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Facies, Microfacies, Diagenesis and Environment of Deposition of Lumshiwal Formation at Thub Top near Ayubia, District Abbottabad

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ABSTRACT

A detailed study of facies, microfacies, diagenesis and environment of deposition of Lumshiwal Formation of Early Cretaceous age from Thub Top near Ayubia has been carried out for the first time. The objective was to study the facies, microfacies, provenance, environment of deposition and diagenesis of the formation in the northwestern part of the oil and gas producing Indus Basin. The formation is producing gas at Nandpur and Panjpir located near Sargodha high in the northern part of Punjab platform.

This section of Lumshiwal Formation is divisible into 5 facies and 20 microfacies. Compositionally all the sandstone horizons are mature. Texturally only one microfacies is immature and one microfacies is super mature, rest of the microfacies are mature to sub-mature. The sandstone is predominantly fine to very fine grained, only one microfacies is medium grained, and two microfacies are coarse grained.

Quartz and glauconite are the common cements while iron oxides, clay and flint occurs as subordinate cements.

Accessory to trace amounts of tourmaline, zircon, epidote and sphene which may occurs either as discrete grains or as inclusions within quartz grains suggest an ultimate derivation from sialic metamorphic-igneous basement with minor contribution from basic sources. The source granitoids were mainly S-type. However, overall mineralogy and texture strongly suggest recycling.

The Lumshiwal Formation was deposited in low energy conditions in the subtidal zone. The formation of glauconite itself suggests slow rates of sedimentation and mildly reducing conditions. Diagenetic history indicates the formation of glauconite followed by flint and kaolinite. This was followed by ferroan calcite and dolomite at a later stage. Suturing of quartz grains occurred during deep burial. Fracturing of quartz grains occurred during tectonic deformation in a brittle regime. Microcrystalline quartz developed along fracture cleavage. The last stage involved the formation of ferroan dolomite during final uplift with parts converting into dedolomite.

INTRODUCTION

The Thub Top section (Lat: 34° 2'45"; Long: 73° 25') of Lumshiwal Formation (Table 1) near Ayubia is 12.80 metre 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 variation in lithologies other than the type locality, Shah (1977) designated the type locality at a section one kilometre north of Lumshiwal Nala (Lat: 32° 51'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 very fine to coarse grained sandstone which is blackish brown, dark greenish 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 whereas the upper contact with Kawagarh Formation is transitional. Millimeteric calcite veins are abundant.

FACIES OF LUMSHIWAL FORMATION

The Lumshiwal Formation at Thub Top, Ayubia can be divided into five facies which from bottom to top are as follows (Table 2 and 3; Figure 1):

TTF-I. Arenaceous Limestone Facies

This facies is dull grey in colour and weathers to earthy white. The clastic part is about 20% and is very fine sand to coarse silt. It is a micrite or mudstone. Generally glauconite varies from 3-10% with an average of about 6%.

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Table 1. Stratigraphic table of Hazara area.

Age	Formation	Lithology
Early Miocene	Murree	Grey and reddish sandstone and shales
Middle Eocene	Kuldana	Maroon to variecolour 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
Middle Paleocene	Lockhart Limestone	Nodular foraminiferal limestone
Early Paleocene	Hangu	Sandstone, claystone, laterite.
------------------D i s c o n f o r m i t y--------------------		
Late Cretaceous	Kawagarh	Fine grained to 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
------------------ D i s c o n f o r m i t y --------------------		
Middle Jurassic	Samanasuk	Limestone with dolomitic patches
Early Jurassic	Datta	Calcareous sandstone, fire clays and shales
-------------- D i s c o n f o r m i t y ---------------------		
Precambrian	Abbottabad	Dolomites with sandstone, shale and boulder bed at base
------------------ U n c o n f o r m i t y --------------------		
Late Precambrian	Hazara	Slates, sandstone and quartzites

TTF-II. Very Fine to Fine Grained Quartz/Carbonate Cemented Quartz Arenite Facies

It is grey to dull grey weathers rusty grey, medium to thick bedded, fine to very fine grained carbonate cemented glauconitic sandstone.

TTF-III. Arenaceous Dolomite

It is dark grey weathers to rusty grey thick bedded, arenaceous dolomite. It may be termed as a dolospar. The clastic portion is very fine grained and well sorted.

TTF-IV. Fine to Coarse Grained Quartz and Glauconite/Iron Oxides Cemented Quartz Arenite

It is fine to coarse grained quartz, glauconite and iron oxide cemented sandstone. The fresh colour of the rock is generally medium grey with greenish tinge due to the presence of significant amount of glauconite. Weathering colour is rusty grey with greenish tinge. This facies on average contains 14% glauconite i.e. more than twice the average of facies no. II.

TTF-V. Quartz Wacke

It is an argillaceous sandstone, with one horizon where glauconite is 15%. Its colour is dark grey. The weathering colour is rusty grey, it is splintery and thin bedded.

The above described five facies contain the following 20 microfacies:

TTF-V. Quartz Wacke

This facies contains only one microfacies as described below:

TTMF-20 Quartz Wacke

This microfacies is texturally sub-mature. It contains minor amounts of iron oxides, epidote, flint and glauconite at places, where as muscovite, biotite, zircon, tourmaline and carbonaceous matter are in traces. The quartz grains have concavo-convex contacts and are often fractured (Plate 1-20).

TTF-IV. Fine to Coarse Grained Quartz, Glauconite, Iron Oxides and Cemented Quartz Arenite

This facies contains seven microfacies as discribed below:

Table 2. Facies and Microfacies of Lumshiwal Formation at Thub Top.

Facies	Thickness of Facies	Thickness of Microf-acies	Microfacies TTMF
TTF-V Quartz wacke	35 cm	35cm	**20.** Quartz wacke.
		30cm	**19.** Coarse grained quartz and glauconite cemented quartz arenite.
		110cm	**18.** Fine grained quartz, glauconite and clay cemented quartz arenite.
		30cm	**17.** Medium grained quartz, glauconite and carbonate cemented quartz arenite.
		20cm	**16.** Coarse grained quartz, iron oxides and glauconite cemented quartz arenite.
		105cm	**15.** Fine grained quartz, glauconite and iron oxides cemented quartz arenite.
TTF-IV Fine to coarse grained quartz, glauconite & iron oxides cemented quartz arenite.	380cm	30cm	**14.** Fine grained quartz , iron oxides and glauconite cemented quartz arenite.
		55cm	**13.** Fine grained quartz, glauconite and iron oxides cemented quartz arenite.
TTF-III Arenaceous dolomite	100 cm	100cm	**12.** Arenaceous dolomite limestone.
		60cm	**11.** Fine grained quartz, iron oxides and glauconite cemented quartz arenite.
		115cm	**10.** Fine to very fine grained carbonate (dolomite), iron oxide glauconite cemented quartz arenite.
		20cm	**9.** Fine grained carbonate (calcite and dolomite), iron oxides, glauconite and clay cemented quartz arenite.
		20cm	**8.** Fine grained quartz, iron oxide, clay and glauconite cemented quartz arenite.
		40cm	**7.** Fine grained quartz, iron oxides and glauconite cemented quartz arenite.
		60cm	**6.** Fine grained carbonate (calcite and dolomite), iron oxides and glauconite cemented quartz arenite.
		270cm	**5.** Fine grained quartz, iron oxides, glauconite and clay cemented quartz arenite.
		100cm	**4.** Very fine grained carbonate (calcite) cemented quartz arenite.
		50cm	**3.** Fine grained quartz clay and glauconite cemented quartz arenite.
TTF-II Very fine to fine grained quartz/carbonate cemented quartz arenite	745cm	10cm	**2.** Fine to very fine grained quartz, carbonate (calcite and dolomite) and glauconite cemented quartz arenite.
TTF-I Arenaceous limestone	20cm	20cm	**1.** Arenaceous limestone

TTMF-19 Coarse Grained Quartz and Glauconite Cemented Quartz Arenite

It is coarse grained moderately sorted quartz and glauconite cemented quartz arenite. At places, glauconite has altered to iron oxides. This microfacies is texturally sub-mature and compositionally mature. The quartz grains have sutured contacts. Muscovite, biotite, zircon, sphene and carbonaceous matter are present as traces in addition to iron and clays in minor quantities (Plate 1, Fig.19).

TTMF-18 Fine Grained Quartz, Glauconite and Clay Cemented Quartz Arenite

This fine grained quartz and glauconite cemented quartz arenite is compositionally mature and texturally sub-mature to mature and well sorted. Quartz grains are sutured and fractured. A few veins of microcrystalline quartz are also present. These occur along fracture cleavage. Glauconite is altered to iron oxides (limonite and hematite) and mainly found in intraclasts. Quartz is the main allegoric mineral while muscovite, microcline, sphene and epidote occur as accessory to trace minerals. This microfacies with more than 15% glauconite may originally have been wackes (Plate 1-18).

TTMF-17 Medium Grained Quartz, Glauconite and Carbonate Cemented Quartz Arenite

It is a medium grained, well sorted quartz, glauconite and calcite cemented quartz arenite which is compositionally as well as texturally mature. This microfacies with 15% glauconite and 15% matrix may originally have been a wacke. Quartz grains have either sutured or concavo-convex contacts and are fractured. Glauconite is partially altered to iron oxides (haematite/ limonite). Calcite veins cut iron oxides. Muscovite flakes are crenulated, bent and broken. Flint, muscovite, albite, microcline, zircon, sphene and epidote are accessories (Plate 1, Fig.17).

Table 3. Estimation of Lumshiwal Formation (near Thub Top) Distt. Abbottabad.

Facies TTF →	V	IV							III	II										I
Microfacies TTMF →	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Quartz	67	81	73	70	85	80	60	75	30	70	44	56	75	80	40	74	50	84	52	20
Glauconite	15	15	15	15	5	12	15	15	4	10	5	5	6	5	5	8	3	5	5	2
Calcite	-	-	-	*10*	-	-	-	-	12	-	4	*12*	-	*Tr*	*25*	-	*42*	-	*30*	*70*
Dolomite	-	-	-	-	-	-	-	-	48	-	37	12	-	-	20	--	-	-	8	6
Iron oxides	0.5	1	1.9	3	9.9	6	23	8	2.9	18	5.4	7.5	9.2	10	9.8	10	3.8	3	2.8	1
Kaolinite	*7*	*1*	*5*	*Tr*	*Tr*	*1*	-	*Tr*	-	*0.5*	*1*	*2*	*4*	*2*	*Tr*	*4*	-	*4*	*0.5*	*0.5*
Illite	9	1	5	Tr	Tr	1	-	Tr	-	0.5	1	3	3	2.5	Tr	3	-	3	0.5	0.5
Muscovite	Tr	Tr	-	0.2	Tr	Tr	Tr	Tr	Tr	Tr	0.5	0.5	Tr	0.5	1	Tr	-	1	Tr	Tr
Biotite	Tr	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Tr
Chlorite	-	-	-	-	-	Tr	-	-	-	-	-	Tr	Tr	Tr	Tr	-	-	-	-	-
Albite	-	-	Tr	Tr	Tr	-	-	Tr	Tr	-	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Microcline	-	-	-	0.3	Tr	Tr	Tr	Tr	1	Tr	-	-	Tr	Tr	-	Tr	Tr	-	-	-
Zircon	Tr	Tr	Tr	Tr	-	-	Tr	Tr	-	-	-	-	-	-	-	-	-	Tr	Tr	Tr
Sphene	-	Tr	-	Tr	-	-	-	-	-	Tr	-	-	Tr	-	-	-	-	-	-	-
Epidote	0.4	-	Tr	Tr	-	Tr	Tr	-	-	-	Tr	-	Tr	Tr	-	-	-	-	-	-
Tourmaline	Tr	-	-	-	-	-	Tr	-	Tr	Tr	-	Tr	-	-	-	Tr	Tr	-	-	-
Amphibole	-	-	-	-	-	-	-	-	-	Tr	Tr	-	-	-	-	1	Tr	-	-	-
Chert	-	-	Tr	-	Tr	Tr	Tr	-	-	Tr	2	-	1.5	-	Tr	Tr	Tr	-	-	-
Flint	-0.5	0.5	-	0.5	Tr	-	Tr	1	2	1	Tr	-	0.5	-	Tr	Tr	Tr	-	-	-
Carbonaceous Matter	Tr	Tr	0.1	1	0.1	-	1.5	1	0.1	-	0.1	2	0.8	Tr	0.2	Tr	1.2	Tr	1.2	Tr

TTMF-16 Coarse Grained Quartz, Iron Oxides and Glauconite Cemented Quartz Arenite

It is a coarse grained, poorly sorted, quartz, iron oxides and glauconite cemented quartz arenite. iron oxides stain some quartz grains. Glauconite is partially altered to iron oxides. It is texturally immature but compositionally mature. Some of the quartz grains are fractured. Microcrystalline quartz is also present along fracture cleavage. Quartz grains are often sutured. iron oxides are found as irregular cement. Clay, muscovite, plagioclase, microcline, flint and chert occur as traces (Plate 1, Fig.16).

TTMF-15 Fine Grained Quartz, Glauconite and Iron Oxides Cemented Quartz Arenite

It is fine to medium grained and moderately well sorted. Quartz and glauconite are the main cements while iron oxides are subordinate and clay is a minor cement. It is texturally sub-mature and compositionally mature. This microfacies with 12% glauconite and 15% matrix may originally have been a wacke. Quartz grains are fractured and sutured. Glauconite is altered to iron oxides (mainly limonite and hematite). Glauconite is found as pellets as well as a cement. Clay occurs as pore fillings. Microcline, muscovite, epidote and chlorite occur as traces (Plate 1, Fig.15).

TTMF-14 Fine Grained Quartz, Iron Oxides and Glauconite Cemented Quartz Arenite

It is fine grained and moderately well sorted. Quartz and iron oxides are the main cements while glauconite is a subordinate cement. Since iron oxides are secondary, the original predominant cements may have been quartz and glauconite. It is texturally sub-mature and compositionally mature. This horizon with 15% glauconite may originally have been a wacke. The quartz grains are fractured. Microcrystalline quartz occurs along fracture cleavage. Tourmaline, muscovite, epidote, zircon, flint and chert are present as trace to accessory minerals (Plate 1, Fig.14).

TTMF-13 Fine Grained Quartz, Glauconite and Iron Oxides Cemented Quartz Arenite

It is a fine grained sandstone which is moderately to well sorted. Quartz and glauconite are the main cements while iron oxides occur as subordinate cement. Clay is present as a pore filling trace to accessory cement. It is texturally mature to sub-mature and compositionally mature. Quartz grains are sutured and fractured. This microfacies with 15% glauconite may originally have been a wacke. Glauconite is altered to iron oxides. Chert, clay, tourmaline, epidote, biotite, chlorite, microcline and muscovite are trace to accessory minerals (Plate 1, Fig.13).

TTF-III. Arenaceous Dolomite

It contains only one microfacies as described below:

TTMF-12 Arenaceous Dolomite

The clastic portion of this unit is well sorted. It is very fine grained. Carbonate occurs mainly as a dolospar. The spar is often idiotopic to subidiotopic. Some calcite veins also occur.

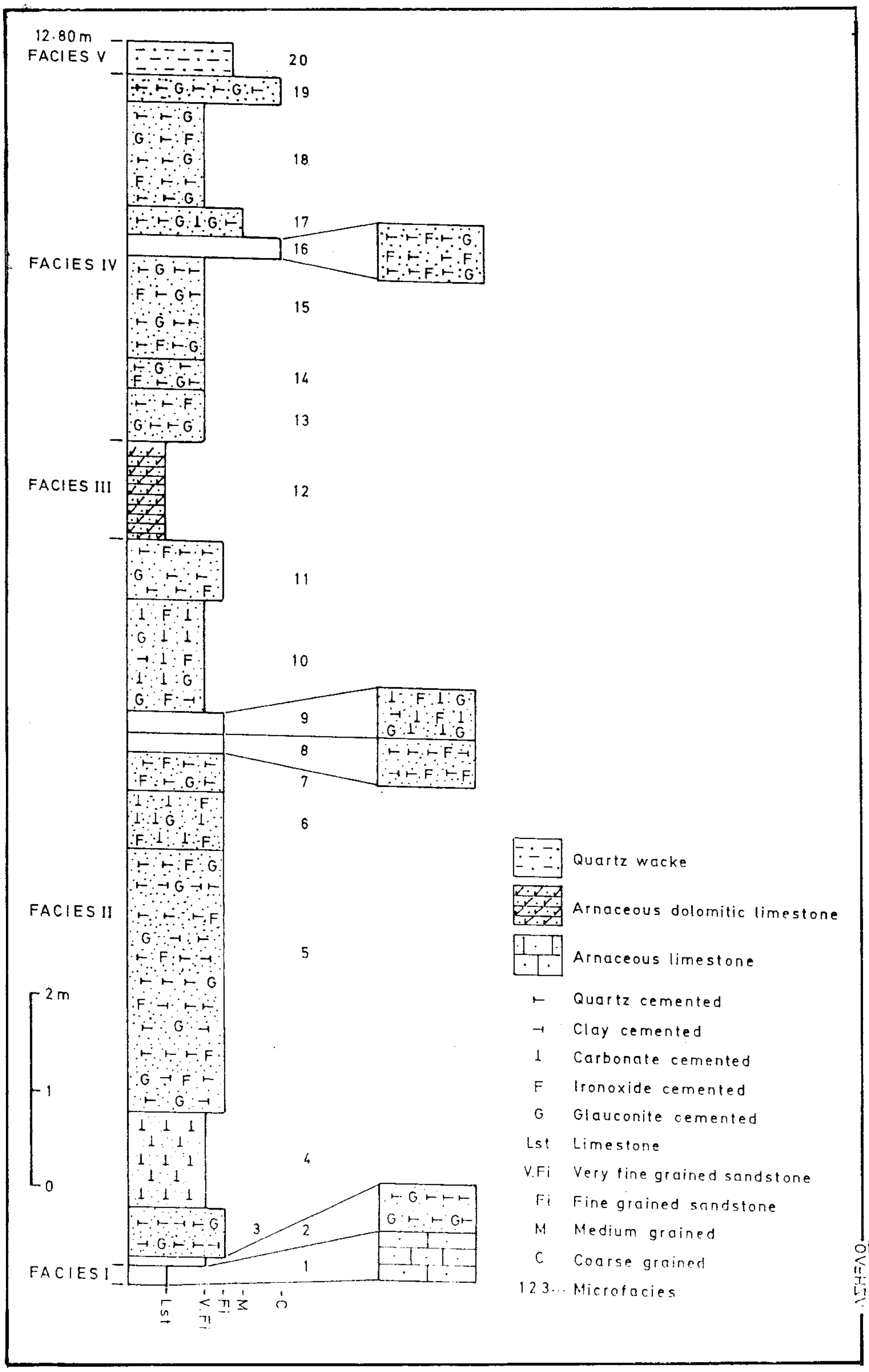

Figure 1- Facies and microfacies log of Lumshiwal Formation at Thub Top.

Quartz is extensively replaced by carbonate. Glauconite is altered to iron oxides (Plate 1, Fig.12).

TTF-II. Very Fine to Fine Grained Quartz/Carbonate Cemented Quartz Arenite

This facies contain ten microfacies which are described in the following:

TTMF-11 Fine Grained Quartz, Iron Oxides and Glauconite Cemented Quartz Arenite

It is a fine grained and moderately sorted sandstone. Quartz and iron oxides are main cements while glauconite is a subordinate cement. It is texturally sub-mature and compositionally mature. Quartz grains are sutured and fractured. Microcrystalline quartz may occur along fracture cleavage. Glauconite grains are altered and corroded by iron oxides. Flint, clay, muscovite, plagioclase, tourmaline, amphibole, chert and microcline are trace to accessory minerals. Muscovite flakes are bent and crenulated (Plate 1, Fig.11).

TTMF-10 Fine to Very Fine Grained Carbonate (Dolomite) Iron Oxide and Glauconite Cemented Quartz Arenite

It is fine to very fine grained, moderately to well sorted, texturally mature to sub-mature and compositionally mature quartz arenite. Dolomite is the main constituent of carbonate. Calcite veins are also present. Glauconite, Iron oxides and clay occur as pore fillings. Muscovite, flint, albite, epidote and tourmaline may occur as trace to accessory minerals. Muscovite flakes may be bent and crenulated. Microcrystalline quartz occurs along fracture cleavage (Plate 1, Fig.10).

TTMF-9 Fine Grained Carbonate,(Calcite and Dolomite) Iron Oxides, Glauconite and Clay Cemented Quartz Arenite

It is a fine grained, moderately to well sorted quartz arenite. It is texturally sub-mature and compositionally mature. Carbonates are the main cements while iron oxides and quartz are subordinate cements. Glauconite and clay are minor cements. The contacts of some quartz grains are sutured. Some grains are fractured. Muscovite flakes are bent. At places glauconite is altered to iron oxides. Tourmaline, albite, chlorite and muscovite are trace to accessory minerals (Plate 1, Fig.9).

TTMF-8 Fine Grained Quartz, Iron Oxides, Clay and Glauconite Cemented Quartz Arenite

It is fine grained and moderately to well sorted, texturally sub-mature and compositionally mature quartz arenite. The quartz grains are well sutured. Some quartz grains are fractured. Quartz is the main cement while clay and glauconite are the minor cements. Chert, microcline, muscovite, flint and epidote are accessory to trace minerals (Plate 1, Fig.8).

TTMF-7 Fine Grained Quartz, Iron Oxides and Glauconite Cemented Quartz Arenite

It is a fine grained and well sorted quartz arenite. It is texturally and compositionally mature. Suturing of quartz grains is common. Veins of microcrystalline quartz are also observed. These occur along fracture cleavage. Quartz is the main cement, iron oxides are subordinate while glauconite and clay are minor cements. Quartz grains have sutured contacts. Epidote, muscovite, microcline and albite are accessory to trace minerals (Plate 1, Fig.7).

TTMF-6 Fine Grained Carbonate (Calcite and Dolomite), Iron Oxides and Glauconite Cemented Quartz Arenite

It is fine grained and moderately to well sorted, texturally sub-mature and compositionally mature quartz arenite. Carbonate is the predominant cement. Glauconite is corroded and partially replaced by iron oxides. Quartz grains are well sutured. A few quartz grains show fractures. Veins of calcite and ferroan calcite were also observed. Muscovite flakes are crenulated and bent. Clay, plagioclase and flint are trace minerals (Plate 1, Fig.6).

TTMF-5 Fine Grained Quartz, Iron Oxides, Glauconite and Clay Cemented Quartz Arenite

It is fine grained, well sorted and texturally as well as compositionally mature quartz arenite. Quartz is the dominant cement while glauconite and iron oxides are subordinate cements. Glauconite is corroded and replaced by iron oxides. Quartz grains have sutured contacts and fractured. Mica flakes are bent. Chert, epidote, tourmaline, microcline, flint and albite are trace to accessory minerals (Plate 1, Fig.5).

TTMF-4 Very Fine Grained Carbonate (Calcite) Cemented Quartz Arenite

It is a very fine grained, well sorted and texturally as well as compositionally mature quartz arenite. Carbonate is the predominant cement. Suturing and fracturing in quartz grains is minor. Glauconite at places, is altered superficially to iron oxides. The major portion of carbonates consists of non-ferroan calcite and minor ferroan calcite. Chert, mica, tourmaline, albite, microcline and flint occur in traces (Plate 1, Fig.4).

TTMF-3 Fine Grained Quartz, Clay and Glauconite Cemented Quartz Arenite

It is fine grained, very well sorted, texturally super mature and compositionally mature quartz arenite. Quartz is the predominant cement. Quartz grains are fractured. Glauconite is corroded by iron oxides. Muscovite and albite are accessory to trace minerals (Plate 1, Fig.3).

TTMF-2 Very Fine Grained Quartz, Carbonate (Calcite and Dolomites) and Glauconite Cemented Quartz Arenite

It is a very fine grained, moderately to well sorted, texturally sub-mature and compositionally mature quartz arenite. Quartz and carbonates are the main cements while glauconite, iron oxides and clay are minor cements. Some quartz grains are fractured. Clay, plagioclase and muscovite are accessory to trace minerals (Plate 1, Fig.2).

TTF-I. Arenaceous Limestone

It contains only one microfacies as described below:

TTMF-1 Arenaceous Limestone

The clastic part is very fine sand and coarse silt. This part is moderately to well sorted. Carbonate occurs as a microsparite, micrite and dolomite. Glauconite, iron oxides, clay, muscovite, albite, microcline and biotite are trace to accessory minerals (Plate 1, Fig.1).

PROVENANCE

The accessory minerals having a bearing on provenance are plagioclase, microcline, tourmaline (green and blue), zircon, epidote, sphene and garnet. The minerals indicate sialic basement with minor basic component as the ultimate source. The granitoid component appears to have been S-type. Blue tourmaline may indicate derivation from thermal aureoles. However restricted suite of heavy minerals, compositional maturity and shape of grains strongly suggest significant recycling.

ENVIRONMENT OF DEPOSITION

The Lumshiwal Formation at Thub Top contains marine fossils like pelecypods, brachiopods as well as belemnites. No ammonite was found. Glauconite is present throughout this section. Organic matter is present in accessory amounts in the sandstone horizons.

Lumshiwal Formation of Thub Top contains pelecepods as well as brachiopods in addition to other benthonic fossils which indicate depths of less than 80 metres within photoic zone. Slightly reducing conditions are indicated by ubiquitous presence of organic matter. The formation of glauconite in Lumshiwal Formation is not related to unconformity since the lower contact of Lumshiwal Formation is transitional with the underlying black shales of Chichali Formation. The upper contact of Lumshiwal formation in Thub Top area is again transitional.

There is evidence of progressive deepening in the upper most part of the Lumshiwal Formation. This is shown by the absence of benthonic fossils. This progressive deepening resulted in the deposition of pelagic Kawagarh Formation at the top of the Lumshiwal Formation (Chaudhry et al., 1992; Ahsan et al., 1993). Glauconite has been related to transgressive episodes (Greensmith, 1981; Odin and Matter, 1981).

Presence of organic matter, glauconite and pyrite indicate reducing conditions below the water sediment interface. The presence of relict hematite and films of pyrolusite strongly suggest halmyrolysis (Krauskopf, 1982). As such the waters above the sediment/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 minerals other than clay. The arenites rich in glauconite therefore must have originally been deposited as quartz wackes.

DIAGENESIS

Lumshiwal Formation generally contains 2-15% glauconite. Textural evidence suggests that glauconite formed from clays during early diagenesis therefore most of the samples were originally quartz arenite with variable amounts of clay. Glauconite forms pellets as well as interstitial cement. Initial porosity may, therefore, have varied from 20-30%. Re-adjustment and rotation of grains may have resulted in tighter packing. However, during shallow burial quartz grains fractured and fractures were filled with either glauconite or carbonate cement. Microscopic veins of micro-crystalline quartz, developed within fracture cleavage during tectonic deformation. The calcite cement appears to have formed during shallow burial. Dolomite is also secondary in origin and may have formed due to magnesium rich solutions ascending from the underlying Chichali Formation during diagenesis.

There is no evidence to suggest an early diagenetic thin rim silica cement, however, quartz overgrowths over quartz are often seen. These overgrowths are in optical continuity with nuclei over which they developed. The boundary between nucleus and overgrowth is not always obvious, especially where impurities like iron oxide and clay are lacking (Pittman, 1972).

There is evidence to suggest that the solubility of quartz increases with increasing temperature and pressure (Fourier 1983). Quartz cementation is also affected by the rate of flow of water. This rate decreases with increasing depth of burial (Blatt, 1979). Silica secreting organisms like siliceous sponges, radiolaria and diatoms contribute dissolved silica to pore water of marine sediments (Hurd, 1972). Since marine waters are undersaturated with respect to silica, the skeleton of these organisms dissolved quickly during early diagenesis. At present it is difficult to estimate the amount of silica contributed by such organisms for silica cementation during early diagenesis of Lumshiwal Formation. It appears that silica cement in the Lumshiwal Formation owes its origin mainly to pressure solutioning and secondarily to water rising from the underlying Chichali Formation which is composed predominantly of shales. These problems have been discussed by Nagtegall (1978) and Fuchtbauer (1967). For a modern summary of silica cementation the reader is referred to the excellent work of BjÆrlykke (1989).

Flint is a common cement in Lumshiwal Formation next to quartz and carbonate. It is erratically and irregularly distributed in the rock. It may occur either as a patchy cement or as small irregular concretions. It is very dense and almost opaque. Flint has developed from the dissolution and reprecipitation of organisms with siliceous skeletons such as diatoms, siliceous sponges and radiolaria.

To sum up, there are three sources which appear to contribute substantially to silica cementation namely silica derived from clay minerals during diagenesis, pressure solutioning (Collins, 1975; Hunt, 1979; BjÆrlykke, 1989) and siliceous skeleton of organisms.

Iron oxide cementation in Lumshiwal Formation consists mainly of hematite and limonite. Some manganese oxide may also be associated with iron oxides. Since iron oxides replace both silica as well as carbonate cement, these appear to have precipitated due to halmyrolysis (Krauskopf, 1982) as well as due to later diagenetic processes involving circulation of oxygenated waters. This process has been discussed by Walker (1974). In the case of Lumshiwal Formation there is evidence to suggest that iron oxides were formed during halmyrolysis as well as during uplift when oxidising meteroic waters started circulating resulting in the oxidation of iron rich minerals especially glauconite.

BURIAL AND UPLIFT HISTORY

The total thickness of beds overlying the Lumshiwal Formation upto residual Hangu Formation in Thub Top section is estimated as 331 m. This includes the thickness of top part of the Kawagarh Formation which weathered to give rise to about 2m thick residual, Hangu Formation. During the first burial the estimated temperature was about 26°C and estimated pressure was 0.08 Kb. During very early diagenesis the glauconite cementation had already taken place. Ground water must have reached Lumshiwal Formation, when Hangu Formation of residual origin was formed during Danian uplift. The 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 temperature and pressure conditions no hydrocarbons were produced.

The second burial started with post Danian transgression which resulted in the formation of shelf carbonates and shales i.e. Lockhart, Patala, Margalla, Chorgali and 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 dolomitization could have come from the underlying Chichali shales (Ahsan et al., 1993).

The Lumshiwal Formation was still not mature for oil generation (T=50°C and P=0.337Kb). According to Seley (1985), minimum temperature of 65°C is essential for the generation of hydrocarbons. Murree Formation was deposited over Kuldana Formation. The total thickness of the overlying sediment at this stage was about 4050m. The temperature was about 148°C and pressure was about 1.0 Kb. It is not certain weather Siwaliks were deposited on the top of Murree Formation in Galiat area. The formation of hydrocarbons and major porosity reduction could therefore have occurred at the end of Miocene. Due to pressure solution microstylolites in carbonates followed by suturing of quartz grains which could have developed during this stage. Reducing conditions may have prevailed in the rock mass during the final uplift and oxidising waters coming from upper levels deposited ferroan calcite in dedolomitized rhombs. Finally the whole area was uplifted and exposed.

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PLATE 1

1.Arenaceous limestone.

2.Fine to very fine grained quartz, carbonate (calcite and dolomite) and glauconite cemented quartz arenite.

3.Fine grained quartz clay and glauconite cemented quartz arenite.

4.Very fine grained carbonate (calcite) cemented quartz arenite.

5.Fine grained quartz, iron oxides, glauconite and clay cemented quartz arenite.

6.Fine grained carbonate (calcite and dolomite), iron oxides and glauconite cemented quartz arenite.

7.Fine grained quartz, iron oxides and glauconite cemented quartz arenite.

8.Fine grained quartz, iron oxide, clay and glauconite cemented quartz arenite.

9.Fine grained carbonate (calcite and dolomite), iron oxides, glauconite and clay cemented quartz arenite.

10.Fine to very fine grained carbonate (dolomite), iron oxide glauconite cemented quartz arenite.

11.Fine grained quartz, iron oxides and glauconite cemented quartz arenite.

12.Arenaceous dolomite limestone.

13.Fine grained quartz, glauconite and iron oxides cemented quartz arenite.

14.Fine grained quartz , iron oxides and glauconite cemented quartz arenite.

15.Fine grained quartz, glauconite and iron oxides cemented quartz arenite.

16.Coarse grained quartz, iron oxides and glauconite cemented quartz arenite.

17.Medium grained quartz, glauconite and carbonate cemented quartz arenite.

18.Fine grained quartz, glauconite and clay cemented quartz arenite.

19.Coarse grained quartz and glauconite cemented quartz arenite.

20.Quartz wacke.

PLATE 1

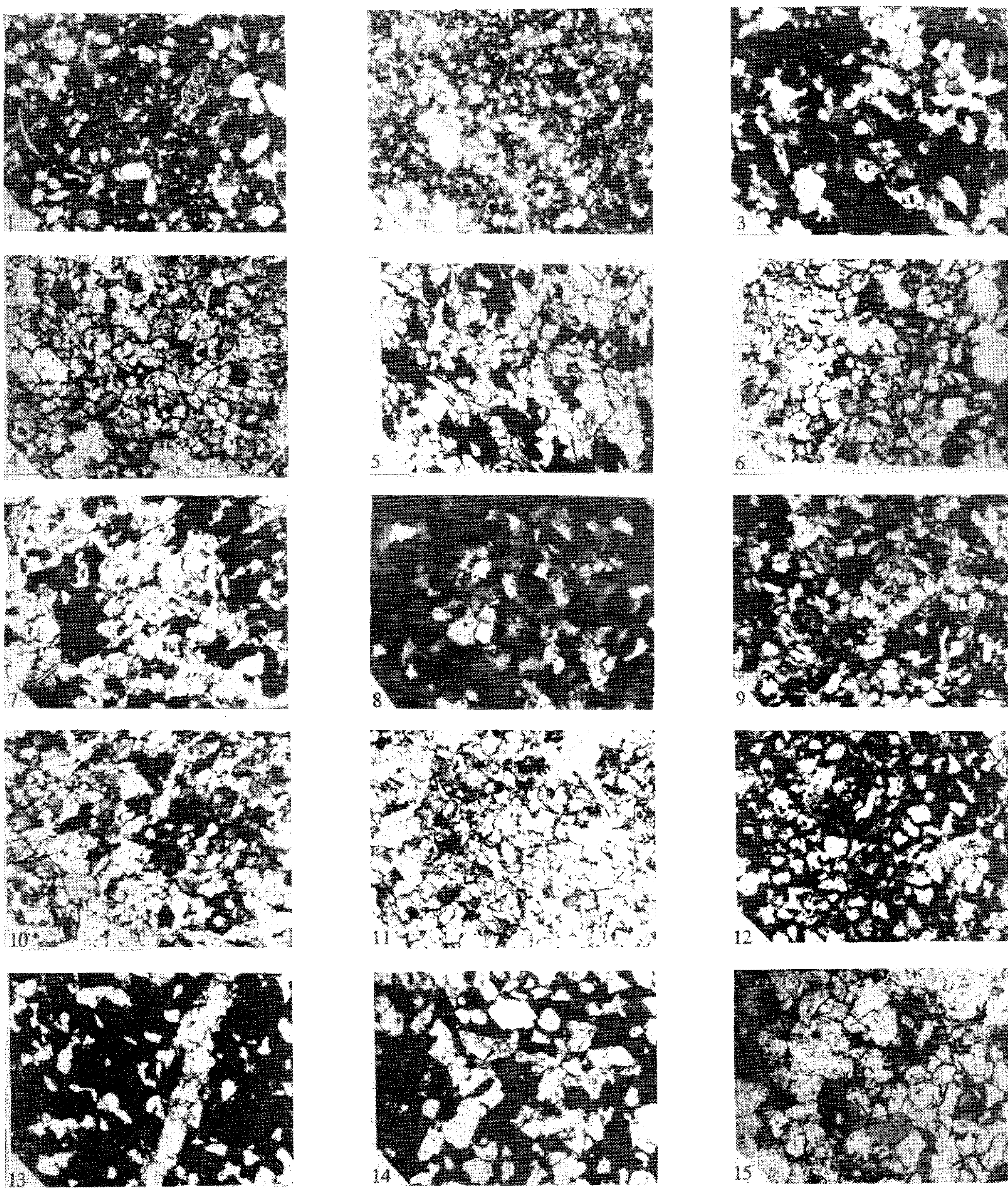
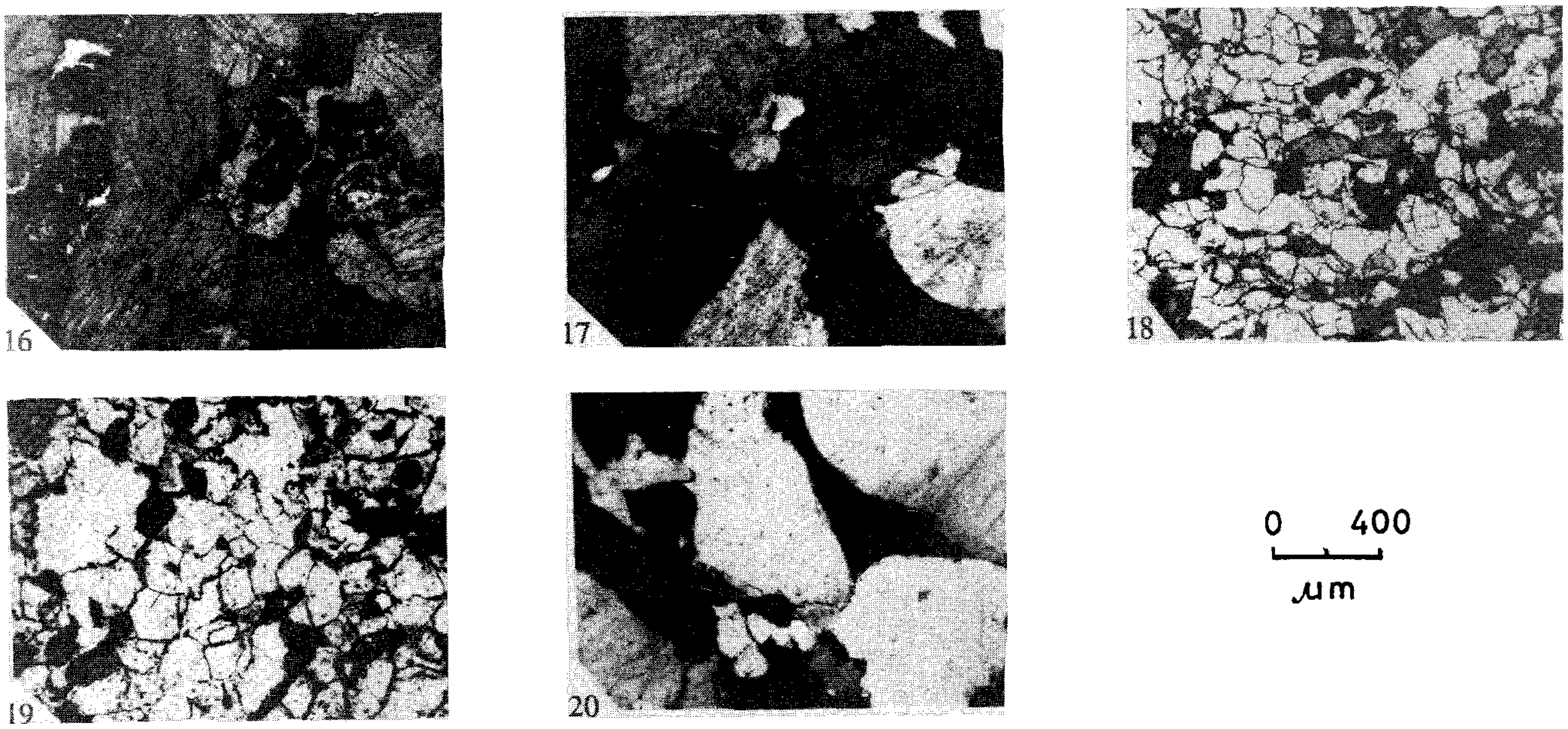


PLATE 1 cont...



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