The
GEOLOGICAL BULLETIN
of the
PUNJAB UNIVERSITY

Number 28 *December*, 1993

CONTENTS

		Page
Stratigraphic Analysis of the Permo-Triassic and Lower-Middle Jurassic Rocks from the "Axial Belt" Region of the Northern Balochistan, Pakistan	*By Muhammad Anwar Ali Nasir Fatmi and Iqbal Hussain Hyderi*	1
Newly Discovered Upper Bajocian Ammonites from Loralai Formation, Northern Balochistan, Pakistan	*By Muhammad Anwar Ali Nasir Fatmi and Iqbal Hussain Hyderi*	21
A Preliminary Interpretation of Microfacies, Deposition and Diagenesis of Kawagarh Formation at Borian Abbottabad-Nathiagali Road, Hazara, Pakistan	*By Naveed Ahsan Mohammad Nawaz Chaudhry Munir Ghazanfar and Shahid Jamil Sameeni*	30
Environment of Deposition and Diagenesis of Pirkoh Limestone and Marl Member Near D.G. Khan Cement Factory, D.G. Khan, Pakistan	*By Saleem Akhtar Muhammad Nawaz Chaudhry Naveed Ahsan and Abdul Qadir Baloch*	41
Clay Mineralogy of the Danintain Mudrocks at Cove, East Berwickshire Scotland	*By Ghulam Nabi and Juliane E. Andrews*	50
Preliminary Sedimentology of the Bibai Formation, Ahmadun Gogai Area, Ziarat District, Balochistan	*By Akhtar Mohammad Kassi Abdul Salam Khan Din Mohammad Kakar Amjad Rashid Qureshi Khadim Hussain Durrani and Hassan Khan*	73
The Loralai Limestone Facies Around Qila Saifullah and Rud Malazai Areas, Northeast Balochistan	*By Akhtar Mohammad Kassi and Abdul Salam Khan*	81
Water and Soil Chemistry from the Bat Kas Drainage System of Battal Area along the Karakorum Highway (KKH), District Mansehra, NWFP, Pakistan	*By Shahzad Aleem Syed Alim Ahmad Fayaz ur Rehman and Mohammad Farooq*	100
Geology and Geochemistry of Battal Area Along the Karakorum Highway (KKH) District Mansehra NWFP, Pakistan	*By Shahzad Aleem Shafeeq Ahmad Syed Alim Ahmad and Fayaz ur Rehman*	104
A Petrified Palm Wood Palmoxylon cf. Sinuosum Sahni from the Chinji Formation (Lower Siwalik) District Chakwal, Potwar, Punjab, Pakistan	*By Akhlaq Ahmad Bhutta and Sarfraz Ahmad*	116

Geol. Bull. Punjab Univ. 1993, 28, 1—20

STRATIGRAPHIC ANALYSIS OF THE PERMO-TRIASSIC AND LOWER-MIDDLE JURASSIC ROCKS FROM THE "AXIAL BELT" REGION OF THE NORTHERN BALOCHISTAN, PAKISTAN

By

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Abstract : *Stratigraphy of the Mesozoic rocks of the Northern Axial Belt region of Balochistan is redefined. These studies indicate that the Middle Permian carbonate rocks containing* **Shichanella passalensis** *Gubler,* **Parafusulina wordensis** *Dunbar and Skinner occur as exotic blocks (Olistostomes) in the Triassic rocks of Muslim Bagh, Wulgai and Gwal sections.*

The newly proposed Khanozai Group is divisible into two formations. The lower newly proposed Gwal Formation is of Early Triassic age and contains **Meekoceras, Owenites, Anakashmirites, Anasibirites, Stephenites, Durqatites, Hemiprionites** *(Late Middle Scythian). The overlying Wulgai Formation is of Late-Middle Triassic in age and has yielded bivalves,* **Halobia, Daonella** *and ammonites* **Cladescites, Jovites, Arietoceltites Anatomites, Juvavites, Arcestes** *of Late Triassic, while the Middle Triassic is based on the radio-rians and conodonts with some Spiriferinid branchiopods in the Takai-Gwal section.*

The Alozai Group includes a lower Spingwar Formation divisible into three members. The Lower Member contains Lower Liassic (Hettangian) ammonites like **Discamphoceras, Waehneroceras, Alsatites, Paradosyceras.** *(Tazi Kash-Kozh Kach section). The middle one has yielded bivalves, brachiopods, corals and flat burrows. The Upprer Member is of Middle Liassic (Sinemurian and Pliensbachian) age containing ammonites like* **Juraphyllites, Oxynoticeras, Arnioceras.**

The upper Loralai Formation unit of the Alozai Group is divisible into two members. The Lower Member contains Upper Liassic (Toarcian) ammonites like **Grammoceras, Polyplectus, Phymatoceras, Protogrammoceras, Neidia** *whereas the Upper Member has yielded Middle Jurassic (Bajocian) fauna in upper part.*

INTRODUCTION

Vredenburg (1904) recognized the presence of Permian rocks on the basis of fossils considering its age to be Permian in the Wulgai area of Northern Balochistan. Williams (1959), Hunting Survey Corporation (1961), Fatmi (1977, 1984), Fatmi et al. (1986), Allemann (1979), Japanese—Pakistani Research Group (1989) and Anwar et al. (1991) have produced some work on the geology and stratigraphy of the area.

The Mesozoic strata is well exposed in the Northern Balochistan. Five stratigraphic sections of the Khanoazi and Alozai Groups were measured and studied in detail in the Takai Gwal, Wulgai, Tazi Kach (Khanozai), Zmari Tangi and Mara Tangi areas (Fig. 1). All these studies were undertaken to redefine the stratigraphic units of the Alozai Group, the Loralai limestone in terms of their lithology and age relationship. Fossils collection was also made from Qila Saifullah area. Two new names, Khanozai Group and Gwal Formation, are being introduced for the first time. The names Alozai Group of Hunting Survey Corporation (1961 and the Wulgai, Spingwar and Loralai Formations of Williams (1959) are accepted but with some modifications. The Northern Balochistan though covers the area from Gwal to Zhob (Gul Kach) in the Axial Belt (Fig. 1), the studies are, however, confined to Alozai type area, Spingwar, Loralai type area and in areas southeast and southwest of Khanozai. The fossils mentioned in this paper were identified by Dr. A.N. Fatimi, the stratigraphic sequence redefined as a result of the present studies is summarized (Fig. 2).

Late Jurassic to Cretaceous

Mona Jhal Group

Mughal Kot Formation

Parh Limestone

Goru Formation

Sembar Formation

—Disconformity—

Lower to Middle Jurassic

Alozai Group

Loralai Formation

Spingwar Formation

——Probably transitional——

Triassic

Khanozai Group

Wulgai Formation

Gwal Formation

(Base not exposed)

In this paper, Triassic to Middle Jurassic rock sequences are described.

STRATIGRAPHY

TRIASSIC

Khanozai Group

The proposed Khanozai Group of Triassic age takes its name after the town Khanozai (Lat. 30°N; Long. 67°20'E, 34J/6), 75 kilometers northeast of Quetta. Previously the Triassic sequence of this area was included in the "Alozai Group" and wrongly confused and mapped in the Gwal and adjoining sections with the Parh Group by Hunting Survey Corporation (1961). The Triassic outcrops are widely distributed south of Gwal, southwest of Khanozai, in the Wulgai and around the Muslim Bagh areas. Around the Muslim Bagh Ophiolitic Complex, the Triassic rocks are associated in a jumbled mess of rocks of different ages. Dark gray to brecciated, fusulinid limestone bodies occur within the Triassic shales in the Wulgai Nala and Gwal sections as olistoliths (Exotic Blocks) and are not in situ. The rock samples of this limestone with fossils were sent to Flugel of Germany who identified the fauna like *Shichanella passalensis* Gubler, *Parafusulina wordensis* Dunbar and Skinner indicating Middle Permian age. The newly introduced Khanozai Group includes the following two formations in ascending order :—

2.	Wulgai Formation	Middle-Late Triassic
1.	Gwal Formation	Early Triasisc

These two formations are separated by a gritty limestone unit containing Spiriferinid brachiopods, and Crinoidal debris (Middle Triassic) mainly with limestone boulders marking disconformity. The whole Triassic sequence is faulted/thrusted and is repeated both in the lower and upper limits in the Takai-Gwal and Wulgai areas. The upper contact with the Sembar Formation is thrusted and the Cretaceous sequence above the thrust is overturned. The complete stratigraphic section of Triassic formations (Wulgai) could not be measured due to complicated structure. The aggregate thickness of the group is more than 530 m in the Taki-Gwal section.

The base of the Khanozai Group is not exposed. Its upper contact is not well known and is probably transitional as suggested in Tazi Kach-Kozh Kach section. On the faunal basis, the age of the Khanozai Group is considered to be Triassic. The fossils recorded from the Gwal Formation (Takai-Gwal section) include mainly ammonites (Figs. 1 - 3) and from the Wulgai Formation are radiolarian, conodonts (Japanese-Pakistani Research Group, 1989) brachiopods, bivalves and ammonites (Figs. 2 - 3). This group with clastic and carbonate turbidites is of deep water origin and is repeated several times due to structural complications around the Muslim Bagh-Khanozai Ophiolitic Complex.

GWAL FORMATION

The name Gwal Formation is introduced from the village Gwal, 60 kilometers northeast of Quetta. The main Lower Triassic outcrop occurs south and southwest of Gwal (south of Quetta-Muslim Bagh Road) constituting low hills faulted against Alozai and Mona Jhal Groups in Takai-Gwal sections.

This formation is composed of variegated shale and limestone interbeds with marl intercalations and occasional mafic intrusions in the Takai Gwal area (Fig. 3). The shale is dark gray to olive, maroon, greenish gray,silty, non calcareous, friable and fissile. The limestone is gray to dark gray, weathering brownish gray, micritic, dense, platy to thin bedded and, at places, it is dolomitized and sandy with some calcite veins and including diabase flow. The formation contains olistostmes (Exotic Blocks) of Permian limestone containing brachiopods, corals etc.

The base of the formation is not exposed. It is more than 350 m thick in the Takai-Gwal section. Its upper contact with the Wulgai Formation is sharp with fossiliferous limestone (conglomeratic) at the base in some areas. On the basis of ammonites including *Meekoceras*, *Owemnites*, *Anakashmiries*, *Anasibirites*, *Durgaites*, *Hemipriontes* etc the age of the formation is Early Triassic (Late-Middle Scythian). The Gwal Formation includes a thin to mediu bedded micritic limestone unit in the upper part and is correlative with Narmia and Mittiwali Members of the Mianwali Formation of the Salt Range.

WULGAI FORAMTION

The name Wulgai Formation is here adopted for the Middle to Late Triassic rocksand is derived by Williams (1959) after the Wulgai village (Lat. 30°58′N ; Long. 67°31′E, 34J/6) near Khanozai.

This formation consists of shale with limestone and siltstone interbeds with dense, thin to medium bedded limestone at the base (conglomeratic) in the Takai-Gwal (Fig. 3), Tazi Kach (Fig. 4) and Wulgai areas. The shale is pruple, olive, brownish gray to greenish gray, well bedded, argillaceous, hard, silty, splintery, non-calcareous, siliceous, laminated and fissile. It contains calcite veins along the bedding planes and is fossiliferous. The limestone is gray to dark gray, weathers brownish gray, micritic, tufaceous, platy to thinly bedded siliceous, fine grained, hard and at places recrystallized and sparitic with occasional siltstone beds.

The thickness of the formation is 180m in the Takai-Gwal section. Its lower contact with the Gwal Formatoion is sharp with fossiliferous limest oneat the base and the upper contact is faulted thrusted against Sembar (Goru ?) Fomation. The fossils that include radiolarian and conodonts (Japanese micro faunal studies) with some Spiriferineid brachiopodsindicating Middle Triassic age occur in the basal limestone unit and upper shale and limestone unit has yielded *Halobia*, *Daonella* (Bivalves) and ammonites like *Cladescites, Jovites, Arietocel-tites,Anatomites, Juvovites, Arcetes* indicating Late Triassic (Carnian-Norian) age in Takai-Gwal section. Hence, the ge of the formation is considered Middle to Late Triassic. The Wulgai Formation is correlative with shallow water near-shore clastic and dolomitic sequences namely Tredian and Kingriali Formations of the Salt Range.

LOWER TO MIDDLE JURASSIC

Alozai Group

The Alozai Group takes its name from the Alozai Village (Lat. 30°38′N; Long.68°38′E 39,B/10 east-southeast of Qila Saifullah in the Zhob River Valley This group is widely distributed in the folded belt south of Qila Saifullah, Zhob Road and north of Loralai, south of Muslim Baghand Khanozai in the "Calcareous Belt' of Hunting Survey Corporation (1961). The Early to Middle Jurassic calcareous rocks belong to the Aozai Group of Hunting Survey Corporation (1961) which is reedefined here from the type locality and adjoining areas of Spingwar (northeast of Loraalai) and Kozh Kach Tazi Kachs (outheast of Khanozai) areas. The authors consider that the Alozai Group should cover rocks of Lower to Middle Jurassic age which are separated by an unconformity with rocks of Late Jurassic to Cretaceous age (Sembar Formation of Mona Jhal Group) The Alozai Group consists of the following two formatoions in ascending order :

2) Loralai Formation	Early to Middle Jurassic
1) Spingwar Formation	Early Jurssic (Pre-Toarcian)

The aggregate thickness of the Alozai Group is more tan 1025 m in the Northern Balochistan. base is not exposed. This group is overlain unconformably by the lower member of the Sembar Formation of Mona Jhal Group. The lower member is a variegated(red. gray, green), siliceous shale (splintery), dense, siliceous limestone and calcarous siltstone with radiolarians and rare belemnites and *Laevyptychus* of Late Jurassic age followed by softer green,gray shale of upper member. The age of this group is considered to range from Early Jurassi to Middle Jurassic on the basis of Lower Liassic cephalopods from the Spingwar Formation and Toarcian fossils from the lower part of Loralai Formation respectively.

SPINGWAR FORMATOION

The name Spingwar Formattion was introduced by Williams (1959) for the Early Jurassic strata with a type section at Spingwar, north of Zmari Tangi, about 35 Kilometers northwest of Loralai (Lat. 30°32′N ; Long-68°19′16″E, 39B/6.

The formation consists of the following three members :—

3. Upper Member
2. Middlle Member
1. Lower Member.

Lower Mmber

It consists of shale with concretions and subordinate limestone. The shale is gray, green, fissile with siliceous,ferruginous concretions. The limestone is gray and micritic. It is exposed mainly in Kozh Kach-Tazi Kach sections where Hettan-gian (Lower Liassic)ammonites include *Waehneroceras, Discamphoceras, Alsatites, Paradosycerass.* This member is not exposed in the type area of Spingwar (Zmari Tangi and Mara Tangi sections) where the cores of anticlines consist of the Middle Member only.

Middle Member

This member consists of limestone with subordinate thin calcareous shale partings. It is gray to dark gray, weathers brown, thin to medium bedded, lithographic, micritic argillaceous, muddy and hard. It contains bivalves (Pectenoids), corals (*Montlivaltia*' flat worm burrows (Plate 1, Fig. 1') brachiopods (*Spiriferina, Terebratula*) and ammonites (*Boucaulticeras*, Plate 3, Fig. 2). This member forms the cores of the anticlines in the Zmari Tangi and Mara Tangi sections.

Upper Member

It consists of marl and shale with subordinate limestone. The marl is greenish gray, very pale gray, splintery and soft. Pencil-shaped weathering is common. The shale is greenish gray, maroon to purple, silty, flaky and fissile. The limestone is gray to dark gray, black, weathers brownish gray, thin to thick bedded, fine to medium grained, lithograpic, hard, muddy, marly and fossiliferous (Figs. 5 & 6). This member contains small bivalves (Ionceramids?) in dark shale and ammonits, echinoidal spines, crinoidal debris belemnites, bivalves and gastropods in limestone beds indicating Sinemurian and Pliensbachian age. The ammonites include *Juraphyllites*, *Oxynoticeras*, *Arnioceras*, *Slatterites* (Plate 3, Figs. 2a, b), *Coeloderoceras* (Plate 4, Figs. 3a, b), *Tropidoceras* (Plate 4,Figs. 4a,-b) and *Metaoxynoticeras* (Plate 4, Figs. 5a, b).

The Spingwar Formation is measured to be more than 140 m, 665 m and 215 in the Tazi Kach, Zmari Tangi and Mara Tangi sections respectively. Its lower contact with the Wulgai Formation is not well seen and is probably transitional in deeper section in Tazi Kach-Kozh Kach whereas its upper contact with the Loralai Formation is transitional. The fossils including ammonites, brachiopods, bivalve, crinoids, corals and shell fragments occur in the Zmari Tangi and Mara Tangi sections. The age is Early Jurassic (Lower-Middle Liassic) on the basis of fossils. The anticlinal cores south of Alozai and north of Loralai expose mainly upper (marl dominated) and middle (limestone dominated) members respectively (Middle Liassic).

LORALAI FORMATION

The name Loralai Formation was introduced by Hunting Survey Corporation (in Williams, 1959) after Lorali town (Lat. 33°54′N ; Long. 68°36′E, 39B/11). Zmari Tangi, 3 km northeast of Ahmaqzai Killi (Lat. 30°32′ 10″N ; Long. 68°18′ 40′E, 39B/6) is proposed as type locality.

The Loralai Formation is divisible into the following two members on the basis of lithology.

(2)	Upper Member	Mainly medium to thick bedded limestone
(1)	Lower Member	Thin to medium bedded limestone interbedded with marl and shale.

Lower Member

This member consists of limestone interbedded with shale and/or marl (Figs. 3 - 5 Plate Fig. 2). The Limestone is gray, dark gray to black, weathers dark gray, thin) to medium bedded, dense, micritic, hard, argillaceous and lithographic. Some beds are mottled and contain chert and ammonites of Toarcian age. The shale is black to dark gral splintery, papery and calcareous and is abundant in this member. The marl is greenish gray, splintery and soft.

Upper Member

This member is mainly composed of limestone with shale/marl intercalations (Figs. 3 - 5, Plate 2, Fig. 1). The limestone is dark gray weathers brownish gray, thin to thick bedded grained sublithographic and hard. It contains oolitic, pisolitic and pelletal beds at places with cherty lenses and nodules in the upper part. Some ammonite fossils of Toarcian age are present in the lower beds. Marl/shale is light gray and thinly bedded. It has a nodular uneven top limestone bed suggests an erosional unconformable surface. It forms cliffs and steep ridges.

The formation is 150 m, 250 m, and 360 m thick in the Tazi Kach, Zmari Tangi and Mara Tangi sections respectively. Its contact with the underlying Spingwar formtion is transitional and is marked by a change into a dominant soft marl and shale litihology of upper Spingwar with argillaceous limestone interbeds as contrasted to hard dense, micritic (thin to medium bedded imestone, shale and marl of Lower Member of Loralai Formation.

The contact with the overlying lower Member of Sembar Formation containing *Laevyptychus* (Mara Tangi, Plate 5, Fig. 7) is disconformable and sharp (Plate 2, Fig. 2) marked by a change in lithology and presence of a thick bed of limestone which is nodular, uneven and pitted (Plate 3, Fig. 1).

The Lower Member of the formation contains *Dactyloceras* (Plat 5. Fig. 6), *Hammatoceras*, (Plate 5, Figs. 1, 2a, b), *Grammoceras Polyplectus*, *Phymatoceras*, *Protogrammoceras*, (Plate 5, Figs. 3, 5) and *Neidia* of Upper Liassic in the ZmariTangi Mara Tangi and Khulgai Ali Khel sections and Middle Jurassic ammonites like *Lissoceras* (Plate 5 Figs. 4a, b) and *Bradfordia* in the Upper Member In adition to this, it is rich in radiolarian. The lower age limit of the formation is clearly Toarcian but its upper limit is extended upto Bajocian times on the basis of poorly preserved ammonite fauna collected by us from the Loralai and Qila Saifullah areas. This formation is correlated with the Anjiral Formation of Southern Balochistan which is a facies equivalent and not an over and underlying unit relationship as contended in Stratigraphy of Pakistan (Fatmi, 1977).

CONCLUSIONS

The present studies in Northern Balochistan lead to the follwing conclusions :

1. Exotic blocks of the Middle Permian Fusulinid limestone occur in the Wulgai and Gwal sections as olitostomes.
2. A new Khanozai Group propased far is the Triassic strata with two formation known as the Gwal (newly proposed and mulgai in the Northern Balochistan
3. The Alozai Group is redefined and includes the Spingwar and Loralai Formation of Early Middle Jurassic age.
4. The Aloazi Group is correlative with the Ferozabad Group of Southern Balochistan.
5. The Spingwar Formation is correlated with the Kharrari and Malikhore Formations of Southern Balochistan.
6. The presence of *Grammoceras*, *Polyplectus*, *Phymatoceras*, *Potogrammoceras* and *Neidia* from the Lower member of Loralai Formation fixes clearly the lower age limit to be Upper Liassc (Toarican), whereas Middle Jurassic (Bajocian) ammonites were found from the Uppe Member of Loralai Formation.
7. The Loralai Formation is the time or facies equivalent of Anjira Formation of Southern Balochistan.

ACKNOWLEDGEMENT

The authors are grateful to Prof. Dr. Aftab Ahmad Butt, Institute of Geology, Punjab University, Lahore for the critical review of the manuscript and useful suggestions.

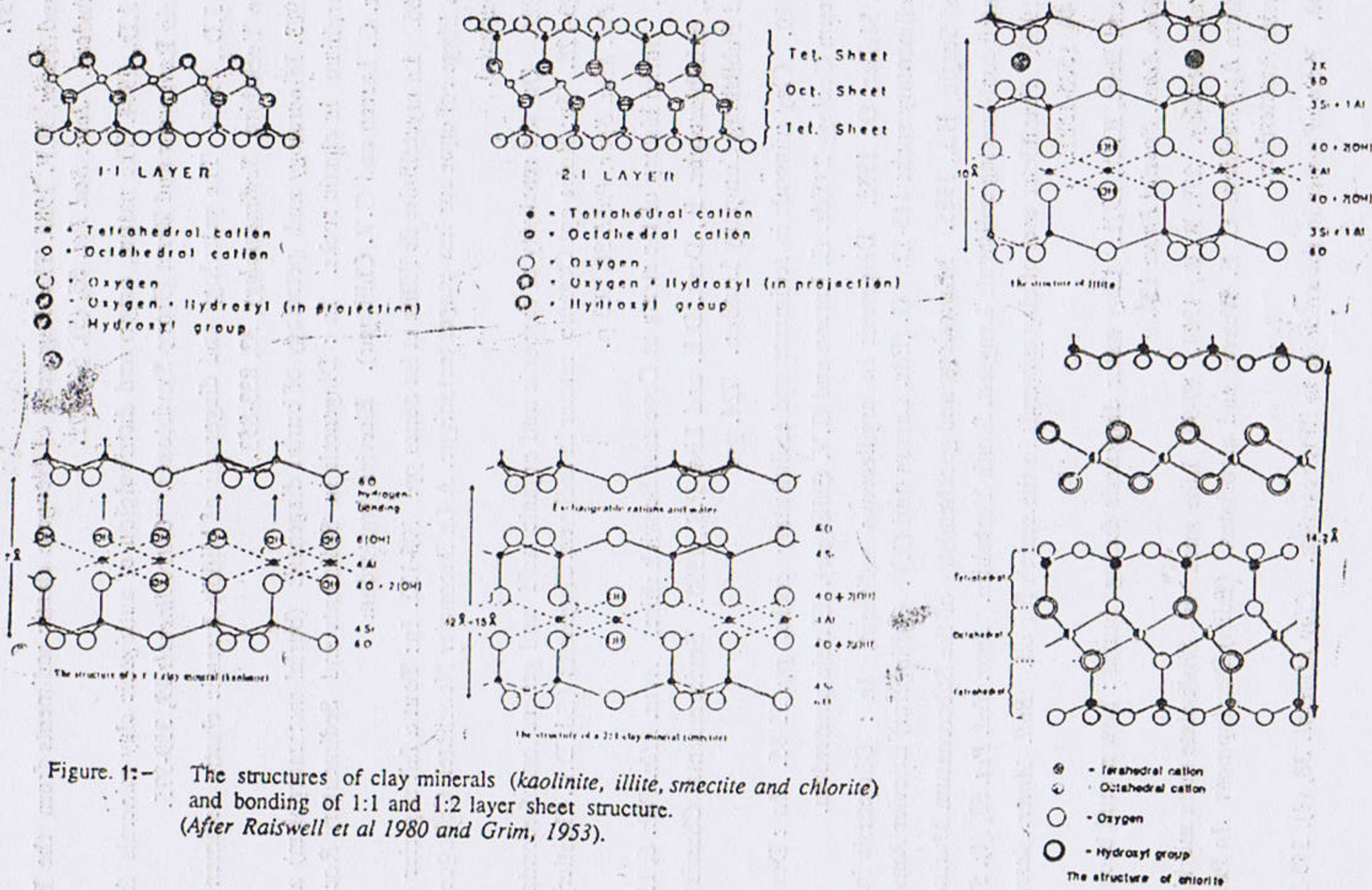

Figure. 1:- The structures of clay minerals (*kaolinite, illite, smectite and chlorite*) and bonding of 1:1 and 1:2 layer sheet structure.
(*After Raiswell et al 1980 and Grim, 1953*).

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EXPLANATION OF PLATES (1 - 5)

(All figures natural sizes)

PLATE 1

Figure 1. Horizontal worm burrows in Spingwar Formation

Figure 2. Bedding in Lower Member of Loralai Formation

PLATE 2

Figure 1. Bedding in Upper Member of Loralai Formation

Figure 2. Contact of Loralai Formation with the overlying Sembar Formation

PLATE 3

Figure 1. Uneven, pitted surface of topmost bed of Loralai Formation

Figure 2. Boucaulticeras sp.

Middle Member of Spingwar Formation, Alozai Group, Sinemurian, Wulgai Killi, Qila Saifullah Road, Northern Balochistan

Figure 3. Slatterites sp.

Upper Member of Spingwar Formation, Alozai Group,Upper Sinemurian, Wulgai Killi Qila Saifullah Road, Northern Balochistan

PLATE 4

Figures 1a, b. Echioceras sp. (Echioceratid ammonite)

Upper Member of Spingwar Formation, Alozai Group, Lower Jurasic (Upper Sine Sinemurian), Wulgai Killi, Qila Saifullah area, Northern Balochistan

Figures 2a, b. Geyeroceras sp.

Upper Member of Spingwar Formation, Alozai Group, Lower Jurassic (Pliensbachian), Wulgai Killi, Qila Saifullah area, Northern Balochistan

Figures 3a, b. Coeloderoceros sp.

Upper Member of Spingwar Formation Alozai Group, Lower Jurassic (Lower Pliensbachian), Wulgai Killi, Qila Saifullah area, Northern Balochistan

Figures 4a, b. Tropidoceras sp. indet.

Upper Member of Spingwar Formation, Alozai Group, Lower Pliensbachian, Wulgai Killi, Qila Saifullah area, Northern Balochistan

Figures 5a, b. Metaoxynoticeras aff. inrolutum. (Pompechj)

Upper Member of Spingwar Formation, Alozai Group Lower Pliensbachian, Wulgai Killi, Qila Saifullah area, Northern Balochistan

PLATE 5

Figures 1, 2a, b. Hammatoceras sp.

Lower Member of Loralai Formation, Alozai Group, Upper Toacrian, Zmari Tangi, Loralai area, Northern Balochistan

Figures 3, 5 Protogrammoceras sp. Clay cast

Lower Member of Loralai Formation, Alozai Group, Upper Toarcian, Zmari Tangi, Loralai area, Northern Balochistan

Figure 4a, c. Lissoceras sp.

Upper Member of Loralai Formation, Alozai Group, Bajocian, Mara Tangi, Loralai area, Northern Balochistan

Figure 6. Dactyloceras sp.

Lower Member of Loralai Formation, Alozai Group, Lower Toarcian, Mara Tangi Loralai area, Northern Balochistan

Figure 7. Lanvyptychus sp.

Lower part of Sembar Formation, Mona Jhal Group, Late Jurassic, Mara Tangi, Loralai area, Northern Balochistan

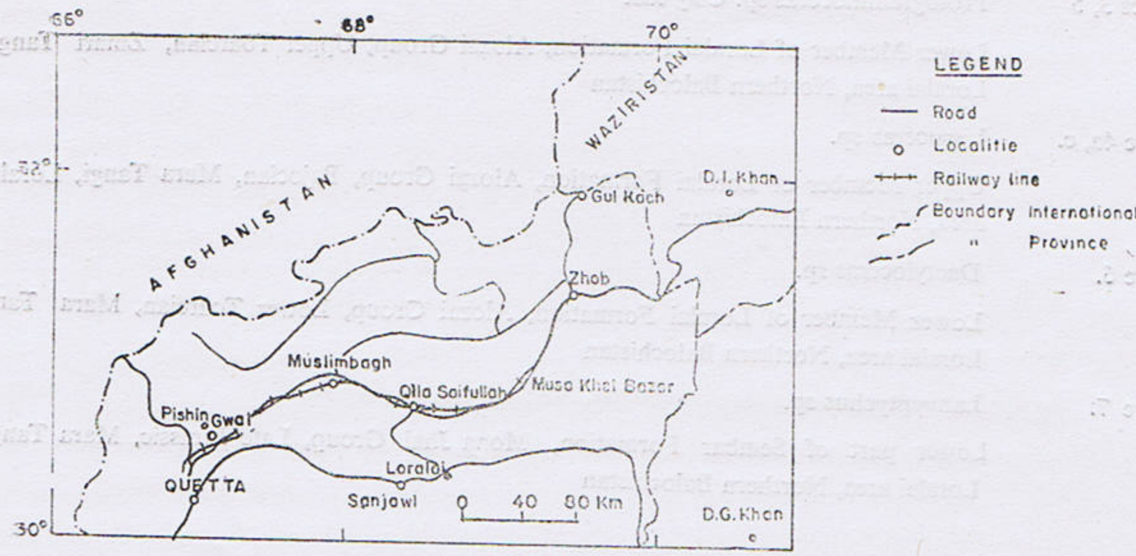


FIGURE Ia. LOCATION MAP OF NORTHERN BALOCHISTAN.

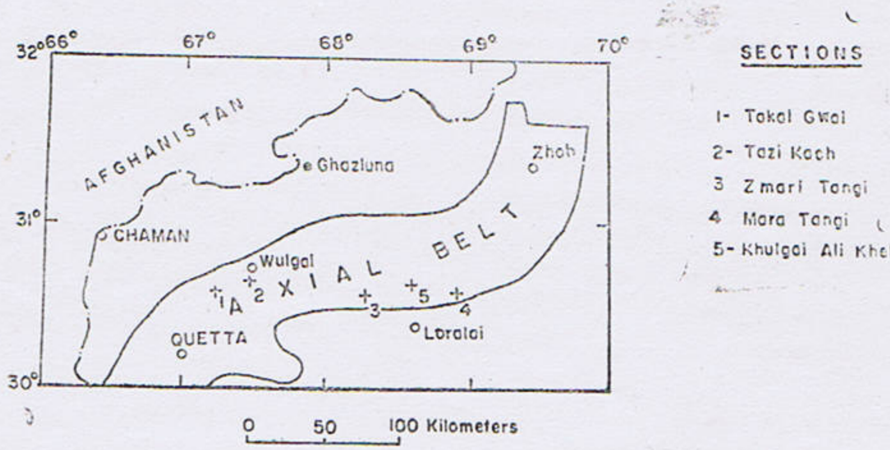


FIGURE I b. MAP SHOWING AXIAL BELT WITH SECTION LOCALITIES (+) IN NORTHERN BALOCHISTAN.

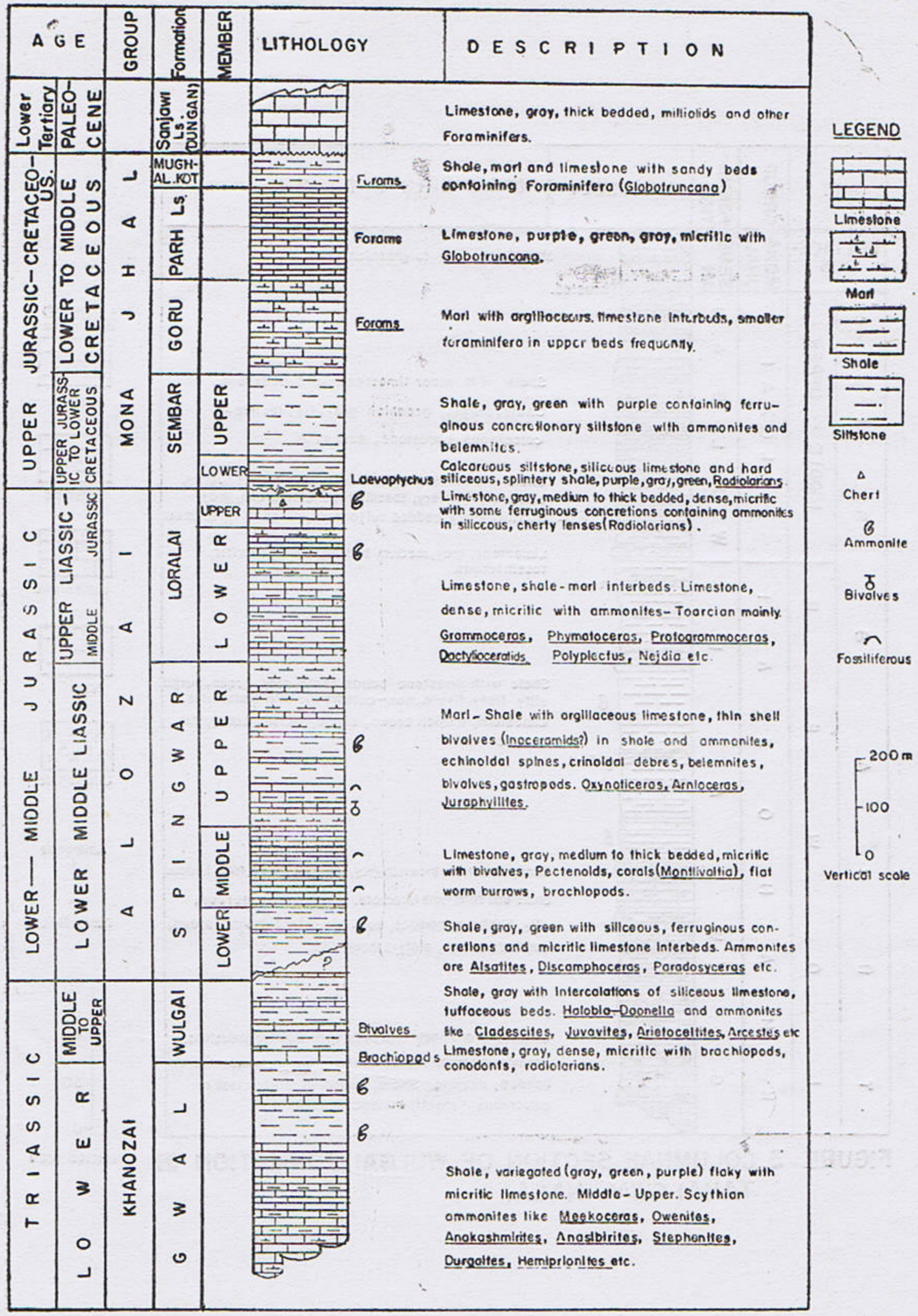


FIGURE 2. COMPOSITE MESOZOIC STRATIGRAPHIC SUCCESSION IN NORTHERN BALOCHISTAN (KHANOZAI - MUSLIM BAGH - ALOZAI - LORALAI AREAS).

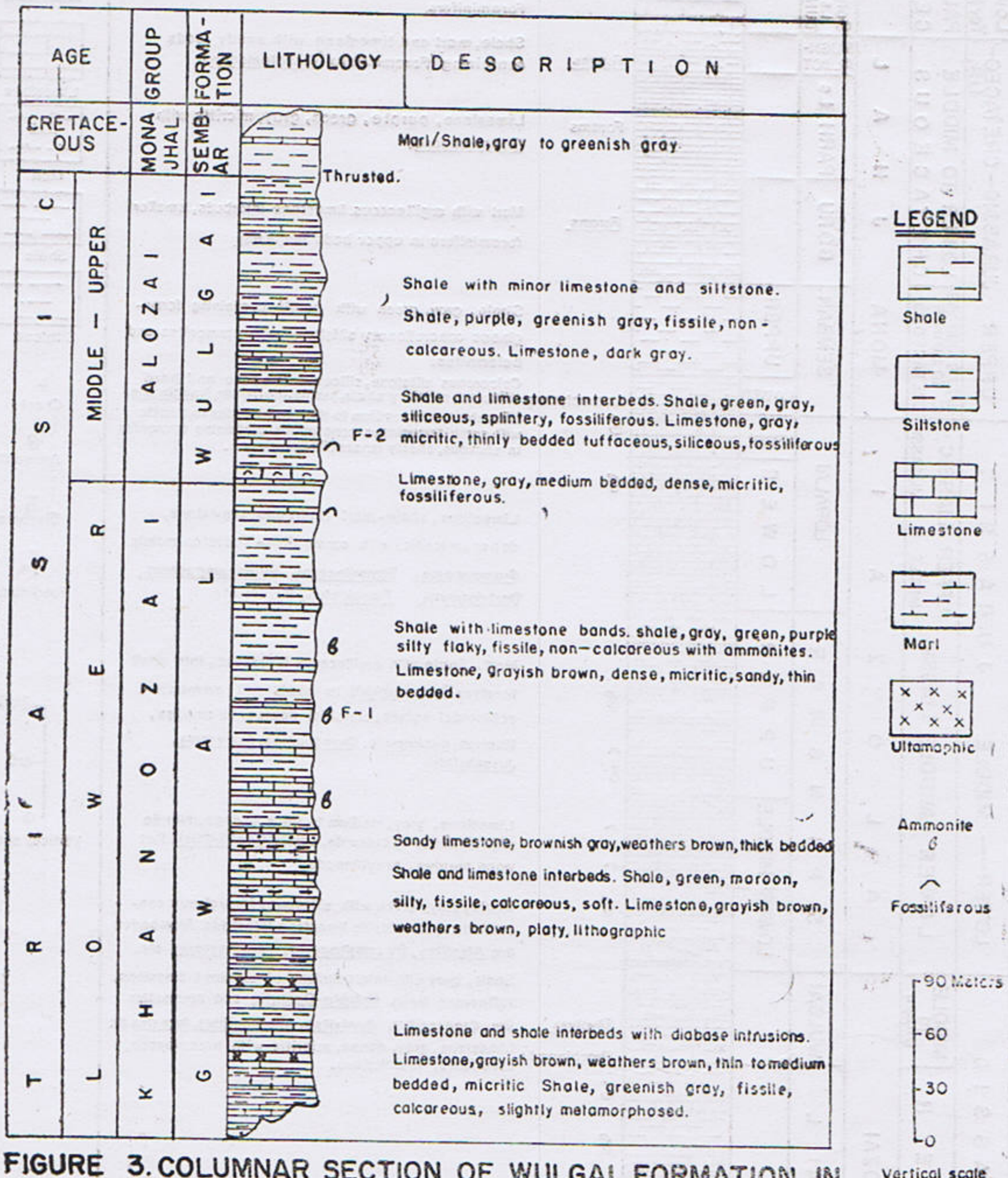


FIGURE 3. COLUMNAR SECTION OF WULGAI FORMATION IN TAKAI GWAL NALA.

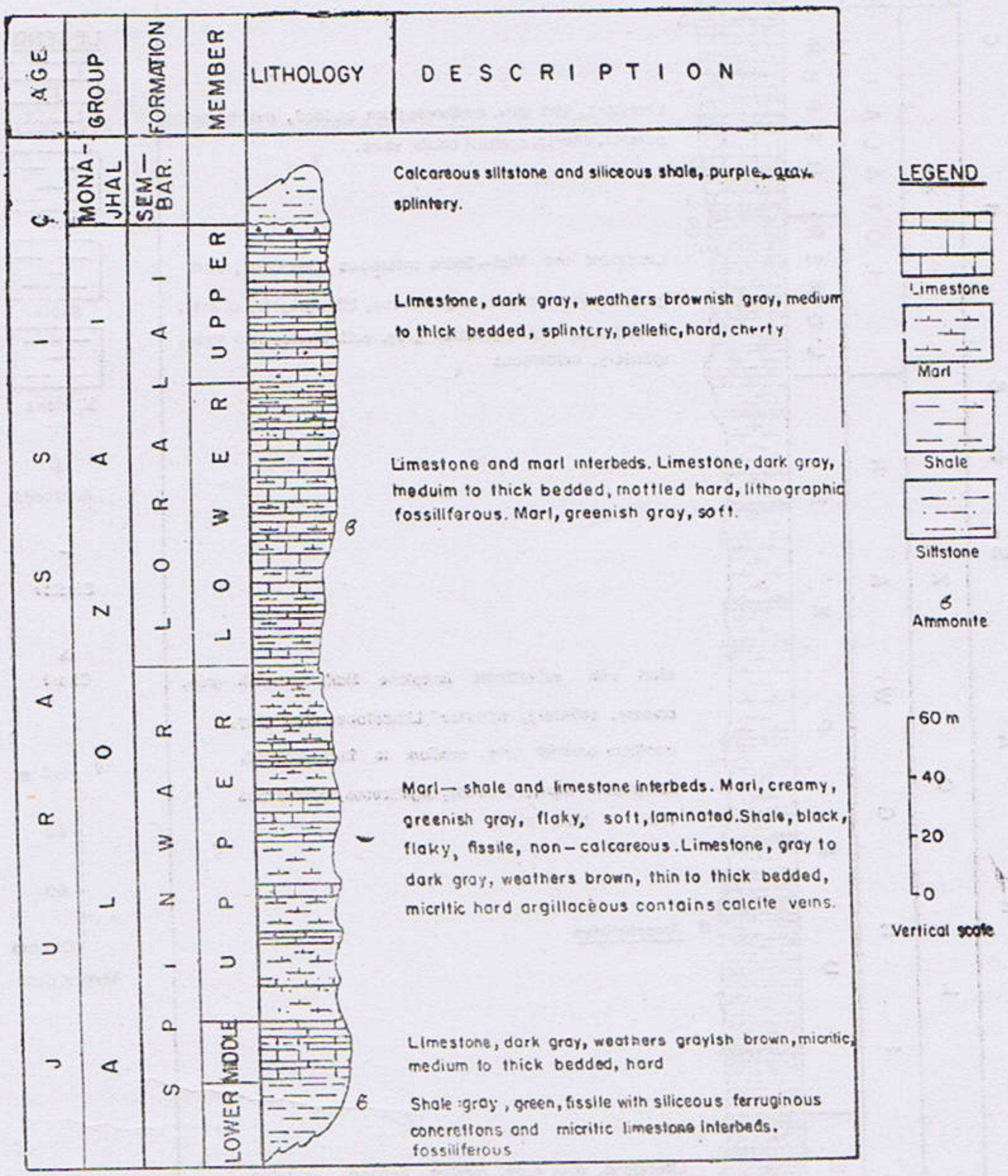


FIGURE 4. COLUMNAR SECTION OF ALOZAI GROUP AT TAZI KACH-KOZH KACH, NE OF KHANOZAI

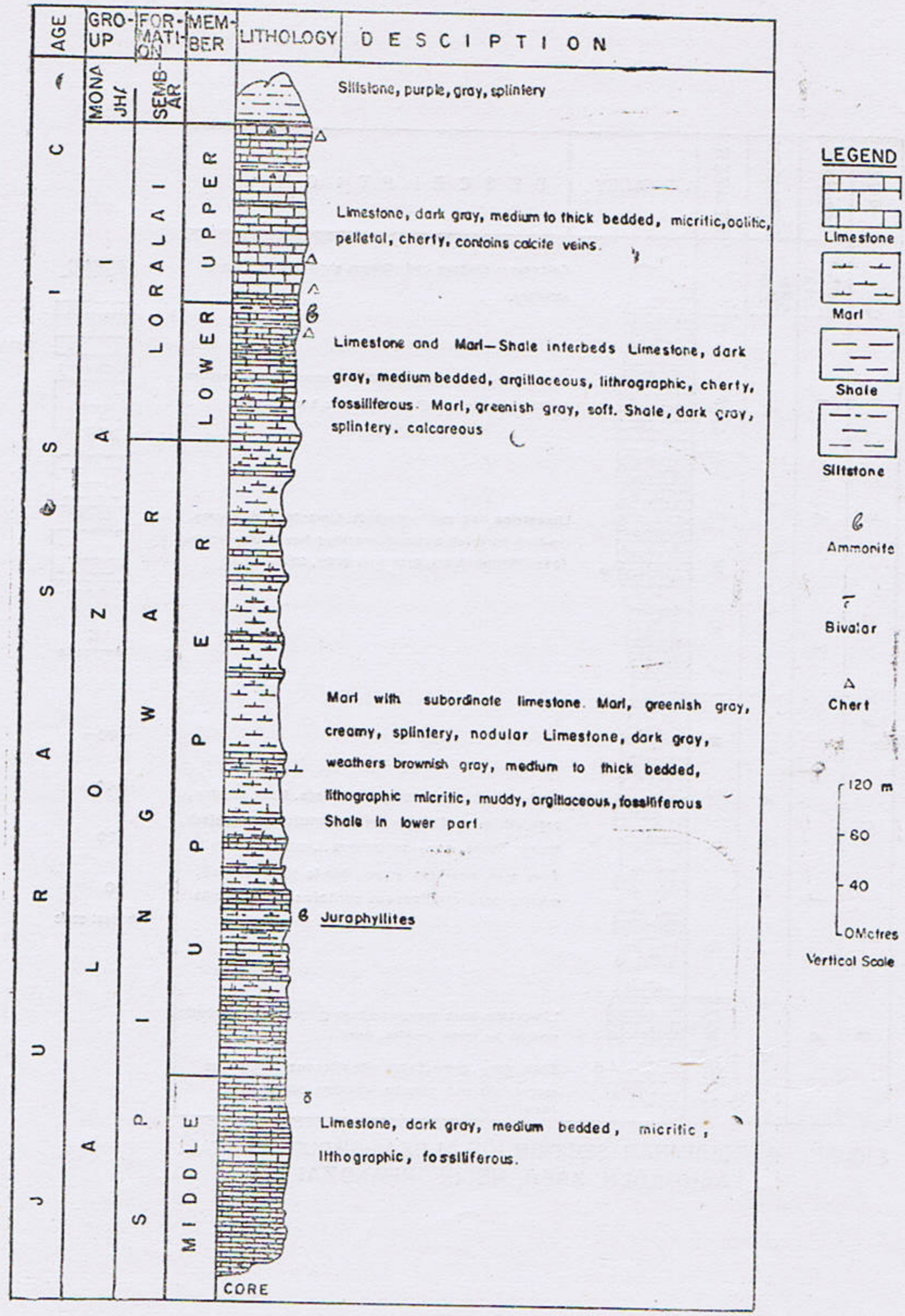


FIGURE 5. COLUMNAR SECTION OF ALOZAI GROUP AT ZMARI TANGI, 22 KM NW OF LORALAI.

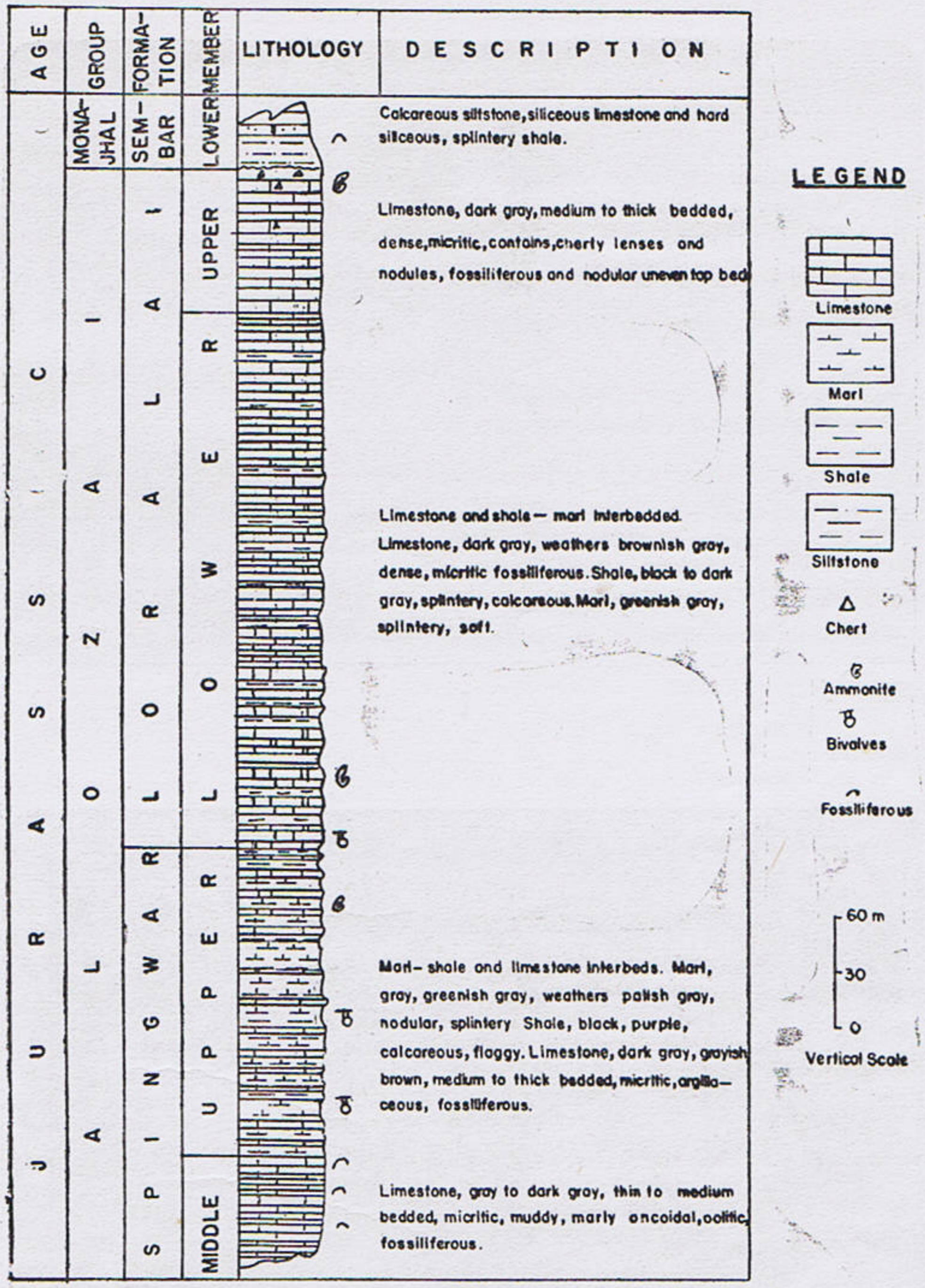
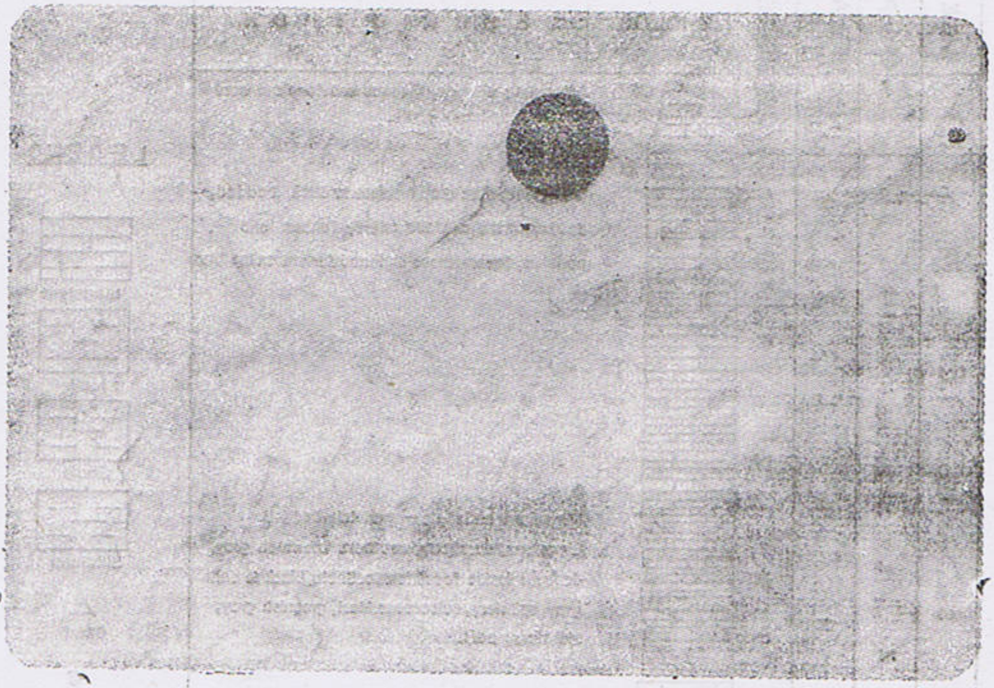


FIGURE-6. COLUMNAR SECTION OF ALOZAI GROUP AT MARA TANGI, 48 KM. NE OF LORALAI.

PLATE 1



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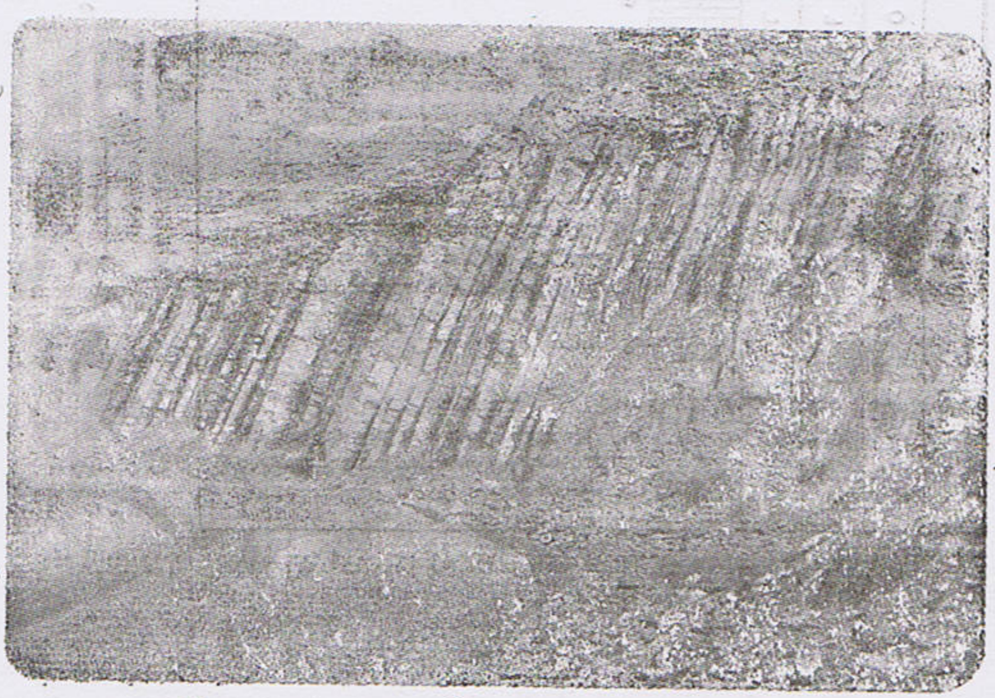

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PLATE 2

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PLATE 3

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PLATE 4

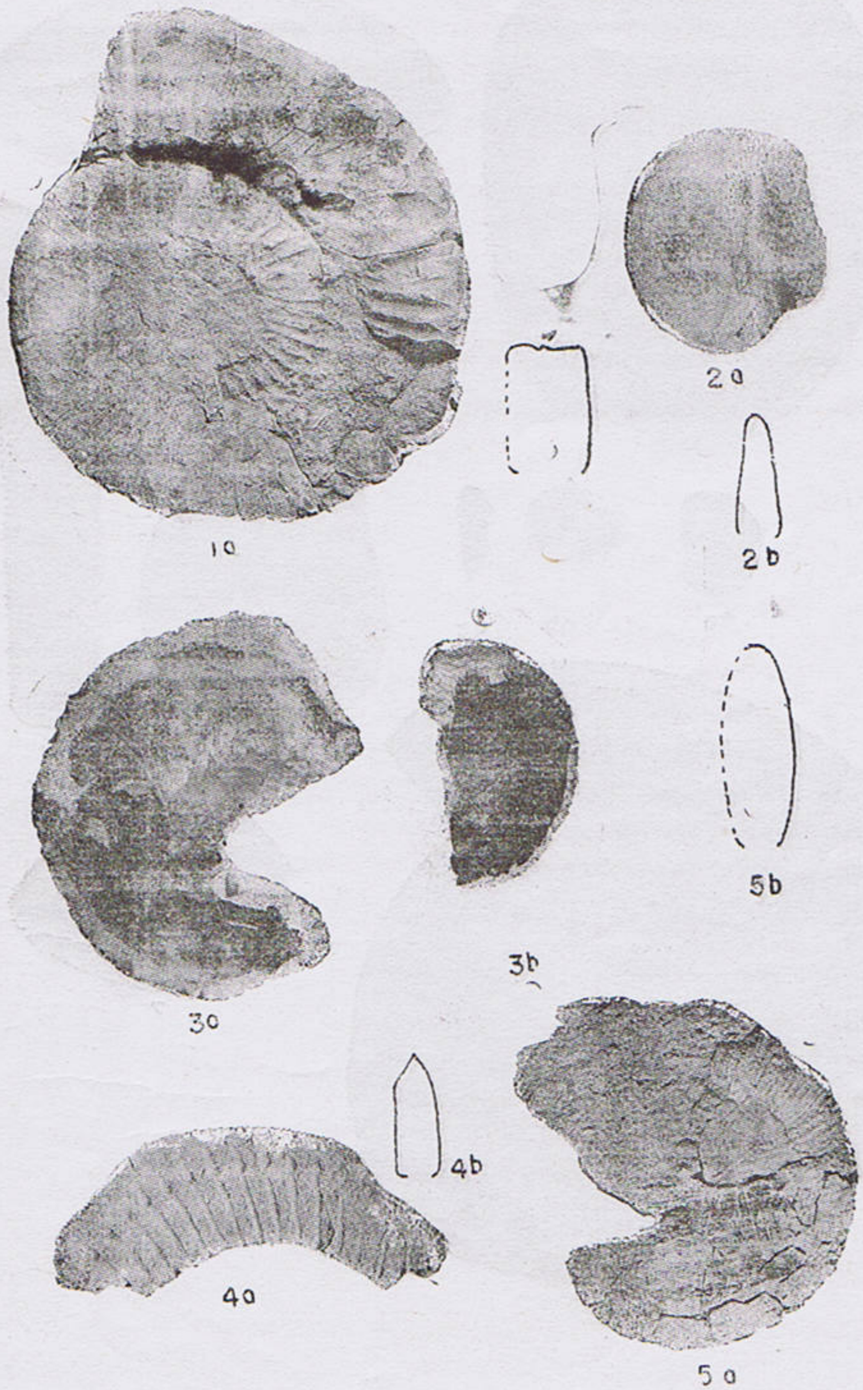
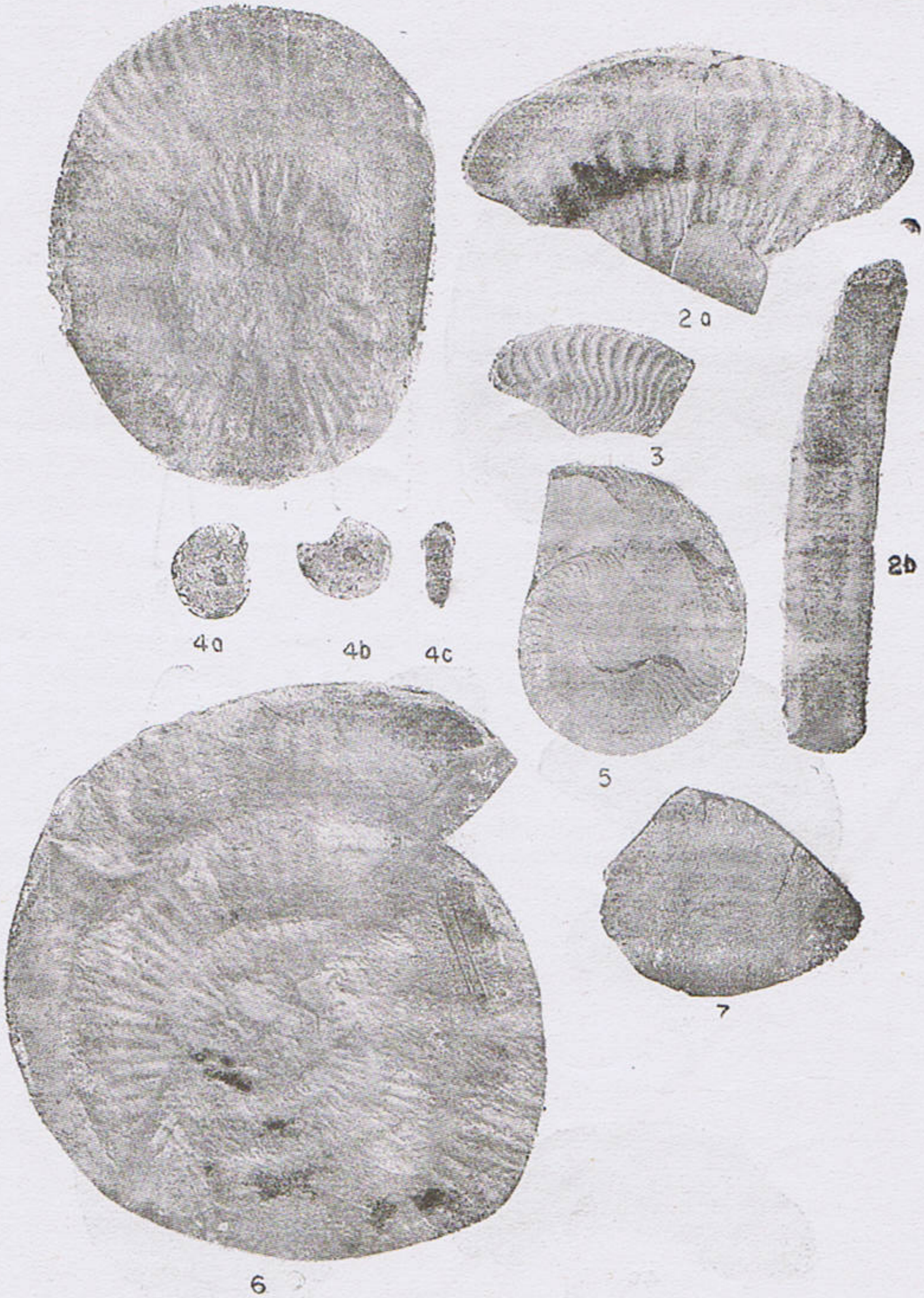


PLATE 5



Geol. Bull. Punjab Univ. 1993, 28 21—29

NEWLY DISCOVERED UPPER BAJOCIAN AMMONITES FROM LORALAI FORMATION, NORTHERN BALOCHISTAN, PAKISTAN

By

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Abstract : *Upper Bajocian ammonites have been newly recorded from the Upper Member of the Loralai Formation exposed along the Loralai-Sanjawi Road about 15 kilometers from the Loralai town. The ammonite fauna includes the diagnostic genera* **Bradfordia, Oppelia, Oecostraustes, Plaisphinctes, Leptosphinctes. Stephanoceras, Procertites, Cleistosphictes, Procerozigzag and Phylloce·-s**

Discovery of the age diagnostic ammonite fauna thus establishes precisely an age from the Lower Toarcian to the Upper Bajocian for the entire Loralai Formation.

INTRODUCTION

Upper Bajocian ammonites have been discovered from the Upper Member of the Loralai Formation exposed along the Loralai-Sanjawi Road about 15 kilometers from the Loralai town (Fig. 1). The discovery was made during the stratigraphic and biostratigraphic investigations of the Loralai area carried out in 1987-88. These fossils are of particular significance in the stratigraphy of Northern Balochistan in defining the upper age limit of the Loralai Formation. This fossil locality is about 12 kilometers in the southwest of the type locality (Zmari Tangi).

This paper is based on the stratigraphic and biostratigraphic studies and faunal collection between Loralai and Sanjawi area. All these fossils were identified by Fatmi. The study is limited to the stratigraphy of the upper part (Upper Member) of the Loralai Formation and the identification of the Upper Bajocian fauna helps us to fix the upper age limit of the Loralai Formation.

The existing knowledge on the stratigraphy, fossils and age of the Loralai Formation is very limited. Williams (1959) dated the formation to be Liassic, because the overlying Anjira Formation yielded Toarcian to Bajocian fossils and the underlying Spingwar Formation contained Liassic ammonites. The Hunting Survey Corporation (1961) assigned its lower age limit to be Late Liassic (Early Jurassic) on the basis of the most diagnostic fossils without defining the upper age limit. Fatmi (1977) considered its age to be Early Jurassic without any sound basis. Anwar et al. (1991) gave an age from Late Liassic upto Bajocian (Middle Jurassic) on the basis of fauna. Fatmi et al. (1993) redefined the stratigraphy of the area and correlated the Loralai Formation with the Anjira Formation (Southern Balochistan). The authors considered that the both formations are a time or facies equivalent and do not overlie each other as contended in the Stratigraphy of Pakistan (Shah, 1977). They also recorded that its lower age limit is Toarcian and the upper limit is extended upto Bajocian. New fauna reported in this paper confirms the upper age limit of the Loralai Formation to the Upper Bajocian (Middle Jurassic) which age was doubtfully determined earlier.

The stratigraphic sequence of the region is summarized as below :—

MONA JHAL GROUP

Sembar Formation
(Late Jurassic)

Variegated (red, gray, green), siliceous shale (splintery), dense, siliceous limestone and calcareous siltstone with ammonites, belemnites and readiolarian.

———disconformity———

ALOZAI GROUP

Loralai Formation (Lower-Middle Jurassic)
(250—360 m)

Upper Member
Middle Jurassic (Upper Bajocian)

Limestone with marl/shale intertions. Limestone; light gray to dark gray, creamy, thin to thick bedded, micritic, dense with ammonites.

Lower Member
Lower Jurassic (Toarcian)

Limestone interbeds with shale/marl. Limestone; gray, dark gray to black, thin to medium bedded, micritic. Shale; black to dark gray, splintery, Calcareous Marl ; greenish gray, soft. It contains ammonites.

———Transitional contact———

Spingwar Formation (Lower Jurassic)
(215—665 m)

Upper Member (Sinemurian-Pliensbachian)

Marl and shale with limestone intercalations. Marl ; greenish gray, splintery, soft. Shale; green greenish gray, maroon to purple, silty, flaky, fissible. Limestone; gray to dark gray, black, thin to thick bedded, fine to medium grained, muddy, marly. It contains ammonites, bivalves, gastropods.

Lower Member (Sinemurian)

Limestone with calcareous shale partings. Limestone; gray to dark gray, thin to medium bedded, fine grained, argillaceous, muddy. It contains bivalves, corals, brachiopods and ammonites. (Base not exposed).

STRATIGRAPHY OF THE LORALAI FORMATION

The Loralai Formation is divided into an Upper Member and a Lower Member on the basis of lithology.

Lower Member

It consists of limestone with interbeds of shale and marl. The limestone is gray, dark gray to black, weathers dark gray, thin to medium bedded, dense and fine grained with some mottled bedsand chert. The shale is dark gray to black, calcareous and splintery. Marl is greenish gray and soft. The fossils recorded earlier contain ammonites that include *Nejdia* sp., *Dactyloceras* sp., *Proteogrammoyeras* sp., *Grammoceras* sp., *Polyplectus* sp., *Phymatoceras* sp., and *Hammatoceras* sp dating clearly its lower age limit to be Toarcian (Early Jurassic).

Upper Member

It consists of limestone with marl/shale as partings. The limestone is dark gray, weathers brownish gray, medium to thick bedded, micritic with oolitic and pelletal beds and cherty lenses and nodules. The upper beds of this member between

Loralai and Sanjawi is creamy, chalky white, light gray, micritic and dense limestone interbedded with rubbyl, marly limestone and marl (Figs. 2a - b). These beds are richly fossiliferous and contains brachiopods, bivalves and ammonites. The ammonites include *Bradfordia* sp. (Plate 1, Fig. 1), *Oppelia* sp. (Plate 1, Figs. 2, 14), *Oecostraustes* sp. (Plate 1, Fig. 3), *Planisphinctes* sp. (Plate 1, Fig. 4), *Leptosphinctes* sp. (Plate 1, Figs. 5, 7 ; Plate 2, Figs. 2a - b), *Stephanoceras* sp. (Plate 1, Figs. 6a - b, ; 11a, b), *Precertites* sp. (Plate 1, Figs. 8, 12, 13, 15, 16), *Cleistosphinctes* sp. (Plate 1 Figs. 1, 10), *Phylloceras* sp. (Plate 2, Figs. 1a - c) and *Procerozigzaq* sp. (Plate 2, Figs. 3a-b) that indicate Upper Bajocian age.

The thickness of the formation ranges from 250 m (Zmari Tangi section) to 360 m (Mara Tangi section). The underlying contact with the Spingwar Formation is transitional and the overlying contact with the Sembar Formation is disconformable and sharp. The age of the formation clearly ranges from Lower Toarcian to Upper Bajocian on the basis of fauna collected during field work.

CONCLUSIONS

Newly discovered ammonite fauna recorded from the upper beds of the Loralai Formation enables the authors to determine the upper age limit of the Loralai Formation to be Upper Bajocian (Middle Jurassic).

ACKNOWLEDGEMENT

The authors are grateful to Prof. Dr. Aftab Ahmad Butt, Institute of Geology, Punjab University for the critical review of the manuscript and useful suggestions. The authors are also thankful to Mr. Abdul Majeed for drafting the illustrations.

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EXPLANATION. OF PLATES (1—2)

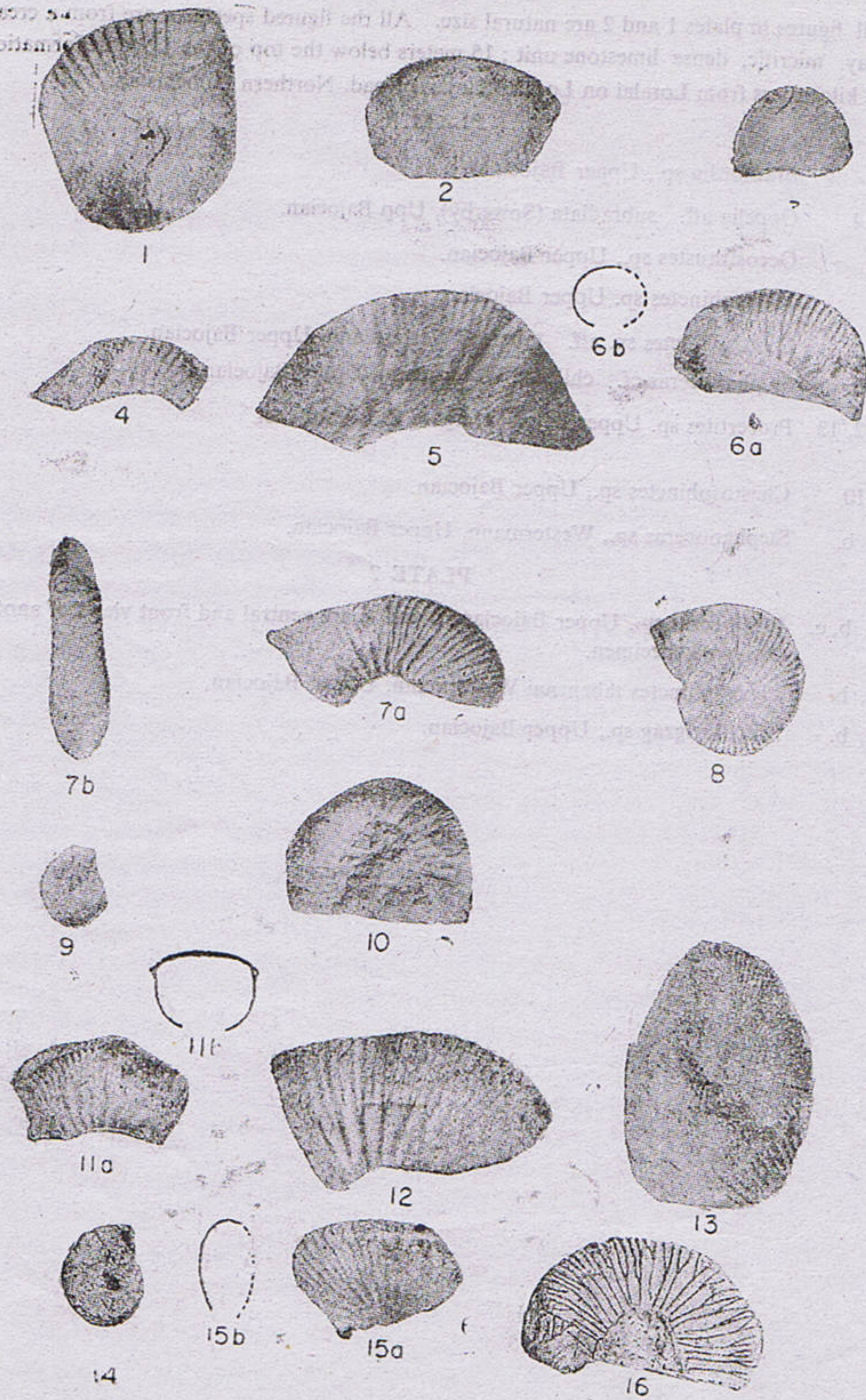
NOTE All figures in plates 1 and 2 are natural size. All the figured specimen are from a creamy, light gray, micritic, dense limestone unit ; 15 meters below the top of the Loralai Formation; about 15 kilometers from Loralai on Loralai-Sanjawi Road, Northern Balochistan.

PLATE 1

Figure 1.	Bradfordia sp., Upper Bajocian.
Figures 2, 14.	Oppelia aff. subradiata (Sowerby), Upp Bajocian.
Figure 3.	Oecostraustes sp., Upper Bajocian.
Figure 4.	Planisphinctes sp. Upper Bajocian.
Figure 5, 7	Leptosphinctes sp. aff. tabernai Westermann, Upper Bajocian.
Figures 6a, b.	Stephanoceras cf. chilensa Westermann, Upper Bajocian.
Figures 8, 12, 13 15, 16.	Procertites sp. Upper Bajocian, figure 13 is latex cast.
Figures 9, 10	Cleistosphinctes sp., Upper Bajocian.
Figures 11, b.	Stephanoceras sp., Westermann, Upper Bajocian.

PLATE 2

Figures 1a, b, c.	Phylloceras sp., Upper Bajocian; b and c are ventral and front views of another poorly preserved specimen.
Figures 2a, b.	Leptosphinctes tabenrnai Westermann, Upper Bajocian.
Figures 3a, b.	Procelozigzag sp., Upper Bajocian.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1a
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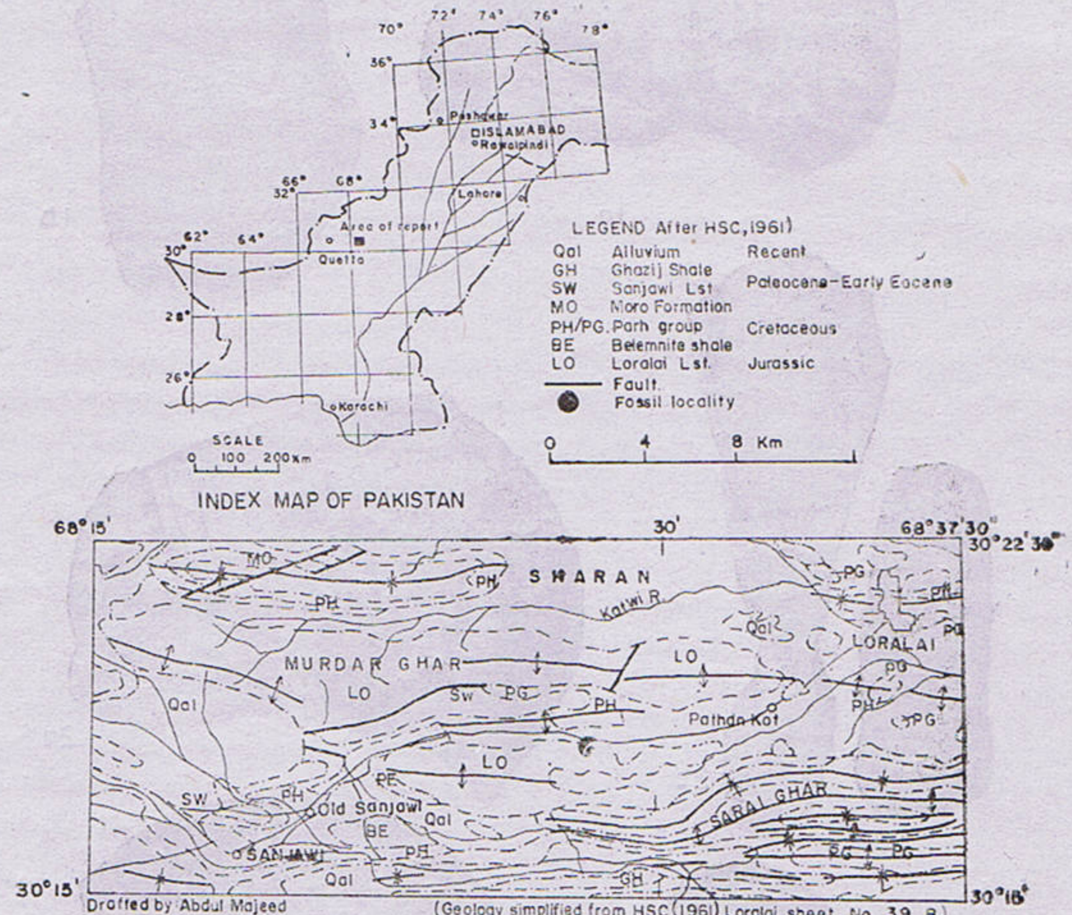

FIG. I .LOCATION AND GENERALIZED GEOLOGICAL MAP OF LORALAI AREA.

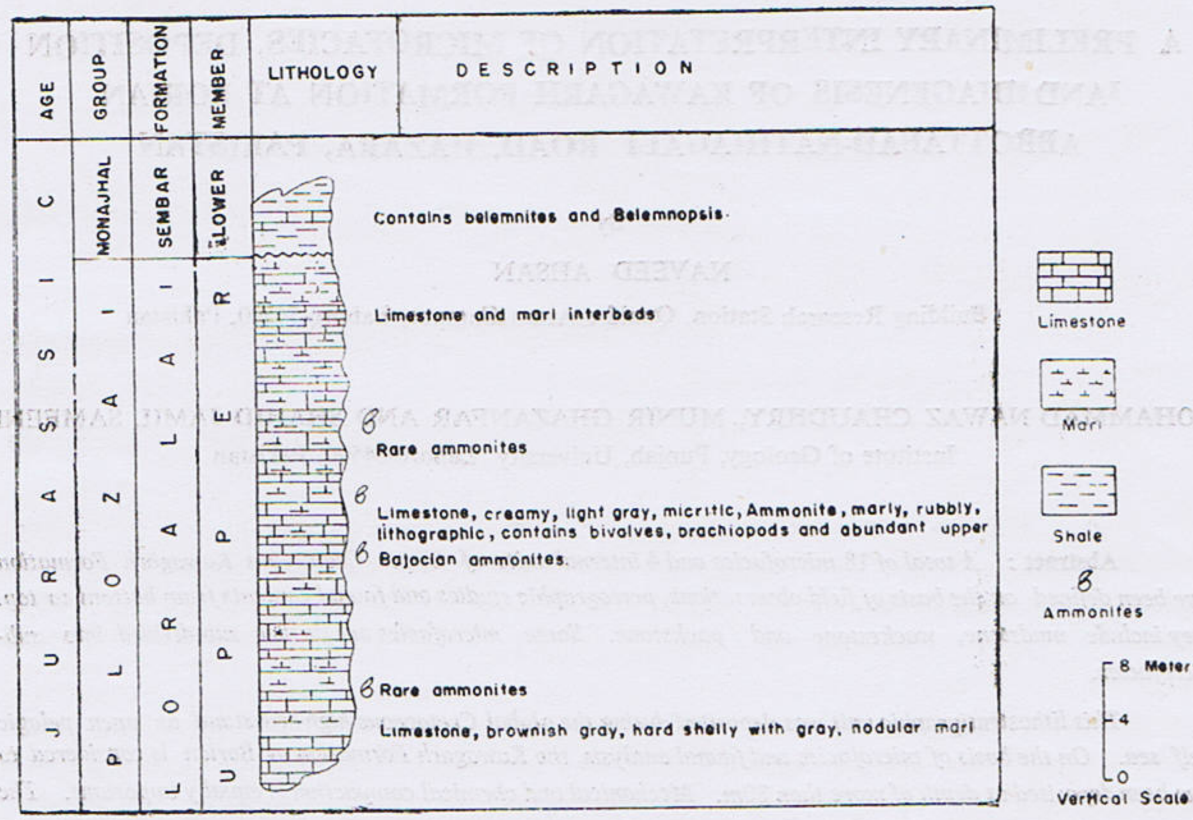

FIG. 2a

FIGURE UPPER MEMBER OF LORALAI FORMATION (BETWEEN LORALAI AND SANJAWI ROAD). 2a. COLUMNAR SECTION, 2b. GENERALIZED SECTION.

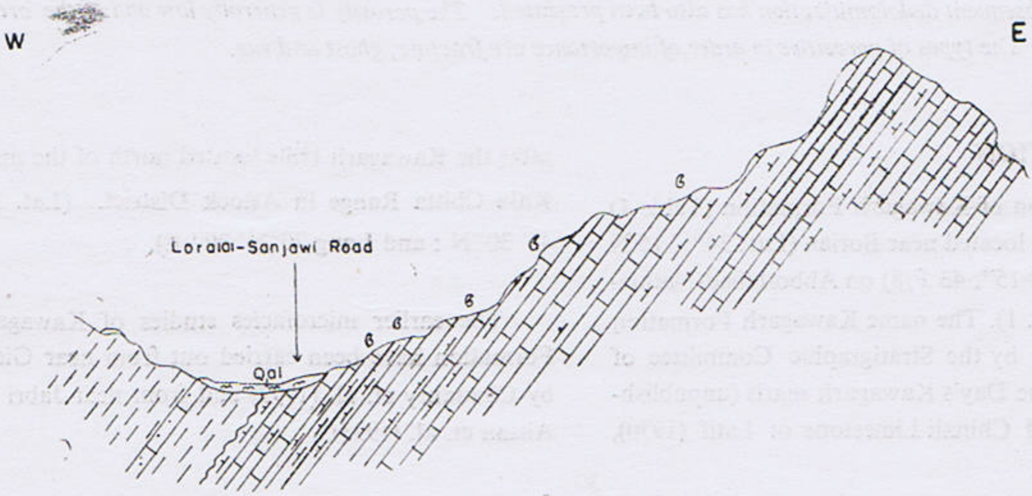

FIG. 2b.

Geol. Bull. Punjab Univ. 1993, **28.** 30—40

A PRELIMINARY INTERPRETATION OF MICROFACIES, DEPOSITION AND DIAGENESIS OF KAWAGARH FORMATION AT BORIAN ABBOTTABAD-NATHIAGALI ROAD, HAZARA, PAKISTAN

By

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Abstract : *A total of* 18 *microfacies and* 4 *internal units of Upper Cretaceous Kawagarh Formation have been defined on the basis of field observations, petrographic studies and faunal contents from bottom to top. They include mudstone, wackestone and packstone. Some microfacies are further sub-divided into sub-microfacies.*

This lithostratigraphic unit was deposited during the global Cretaceous high sea stand on open pelagic shelf sea. On the basis of microfacies and faunal analysis, the Kawagarh Formation at Borian is considered to have been deposited at depth of more than 80*m. Mechanical and chemical compaction is equally important. The upper part of this stratigraphic unit has been partly dolomitized by the influx of meteoric water related to the surface of Hangu unconformity. Dolomitization at other horizons may be accompanied by the presence of gypsum. As such hyper-saline magnesium rich solutions ascending during the compaction of Chichali Formation (deposited under restricted water conditions) appears to have played significant part in dolomitization here. Evidence of subsequent dedolomitization has also been presented. The porosity is generally low and of the order of* 0.5 *to* 6%. *The types of porosities in order of importance are fracture, ghost and vug.*

INTRODUCTION

The section of Kawagarh Formation (Table 1) under study, is located near Borian (Lat: 34°9' 15'N Long : 73° 17' 15", 43 F/8) on Abbottabad-Nathiagali Road (Fig. 1). The name Kawagarh Formation was approved by the Stratigraphic Committee of Pakistan for the Day's Kawagarh marls (unpublished report) and Chinali Limestone of Latif (1970), after the Kawagarh Hills located north of the main Kala Chitta Range in Attock District. (Lat. 33° 45' 30"N : and Long 70°25' 30" E).

The earlier microfacies studies of Kawagarh Formation have been carried out from near Giah, by Chaudhry et. al. (1992) and from near Jabri by Ahsan et. al. (1993).

The Kawagarh Formation at Borian is 77m thick, extends NE-SW and comprises mainly of very fine grained limestone with fine to medium grained dolomite rhombs. 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, and red maroon to pale maroon on fresh surface. It weathers to light yellowish grey, whitish grey and creamish maroon to very pale maroon colours. The formation is generally thick bedded with beds ranging generally from 0.3m to 1.8m. Calcite veine are abundant and some of them are dolomitized and a few contain crystals of gypsum A joint set perpendicular to bedding, where closely spaced imparts a shattered appearance to the formation. It is tough to hammer and breaks with conchoidal fracture, but some horizons, especially dolomitic break with irregular fracture.

The yellowish horizone are dolomitic relatively coarse grained, show chopboard weathering, small solution depressios and micro ridges at places. The maroonish horizone are dedolomitized limestone and contain holes due to solutioning.

The classification of carbonate rocks followed here is generally after Dunham (1962) and Folk (1959, 1962). Staining techniques of Dickson (1966) have been used to study various carbonate minerals.

We are using the word sub-microfacies to subdivide a microfacies, parts of which have undergone mineralogical/textural modification subsequent to deposition.

Micropaleontology and Age

Micropalaentological study shows the presence of the following Upper Cretaceous age diagnostic species : *Glodotruncana* sp., *Globigerina* sp., *Rugoglobigerina rugosa*, *Heterohelix reussi*, *Plannularia* sp., *Oligostegina* (which is abundant through out the formation) and some Ostracodes.

A SUMMARY OF INTERNAL UNITS AND MICROFACIES

Eighteen microfacies (KB 1 to 18, Fig. 2) have been identified by microscopic studies which have been grouped here in four internal units (BU). These are presented as Table 2.

BU-I Mixed Wackestone, Packstone and Dedolomite Unit.

This unit overlies the Lumshiwal Formation and contains two microfacies (KB-1 and 2), KB-2, packstone, has been divided into three sub-microfacies (KB-2A, 2B and 2C).

Wackestone : It (KB-1) comprises of creamish to brownish grey, yellowish grey to rusty grey limestone which weathers to light grey to rusty grey shades. Partially dolomitized cross cutting calcite veins are numerous. Allochems are embedded in non ferroan calcite. Some of the globigerinids are broken and show no orientation.

Table 1. Stratigraphic Table of Hazara Area.

Age	Formation	Lithology
Early Miocene	Murree	Grey and reddish sandstone and shales
Middle Eocene	Kuldana	Maroon to varie-colour shales and maris
Early to Middle Eocene	Chorgali	Thiniy bedded limestone and maris
Early Eocene	Margala Hill Limestone	Nodular foraminiferal limestone
Late Paleocene	Patala	Greenish grey Khakl shales with limestone
Middle Paleocene	Lockhart Limestone	Nodular foraminiferal limestone
Early Paleocene	Hangu	Sandstone, crlaystone laterite.

——Disconformity——		
Late Cretaceous	Kawagarh	Fine grained light grey limestone
Early Cretaceous	Lumshiwal	Grey to brownish coarse sandstone
Late Jurassic to Early Cretaceous	Chichali	Dark grey shales with sandstone beds, medium grained
——Disconformity——		
Middle Jurassic	Samanasuk	Limestone with dolomitic patches
Early Jurassic	Datta	Sandstone
——Disconformity——		
Precambirian	Abbottabad	Dolomites with sandstone, shale and boulder bed at tase
——Unconformity——		
Late Precambrian	Hazara	Slates, sandstone and quartzites

Unit KB	Micro-facies KC	Rock Name
	18 E	Wackestone
	18 D	Calcitic dolomite
	18 C	Wackestone
	18 B	Calcitic dolomite
	18 A	Wackestone
	17	Mudstone
	16	Intraclast bearing Wackestone
	15	Musdstone
	14	Wackestone
	13 D	Mudstone
IV	13 C	Dolomitic musdstone
	13 B	Mudstone
	13 A	Dolomitic mudstone
	12	Wackestone
	11	Mudstone
	10	Wackestone
	9 C	Mudstone
	9 B	Dolostone
	9 A	Mudstone
	8	Wackestone
III	7	Packstone
	6	Mudstone
	5	Wackestone
II	4	Mudstone
	3	Wackestone
	2 C	Packstone
	2 B	Dedolomite
I	2 A	Packstone
	1	Wackestone

Detrital quartz graine (1.8%) are subrounded to rounded. Groundmass is partially dolomitized. however the dolomitization of some allocheme is selective (Plate la). Porosity is in the form of tiny fractures (1%).

Packstone : This light grey to rusty yellowish grey microfacies (KB-2A & 2C) weathers to dirty grey, brownish grey and rusty grey colours in the field. Fragmented globigerinide and oligoetegina are the main allocheme in micritic groundmass. Ostracodes are few and, at places, allochems are compacted in a dense matrix. Dolomite replaces some allochems. The percentage of diverseallochems is almost equal in KB-2A and 2C and most of them show a higher degree of fragmentation due to relatively high energy conditions (Plate 1b).

Dedolomite (Sparite) : This sub-microfacies (KB-2B) in the field is yellowish to pinkish yellow. It marks two diagenetic events dolomitization and ii) dedolomitization. It consists of ferroan dedolomitic crystale (Plate II), angular to subrounded authigenic and detrital quartz and some traces of glauconite. This facies does not give any information about the original depositional fabrics.

BU-II Mixed Mudstone to Wackestone Unit

It contains four microfacies (Table 2).

Wackestone : This facies (KB-3 & 5) is light to dirty grey and pinkish grey on weathered surface and dirty grey on fresh surface mainly. It contains broken shells of *globigerinids* and few ostracodes (KB-3) along with *Oligoslegine*. The percentage of allocheme is less in KB-5 (Plate 1 c) than in KB-C Dolomitization, at places, is also present. Quartz grains (authigenic) are relatively less in KB-3.

Mudstone : This facies (KB-4 & 6) is creamish grey, pale grey and light grey on fresh surface and weathers to dirty to very light grey shades. The allochems which can not be identified are mostly broken and settled at the site of deposition as suspended load. A few dolomitic crystals are present. The groundmass is non ferroan calcite (Plate 1d).

BU-III Packstone Unit

This, 0.91m thick, unit contains only one microfacies (Packstone, KC-7) and is dark grey on fresh surface. It weathers to light to dirty grey colour. It contains *Oligostegina* (Plate 1 e) and other unidentified fragmentary allochems. The algal seeds are almost intact.

BU-IV Mixed Mudstone, Wackestone, Intraclast Bearing Wackestone and Dolostone Unit

This unit contains eleven microfacies. The microfacies association KB-9, 13 & 18 of this unit have further been divided into sub-microfacies.

Wackestone : It contains six wackestones (KB-8, 10, 12, 14, 16 & 18). is KB-18 is subdivided into three sub-microfacies (KB-18A, 18 C & 18E). They are generally medium to dark grey on fresh surface and weather to light grey to off-whitish grey colour. These facies contain various proportions of allocheme (Plate 1f).

In KB-8 allochemr show a clusterous pattern and some of *Oligostegina* is deformed due to compaction and in KB-12 (Plate 1i) some secondary gypsum crystal are present. The distribution and fragmentation of allochemr suggests relatively high energy conditions. However, variable degree of rounding and fragmentation implies that the allochems with different histories of reworking are present KB-16 contains some intraclasts (Plate 1j) which comprise of subrounded detrital quartz, *oligostegina* and *globigerinids* as fragments. Sub microfacies (KC-18A, 18 C and 18E) of KC-18 resembles with the other microfacies.

Mudstone : The mudstone microfacies associations (KB-9, 11, 15 & 17) of this unit are pinkish grey, light grey, brownish grey and dirty grey which weather to light grey, dirty grey and palegrey colour. Microfacies KB-9 & 13 are further subdivide into sub-mi crofacies (Table 2) The groundmass is non ferroan calcite. The allochems are in the form of fragments of *globigerinids*, *oligostegina* and few unidentified bioclasts. Dloomitic solutions were introduced in KB-9A by a ca calcite vein (Plate 1 g). In KB-9C & 13D groundmass is slightly neomorphosed with few gypsum crystals introduced by olutions through fractures. This facies marks a relatively stable portion of the pelagic shelf where all the allochems settled down as suspended material.

Dolostone, Dolomitic mudstone and Calcitic dolomite : Dolostone (KB-9B, a sub-microfacies of KB-9) is pinkish maroon to brownish pink which weathers to pinkish grey limestone. It is 1.2m thick and consists of dedolomite. However, at few places clay core of dolomite is present (Plate 1h) All the crystals have sutured contacts. The calcite is ferroan and is stained with limonite now.

The sub-microfacies associations KB-13A & 13C are dolomitic mudstone which weathers to dirty grey. These are light brownish grey on fresh surface. They contain dark cubic dolomitic crystals which replace allochems and micrite. Authigenic quartz has also formed, at places, in KB-13C. A few dolomitic rhombs have changed to ferroan calcite. Haematie is present as patches.

The sub-microfacies KB-18B & 18D represent calcitic dolomite of this unit (BU-IV). They are brownish to yellowish grey on fresh surface in the field and weather mainly to rusty shades of brown. They predominantly comprise of dolomite (80%) which is ferroan to non feerroan (Plate 1k). They contain various proportions of intact to fragmentary allochems.

ENVIRONMENT OF DEPOSITION

The Kawagarh Formation is completely devoid of benthonic fauna. There is hardly any bioturbation noticed in the measured section. The for mation is composed mainly of wackestone to mudstone with subordinate packstones in the basal part.

The biota is almost entirely planktonic and composed of pelagic foraminifera with some *oligostegina*. The minimum depth of deposition for similar sediments has been considered at least 80m (Friedman and Sanders, 1978). A complete lack of slump structures, gravity flow deposits and turbidites show that the Kawagarh Formation was deposited above the shelf slope.

DIAGENETIC HISTORY

Groundmass

Only microcrystalline calcite (micrite, of Folk, 1959) is penecontemporaneous with deposition. This type of calcite is 1 to 4 microne in diameter, and subtranslucent with a faint dusty cast in thin section.

After the dissolution of earlier calcitic matrix the equant coaree grained ferroan microspar, with poikilotopic texture, may occur as a replacement which often post dates earlier matrix and features and is found in veins, cavities or broken grains. Such cementation has been discussed by Meyers (1974) ; Grover and Read (1978, 1983) and More and Druckman (1981). This cement may owe its origin to post depositional and lithification replacement.

Dolomitization

Late diagenetic dolomitization is an important phenomenon in the Kawagarh Formation. In some dolomitic microfacies all the limestone has been replaced by dolomite. The dolomitic crystals (4 to 140 microns) are present as equigranular to idiotopic crystals. The dolomitic rhombs, at places, replace the allochems. The dolomitizing solutions ascending from the underlying Chichali Formation and Lumshiwal Formation occasionally with some gypsum dissoved from the restricted water facies of Chichali Formation invaded the Kawagarh Formation through microfractures and fractures and deposited dolomite and gypsum at places. The role of hypersaline Mg^{++} bearing solutions emanating from shales in dolomitization has been discussed by Loucks (1977).

However, the dolomitization of KB-18B & 18D is due to meteoric water influx during the development of the major unconformity (Tucker, 1981) at K-T boundary marked by Hangu laterite.

Dedolomitization

In some sub-microfacies dolomite has been completely replaced by calcite. The newly formed crystals of calcite are more than 10 microns in size and exhibit various textures from porphyrotopic to poikilotopic. The dedolomitized part is distinctively pinkish in colour For discussion on dedolomitization the reader is reffered to Shearman et al 1961 aad chilingar et al 1979 In some facies, original boundaries of dolomitic rhombs are present while the crystals have been replaced by ferroan to non-ferroan calcite. Such calcitization can take place through contact with meteoric waters (Tucker, 1981). However the development of ferroan calcite took place when the meteoric water had lost much of the oxygen through reduction.

Compaction

Well preserved evidence of mechanical compaction (Plate 1f) are present such as denser configuration of sediments, intrusion of clay, fractured quartz grains, displacement in calcite veins and fractures in some oligostegina.

Compaction by chemical processes is shown by (1) fused boundaries between allochems (Plate 1c) and ii) dissolution within cemented sediments along an irregular path. These stylolites are of very low to high amplitude and are present throughout the Kawagarh Formation. The depth of stylolite formation may range from 600m to 1000m (Dunnington, 1967 ; Mossop, 1972), but it may also depend more or less on the nature of the rock and water chemistry (Meyers, 1980). In the Kawagarh Formation sutured seam solutions and non sutured seam solutions are responsible for the concentration of dark clay, organic matter or iron oxides. Similar features have been discussed in general by Wanlese (1979).

Another important diagenetic event is the late stage neomorphism and dissolution of earlier formed cements through stylolites which may be a source of microspar.

Porosity

Primary porosity especially in the packstone facies has been destroyed by cementation as it is associated with depositional and diagenetic fabrics (Choquette and Pray, 1970; Wardlaw, 1978) and is a function of sediment sorting and shape. However, some of the dolomitic facies have some secondary porosities, as vugs and ghosts (Plate 1c).

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PLATE 1

(a) Sparse biomicrite/Wackestone. KB-1/BU-I, (5x). Dolomite rhombs (e) replacing fossils and micrite

(b) Packed biomicrite/Packstone, KB-2A/BU-I, (5x) Well developed dolomite(s) bioclasts and *oligostegina.(n)*

(c) Sparse biomicrrite/Wackestone, KB-5/BU-II, (5x) Vug (o) by dissolution of calcite vein and *oligostegina*

(d) Fossiliferous micritez/Mudstone, KB-6/BU-II, (5x). A few *oligostegina.*

(e) Packed biomicrite/Packetone, KB-7/BU-III, (5x). Numerous *oligostegina* (rounded in lime mud).

(f) Sparse biomicrite/Wackestone, KB-8/BU-IV, (5x). *oligostegina* and other bioclasts.

(g) Fossiliferous dolomicrite/dolomitic Mudstone, KB-9A/BU-IV (5x). Dolomitized calcite vein which introduced the dolomitizing solutions. Intensity of dolomitization dies out away from the vein (right)

(h) Dolostone/Sparite, KB-9B/BU-IV, (5x) Dolomite has been replaced by calcite with sutured contacts contacts (y) and at places clay core present.

(i) Sparse biomicrite/Wackestone, KB-13B/BU-IV, (3x). Metasomatic gypsum crystals (q) in micrite introduced by gypeiferous vein and few bioclasts.

(j) Intraclast bearing sparse biomicrite/Wackestone, KB-16/BU-IV, (10x). Well rounded intraclast in wackestone. Oligostegina (n) authigenic quartz (p), and other neomorphosed bioclasts (u) in intraclast

(k) Calcitic dolomite, KB-18D/BU-IV (5x) Dolomite rhombe (s) filled by calcite and vug (o)

(l) Sparite/Dedolomite, KB-2B/BU-I, (5x). CNL. Totally replaced dolomite (m) with sutured contacts(y) and authigenic quartz (p).

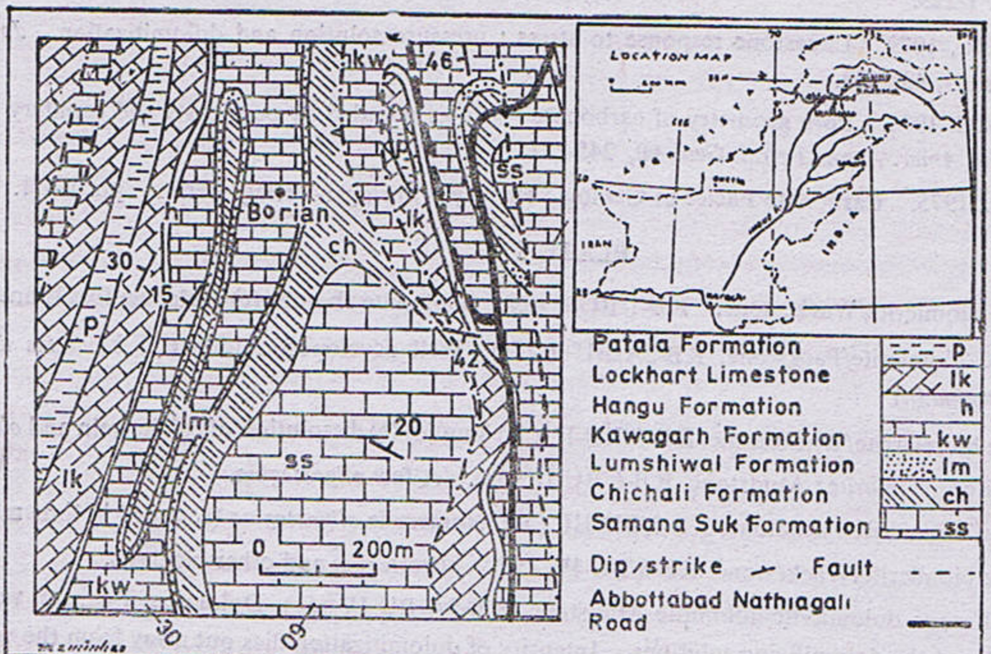


Fig. 1. Geological map of Borian, Abbottabad, Pakistan

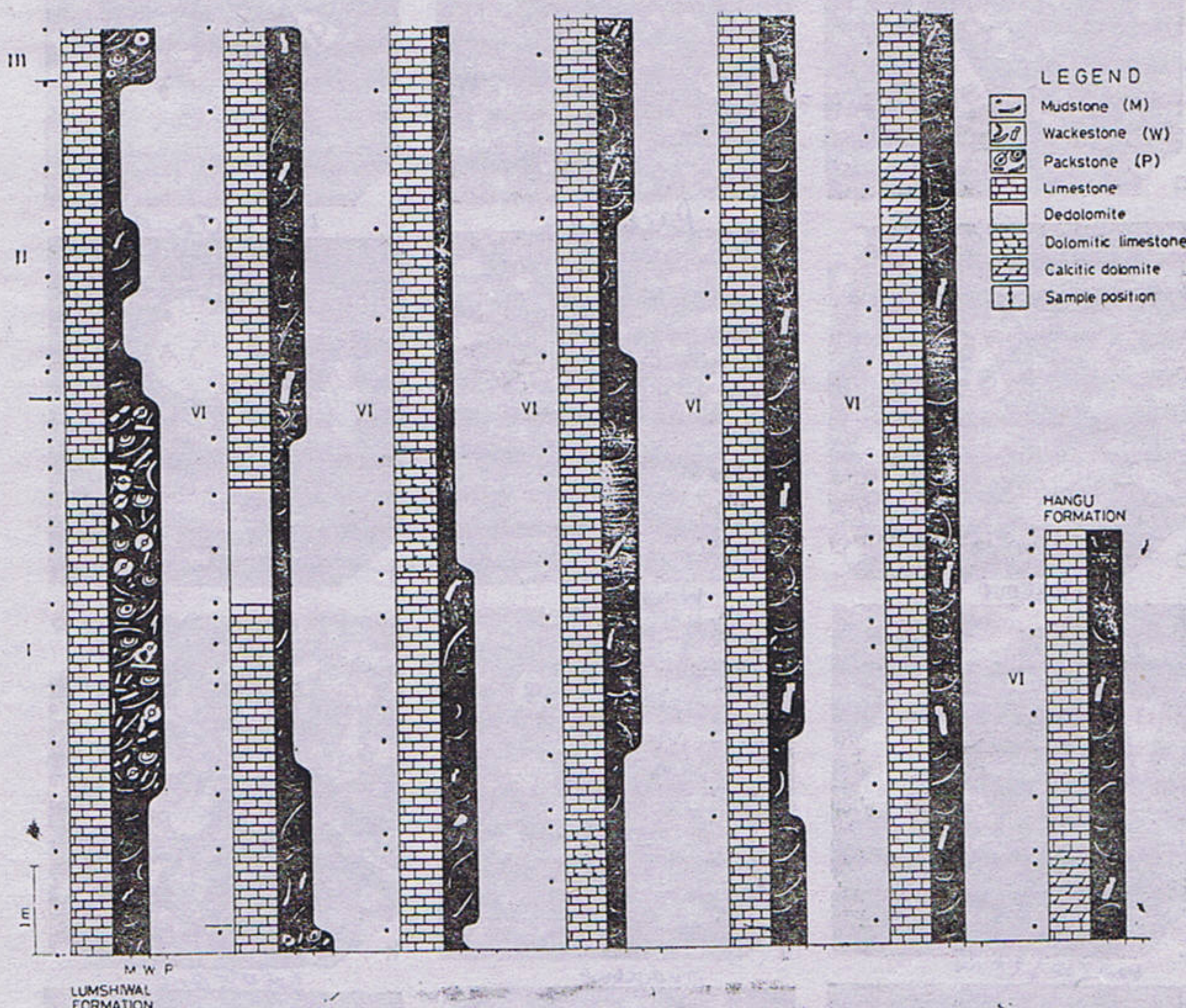
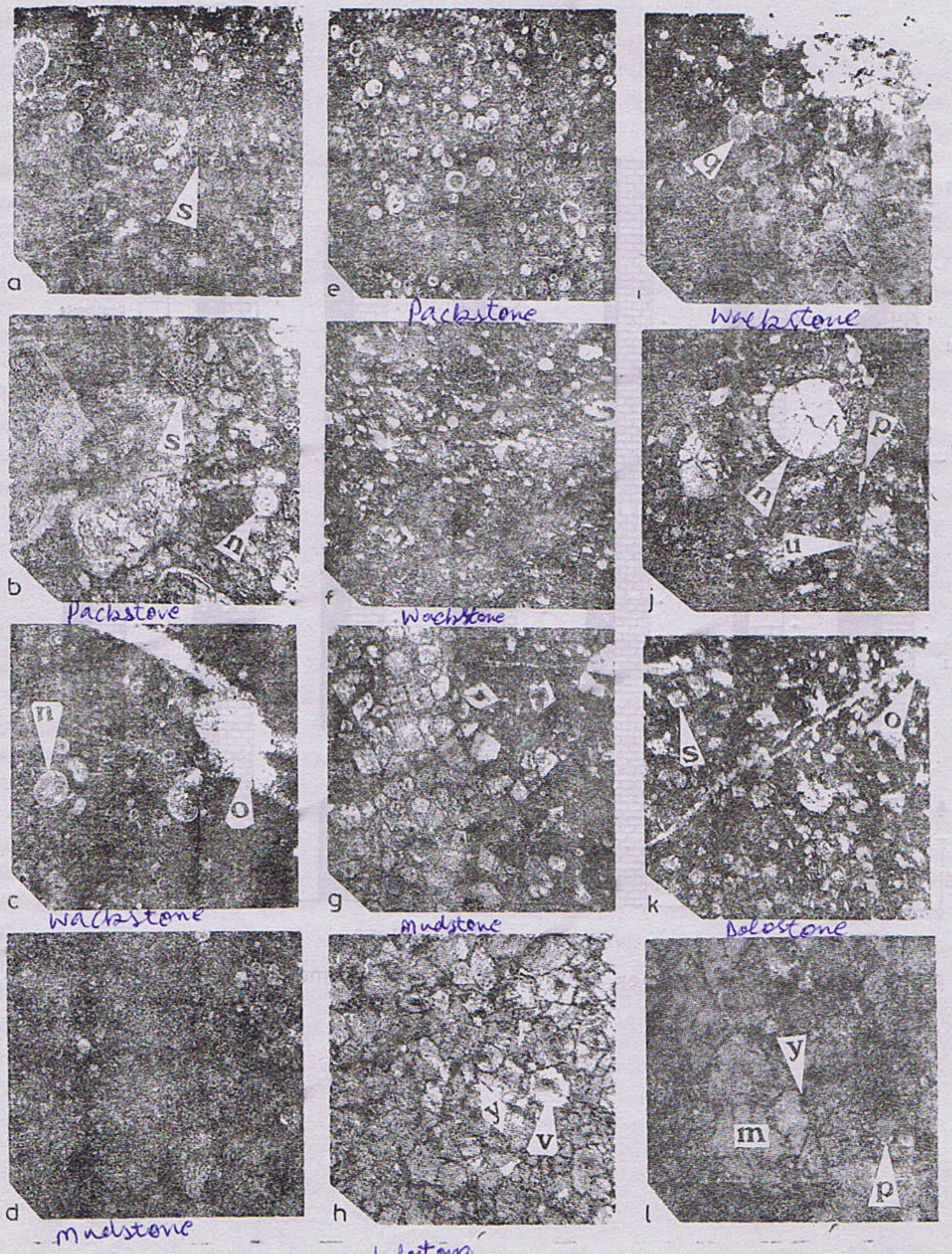


Fig.2 Litho and microfacies column of 'Kawagarh Formation' at Borian

PLATE I



Packstone (e)
Wackstone (i)
Packstone (b)
Wackstone (f)
Wackstone (c)
Mudstone (g)
Dolostone (k)
Mudstone (d)
dolostone (h)

Geol. Bull. Punjab Univ. 1993, **28**, 41—49

ENVIRONMENT OF DEPOSITION AND DIAGENESIS OF PIRKOH LIMESTONE AND MARL MEMBER NEAR D.G. KHAN CEMENT FACTORY, D.G. KHAN, PAKISTAN

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Abstract : *The Pirkoh Limestone and Marl Member is divided into 18 microfacies. These microfacies are discussed under 4 groups on the basis of relative percentage by number of large forams to pelagic fauna and texture. This member was deposited during two significant transgressions and one regression. Deposition of group-I started after supratidal conditions of Sirki shale during a transgression on open shelf in upper to middle subtidal zone. Group-II was deposited in a lower subtidal zone after an accelerated transgression. During the deposition of group-III relatively high energy conditions dominated the shelf with increased production of large foraminifera (50.1%) as compared to negligible contents of the same in group-II. This group was laid down in middle subtidal zone. The group-IV was deposited in lower subtidal zone during a rapid transgression.*

Bioerosion, mainly, produced microcrystalline calcite which has now been neomorphosed, at places. Dolomitisation took place due to Mg^{++} rich solutions ascending from the underlying Sirki shale during compaction. Both physical and chemical compaction processes were active during diagenesis. Porosity types have also been classified.

INTRODULTION

This paper presents a study of microfacies, environment of deposition and diagenesis of the Pirkoh Limestone and Marl Member near D.G. Khan Cement Factory (Fig. 1.)

The studied section (10.49m thick) of the Pirkoh Limestone and Marl Member is a part of Kirthar Formation. The Kirthar Formation consists of four easily distinguishable members in parts of Eastern Sulaiman Province (Fig. 2).

The Pirkoh Limestone and Marl Member (Shah, 1977) is overlain by Drazinda Member (Drazinda Shale of Hemphill and Kidwai, 1973). It is light greenish gray and chocolate colored claystone, silty shale, calcareous marl, greenish grey sandstone and buff colored limestone.

The Pirkoh Limestone and Marl Member overlies the Sirki Member (Sirki Shale of Eames, 1952). This limestone is thin to medium bedded with millimetric laminations. Fresh color is chocolate grey, dirty grey, light grey, creamish off white to off whitish grey. The weathering color is brownish off white, pale off white and yellowish off white.

This member is underlain by Sirki Member. It consists mainly of brownish to chocolate colored claystone, sandstone, and limestone with interbedded gypsiferous shale.

This Pirkoh Limestone and Marl Member resembles Pirkoh Limestone and Marl Member at Dhar (Ahsan et al., 1993) and differs from the unit present at Rakhi Gaj (Chaudhry et al., 1993).

Staining techniques of Dickson (1966) were used for identification of carbonate minerals.

FAUNA AND AGE

The measured section at Rakhi Gaj was studied for its larger foraminiferal content also. The following species were identified. *Lockhartia conditi, Lockhartia tipperi, Nummulities atacicus, Nummulities mamillatus, Assilina subspinosa, Assilina granulosa, Discocyclina dispansa, Discocyclina ranikotensis and Ranikothalia solimani.* These forams have also been reported by Sameeni and Ahsan (1993) and Sameeni et al. (1994). On the basis of larger foraminifera the age assigned to this formation is Early Eocene.

Most of the section, however, is rich in pelagic foraminifera. The pelagic fauna is being studied. The benthic fauna of this member from Dhar, Taunsa area has been studied by Ahsan et al. (1993) and from Rakhi Gaj by Chaudhry et al. (1993).

MIRCROFACIES AND ENVIRONMENT OF DEPOSITION

The Pirkoh Limestone and Marl Member near D.G. Khan Cement Factory is divided into 18 microfacies on the basis of relative percentage by number of larger forams to pelagic fauna and texture through a study of 38 thin sections. These microfacies are discussed under 4 groups. The microfacies are indicated in bold letters (Table 1) and the local minor variants are given in ordinary type. A microfacies log is also presented (Fig. 3).

Group-I Packstone, Dolomitic Wackestone, Wackestone-(Packstone) and Marl

This group (Table 1) contains 3 packstones (PC-1, 3 and 5), 3 wackestone-(Packstone) (PC-2, 4 and 7) and 1 dolomitic wackestone (PC-6). The groundmass of this group is micrite which has changed to microsparite (Folk, 1959), at places, and contains variable proportions of foraminifera (Table 1). PC-8 is a marl. The microfacies of this group are discussed in the following.

Packstone : The microfacies PC-1 overlies the Sirki Shale. It contains fragmented larger foraminifera in a mud matrix as other associations (PC-3 and 5) do. The micrite has changed to microsparite as a result of late diagenetic processes. A few pelagic forams are randomly distributed through out the body of this microfacies. Some patches of neomorphic spar, shapeless vugs and mouldic porosity are also the characteristic features. Limonite and pyrite occur at a few places. Micritization of some larger allochems is often observed. Other packstones (PC-3 and 5) of this group also exhibit the above cited features. Porosity is mainly in the form of vugs.

Environment of Deposition : The general characteristic of these packstone microfacies associations of this group is well fragmented, disarticulated and worn shells of larger benthic forams and a few brachiopodes. It is inferred that these allochems were transported from shallow regions of shelf by currents. These currents were also resposible for fragmentation, downward transportation and partial alignment of allochems to the place of deposition. So on the basis of fragmentary allochems, microcrystalline calcite and paucity of pelagic fauna it is concluded that packstone microfacies of group-I were deposited on open shelf in shallow subtidal zone (Flugel, 1982) following a transgression over the supratidal Sirki shale. However, the upper most microfacies, PC-7 and PC-8, were deposited in middle subtidal zone.

Wackestone — (Packstone) **and Dolomitic Wackestone :** Three microfacies associations (PC-2, 4 and 7) of this group are dominantly wackestones (Plate A-1 and A-3) but some patches of packstone also occur in micritic groundmass. The boundary between the wackestone and patches of packstone is generally sharp. The allocheme are well to moderately fragmented and include both larger and pelagic fauna (Table 1) along with some non-ferroan calcite and brachiopod spines. Larger forams are truncated by small fractures. Pyrite is an accessory mineral. Porosity is vugy and fracture type.

Dolomitic wackestone (PC-6) contains rhombs of none-ferroan dolomite (Plate A-2). They vary from 35 to 50 microns in size. They have mostly been replaced by ferroan calcite and a few are now only ghosts. They, at places, replace the allochems usually larger forams, which are generally present as shell hash. Vuggy and fracture porosity is 2-3%. Finely disseminated organic matter and clay are accessories.

Environment of Deposition : The microfacies associations (PC-2, 4, 6 and 7) of this group contain almost the same proportions of larger forams to pelagic fauna by number (Table 1) as the other packstone associations (PC-1, 3 and 5). Keeping in view the relative percentage of lime mud and bioclasts it can be argued that :1) either the production rate of lime mud was fast or ii) the allocheme were less abundant, iii) or both. As hardly any intact larger foram is present, it seems porper to infer that bioclasts (larger forams especially) were transported from upper parts of the shelf by local currents or as suspended load. There occured local fluctuations in sea-level to deposit these associations (PC-2,4 and 7) of group-I in close proximity to middle subtidal zone (Flugel, 1968). However, PC-7 contains relatively more pelagic fauna, which gives an indication of open marine conditions with some deepening of the shelf.

Group-II Wackestone-(Packstone and Mudstone)

This group (Table 1) contains one microfacies, PC-9 (Plate A-4). It is dominantly a wackestone with some local mudstone layers and packstone patches. These mudstone layers are poor in fossils and composed of dull microcrystalline calcite. The pelagic bioclasts are randomly distributed in mudstone layers.

Wackestone contains abundant pelagic fauna. The fauna show a clusterous pattern as well as partial alignement within micritic groundmass. Micrite, at certain places, is compressed and shows an intertwinning network of microstylolites in wackestone part of thin sections. Some horizons are very porous. Shapeless vugs are common.

Environment of Deposition : The preceding microfacies (PC-1 to 7) have very low percentage of pelagic fauna, but this microfacies (PC-9) is very rich in this fauna (Table 1). The larger forams are merely the winnowed fragments that settled as suspended load or were transported by bottom currents. The partial alignment of fauna is due mainly to currents. But some role was also played by overburden compaction. On the whole, this microfacies may have been deposited in lower subtidal zone as a result of rapid transgression. The variation in this microfacies association is due to uneven distribution of fauna which resulted due to segregation caused by bottom currents.

Group-III Wackestone - (Packstone)

This group contains one microfacies, PC-10

(Plate A-5). It contains almost equal percentage of larger and pelagic fauna. Some patches of packestone are present. A few of the larger forams are intact while the rest are fragmented. They are aligned almost parallel to the bedding. However, they are variably (slightly to moderately) deformed due to over burden. The groundmass is micritic which has, at places, changed to microsparite. Pyritization of some shells is observed. Vug, channel and mouldic porosities have developed.

Environment of Deposition: This group marks a regression, during which larger forams were more abundent as compared to group-II. This facies was deposited in a relatively high energy middle subtidal environment.

Group--IV Fossiliferous marl, Marl and Wackestone

This group (Table 1) contains 2 fossiliferous marls (PC-11 and 13), 2 marls (PC-15 and 17) and 4 wackestones (PC-12, 14 and 18).

Fossiliferous marl : The fossiliferous marls (PC-11 and 13) contain intact pelagic fauna and most of them are pressure and current aligned. Occasional pyritization and vugy porosity is common. Few fragments of larger forams are also present. They are abraded and worn out.

Environment of Deposition : After the deposition of group-III a transgression deposited these pelagic marls due to terrigenous influx in lower subtidal zone.

Wackestone : This microfacies (Plate A-6 and A-7) contains intact insitu pelagic fauna in a mud matrix. Larger forams are in the form of fragments. The larger bioclasts are aligned. There is clear evidence to suggest mechanical compaction. Fracture and mouldic porosity is present.

Environment of Deposition : These microfacies contain a large number of pelagic fauna, whereas larger forams are negligible and those present, were transported from upper areas of the shelf, These conditions show a transgression and the facies were deposited in lower subtidal zone.

DISCUSSION

Depositional environments for individual microfacies have already been discussed. In the following a summary of the same is presented.

The first group oft he Pirkoh Limestone and Marl Member overlies the Sirki shale which is a supratidal deposit. The allochems present in this group are generally found on open shelf.

This group was therefore deposited mainly on open shelf in shallow subtidal zone. But microfacies PC-7 and PC-8 were deposited in middle subtidal zone. The pelagic fauna are mostly negligible.

The group-II marks accelerated on-lap which provided favourable conditions where only pelagic fauna could flourish. This group was deposited in lower subtidal zone. The benthic fauna were transported from open shelf area.

The group-III represents an off-lap facies. It was deposited in middle subtidal zone. The pelagic fauna are intact but larger forams are mainly transported.

The last group is again an on-lap deposit with terrigenous influx (PC-11, 13, 15 and 17), at places. This group was deposited in lower subtidal zone.

It is inferred that this section of the Pirkoh limestone and marl member marks two significant transgressions and one regression.

DIAGENETIC HISTORY

A mixture of minimicrite (Folk, 1974) and micrite (Folk, 1959) occurs as the main groundmass in the section under study (except PC-11 & 13). They are non-ferroan and are characterised in the thin sections by grain fabric consisting of irregular calcite crystals at high magnifications. Their origin is due to the abrasion and mechanical break down of larger allochems mainly. The mechanism of such mud production has been discussed by Stieglit. (1972) ; and Milliman (1974).

Some patches of ferroan neomorphic calcite are present at places. The crystals are anhedral to subhedral and, at places, they are equigranular, Their boundaries are usually clay coated. Such patches also corrode the bioclasts. Its origin is related to meteoric phreatic zone (Bathurst, 1958) during late diagenetic processes.

PC-6 contains dirty and yellowish dolomite rhombs which formed during late diagenetic stage by the upward migration of Mg^{++} bearing solutions from Sirki member and interbedded marls, Some horizons contain a few clear dolomitic rhombs which might have formed by circulating meteoric waters (Folk, 1974). However, most of these rhombs have been reverted to ferroan calcite. Some of them are now present as ghosts with yellowish and rusty boundaries.

Reoriented and realigned pelagic fauna and fractured larger forams strongly suggest physical compaction. Pelagic fauna are, however, much less affected by overburden pressure.

Later, during subsidence solution seams and microsylolites developed. For discussion on genesis see Wanless (1979) and Gillett (1983). This chemical compaction also affected the groundmass and produced inter-twinning network in micrite in certain parts. Some stylocummulates also contain clay and iron oxides.

Vug, shelter, channel and fracture porosities are common (upto 10%). Dissolution and removal of dolomite rhombs and some fossils enhance porosity in certain horizone.

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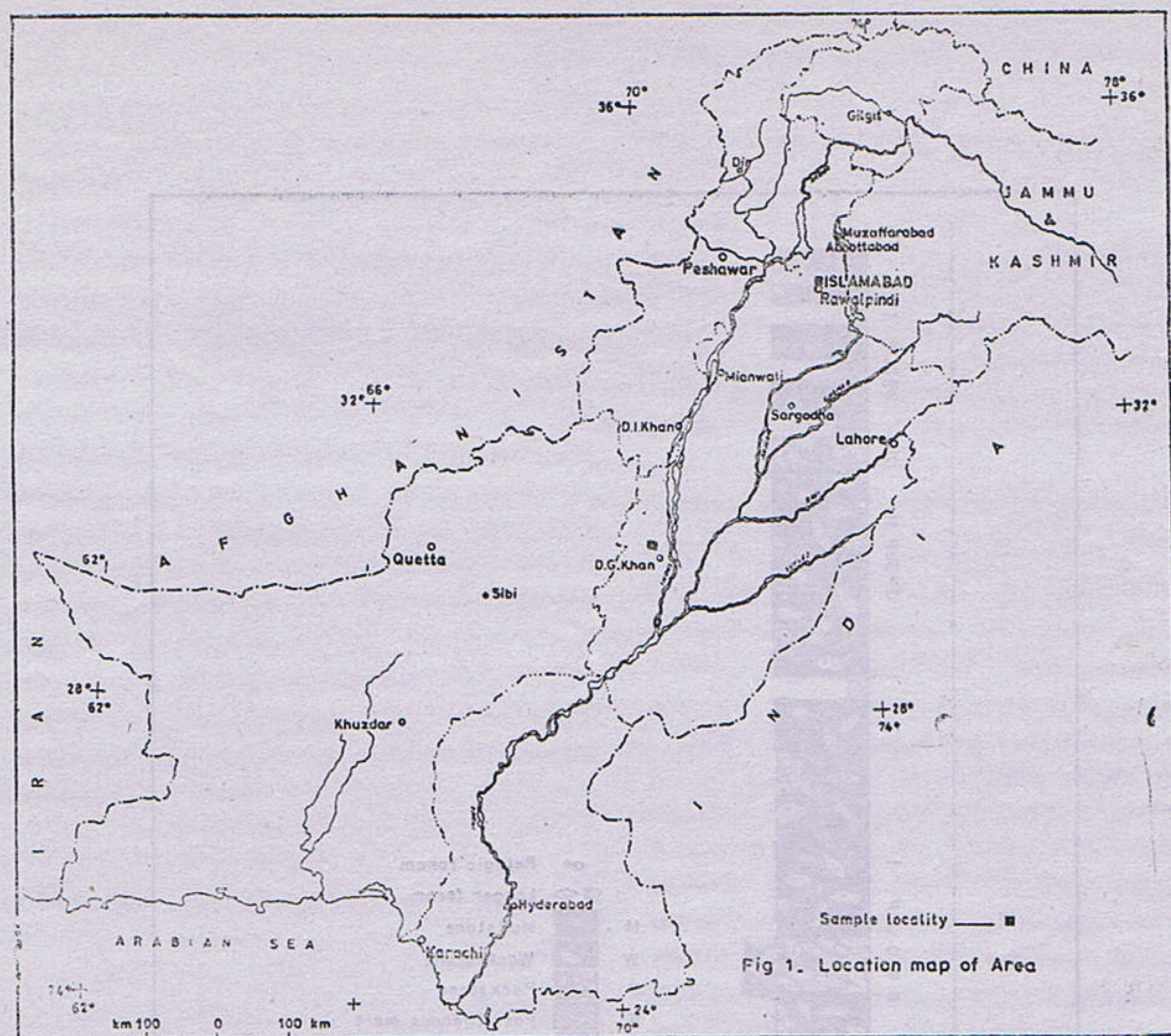
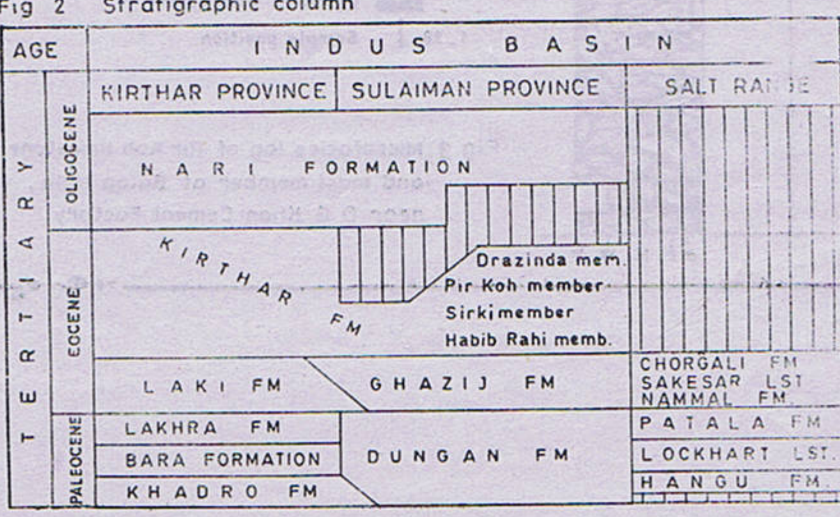


Fig 1. Location map of Area

Fig 2 Stratigraphic column



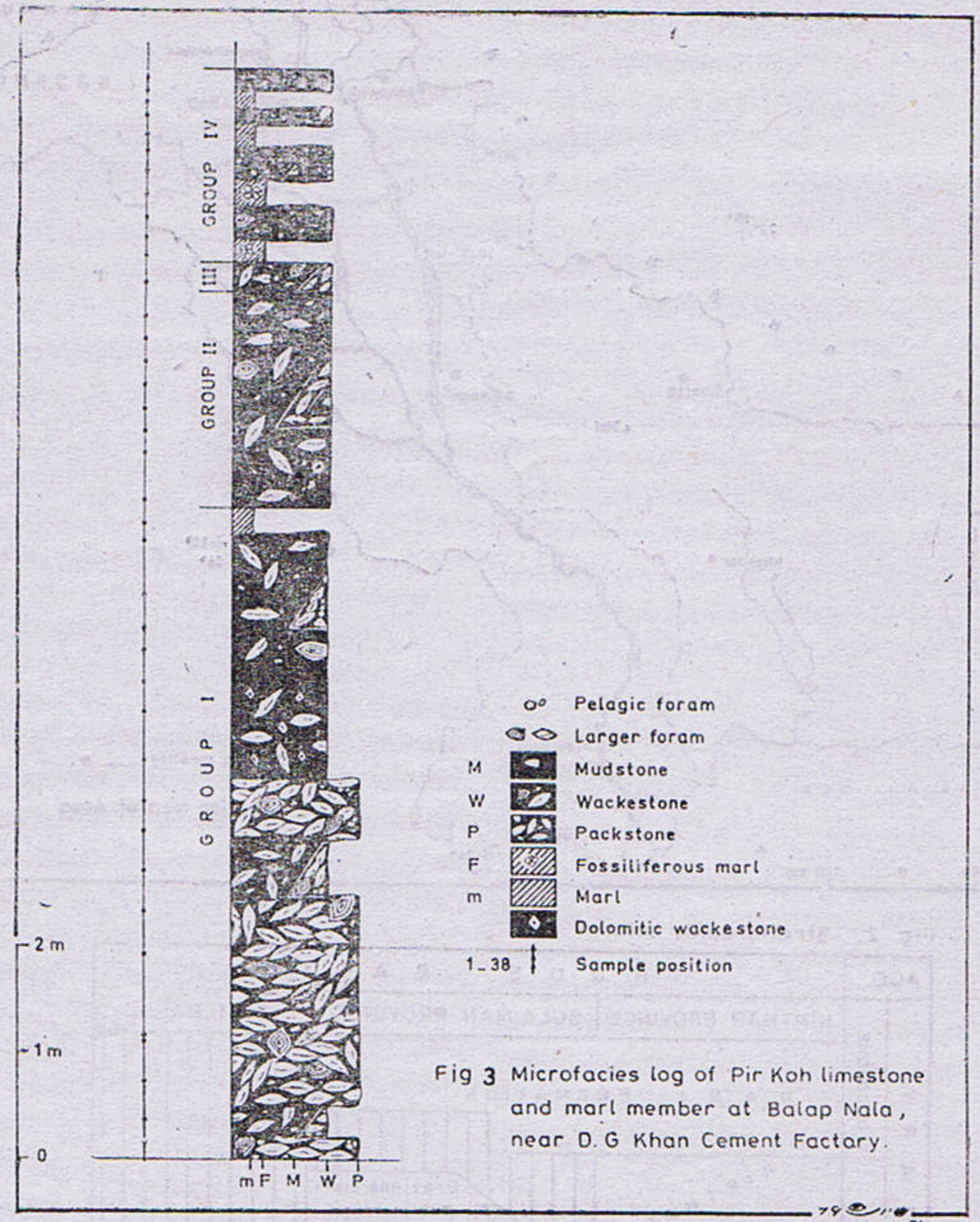


Fig 3 Microfacies log of Pir Koh limestone and marl member at Balap Nala, near D. G Khan Cement Factory.

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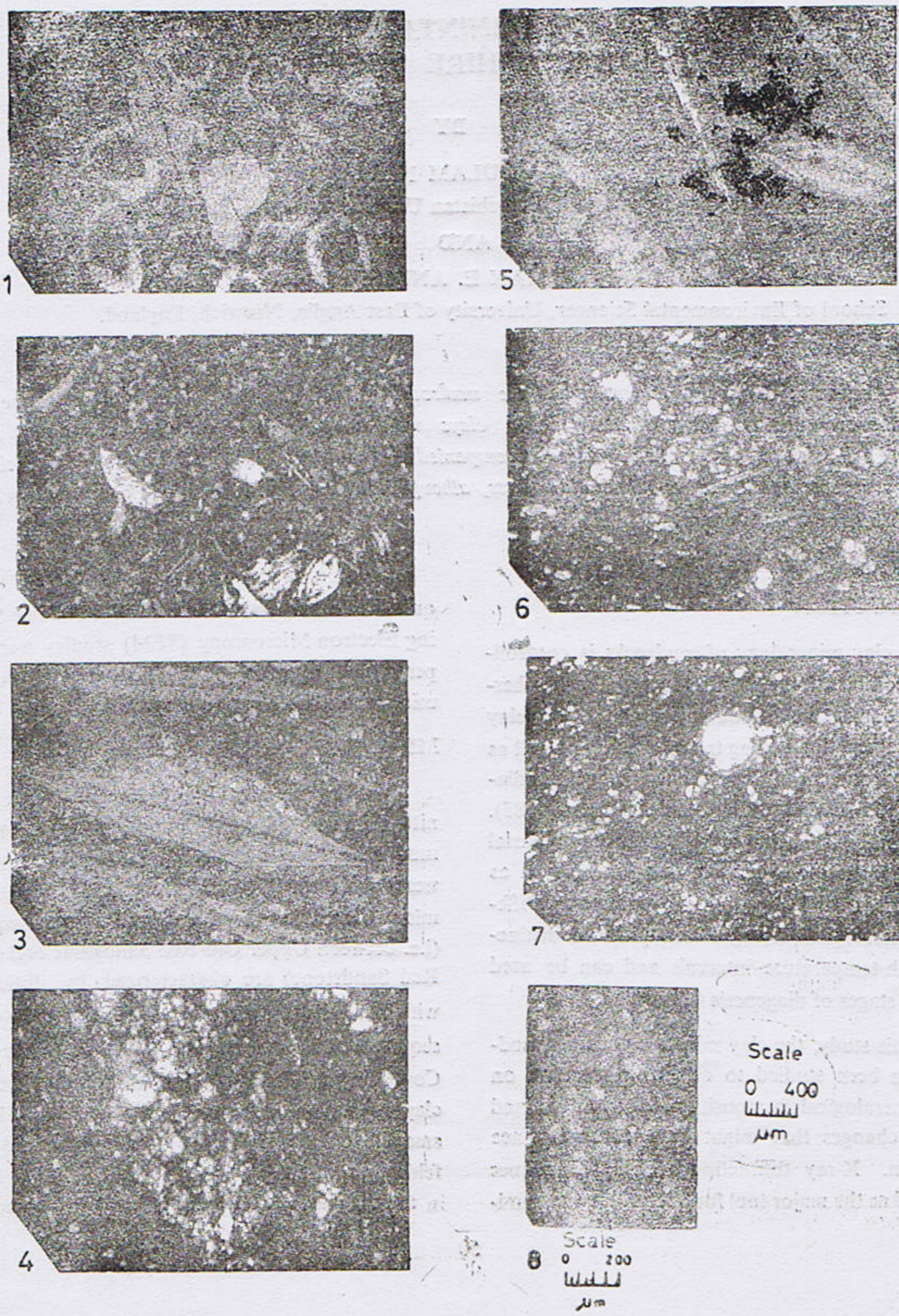
PLATE - A



Geol. Bull. Punjab Univ. 1993, 28. 50—74

CLAY MINERALOGY OF THE DANINTAIN MUDROCKS AT COVE, EAST BERWICKSHIRE SCOTLAND

BY

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Abstract : *The clay mineralogy of the mudrocks associated with dolomitic cementstone at the base of the sequence is characterised by illitic clays with kaolinite and chlorite. Elsewhere in the sequence, kaolinite is the dominant clay mineral accompanied only by illite. It is uncertain how much the clay mineraogy reflect inheritance vs diagenetic effects, alhough it is clear that some of the kaolinite is lormed by diagenetic alteration of felsdspar.*

INTRODUCTION

The clay mineralogy of mudrocks is controlled by a combination of factors such as the weathering environment in the source area, lithology, clay particle segregation during transportation as well as in the environment of deposition, and possible diagenetic modification during burial (Hurst. 1985). Clay mineralogical changes that occur during burial of argillaceous sediments are due to chemical as well as physical (compaction) processes. Different mineralogical changes take place at distinctive depth temperature intervals and can be used to define stages of diagenesis (Curtis, 1980).

In this study, the clay mineralogy of the mudrocks has been studied to obtain information on their mineralogical composition, distribution and possible changes that might have occurred since deposition. X-ray diffraction (XRD) techniques were used as the major tool for qualitative and semi-quantitative mineral identification, but some Scanning Electron Microscopy (SEM) studies were also performed to identify the crystal morphologies using secondary electron images.

MINERALS

The clay minerals identified by XRD were kaolinite, illite and chlorite. During the study of these mudrocks two distinct clay mineral assemblages were observed. The clays associated with dolomitic cementstones at the base of the sequence (i.e. between Upper Old Red Sandstone and Horse Red Sandstone) are characterized by illitic clay with kaolinite and chlorite, whilst elsewhere in the sequence (i.e. between Kip Carle Sandstone and Cove Harbour Sandstone) kaolinite is the dominant clay mineral accompanied only by illite. Illite / smectite mixed layer clays, vermiculite, quartz, feldspar and ferroan dolomite were found as traces in the clay mineral separations. The characteristies of these clays are outlined below :—

Kaolinite

These are 1 : 1 (Fig. 1) clay minerals which are characterized by their diffraction reflections at 7.1Â (001 and 3.5Â (002) (Fig. 2a). They are not affected by glycol treatment, but heating the specimen to 550°C causes complete destruction of its stture (Fig. 2b, 2c).

Kaolinite was the only mineral among the group to be identified in the samples. Other minerals of the group have more specific features. For example, in hallosite the basal spacing expands on glycolation by replacing its water layer with a single sheet of glycol molecoles (Hardly and Tucker, 1988) which was not recorded in these samples. Dickite. the other main mineral of the group shows a higher degree of crystallinity than kaolinite, which was not observed in the XRD traces of these samples.

In the clay mineral assemblages which contained both kaolinite and chlorite it was sometimes difficult to differentiate between them as these particular chlorites have a low first and third order reflection and the second and fourth order reflection coincides with the first and second order peaks of kaolinite. Therefore, the (002) reflection of kaolinite and the (004) reflection of chlorite at about 3.5Â was resolved by a slower scanning time (1/4°20 minute (Fig. 3a, 3b) as suggested by Biscay (1964). Also, dilute hydrochloric acid treatment was used to differentiate between kaolinite and chlorite, as chlorite is dissolved by acid treatment while kaolinite remains unaffected (Spears and Sezgin, 1985).

SEM examination of the samples revealed that two types of morphology are present, smal. poorly-crystalline books (Plate No. 1) and a coarse-grained well-crystallized form. The poorly-crystallized type probably formed froum the alteration of feldspar during early diagenesis while the well crystallized form is due to precipitation after the forma· tion of secondary porosity, following burial diaenetic feldspar alteration.

Illite

Illite is a 2 : 1 clay mineral (Fig. 1) characterized by a series of reflections at 10Â (001), 5Â (002) and 3.35Â (004) (Fig. 4a) with a non-expanding lattice. Heat treatment (Fig. 4c) causes no shift in lattice spacing (Hardy and Tucker, 1988) but results in a slight increase in the peak instities. Illite is present throughout the suite of samples studied. In some samples the illite has a well crystallized dioctabedral nature haying an intensity ratio of the (001) / I I (002) Â4 (Table 1) with a sharp and symmetrical reflection at 10Â. In other samples it is more poorly crystalline, asymmetrical at the 10Â (001) reflection with a tail towards the higher angle side which suggests a mixed-layer structure of smectite and illite, which kis probably due to the degradation of illite by weathering. The structure of the illite/smectite interlayering is random. The X-ray diffraction traces shows that this illite/smectite tite is a minor mixed-layer component which is too small to be accurately quantified. The SEM and a platy form.

Chlorite

This is a 2 : 1 : 1 mineral (Fig. 1) characterized by a series of basal reflections at about 14Â. 7.1Â, 4.8Â, 4.8Â and 3.5Â (Fig. 5a). These spacing are not affected by glycol treatment, while heat treatment at 550 °C causes a change in the chlorite structure with an increase in the 001 reflection at 14Â together with a slight shift from 14Âto 13.6Â. This increase and shifting from 14Â to 13.6Â is probably due to partial dehydration (Brown, 1961). Minor amounts of chlorite (Fig. 5b) were found in these samples which were identified after heating (which had collapsed the superimposed 7Â kaolinite peak). The chlorite of these mudrocks is an Fe-rich type with very low (001) and (003) reflections Chlorite crystals are observed by SEM (Plate 2).

Vermiculite

Vermiculite is a 2 : 1 layer silicate giving an XRD reflection of 14Â (Fig. 5a). Vermiculites in their magnesium saturated form remain unaffected by glycol treatment (Hardy and Tucker, 1988) but collapse to 10A on heat treatment at 450 °C from their original reflection at 14Â (001). In these samples this is difficult to observe because of the small peak area and overlap with the mixed layer clay peak. The percentage of the vermiculite was very low and its peak usually appeared as a shoulder at 17Â.

Illite/Smectite Mixed Layer

A careful examination of the diffractogram produced after each successive treatment is essential to establish the nature of any mixed-layer clay spresent in a mixture with discrete minerals. A mixed-layer mineral tends to show a broad diffraction peak between the basal spacings normally shown by its pure compoents. The presence of a peak between 10Â and 14Â in some samples indicates a mixed-layer of smectite with components of illite. This clay was observed after glycolation and heating to 550°C as it expanded and disappeared in the respective traces.

Whole Rock Analyses

The X-ray diffraction patterns of the whole rock samples whom that the major non-clay minerals are quartz and feldspar with carbonates such as dolomite. Pyrite was recorded in some samples, probably associated with organic matter. Siderite was observed only in the XRD traces of concretions present in the mudrocks (Fig. 6).

QUANTITATIVE ANALYSIS

There is no particular method for exact measurement of the percentage of clay minerals present in any given sample of <2 um material. Most workers use a comparison of strong characteristic XRD reflections of each mineral in the mixture with that of a standard. The drawback of this measurement is due to dissimilarity between the standard and the unknown, particularly the variability caused by particle size, specific gravity, and crystallinity differences. Therefore, a semi-quantitative X-ray diffraction method for clay mineral percentage evaluation was used in the present work. The semi-quantitative measurements only consider the relative proportion of discrete clay minerals to each other, irrespective of other minerals present. It is difficult to compare between clay minerals and non-clay minerals due to the distortion in the relative intensities caused by the difference in the degree of orientation and mineral structure of the clay par particles and non-clay particles.

The Biscaye (1965) method was adapted in the present study to obtain a measure of the relative percentage of different clay minerals present in the mudrocks.

The mineral content in the less than 2 micron fraction of mudrocks in the sequence between the Kip Carle and Cove Harbour Sandstone (Fig. 7b) is dominated by kaolinite (mean=82%) along with illite (mean = 18%). No chlorite was detected in these samples. The clay mineral constituents of the sequence between the Upper Old Red Sandstone and Horse Roads Sandstone (Fig. 7a) are dominated by illite (mean = 62%) and kaolinite (mean = 35%) along with a low percentage of chlorite and vermiculite. Illite smectite mixed-layer is present as minor traces in both sequences.

CRYSTALLINITY

Kaolinite crystallinity was nearly similar in all samples, while illite was usually well crystallized except in the sequence between the Kip Carle—to Cove Harbour Sandstones. Chlorite could not be observed directly on diffraction traces because of the lack of its (001) reflection at 14Â and the overlap of its (002) reflection at about 7Â by the (001) reflection of kaolinite and, therefore, its crystallinity—could not be assessed directly.

ILLITE CRYSTALLINITY

The effect of deep burial on clayey sediment has been investigated by the study of the crystallinity of illite. The crystallinity of illite increases with increasing degree of burial diagenesis (Kisch, 1983). The illite crystallinity is determined by the sharpness ratio of Weaver (1960), and is measured from the ratio of the height of the illite 001 peak at 10Â to the height above the base line at 10.5Â (Fig. 8). Weaver's (1960) sharpness ratio and the crystallinity index (width of the 10Â peak at half height) of Kubler (1966) are both related to the shape of the (001) illite peak toi to illite crystallinity and burial temperature. With increasing temperature of (001) diffraction peak of illite tends to sharpen as the crysallin My increeases.

Illite crystallinity depended not only on the temperature of recrystallization but also to the chemical composition of the octahedral layer (Weaver and Bradley, 1984). The level of aluminum in the octahedral layer of illite plays an important role in this relationship with an incrdase in the Al/(Fe-Mg) ratio, with increasing metamorphic grade (Hardly and Tucker, 1988). The distribution of aluminous and ferro-magnesian components in illite is determined by calculating in tensity ratio of the illite 5Â and 10Â peaks, i.e. I (002) / I (0021) (Table 1). Aluminous illite attains a strong crystallinity and thus the I (002)/-(001) ratio will be greater than 0.26. Also an increase in K+ causes an increease in the (002)/-(001) ratio and an increase in Fe causes a decrease in the ratio (Weaver and Bradley, 1984). During increasing illite crystallinity the peak betweeh 10Â-12Â gradually narrows around 10Â as the interlayer water is lost and potassium is absorbed.

The illite in these mudrocks has a high Weaver crystallinity index varying from 1=53-3=67 (Table 1). These values probably reflect the fact that illite was mainly derived by the transformation of a pre-existing illite-smectite mixed-layer clay or a more poorly crystallised illite.

DISCUSSION

In this study the most important clay minerals are kaolinite and illite : Chlorite, illite/smectite and vermiculite are found as minor phases, while attendant minerals feldspar, quartz, ferroan dolomite and pyrite occur in the XRD traces. These clay minerals are discussed in the order of their probably paragenetic formation.

Kaolinite

Kaolinite has either a detrital or diagenitic origin. Detrital kaolinite is formed in part by the erosion of sediments containing kaolinite, while diagenetic kaolinite is formed by the transformation of illitic clays or feldspars in the presence of acidic water containing high concentrations of organic material.

Curtis (1983) has suggested that a considerable amount of kaolinite may precipitate from acidic waters derived from underlying compacting organic-rich shales. At low pH the solubility of aluminum is higher and, therefore, feldspars are unstable and their dissolution to form kaolinite occurs. The potash feldspar acts as a source of Al_{+3} and Si_{+4} ions and the presence of partly degraded illite could act as an acceptor for the excess of K_{+} ions which are released during feldspar decomposition (Bucke and Mankin, 1971). Kantorowicz (1985) postulated that the early diagenetic mineral reactions soon after deposition include the partial alteration of muscovite to kaolinite, the partial dissolution of feldspar and the precipitation of kaolinite or chlorite. Bjorkum et al., (1990) suggested that the K-feldspar is transformed to kaolinite by the following equation :—

(K—feldspar) (Kaolinite)

$$2KAISi_3O_8 + 2H_2CO_3 + H_2O \longrightarrow Al_2Si_2O_5(\ )H_4 + 4SiO_2 + 2HCO_3- + 2K^+$$

The authigenic kaolinite may occur by degradation of muscovite according to the following reaction :—

fmus (Muscovite) (K-feldspar)
(Kaolinite)

$KAl_3Si_3O_{10}(OH)_2 + 2SiO_2 + H_2O =$
$KAlSi_3O_8 + Al_2Si_5O_2(OH)_4$

Authigenic kaolinite and feldspar may thus form simultaneously from water supersaturated with respect to quartz.

Illite

Illite occurs as a detrital mineral, as an authigenic phase and as an alteration product of kaolinite, micas, and feldspars. Illite is stable under alkaline conditions and is stable in preference to kaolinite with increasing temperature. Authigenic illite probably forms by the illitization of kaolinite in a closed system at intermediate burial depth (3-4 km) at temperatures of 130-15° C with K-feldspar as a source for the potassium (Bjorkum and Gjelsvik, 1988). It may also form by the degradation of smectite at temperatures around 100°C (Hower *et al.*, 1976). It is suggested that illite-smectite phases undergo progressive illitization during the burial of sediment) Imam and Shaw, 1985). The illitization probably commences at about 60°C and produces a significant reduction in the proportion of smectite lavers at burial temperatures of 100°C-110°C. Shaw (1980) postulated that in the presence of alkaline pore water the smectites are progressively transformed to illite through dehydration, absorption of alkaline cations and lattice rearrangements via illite/smectite mixed layers (or the promotion of chlorite formation via chlorite/smectite mixed-layer phases depending on whether the pore waters are potassium-or magnesium-rich))Fig. 9). He also suggested that vermiculite progressively transformed to illite or chlorite via vermiculite/illite or vermiculite/chlorite mixed-layer phases.

Illitization probably involves three fundamental process, dissolution, solute mass transfer and precipitation or crystallization (Whitney, 1990). In a fluid deficient smectite system, as the primary smectite dissolves and more stable illite begins to form, the rate and extent of illitization is affected by the abundance of water in the system- (reducing the water content retards illitization). Weaver and Beck (1971) suggested that potassium feldspar is the main source of potassium for the illitization during diagenesis. Meshri (1986) postulated that illite can be formed by the conversion of microcline at 25 °C and 1 bar pressure in H2CO3 such that :

(Microcline) (Carbonic) Acid) (Illite)
$3KAISi_3O_8 + 2H\_CO_3 + 12H_2O \longrightarrow KAl_3\ Si_3O_1O$
$(OH)_2\quad 2K+ + 6H_4SiO_2 + 2HCO_3—$

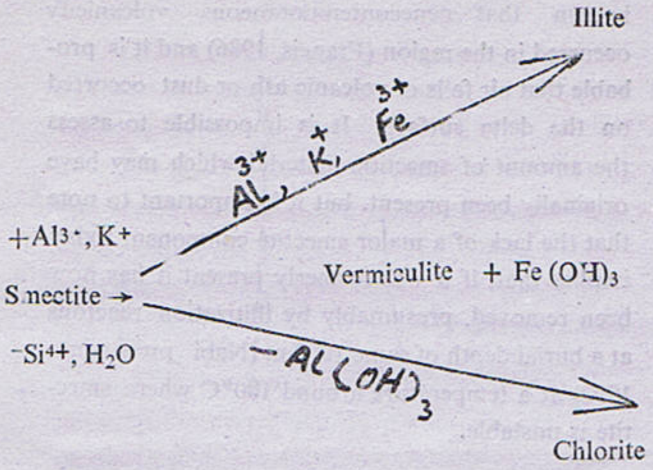
Chlorites are usually derived from weathering profiles, where in early diagenesis smectites are transformed into chlorite. During burial diagenesis chlorites are more stable and regular. It is suggested that reducing pore waters cause the reduction of ferric iron to ferrous iron involving a raise of pH. In these alkaline conditions chlorite forms instead of kaolinite (Curtis, 1977), Kantorowicz, (1984) Chlorite is also formed from kaolinite by reaction with Fe^{2+3+} and Mg^{+2} present in the sediment as temperatures increqse during burial causing kaolinite instability. The Fe is believed to come from siderite (Weaver and Bradley, 1984). Houer et al., (1976) suggested that chlorite is most likely formed from iron and magnesium released from smectite during diagenesis.

Illite/Smectite

Illite/smectite mixed layer clays are probably produced by the mechanical rearrangement of layers facilitated by wetting and drying in an open system which fixes the K+ between the high charge smectite layers (Whitney, 1990). Smectite in compacting shale will expel water in excess of two water layers at temperatures below 60°C, one of the two remaining layers will then expel at temperatures of 67°-81°C, the last water being lost at 172°-192°C (Colten—Bradley, 1987).

Vermiculite

The minor traces of vermiculite in some samples (measured section between the Upper Old Red Sandstone and the Horse Roads Sandstone) is probably due to the conversion of smectite to illite during burial by absorbing the amorphous Fe_2O_3 and / or Al_2O_3 (Singer and Muller, 1983) according to the following process:—



It is also possible that the vermiculite is a product of weathering and probably originated by the alteration of the pre-existing chlorite or mica. The original layer charge on the mica or chlorite may be reduced slightly during the alteration to vermiculite by oxidation of octahedral ferrous iron or by hydroxylation of O to OH.

It is suggested on the basis of the clay mineral assemblages of the mudrocks of these sequences that these minerals have formed during middle diagenesis as defined by Dunoyer de Segonzac (1970). The presence of kaolinite in the mudrocks possibly indicates a tropical humid palaeoclimate (Andrews, 1987, Hurst, 1985, Bjorkum *et. al.*, 1990). Figure 10 is a plot of the W.I. (Weaver Sharpness Ratio) versus K.I (Kublar Index) values of these mudrocks. The results indicate that the crystallinity indices of the illites are in the diagenetic field rather than in the anchizone or epizone fields (see also Weaver and Bradley, 1984). The intensity ratio of illite (I (002) / I (001) has been plotted (Fig. 11) against the Kublar index (10Â peak width at half height) and it is found that the intensity ratio of the illite ranges from 0.4 to 0.95 As Dunoyer de Segonazac (1970) suggests that aluminous illites have a I (002) / I (001) ratio greater than 0.26, the illites of these mudrocks are clearly aluminous. Increasing the ratio of I (002) / (001) is explained by an increase in the Al / (Fe+Mg) ratio, therefore, Figure 11 also shows that the illite in the samples between the Kip Carle to Cove Harbour Sandstones are more aluminous than the samples between the Upper Old Red Sandstone to Horse Road Sandstone. This indicates that the illite crystallinity in the samples between the Kip Carle to Cove harbour is higher than in the samples between the Upper Old Red Sandstone to Horse Roads-Sandstones. It is also indicated that the measured values of the illite crystallinity in some samples of the sequence between the Kip Carle and Heathery Heugh—Sandstone range from diagenetic to marginal anchizone values (deep zone of diagenesis (Dunoyer de segonzac, 1970) or (zone between late diagenesis and epizone (Gilll *et al.* 1977).

It is also suggested that the abundance of kaolinite in the sequence (between the Kip Carle to Cove Harbour Sandstones) (Figs. 13-15) is reflected probagly both in high Al_2O_3% and Al_2O_3 SiO_4, which might be due to the dissolution of feldspar, although some kaolinite might be of detrital origin It may also be suggested that the kaolinite is linked to synsedimentary soil-forming conditions, under which degradation and the loss of illite took place. The decrease of kaolinite in the sequence between the Upper Old Red Sandstone and Horse Roads Sandstone (Fig. 12) may reflect the diagenetic instability of kaolinite although it could be due to a lower abundance if of kaolinite in the original detrital clay assemblage.

The distributation of kaolinite in the sandstones of the above sequences is always in pore spaces (observed by cathodoluminescene microscopy) in the form of clusters adjacent to the quartz or feldspar grains. This supports the idea that the kaolinite in the mudrocks is at least in part due to authigenic grrowth. The intercalation of coal with mudstones in the sequence also suggests that the formation of diagenetic kaolinite might have been favoured by the presence of organic material which maintains a low pH one of the major factors encouraging the dissolution of feldspar. Indeed Curtis (1990) has postulated that soil clay mineralogy is strongly influenced by vegetation (organic content).

The dominance of illite between the Upper Old Red Sandstone and the Horse Roads Sandstone might be a weathering product but some illite may be formed by the transformation of smectite during burial. It is suggested that in Figure 16 the difference in the ratio of Ki/Wi values of the mudrocks of the sequence from the Upper Old Red Sandstone to Horse Roads Sandstone and the sequence from the Kip Carle to Cove Harbour Sandstones might be due to changes in the source of the clays rather than diagenesis. For example, it could reflect a change from the erosion of relatively weathered Southern Uplands Silurian metagraywakes during the early part of the Carboniferous, to the erosion of more fresh (Silurian) bedrocks as base level lowering progressed.

The simplest explanation is that illite in these sequences is largely an inherited clay-mineral, i.e. that it is a weathering product of hinterland basin erosion. Having said this, it is possible that some illite has formed diagenetically from the modification of smectitic clays. The burial history curve (Nabi, press com., 1992) shows that the sequence was buried to at least about 2 km by the end of Carboniferous time. Burial to this depth would have dehydrated smectite in the sequence.

The origin of the kaolinite is equally problematic. Again an inherited source is possible, and soil forming environments might have led to some kaolinite authigenessis, especially in sequences where seat earths are common. However, petrographic and SEM examination of associated siltstone and sandstones show that some kaolinite has a diagenetic origin from feldspar alteration.

Finally, it is difficult to assess the former content of smectite clays in the sequence. Idt is well known that penecontemporaneous volcanicity occurred in the region (Francis, 1986) and it is probable that air falls of volcanic ash or dust occurred on the delta surface. It is impossible to assess the amount of smectitic material which may have originally been present. but it is important to note that the lack of a major smectite component today implies that, if it was formerly present it has now been removed, presumably by illitization reactons at a burial depth of same 1800 m (Nabi press com., 1992) at a temperature around 100°C where smectite is unstable.

CONCLUSION

The impression which arises from a first glance at the clay-mineralogical results obtained from the studied sequence indicate that the sediments of this area were controlled by a complex mixture of clays supplied from different sources.

Based upon the clay mineralogy, the sequence was divided into two mineral assemblages. The dominance of Kaolinite over illite content and the lack of chlorite were major characteristics of mineral assemblage.

1. Assibmlage 2, on the other hand, was characterized by the dominance of illite over kaolinite along with minor chlorite content, especially in the mud rocks which are associated with the cementstone. Assemblage 1 occurreed in the sequence between the Kip Carle Sandstone and the base of the Bilsdean Sandstone, while assemblage 2 represented the Upper Old Red Sandstone.

In general, there is a suggestion that kaolinite content increases in those mud rocks associated with silty and sandy interbeds and it is suspected that much of the mud rock kaolinite has a diagenetic origin.

ACKNOWLEDGEMENTS

Thanks are due to Professor Aftab A. Butt, Institute of Geology, Punjab University and Dr. Abdul Salam Khan, Geology Department, University of Balochistan, Quetta for critical review of the paper and useful suggestions. The authors wishes to express their appreciations to the individual of East Anglia University, Norwich, England for their co-operation and assistance in laboratory studies. G. Nabi is very thankful to the Government of Pakistan for the financial support during his stay in England.

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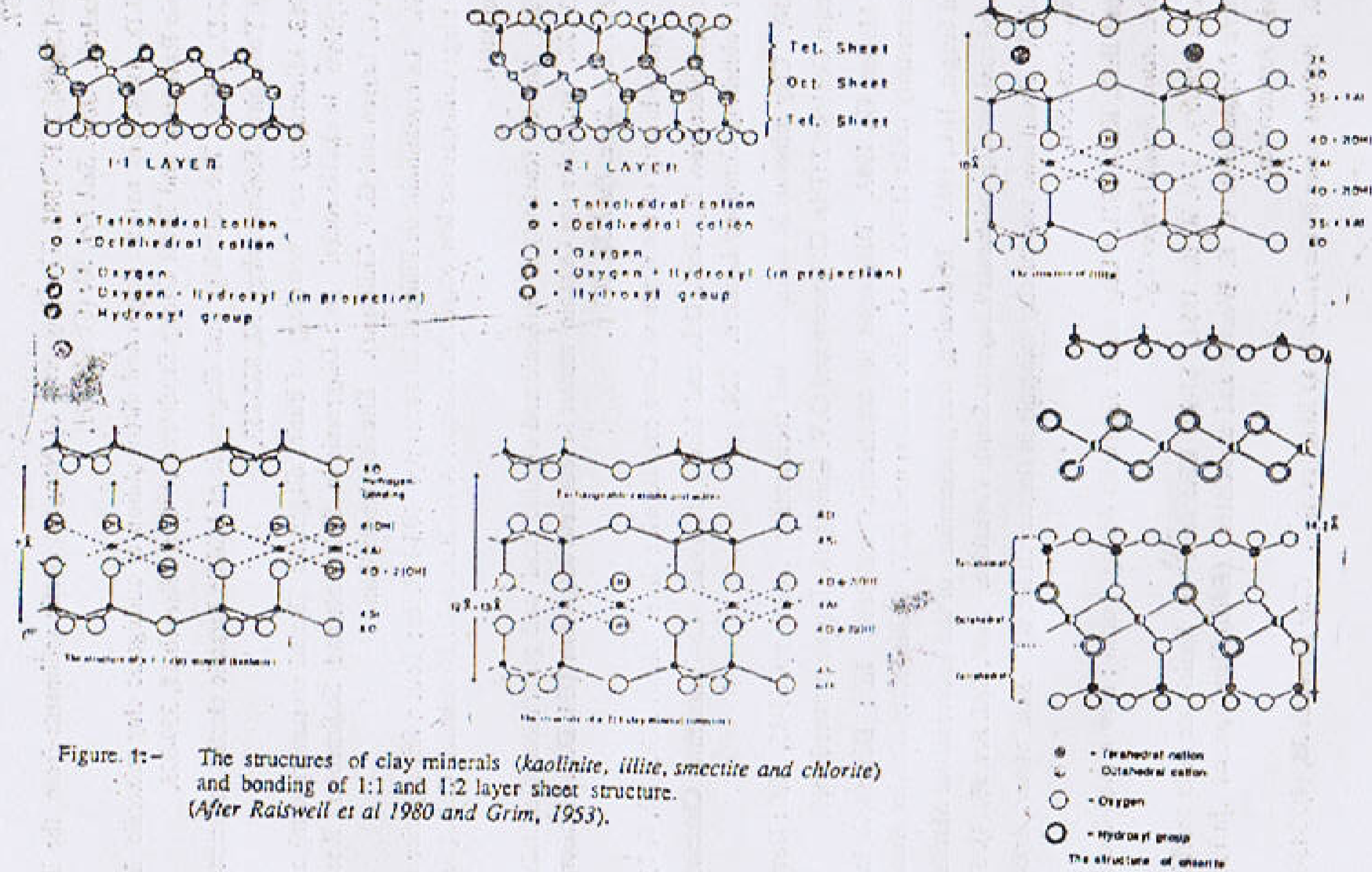


Figure. 1:– The structures of clay minerals (*kaolinite, illite, smectite and chlorite*) and bonding of 1:1 and 1:2 layer sheet structure.
(*After Raiswell et al 1980 and Grim, 1953*).

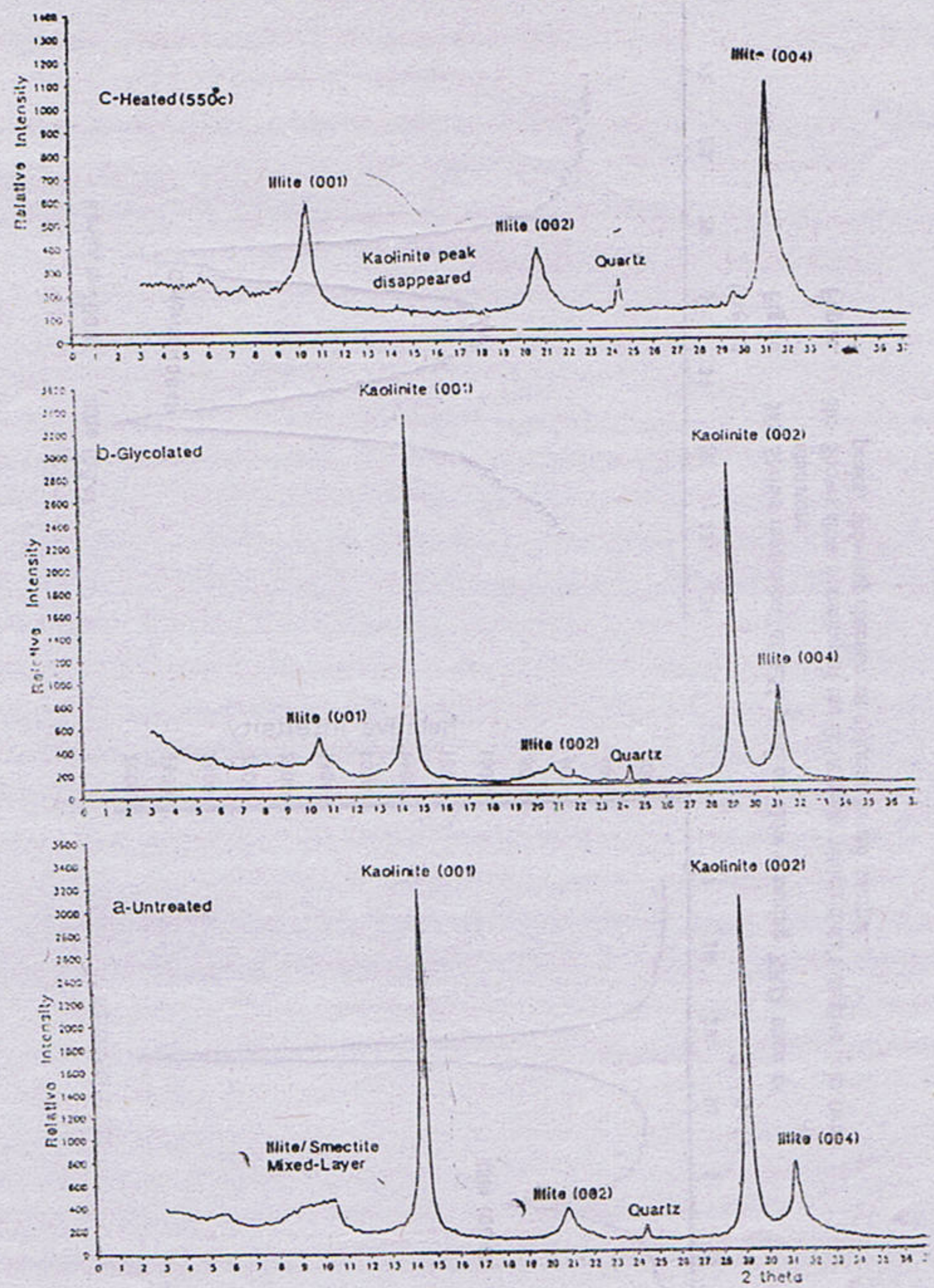
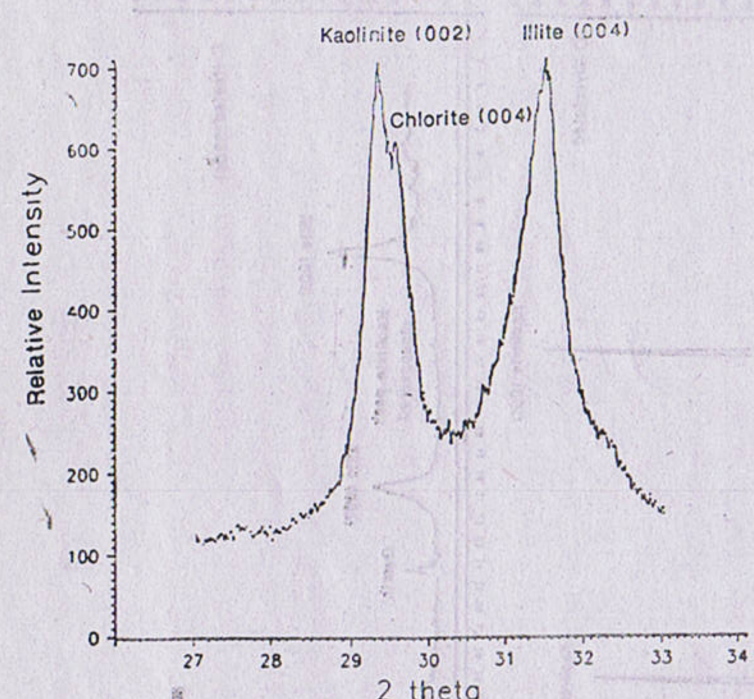


Figure 2:- XRD traces of mudstone showing Kaolinite reflection.
(a- untreated, b- Glycolated c- Heated 550°c)



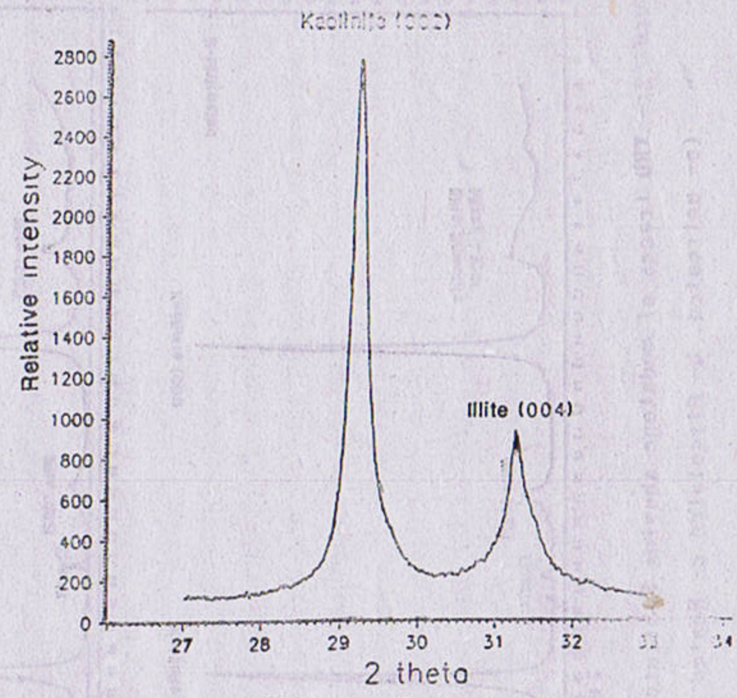


Figure. 3a:- Shows resolution of 3.5Å peak on slow scanning XRD trace of mudstone.

Figure. 3b:- Shows slow scanning of the 3.5Å peak, which didn't resolve into two peaks, showing absence of chlorite in the sample.

Plate 1:- Books of Kaolinite in SEM photograph

Plate 2:- Chlorite crystal flakes in SEM photograph

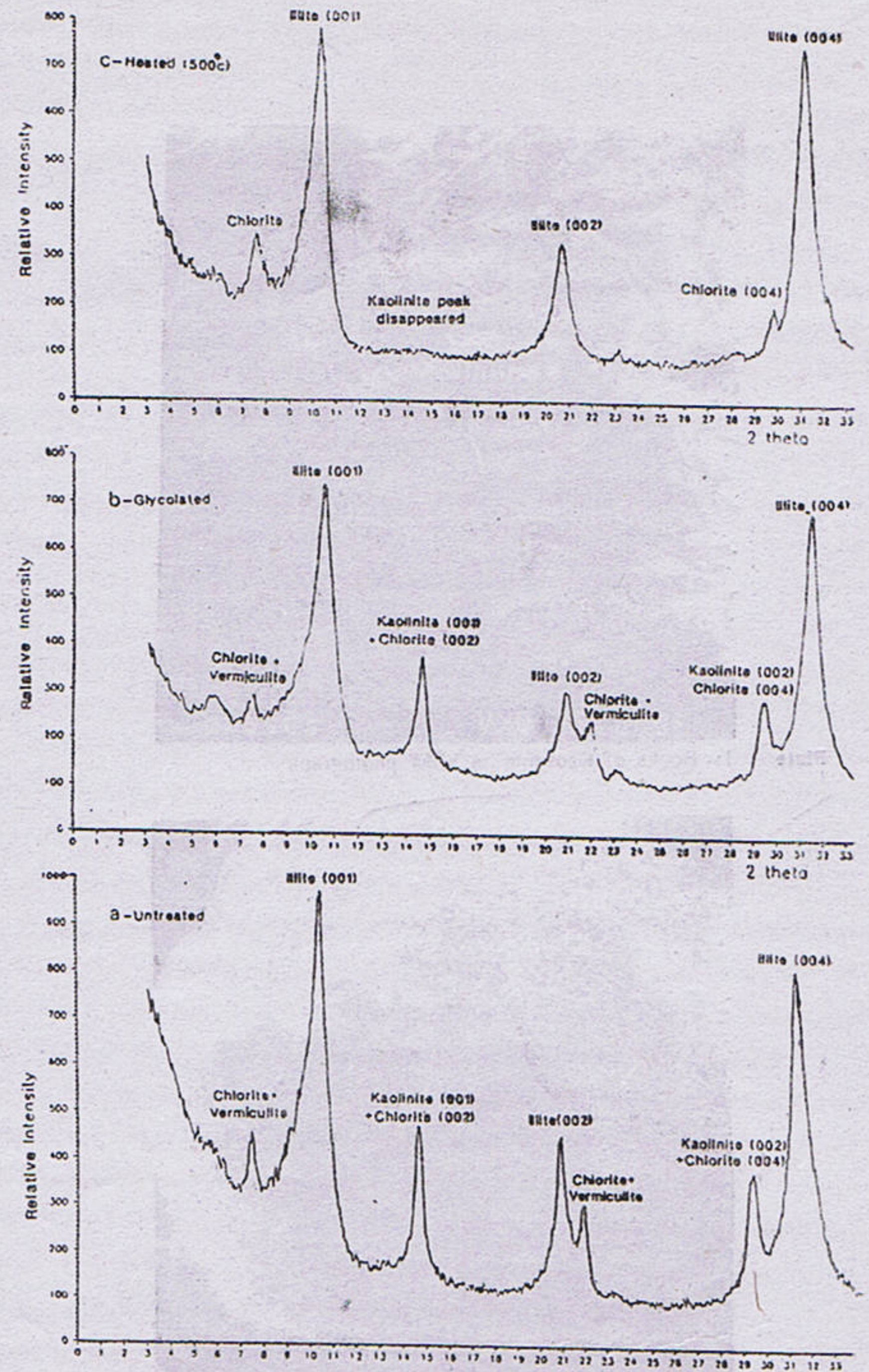


Figure. 4 - XRD traces of mudstone showing illite reflection (a- untreated, b- Glycolated c- Heated 550°c).

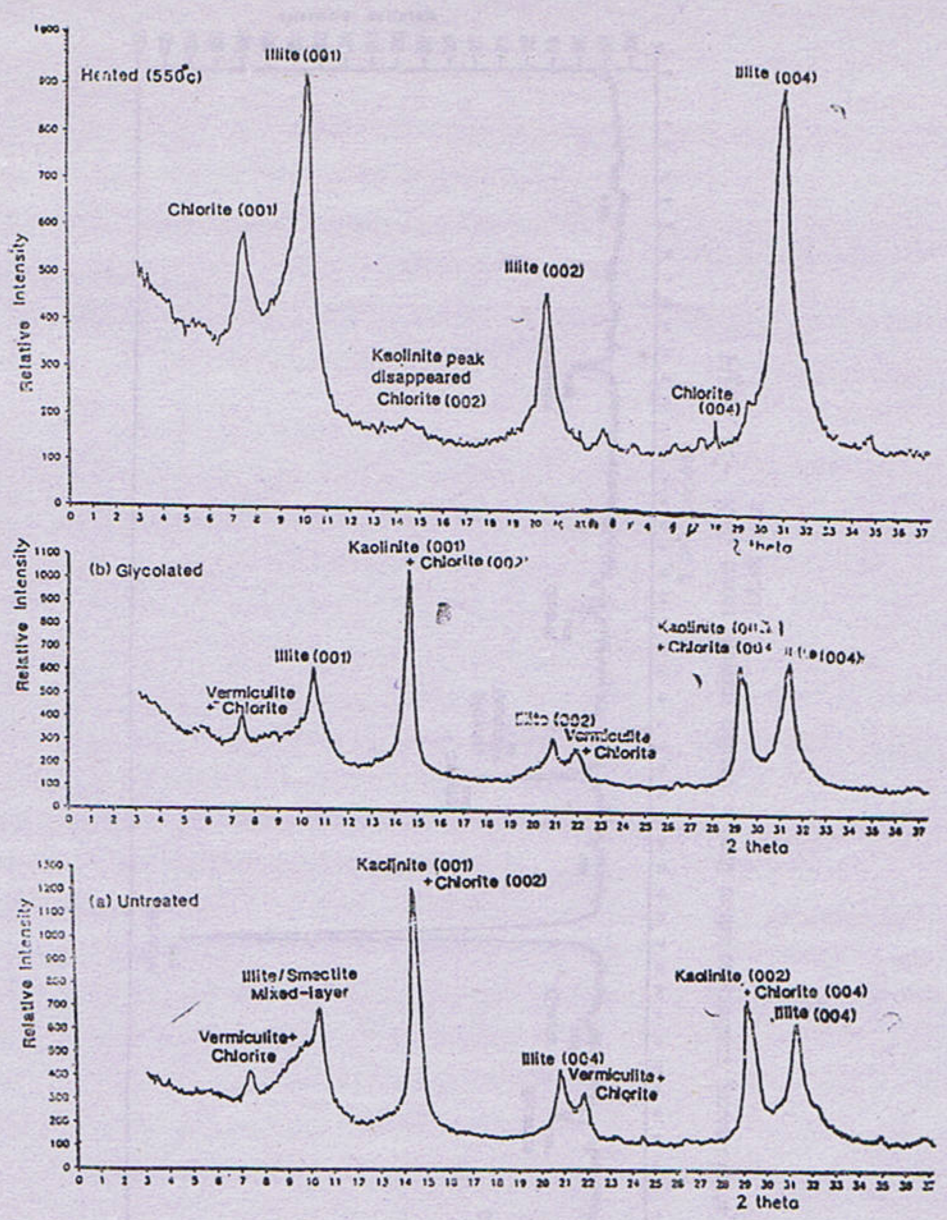


Figure. 5:- XRD traces of mudstone showing chlorite & vermiculite reflections reflection (a- untreated, b- Glycolated c- Heated 550°c)

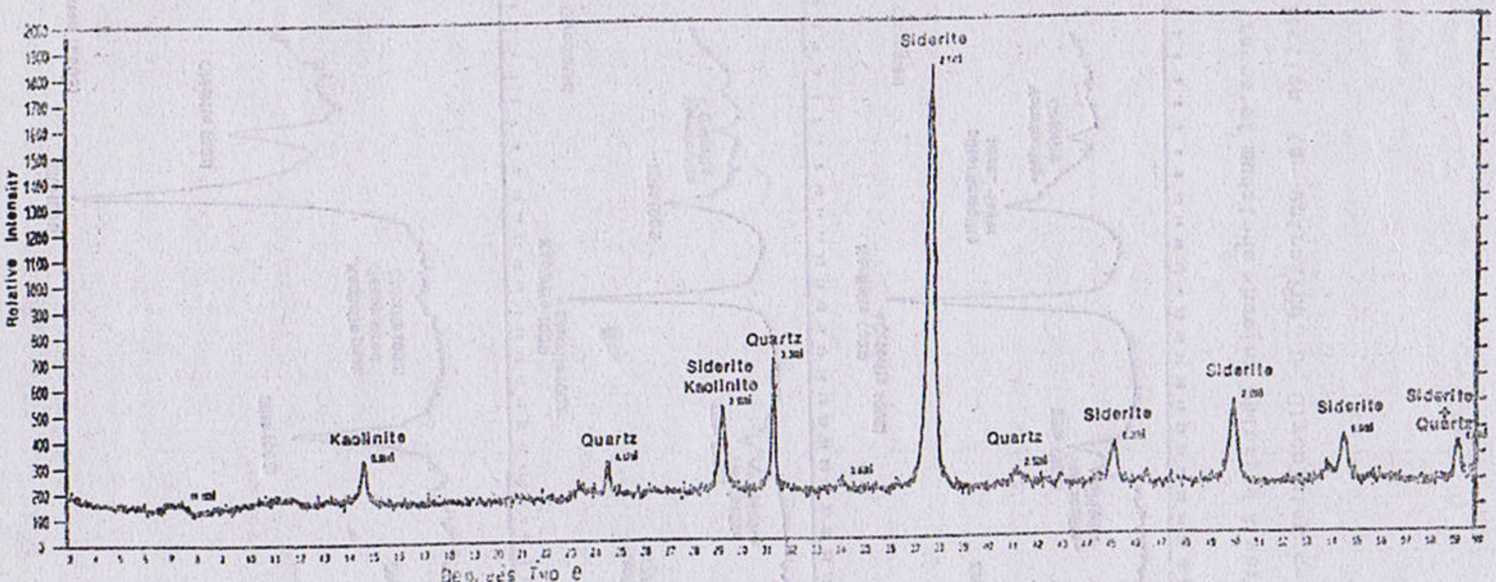


Figure. 6:- XRD traces showing siderite mineral in the concretions present in the mud rocks.

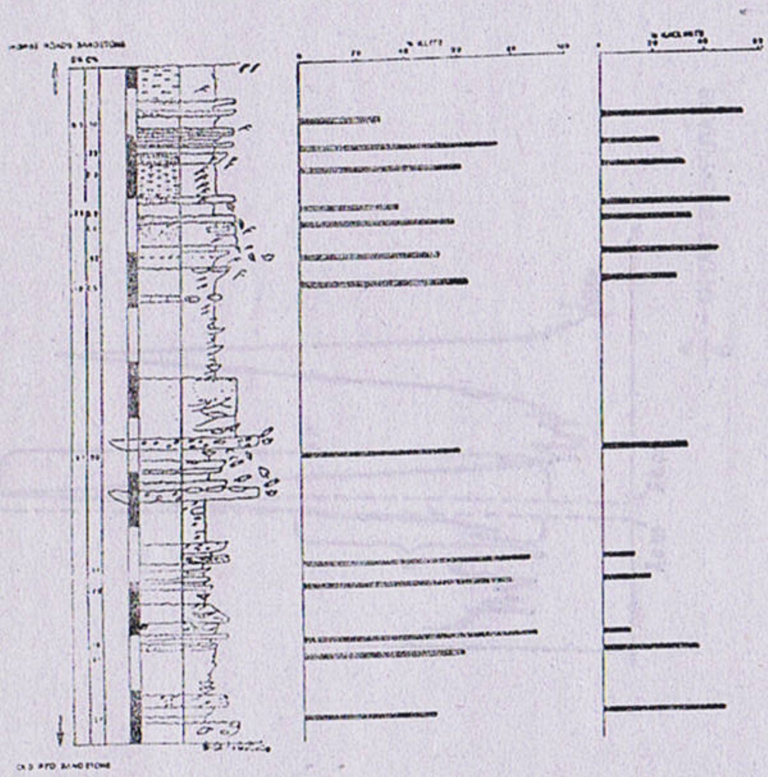


Figure. 7a:- Clay mineral percentage of the mudrocks between the top of the Upper Old Red Sandstone and base of the Horse Roads Sandstone (Measured section of M.Turner & J.Andrews)

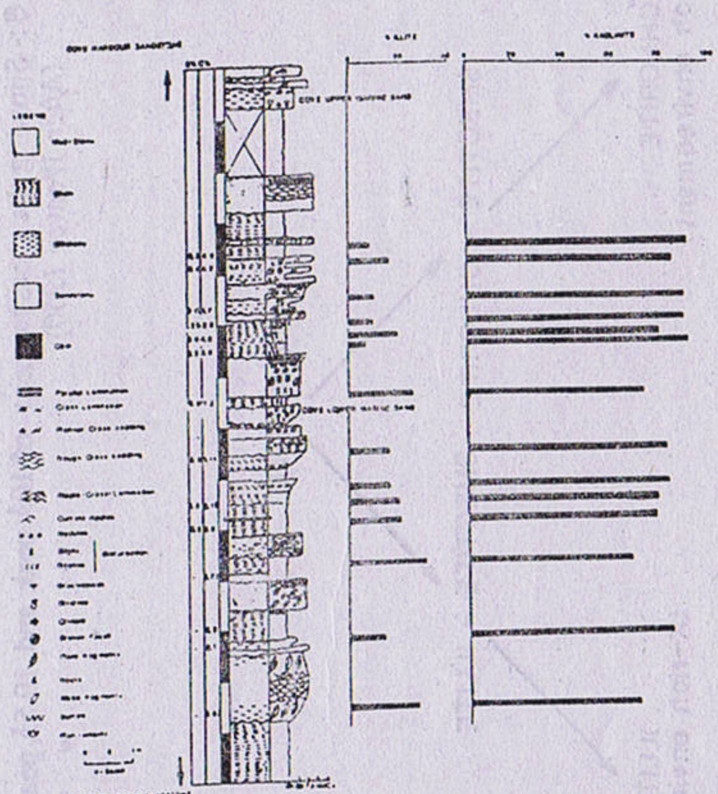


Figure. 7b:- Clay mineral percentage of the mudrocks between top of the Heathery Heugh Sandstone and the base of the Cove Harbour Sandstone.

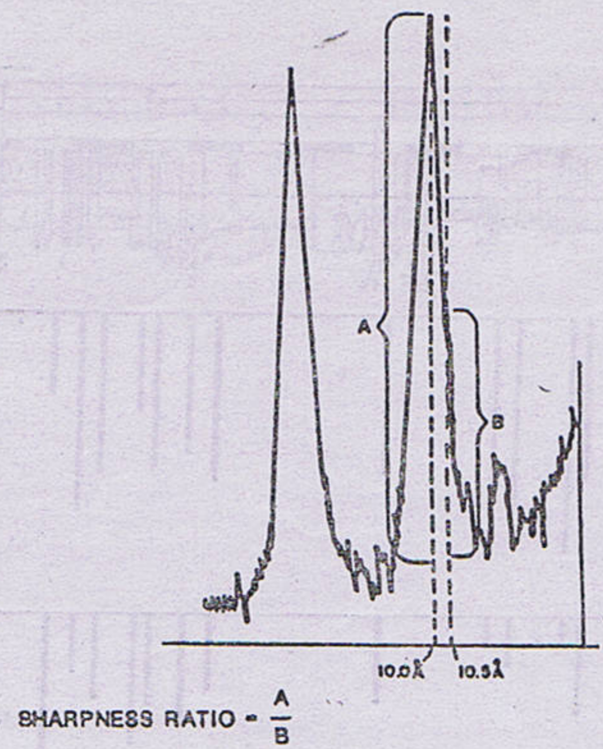


Figure. 8:- Showing the measurement of 10Å peak and 10.5Å peak and their ratio. (*After Weaver 1960*)

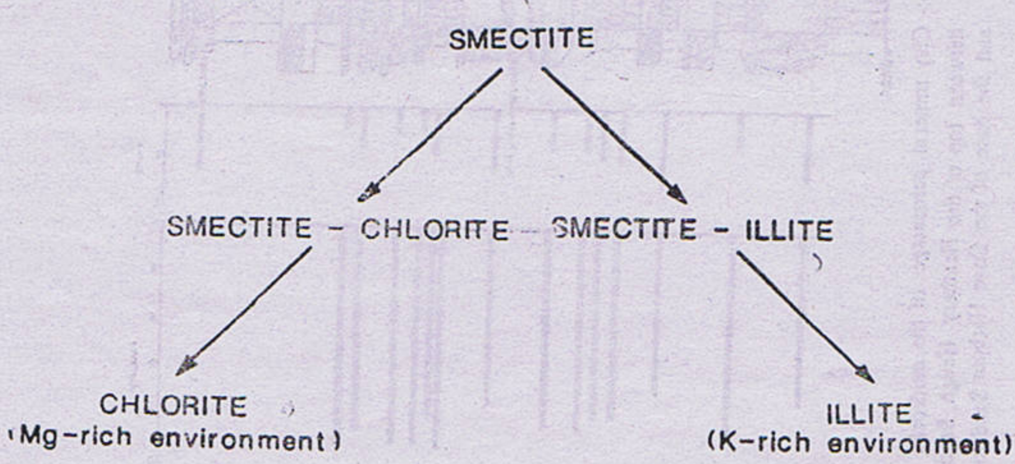


Figure. 9:- Transformation of smectite during burial diagenesis.

TABLE- 1

Samples of the mudrocks from Upper Old Red Sandstone to Horse Roads Sandstone.

Sample	10Å Peak Height (mm)	10.5Å Peak Height (mm)	5Å peak Intensity (mm)	1/2(10Å) Peak Width(mm)	Sharpness Ratio (mm)	Intensity Ratio(mm) 001/002	Intensity Ratio(mm) 002/001	KI/WI	KI/RATIO OF 002/001
05888-01	46.00	24.00	30.00	10.00	1.92	1.53	0.65	5.22	15.33
05888-02	128.00	72.00	62.00	12.00	1.78	2.06	0.48	6.75	24.77
05888-04	115.00	70.00	70.00	15.00	1.64	1.64	0.61	9.13	24.64
05888-03	114.00	60.00	53.00	12.00	1.90	2.15	0.46	6.32	25.81
J05888-01	47.00	24.00	29.00	8.00	1.96	1.62	0.62	4.09	12.97
J05888-02	115.00	75.00	67.00	16.00	1.53	1.72	0.58	10.43	27.46
05888-03	65.00	37.00	62.00	12.00	1.76	1.05	0.95	6.83	12.58
J05888-04	19.00	7.00	11.00	7.00	2.71	1.73	0.58	2.58	12.09
05888-05	48.00	27.00	31.00	11.00	1.78	1.55	0.65	6.19	17.03
05888-06	50.00	14.00	28.00	7.00	3.57	1.79	0.56	1.96	12.50
05888-07	118.00	36.00	47.00	8.00	3.28	2.51	0.40	2.44	20.09
05888-08	70.00	35.00	50.00	10.00	2.00	1.40	0.71	5.00	14.00
02888-15	40.00	11.00	20.00	7.00	3.64	2.00	0.50	1.93	14.00

Samples of the mudrocks from Kip Carle Sandstone to Heathery Heugh Sandstone.

Sample	10Å Peak Height (mm)	10.5Å Peak Height (mm)	5Å peak Intensity (mm)	1/2(10Å) Peak Wedith	Sharpness Ratio (mm)	Intensity Ratio(mm) 001/002	Intensity Ratio(mm) 002/001	KI/WI	KI/RATIO OF 002/001
21889-04	19.00	6.00	17.00	6.00	3.17	1.12	0.89	1.89	6.71
17889-21	23.00	7.00	18.00	6.00	3.29	1.28	0.78	1.83	7.67
21889-3	9.00	5.00	8.00	6.00	1.80	1.13	0.89	3.33	6.75
17889-19	15.00	5.00	9.00	6.00	3.00	1.67	0.60	2.00	10.00
17889-18	6.00	2.00	3.00	7.50	3.00	2.00	0.50	2.50	15.00
21889-1	22.00	9.00	12.00	9.00	2.44	1.83	0.55	3.68	16.50
17889-16	12.00	4.00	7.00	7.00	3.00	1.71	0.58	2.33	12.00
20889-11	16.00	5.00	9.00	6.00	3.20	1.78	0.56	1.88	10.67
20889-8	17.00	6.00	9.00	8.00	2.83	1.89	0.53	2.82	15.11
20889-4	7.00	2.00	6.00	5.00	3.50	1.17	0.86	1.43	5.83
20889-3	9.00	4.00	5.00	7.00	2.25	1.80	0.56	3.11	12.60
16889-19	4.00	2.00	3.00	5.00	2.00	1.33	0.75	2.50	6.67
20889-1	9.00	3.00	8.00	5.00	3.00	1.13	0.89	1.67	5.63
16889-16	6.00	3.00	4.00	5.00	2.00	1.50	0.67	2.50	7.50
16889-21	8.00	4.00	7.00	6.00	2.00	1.14	0.88	3.00	6.86
16889-13	6.00	2.00	5.00	7.00	3.00	1.20	0.83	2.33	8.40

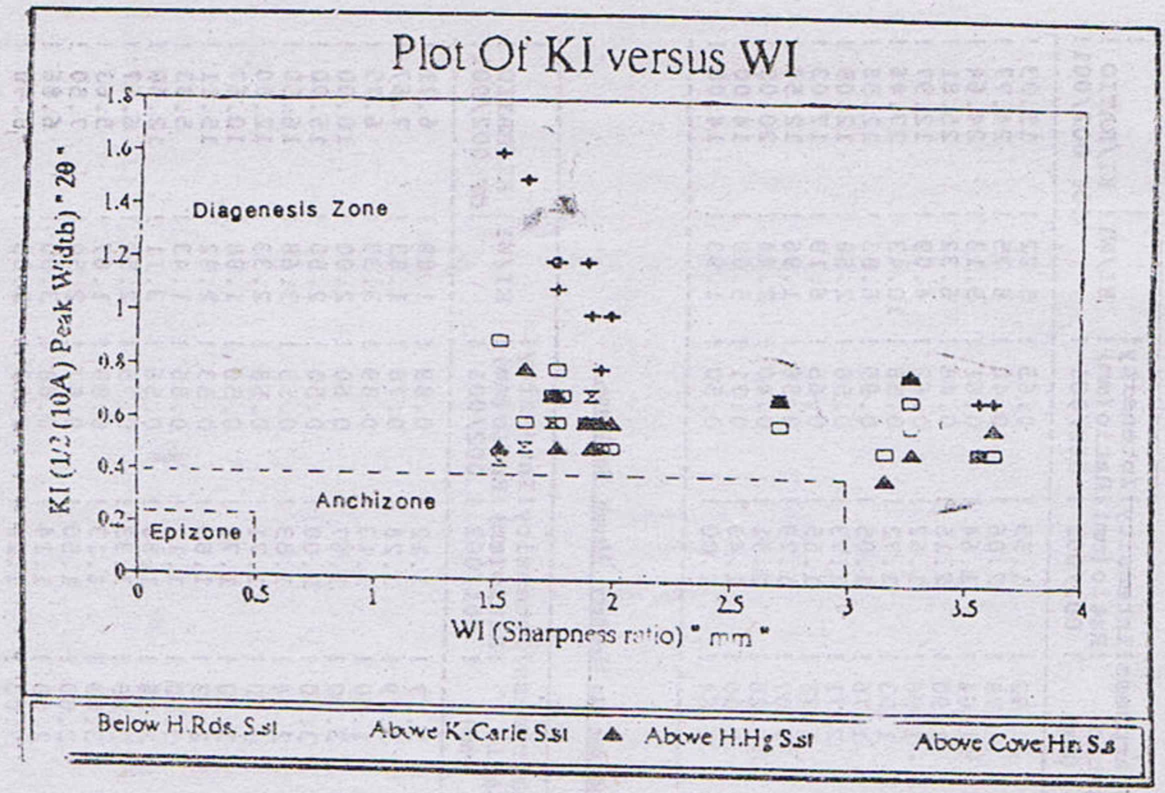


Figure. 10:-A plot of the sharpness ratio (WI) versus Kublar index (KI).

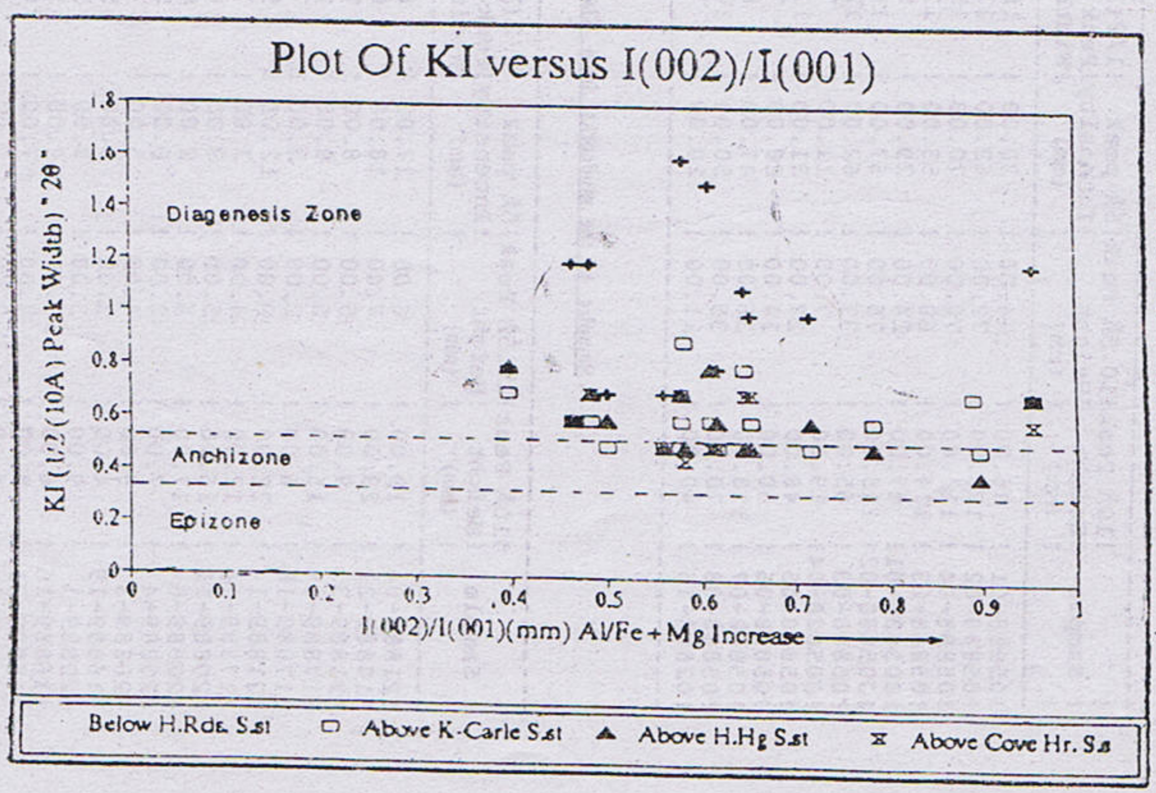


Figure. 11:-Plot of the I(002)/I(001) ratio against the Kublar index (KI).

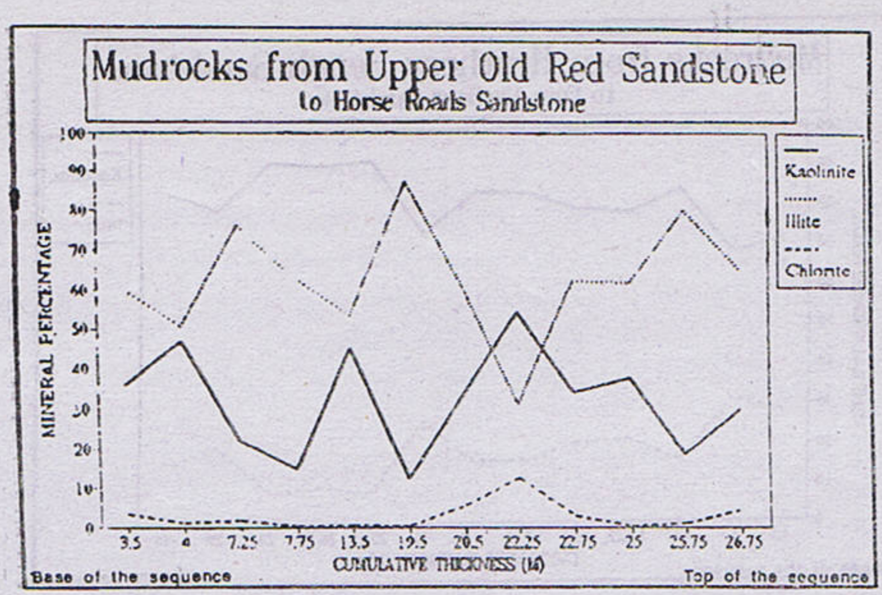


Figure. 12:- Graph showing the percentage of kaolinite and illite in the mudrocks in the sequence between the Upper Old Red Sandstone and Horse Roads Sandstone.

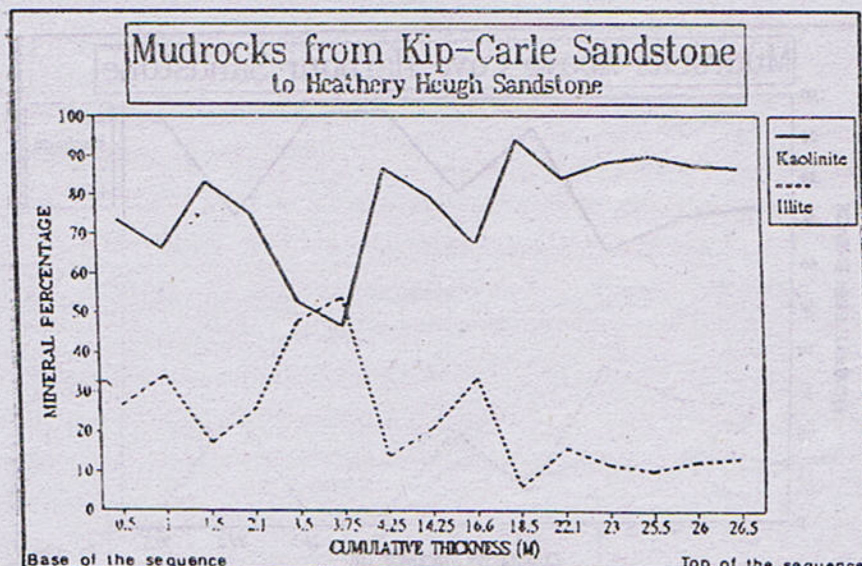


Figure. 13:- Graph showing the percentage of kaolinite and illite in the mudrocks between the Kip-Carle Sandstone and Heathery Heugh Sandstones

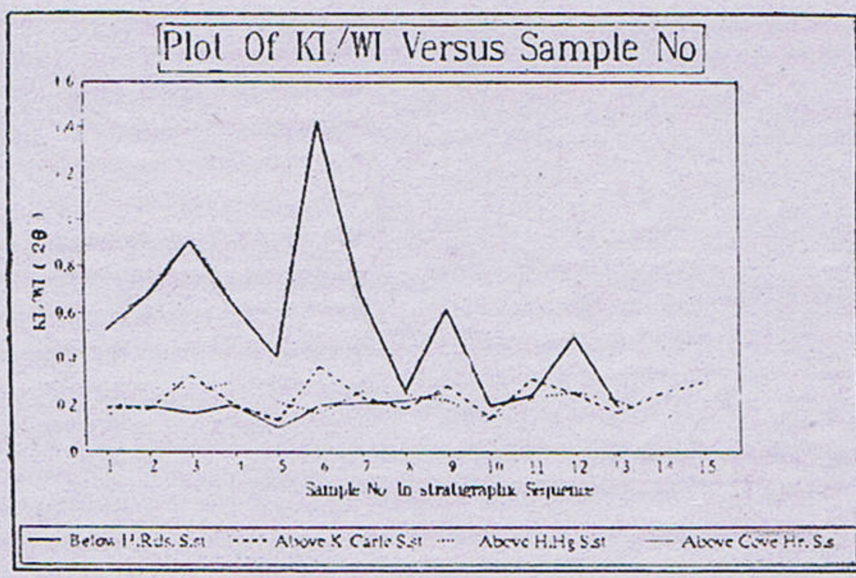


Figure. 16:-Plot of ratio of KI/WI versus sample No's in stratigraphic sequence

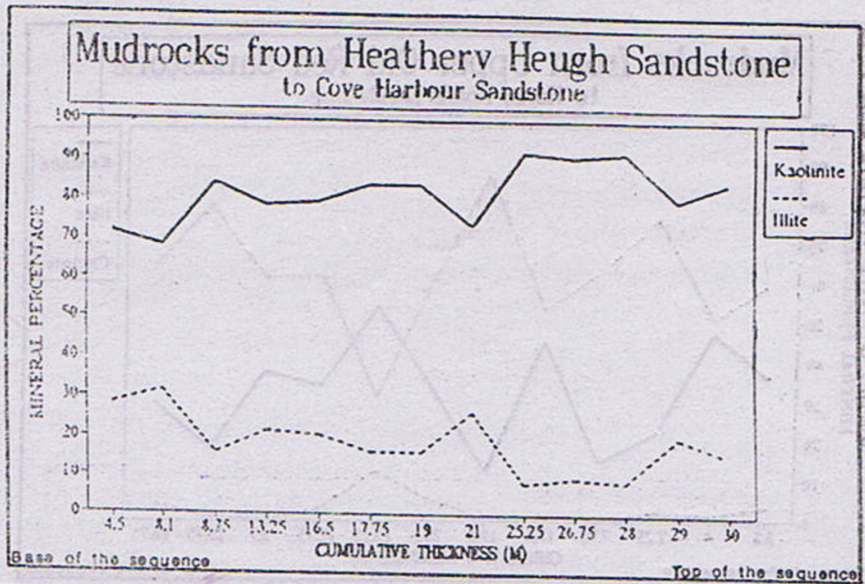


Figure. 14:- Graph showing the percentage of kaolinite and illite in the mudrocks between the Heathery Heaugh Sandstone and Cove Harbour Sandstones.

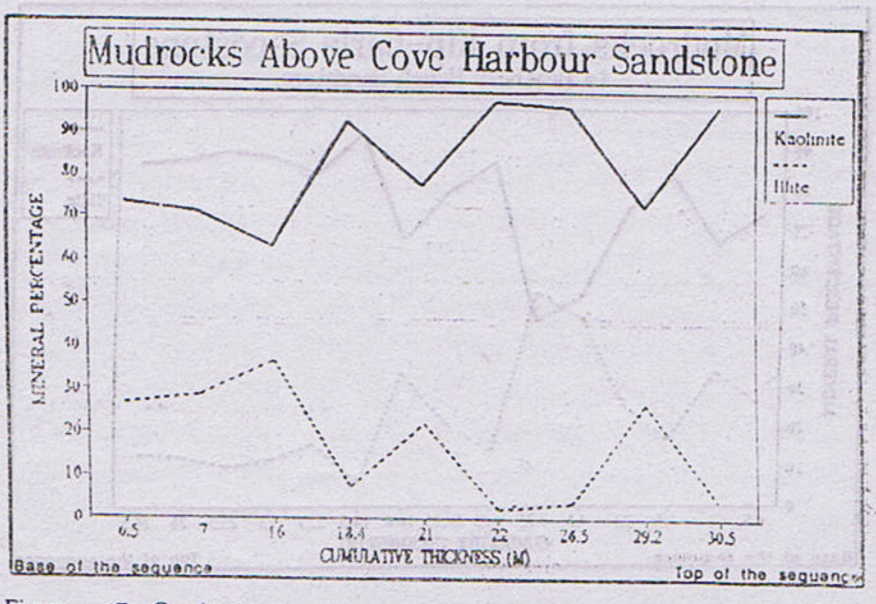


Figure 15:- Graph showing the percentage of kaolinite and illite in the mudrocks in the sequence above the Cove Harbour Sandstone.

Geol. Bull. Punjab Univ. 1993, 28, 73--80

PRELIMINARY SEDIMENTOLOGY OF THE BIBAI FORMATION, AHMADUN GOGAI AREA, ZIARAT DISTRICT, BALOCHISTAN.

BY

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Abstract: *The Bibai Formation near Gogai and Ahmadun area of the Ziarat District is characteristic of (a) pelitic turbidites and (b) subordinate traction dominated thin turbidites of shallow marine origin indicated by the presence of bivalves within the interbeded mudstone and shale horizons. Composition of agglomerate and sandstone, and palaeocurrents suggest derivation of detritus from the nearby "Bibai Volcano" east of Ahmadun.*

INTRODUCTION

The Upper Cretaceous Bibiai Formation (Kazmi, 1979 ; Allemann, 1979) in the Ahmadun-Gogai area of the Ziarat District, comprises a succession of sedimentary and volcanic rocks which conformably overlies the Parh Limestone and ununderlies the Dunghan Limestone. The rocks have been named after the Bibai Peak where they attain maximum thickness (Kazmi, 1979). The Bibai Formation consists of mudstones, sandstones, agglomerates, volcanic ash, tuffs and lava flows.

Two distinct lithostratigraphic subdivisions may be distinguished, namely, the lave dominated portion and the sedimentary succession.The lava dominated part is best developed east of the Ahmadun (Fig. 1), while the sedimentary succession is exposed around Ahmadun-Gogai and further westward, where volcanic ash and mudstones (with occasional sandstone) sequences are dominant. These sedimentary sequences contain a variety of molluscan shells and trace fossils which are characteristic of shallow marine environments.

This paper is a sedimentogical study of the Bibai Formation of Ahmadun and Gogai Villages of the Ziarat District situated 65 miles from Quetta and accessible by Quetta-Ziarat Road. (Fig. 1),

SEDIMENTARY STRUCTURES

Various types of sedimentary structures, namely, graded bedding, (from coarse sandy to silty and muddy), sole marks, parallel cross-lamination, current ripples, parting lineations and trace fossils etc. which are characteristic of turbidites are found in the Biabi Formation. Grading is mostly notable in the lower and upper parts of the sandstone horizons. Among sole marks, flute marks, longitudinal ridges and various other types may be observed. Cross-lamination is mostly of trough type and form very thin sets (a few cm to 5 cm)., thick bedded sequences, correspondingly possess thicker sets (up to over 10 cm), current ripples are mostly of sinuous and linguoid types and in some localities are remarkably consistent. Sandstone beds with pinch and swell and highly undulatory upper surfaces are also common. Trace fossils are very common, mostly on the upper surfaces of the arenaceous beds (Fig. 4), and within the pelitic sequences.

LITHOFACIES ASSOCIATIONS

Three sections (Figs. 2-4) were studied, where two main lithotypes were established.

(a) the dark grey and dark brownish grey to almost black shales and mudstones which are mostly massive with som esilty and parallel laminated intervals (mostly Tde, Te of Bouma, 1962) interbedded with occasional sandy horizons possessing characters of the distal turbidites (Tcd, Tbc of Bouma, 1962),

(b) Mixed horizons (A—H, Figs. 2-4) which possess both pelitic (mixed pelagic, hemi-pelagic and turbidites) and sandy turbidite sequences. The pelitic horizons of these mixed zones are also dark grey, dark brownish grey and black and mostly massive and parallel laminated (Tde, Te of Bouma, 1962). The sandy turbidite sequences are mostly fine to very fine grained and occasionally medium to coarse grained, moderatley sorted and dark brownish grey to dark greenish grey in color. They are mostly very thin bedded (few cm - 10 cm), and some beds are up to 35 cm thick. Most of the turbiditic beds are Tbce, Tce and Tde sequence of Bouma (1962).

However, a few Tabec, de sequence are also present (Figs. 2-4). Such an association of lithofacies resemble with the D1 Facies of Mutti and Ricchi-Lucchi (1975). Their characters indicate that they are the product of very low energy turbidity currents, and it seems that such conditions were persistent for a considerable time period during the depositional history of the Bibai Formation, except only a few thick coarse sandy horizons which may have been deposited by high energy turbidity currents.

PALAEOCURRENT DIRECTIONS

Palaeocurrent directions, based on sole marks, cross lamination, current ripples and parting lineations were measured where observable. Marked contrasts exists between the data obtained from sections near Gogai and those of Ahmadun Nala sections. However, it seems that data of the Ahmad Nala Section is more reliable, because the Ahmadun Nala Section represents a normal sequence placed between the underlying Upper Cretaceous Parh Limestone and the overlying Paleocene Dungan Formation. On the other hand, the sections near Gogai Village represents thrust sheets of the Gogai Nappe which have been tectonically transported several miles from the north, in response to several episodes of thrusting and folding (Niamatullah et al., 1989 ; Kazmi, 1979). Current directions of the Ahmadun Nala Section are also in conformity with Kazmi's suggestion of derivation of the volcanics near Bibai Peak (9934 feet) nearly 4 miles east of the Ahmadun. (Kazmi, 1979)

DISCUSSION

The Hunting Survey Corporation (1960) correlated the volcanic rocks of their Parh Group in Zhob Valley (the Bibai Formation of Kazmi, 1979) with those of the Belal Volcanics and suggested that they were formed in marine environments, apparrently due to the presence of bivalves and gastropods with the andesitic lavas and agglomerates. They sugested that petrology, tectonic framework and rock associations of the Bela Volcanics are consistent with those of asemblages found in Island-Arc systems and do not correspond to the Deccan Trap in either age or origin, as suggested by Vredenberg (1909). DeJong and Subhani (1979) concluded that the Porali Intrusions (Bela Volcanics) and volcanic rocks of the Biabi Formation are rather similar and that during Late Cretaceous, a Volcanic-Arc was formed on shelf of the western margin of the Indo-Pakistan Subcontinent. The Late Cretaceous basaltic and andesitic lavas and pyroclasts of the Bibai Formation were regarded by Kazmi (1979) and DeJong and Subhani (1979) to be of Late Cretaceous Island-Arc origin brought about by subduction of the oceanic plate of the Tethys.

The volcanics and agglomerate of the Biabi Formation to the east of Ahmadu containing cobbles of abasalt, andesite and decite compositionally resemble with the sills and dikes of basalt, dacite and andesite found in the northern margin of calcareous zone and, therefore, are co-magmatic (Otsuki et al. 1989). Otsuki et al. (1989) believe that volcanics of the Biabi Formation are the product of temporal island-arc magmatism and propose two possible explanations for its temporal nature : i) Initiation of another subduction zone as the subduction of the mid-oceanic ridge was throught to be difficult ; ii) Exceptionally high convergence rate (15-17.5 cm!yr) during 50 — 90 Ma, namely the "India's northward flilt" (Johnson et al., 1976) may have caused complementary subduction. This may be a plausible cause of the origin of the Late Cretaceous Island-Arc in the northern margin of the Indo-Pakistan subcontinent.

Our own study of the sedimentary rocks of the Bibai Formation indicates that volcanism was submarine where conditions were fairly shallow, as have been indicated by the association of shallow marine bivalves and millusks (Fig. 4). We think that turbidity currents were frequently generated and were perhaps related to the process of volcanism.

It has been observed that the volcanic sequence in some localities near the Bibai Peak, east of Ahmadun, locally show evidence of disconformity with the overlying Paleocene Dungan Formation, represented by occurrence of yellowish and brownish grey oxidized zone in between indicating that part of the Biabi Volcano was exposed. These evidences support the temporal island-arc magmatism, as have been proposed by earlier workers (Hunting Survey Corporation, 1960 ; Kazmi, 1979; DeJong and Subhani, 1979; Otsuki et al., 1989).

CONCLUSIONS

(1) The Bibai Formation is characteristic of a turbidite facies.

(2) Sandstone petrology shows that detritus has been derived from a volcani terrain. The composition of agglomerate also confirm similar source area.

(3) Palaeocurrent directions suggest derivation from the east, more likely from the "Bibai Volcano" (Biabi Peak) east of the Ahmadun.

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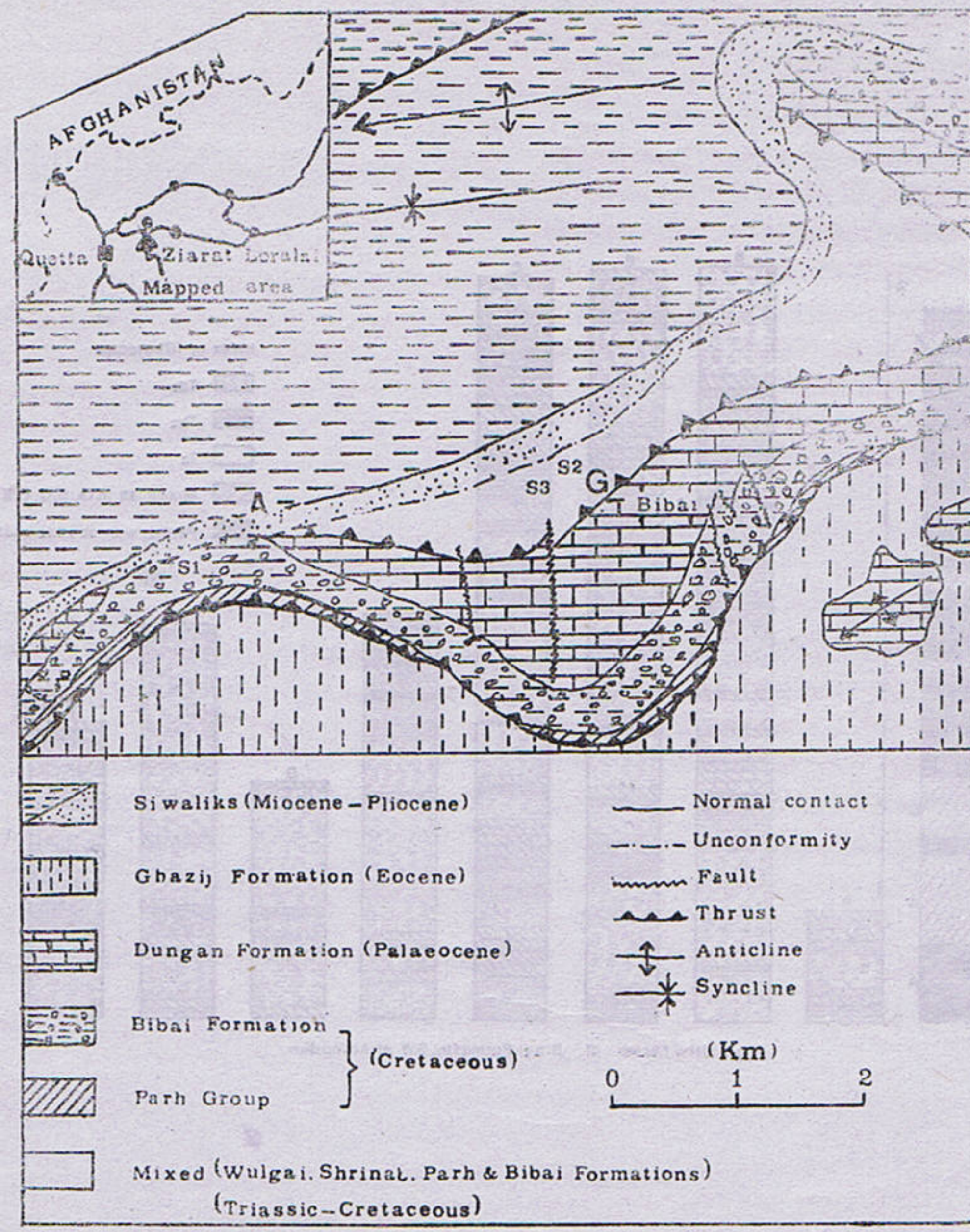

Fig.1 Geological map showing **studied Sections**, Ziarat District

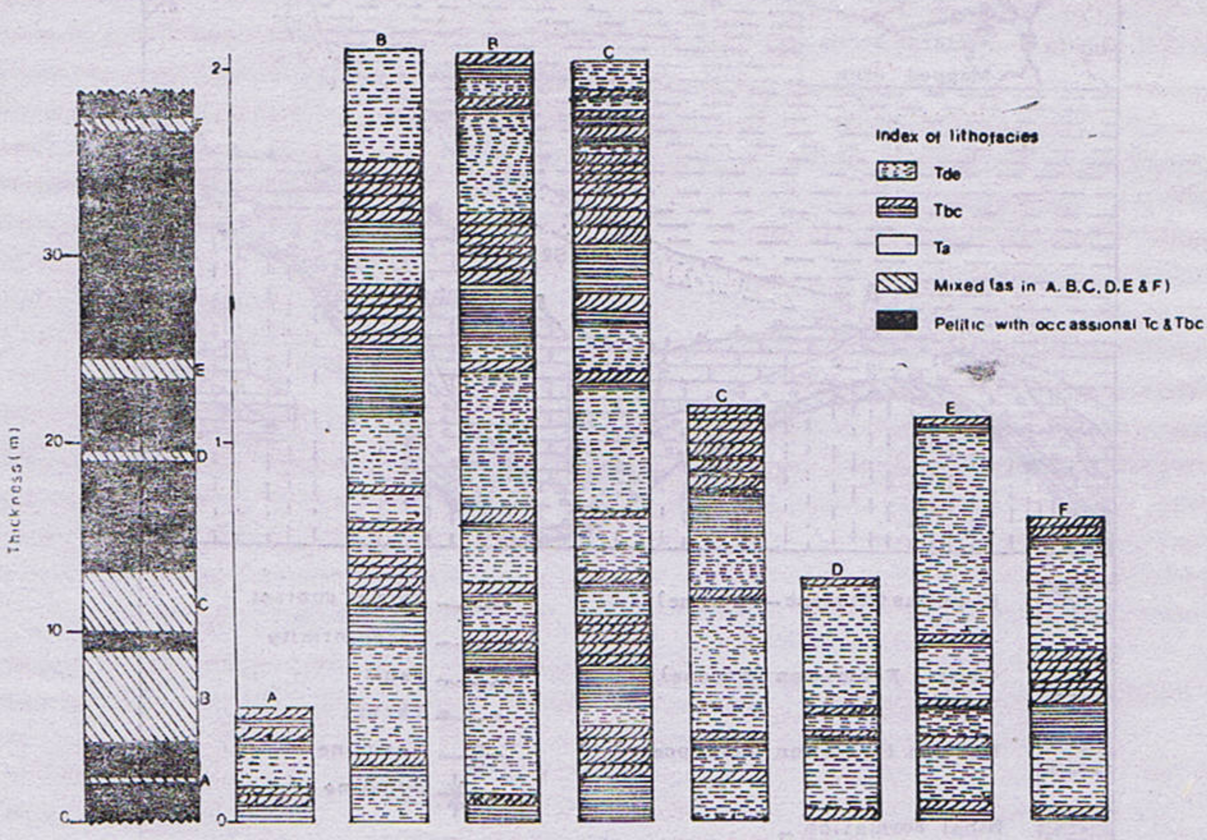

Fig 2 Litho facies of Bibai Formatin, SW of Ahmadun

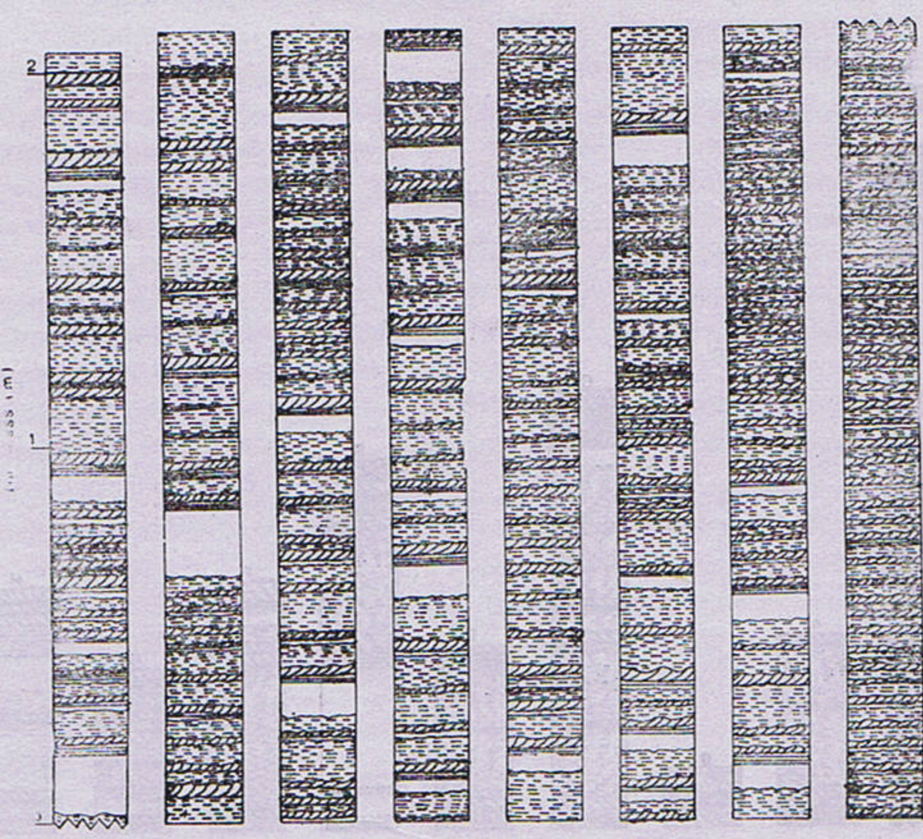

Fig 4 Litho facies of Bibai Formation, W of Gogai

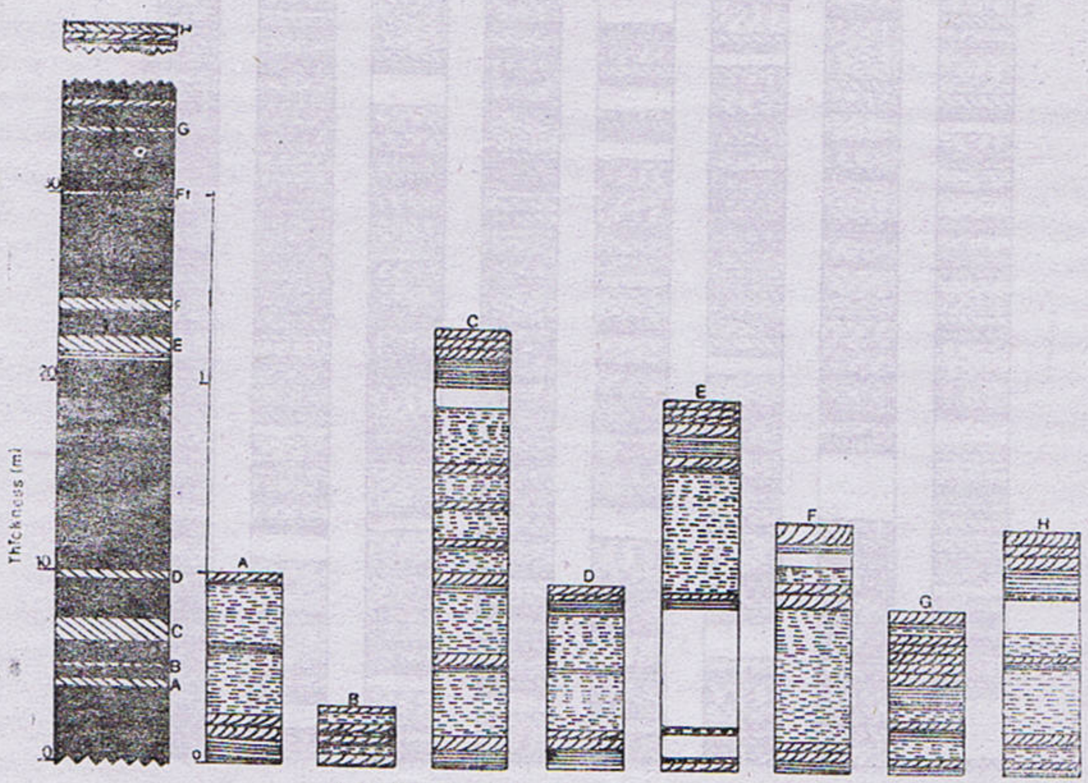

Fig 3 Litho facies of Bibai Formation, NW of Gogai

Geol. Bull. Punjab Univ. 1993, **28**. 81—90

THE LORALAI LIMESTONE FACIES AROUND QILA SAIFULLAH AND RUD MALAZAI AREAS, NORTHEAST BALOCHISTAN

BY

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Abstract : *The Loralai Limestone studied in three selected sections near Qila Saifulah, Rud Malazai and surroundings exhibits three different Limestone Lithofacies such as (a) Micritic and biomicritic limestone, (b) Limestone turbidites and (c) Intraformational conglomeratic limestone. The environment of deposition of the Loralai Limestone is discussed in the light of lithofacies variation.*

INTRODUCTION

The name Loralai Limestone was introduced by Williams (1959) and later accepted by the Hunting Survey Corporation (1960) for the Jurassic limestone sequence near the town of Loralai. The formation is widely exposed around Qila Saifullah, Loralai, Chingan and Rud Malazai areas of the northeast Balochistan (Fig. 1).

The formation is comprised dominantly of very finely crystalline (micritic and biomicritic) and subordinately arenaceous, oolitic and intraclastic limestone possessing characters of turbidites, interbedded with minor shale which become proportionally higher towards the lower part. The formation conformably and transitionally overlies the Alozai Group and underlies the Upper Jurassic-Lower Cretaceous Sember Formation of the Parh Group.

This paper describes the facies associations and lithological characters of the Loralai Limestone studied in three sections, one near the Kosh Kach Village of the Rud Malazai area and two southeast of the Qila Saifullah town (Fig. 1).

FACIES ASSOCIATIONS

1. Kozh Kach Section

Section studied near the Kozh Kach Village (Fig. 2) comprises dominantly of limestone turbidites (LT), subordinately micritic and biomicritic limestone (LBm) and very rarely intraformational conglomeratic limestone (LIc) facies which are interbedded with thin (mostly 10 cm and occasionaly up to 50 cm) pelitic sequences (Sh.) The turbidites are characterized by very coarse to fine grained, oolitic and intraclastic sequences possessing various types of sedimentary structures like grading, parallel and cross lamination, current rippls, flute marks, load casts and other irregular sole marks. Flute casts are very large sized indicating very high energy conditions. An overall grading from very coarse sandy and conglomeratic to very fine sandy and silty texture is common. Some limestone beds in the lowermost part of the measured section and some in the middle part are micritic and biomicritic (Fig.2) which are devoid of turbiditic characters. The lithological character of the rocks, sedimentary structures and Bouma sequences (1962) within the Kozh Kach Section allow us to recognize the Cl and C2 facies of Mutti and Ricci Lucchi (1975) of this four lithofacies types, namely, the Al, Cl, C2 and D1 which are briefly described below :—

Facies A1 : Thick, massive, chaotic and disorganized conglomerate, with profus sion of rip-up clasts, Bouma sequenences not recognizable.

Facies C1 : Thick (40 cm—5 m), massive or poorly graded, Tae and/or Tae bc sequences. Amalgamation is common.

Facies C2 : Medium thick (10 cm—40 cm), well graded, Tabcde, Tbcde, Tcde and Tacde sequences.

Facies D1 : Thin bedded (mostly 10 cm), Tcde, Tde and/or T b cde sequences.

The occurrence of Cl and C2 facies of Mutti and Ricci Lucchi (1975) is accompanied by the "second order" thickening upward cycles nearly 30-40 m thick which suggest a progradational trend of the turbidite submarine fan. Palaeocurrent directions may easily be determined by the help of flute marks and currrent ripples which suggest a general northeastward trend.

2. Section South of the Garang Manda Near Qila Saifullah

Section of the Loralai Limestone in a stream south of the Sarang Manda (Fig. 3) is comprised dominantly of very finely micritic and biomicritic limestone (LBm) interbedded with shale (Sh) which proportionally decreases upwards. The biomicritic limestone in this section is dark brownish grey and medium dark grey and possesses various types of trace fossils. Bedding surfaces are highly undulatory and possess profusion of iron concretions and ammonite fauna. Succession in middle part of the measured section becomes arenaceous having very coarse to fine sandy, oolitic and occasionally conglomeratic texture possessing characters of turbidite i.e. grading, sole marks, parallel lamination and cross-lamination Bouma (1962). A general thining-upward trend may be suggested within the turbidite sequence and lithofacies C2 of the Mutti and Ricci Lucchi (1975) is recognizable. The upper part of the measured section is dominantly argillaceous with minor thin beds of arenaceous limestone (LT) which are again followed by biomicritic limestone with thrust zone in between.

3. Road Section Southeast of Qila Saifullah

Section of the Loralai Limestone on the Loralai Qila Saifullah Road in Garang area, nearly 3 km from the Qila Saifullah Town (Fig. 4) is comprised predominantly of very finely crystalline micritic and biomicritic limestone (LBm) with interbedded shale (Sh). The proportion of interbedded shale gradually decreases towards the upper part of the sequence (Fig. 11). The limestone is medium dark grey and dark brownish grey and medium to thick bedded (10-60 cm). Bedding planes are highly un dulatory and in some places posses remarkable fossils. Ammonite fauna and iron concretions are commonly present. This section is devoid of arenaceous beds having characteristics of turbidites lithofacies LT.

COMPARISON OF THE THREE MEASURED SECTIONS

In all three sections, the Loralai Limestone has a conformable and transitional lower contact with the Triassic Alozai Group and a similar upper contact with the Upper Jurassic—Lower Cretaceous Sember Formation of the Parh Group. Therefore, there remains little doubt that the three measured sections and also those of the nearby areas are the true Loralai Limestone of Otsuki et al., (1989). These columnar profiles (Figs. 2, 7 and 11) indicate that the three maj or lithofacies types described are represented in these sections. However. the Kozh Kach Section and

Road section to the southeast of Qila Saifullah represent two extremes with regards to the proportions of the two main facies types LT and LBm. The Kozh Kach Section is highly abundant in limestone turbites (LT) with minor amount of micritic and bio-micritic limestone (LBm), whereas, the road section near Qila Saifullah is almost devoid of limestone turbidites (LT). Section to the south of Garang Manda, however, is comprised dominantly of micritic and biomicritic (LBm) in the lower and upper parts and limestone turbidites (LT) in the middle part. In view of the contrasting lithofaciees associations in these sections, it may be suggested that the Loralai Limestone was deposited in partly contrasting depositional conditions, whereby, the Loralai Limestone of the Rud Malazai area was mostly deposited by turbidity currents and in Qila Saifullah area it was deposited in calm shallow marine conditions with minor influxes of turbidity currents in middle part. The other areas near Qila Saifullah, Chingan and Loralai were having very minor turbidity currents.

The third lithofacies types i.e. the intra-formational conglomeratic limestone (LIC) was not observed in the measured sections, except in very minor amounts in Kozh Kach Section. However, it was observed in Chingan, Ghunda Manra area south of Bagh and south of the Garang area.

PETROLOGY

Field observations and thin section study of the samples obtained from the Loralai Limestone of Chingan and Zamarai Tangai area of the Loralai District, Ghuaziz area of the Ziarat District and Rud Malazai area of the Pishin District show that the formation may broadly be categorized into finely crystalline micritic and biomicritic and intra-oosparitic types based on Folk's classification, (1959) which are described in detail below :—

(*i*) Finely Crystalline Micritic Limestone

This type of limestone is of micritic and biomicritic texture containing radiolaria and other microfossils. Large fossils, in general, are not very common except in certain horizons, north of Chinga and Garang area where ammonites were observed. Such type of limestone is predominant in Qila Saifullah, Chingan and Zamarai Tangai area of the Loralai District where occasional beds of intra-oosparitic types of limestone were found.

(*i*) Intra - oosparite

This type of limestone mainly consists of intraclasts, colites, fossil fragments and occasional quartz and feldspar grains in a sparitic matrix. Somt horizons are very rich in pellets, oolites and intraclasts. These clastic limestones may be categorized as oosparite intra-oosparite, intra-pelsparite, bioin-intra-oosparite and intra-oomicrite types according to Folk's classification (1959). Although intraclasts, oolites, pellets and fossil fragments are intrabasinal, the quartz and feldspar grains, which are very rarely present, may essentially have been derived from outside the basin. A few samples also contain glauconite in rare amount. Characters of intraclasts closely resemble with the finely crystalline micritic, biomicritic and radiolarian limestone beds and, therefore, have been derived from within the basin. The oolites found in these limestones are mostly concentric having quartz and fossil fragments in their nuclei. The sparitic matrix in some samples have been recrystallized and/or dolomitized. Such type of limestone is predominant in Kozh Kach Section, stream section south of Garang near Qila Saifullah and section near Ghuaziz Village, Ziarat District. Similar facies were observed near Kardgap area of Kalat District. In these localities the finely crystalline micritic and biomicritic limestone horizons are rare.

INTERPRETATIONS

The very finely crystalline micritic and biomicritic limestone facies (LBm) and the interbedded shale (Sh) are the product of calm shallow marine conditions where gradient was low and biological activity was common. Abundance of concentric iron concretions and highly undulatory bedding surfaces indicate agitation by waves. The limestone turbidites (LT) were formed by turbidity currents within a proximal turbidite system. However, cyclicity is not very obvious in limestone turbidite facies of the Qila Saifullah area. Morphological characters of the intra-formational conglomeratic limestone facies (LIC) have not been studied yet. However, it may be suggested that they were perhaps the product of slumping and subsequent downslope transport of the limestone detritus from within the basin. Petrological characters of the limestone turbidites (LT) also indicate derivation of detritus mostly from within the basin.

In the light of above, we suggest that the Loralai Limestone is the product of generally shallow marine conditions where downslope transport, of the limestone detritus derived mostly from within the basin, by turbidity currents and slumping was frequent and, in places, full fledged turbidite system may have been formed.

DISCUSSION

Subdivisions of the rocks of Jurassic age are mainly based on lithological characters by early workers (Williams, 1959; Hunting Survey Corporation, 1960) and a firm fossil control is lacking. In some areas it is even difficult to draw contact between the rocks of Triassic and Jurassic age on the basis of fossil evidence. In Balochistan lateral variations are common within the rocks of Jurassic age, and these lateral variations led the previous workers to name them as separate formations (Williams, 1959; Hunting Survey Corporation, 1960). The Jurassic limestone, underlying conformable and transitionally the Parh Group(Cretaceous), possesses characters of tubidites in Rud Malazai area and becomes very finely crystalline (micritic) towards Chingan, Qila Saifullah and Loralai areas. It has been observed that the Loralai Limestone of these areas also possesses lithological characters comparable with that of the Chiltan Limestone of Quetta region.

Otsuki et al. (1989) argue that the sequence of the Alozai Group, Loralai Limestone and Parh Group, mapped by Hunting Survey Corporation (1960) within the Axial Zone of Muslimbagh area are lithologically different and are not actually those of Triassic, Jurassic and Cretaceous ages respectively. They, instead, name them as false Group, false Alozai Group and false Loralai lime stone and assign Triassic age to all of them among which the false Parh Group being oldest of all. However, it may be observed that the three sections studied by us clearly comprises the Alozai Group, Loarlai Limestone and Parh Group overlying oneanother with transitional and conformable contacts respectively and fall within the Calcareous zone of Otsuki et al. (1989). It is interesting to note that the contact between the Parh Group and Lor Loralai Limestone in measured sections is transitional and shows no evidence of disconformity in contrast to the Quetta area and all along the Kirthar Range where the Sember Formation disconformably overlies the Chiltan Limestone. The conformable and transitional nature of the contact between the Sember Formation of the Parh Group and Loralai Limestone in Qila Saifullah, Chingan and Red Malazai areas suggest that emergence after the deposition of Jurassic was not so widespread and did not extend towards the northeast Balochistan.

The Alozai Group of Triassic age in Rud Malazai, Kozh Kach, Ghingan, Qila Saifullah, Tangai and Gwal areas possess characters of distal outer-fan (fringe) turbidites (Kassi, 1986) characteristic of the deeper marine sedimentation. In Tangai area they display "second order" thickening-upwards cycles (Kassi, 1986) but in Kozh Kach they are highly disturbed and backed by intrusions and no trend of the second order cycles is determinable. However, section of the Loralai Limestone in Kozh Kach area, possessing characters of proximal mid-fan turbidites, also show "second order" thickening-upwards cycles (Fig. 2-3). These cycles, along-with a general trend from deeper marine sediments of Triassic age to shallower marine sediments of Jurassic age, indicate an overall regressional trend of the Tethyan Ocean from Triassic to Jurassic age. In Chingan, Qila Saifullah, Loralai and surrounding areas also an overall general trend from deeper distal turbidite sequence of the Alozai Group (Triassic) to thick bedded and micritic shallow marine sequence of the Loralai Limestone (Jurassic) is evident showing an overall regression of the Tethyan Ocean from Triassic to Jurassic age.

CONCLUSIONS

1. The Loralai Limestone in Rud Malazai, Qila Saifullah and Chingan area shows various combinations of lithofacies such as : *i*) very finely crystalline (micritic and bio-micritic facies—LBm), (*ii*) limestone turbidite (LT), (*iii*) intraformational conglomeratic limestone (LIC) and (*v*) shale (Sh). LBm is the most widespread lithofacies type.

2. The Loralai Limestone is the product of an overall shallow marine conditions where downslope transport by turbidity currents and slumping was not uncommon, sediment was derived mostly from within the basin and in some areas full fledged turbidite submarine fans may have been developed.

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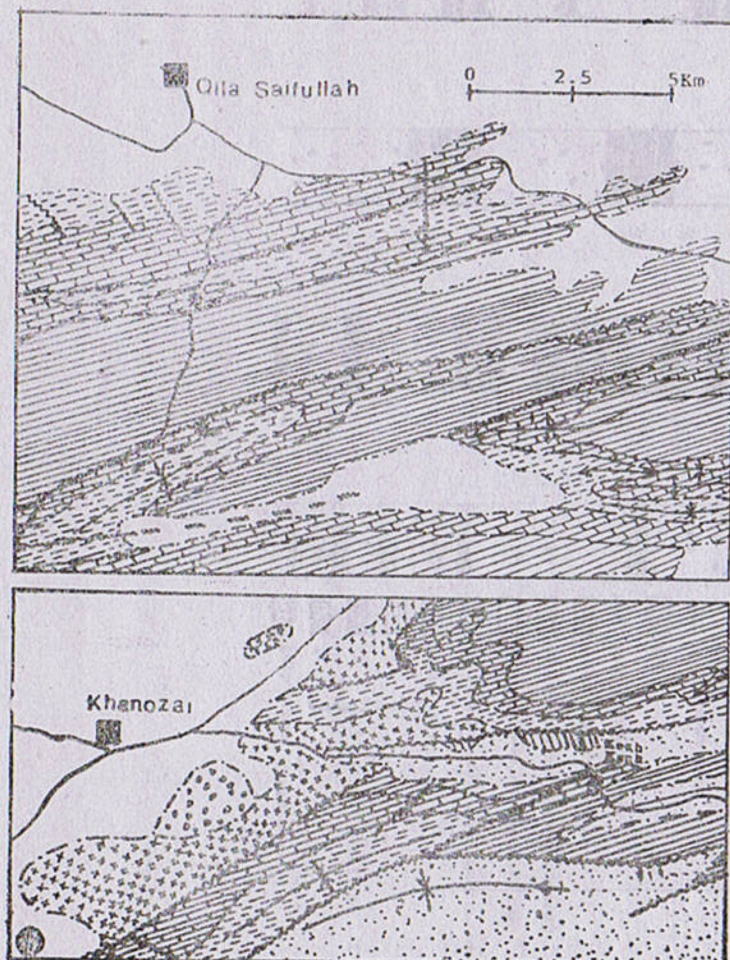

Fig.1 Geological map of the studied area and surroundings.

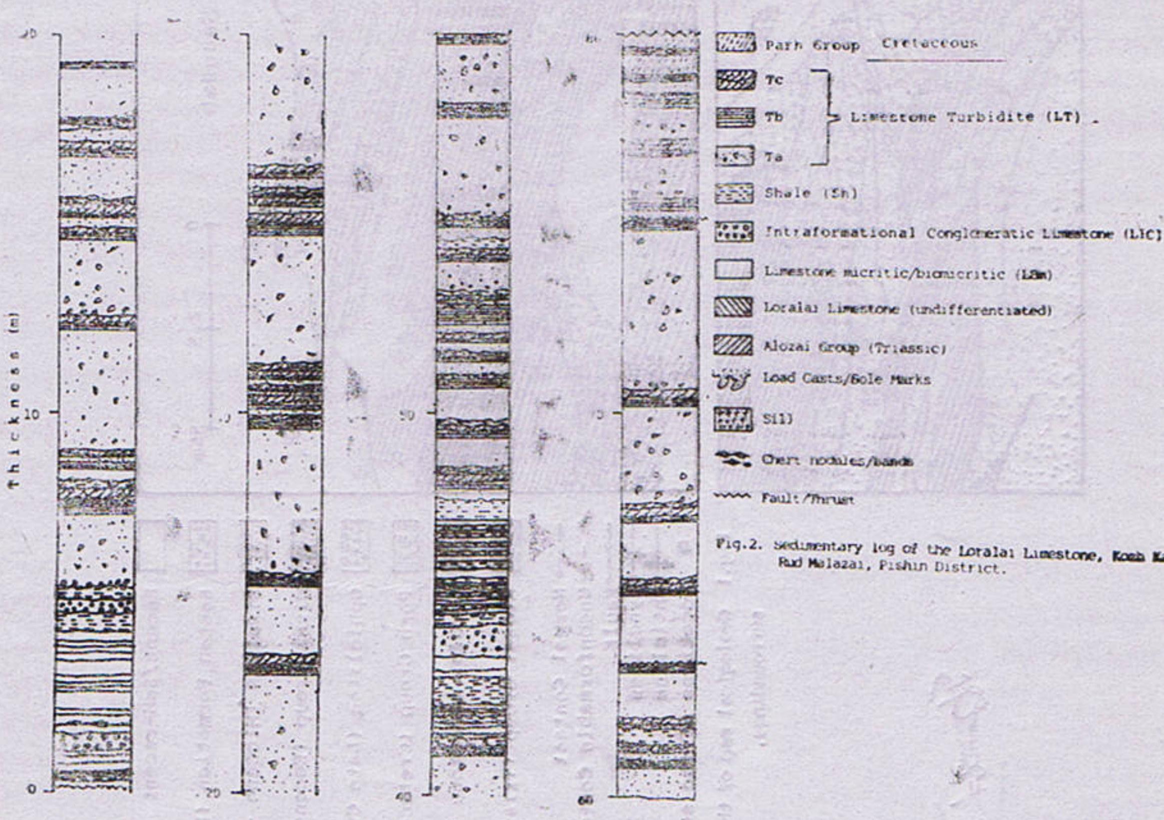

Fig.2. Sedimentary log of the Loralai Limestone, Kosh Kach, Rud Malazai, Pishin District.

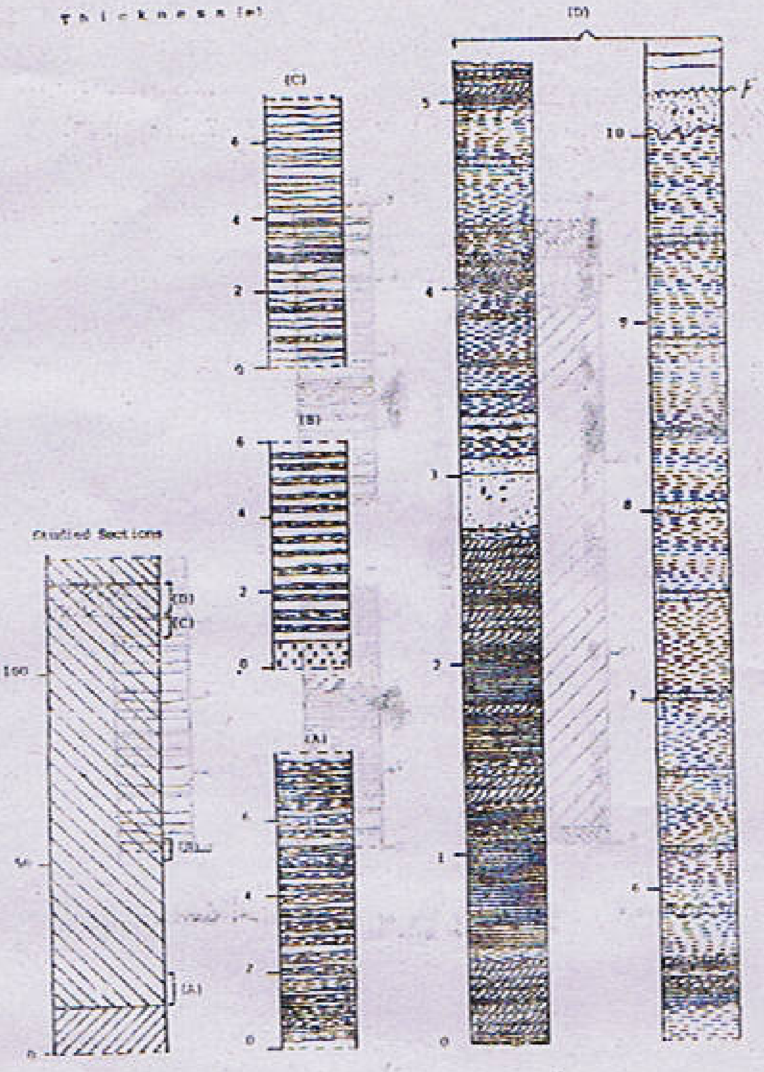

Fig 3 Sedimentary log of the Loralai Limestone, south of the Garang Manda near Qila Saifullah (See Fig.2 for legend).

Fig.4 Sedimentary log of the Loralai Limestone from section near Qila Saifullah

Geol. Bull. Punjab Univ. 1993, **28**, 91—104

WATER AND SOIL CHEMISTRY FROM THE BAT KAS DRAINAGE SYSTEM OF BATTAL AREA ALONG THE KARAKORUM HIGHWAY (KKH), DISTRICT MANSEHRA, NWFP, PAKISTAN.

BY

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Abstract : *Chemical analysis of twenty one water samples of the Bat Kas Stream and its tributaries, while twenty one soil samples from its adjoining area show that the chemistry of this drainaige system is mainly controlled by the rock weathering processes. The XRD results of five soil samples indicate the presence of both stable minerals such as illite, saponite and sepiolite and metastable clay minerals such as muscovite, albite, phlogopite and clinochlore. The alteration process from metastable clay minerals to the most stable minerals, i.e., kaolinite, smectite, vermiculite and iron oxides, is found to be in progress by leaching major ions into the aquatic system through various weathering processes*

INTRODUCTION

The Karakorum Highway (KKH) is an important man made feature running across the Himalayas and KarakorumRanges, northern Pakistan. The studied area represents a part of District Mansehra along the Karakorum Highway (KKH) and covers about 36 square kilometers including Battal, Chinarkot and Kandla villages. A detailed geological map of the area is shown in Figure 1.

The present study includes a detailed investigation of water and soil chemistry of Bat Kas Drainage System of Battal Village and its surrounding area along the KKH. The research is mainly focused on the determination of major cations and anions present in surface waters and soil extracts, and their interpretation in terms of agricultural point of view. XRD studies of five soil samples were also carried out to determine the mode of weathering in the area.

GEOLOGY

The general geology of the area is composed of Precambrian Garnet Mica Schist and Granite Gneiss which are dissected by acidic/basic minor intrusions, such as pegmatites, quartzofeldspathic veins and amphibolites at places. The Granite Gneiss is highly schistose. Generally, the grade of metamorphism and schistosity increases towards north.

MATERIAL AND METHODS

Water and soil samples, twenty one each, were collected from Battal Village and its surrounding area in March 1993. Both water and soil extracts were analyzed for major cations and anions. The mineralogy of some of five soil samples were carried out by XRD studies. Standard analytical procedures were adopted from Richards (1968) for the determination of major cations and anions in the water samples which are summarrzed as follows :

WATER CHEMISTRY

Twenty one stream water samples were collected from the study area and has been analyzed for major cations and anions. Six of them are from the main stream (Bat Kas) and the rest are from the adjoining tributaries. The spatial distribution of the water and soil samples is given in Figure 2. The geochemical data for the same is given in Table 1. Among major cations, Ca varies from 0.7 to 1.6 meq/l with an average of ¯1.1 meq/l, Mg varies from 0.1 to 0.8 meq/l with an average of ¯0.44 meq meq/l, Na varies from 0.3 to 0.6 meq/l with an average of ¯0.4 meq/l, K varies from 0.02 to 0.06 meq/l with an average of ¯0.04 meq/l. Among major anions HCO_3 varies from 0.7 to 1.7 meq/l with an average of ¯1.2 meq/l, CO_3 being absent, Cl varies from 0.3 to 0.8 meq/l with an average of ¯0.5 meq/l, SO_4 varies from 0.1 to 0.7 meq/l with an average of ¯0.4 meq/l.

SOIL CHEMISTRY

Twenty one soil samples were collected from the study area and have been analyzed for major cations and anions of water soluble extract. The geochemical data for the same is given in Table 2. Among major cations Ca varies from 2.5 to 11.0 meq/l with an average of ¯4.9 meq/l, Mg varies from 2.0 to 12.5 meq/l with an average of ¯4.45 meq Na varies from 1.0 to 4.8 meq/l with an average of ¯0.07 meq/l. Among major anions HCO_3 varies from 0.2 to 5.0 meq/l with an average of ¯2.3 meq CO_3 being absent, Cl varies from 1.0 to 4.0 meq/l with an average of ¯2.45 meq/l, SO_4 varies from 1.0 to 15.5 meq/l with an average of ¯7.2 meq/l.

RESULT AND DISCUSSION

The geochemical data for both twenty one stream water samples and twenty one soil samples along with their averages is given in Table 1 and 2 respectively. The ionic species in water play an important role in interpretation of the geochemistry of water and also indicates the rate of dissolution and nature of the surrounding rocks. Three natural mechanisms are said to control the chemistry of surface waters; atmospheric precipitation, rock dominance and the evaporation-crystallization process (Gibbs 1970 ; Kilham 1990). Furthermore, the waters on the Earth's surface can be distinguished from each other on the basis of both their total ionic contents (salinity) and the mutual proportions (ionic ratios) in which their various ions are present (Chester, 1990). Therefore, a relative importance of each mechanisms can be a evaluated by plotting the weight ratio of Na/(Na+Ca) as a function of total dissolved salts (Fig. 3). Gibbs (1970) showed that if the three mechanisms are of equal importance, then a boomerang-shaped envelope of the data is observed. The end-member formed by the atmospheric precipitation is mainly characterized by the low weathering intensity and high rates of evaporation (upper diagonal arm), while rock dominance end-member are characterized by high weathering intensity and low rates of evaporation (middle), and an evaporatio crystallization end-member (Fig. 3.) are characterized by high weathering intensity and high rates of evaporation (bottom arm). see The weight rates of Na/(Na+Ca) of the stream samples collected from the Bat Kas area are, therefore, plotted on a boomerang-shaped envelope of Gibbs (1970), as a function of total dissolved salts (Fig. 3). It is clear from the figure that all samples lie in the middle part of the boomerang-shaped evnelope indicating that the chemistry of the stream samples from the studied area are mainly controlled by the rock weathering processes.

For the purpose of establishing a variation trend in different species present in the Bat Kas Stream, the major species present in the waters of the main stream are plotted (Fig 4) from upstream to downstream. It can be seen from this figure that the concentration of each species increases as the water runs downstream. This increase in the concentration of various species is expected due to the addition of its ajdoining tributaries into the main stream, i.e., Bat Kas. However, the important points which can be made from this plot are the strong correlation among the various species, e.g., Ca and HCO_3 make a separate set, hence indicating the presence of Ca as $CaHCO_3$ which, in turn, reflects the idea of dissolution of $CaCO_3$ from the surrounding rocks. On the other hand, Mg and SO_4 make a second pair, indicating the presence of Mg as $MgSO_4$. The Cl does not fulfill the requirement of Na+K and, therefore, the addition of Na +K may be partly due to the dissolution of the salts present in the metasediments as secondary deposits and partly due to the dissolution of feldspars present in the granite gneiss, and also in the metasediments. To see more deeply into the matter, a comparison of the average chemistry of the tributaries coming from two distinctive catchment areas (i.e., the tributaries coming from metasediments and the tributaries coming from granite gneiss) along with the main. Bat Kas, Stream, in which all tributarries tail, is presented (Fig. 5 a-b) as sum of total percentage of each cation and anion. The tributaries coming from metasediments include the samples 5, 6, 10, 11, 12, 15, 18 and 22, and the tributaries coming from granite gneiss include the samples 1, 2, 3, 4, 13, 14 and 20, and the main stream comprises of samples 7, 8, 9, 16, 17 and 21. It can be seen from Figure 5 (a) and 5 (b) that among the major cations and anions Ca and HCO_3 are the highest in all the three sets. The probable source of Ca is the dissolution of $CaCO_3$ in metasediments and the dissolution of feldspars in granite gneiss which is apparent from the relatively high contribution of Na by the tributaries coming from the granite gneiss. The addition of SO_4 into the main stream is mainly from the tributaries coming from the metasediments. One thing which is evident from the Figure 6 that the average chemical composition of the main stream, i.e., Bat Kas, shows almost an average values of the concentrations of major cations and anions of the tributaries coming from metasediments and granite gneiss. This also proves that no other phenomenon (e.g., precipitation, evaporation, etc) except rock weathering is occurring in the water samples of the Bat Kas area.

As far as the water quality of the Bat Kas main stream and its adjoining tributaries is concenred, important ratios such as Sodium Adsorption Ratio (SAR), Residual Sodium Carbonates (RSC), Exchangeable Sodium Percentage (ESP), Hydrogen Ion Concentration (pH) and Electric Conductivity (EC) are given (Table 1) In general, the waters from Bat Kas Drainage System belong to soft water category, i.e., average hardness of 21 samples is 85 and the low values of SAR, i.e., from 2 to 4 are the good signs of a good irrigation water for various crops (Richards, 1968).

Soil chemistry in relation to the water chemistry sometimes plays an important role in interpreting not only the irrigation objectives but also in assessing the weathering style and intensity in the area. The geochemical data for the twenty one soil samples which represent the Bat Kas Drainage System is given (Table 2). The average spatial distribution of the same samples is presented in Figure 2. The average geochemical data of these samples reveals that the soil of Bat Kas Drainage System is of 'Normal Soil', i.e., pH < 7.5 to 8.0, EC < 4 mmhos/cm and ESP < 15 (United States Salinity Laboratory, 1953). However, the lower pH values of some of the soil samples indicates the favourable condition for 'TEA' cultivation.

As the drainage system in the studied area is spread over two distinct rock units, i.e.,metasediments in the north and west and granite gneiss in the east, therefore a variation in the soil chemistry is expected on both sides of the Bat Kas. To see the variation in two sets of soil samples, one which are directly influenced by the metasediments and those which are directly influenced by the granite gneiss, are presented (Table 2) with the symbols M for metasediments and G for granite gneiss. The average concentration of major cations and anions of these have been plotted for comparison purposes (Fig. 7). It is clear from this figure that the dissolved salts present in the soils which are influenced by the metasediments have relatively higher values in many respect. For example, the concentration of Ca, Mg HCO_3, Cl and SO_4 are relatively high in the soils associated with metasediments as compared to the soils associated with the granite gneiss. While concentration of Na and K are relatively high in the soil samples associated with the granite gneiss as compared to the soils associated with metasediments This relatively high concentration of Na and K is due to the dissolution of feldspars in the granite gneiss rocks which has also been indicated by the relative high concentration of Na and K in stream water samples coming from the granite gneiss area.

The decomposition/alteration has taken place can be examined by the identification of stable clay minerals present in the soil sammples of Bat Kas drainage system. For this purpose XRD of five soil samples have been carried out for the characterization of mineral phases. Velde, (1992) described the end members of a series of common minerals present in metasediments and acidic igneous rocks, i.e.

Quartz	—	Quartz
Plagioclase	—	Kaolinite
Muscovite	—	Smectite or Dioctahedral vermiculite
Orthoclase and Muscovite	—	Illite
Biotite	—	Kaolinite + Smectite/Mica (Interstratified)
or		
Biotite	—	Kaolinite + Trioctahedral vermiculite

However, the intensity of weathering and the weathering style play an important role in the alteration of primary minerals into the most stable end members which is indirectly indicated by the presence of unstable/stable minerals present in a system. In the present study it can be seen that the main minerals present in these samples are quartz, muscovite, phlogopite, albite, illite, clinochlore, saponite and sepiolite, hence can be divided into three categories, i.e.,

Stable Phase	Metastable/ Unstable Phase	End Members/Stable Clay Minerals

Quartz		Quartz
	Amphibole	Saponite
	Phlogopite	
	Clinochlore	
	Muscovite	Saponite or Illite
	Albite + Biotite	Illite

In this framework, resistance minerals like quartz is expected to remain as it is during weathering cycle while others may undergo from metastable stage to more stable clay minerals. The minerals which successively become unstable are plagioclase, biotite, muscovite and to certain extent, potassium feldspar. In the present study, the end member clay minerals are saponite, sepiolite and illite. The formation of saponite may be due to the alleration of amphibole and micas. The clay mineral illite is formed by the interactions of feldspars and mica which is found as end mineral in all the soil samples. It is evident that no signs of kaolinite has been found in the results of five XRD soil samples despite the fact that a fair amount of plagioclase is present in the surrounding rocks. The presence of illite and absence of kaolinite indicates that the former is probably not the result of present soil formation process but has been introduced from the pre-existing surrounding rocks. However, the presence of sepiolite (Mg rich) in the area is confusing because it is formed usually in the evaporatic sedimentary environments and indicates that the soil horizon was formed in arid or semi-arid conditions (Velde, 1992).

It may be, therefore, concluded that the soils of the studied area are immature and continuously on their way to degradation and decomposition to form the end minerals through weathering. This is evident from the presence of some primary minerrals, e. g., plagioclase is not decomposed into kaolinite. The presence of illite, saponite and sepiolite is troublesome because the same minerals can also be introduced into the system from the surrounding metasediments of pre-Cambrian age. However, the presence of phlogopite which is a metastable minreral indicates the early stages of maturity.

CONCLUSIONS

The chemistry of the Bat Kas Drainage System is mainly controlled by the rock weathering processes and the contribution of dissolved salts into the Bat Kas Stream is from the tributaries of two distinctive catchment areas, i.e., metasediments and granite gneiss. The chemistry of Bat Kas Stream is characterized by the high concentrations of Ca and HCO_3 but within the desired limits of a good irrigation water.—The average chemistry of the two set of tributaries coming from the metasediments and granite gneiss reveals that the addition of Ca, Mg, Cl and SO_4 into the main Bat Kas stream is mainly from the dissolution/decomposition of the primary minerals presents in the metasediments while the addition of Na and K into the Bat Kas Stream is mainly from the dissolution of feldspars in granite gneiss and also in the metasediments. The chemistry of soil extract is characterized by the high concentrations of Ca, Mg and SO_4 ions. The soil samples around Bat Kas Stream falls in the category of 'Normal soil'. The lower values of pH in some samples indicate the favourable conditions for 'TEA. cultivations in these mountainous areas. The XRD results of some soil samples indicate the presence of end minerals as illite, saponite and sepiolite which are supposed to be introduced from the surrounding metasediments of Precambrian age and are not formed during the recent soil formation process. Among metastable clay minerals are the phlogopite and clinochlore. The probable end minerals of the studied system would be the formation of kaolinite, smectite, vermiculite and iron oxides through weathering processes.

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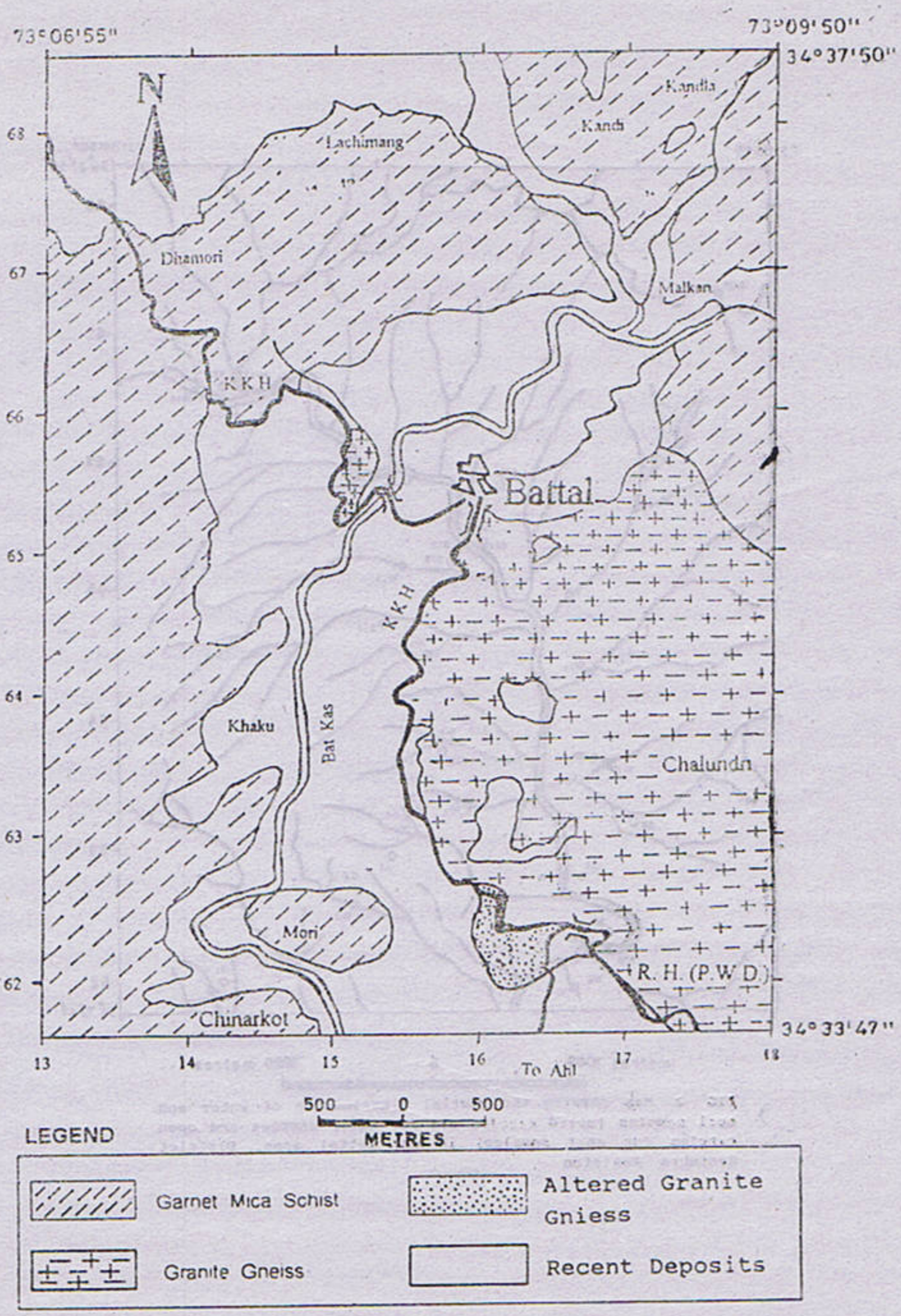

FIG. 1. Geological map of the Battal area, District Mansehra Pakistan. topo-sheet 43 F/2

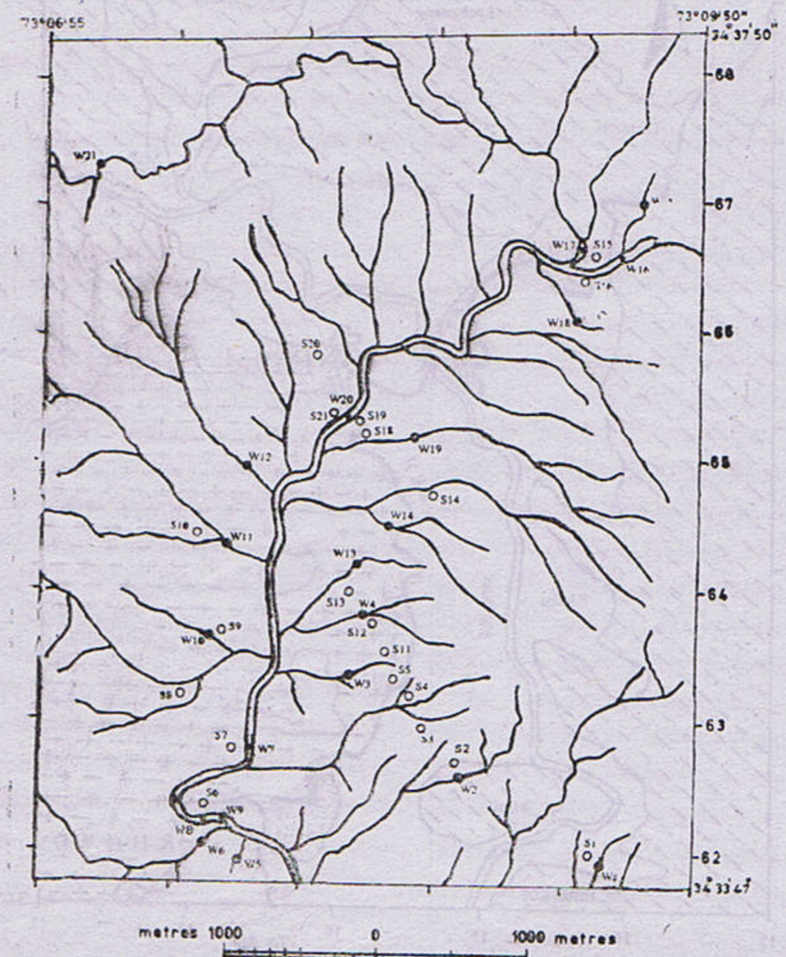

FIG 2 Map showing the spatial distribution of water and soil samples (solid circles are for water samples and open circles for soil samples) in the Battel area, District Mansehra Pakistan

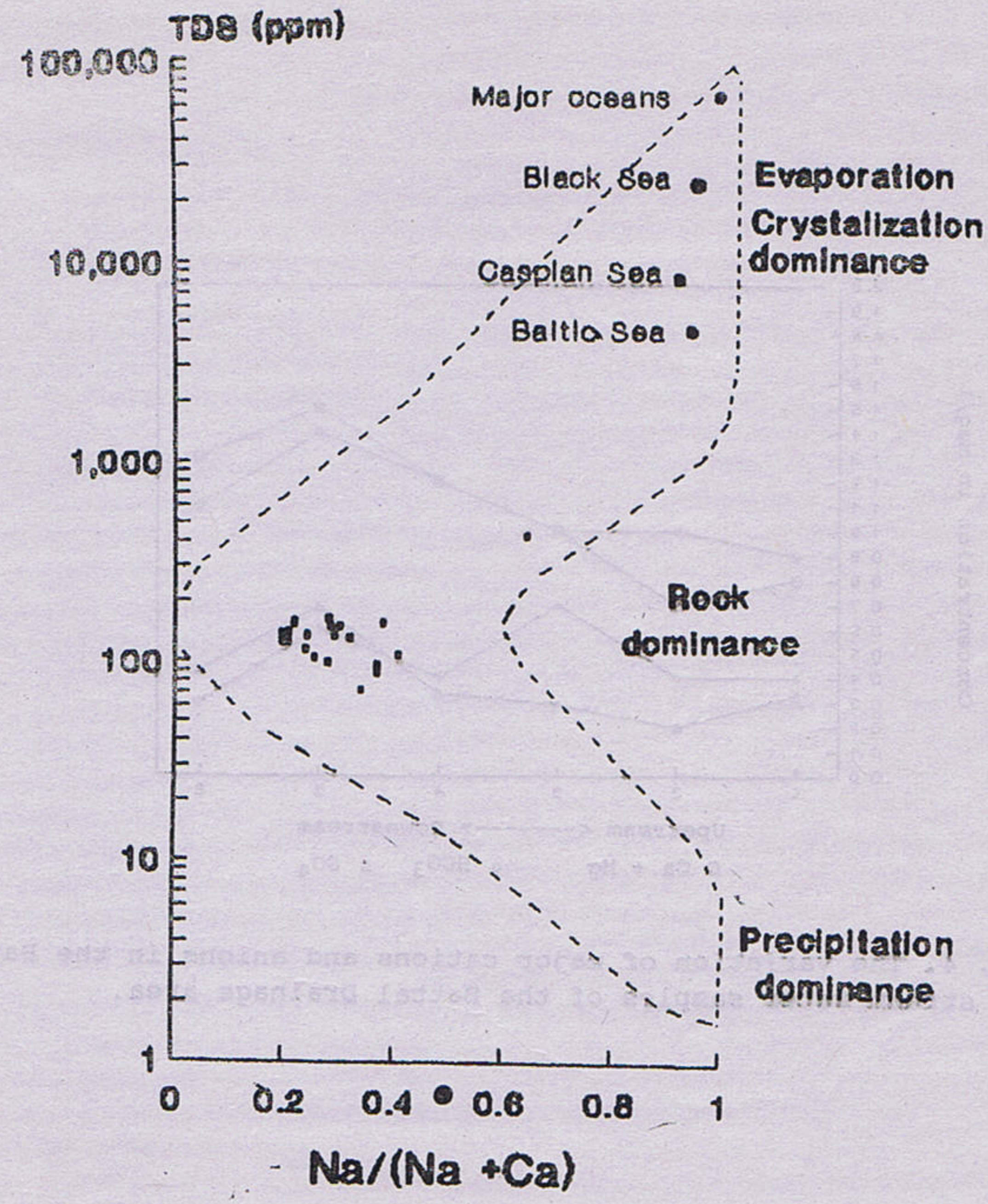

FIG. 3. Gibbs Boomerang-Shaped Envelope showing the Na/(Na + Ca) ratio of different water samples as a function of total dissolved salts.

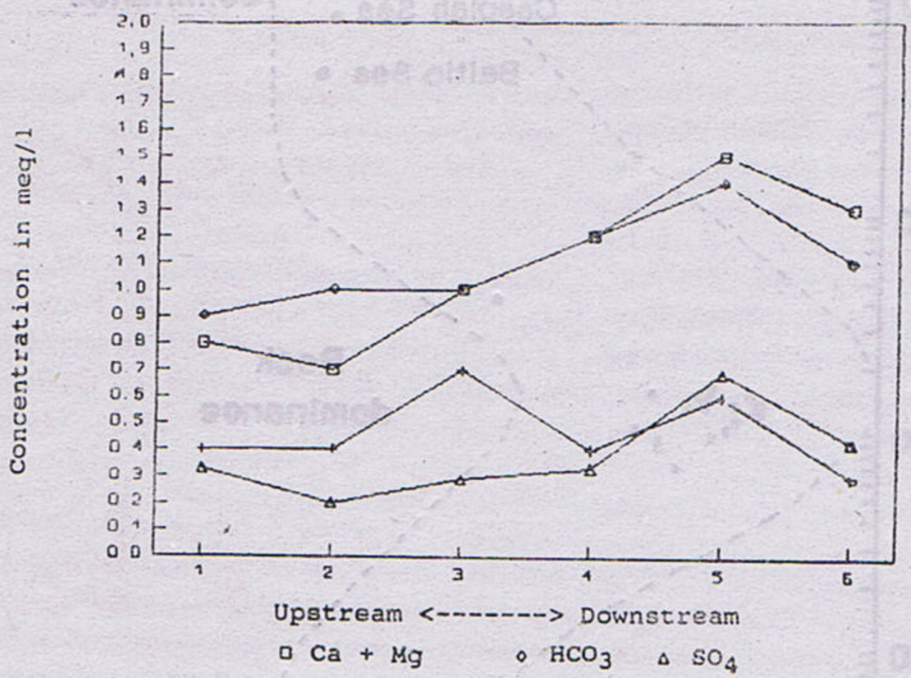

FIG. 4. The variation of major cations and anions in the Bat Kas stream water samples of the Battal Drainage area.

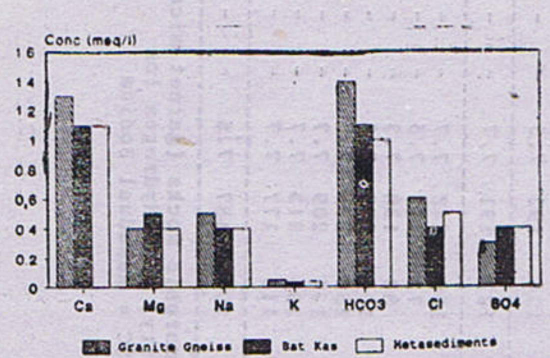

FIG. 6. Three sets of water samples, coming from different rock units, showing the average chemical composition of the major cations and anions in the Bat Kas stream.

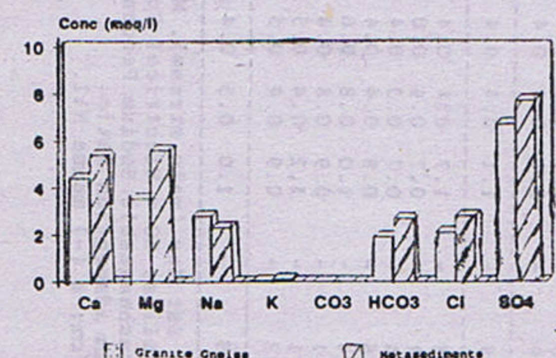

FIG. 7. The average chemical composition of two sets of soil samples from the Battal Drainage area.

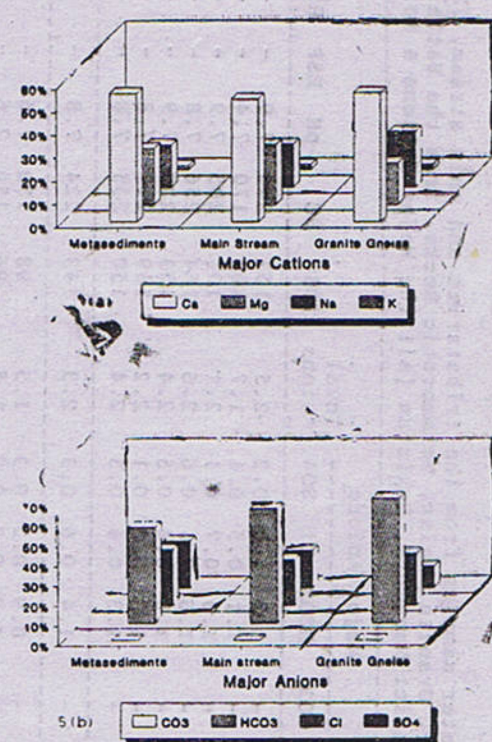

FIG. 5(a) & 5(b). Total percentage of sum of each cations 5(a) and anions 5(b) in the Bat Kas stream water samples of the Battal Drainage area.

TABLE 1. Chemical composition of water samples from the tributaries and main stream, running through different rock units, i.e., Granite Gneiss, Metamorphic Rocks, from the Battal village and its surrounding area, District Mansehra, Pakistan (All the Major Cations & Anions are in meq/l)

S.No.	Major Cations Ca	Mg	Na	K	Total Cations	Major Anions CO3	HCO3	Cl	SO4	Total Anions	TDS	EC	pH	ESP	RSC	SAR	Na/K
G20	1.0	0.8	0.6	0.06	2.5	-	1.3	1.0	0.2	2.5	157	246	7.9	-	-	0.6	10
G14	0.9	0.2	0.6	0.05	1.8	-	1.1	0.5	0.1	1.7	109	170	7.4	-	-	0.8	12
G13	1.1	0.4	0.5	0.05	2.1	-	1.3	0.7	0.1	2.1	131	205	7.9	-	-	0.6	10
G4	1.6	0.3	0.6	0.06	2.6	-	1.6	0.4	0.6	2.6	164	256	7.8	-	-	0.6	10
G3	1.5	0.5	0.4	0.03	2.4	-	1.5	0.4	0.5	2.4	153	239	7.9	-	-	0.4	13
G2	1.6	0.1	0.4	0.04	2.1	-	1.6	0.5	0.1	2.2	139	217	7.8	-	-	0.4	10
G1	1.3	0.5	0.5	0.05	2.4	-	1.3	0.6	0.5	2.4	150	235	7.8	-	-	0.5	10
Mean=	1.3	0.4	0.5	0.05	2.3	-	1.4	0.6	0.3	2.3	143	224	7.8	-	-	0.6	10.8
B16	0.8	0.4	0.3	0.03	1.5	-	0.9	0.3	0.3	1.5	98	153	7.6	-	-	0.4	10
B17	0.7	0.4	0.4	0.04	1.5	-	1.0	0.3	0.2	1.5	96	150	7.6	-	-	0.5	10
B21	1.0	0.7	0.4	0.03	2.1	-	1.0	0.8	0.3	2.1	134	209	7.7	-	-	0.4	13
B7	1.2	0.4	0.3	0.03	1.9	-	1.2	0.4	0.3	1.9	124	193	7.7	-	-	0.3	10
B8	1.5	0.6	0.4	0.03	2.5	-	1.4	0.4	0.7	2.5	159	249	7.9	-	-	0.4	13
B9	1.3	0.3	0.3	0.03	1.9	-	1.1	0.4	0.4	1.9	124	193	7.5	-	-	0.3	10
Mean =	1.1	0.5	0.4	0.03	1.9	-	1.1	0.4	0.4	1.9	122	191	7.7	-	-	0.4	11.1
M22	1.5	0.5	0.4	0.05	2.5	-	1.7	0.4	0.4	2.5	159	248	7.7	-	-	0.4	8
M13	0.6	0.2	0.3	0.03	1.1	-	0.7	0.4	0.0	1.1	72	113	7.5	-	-	0.5	10
M18	0.7	0.2	0.4	0.05	1.4	-	0.7	0.3	0.4	1.4	88	138	7.3	-	-	0.6	8
M12	0.9	0.4	0.3	0.03	1.6	-	0.8	0.4	0.4	1.6	104	163	7.5	-	-	0.4	10
M11	1.2	0.6	0.5	0.05	2.4	-	1.0	0.8	0.6	2.4	150	235	7.7	-	-	0.5	10
M10	1.3	0.4	0.4	0.03	2.1	-	0.9	0.8	0.4	2.1	134	209	7.7	-	-	0.4	13
M6	1.3	0.5	0.3	0.03	2.1	-	1.2	0.4	0.5	2.1	136	213	7.7	-	-	0.3	10
M5	1.0	0.5	0.3	0.02	1.8	-	0.9	0.4	0.5	1.8	113	177	7.7	-	-	0.3	15
Mean =	1.1	0.4	0.4	0.04	1.9	-	1.0	0.5	0.4	1.9	120	187	7.6	-	-	0.4	10.5

NOTE: G = Granite Gneiss, B = Bat Kas (main stream), M = Metamorphic Rocks (garnet mica schist), TDS = Total Dissolved Solids; EC = Electrical Conductivity; pH = Hydrogen Ion Concentration; ESP = Exachangeable Sodium Percentage; RSC = Resedual Sodium Carbonates; SAR = Sodium Adsorption Ratio.

UNITS: TDS in ug/ml; EC in µS/cm; & (-) means Nil.

TABLE 2. Chemistry of Soil Samples collected from soil patches representative of the Battal Village and its surrounding area, District Mansehra, Pakistan. (All the Major Cations & Anions are in meq/l)

S.NO	Major Cations: Ca	Mg	Na	K	Total Cation	Major Anions: CO3	HCO3	Cl	SO4	Total Anions	TDS	EC	pH	ESP	RSC	SAR	SP
G1	3.0	2.0	2.0	-	7.0	-	0.5	1.5	5.0	7.0	448	700	7.4	-	-	1.3	35%
G2	3.0	2.5	2.5	-	8.0	-	0.2	1.0	6.8	8.0	512	800	7.4	-	-	1.5	30%
G3	6.5	5.3	1.4	-	12.9	-	0.3	1.5	11.3	13.0	1152	1800	7.0	-	-	0.6	36%
G4	2.5	2.5	1.9	0.1	7.0	-	0.3	1.5	5.3	7.0	448	700	7.5	-	-	1.2	30%
G5	3.0	2.5	1.5	-	7.0	-	2.5	1.5	3.0	7.0	448	700	7.6	-	-	0.9	30%
G11	3.0	3.0	1.9	0.1	8.0	-	3.0	1.5	3.5	8.0	512	800	7.7	-	-	1.1	38%
G12	9.5	4.5	4.8	0.1	18.9	-	3.0	3.0	12.9	18.9	1152	1800	6 4	-	-	1.8	30%
G13	3.5	2.5	2.9	0.1	9.0	-	2.5	3.0	3.5	9.0	576	900	7.2	-	-	1.7	38%
G14	7.0	4.0	9.5	-	20.5	-	5.0	3.0	12.5	20.5	1216	1900	6.7	-	-	4.1	36%
G18	4.5	5.0	1.5	-	11.0	-	2.5	3.0	5.5	11.0	512	800	6.8	-	-	0.7	35%
G19	2.5	4.5	1.0	-	8.0	-	1 0	3.0	4.0	8.0	512	800	6.5	-	-	0.5	48%
Mean =	4 4	3.5	2.8	0.04	10.7	-	1.9	2.1	6.7	10.7	681	1064	7.1	-	-	1.4	35%
M6	4.0	2.5	1.5	-	8.0	-	1.0	2.5	6.5	10.0	640	1000	6.8	-	-	0.8	32%
M7	3.5	4.0	1.5	-	9.0	-	2.0	1.5	5.5	9.0	576	900	7.3	-	-	0.8	39%
M8	11.0	9.0	2.9	0.1	23.0	-	5.0	3.0	15.5	23.5	1344	2100	7.5	-	-	0.9	33%
M9	3.0	3.5	1.5	-	8.0	-	3.5	2.0	2.5	8.0	512	800	7.6	-	-	0.8	35%
M10	5.0	7.0	4.6	0.2	16.8	-	1.0	1.5	14.0	16.5	1024	1600	7.0	-	-	1.9	37%
M20	6.0	12.5	3.4	0.1	22.0	-	3.5	3.0	15.0	21.5	960	1500	7.0	-	-	1.1	41%
M21	4.5	5.5	2.0	-	12.0	-	4.0	3.0	1.0	8.0	512	800	7.3	-	-	0.9	40%
M15	5.5	2.0	1.4	0.1	9.0	-	3.5	3 5	2.0	9.0	448	700	7.0	-	-	0.7	38%
M16	5.5	4.0	1.5	-	11.0	-	1.5	4.0	5.5	11.0	704	1100	6.7	-	-	0.7	47%
M17	5.5	5.5	3.0	-	14.0	-	1.5	3.5	9.0	14.0	704	1100	6.9	-	-	1.3	36%
Mean =	5.4	5.6	2.3	0.1	13.3	-	2.7	2.8	7.7	13.1	742	1160	7.1	-	-	1.0	38%

NOTE: TDS = Total Dissolved Solids; EC = Elctrical Conductivity; pH = Hydrogen Ion Concentration; ESP = Exchangeable Sodium Percentage; RSC = Residual Sodium Carbonates; SAR = Sodium Adsorption Ratio; SP = Saturation Percentage; G = Granite Gneiss; M = Metamorphic Rocks;

UNITS: TDS in ug/ml; EC in μS/cm; & (-) means Nil

Geol. Bull. Punjab Univ. 1993, **28** 104—115

GEOLOGY AND GEOCHFMSTRY OF BATTAL AREA ALONG THE KARAKORUM HIGHWAY (KKH) DISTRICT MANSEHRA N. W. F. P., PAKISTAN

By

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Abstract : *Geological and geochemical studies of the Battal area along the Karakorum Highway (KKH), District Mansehra, have been carried out for the characterization and tectonic set up of the area. About thirty six square kilometer area has been geologically mapped. Two main rock units, the metasediments and igneous, have been identified in the area. The metamorphic rocks are Garnet Mica Schist and can be related to the Precambrian Tanol Formation. The Granite Gneiss is a part of Precambrian Susalgali Granite Gneiss. The studied area has experienced the regional polymetamorphism ranging from medium to high grade metamorphism. The igneous activity in and around the area is partly related with the Pre-Himalayan Orogenic Event, i.e. Susalgali Granite Gneiss and partly associated with the early stages of Himalayan Orogeny, i.e., Mansehra and Hakley Granites.*

INTRODUCTION

The Karakorum Highway (KKH) is an important man made physiographic feature running across the Himalayas and Karakorum Ranges in northern Pakistan. The Himalayas have been regarded as the type example of continent to continent collision between the Indian and Asian Plates causing a rapid uprise of the Karakorum and Himalayan Ranges (Treloar and Searle, 1990). The project area comprises part of District Mansehra, along the KKH and covers about 36 square kilometers including Battal, Chinarkot and Kandla villages.

The present study is aimed at the detailed investigation of the Battal Village and its surrounding areas along the KKH. The research is mainly focused on the general geology, geochemistry and mineralogy of the rocks present in and around the studied area.

The studied area (topo sheet 43 F/2 latitude 34° 33' 42" and 34° 37' 50" N ; longitude 73° 6' 55" and 73 9' 50" E.) starts from PWD Rest House near Ahl Village and covers about 36 square kilometers north of Mansehra. The KKH runs along the main stream called Bat Kas. The area is accessible by metalled road from Lahore to Mansehra and then about 40 kilometers from Mansehra towards

Batgram by KKH. The area falls in the sub-humid to subtropical continental climatic region. The highest peak in the area is near Chalundri Village at 6641 feet. The area may be characterized as a medium to high relief.

The studied area represents a part of Lesser Himalayas. In this classsification, the Main Central Thrust (MCT) separates the Higher Himalayas from Lesser Himalayas and Main Boundary Thrust (MBT)separates the Lesser Himalayas from the Outer Himalayas (Wadia 1957 ; Gansser, 1964). The Main Central Thrust (MCT) runs in the north of the project area while Main Boundary Thrust (MBT) lies in the south. Also, there runs N-S Oghi Shear Zone in the west and syntaxial loop of the Lesser Himalayas in the east. Structurally, it may be considered as the outer part of the 'syntaxial loop' or 'hairpin bend' or the Kashmir Syntaxial Bend' of the northwest Himalayas.

GEOLOGY AND GEOCHEMISTRY

The general geology of the area (Fig. 1) is composed of precambrian Garnet Mica Schist and the Granite Gneiss which are dissected by acidic/ basic minor intrustions, such as pegmatites, quartzo-feldspathic veins and amphibolites at places. The Granite Gneiss is highly schistose. Generally, the grade of metamorphism/schistosity increases towards north. A soft, friable, greyish to white material exposed near Ahl Village is the striking part of the area from economic point of view. The rock units present in the studied area can be described as below :—

(A) Metosediments (Garnetmica Schists)

The northeast and southwestern parts of the area, i.e., Kandla, Dhamor and Chinarkot villages, mainly comprises metasediments. These are dominantly Garnet Mica Schists interbeded with quartzite at some places. The thickness of these quartzite varies from inches to feet at various localities. Furthermore, the metassediments are dominantly dissected by quartzo-feldspathic and amphibolite veins. These veins have concordant/ discordant relationship with the country rocks at places. On the basis of their relationship with the country rocks it is concluded that these are younger than the country rocks. The mineralogical composition of the ten samples of metasediments collected from various localities is given in Table-1.

The garnet minerals can easily be seen on the planar surface of the schistose rocks in the field and are indicative of medium to high grade metamorphism. The color of the metasediments varies from light brown to dark brown and at some places it is greyish brown. The schistosity is well developed and micaceous sheen can also be seen in these schists.

Furthermore, the basic sills/dykes cross cutting the country rocks are widely scattered throughout the area and are usually metamorphosed. Boudinage and lensnes are the common structural phenomenon present in these rocks. Generally, the grade of metamorphism increasing towards north. On the basis of preserved relationship of the dykes of different origin and gneissification, it is assumed that these rocks have undergone polymetamorphism which may be related with the different Himalayan and pre-Himalayan orogenies. Similar results have been concluded in other parts of the Lesser Himalayas by various workers (Chaudhry 1964 ; Gansser 1964 , 1981 ; Naha and Ray 1971 ; Shams 1983 ; Chaudhry et al. 1983).

(B) Granite Gneiss

The second major rock unit in the area comprises Granite Gneiss. This gneissic unit is spread all over the eastern and southeastern part including Chalundri and Terakhar villages. This is the most important member of the Mansehra Plutonic Complex and believed to be an older rock (Shams, 1967).

The intensity of foliation in the Granite Gneiss generally increases towards north as the grade of metamorphism increases in metasediments. This rock varies in colour from greyish white to whitish grey. Feldspar crystals of a few cm can also be seen at some places and are separated from the surrounding rocks by micaceous material segregated from the surrounding rocks by micaceous material segregated in the form of thin flakes. Quartzo-feldspathic intrusions are also present varying in size from a few inches to feet in the form of lenses. This gneissic unit is also dissected by acidic intrusions, i.e., pegmatites/feldspar, having the same relation as in the metasediments. The mineralogical composition of four samples of Granite Gneiss along with the acidic/basic minor intrusions collected from various localities is given (Tables 2 — 3)

(i) Basic Minor Intrusions (Amphibolites) :

These intrusions comprise of amphibolites intruded both in the metasediments in the northern and northeastern part of the area including Lachimag and Kandla villages, and Granite Gneiss in the eastern part. The mineralogical composition of three basic minor bodies are given in Table 3. The average mineralogical composition of these basic bodies reveals that they are composed of amphiboles (68.7%), quartz (7.0%), K-feldspar (6.7%), zoisite (6.0%), sphene (2.3%), epidote (2.2%), magnetite (2.0%), plagioclase (1.0%) and micaceous minerals (3%). The contact with the surrounding rocks is very sharp. These are in the form of sills and dykes having their length about 15 to 40 feet long and even larger at some places, i.e., upto 100 feet or more specially in the Kandla and Kandi villages in the northeastern part of the area.

(ii) Acidic Minor Intrusions Fdldspathic Veinns Pegmattes

The acidic minor intrusions are common in the eastern part of the area dissecting the Granite Gneiss. The mineralogical composition of three acidic bodies is given in Table 3. Generally, three types of acidic minor bodies are found, i.e., those rich in feldspar named as K-feldspars, rich in quartz named as Quartzite and those rich in Tourmaline and quartz are named as Q-T veins. Among these minor bodies K-feldspars comprise of K-feldspar (60.0%), quartz (19.0%), plagioclase (18.0%), biotite (1.5%), muscovite (1.0%) and epidote and magnetite (traces), Quartzitic rock comprises of quartz (91.0%), K-feldspar (7.0%), muscovite (2.0%) and magnetite (traceces) Quartz-Tourmaline rock mainly composed of quartz (54.0%), muscovite (18.0%), touramaline (13.0%), Chlorite (9.0%) and magnetite (6.0%). The extension of feldspathic veins/pegmatites varies from a few feet to 50 feet rarely but mostly they have smaller in sizes. Feldspathic veins/pegmatites make cordant contact at one end and discordant at the other. Folding is also present within these feldspathic/pegmatitic veins and are invariably sheared These bodies form tabular, lensoid, lenticular, podike and branching structure gniwith the surround rocks. Boundinage structure can be seen at some places. These feldspathic / pegmatitic veins are also folded along the foliation of the gneiss The acidic minor bodies show different degree of tectonic involvement and have suffered variety of structures, i.e., tear - faulting, shearing and boundinage.

RESULTS AND DISCUSSIONS

The mineralogical and geochemical results of various rock units have been compiled (Tables 1—4). The studied area is characterized by igneous and metamorphic activity. Two main rocjk units have been identified in the area. The metasediments covers 40% of the studied area. These rocks show high grade metamorphism. In general, metamorphism of Himalayas reached upto amphibolite facies (Ghazanfar and Choudhry, 1986) and the grade of metamorphism is medium to high and is of Precambrian age (Frank et al., 1973 ; Le Fort, 1975; Bird, 1978 and Bard et al., 1980). The mineralogy (Table-1) of these metasediments and the field observations reveal that these rocks, on the average, contains quartz (45.0%), muscovite

(19.3%), biotite (12.3%), chlorite (10.2%), garnet (9.1%) and magnetite (2.0%), and therefore, better be termed as Garnet Mica Schists. As these metamorphic rocks represent the western marginal rocks of the syntaxial loop and can be related to the sedimentary origin, may be of the Indian Shield, i.e., Tanol Formation of Ali (1962), or Tanawal Formation of Calkins et al. (1975) or Tanol Group of Wynne (1879), or a part of Hazara Formation of Choudhry and Ghzazanfar (1992). On the other hand, granitic rocks covers 30% of the studied area and represent a part of the Mansehara granitic complex, Shams (1961) and Shams and Rahman (1966) correlated these granitic rocks with Susalgali Granite Gneiss.

It is, therefore, concluded that the metamorphic rocks present in the area are of medium to high grade garnet bearing rocks, i.e., Garnet Mica Schist and can be related to the Tanol Formation of early Precambrian. The Granite Gneiss exposed in the area is a part of Susalgali Granite Gneiss of late Precambrian.

For the purpose of a comparison and to unscramble the tectonic events occurred in the area, the average chemical composition along with the CIPW norm data of various igneous bodies in and around the studies area is presented in Table 4. It can be seen from this table that all the samples have one thing common, i.e., 225% of K-felspar indicating the mode of occurence,. The K_2O/Na_2O ratios sometimes play an important role in the discrimination of igneous rocks. For this purpose, the K_2O/Na_2O of various rock units are plotted against SiO_2 in Figure-2. It is clear from this figure that the K_2O/Na_2O ratio varies from 1.23 to 1.64 inferring the same mode of occurrence. To see the tectonic relationship among these rock bodies, the average chemical composition of the rock units in and around the studied area is plotted on the tectonic discrimination diagram (Fig. 3) as explained by Batchelor and Bowden (1985), in which almost all the samples are strongly associated with the syn-collision event.

The geochemistry and petrographic data of the rocks present in and around the study area suggest that the granite gneiss is the 'part of Susalgali Granite Gneiss as pointed out above, and considering the Precambrian age of the Susalgali Granite Gneiss as predicted by the above authors, this granite seems to be related with the pre-Himalayan orogenic event (Fig. 3). On the other hand, the age of other granitoid, pegmatitic and mafic bodies are, therefore, related with the later orogenic events, i.e., collisional and post-collisional events (Chaudhry et al., 1984).

The presence of small acidic/basic sills/dykes in both igneous and metamorphic rocks indicates the idea of polymetamorphism/migmatization, especially the minor basics which are mainly composed of amphibolesa are the alteration of the pre existing dolerite sills/dykes under the process of polymetamorphism. No other simple theory can be explained of their presence. Similarly, the minor acidic bodies may be the result of migmatization of the formation of pegmatites.

It is, therefore, concluded that the studied area had certainly experienced the polymetamorphism at different stages of orogeny.

No sharp and well defined contact between the Granite Gneiss and the metamorphic rucks was found inthe field. Howevey, a faulted contact between Granite Gneiss and the metamorphic rocks most probably runs along the Bat Kas stream. Furthermore, some of the minor bodies show a great deal of folding and shear faulting at places thus indicating tectonic activity.

It is, therefore, concluded that the studied area has undergone tectonic activity in later stages of orogeny which is evident from the structures of the minor bodies.

CONCLUSIONS

Two main rock units have been identified. The metamorphic rocks are Granet Mica Schist, and can be related to the Tanol Formation of early Precambrian The average mineralogical composition of these metasediments is quartz (45.0%) muscovite (19.3%), biotite (12.3%), chlorite (10.2%) garnet (9.1%) and magnetite (2.0%). Generally the metamorphic grade increases towards north.

The Granite Gneiss is a part of the Susalgali Granite Gneiss of late Precambrian The essential minerals present in this unit are K-feldspar (49.8%), quartz (21.8%), plagioclase (14.5%) muscovite (7.8%), biotite (6.3%) and magnetite (traces). The gneissosity increases as the metamorphic grade increases, towards north, hence showing the signs of regional metamorphism.

The structural changes in the minor bodies strengthens the idea of various tectonic events appearing in later stages of orogeny such as the effect of hairpin bend loop on these rocks The presence of amphibolites in the form of sills/dykes is an indication of polymetamorphism of the pre-existed dolerite sills/dykes present in both metammorphic and igenous rocks A faulted contact between the metamorphic rocks and the Granite Gneiss is believed to run along the Bat Kas Stream.

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TABLE 1. Mineral estimation of garnet mica schist of Battal Village and its surrounding area, District Mansehra, Pakistan.

Sample No.	M1	M2	M3	M4	M5	M6	M7	M8	M9
Minerals :	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Quartz	19	45	56	48	34	56	51	56	60
Garnet	16	7	6	14	7	8	2	13	4
Muscovite	49	27	17	7	46	3	9	6	6
Biotite	12	8	10	21	5	14	36	9	9
Chlorite	1.5	12	7	9	6	17	Tr	14	19
Magnetite	20	1	4	1	2	2	2	2	2

TABLE 2. Mineral estimation of granite gneiss of Battal Village and its surrounding area, District Mansehra, Pakistan.

Sample No.	G1	G2	G3		G4	
Minerals :	(%)	(%)	(%)	(%)	(%)	Average
	22	20	25		20	22
Quarts	22	20	25		20	22
K-Feldspar	44	50	52		53	50
Muscovite	10	11	5		5	8
Biotite	12	6			4	63
Plagioclase	12	13	18		15	
	—	—	—		—	
Magnetite	Tr	Tr	Tr		Tr	Tr

TABLE 3. Mineral estimation of Acidic and Basic intrusions both in granite gneiss and metamorphic rocks in Battal villages and its surrounding area, District Mansehra, Pakistan.

		......1....			......2...........			..3....		..4....
S. No.		F1	F2	Mean	Am1	Am2	Am3	Mean	Q1	Q-11
Minerals :		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%%
Amphiboles		—	—	—	72	63	71	69		— —
Quartz	13	25	19	9	6	6	7		91	54
Plagioclase		17	19	18	Tr	3	—		<3	— —
Muscovite		2	—	1	2	Tr	—		<2	2 18
Biotite		3	Tr	<3	1	4	0.5	2	—	—
Chlorite		—	—	Tr	—	0.5	<0.5	—		9
Sphene		—	—	3	1	3	3	2	—	—
K-Feldspar		65	55	60	—	13	7	7		7
Epidote	—	Tr	Tr	5	1	0 5	2		—	—
Zoisite	—	—	—	6	3	9	6	—		—
Tourmaline		—	—	—	—	—	—	—		13
Calcite	—	—	—	—	4	Tr	<4	—		—
Magnetite		Tr	Tr	Tr	2	2	2	2	Tr	6

NOTE : 1 — K-feFeldspars, 2 — Amphibolites, 3 — Quartzite, Ave. — Average,
4 — Quartz — Tourmaline Rock.

TABLE 4. Average chemical composition of various Granitic bodies in and around the studies area, District Mansehara, NWFP, Pakistan (units; major oxides ! CIPW NORM in weight percentages (%)

	1	2	3	4	5	6
SiO_2	70.91	71.34	69.69	72.07	—	—
TiO_2	0.55	0.56	0.42	0.16	—	—
Al_2O_3	14.67	14.33	15.19	15.63	—	—
Fe_2O_3	3.96	3.77	3.72	1.48	—	—
MnO	0.10	0.52	0.06	0.48	—	—
MgO	0.73	0.79	1.10	0.95	—	—
CaO	1.33	1.47	1.47	0.71	—	—
Na_2O	2.59	2.53	3.25	3.34	—	—
K_2O	4.26	4.07	4.39	4.12	—	—
P_2O_5	0.19	0.18	0.22	0.24	—	—
L01	1.04	0.81	0.64	1.22	—	—
Total	100.33	100.37	100.15	100.04	—	—
			MODAL ANALYSIS			
Quartz	—	—	—	—	19.0	21.8
K-Feldspar	—	—	—	—	60.0	49.8
Muscovite	—	—	—	—	1.0	7.8
Biotite	—	—	—	—	<3	6.3
Plagioclase	—	—	—	—	18.0	14.5
Epidote	—	—	—	—	Tr	—
Magnetite	—	—	—	—	Tr	Tr
			CIPW NORM			
Q	—	37.22	29.81	34.61	—	—
Or	—	24.06	25.95	24.35	—	—
ab	—	21.41	27.50	28.26	—	—
an	—	6.12	5.86	1.95	—	—
C	—	3.52	2.95	4.96	—	—
hy	—	1.97	2.74	2.37	—	—
mt	—	0.07	—	1.10	—	—
il	—	1.06	0.13	0.30	—	—
hm	—	3.72	3.72	0.72	—	—
ap	—	0.43	0.52	—	—	—
ru	—	—	0.35	0.57	—	—
Total	—	99.52	99.52	99.19	—	—

1 — Susaligali granite gneiss (Shams, 1966)
2 — Mansehra granite (Shams, 1966)
3 — Andulasite granite (Shams, 1966)
4 — Hakale granite (Sch (Shams, 1966)
5 — Acidic minor bodies (present study)
6 — Granite gneiss (present study)

Note : LOI — Loss on ignition, Q—Quartz, or—Orthoclase, ab—Albite, an—Anorthite, VC — Corundum, hy — Hypersthene,, mt — Magnetite, il — I lmenite, hm — Hematite, ap — Apatite, ru — Rutile.

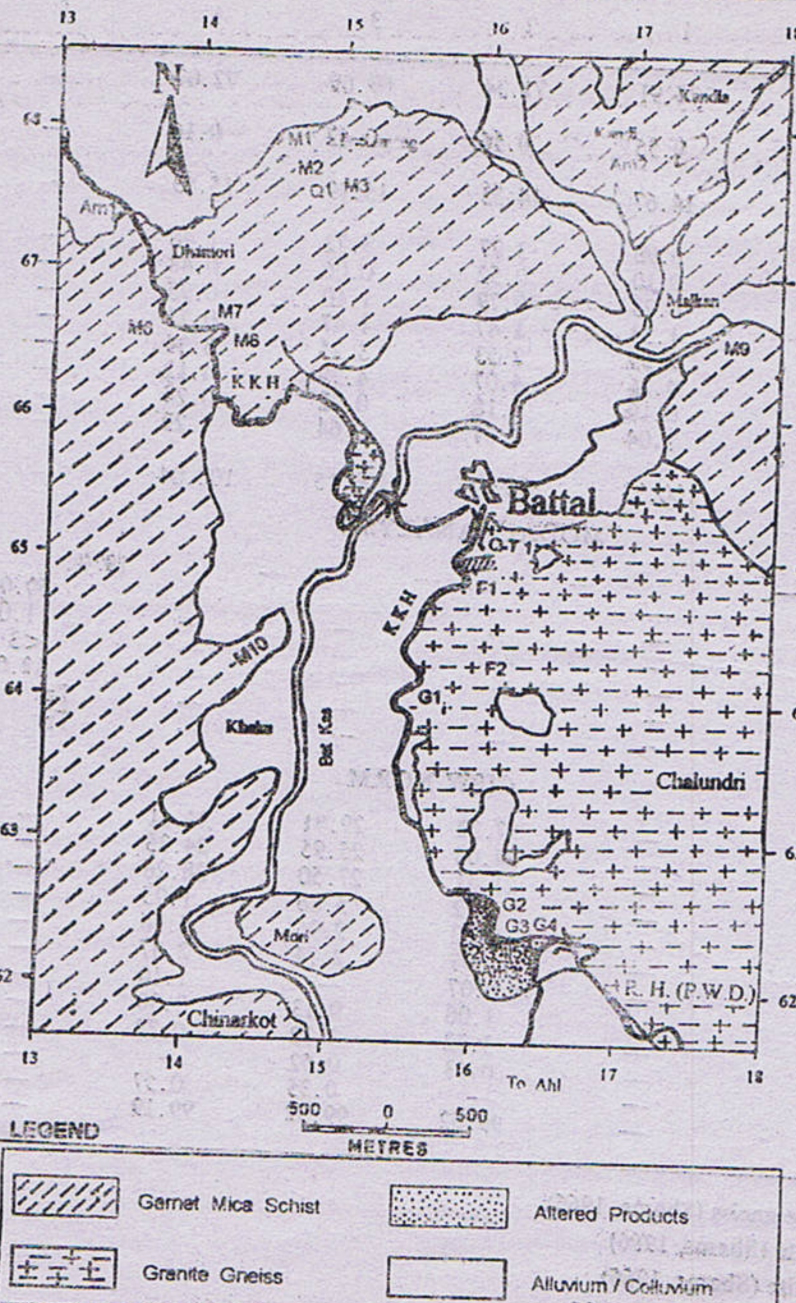

FIG. 1. Geological map of the Battal village and its surrounding area, District Mansehra, Pakistan

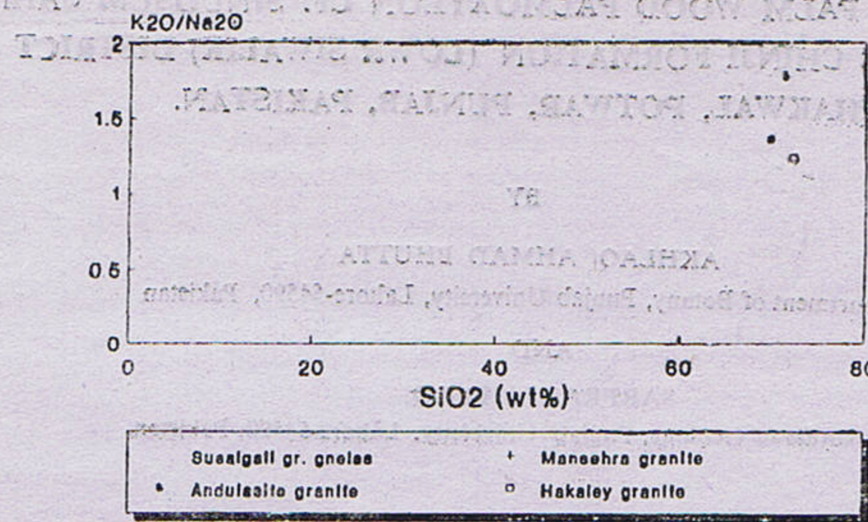

FIG. 2 Figure showing the K_2O/Na_2O ratio plotted against average SiO_2 values.

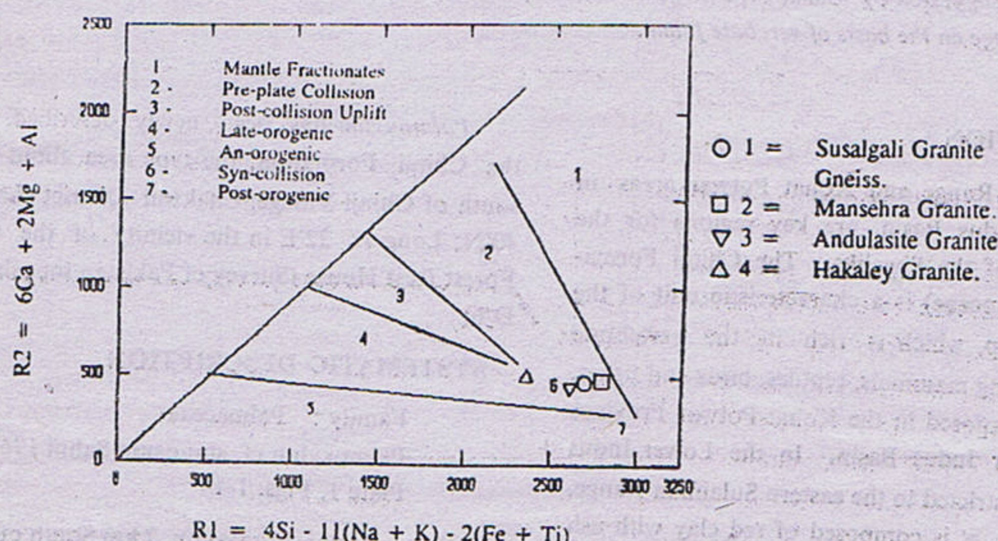

FIG 3. Tectonic discrimination diagram indicating the Syn-collision emplacement of Mansehra Complex (After Batchelor and Bowden, 1985).

Geol. Bull. Punjab Univ. 1993, **28**, 116—120

A PETRIFIED PALM WOOD PALMOXYLON CF. SINUOSUM SAHNI FROM THE CHINJI FORMATION (LOWR SIWALIK) DISTRICT CHAKWAL, POTWAR, PUNJAB, PAKISTAN.

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Abstract : *A petrified wood discovered from the Chinji Formation, District Chakwal, Potwar, has been described and assigned to Palmoxylon cf. sinuousum sahni. The wood has shown cerain similarities with Palmoxylon amriense Khan et al. Anatomical details have shown its closer comparison with Group III—Veqinata suggested by Sahni* (1964). *The discovery of present flora endorses the previously recovered Late Miocene age on the basis of verebate fauna.*

INTRODUCTION

The Salt Range and Kohat Potwar areas in the Upper Indus Basin, are key regions for the stratigraphy of the Siwaliks. The Chinji Formation (Late Miocene) is a characteristic unit of the Siwalik Group, which is rich in the vertebrate fossils including mammals, reptiles, birds and fishes. It is widely exposed in the Kohat-Potwar Province of the Upper Jndus Basin. In the Lower Indus Basin, it is restricted to the eastern Sulaiman Range. Lithologically, it is composed of red clay with ash grey to brown sandstone. Suboridnate clay deposits are also present at places.

Bhutta et al. (1987) discovered Angiospermic fossil woods from the Nagri Formation and recorded seventeen different petrified (silicified) woods of Angiosperms.

Palmoxylon has been newly described from the Chinji Formation, the type area about 7 km south of Chinji Village, Chakwal District (Lat. 32° 40'N; Long 72° 22'E in the vicinity of the Chinji Forest Rest House (Survey of Pakistan toposheet 43 D/6)

SYSTEMATIC DESCRIPTION

Family : Palmaceae

Palmoxylon cf. sinuosum Sahni 1964

Plate 1, Figs. 1-4

Locality : Chinji Formation, 7 km South of Chinji Village near Chinji Forest Rest House.

Material : Block No. Chinji 16481/3-7
Slide Nos. G.D. 1-3 (Ch. 16481/3-7
Peel 1-9 (Ch. 16481/3-7

Morphology: The main block was cut into five different pieces, out of which working block is reproduced (Plate 1, Fig. 1) The block is 7.5 cm long, 4.5 cm wide and 3 cm thick. The material is silicified. Apparently the preservation seems to be moderate but while making peel sections, parenchyma is very poorly preserved.

ANATOMICAL DESCRIPTION

The bundles are reniform to ovulate, variable in size. About 25-30 cm^2 and are about 0.3-0.5 apart. Fibero vascular bundles are about 0.71x 1.2 mm Fibro vascular ration is about 3: 4 to 3: 1. Scleronchyma lacunate, isodiametric, circular to elliptical in outline around the vessel.

Ground tissue uniformly thin walled but poorly preserved. Patenchyme, around the vascular bundle, tubular, 1-2 layered in thickness. Each vascular bundle possesses wide vessels with a diameter of 170 *um* Plate 1 Fig. 2. The cellular details are not very well defined but radial longitudinal section shows straight to slightly oblique end walls in the vessels. The fiberous cells are elongated, pointed and very fine (Plate 1, Figs. 3-4). Xylem parenchyma poorly preserved. Sclerenchyma bands forming reniform outline.

COMPARISON AND DISCUSSION

The section is from subdermal region. Stenzel (1904) has classified the Palm woods in 4 divisions A-Z. Stenzel 's division 'C' as *Cocos* like, in which outer and inner bundles uniformly distributed, less than 1 diameter apart in size and structure, sclerenchyma reniform. Stenzel has divided division 'C' as *Cocos* like into three groups.

Group I Reniform :	Sclerenchyma reniform
Group II Lunaria :	Sclerenchyma lunate, ventral Sclerenchymatous arch ab-
Group III Veginata	Sclerenchyma lunate ventral sclerenchymatous arch present present.

Sahni (1964) has described 33 *Palm* woods out of which 14 belong to Renifor maGroup. The present investigated specimen has shown closer resemblane with *Palmoxylon sinuosum* Sahni (Sahni 1964, p. 52, pl. 5, Figs. 40-41) Its comparison can, however, be made with *Palmoxylon amriense* Khan et al. (1971) but has differences in having less frequently distributed vascular bundles and also in the morphology of vessels, in the absence of fiberous bundles and stegmata. The species described by Sahni (1964) seems to be more closely related with the present *Palm* wood. Its certainty is, however, limited till more ground sections of the material are made available. Comparison of *Palm* woods has been tabulated (Table 1.)

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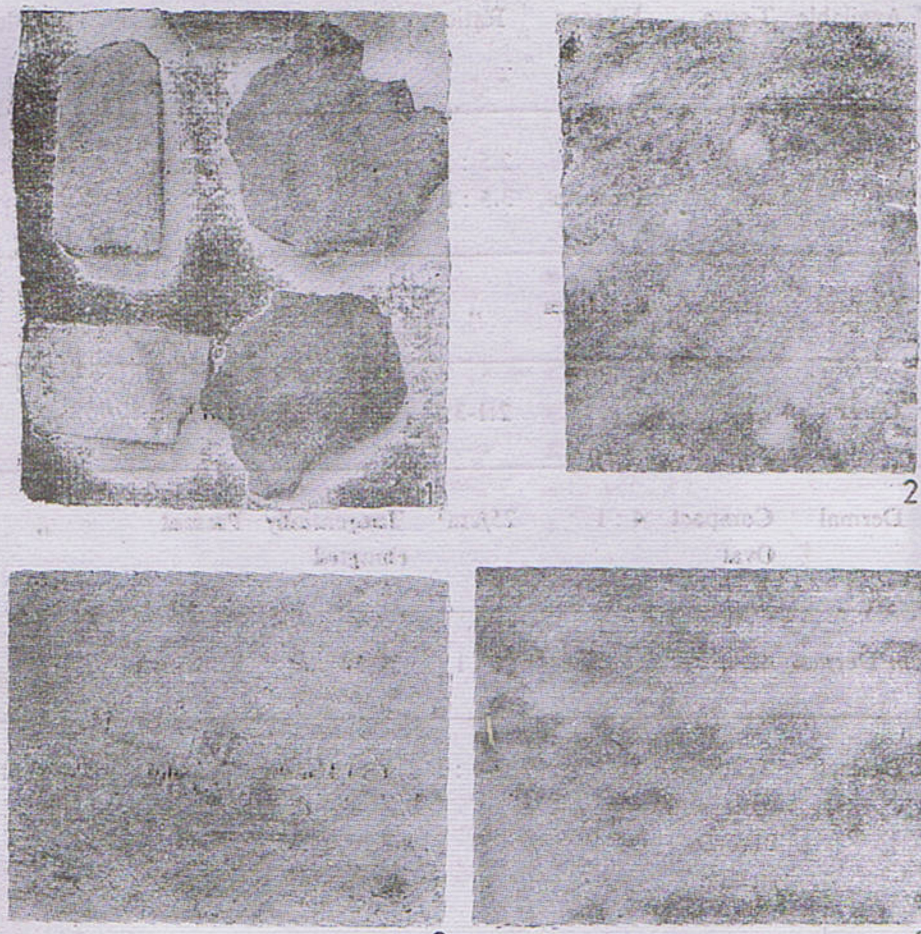
TABLE I

Synoptic Table of the Descriptions of certain Comparable Petrified Palm Woods.

Sr. No.	Name of Species	Parts Available	Ground Tissue	Shape of Fibrous Bundls	F.V. Ratio	Frequency of F.V.BS.	Parenchyma arround the F.V.BS.	Fibrous Bundles	Age
1.	*Palmoxyjon chhindwarense*	Central	Lacun-ate	Oval to reniform	2.5 : 1- 3.5 : 1	6-100/cm^2	Tabular	Absent	Tertiary
2.	*P. eocenum*	Central	,,	Reniform	,,	30-60/cm^2	Radiating	,,	Eocene
3.	*P. arcotense*	Centr	,,	,,	2:1-3:1	20-25/cm^3	Tablular	,,	,,
4.	*P. surangei*	Dermal	Compact Oval	4 : 1	25/cm^2	Tangentially elongted	Present	,,	
5.	*P. sclerodermum*	Dermal	,,	,,	6 : 1	30-50/cm^2	Radiating	,,	,,
6.	*P. slnuosum*	Dermal	Tenden-cy become stellate	Ov to to reniform	3-4 : 1	Not known	Tabular	Absent	,,
7.	*P. amriense*	Dermal and sub-dermal	Lacuna-te	,,	2.5-1 to 3 : 1	35-40/cm^2	Tobular Tabular	,, ,,	Paleocene Palecene
8.	*P. cf. sinuosum*	Sub-dermal		,,	,,	3 : 4-:31/cm^2	Tabular	,,	Miocene

PLATE I



3 4

Explanation of Plate I

Fig.1.	Petrified wood blocks of <u>Palmoxylon</u> cf. <u>cinuosum</u> sahni cut in different plane of sections x 1/2
Fig.2.	Transverse section showing Vessels x 25
Fig 3	Radial longitudinal section showing Vessels with straight end walls. x 25
Fig 4	Radial longitudinal section showing Vessels x 35