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Vol.6, No.1&2 (January & July 1994), P.41-52, 1 Fig., 3 Tables, 1 Plate

Petrology of Lumshiwal Formation from Gulagah Nala Near Chinali Bridge, Abbottabad-Nathiagali Road, Hazara with Special Reference to Nandpur Gasfield, Punjab Platform

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ABSTRACT

A detailed study of petrology of Lumshiwal Formation of Early Cretaceous age from Gulagah has been carried out for the first time. The objective was to study the petrography, provenance, environment of deposition and diagenesis of the Formation and to compare it broadly with Nandpur gasfield section of Punjab Platform where it is a gas reservoir.

The section of Lumshiwal Formation from Gulagah Nala near Chinali Bridge is medium to thick bedded glauconitic sandstone with intercalations of shale. This is petrographically divisible into 8 internal units. The unit overlying Chichali Formation is clay and quartz cemented quartz arenite. The other units are mainly quartz, glauconite and carbonate cemented, moderately well to well sorted, sub-mature to mature quartz arenites and shale. The maximum development of glauconite is in the central part. Since glauconite appears to have originated from clay, the glauconite rich arenites might have originally been wackes. Some horizons are selectively cemented with flint. However intraclasts of quartz grains cemented with flint are also observed towards the top of the Formation.

Accessory tourmaline, zircon, epidote and sphene which may occur either as discrete grains or as inclusions within quartz grains suggest an ultimate derivation from sialic igneous metamorphic basement with minor contribution from basic sources. Granitoids were mainly S-type. However, overall mineralogy and texture suggest recycling.

The Lumshiwal Formation indicates low energy conditions in the sub-tidal zone. The formation of glauconite itself reveals slow rates of sedimentation and mildly reducing conditions. Diagenetic history indicates the formation of glauconite, secondary quartz, feldspar and flint earlier and ferroan calcite and dolomite at a later stage. Development of stylolites in the carbonate parts and suturing of quartz grains occurred during deep burial. The last stage involves the formation of ferroan dolomite during final uplift with parts converting into dedolomite.

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INTRODUCTION

The studied section of the Lumshiwal Formation at Gulagah Nala (lat 34° 08' N, long 73° 22' 30" E) near Chinali Bridge is 32.61m thick. The name Lumshiwal Formation was amended by the Stratigraphic Committee of Pakistan for Main Sandstone series of Davies (1930) in Hazara and Lumshiwal sandstone of Gee (1945) in the Salt Range. Due to variations in lithologies other than the type locality, Shah (1977) designated the type locality a section one km north of Lumshiwal Nala (lat. 32° 5.1' N, long. 71° 09' E). Fatmi (1972) designated three principal reference sections to illustrate the facies changes: (i) the Fort Lockhart road section in the Samana Range, (ii) Wuch Khwar section in the Nizampur area, and (iii) Jhamiri Village section on Haripur-Jabrian road in Hazara. The Formation comprises mainly of coarse to medium grained sandstone which is blackish brown, dark greenish grey to light grey and mustard brown to reddish grey on fresh surface. At places, fresh surface shows greenish tinge which becomes darker green on wetting. The sandstone weathers to rusty brown, rusty maroonish brown, rusty blackish grey to brownish black colours. However, at places, it is light creamish grey and certain horizons show irregular nodules. The basal part is coarse grained with large quartz grains (4 to 5 mm across). Maroonish, rusty to brownish coloured horizons of splintery shale are also present. The lower contact with Chichali Formation is sharp where as the upper contact with Kawagarh Formation is transitional. Millimeteric calcite veins are abundant. The stratigraphic sequence in Galiat area is given in Table 1).

PETROGRAPHY OF LUMSHIWAL FORMATION

The measured section of Lumshiwal Formation (Table 2. Figure 1) is a glauconitic sandstone intercalated with shales. The detrital constituent (Table 3) is mainly quartz. Tourmaline, zircon, iron oxides, epidote and

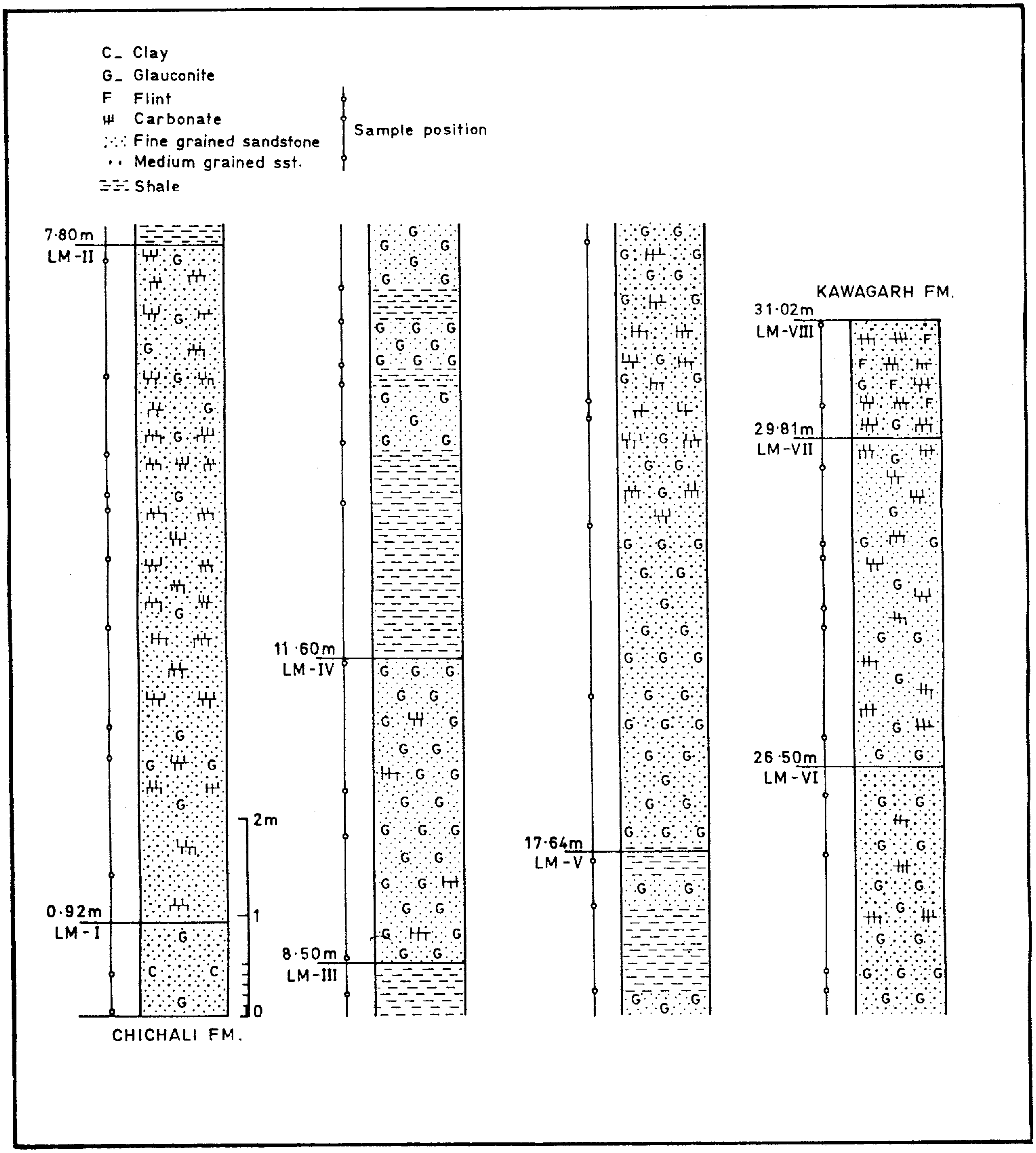

Figure 1– Lithofacies column of Lumshiwal Formation, Gulagah Nala near Chinali Bridge.

Table 1. Stratigraphic table of Hazara area.

Age	Formation	Lithology
Miocene	Murree	Grey and reddish sandstone and shales
Middle Eocene	Kuldana	Maroon to varicoloured shales and marls
Early to Middle Eocene	Chorgali	Thinly bedded limestone and marls
Early Eocene	Margala Hill Limestone	Nodular foraminiferal limestone
Late Paleocene	Patala	Greenish grey/khaki shales with limestone beds
Middle Paleocene	Lockhart Limestone	Nodular foraminiferal limestone
Early Paleocene	Hangu	Sandstone, claystone, 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	Samana Suk	Limestone with dolomitic patches
Early Jurassic	Datta	Sandstone, quartzite, microconglomerate
———	Disconformity ———	———
Early Cambrian	Hazira/Galdanian	Calcareous siltstones and shales
Precambrian	Abbottabad	Dolomites with sandstone, shale and boulder bed at base
———	Unconformity ———	———
Late Precambrian	Hazara	Slates, sandstone and quartzites

Table 2. Measured section of Lumshiwal Formation (Gulagah Nala) near Chinali bridge, Distt. Abbottabad.

Cumulative thickness (m) of zone	Sample No.	Sample Position(m)	Description of Each zone
			Kawagarh Formation
LM-VIII	L-39	30.97	**Fine to medium grained carbonate cemented quartz arenite.**
31.02	L-38	30.14	
			Thick bedded and massive looking, tough to hammer, very fine grained sandstone. The calcite veins are oblique to the bedding. Mustard brown on weathered surface while rusty brown is the fresh colour. Flint is present on the surface which is tough and dark black. It is present as patches even within the rock.
LM-VII	L-37	29.51	**Fine grained, glauconite and carbonate cemented quartz arenite.**
29.81	L-36	28.72	
	L-35	28.60	This unit is medium bedded and fine grained glauconite and carbonate cemented sandstone. Fresh surface is greenish grey to light grey while weathered surface is grey. Tough to hammer. Calcite veins are parallel to the bedding. Black patches of flint are present at places.
	L-34	28.10	
	L-33	27.90	
	L-32	26.80	
LM-VI	L-31	26.20	**Fine to medium grained, glauconite, carbonate and quartz cemented quartz arenite.**
26.50	L-30	25.60	
	L-29	24.40	
	L-28A	24.22	Medium bedded, beds ranging in size from 1.50m to 2.50m. Medium grained, glauconite, carbonate and quartz cemented sandstone. Fresh surface colour is greenish grey to dark grey while weathered surface is yellowish brownish grey to blackish green. Sand size black grains probably of glauconite are abundant. Calcite veins are perpendicular to the bedding ranging in size from 4 to 7mm.
	L-28	23.82	
	L-27	22.22	
	L-26	22.05	
	L-25	20.92	
	L-4C	19.22	
LM-V	L-24B	17.54	**Fine grained, glauconite cemented arenite interclated with shale.**
17.64	L-24A	17.10	
	L-24	16.21	Thin bedded glauconite and quartz cemented sandstone is maroonish brown on weathered surface while fresh surface is greenish grey. Sandstone beds are thin, ranging in thickness from 0.34m to 1.6m. Fractures are common and visible. The shale beds are highly weathered. These are dark green on wheathered surface and light greenish grey on fresh surface
	L-23	15.35	
	L-22	15.01	
	L-21	14.59	
	L-20	14.39	
	L-19	13.79	
	L-18	13.19	

Table 2 (continued).

Cumulative thickness (m) of zone	Sample No.	Sample Position(m)	Description of Each zone
LM-III	L-13	8.05	**Shale**
8.50			
			The shale is dark blackish grey on weathered surface and greenish grey on fresh surface.
LM-II	L-12	7.76	**Fine to medium grained carbonate and quartz cemented quartz**
7.80	L-11	6.46	**arenite.**
	L-10	5.66	
	L-9	5.25	Thick bedded, medium to fine grained carbonate and quartz cemented sandstone is tough to hammer. Fresh colour is rusty brownish grey to dark grey, and weathered colour is brownish grey to blackish grey. Some grains are very coarse. Specks of iron oxides are common. Some parts are slightly friable. Some beds are nodules bearing and fractured, the nodules are darker in colour as compared to rock. Calcite veins are upto 2 mm thick and are parallel to bedding.
	L-8	5.10	
	L-7	4.60	
	L-6	3.90	
	L-5	2.90	
	L-4	2.58	
	L-3	1.42	
LM-I	L-2	0.42	**Fine to medium grained, clay and quartz cemented quartz arenite**
0.92	L-1	0.02	**with carbonaceous matter.**
			Thin bedded, highly weathered and friable. The sand grains are medium grained. Fractures are common. Sandstone is slightly fissile. Fractures are probably filled with clay and carbonaceous matter. The sandstone is nodular at places. Fresh colour is dark blackish grey while weathered colour is rusty dark grey.
		(0)	
			Chichali Formation

PLATE - A

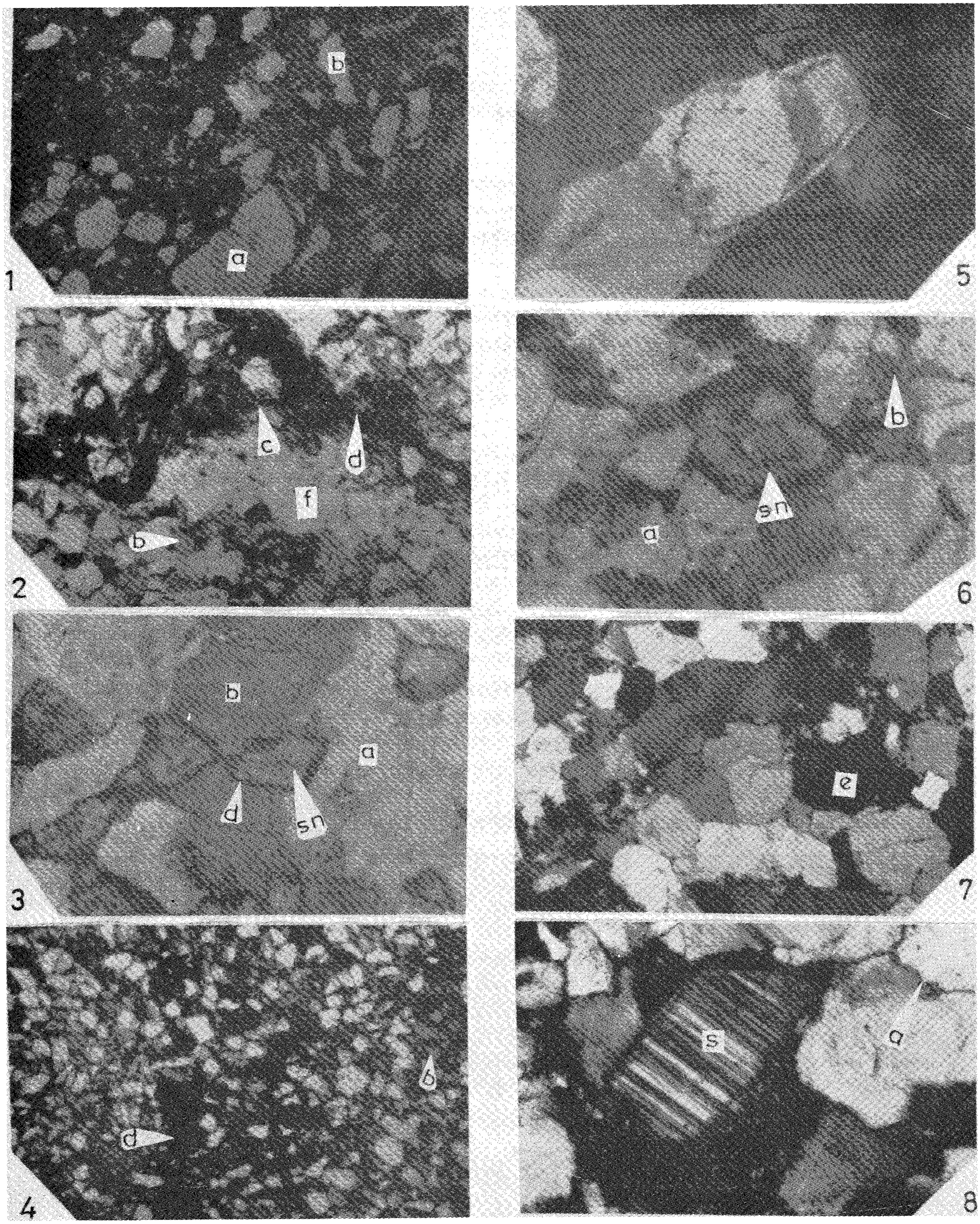

PLATE A
(Description)

1) Dolomite is replacing intraclast of flint cemented quartz grains (LM-I/L-39), PPL. 10 x 2.5. Quartz (a), glauconite (b), and Flint (left half).

2) High amplitude stylolite along with clay (c), iron oxide (d), Flint (f), and glauconite (b) has been deposited (LM-II/L-33), PPL. 10 x 25.

3) Dolomite (sn), corrode quartz (a), and glauconite grains (b) (LM-III/L-28A), PPL. 10 x 10. See the staining of iron oxide (d) at the borders of dolomite rhombs.

4) Iron oxide (haematite) as a patchy cement (LM-IV/L-19), PPL. 10 x 10. Glauconite (b), haematite (d), and quartz grains (whitish).

5) Quartz overgrowth (LM-III/L-27), CNL. 10 x 10. The clay film over detrital quartz grains in visible and makes easy to observe the overgrowth.

6) Well zoned dolomite rhombs (LM-V/L-15), PPL. 10 x 10. Glauconite (b), dolomite (sn), and quartz (a).

7) Sutured contacts of quartz grains (LM-VII/L-9) and the effect of pressure solutions are quite dominent, CNL. 10 x 2.5. Overgrowth (e).

8) Excellent view of feldspar over feldspar overgrowth (LM-VIII/L-1), CNL. 10 x 10. Plagioclase (s), and sutured quartz grains (a).

sphene are the accessories. The sandstones are compositionally mature and texturally sub-mature to mature. The detailed data on porosity as well as grain size of individual samples is available on request.

This section of Lumshiwal Formation is divided into eight internal units on the basis of petrography. The details of each unit are given below.

LM-I: Fine to Medium Grained, Clay and Quartz Cemented Quartz Arenite with Carbonaceous Matter

The quartz grains are subangular to angular (Plate A-8). This unit is compositionally as well as texturally mature and well to very well sorted. This unit was deposited as an arenite. In between quartz grains clay or carbonaceous matter is present. For this reason most of the contacts are tangential or long. However, quartz grains are in sutured contacts (Plate A-8) with one another, at places. The accessory minerals are tourmaline, epidote, muscovite, chert and plagioclase. Glauconite and flint are present in trace amounts. Quartz over quartz and feldspar over feldspar overgrowths are prominent (Plate A-8). The cementing material apart from quartz is clay, flint and some carbonaceous matter.

LM-II: Fine to Medium Grained Carbonate and Quartz Cemented Quartz Arenite

It is (Plate A-7) moderately well sorted, texturally sub-mature and compositionally mature. This unit was deposited predominantly as an arenite. Quartz grains are mostly in long or tangential contacts but at places these contacts are concavo-convex and sutured (Plate A-7). Low to high amplitude stylolites along with clay and iron oxides are prominent at places. Microstylolites are developed along sutured quartz grains. The inclusions of tourmaline and rutile needles occur in the quartz grains. Random fractures are common in some quartz grains and are filled partially by glauconite and carbonate. There is hardly any matrix. Quartz over quartz overgrowths are common (Plate A-7). However, feldspar over feldspar overgrowths are less common. The main cementing material was dolomite which has dedolomitized to ferroan and non-ferroan calcite at places. Dolomite replaces quartz grains. The content of glauconite varies erratically in this unit. Flint is a minor cement. The suite of accessory minerals may include tourmaline, epidote, sphene, muscovite, chlorite, iron oxides and zircon in trace amounts.

LM-III: Shale

This unit is composed entirely of greenish gray to dark green glauconitic shale.

LM-IV: Fine Grained Glauconite and Carbonate Cemented Quartz Arenite

This fine grained, moderately well to well sorted, compositionally mature, texturally sub-mature to mature unit forms the glauconite and carbonate cemented quartz arenite (Plate A-6). Since glauconite has formed from clay therefore this unit originated mainly as a wacke. Carbonate is dolomite which dedolomitizes to ferroan and non-ferroan calcite. The zoning in dolomite

Table 3. Mineral estimation of Lumshiwal Formation (Gulagah Nala) near Chinali bridge, District Abbottabad.

Zone	LM-VIII		LM-VII						LM-VI									LM-V			
Sample No.	L-39	L-38	L-37	L-36	L-35	L-34	L-33	L-32	L-31	L-30	L-29	L-28A	L-28	L-27	L-26	L-25	L-24C	L-24B	L-24A	L-24	L-23
Quartz	8.4	58.8	72.2	79	78.9	80.5	77.6	77.1	77.8	63.1	63.9	62.0	84.5	63.8	70.1	71.7	49.5	-	66.9	-	66.1
Carbonate	48.7	37.1	16.7	9	7.2	6.2	-	10.2	-	7.4	6.3	2.0	-	9.2	14.4	2.0	-	-	-	-	-
Glauconite	1.9	1.1	5.2	7	10.3	8.2	16.3	6.1	16.5	26.3	26.3	31.3	12.4	20.4	12.4	25.3	44.0	-	28.3	-	27.1
Ore	-	-	1.0	1	2.1	2.1	1.0	2.0	2.1	1.0	1.2	2.2	1.0	2.0	1.0	-	4.1	-	4.0	-	4.2
Tourmaline	-	Tr	0.5	Tr	0.5	0.5	0.6	Tr	Tr	Tr	0.3	0.5	Tr	-	-	-	Tr	-	0.3	-	0.5
Sphene	-	-	0.3	-	-	-	-	-	Tr	-	-	Tr	-	-	-	-	-	-	-	-	-
Epidote	-	-	-	-	-	-	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	Tr
Zircon	-	-	-	-	-	-	Tr	-	-	-	-	-	-	-	-	-	Tr	-	-	-	Tr
Chert	-	-	1.0	1.5	-	0.5	-	1.5	1.5	-	-	-	-	2.0	-	-	-	-	-	-	-
Clay	-	-	-	-	1.0	1.0	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	1.6
Muscovite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plagioclase/Albite	-	-	Tr	1.5	-	1.0	Tr	Tr	-	Tr	-	Tr	-	-	-	-	-	-	-	-	Tr
Flint	41.0	3.0	3.1	1.0	-	Tr	3.0	3.1	2.1	2.1	2.0	2.0	2.1	2.6	2.1	1.0	2.4	-	0.5	-	0.5
Chlorite	-	-	-	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-	-	-	-	-
Carbonaceous matter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Porosity	2	3	4	1	3	4	2	2	3	5	5	4	3	2	2	1	3	-	1	-	4

Zone	LM-V					LM-IV				LM-III	LM-II										LM-I	
Sample No.	L-22	L-21	L-20	L-19	L-18	L-17	L-16	L-15	L-14	L-13	L-12	L-11	L-10	L-9	L-8	L-7	L-6	L-5	L-4	L-3	L-2	L-1
Quartz	-	50.6	-	61.9	-	63.9	72.8	70.9	84.3	-	72.9	70.4	61.1	88.9	75.2	72.8	80.5	73.5	61.7	86.0	83.9	83.1
Carbonate	-	-	-	-	-	-	7.1	-	6.1	-	15.6	15.9	32.8	Tr	16.5	20.2	10.4	20.4	20.8	5.0	-	-
Glauconite	-	40.2	-	25.0	-	3.0	12.1	25.3	6.1	-	8.2	11.4	-	5.1	2.6	-	4.1	-	12.5	-	-	Tr
Ore	-	4.6	-	9.1	-	1.0	2.5	2.0	1.5	-	0.5	0.6	1.5	1.5	2.1	1.5	1.0	2.0	2.6	1.5	-	-
Tourmaline	-	Tr	-	Tr	-	Tr	0.5	Tr	0.5	-	0.3	0.6	Tr	Tr	Tr	Tr	Tr	Tr	0.3	0.2	Tr	Tr
Sphene	-	-	-	0.6	-	-	Tr	0.3	-	-	-	-	-	-	-	-	Tr	-	-	-	-	-
Epidote	-	-	-	-	-	-	Tr	-	Tr	-	-	-	-	-	-	-	-	Tr	-	-	Tr	Tr
Zircon	-	-	-	-	-	-	Tr	-	Tr	-	-	-	-	Tr	-	-	-	-	-	-	-	-
Chert	-	-	-	-	-	Tr	-	-	-	-	-	-	-	-	1.5	1.0	1.0	1.0	0.5	1.5	-	0.5
Clay	-	2.3	-	2.3	-	2.0	1.5	-	-	-	-	-	1.5	1.5	-	1.5	-	-	1.0	4.0	12.1	10.9
Muscovite	-	Tr	-	-	-	1.0	Tr	Tr	Tr	-	-	-	-	2.0	Tr	0.5	0.5	-	Tr	-	0.5	1.5
Plagioclase/Albite	-	-	-	Tr	-	0.5	0.5	Tr	Tr	-	1.0	1.1	-	Tr	Tr	Tr	1.0	Tr	0.6	1.0	1.5	2.0
Flint	-	2.3	-	1.1	-	2.0	3.0	1.5	1.5	-	1.5	-	3	1	2.1	2.5	1.5	3.1	Tr	Tr	1.0	-
Chlorite	-	-	-	-	-	-	-	-	-	-	-	Tr	Tr	Tr	Tr	-	-	-	-	-	-	-
Carbonaceous matter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0	2.0
Porosity	-	3	-	2	-	2	1	2	2	-	3	2	2.5	1	3	2	3	2	44	2	0.5	0.5

rhombs is quite prominent (Plate A-6). Partial glauconitization of quartz and chert grains is observed. However, most of the glauconite grains are well developed and may be partially replaced by dolomite rhombs. Quartz grains show point, long and concavo-convex contacts with one another. Low amplitude composite stylolites along with iron oxides and some carbonaceous matter are present. Clay seams are also present towards the base of this unit. Quartz over quartz, feldspar over feldspar and tourmaline over tourmaline overgrowths are often seen. Intracement as well as open rock fracture pore porosity is present. The accessory minerals are tourmaline, sphene, epidote, iron oxides and zircon. Indicolite as well as schorl grains are present.

LM-V: Fine Grained, Glauconite Cemented Quartz Arenite Intercalated with Shale

The sandstone is well to moderately well sorted, compositionally mature and texturally sub-mature to mature. The quartz grains are generally sub-rounded to sub-angular (Plate A-4). Since glauconite appears to have formed from clay, most of this unit was originally a wacke rather than arenite. The main cementing material is glauconite. Iron oxides are also present as a patchy cement at places (Plate A-4). The quartz grains are in long or point contacts with one another but slightly in concavo-convex contacts at places. Quartz over quartz and tourmaline over tourmaline overgrowths are present. The haematite filled veins cut across quartz and glauconite grains. Quartz grains are corroded by glauconite and in turn both quartz and glauconite are corroded by iron oxide (haematite). The porosity types are intergranular, intracement and oversized fabric selective. Tourmaline, epidote, iron oxides and zircon are the accessory minerals.

LM-VI: Fine to Medium Grained, Glauconite, Carbonate and Quartz Cemented Quartz Arenite

This fine to medium grained, glauconite, quartz and carbonate cemented quartz arenite is compositionally mature, texturally sub-mature to mature and moderately well to well sorted (Plate A-3). Most of this zone was originally a wacke. Due to the conversion of clay to glauconite, it now appears to be an arenite. The quartz grains are sub-rounded to sub-angular. The contacts of quartz grains are sutured and slightly concavo-convex. Random fractures are common in quartz grains which are partially filled by iron oxide and glauconite. Composite stylolites of low amplitude also occur. Quartz over quartz overgrowths are a common feature. A thin film of clay marks the boundary between detrital grain and overgrowth. One of the distinguishing feature of this unit is the very well developed dark green glauconite grains which corrode quartz grains. Dolomite rhombs corrode quartz as well as glauconite grains (Plate A-3). Polycrystalline quartz and chert grains (slightly glauconitized) are also present. The porosity types of this unit are open rock fracture pore, open intergranular fracture pore, intergranular, intracement and oversized fabric selective.

LM-VII: Fine Grained, Glauconite and Carbonate Cemented Quartz Arenite

It is fine grained, moderately well sorted glauconite and carbonate cemented quartz arenite (Plate A-2) which is compositionally mature and texturally sub-mature. Horizon with more than 10% glauconite may originally have been wackes (Table 3). Quartz grains are either sutured or in concavo-convex contacts. Quartz over quartz, feldspar over feldspar and tourmaline over tourmaline overgrowths are often seen. Glauconite, flint, clay and dolomite rhombs are concentrated along high amplitude stylolites. However, low amplitude composite stylolites are also abundant. A layer of polycrystalline quartz has been observed in this zone. The main cements are dolomite and glauconite with some flint. Dolomite has two generations: (1) non-ferroan dolomite, (2) dedolomite to ferroan and non-ferroan calcite. Dolomite rhombs are well zoned. There are a number of veins which are partially filled with glauconite and haematite. The porosity is mainly intracement and is developed in dolomite rhombs and glauconite grains. However, oversized fabric selective porosity is also observed. Tourmaline, sphene, epidote, zircon and iron oxides are the accessory minerals.

LM-VIII: Fine to Medium Grained Flint Cemented Quartz Arenite

This fine to medium grained flint cemented quartz arenite is compositionally mature and texturally mature to sub-mature (Plate A-1). It is moderately to well sorted. Quartz grains mostly float in the cement. However, some grains are in point or long contacts with one another. Quartz over quartz and tourmaline overgrowths are present. The porosity is intracement. Polycrystalline quartz grains and few grains of chert are also seen. Glauconite is mainly found in intraclasts. This zone is extensively replaced by dolomite which in turn dedolomitizes to non-ferroan calcite.

ENVIRONMENT OF DEPOSITION

The Lumshiwal Formation contains ubiquitous glauconite, accessory amounts of organic matter and pyrite. Marine fossils like belemnites, brachiopods, pelecypods and very rarely ammonites occur in this formation. Glauconite is often a very important and prominent constituent of this formation.

Glauconite has been variously interpreted in terms of environment of deposition. According to Galliher (1935) glauconite develops in marine conditions at depths from 9 to 110m. Cloud (1955) regards the depth of formation of glauconite between 18 to 730m. Greensands, at present, are also forming near the continental edge. In offshore areas of California it occurs between 40 to 500m. Greensmith (1981) and Pettijohn et al (1987) regard slightly reducing nearshore shallow water conditions as suitable for the formation of glauconite.

It is generally agreed that glauconite forms in mildly alkaline environment (pH 7-8, Eh 0-200m). Although glauconite is predominantly a marine mineral yet it is also known to occur in slightly alkaline continental environments. According to Greensmith (1981) principal deposits in the modern oceans occur in warm waters (15-20 °C).

Presence of glauconite suggests low rates of sedimentation (Porrenga, 1967; Odin and Matter, 1981) or halmyrolysis (Krauskopf, 1982) in the presence of oxygen, carbon dioxide, iron and manganese.

Glauconite forms either pnecontemporaneous with sedimentation or during early diagenesis (Seed, 1965; Bell and Goodell, 1967; and Velde, 1977).

Glauconite has also been related to unconformities, regressive as well as trangressive phases (Greensmith, 1981; Porrenga, 1967; Odin and Matter, 1981; and Shah, 1977).

Glauconite may form just a few cms below the sediment water interface even where the overlying waters are mildly oxidising.

So glauconite by itself can not be used as an indicator of depth, pH, salinity or state of oxygenation of water overlying the sediments.

Much more important is the macroenvironment (as opposed to megaenvironment) just a few cms. below the sediment water interface. High biogenic activity coupled with low rates of sedimentation can produce reducing environments (pH form 7 to 5) a few cms. below the water sediment interface. Under these conditions besides clay, chert and quartz may be partially replaced by glauconite. Micropores and cracks in quartz and chert provide suitable microenvironment for glauconitisation in silica minerals (Odin and Matter, 1981; Bornhold and Giresse, 1985). Shells of organisms may also provide suitable environments for glauconite to form.

The development of glauconite a few cms. below the water sediment interface may well mean that this mineral may develop between pH 5-8.

In our opinion the association of glauconite with transgressive or regressive phases or of unconformities (so often emphasized) is valid only to the extent that such phenomenon may in some cases be accompanied by extremely low rates of sedimentation, halmyrolysis, accompanied by high biogenic activity and prevalence of suitable macro and microenvironments below water sediment interface.

The Lumshiwal Formation overlies the black shale belemnite rich Chichali Formation. The contact between them is transitional. Therefore the glauconite here is not related to any unconformity. The upper contact of the Lumshiwal Formation has been regarded unconformable with the overlying Kawagarh Formation in Hazara area (Shah, 1977). In Galiat area of Hazara the contact is completely transitional.

Of course the evidence of progressive deepening in the upper part of the Formation resulting in the deposition of the pelagic shelf sea Kawagarh Formation (Chaudhry et al, 1992 and Ahsan et al, 1993) on top suggests a major transgression. Quartz and glauconite occur in the lower most part of Kawagarh Formation (Chaudhry et al, 1992; Ahsan et al, 1993).

Since Kawagarh Formation is a pelagic shelf sea deposit lacking benthonic forams altogether therefore the maximum depth to which this formation was subjected must have exceeded 80m. Therefore the upper parts could well have been deposited near the continental shelf edge. The lower parts could have been deposited under relatively shallower subtidal waters as is evidenced by the presence of benthonic fauna. This formation in Galiat area is entirely marine in origin as indicated by the presence of marine fossils coupled with glauconite.

Presence of organic matter, glauconite and pyrite indicate reducing conditions below the water sediment interface. The presence of relict haematite and films of pyrolusite strongly suggest halmyrolysis in the presence of O_2 and CO_2. As such the waters above the sediments/water interface may have been mildly oxidising rather than reducing. Such conditions also help in fixing ferric iron in glauconite grains exposed to the surface.

There is no textural evidence to suggest that significant amounts of glauconite formed from any mineral other than clay. The arenites rich in glauconite therefore must have originally been wackes.

Provenance

The accessory minerals relevant to provenance are tourmaline (green and blue), zircon, epidote and sphene. These minerals indicate sialic basement with minor basic component as the ultimate source. The grainitoid component appears to be S-type. Blue tourmaline may indicate derivation from thermal aureoles.

However, compositional maturity, restricted suite of heavy minerals and shape of grains strongly suggest significant recycling.

DIAGENESIS

Physical Diagenesis

Considering the grain shape, size and paucity of matrix the initial porosity of the sandstone could well have been 30 to 40%.

However, the glauconite rich rocks were originally wackes and may have had lesser porosity. After initial rearrangement through slippage, rotation and reorientation a tighter packing resulted.

This was followed by fracturing of quartz grains at greater depths of burial. These fractures were then filled by remobilised carbonate and glauconite cements.

Chemical Diagenesis

Glauconite Cement: Glauconite cementation is early diagenetic. This mineral occurs as pellets as well as irregular interstitial cement. It was remobilised and filled fractures in quartz grains during physical diagenesis at greater depth. Silica cementation followed early glauconite cementation. Quartz overgrowths over quartz in optical continuity are common. The boundary between the host and the overgrowths is marked by impurities like clay and iron oxides.

Most of the quartz cementation appears to have taken place at relatively shallower depths prior to strong compaction. This is shown by fractures cutting both the quartz grains and overgrowths cementation.

Flint, most probably was formed by the dissolution of skeletal parts of siliceous organisms. This appears to be an early diagenetic process.

It was during deepest burial that pressure solutioning and micro stylolites developed in quartz grains.

K-feldspar overgrowth similarly developed at shallow depths. it is not uncommon for K-feldspar to precipitate as secondary growths around detrital K-feldspar grains (Blatt, 1979). As modern sea water is undersaturated with respect to microcline and plagioclase, therefore authigenic K-feldspar and plagioclase require pore fluids enriched in Si, Al, K, Ca and to some extent Na. Dissolution of K-feldspar and plagioclase in turn is believed to act as an important process for release of these ions. Kastner and Seiver (1979) pointed out that there seems to be a genetic relationship between rock type and authigenic feldspar mineralogy. So the post depositional history of the Lumshiwal Formation reveals that there were interstitial pore waters enriched in these ions during burial so that authigenic feldspar could develop.

Textural criteria suggest that K-feldspar overgrowths formed prior to quartz overgrowths and carbonate cement. Euhedral feldspar overgrowths protrude into the originally open pore space which was subsequently cemented by anhedral quartz (Plate A-7). In some samples both quartz and K-feldspar rims are replaced by carbonate. The above mentioned features have been reported by many authors (Baskin, 1956; Fuchtbauer, 1967; Ali and Turner, 1982), regarding K-feldspar precipitation as a shallow burial process.

CARBONATE CEMENTATION

After initial thin rim quartz cementation, ferroan calcite and ferroan dolomite were formed from calcite. The main carbonate cement is dolomite which was dedolomitized at a later stage. Nash and Pittman (1975) suggest that with increasing depth, a transition may take place from low magnesian calcite through ferromagnesian calcite to dolomite. This observation is valid since ferroan dolomite corrodes the earlier formed ferroan calcite in the Lumshiwal Formation. Ferroan dolomite may be found as uniformly or patchily distributed pore fillings and replacements. The dolomitic rhombs are 90 to 210 micron in size and perfectly zoned.

During progressive burial due to decaying organic matter reducing conditions prevailed. Since the Lumshiwal Formation is rich in iron oxides any calcite present was converted to ferroan calcite and dolomite was converted to ferroan dolomite. Such transformations have been discussed by Tucker (1987). The carbonate cements corrode and replace quartz cements.

BURIAL AND UPLIFT HISTORY

The total thickness of beds overlying the Lumshiwal Formation upto residual Hangu Formation is estimated at 331m. This includes the thickness of top part of the Kawagarh Formation which was weathered to give rise to about 2m thick residual Hangu Formation. The temperature during this first burial was about 26 °C and pressure was about 0.08Kb. The glauconite cementation had taken place during very early diagenesis. Silica rim cement during this stage of burial probably preceded carbonate and ferroan calcite cementation. During Danian uplift when Hangu

Formation of residual origin formed, ground water must have reached Lumshiwal Formation. This water could carry carbonate as well as certain amount of leached silica. The organic matter in Lumshiwal Formation coupled with influx of carbonate rich solutions resulted in the formation of ferroan calcite. Due to low pressure and temperature conditions no hydrocarbons were generated.

The second burial started with post Danian Transgression which resulted in the formation of shelf carbonates and shales which were topped by marine to continental transitional Kuldana Formation. The total thickness of sediments at this stage above the Lumshiwal Formation was about 1020m.

The temperature of the rock at this stage was about 50 °C and pressure was about 0.37 Kb. At this stage the porosity reduction was accompanied by ferroan dolomite cementation. Mg for dolomitisation could have come from underlying Chichali shales (Ahsan et al, 1993).

The Lumshiwal Formation was still above the oil window (T=50 °C and P=0.37 Kb). For the generation of hydrocarbons a minimum temperature of 65 °C is essential (Selley, 1985). Miocene Murree Formation was deposited over Kuldana Formation. The total thickness of the overlying sediment at this stage was about 4050m.

The estimated temperature was about 148 °C and pressure of approximately 1.0 Kb. It is doubtful weather Siwaliks were deposited on the top of Murree Formation in Galiat area. The significant porosity reduction and formation of hydrocarbons could therefore have occurred at the end of Miocene. Abundant microstylolites in carbonates and quartz grains due to pressure solution could have developed during this stage. Reducing conditions may have prevailed in the rock mass during the final uplift and oxidizing waters coming from upper levels deposited ferroan calcites in dedolomitized rhombs. Finally the whole area was uplifted and exposed.

COMPARISON WITH NANDPUR GASFIELD

Lumshiwal Formation in Nandpur gasfield (Punjab platform) has produced low btu gas where it is represented by a sandstone dominated facies with significant layers of limestone and shale in the upper and lower parts. The formation here is conformably overlain by limestones and shales of Sujhanda Formation and underlain also conformably by sands of Chichali Formation. The thickness of Lumshiwal in Nandpur is about 125 meters.

There is a marked decrease in thickness of the formation in Gulagah as compared to Nandpur. Also limestones are nearly eliminated in Gulagah which are significant in Nandpur. Unlike the Gulagah, the formation in Nandpur seems to be deposited in a shallow marine environment of a regressive phase.

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