MICROFACIES AND DIAGENETIC ANALYSIS OF AMB FORMATION WESTERN PART OF CENTRAL SALT RANGE, PAKISTAN

N. Aadil, M. Qasim and A. Hussain

Department of Geological Engineering, University of Engineering & Technology, Lahore-Pakistan
Corresponding Author E-mail: naadil@yahoo.com.au

ABSTRACT: An almost 76m thick deposit of Amb Formation of Zaluch Group at its type locality, in Warchha Gorge near Amb village in western part of Central Salt Range Pakistan, is divided into three prominent lithological units, i.e. lower sandstone, middle calcareous sandstone with sandy limestone and upper sandstone with shale unit. In this study, 29 samples were studied from different levels of Amb Formation at its type locality which were used for microfacies analysis. Ten microfacies were identified and their salient features are discussed in this paper. Some diagenetic processes, such as compaction, cementation, dolomitization and bioturbation, were also observed in Amb Formation. Different types of fauna, observed in the formation, include brachiopods, bryozoans, crinoids, bivalves and foraminifera (fusulinids). On the basis of fusulinids (first foraminifera appearing in Pakistan in Amb Formation) and different sedimentary structures observed, it is considered that Amb Formation of Central Salt Range, Pakistan was deposited in a shallow marine environment during Late Permian (Artinskian).

Keywords: Amb Formation; Central Salt Range; Microfacies Analysis; Fusulinids; Diagenetic Processes; Shallow Marine Environment

INTRODUCTION

Almost 160km long and 20km wide East-West trending fold belt of Salt Range in Pakistan is no doubt a "Field Museum of Geology" because of its easy accessibility and the wealth of geological and paleontological features exposed in it. Rising abruptly from Punjab plains, Salt Range is present in northern portion of Punjab Province of Pakistan, from River Jhelum in the east to River Indus in the west and bounds hydrocarbon containing Potwar Plateau in south.

Geologically it is divided into three parts. Boundaries between these parts are arbitrary and different authors proposed different boundaries. The Eastern Salt Range covers the area from Jogi Tilla to Nilawahan, the Central Salt Range extends from Nilawahan to Warchha Mandi and the Western Salt Range occupies the area between Warchha and Mari Indus (Fatmi, 1973). Study of Amb Formation was carried out in western part of Central Salt Range in Warchha Gorge near Amb village, type locality of Amb Formation.

Geological Setting & the Study Area: Drift in Gondwana Fragments, Indian Plate being one of them, is believed to have begun in Mid-Jurassic. Fast northward movement of Indian Plate, along with its counterclockwise rotation, caused it to collide with Eurasian Plate, probably in Late Cretaceous (55 Ma or 65Ma). Himalayas, thus formed, are considered as young collisional mountain belt. Ongoing northward movement of Indian Plate caused crustal shortening that gave rise to some fold and thrust belts, Salt Range being one of those. The Salt Range and Potwar Plateau are the external and the most recent expression of Himalayan shortening; a thin skinned fold-and-thrust belt in which Paleozoic to Holocene sediments are shortened above a ductile substrate of thick Eocambrian evaporites of the Salt Range Formation (Lillie *et al*., 1987; Butler *et al*., 1987 and Baker, 1987; Nizami and Sheikh, 2007).

Study area lies at the western edge of Central Salt Range (Figure 1). Major structural features of this area include number of broad, flat-based synclines, separated by somewhat narrow, sharp-crested anticlines. Synclines form the ridges while the streams flow along the anticline axis. This inverted topography is the result of ductile upward flow of incompetent sequence of basement Salt Range Formation. The present day structural style of the project area is the result of two episodes; first one being collisional/ compressional regime, during which folding and thrusting occurred. Streams started to flow along the anticline axis which is the onset of second tectonic episode i.e. extensional regime. Due to the unloading of sediment along the anticline axis, the ductile material of Salt Range Formation began to flow upward through these axes to maintain its isostatic equilibrium. This phenomenon of "Halokinesis" caused normal faulting in this area e.g horst and graben structures. Fig. 1 is showing major tectonic elements of Northern Pakistan along with the location of the project area.

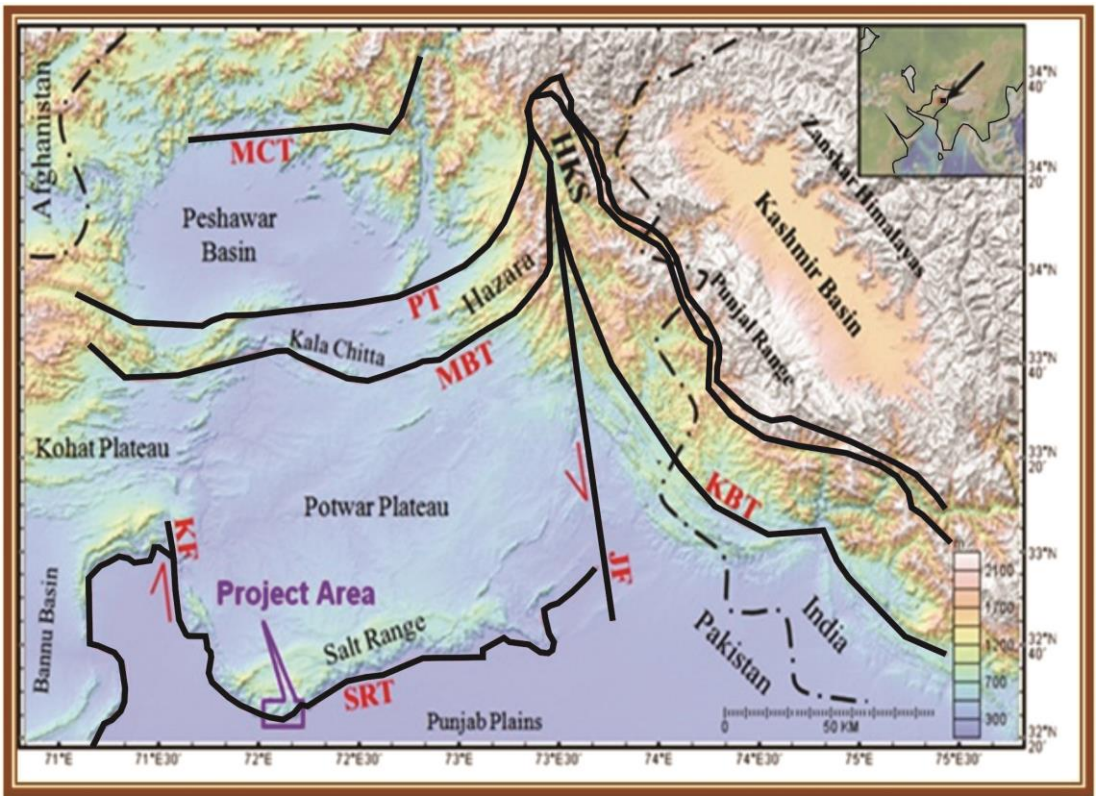


Figure 1: Map showing major tectonic elements of Northern Pakistan and location of the project area. (HKS: Hazara Kashmir Syntaxis, JF: Jhelum Fault, KBT: Kashmir Boundary Thrust, KF: Kalabagh Fault, MBT: Main Boundary Thrust, MCT: Main Central Thrust, PT: Punjal Thrust, SRT: Salt Range Thrust) (Modified after Ahsan et al., 2010)

Amb Formation: The largest basin of Pakistan, Indus Basin, is divided into three sub-basins, Upper Indus Basin (Kohat-Potwar Province), Central Indus Basin (Sulaiman Province) and Lower Indus Basin (Kirthar Province). Late Permian of Upper Indus Basin is represented by Zaluch Group, the term introduced by Teichert (1966). The group includes sandstone, shale and sandy limestone of Amb Formation in addition to Wargal Limestone and Chhidru Formation (Table 1). At the type locality of Amb Formation in Warchha Gorge (Long: 71^{o} 57' 47"E, Lat: 32^{o}27'55"N), near Amb village, western Part of Central Salt Range, the formation has a total thickness of 76m and is broadly divided into three distinct lithological units; Lower sandstone unit, middle calcareous sandstone with sandy limestone unit and upper sandstone with shale unit.

Amb Formation has always been an attraction for paleontologists because of its abundance of fauna. Thin limestone beds associated with lower sandstone unit are full of fusulinids (Plate 1). Fusulinids are the fusiform foraminifera that first appeared in Early Carboniferous and became extinct during Permian-Triassic extinction. In Pakistan they first appeared in Amb Formation and represent the oldest foraminifera in this area. Fusulinids are important because of their short vertical range but long geographical distribution; hence used for correlating rocks of same age far apart on the Earth, as upper part of Chihsia Limestone of Southern China (Chen, 1934) correlated with the American zone of *parafusulina*. Rocks of upper Permian age that contain a large fusulinid fauna occur in a narrow belt that extends from the eastern part of the Mediterranean Sea of Africa and Europe, across Asia Minor, across southern Asia and Japan, from British Columbia to Oregon in northwestern North America. This upper Permian fauna is not found in any other part of the world outside this narrow belt. The sea in which it lived is referred to as the Tethys Sea. Such Tethys Sea fauna has been described from many areas of the world, including Sicily (Silvestri, 1933), Asia Minor (Chaput, 1932) and French Indo-China (Deprat, 1912, 1913; Gubler, 1935). Apart from fusulinids, other fauna observed in Amb Formation includes brachiopods, bryozoans, crinoids and bivalves.

At its type locality, its lower contact is transitional with Sardhai Formation while its upper contact is conformable with Wargal Limestone and placed over the topmost plant bed of Amb Formation. A number of sedimentary structures were also observed in Amb Formation especially cross bedding in sandstone beds and burrows (horizontal and vertical) in shale beds.

Plate 1: Facing NE showing a large number of fusulinids in a fractured sandy limestone bed of Amb Formation, Warchha Gorge Section, Rukhla Mandi, District Khushab-Pakistan (Long: 71°57'47"E; Lat: 32°27'55"N)

Microfacies of Amb Formation: Following ten microfacies, starting from MF1 to MF10, were observed in Amb Formation at Warchha Gorge section. These facies are shown in Figure 2.

A. **Quartz Wacke Facies (MF1):** This facies is 4.11m thick in the field. It is friable sandstone that has whitish grey fresh color and dusky yellowish white weathering color. This facies is comprised of only one bed. Bedform is planer. Petrographically, this facies has about 63% quartz grains, and the remaining about 27% is fine grained matrix. Quartz grains are angular to sub-rounded and show straight extinction. Some fine grained matrix is fine quartz. No prominent fossils are observed in it.

Table 1. Stratigraphic column showing stratigraphic position of amb formation of late permian

Eon	Era	Period	Epoch	Group	Rock Unit
Phanerozoic	Mesozoic	Triassic	Early	Musakhel Group	Mianwali Formation
	Paraconformity				
	Paleozoic	Permian	Late	Zaluch Group	Chhidru Formation
					Wargal Limestone
					Amb Formation
			Early	Nilawahan Group	Sardhai Formation
					Warchha Sandstone
					Dandot Formation
					Tobra Formation
		Disconformity			

B. **Medium grained Dolomitic Calcareous Sandstone Facies (MF2):** This facies is 4.21m thick. Alternating beds of sandy limestone and calcareous sandstone are present. Limestone beds are full of fusulinids and crinoids. Base is thickly bedded while at the top, beds are highly fractured. Bedform is planer. This facies consists of more than 70% quartz grains. Matrix is mostly calcitic with very rare iron oxide. Calcite is largely dolomitized. Quartz grains are sub-angular to sub-round, extensively fractured and show straight extinction.

C. **Brachiopod, Bivalve Calcareous Sandstone Facies (MF3):** This facies is 4.74m thick. This is the most striking unit of Amb Formation. Overall it is calcareous sandstone. It has seven beds that are medium to thick bedded. The lower most bed is brown grey to light black calcareous sandstone that is highly fossiliferous. Second bed has burrows, vertical as well as horizontal. Third bed is greenish grey in color. Fourth bed is brownish in color and has graded bedding, with fining upward sequence. Fifth bed has intra-formational micro-conglomerate having yellowish brown pebbles. Both sixth and seventh beds are coarse grained calcareous sandstone having fining upward sequence. The difference is that former unit is light grey while later has brown color. Upper part is much coarser than lower part. There are overall 6 smaller cycles of graded bedding (fining upward sequence). Bedforms are planer. This facies has more than 80% quartz. Bioclasts are less than 15% while the remaining 5% is calcareous matrix. Predominant fossils are only some clasts of brachiopods and bivalves. Quartz grains in the lower part of a single cycle of graded bedding are well rounded and show black colored inclusions while in the upper part they are angular. Quartz grains show straight extinction.

D. **Crinoids, Bivalve, Brachiopodal Sandy Wackestone Facies (MF4):** This facies is 8m thick and has two beds. Lower bed is blackish grey, fine grained calcareous sandstone. At the base nodules are of reddish brown, coarse grained sandy limestone found. The upper unit is sandy limestone. Limestone is full of brachiopods and larger fossils. Sample was taken from sandy limestone bed. Bedforms are planer.

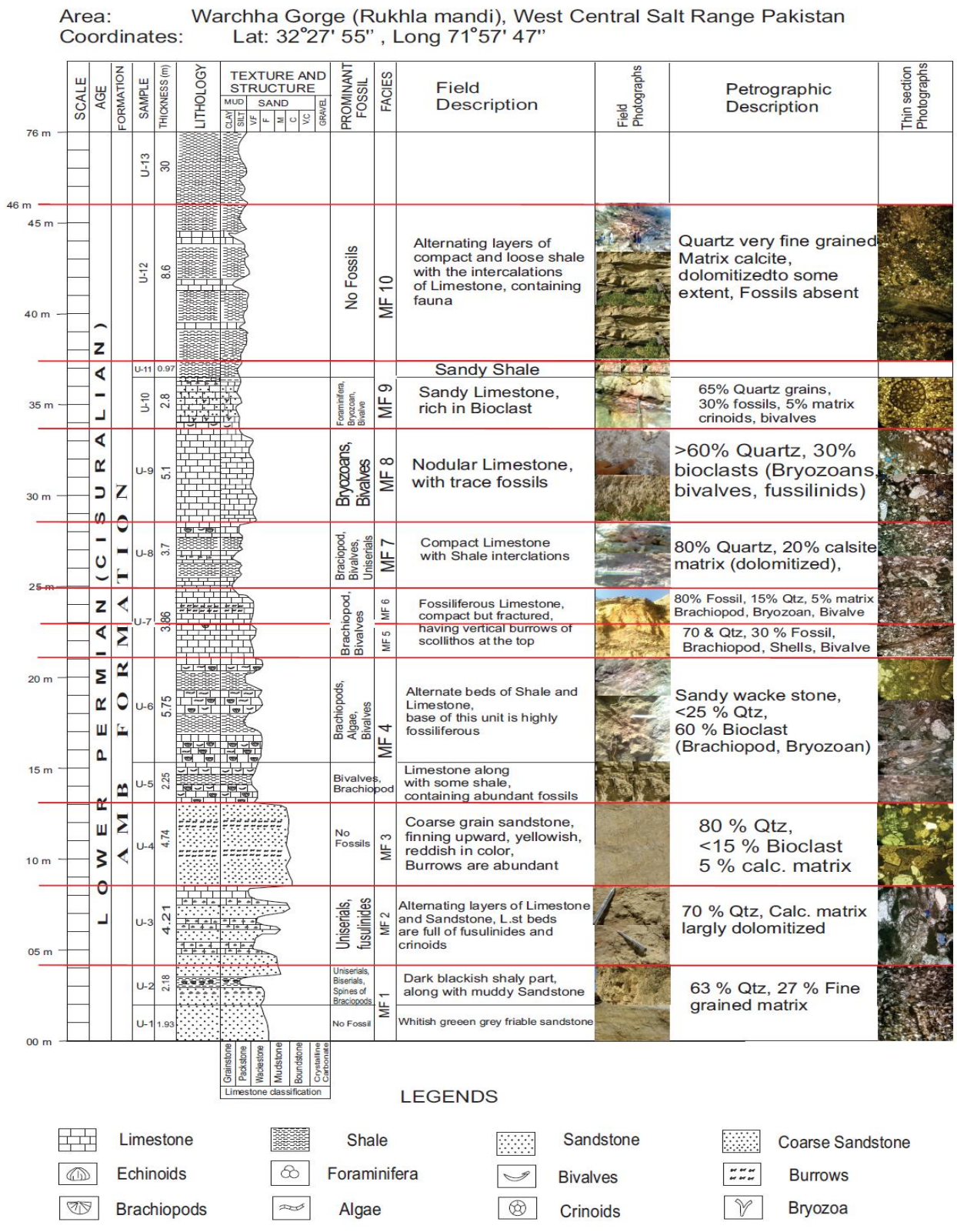


Figure 2: Depositional synthesis log showing microfacies analysis of Amb Formation at Warchha Gorge section, west Central Salt Range-Pakistan

This facies is sandy wackestone having quartz grains less than 25%. Bioclasts are about 60% and includes predominantly brachiopods, bivalves and different types and shapes of brachiopod spines. The layered structure of brachiopods is very clearly evident in the thin section. Quartz grains are sub-angular to sub-rounded and show straight extinction.

E. **Bryozoan, Bivalve, Brachiopodal Calcareous Sandstone Facies (MF5):** This facies is 2m thick. It has dull white weathering color. This unit has horizontal as well as vertical burrows. Fossils such as brachiopods and crinoids are clearly observed on weathered outcrop surface. Bedform is planer. This is calcareous sandstone facies having quartz 70% to 75% and fossils upto 20% to 25%. Fossils include brachiopod shells and spines, bivalves, bryozoans. Intensity of fossils is small as compared to detritus grains. Some quartz grains are highly fractured. Quartz grains are sub-angular to sub-rounded and show straight extinction. Cement is iron oxide, micro quartz and rare calcite.

F. **Bivalve, Brachiopodal Sandy Packstone (MF6):** This facies is 1.86m thick. Its weathering color is yellowish white. This facies is very compact and highly fractured. Bedform is planer.

This facies has almost 80% fossils, about 15% quartz grains and 5% matrix. Fossils include small sized brachiopods, bryozoans and bivalves. Quartz grains are sub-angular to sub-rounded and show straight extinction.

G. **Fine grained Dolomitic Calcareous Sandstone Facies (MF7):** This unit is about 3.7m thick. It consists of calcareous sandstone and siltstone along with inter-layered carbonaceous shale. The weathering color of calcareous sandstone is dull grey to light grey while that of siltstone and some part of shale is light greenish grey. Cruziana ichnofacies are present in soft calcareous sandstone bed. Bedform is planer. This facies consists of about 80% quartz grains while remaining about 20% is calcitic matrix. Quartz grains are medium to coarse grained. These grains are angular to sub-rounded and show straight extinction. The calcitic matrix is dolomitized and even dedolomitized at some places.

H. **Bryozoan, Bivalve, Fusilinidal Calcareous Sandstone Facies (MF8):** This facies is 5.1m thick nodular sandy limestone, with weathering color of rusty yellowish to grayish brown. Lower part of the facies is fine grained while its upper part is light reddish to dark brown, highly fossiliferous coarse-grained. Lower part has developed nodularity. Upper bedform is planer while lower is wavy. This facies has more than 60% quartz grains and about 30% bioclasts. Prominent fossils are bryozoans, bivalves and fusulinids. Bryozoans and fusulinids are relatively larger in size as compared to bivalves (Plate 2h). Quartz grains are angular, medium to coarse grained and show straight extinction. Thread like bivalves are also present surrounded by quartz grains.

I. **Crinoid, Bivalve, Brachiopod, Fusulinid, Bryozoanal Calcareous Sandstone Facies (MF9):** This facies is 3.77m thick. Weathering color of this facies is reddish brown to grey. It is highly fossiliferous i.e. crinoids and brachiopods can be seen on outcrop surface. Bedform is planer. This facies contains about 65% quartz grains with 30% fossils and almost 5% matrix. Bioclasts are crinoids, bivalves, brachiopods, fusulinids and bryozoans. Bryozoans are the most abundant and larger in size as compared to other fossils. Matrix is calcitic.

J. **Calcareous Shale Facies (MF10):** This facies is about 8.6m thick. It has numerous beds with increase in thickness of each bed towards top. Weathering color of this facies is light grey to yellowish grey. Bedforms are mostly planner. Quartz grains are very fine grained. Matrix is of calcite which is somewhat dolomitized. Fossils are absent.

Diagenetic processes: Diagenetic processes play an important role in shaping the ultimate characteristics of sedimentary rocks. To interpret the depositional history of these rocks properly, it is necessary to recognize and distinguish between the primary features caused by depositional processes and the secondary features resulting from later diagenetic alteration. Among a number of different diagenetic processes, compaction is mainly physical process. Cementation, authigenesis, recrystallization, replacement and dissolution are mainly chemical processes. Bioturbation is mainly biologic process. Alteration of sediments through organic activity is commonly the earliest diagenetic process. Cementation may also occur quite early but can continue throughout burial and uplift. Compaction begins as soon as sediments are buried and continues through deep burial. The other diagenetic processes occur at various stages of sediment burial and uplift.

From the microfacies analysis of Amb Formation, following diagenetic processes are recognized in it at Warchha Gorge Section.

A. **Dolomitization:** Commonly in supratidal sabkha areas, magnesium [Mg^{2+}] ions from the evaporation of seawater replace calcium [Ca^{2+}] ions in calcite, forming the mineral dolomite increasing the pore space in the rock by 13% (volume of dolomite is less than that of calcite). Dolomitization can occur during deep burial diagenesis. It is observed in MF5 and MF7. (Plates 2a, 2b)

B. **Compaction:** Squeezing together of sediment grains during burial owing to the weight of overlying sediment causes reorganization of grain packing to produce a more tightly packed fabric.

1) **Mechanical compaction:** Grain to grain contact reflects the intensity of packing of grains. Point contact, also called tangential contact, occurs only in loosely packed sediments or sedimentary rocks. Mechanical compaction is observed in MF5 and MF9 -- point contact and planar contact between the grains (Plates 2c, 2d).

2) **Chemical compaction:** Concavo-convex contacts and sutured contacts occur in rocks that have undergone considerable compaction as observed in case of MF5 (Plate 2a).

C. **Cementation:** Cementation is the process whereby new minerals are precipitated from the pore fluid onto the surface of grains, or chemical substances are added as syntaxial overgrowth on existing mineral grains. Cements bind sedimentary particles together and cementation is the principle chemical process that produces lithification of sediments. Cementation occurs mainly during the early to middle stages of diagenesis.

Following types of cements were observed in Amb formation at measured sections:

- Equant Blocky observed in MF1 and MF5 (Plate 2e)
- Isopachous Drusy cement in MF1 (Plate 2f)
- Cavity filling spar in MF8 (Plate 2h)

D. **Bioturbation:** The burrowing, boring, feeding, and locomotion activities of organism can produce a variety of trails, depressions, and open burrows and borings in mud or semiconsolidated sediment bottoms. Bioturbation is observed in MF9 (Plate 2g).

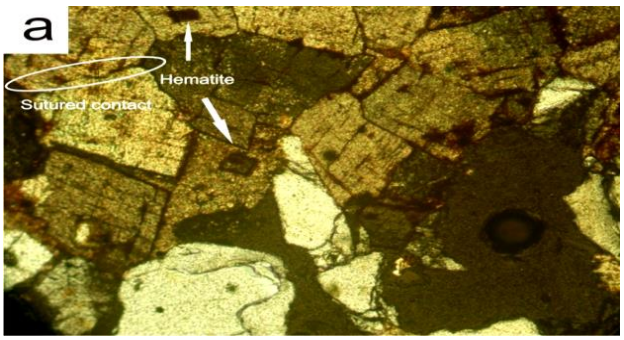


Plate 2a. Dolomitization + sutured contact / pressure solution in MF5, 10x

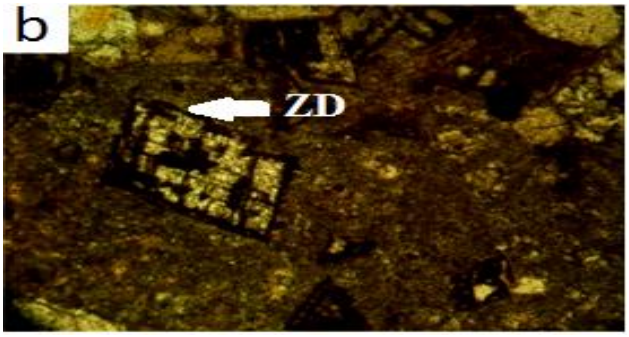
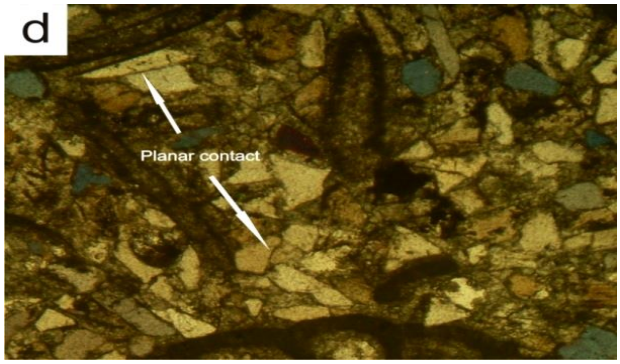


Plate 2b. Development of zoned dolomite (ZD) in MF7, 10x.

Plate 2c. Planar contact between quartz grains in MF5, 10x



Planar contact between different grain in MF9, 4x.

Plate 2d. Equant blocky + Bladed type cement in MF5, 10x.

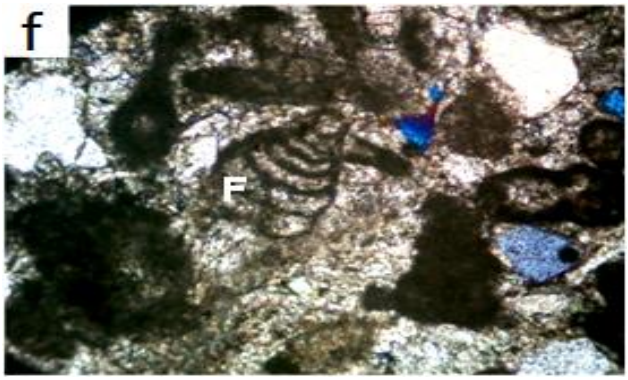


Plate 2e. Drusy cement around foraminifera (F) in MF1. 10x.

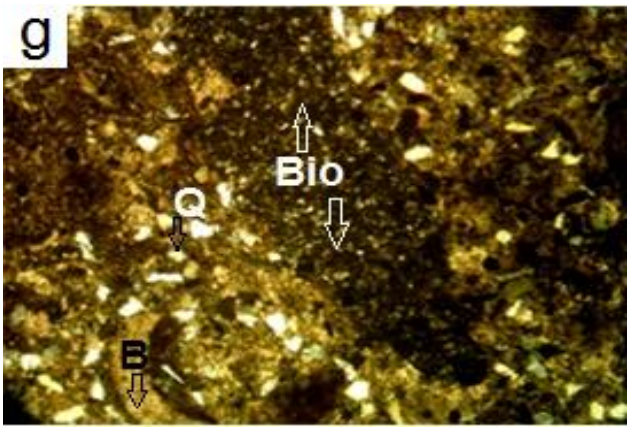


Plate 2f. **Bioclastic calcareous sandstone of MF9 showing boring (central dark colored part) i.e. Bioturbation (Bio), filled later by fine grained material (quartz). Quartz grains (Q) are sub-rounded and show straight extinction. Brown color is of dolomitized matrix. Brachiopod shell (B) is also present. xpl, 4x.**

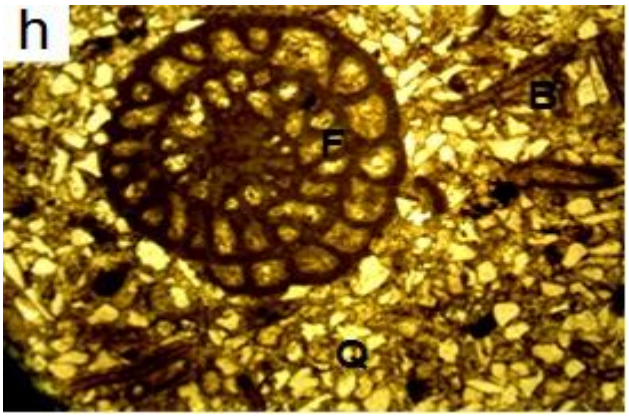


Plate 2g. **A cross section of complete Fusulinid (F). Thread like Bivalves (B) are also present along with fine grained sub-angular quartz rains (Q) showing straight extinction, also present in chambers of fusulinid as a cavity filling spar ppl, 4x**

Conclusion: In Pakistan, one of the Formations of Zaluch Group (Late Permian) is Amb Formation which, at its type locality Amb village, western part of Central Salt Range, can be divided into three lithological units - Lower sandstone, middle calcareous sandstone and sandy limestone and upper sandstone and shale unit. Sandstone of lower unit is fine to medium grained with brachiopods scattered at its basal part. Middle unit has abundant fusulinids present in the calcareous beds. Shale of upper unit is compact and contains vertical burrows. Some of the diagenetic processes were also observed in the formation, including compaction, cementation, dolomitization and bioturbation. Fusulinids (range from Carboniferous to Permian) represent the oldest foraminifera present in Pakistan. Microfacies analysis of Amb Formation and the presence of fusulinids in it suggest that it is a shallow marine sedimentary rock sequence, deposited during Late Permian (Artinskian). On the basis of presence of fusulinids of Late Permian in it, Amb Formation may be correlated with upper part of Chihsia Limestone of Southern China (Chen, 1934) and with the American zone of parafusulina.

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