cyclic deposits in Hazara and Azad Kashmir as a result repetition of shale, limestone, coal and ironstone has been observed. Such cyclotherums are typically associated with unstable shelf or interior basin conditions in which alternate marine submergence and emergency occurred. During the emergent stages, local disconformities may be developed in the previously deposited sediments before the succeeding unit is deposited. Shale, clay and silt derived from rising elements in source areas were deposited over the low emergent plain mainly as alluvial detritus. As the source areas were lowered by erosion these were succeeded by marl and fresh water limestone deposits. The inflow of detrital material diminished and the broad plain was occupied by swamps or marshes. Such conditions were suitable for the accumulation of peat which was later transformed to coal. The accumulation of peat required fresh to brackish water conditions. These conditions were followed by a relative clearing of sea during which limestone was deposited. Restricted shallow marine conditions commonly developed after the initial limestone deposition to form the black laminated shale. As the cycle of sedimentation progressed, the environments lost its restrictions, developed open circulation and eventually the bio-sarite limestone was deposited in shallow current agitated water. The Patala Formation is highly fossiliferous and contains abundant foraminifers, mollusks and Ostracods. Latif [10], reported the macrofossils and microfossils from the formation at difference areas of Hazara.

In present study the detailed work on the foraminiferal assemblage of the formation is presented. The study indicates the occurrence of following species of foraminifera:

Lockhartia haimei, Lockhartia conditi, Lockhartia tipperi, Lockhartia conica, Lockhartia prehaimei, Operculina salsa, Operculina patalensis, Operculina subsala, Ranikothalia nuttalli, Ranikothalia sindensis, Miscellanea miscella, Discocyclina ranikotensis, Nodosaria sp., *Textularia punjabiensis, Textularia* sp., *Quinqueloculina* sp., *Pseudophragmina* sp., *Spiroloculina* sp., *Actinosiphon tibetica, Anomalina acuta, Anomalina bandyi, Globorotalia* sp., *Pseudogloborotalia membranacea, Cibicides* sp., *Clavulina parisiensis* and *Clavulina* sp. (Fig. 3).

On the basis of above mentioned microfaunal assemblage, the Upper Paleocene age has been assigned to the Patala Formation.

Margala Hill Limestone

The formation is essentially a nodular limestone with insignificant intercalations of marl and shale. It is dark grey on freshly broken surfaces and grey to pale grey on weathered surfaces. The weathered surfaces show concentration of larger foraminifera, which range in size from 2 to 6 mm. The limestone is typically nodular; the nodules range 12 cm to 26 cm in length and up to 32 cm in breadth. The nodules are surrounded by argillaceous material. Calcite veins are frequent, particularly where the limestone is massive. In the upper parts, pyrite specks have been noticed. There is a gradual change from the shale of the Patala Formation to the limestone of Margala Hill Limestone. The relatively resistant limestone forms as cliffs and occasionally dip slopes, as seen near Patala, Dunga Gali, Kuza Gali, Reechmari, Tattapani and Yadgar. The authors have measured the section in detail at Kuza Gali. The formation at this section primarily comprises of nodular limestone. The limestone is light grey to dark grey, weathers dull to brownish grey, fine to medium grained, thick bedded, massive nodular and nodules vary from 2 to 22 cm in diameter. The limestone gives foetid smell from the freshly broken surfaces. Prominent joints, fractures and slickenside surfaces occur in the lower part of the section. The lower limestone unit of the formation is highly fossiliferous, contains abundant foraminifers of larger size, which are visible with the naked eye. This is a distinguishing characteristic of the unit. Similar situation prevails elsewhere in the area.

The lithology of formation does not represent any marked deviation. The unit measures from 25 to 159 meters in the Hazara area. The formation forms high cliffs, ridges and escarpments, visible from the distance. The nodular aspects of the Margala Hill Limestone is a result of the differential compaction of the limestone and intervening argillaceous material which surrounds the nodules, pointing out the sedimentary origin as is the case with Upper Paleocene Lockhart Limestone. The digenetic fabrics of Margalla Hill Limestone are produced with effects of chemical compaction, pressure solution and mechanical compaction.

Abundant occurrence of larger foraminifera in the formation is the indication of shallow marine environment. The barrier like shoals more or less parallel to the coast created restricted shelf and open shelf environment. This is characterized by relatively high water energy, rich assemblage of heavy ornamented larger foraminifera, particularly species groups of *Alveolina*, *Orbitolites* and *Nummulites* Hottinger (1974). working on ecological condition of *Alveolinids* established that the carbonate environment form reef facies shoals in many places with similar environments. The formation consists primarily of limestones, which are mostly non-terrestrial origin depicted by the presence of foraminiferal and other fossils. The shallow sea is probably the place of the most expensive deposition of lime. The dark color of the limestone points to a higher organic contents. The fetid smell from the freshly broken surface of the limestone indicates the presence of bituminous matter and applies stagnation of water during the depositional process.

The Margala Hill Limestone is highly fossiliferous. The formation contains foraminifera, mollusks and echinoids. The other fossil remains from various sections of the area identified include pieces of corals, bryozoans, echinoderm spines and sponge spicules. The authors have carried out detailed work on the foraminiferal assemblage of the unit. For this purpose thin sections were studied from Kuza Gali, Khaira Gali, Tattapani, Kamroti and Yadgar areas. The cumulative study of the thin sections has indicated the occurrence of the following foraminifers:

Nummulites atacicus, Nummulites mamillatus, Assilina granulosa, Assilina spinosa, Assilina laminosa, Assilina subspinosa, Ranikothalia sindensis, Operculina patalensis, Lockhartia *tipperi, Lockhartia conditi, Alveolina* sp., *Pseudophragmina* sp., *Discocyclina dispansa, Discocyclina ranikotensis, Rotalia perovalis, Rotalia trochidiformis* and *Alveolina* sp.(Fig. 3).

On the basis of above mentioned microfossil assemblage the Lower Eocene age is assigned to the Margala Hill Limestone.

Chor Gali Formation

The Chor Gali Formation generally consists of limestones, marly limestone, argillaceous limestone, marl and subordinate shale. The limestone is rarely massive and generally shows a flaggy/platy habit, the flaggy habit is probably due to the increasing marly intercalations. The limestones weather into creamy light yellow and light grey colours and their freshly broken surfaces are light grey. The Margala Hill Limestone passes upwards with a gradual change of lithology into the Chor Gali Formation. However, the presence of larger foraminifera helps in its identification in the field. Occasionally these limestones of the formation weather to a chalky appearance. The marls of unit are generally in very light shades from khaki to grey. There is a significant increase in the argillaceous content towards the upper part of the formation which may range from argillaceous limestone to calcareous mudstone. The rock unit is generally thin bedded and less dense in nature and light to medium grey in colour, so visibly devoid of any fossils. The formation is occasionally found to be intensely folded, sheared and brecciated due to its less competent nature. It is fine grained at places, shows secondary calcite veins and gives bituminous smell from the freshly broken surfaces. Some of the beds are nodular and argillaceous. The shale is greenish grey and thin bedded. They are soft and calcareous and alternate with flaggy limestone.

The digenetic fabric of the rock unit is produced by the chemical compaction and pressure dissolution, which are very important burial processes. Apart from producing a range of dissolution textures, they also result in the dissolution of grains and sediments, and this may be a significant source of lime for burial cementation. Pressure dissolution arises from the increased solubility of material at grain contacts and long sediment interfaces as a result of applied stress.

The Chor Gali Formation consists of alternating beds of hard limestone and platy limestone within the shale sequence with abundant dissolution seams in wackstone / packstone. This is an example of fitted fabrics Tucker, M.E. and V.P. Wright, (1992). Bedding planes are developed in platy limestone. They are mostly destroyed by bioturbation. It appears that hard layers were selectively cemented earlier and eventually mechanical and chemical compaction affected the less cemented layers to produce platy limestone and bedding planes. This indicates that cementation of sediment was taking place periodically during shallow burial beneath the seafloor. Topographically, the formation generally forms slopes and low cliffs.

The Chor Gali Formation is fossiliferous particularly in the lower part. It contains foraminifers, Ostracods and mollusks. Vertebrate remains have also been reported from the formation in parts of Kohat and Kotli areas of Azad Kashmir Wells, N.A. and P.D. Gingerich,(1987).and Wells, N. A. and P.D. Gingerich, (1983).

The foraminifera have been studied in detail from the formation. Their preservation is poor in many parts of the relevant areas. The following foraminifers are reported from various lithobiosections of Hazara and Azad Kashmir:

Assilina granulosa, Assilina *spinosa, Assilina subspinosa, Assilina laminosa, Nummulites atacicus, Nummulites mamillatus, Lockhartia conditi, Lockhartia tipperi, Rotalia perovalis, Rotalia trochidiformis, Rotalia* sp., *Textularia punjabensis, Textularia* sp., *Nodosaria* sp., *Orbitolites complanatus, Globorotalia* sp., *Globorotalia aff. Prolata, Quinqnuloceline* sp., *Dictyoconus indicus, Spiroloculina* sp., *Globanamalina ovalis, Valvulineria* sp., *Bigenerina nodosa, Coskinolina* and *balsillei* (Fig. 3).

On the basis of these microfossils assemblage a Lower Eocene age is assigned to the Chor Gali Formation.

Kuldana Formation

The Kuldana Formation comprises dominantly of vary coloured shale, marl, limestone, gypsum and sandstone. The shale is purple, red, buff, crimson, pale grey to brownish grey, generally gypsiferous or arenaceous whitish or violet bentonitic. The clays are occasionally gypsiferous as observed in Bansra Gali. They have been excavated for sometimes in the area. They are plastic in nature, but have very limited extent. Marl is grey to greenish grey, compact, thin bedded and arenaceous. At places, these marls are leached and produced a vuggy structure. Impure gypsum is quite well developed near Mochidhara Cantonment.

The limestone is grey, marly, argillaceous, brecciated and fine grained. They are highly weathered and burrowed. The sandstone is embedded at different levels. These beds are composed almost entirely of distinctive, iron-stained and calcareous granules. These sandstones contain lithic grains of quartzite, chert, sandstone and limestone in coarser size. Most calcareous granules have matrix of small calcite rhombs. The granules are clearly recrystallized and degraded. Most granules have concentric rings of haematite. The features suggest that the granules are reworked soil nodules that grew under arid or semi arid conditions in calcareous soil. Calcareous soil nodules with radial fabrics and rims have been described by Asserto and Folk Frieindman, G.M. and J.E. Sanders, (1978).similar nodules are described by Wells Wells, N.A. and P.D. Gingerich, (1987).from lower Kuldana beds of Kohat area. Cracking and episodic haematite staining and coating of growing nodules could occur in an alternating wet and dry soil environment Siesser, W.G., (1973). Calcareous mud flats and minor erosion and winnowing of the clay during floods and stream channels incision could easily have produced significant lag concentrates, particularly in the absence of any other coarse material. Coarse interclastic limestone rudestone/ floatstone and dolomite occur at places.

Rendzina soil profiles are typical feature of the Kuldana Formation. These profiles have a very dark brown horizon that passes down into a zone of nodular calcite. In some cases nodules collapse to form a solid layer. Rendzina soil primarily indicates a calcareous substrate. They are common under grasslands on marl and limestone in humid to semi-arid climates. Similar conditions have been described by Wells Wells, N.A. and P.D. Gingerich, (1987).in Kohat area.

The red colouration of the clays of the formation is result of oxidation. Nacrite is relatively rare mineral occurring for the most part in association with metallic ores. The formation is generally calcareous at the base and arenaceous towards the top.

The Kuldana Formation with abundant clays indicates a condition of standing water in the immediate areas and high local environmental diversity with nearness to sea. The purple clays indicate a relatively high water table. The overlying marine beds with limestone and marl suggest that base level was rising. The presence of an aquatic fauna indicates that the rivers of the area were perennial rather than ephemeral.

Wells, N.A. and P.D. Gingerich, (1987).commented on the preservation of the Kotli, Azad Kashmir and Kala Chitta vertebrate fossils. The occurrence of mammals' bones suggests a greater rate of subsidence and sedimentation, which may have supported the burial and preservation. The sandstone did not appear to be the result of meandering streams. They are thin and appear to be deposited/ laid down by one or two floods. Most of the perennial streams may have entered the upper Kuldana coast and have removed most of the sediments during floods. The granulestone within the red beds apparently represents inland environments that were derived and scrub covered plains crossed by small and briefly active streams which apparently supported a sparse and limited fauna. They represent lags or low bars in large and mostly mud filled channel. It is also possible that streams wander area all over the landscape, thereby indicating its flatness.

Extreme flatness of the formation surely contributed to the immaturity of the early drainage system. Common over bank flooding and channel from sandstone occur at all levels. However, enormous clay deposits suggest additional input of clay by other processes like sheet wash and wind action. The impressed aggradations of red bands suggest that the draining of the sea by evaporation process left the basin floor below grade.

The Kuldana Formation represents a varied lithology consisting of marl, siltstone, limestone and oyster beds, which are interpreted to be deposited as white marls with commonly leached features are deposited as marsh, lake, or lagoon limestone. Some of the leached white marls have rough and irregular, solution pitted features, as a result of exposure and baking in the sun. Limestone/ bioclast, wackestone commonly gastropodal in thin sections are brackish water deposits.

Carbonates, particularly with purple and violet hue, show an extensive evidence of iron staining. They occur as nodules with unusual networks of curvilinear cracks. These are produced by soil forming processes, particularly those working in marshy conditions.

Oyster beds at the top of the Kuldana Formation are accompanied by one or more thin beds of broken shells. Because oysters are sessile and cannot tolerate rapid sedimentation in very muddy water, the sequence is believed to represent slow sedimentation under brackish water.

Coarse intraclastic limestone/ rudstone/ floatstone and dolomite in sandstone, siltstone and clays are caused by high energy conditions or by reworking of clasts formed by mud cracking or evaporate dissolution under lower energy conditions.

The flood plain clastic sediments having laminated gypsum beds /lenses represent extremely shallow water to emergent environments. The laminated gypsum resembles the quiet and shallow water deposits Schreiber,B.C., (1978).the reddish yellow gypsiferous shale with isolated selenite crystals, possibly represent a synsedimentary or very early diagenetic sabkha or subsankha muddy crystal mesh. The variegated red and green shale with long fan shaped gypsum crystals are similar to some of the crystals described from sabkha settings by Schreiber (1978) these shales may be the emergent feather-edge forms and the associated gypsum crystals may be formed under subaqueous conditions.

A brackish back-bar bay or lagoon that trapped mud and animal remains carried out to sea from the marshes along the shore.

On shore clays, completely pedogenized and apparently representing very slow sedimentation until the earliest Himalayan molasses was swept into the region.

The authors have identified foraminifera from the formation which include:

Assilina dandotica, Assilina granulosa, Assilina sp., Nummulites atacicus, Nummulites mammillatus, Nummulites sp., Quinqueloculina sp. and Milliolids (Fig.3).

On the basis of above mentioned faunal assemblage a Middle Eocene age is assigned to the Kuldana Formation.

Summary and Conclusion

The detailed field investigations, sample analysis, microfacies analysis and palaeontological study of Hazara, Balakot and Azad Kashmir areas lead to following conclusions.

The basinal evolution of the area started in the Mesozoic. The deposition of the Upper Cretaceous Kawagarh Formation in Hazara exhibits the deepening of narrow trough by containing planktonic foraminifera like *Globotruncana, Rugoglobigerina* and *Heterohelix*. However in Azad Kashmir, the area remained uplifted during the Upper Cretaceous and no Kawagarh Formation was deposited. The sequence from Ordovician to Cretaceous have been eroded or not deposited during pre-Paleocene tectonic uplift.

Having much time gap during Maastrichtian to Danian, the Kawagarh Formation was subjected to chemical weathering processes. It is inferred from overlying residual deposits and by missing fauna of Maastrichtian. The overlying pisolitic laterite, limonite, oolitic haematite and bauxite mark the first major stratigraphic break of the Cretaceous-Tertiary strata. This unconformity has a long time gap from Ordovician to Lower Paleocene in Azad Kashmir and Balakot regions by resting residual deposits of Hangu Formation on cherty dolomites of the Abbottabad Formation.

The Upper Cretaceous Kawagarh Formation records the shelf marine sedimentation which occurred during the subduction of the Indian plate below the Kohistan Island arc. The Kawagarh Formation deposited during major transgressive cycle from Coniacian to Campanian.

The start of initial collision of the Indian plate and Kohistan Island arc in the Maastrchtian- Early Paleocene, a major regressive cycle occurred in the Hazara area. The regressive cycle of Neotethys Ocean occurred due to pre-Paleocene tectonic uplift in the area. This regressive cycle deposited the basal part of the Early Paleocene Hangu Formation.

The laterite/ bauxite of the lower part of the Hangu Formation deposited during tropical to subtropical conditions where the sandstones, siltstones, carbonaceous shale and coal seams of the upper part of the Hangu Formation deposited under restricted shallow marine to lagoonal environments. The second transgressive cycle of Neotethys ocean deposited shallow marine shelf carbonate and shale sequence during Late Paleocene to Early Eocene .The formations which deposited during second transgressive cycle include Lockhart Limestone, Patala Formation, Margala Hill Limestone and Chorgali Formation.

The deposition of Lockhart Limestone with larger benthic foraminifer took place during the Upper Paleocene (Thanetian) after the transgression of the Neotethys Ocean in Hazara and Azad Kashmir. These carbonates (nodular limestone) microfacies are indicative of marine shallow shelf environments. Subsequently, shaly deposits of Patala Formation with interbeds of limestone seem to show a considerable regression of the sea with mostly quiet water deposition.

The shallow shelf carbonate deposition of the nodular Margala Hill Limestone continued in the Early Eocene time. The presence of dark shale and foetid fossiliferous limestone that accumulated in slight higher energy water has a basinal configuration across the Paleocene-Eocene boundary.

The pre-existing paleogeographic setting of the basin has been changed after the depositions of Margala Hill Limestone when a trend of younging of units towards the south has been observed during the Early Eocene. The flaggy limestone of the Chorgali Formation comprises near shore deposits and shows a single regression late in the Early Eocene marked southward shift in the basinal configuration that left the land dry during Middle Eocene fluctuations of the shoreline to the north and to the west.

In Middle Eocene the Kuldana Formation deposited under transitional environment. This indicates the closing of the Neotethys Ocean and strengthening the argument of the southward shift of the paleogeographic setting and the development of the Hazara- Kashmir foreland basin which marks the end of the Paleogene deposition in the area. The Middle Eocene is the time of main Himalayan collision in northern Pakistan and the formation of Hazara-Kashmir foreland basin. The Himalayan molasse initiated deposition as Murree Formation during Middle Eocene in Azad Kashmir and Miocene in the Hazara area. This indicates that the Himalayan molasse of the Murree Formation is time transgressive unit.

The occurrence of abundant foraminiferal fauna laterally and vertically in the succession from Upper Cretaceous to Paleogene made it possible to establish biozonation on the basis of several age diagnostic species. The zonal species belongs to three main groups of planktonic, larger benthic and smaller benthic foraminifera. The Upper Cretaceous Kawagarh Formation represents the planktonic genera *Globotruncana, Heterohelix, Rugoglobigerina, Planularia, Lenticulina, Globorotalites, Buliminella* and *Vaginulina* of foraminifera. The Paleogene strata consists mainly of larger and smaller benthic foraminiferal genera such as *Daviesina, Operculina, Miscellanea, Lockhartia, Ranikothalia, Rotalia, Globorotalia, Quinqueloculina, Textularia, Nodosaria, Clavulina, Thalaminita, Anomalina, Assilina* and *Nummulites*.

The Cretaceous-Tertiary Boundary on the basis of fossils can not be marked in Hazara as there is no record of Maastrchtian and Danian fauna. However, the K–T Boundary can be placed at the base of Lower Danian basal residual part of the Hangu Formation. The Upper Danian unfossiliferous upper part of the Hangu Formation at places shows very shallow marine lagoonal facies. The Paleocene-Eocene Boundary is placed by the disappearance of *Operculina salsa* and *Miscellanea miscella* and the appearance of *Nummulites atacicus* and *Nummulites mammillatus* in the upper part of Patala Formation and basal part of the Margala Hill Limestone respectively. In Hazara and Azad Kashmir, the whole succession from Upper Cretaceous to Middle Eocene was deposited by double cycle of transgression and regressions of Neotethys Ocean before the initiation of Himalayan molasse during the Middle Eocene to Miocene Himalayan collision.

Acknowledgments

The first author gratefully acknowledges the financial assistance of Pakistan Science Foundation under the research project grant No: PSF/Res/AJK/Earth (70).

The laboratory facilities for microfossils separation and preparation are used at the Institute of Geology, University of Azad Jammu and Kashmir, Muzaffarabad .The chemicals and glass wares provided by HEC through strengthening of labs scheme for University of Azad Jammu and Kashmir is highly appreciated. The computer laboratory of the HEC Integrated Geosciences Research Project provided the computer facilities during the preparation of this manuscript.

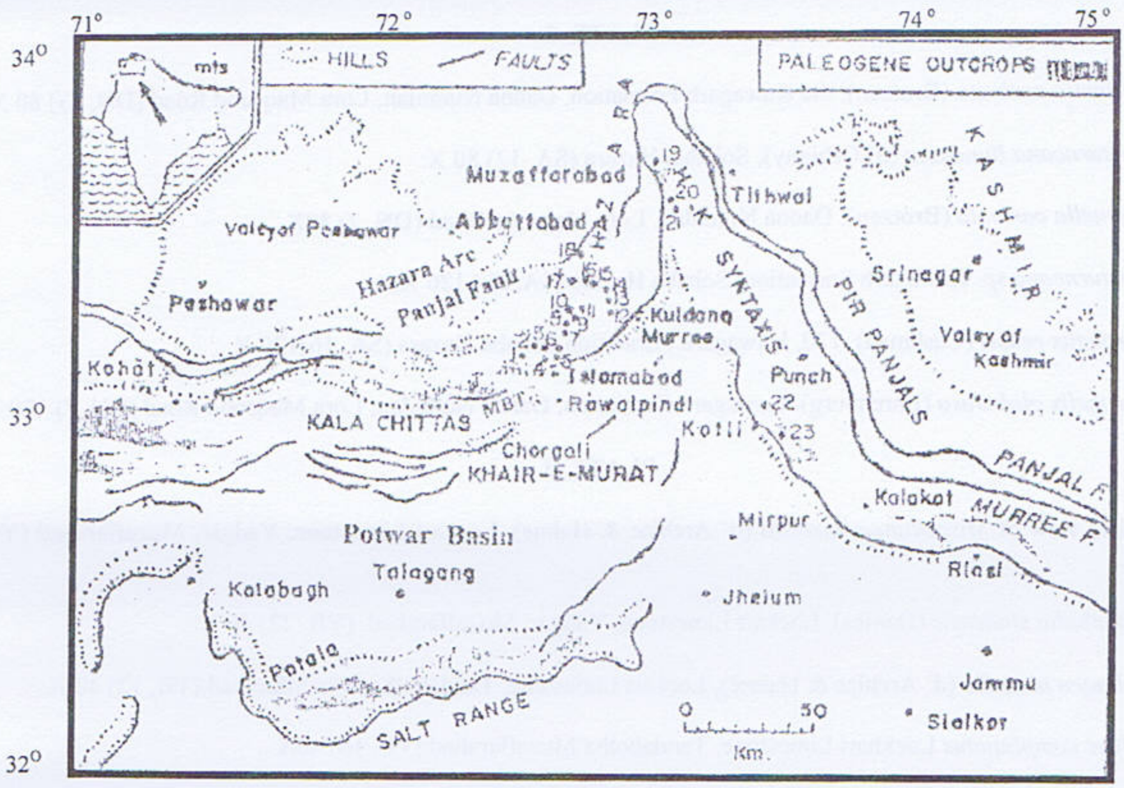

Fig. 1 Location map of Northwest Himalaya (Modified after Wells, N. A. and P.D. Gingerich, (1983).showing distribution of lithostratigraphic sections around the Hazara-Kashmir Syntaxis. Dananural (1), Lassan (2), Jabri (3), Sangjani (4), Sohaba (5), Mandibani (6), Chanali (7), Hothla (8), Jhan (9), Kalsan (10), Jhansa (11), Khaira Gali (12), Changla Gali (13), Chumbi (14), Kuza Gali (15), Kundla (16), Mochidhara (17), Kalas (18), Reechmari (19), Yadgar (20), Tandabotha (21), Tattapani (22) and Kamroti (23).

PLATE 1

Fig.1 Thin to medium bedded Upper Cretaceous Kawagarh Formation near Danna Nuranlan, Lora Maqsood Road, Hazara.

Fig.2 Overturned sequence showing the Paleocene Lockart Limestone at the base and the Upper Cretaceous Kawagarh Formation above intervened disconformably by oolitic haematite.

Fig.3 The contact between Cambrian Abbottabad Formation, Paleocene Hangu Formation and the Lockart Limestone at Yadgar, Muzaffarabad.

Fig.4 The Early Eocene Margala Hill Limestone, the Chor Gali Formation, and the Middle Eocene Kuldana Formation are exposed near Yadgar Neelum River, Muzaffarabad.

Fig.5 Thick bedded nodular Early Eocene Margala Hill Limestone near Kuza Gali, Hazara.

Fig.6 The variegated shales of the Middle Eocene Kuldana Formation (a) are in contact with the Early Eocene Chor Gali Formation (b) near Kamroti, Kotli.

PLATE 2

Fig.1 *Dicarinella carinata* (Brotzen), the Kawagarh Formation, Danna Nuranlan, Lora Maqsood Road (DN, 13) 80 X.

Fig.2 *Globoturncana linneiana* (d' Orbigny), Sohaba, Hazara (SA, 12) 80 X.

Fig.3 *Dicarinella carinata* (Brotzen), Danna Nuranlan, Lora Maqsood Road (DN, 7) 80X.

Fig.4 *Globoturncana sp.* Kawagarh Formation, Sohaba Hazara (SA,16) 120 X.

Fig.5 *Heterohelix reussi* (Cushman), 120, Kawagarh Formation Sohaba Hazara (SA, 16)120 X.

Fig.6 *Heterohelix globulosa* (Ehrenburg), Kawagarh Formation, Danna Nuranlan, Lora Maqsood Road (DN, 7) 120 X.

PLATE 3

Fig.1 Vertical view of *Miscellanea miscella* (d' Archiac & Haime), Lockart Limestone, Yadgar, Muzaffarabad (YR, 22) 40 X.

Fig.2 *Ranikothalia sindensis* (Davies), Lockart Limestone, Yadgar, Muzaffarabad. (YR, 22) 40 X.

Fig. 3 *Miscellanea miscella* (d' Archiac & Haime), Lockart Limestone, Tandabotha, Muzaffarabad (TB, 12) 40 X.

Fig.4 *Orbitolites complanatus* Lockhart Limestone, Tandabotha Muzaffarabad (TB, 16) 40X.

Fig.5 *Dasycladacean* Packstone with *Spiroloculina* sp. in the center, the Lockhart Limestone, Yadgar Muzaffarabad (YR, 23) 40X.

Fig.6 *Miscellanea miscella* (d' Archiac & Haime), Lockart Limestone, Khaira Gali, Hazara (KG, 29) 40 X.

PLATE 4

Fig.1 *Lockhartia diversa* (Smout), Lockhart Limestone, Tattapani, Kotli (TP, 8C) 40 X.

Fig.2 *Dictyoconus* (Davies), Lockhart Limestone Yadgar, Muzaffarabad (YR, 19) 40 X.

Fig.3 *Lockhartia conditi* (Nuttall), Lockhart Limestone, Yadgar, Muzaffarabad (YR, 23) 40 X.

Fig.4 *Ranikothalia sindensis* (Davies), Lockhart Limestone, Yadgar, Muzaffarabad (YR, 17) 40 X.

Fig.5 *Ranikothalia sindensis* (Davies), Lockhart Limestone, Yadgar, Muzaffarabad (YR, 15) 40 X.

Fig.6 *Ranikothalia sindensis* (Davies), Lockhart Limestone, Tandabotha, Muzaffarabad (TB, 9) 40 X.

Fig.7 Bioclastic packstone with laminated *pelecypod*, Margala Hill Limestone, Tattapani, Kotli, Azad Kashmir (TP, 18) 20 X.

PLATE 5

Fig.1 *Nummulites mamillatus* (Fichtel & Moll), Margala Hill Limestone, showing umbonal pillars and thick wall, Tattapani, Kotli (TP, 14) 20 X.

Fig.2 *Nummulites mamillatus* (Fichtel & Moll), Margala Hill Limestone, Kamroti, Kotli (KM, 18) 20 X.

Fig.3 *Nummulites atacicus* (Leymerie), Margala Hill Limestone, Kamroti, Kotli (KM, 16) 20 X.

Fig.4 *Nummulites atacicus* (Leymerie), Margala Hill Limestone, Kamroti, Kotli (KM, 16) 20 X.

Fig.5 Micropheric individual *Nummulites mamillatus* (Fichtel & Moll), Kuldana Formation, Yadgar/ Makra, Muzaffarabad (YR, 57) 20 X.

Fig.6 *Assilina granulose* (d' Archiac), Maragala Hill Limestone, Tattapani, Kotli, (TP, 12) 20 X.

PLATE 6

Fig.1 *Assilina subspinosa* Davies & Pinfold, Margala Hill Limestone, Tattapani, Kotli (TP, 14) 20 X.

Fig.2 *Assilina granulosa* (d' Archiac), Maragala Hill Limestone, Yadgar, Muzaffarabad Lockhart (YR, 12) 5 X.

Fig.3 *Assilina subspinosa* Davies & Pinfold, Chor Gali Formation, Yadgar area, Muzaffarabad (YR, 41).

Fig.4 *Assilina subspinosa* Davies & Pinfold, Margala Hill Limestone, Kamroti, Kotli (KM, 17) 10 X.

Fig.5 *Nummulites atacicus* (Leymerie), Margala Hill Limestone, Tattapani, Kotli (TP, 12) 10 X.

Fig.6 *Nummulites atacicus* (Leymerie), Chor Gali Formation, Kamroti, Kotli (KM, 16B) 10 X.

Fig.7 *Nummulites mamillatus* (Fichtel & Moll), Margala Hill Limestone, Kamroti, Kotli (KM, 16B) 10 X.

Fig.8 *Nummulites atacicus* (Leymerie) and *Alveolina* sp., Margala Hill Limestone, Kamroti, Kotli (KM, 25) 10 X.

Fig.9 *Assilina Laminosa* (Gill), Margala Hill Limestone, Tattapani, Kotli (TP, 12c) 5 X.

Fig.10 *Nummulites atacicus* (Leymerie), Margala Hill Limestone, Kamroti, Kotli (KM, 18)

PLATE 1

Fig. 1

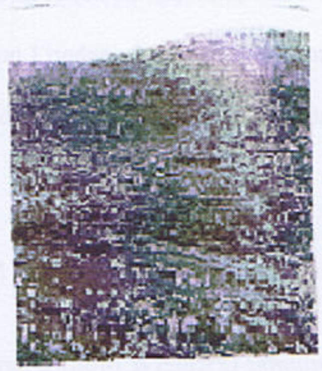

Fig. 2

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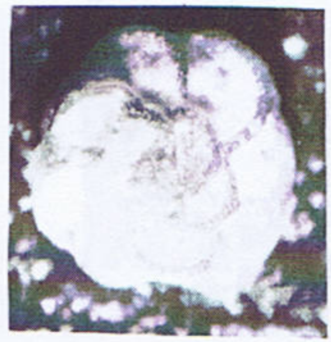
Fig. 5

Fig. 6

PLATE 2

Fig. 1



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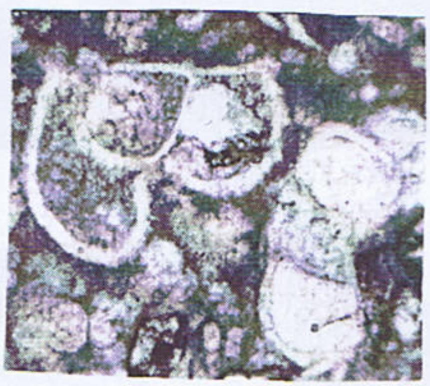

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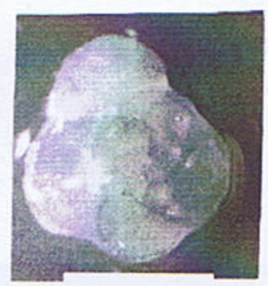


Fig. 4

Fig. 5

Fig. 6

PLATE 3

Fig. 1

Fig. 2

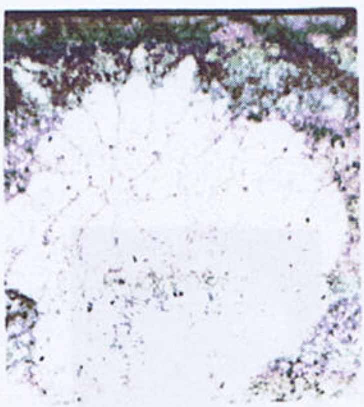
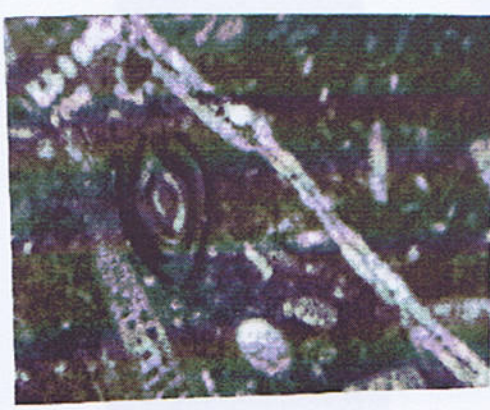


Fig. 3

Fig. 4



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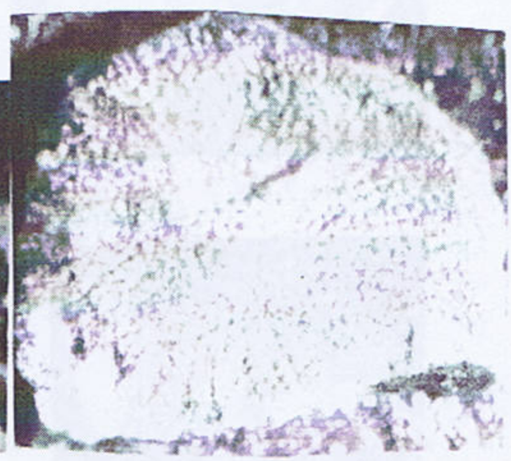


Fig. 6

PLATE 4

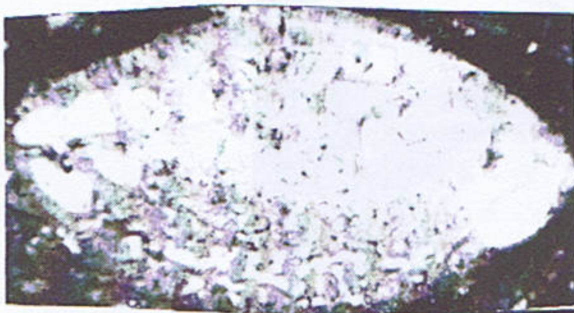


Fig. 1

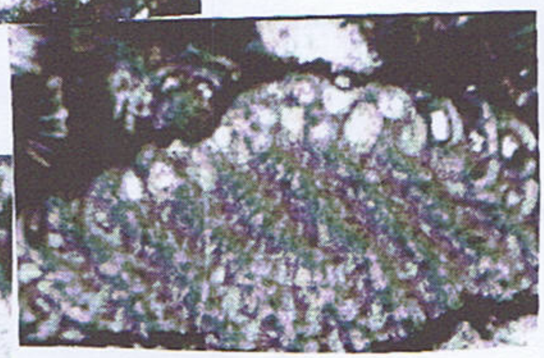


Fig. 2

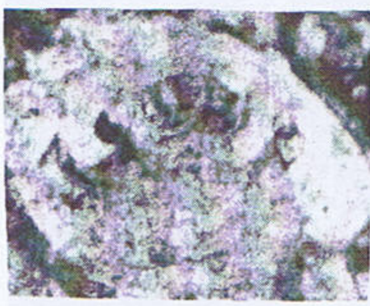


Fig. 3

Fig. 4

Fig. 5

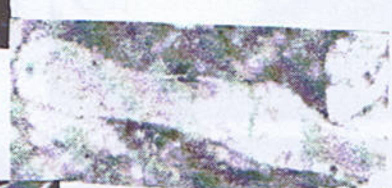


Fig. 6

Fig. 7

PLATE 5

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

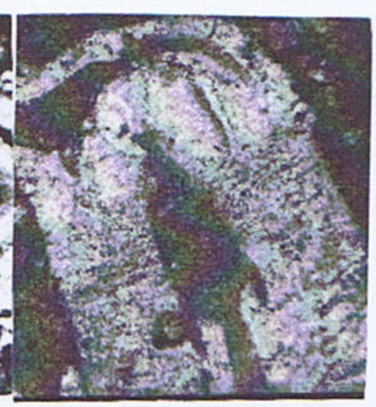
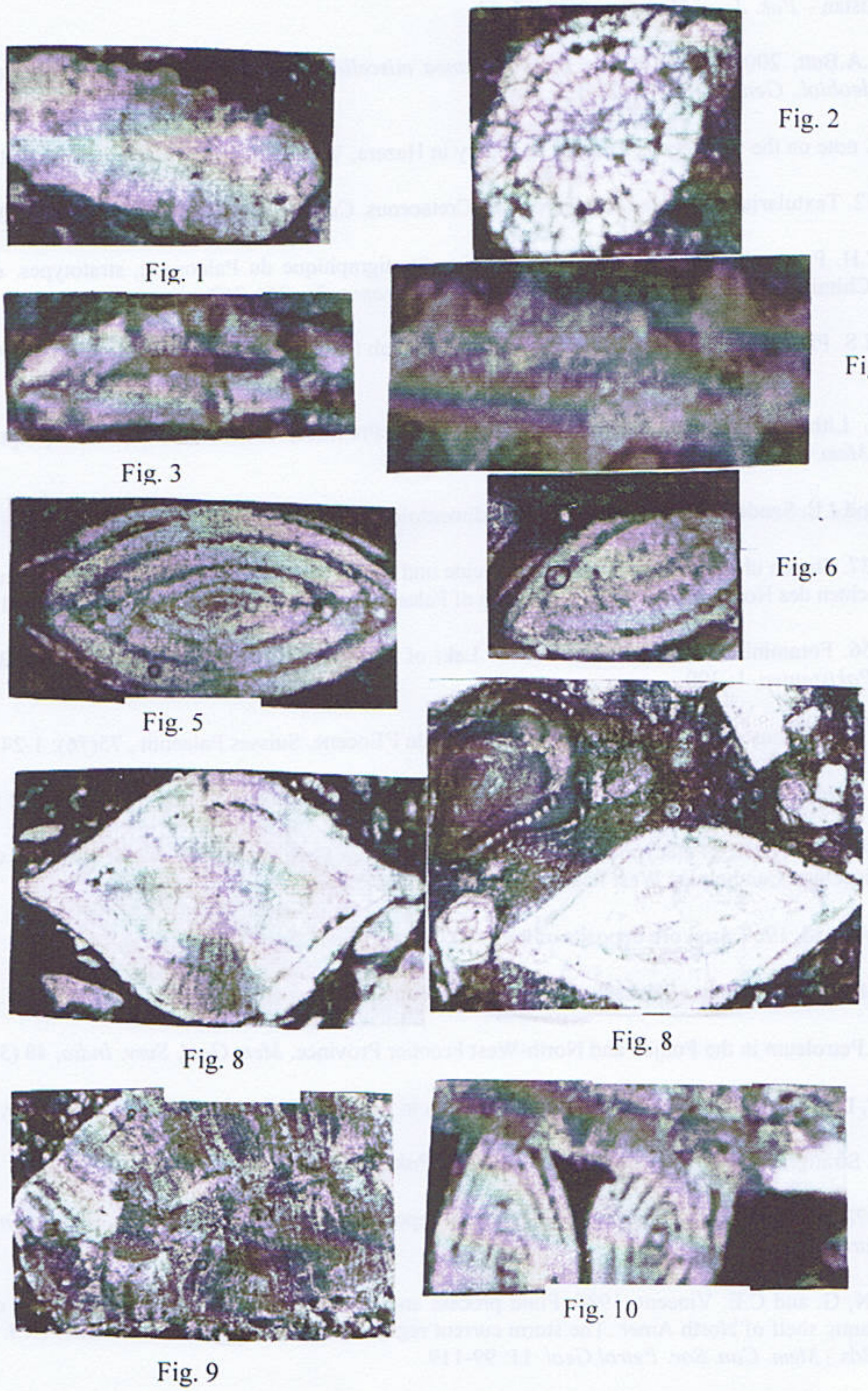


Fig. 6

PLATE 6



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SLOPE STABILITY ANALYSIS AT ALTERNATE SANDSTONE, CLAYSTONE/SILTSTONE BEDS OF DHOK PATHAN FORMATION AT PIR PEHAI AREA DISTRICT MIANWALI, PAKISTAN

BY

MUSTANSAR NAEEM AND MUHAMMAD SAEED FAROOQ
Institute of Geology, Quaid-e-Azam Campus, University of the Punjab, Lahore 54590, Pakistan
Email: naeem29pk@yahoo.com

Abstract: *Slope stability analysis was undertaken on alternate sandstone, claystone/ siltstone beds, of Dhok Pathan Formation, exposed at Pir Pehai area. Studies were carried out to determine the geotechnical behaviour of the sequence with respect to excavation of cut slopes in the area. Investigation involved the evaluation of slope stability parameters using wedge method of analysis. Bedding shears were encountered in the claystone/siltstone beds, which are considered the potential failure surfaces. Based upon the studies various angles are proposed for stable cut slopes in these rocks.*

INTRODUCTION

Slope stability analysis was carried out on the alternate sandstone, claystone/ siltstone beds of Dhok Pathan Formation at Pir Pehai area, district Mianwali, Pakistan (Fig 1). The project area lies in sedimentary rocks dating from Pre-Cambrian to Recent (Shah, 1977). Regionally it spreads over three separate geological provinces (Taseer et. el. 1989) Surghar Range, Salt Range and Potwar-Kohat Plateau (Fig 2). Geological sequence in the area is comprised of Dhok Pathan Formation, river channel deposits, stream deposits, and terrace deposits. Dhok Pathan Formation is the main unit present which consists of alternate sandstone, claystone/siltstone beds with occasional lenses of gravels. Sandstone is hard, well cemented to very soft and poorly cemented having thickness from few meters to more than 90 meters. While claystones are hard dark grey, greenish grey or brown overconsolidated silty clays (Malik & Farooq, 1988), laminated at places containing some calcium carbonate. The claystone beds are variable in thickness and composition and contain siltstone layers at places. The thickness of claystone/siltstone sequence between sandstone beds varies from 0.5 to 30 meters. The siltstones are commonly found either at the base of the sandstone or within a claystone sequence. It is hard, yellowish brown to brown clayey and sandy silts with calcium carbonate. The thickness varies from 0.5 to 11 meters. For detailed engineering geological investigations Kalabagh Consultants (1984) have distinguished sandstones in to nine beds from highest to lowest in the sequence. Claystone/siltstone units between two sandstone units are described by the number of the overlying sandstone with the addition of negative sign. Brief description is given in table -1.

Dhok Pathan Formation is widely exposed in Potwar area of Pakistan (Shah, 1977). These rocks have geotechnical importance due to the presence of Mangla and proposed Kalabagh dams. Most of the small dam projects are also being considered in similar rocks. The claystone/siltstone beds present in the area need special attention because of their problematic nature (William, 2002b). Shear zones are encountered in claystone/siltstone beds. Exploratory adits and trenches have been used to explore the fresh surfaces for the demarcation of shear zones present in claystone/ siltstone beds. The shear zones seriously affect the geotechnical behaviour of these rocks. The presence of shear zones in claystones/siltstone renders a great difference in the intact and residual strength parameters (Malik & Farooq, 1988). Considering the importance of these rocks for future geotechnical projects, slope stability analysis has been carried out. Results of the studies can be applied in the geotechnical evaluation of the engineering projects of the area.

Table-1
Lithological details of the Dhok Pathan Formation at Pir Pehai area

Unit Number	Thickness (meters)	Description
1	53	Contains lenses of Claystone/siltstone
-1	12	Bedding shear is present
2	6	Sandstone bed
-2	6-8	Claystone/siltstone bed
3a	9	Sandstone
-3a	15-17	Claystone/siltstone
3b	27-30	Sandstone
-3b	5	Claystone/siltstone
4a	8	Sandstone
-4a	3	Claystone/siltstone
4b	6-9	Sandstone
-4b	3-9	Having sandstone lenses in some areas
5&6		Merges in to a single sandstone unit.
-6	15-27	Alternation of Claystone, siltstone & thin sst..
7	32-40	Sandstone
-7	21	Alternation of siltstone/Claystone
8	12-15	Sandstone
-8	11-12	Claystone/siltstone
9	14-17	Sandstone
-9	27-30	Claystone/siltstone

MATERIALS AND METHODS

Sandstone, claystone/siltstone beds of Dhok Pathan Formation are dipping at an angle of 4 to 5 degree. Investigated area is underlain by sandstone # 4 to 9 and associated claystone/ siltstone beds. Shear zones have been identified in claystone beds.

Slope stability analysis

The area is comprised of alternate sandstone, claystone/siltstone beds with persistent shears. Therefore Wedge method of analysis has been employed to carry out slope stability studies of these rocks. The method is useful to analysis of rock slopes in layered strata, where a discontinuity locates the failure surface (Bowles, 1984). This method is particularly appropriate to those slope situations where potential shears surfaces are constrained by the presence of bedding plane structural features (Attewell et. el 1976). Claystone/siltstone bed (-6) with persistent bedding shear, having low value of Φ, (KC, 1984) is exposed in the area. Therefore, it has been considered, during analysis, the potential failure surface. For convenience sides of the excavation are named A & B and accordingly both the cases are delt separately for each angle (Figs. 3a, 4a, 5a and 6a). The sides A and B are further, subdivided in to Active and Passive Wedge (Bowles, 1984). The analysis consists of four angles 30°, 38°, 45° and 60° and three trial factors of safety are assumed for each angle. The resultant earth forces acting at the vertical boundaries of the passive and active wedges are determined by constructing force polygons. So, the force polygons are made for both the wedges and calculated the values of E_A, the earth force of the active wedge and E_P, the earth force of the passive wedge. The magnitude of resultant forces, E_A and E_P depend upon the trial factor of safety. The notations W_A W_P and F_A F_P used in the figures (Figs. 3b, 4b, 5b and 6b) for force polygons show the weights and frictional forces for the Active and Passive Wedge respectively.

The values of cohesion, angle of internal friction and density are taken from the report of Kalabagh Consultants (1984).

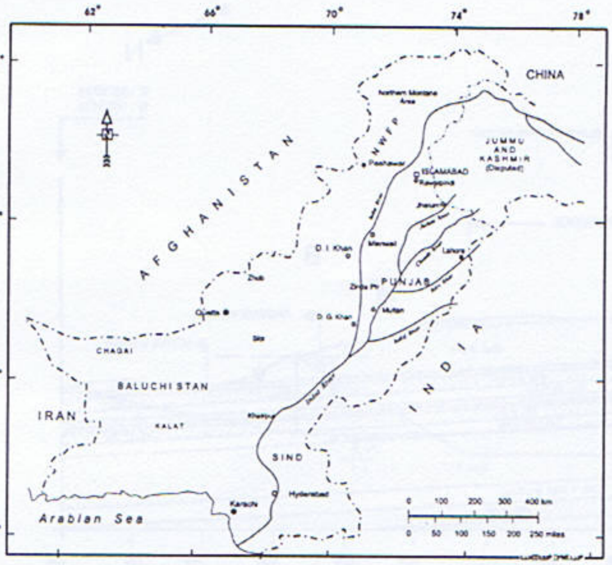

Fig. 1: Map of Pakistan

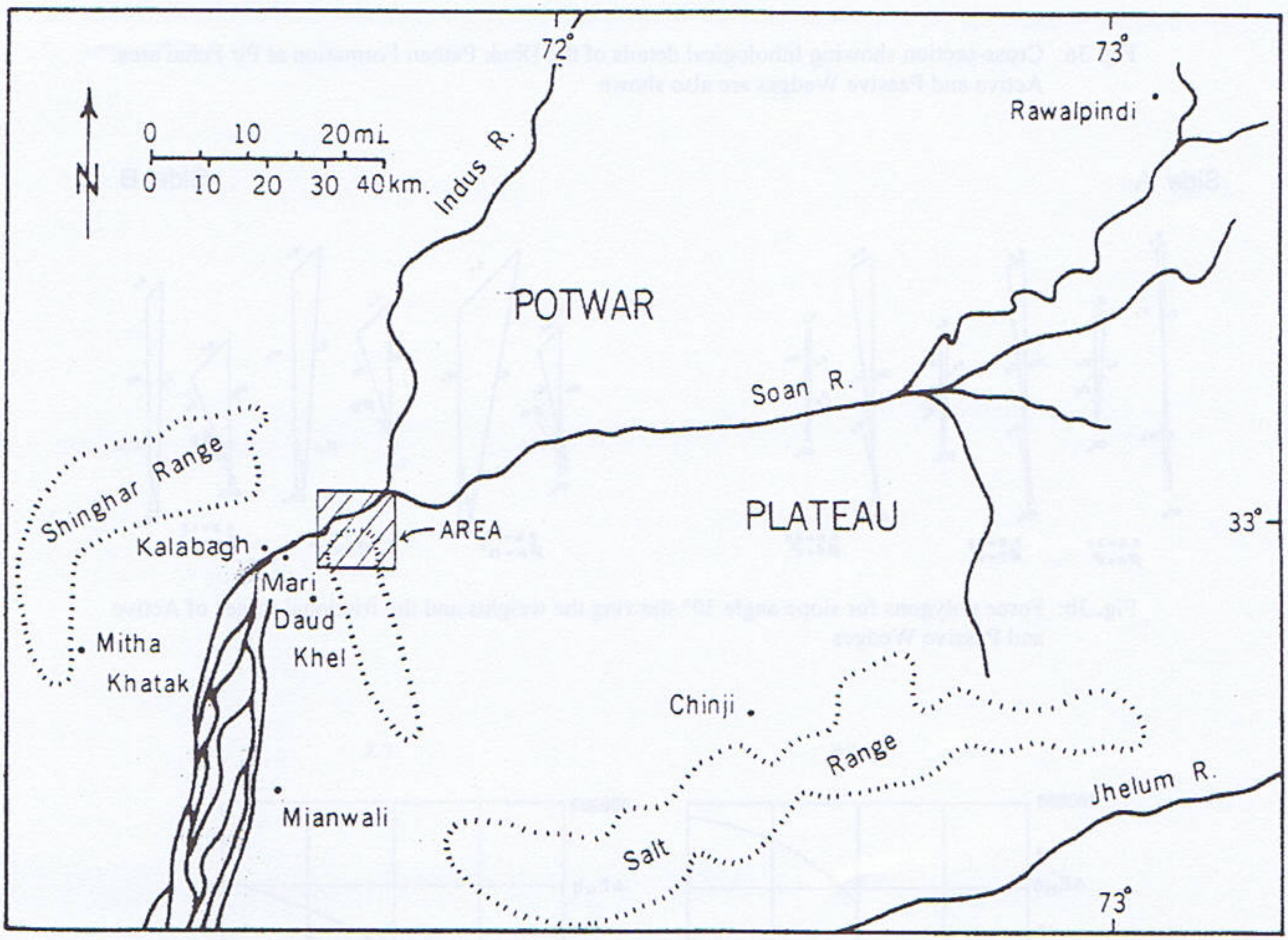

Fig. 2: Location map showing the project area

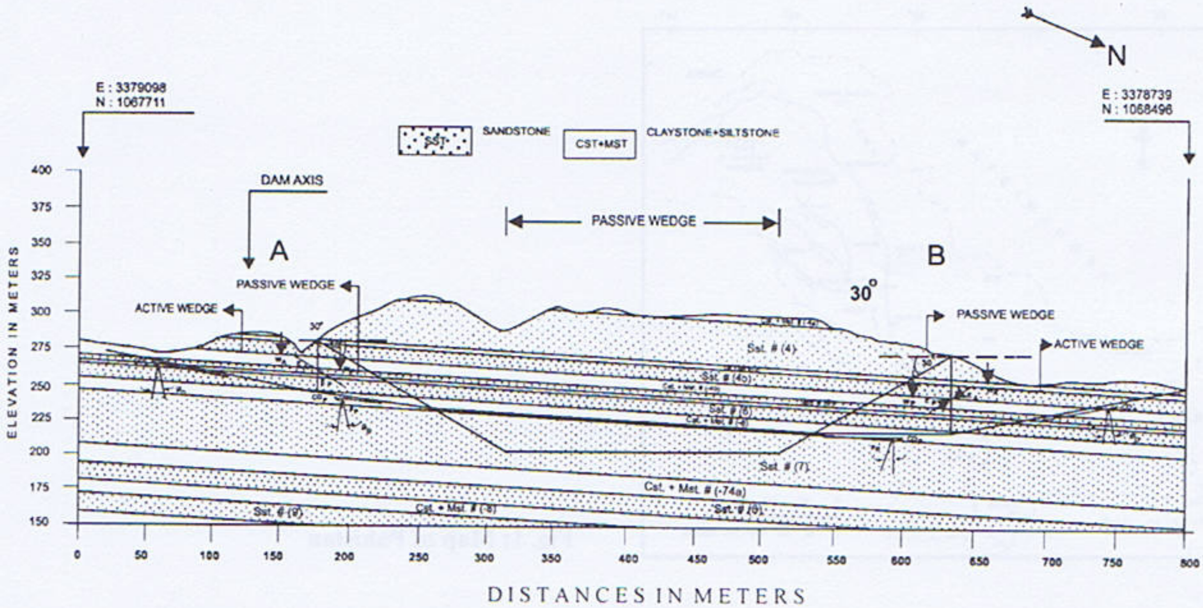

Fig. 3a: Cross-section showing lithological details of the Dhok Pathan Formation at Pir Pehai area. Active and Passive Wedges are also shown

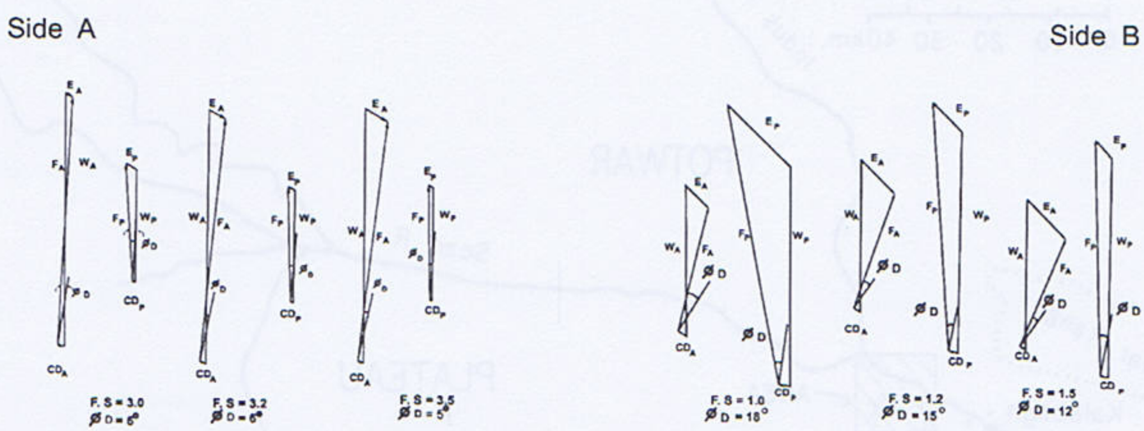

Fig. 3b: Force polygons for slope angle 30° showing the weights and the frictional forces of Active and Passive Wedges

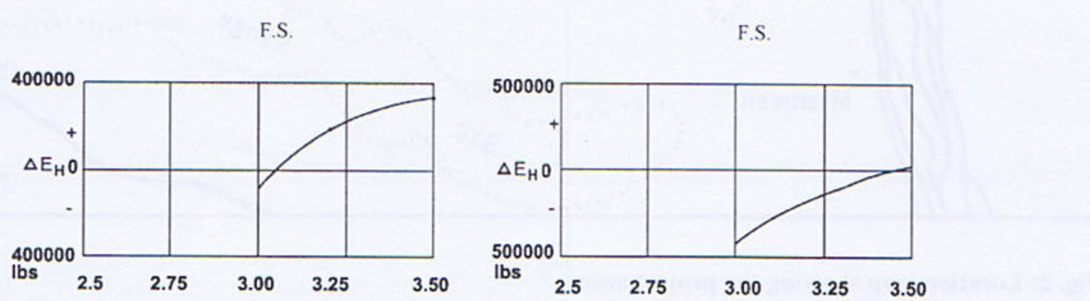

Fig. 3c: Trial Factor of Safety (F.S.) versus Net Effective Force (ΔE_H) to obtain the value at which ΔE_H=0

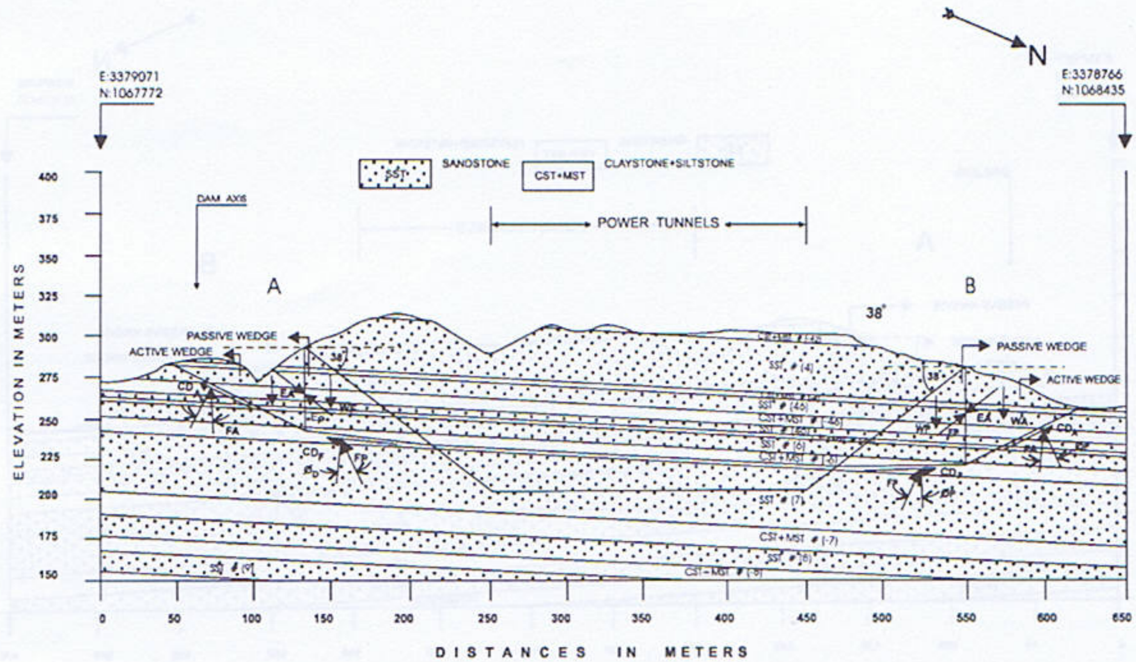

Fig. 4a: Cross-section showing lithological details of the Dhok Pathan Formation at Pir Pehai area. Active and Passive Wedges are also shown

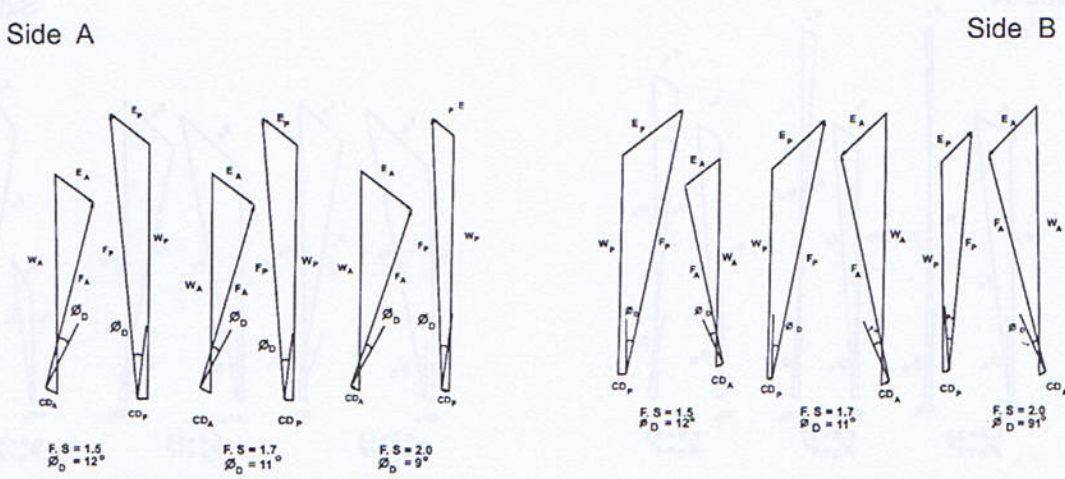

Fig. 4b: Force polygons for slope angle 38° showing the weights and the frictional forces of Active and Passive Wedges

Fig. 4c: Trial Factor of Safety (F.S.) versus Net Effective Force (ΔE_H) to obtain the value at which ΔE_H=0

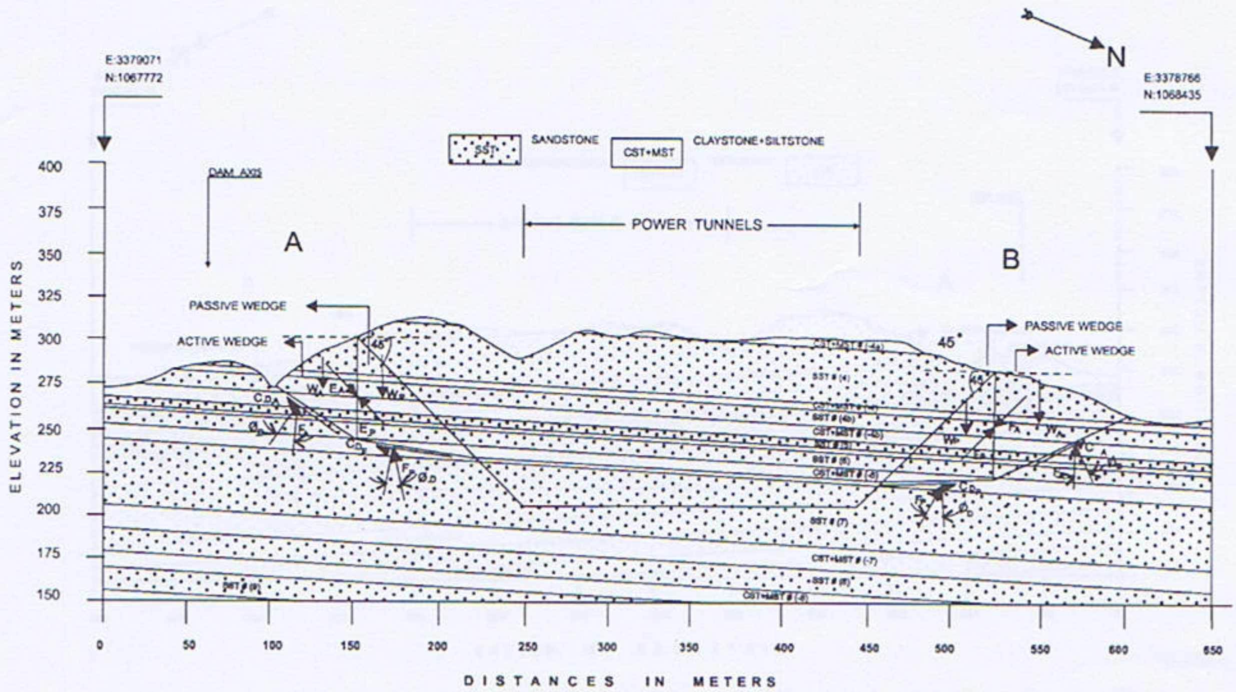

Fig. 5a: Cross-section showing lithological details of the Dhok Pathan Formation at Pir Pehai area. Active and Passive Wedges are also shown

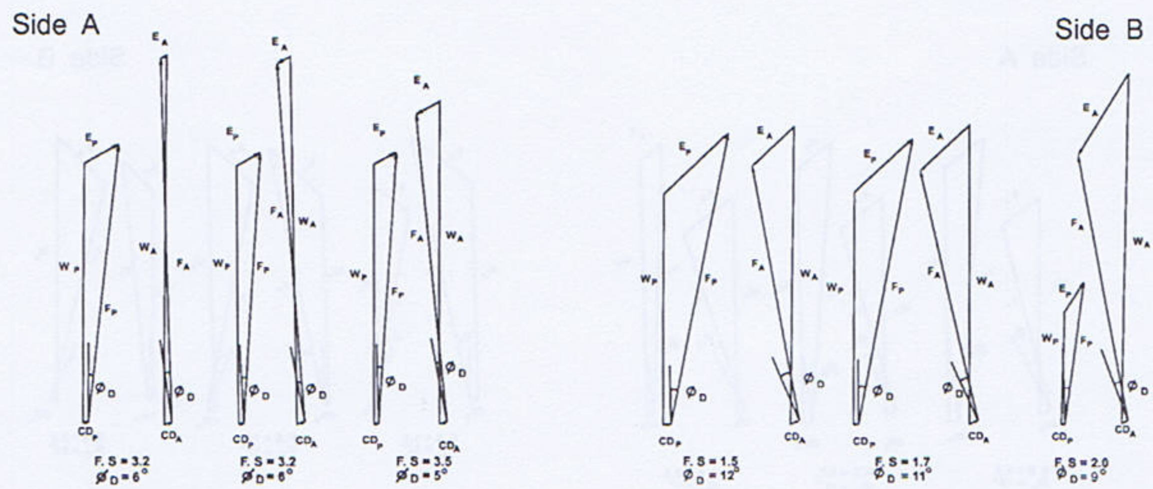

Fig. 5b: Force polygons for slope angle 45° showing the weights and the frictional forces of Active and Passive Wedges

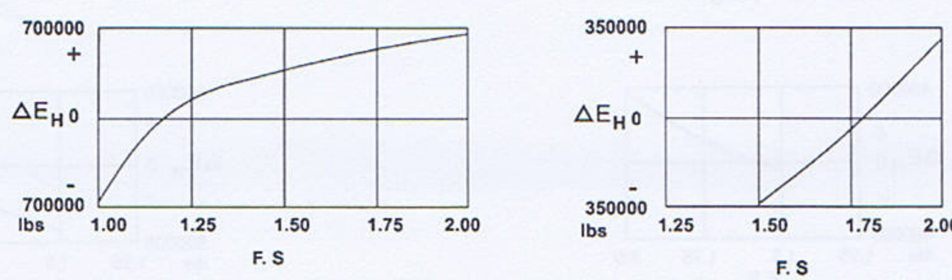

Fig. 5c: Trial Factor of Safety (F.S.) versus Net Effective Force (ΔE_H) to obtain the value at which $\Delta E_H=0$

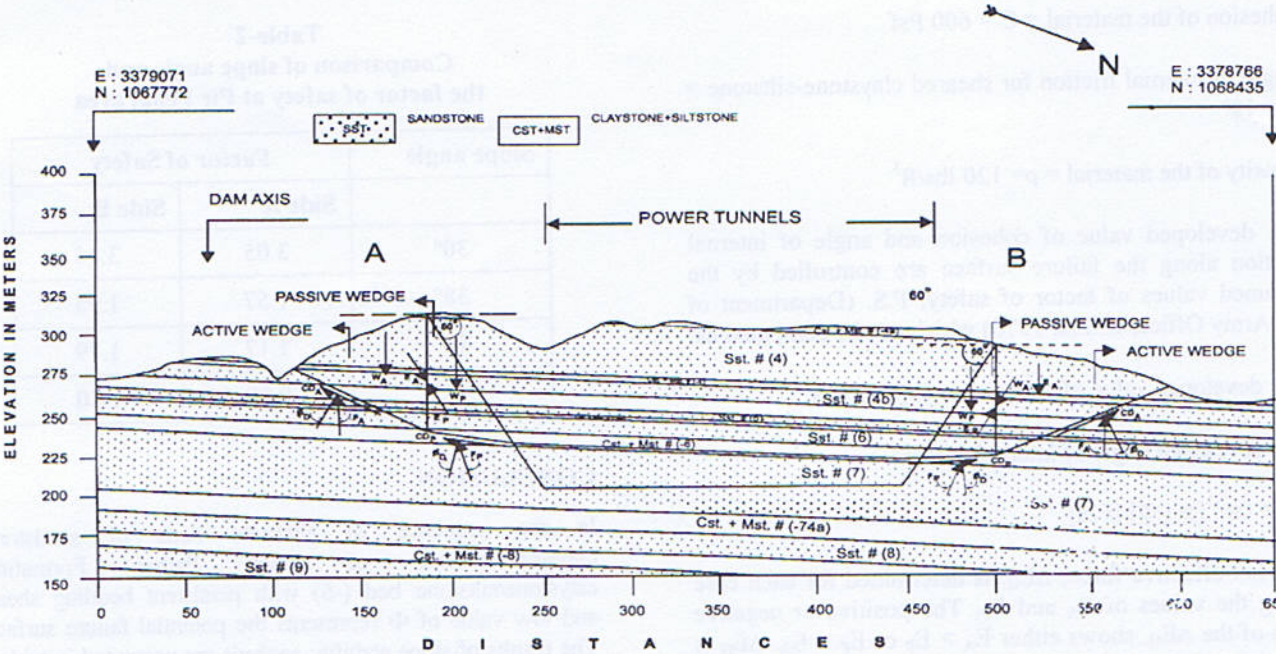

Fig. 6a: Cross-section showing lithological details of the Dhok Pathan Formation at Pir Pehai area. Active and Passive Wedges are also shown

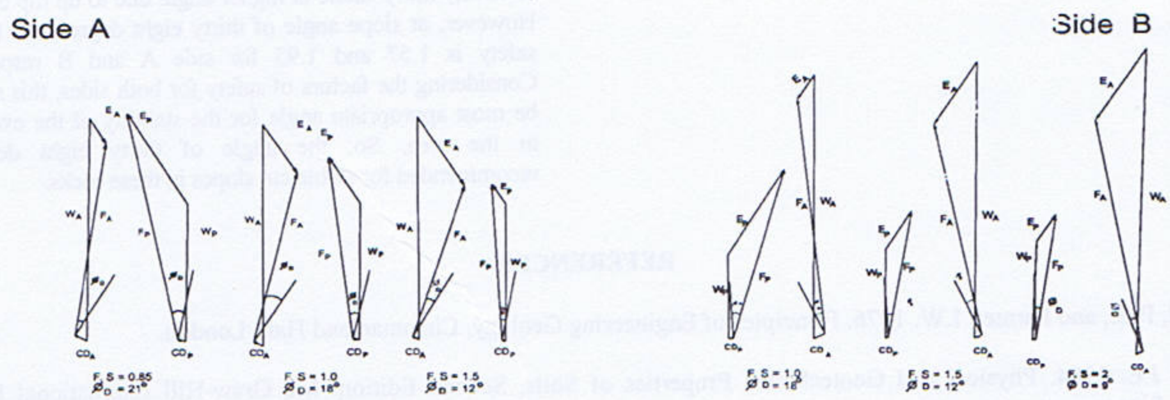

Fig. 6b: Force polygons for slope angle 60° showing the weights and the frictional forces of Active and Passive Wedges

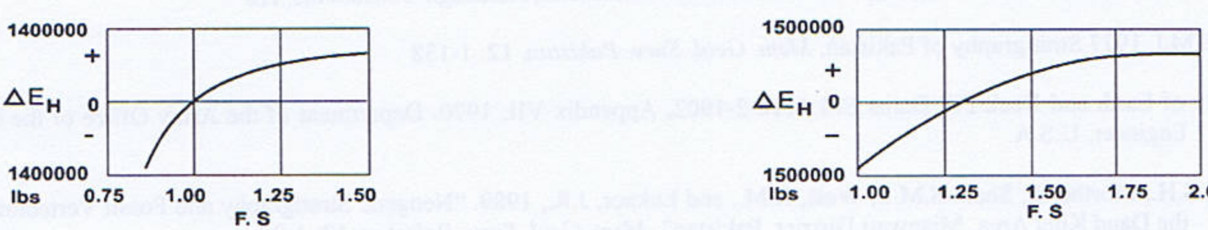

Fig. 6c: Trial Factor of Safety (F.S.) versus Net Effective Force (ΔE_H) to obtain the value at which ΔE_H=0

Cohesion of the material = C = 600 Psf

Angle of internal friction for sheared claystone-siltstone = $\Phi = 18°$

Density of the material = ρ= 120 lbs/ft^3

The developed value of cohesion and angle of internal friction along the failure surface are controlled by the assumed values of factor of safety, F.S. (Department of the Army Office, U.S.A, 1970) which can be computed as

The developed value of cohesion = C_D = C/F.S.

The developed angle of internal friction

$\Phi_D = \tan^{-1}[\underline{\tan \Phi}]\ [F.S]$

The net effective force, ΔE_H, is determined for each case using the values of E_A and E_P. The positive or negative sign of the ΔE_H, shows either $E_A > E_P$ or $E_P > E_A$. ΔE_H is plotted versus trial factors of safety to obtain the value at which ΔE_H is zero (Figs. 3c, 4c, 5c and 6c). This is the factor of safety required to balance the forces, E_A and E_P for sliding surface being analyzed. Results are presented in the table 2.

Table-2
Comparison of slope angle and the factor of safety at Pir Pehai area

Slope angle	Factor of Safety	
	Side A	Side B
30°	3.05	3.45
38°	1.57	1.95
45°	1.17	1.79
60°	0.99	1.30

CONCLUSION

In the sequence of alternate beds of sandstone, claystone/siltstone of Dhok Pathan Formation, claystone/siltstone bed (-6) with persistent bedding shears and low value of Φ represents the potential failure surface. The results of slope stability analysis are presented in table-2 showing factors of safety for side A and B against different slope angles. The table indicates that values of factors of safety are gradually decreasing as the slope angle is getting higher. This effect is more pronounced for side A due to down dip direction as compared with side B which is relatively more stable at higher angle due to up dip direction. However, at slope angle of thirty eight degree, the factor of safety is 1.57 and 1.95 for side A and B respectively. Considering the factors of safety for both sides, this seems to be most appropriate angle for the stability of the excavation in the area. So, the angle of thirty eight degree is recommended for stable cut slopes in these rocks.

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