PALEOCENE CARBONATE OF KOHAT-POTWAR SUB-BASIN OF UPPER INDUS BASIN, PAKISTAN

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ABSTRACT: The carbonates of Paleocene age Lockhart Limestone give good exposures for sedimentological studies in the Kohat-Potwar sub-basin of northern Pakistan. For this purpose two sections of Samana Range and Daud Khel have been selected for detailed sedimentological studies, environmental interpretations and carbonate platform architecture. The studies show that the facies assemblages correspond to inner platform/ lagoon, platform margin and slope settings which show deposition in the inner, middle and outer parts of platform in supratidal, intertidal and subtidal environments. These carbonates are of characteristically nodular in morphology. Dolomitization and development of different porosity types are important diagenetic features of Lockhart Limestone which make it potential candidate as hydrocarbon reservoir in the region. The sedimentological data support to understand the Paleocene carbonate platform of Kohat-Potwar sub-basin from restricted to open marine setting.

Key Words: Lockhart Limestone, Kohat-Potwar Basins, Paleocene age, Northern Pakistan, Sedimentology.

1. INTRODUCTION

In view of importance of Paleocene carbonates as reservoir rocks for oil and gas and their future potential, detailed and comprehensive sedimentological studies of Paleocene carbonates of Kohat-Potwar Sub-basins have been carried out. Oil and gas reservoir rocks in the sedimentary basins of Pakistan range in age from Cambrian to Miocene which comprises both carbonate and siliciclastic rocks. Among these Paleocene/ Eocene carbonates are most favorable exploration targets as well as producing oil and gas reservoirs. The sedimentary basin of Pakistan is classified as Indus Basin and Baluchistan Basin which have been evolved through different sedimentological and geotectonic episodes. The ongoing geological and tectonic processes have further subdivided the Indus Basin into Upper Indus Basin and Lower Indus Basin. The generalized map of Pakistan at Figure-1 illustrates Indus Basin its sub-divisions and location of study area. The Upper Indus Basin is separated from the Lower Indus Basin by Sargodha High. The Upper Indus Basin is further subdivided into Potwar and Kohat Sub-basins. The eastern part is Potwar Sub-basin whereas western part is Kohat Sub-basin and separated by Indus River. Both Potwar and Kohat Sub-basins are significantly comprised of thick sedimentary succession from Pre-Cambrian to Quaternary. These sedimentary sub-basins consist of mainly carbonates, siliciclastic and clays etc. which are separated by unconformities at various stratigraphic levels. The Paleocene rocks of Potwar/Kohat Sub-basins have been studied by different authors [1, 2, 3, 4, 5, 6, 7& 8]. These studies are mainly related to regional stratigraphy and paleontology etc.

Tectonic evolution of Paleocene rocks has also been discussed by some other authors as: [9, 10,
).
11, 12, & 13]. Moreover, petroleum exploration companies working in the area and research organizations carried out various types of geological studies for specific purposes [14]. However, very little is known about sedimentology, microfacies and their depositional framework, diagenesis, history of carbonate platform development and reservoir characterization etc. therefore, two principal/representative sections of Paleocene carbonate rocks each from Samana Range and Daud Khel area of Kohat and Potwar sub-basins have been selected to substantiate the research outcome with respect to specific sedimentological studies (Figure-2).

2. REGIONAL SETTING

The presence of three lithospheric plates in northern area of Pakistan namely Indian, Eurasian and Arabian and their interaction along with active plate boundaries has resulted into development of spectacular mountain belts including Himalayas, Karakorum and Hindukush. Precambrian to Recent rock units of these belts records the tectonic history of the region. Permo-Triassic time is supposed to be the initiation of rifting of Gondwana and development of Atlantic type passive continental margin [15]. The Tethys Ocean ultimately closed with the continuous drift of India to the north forming continental margin with Eurasia. The northern suture is called Main Karakoram Thrust (MKT) while the southern suture that separates the terrain from the Indian Plate is known as Main Mantle Thrust (MMT The MBT is more or less EW trending in central Himalayas. The Panjal Thrust in the north (MCT) [17] runs parallel to MBT and it coalesces with MBT at the western flank of Hazara Kashmir Syntax is along the NNW trending, left lateral, strike-slip Jhelum Fault. The Kala Chitta is an intensely deformed fold and thrust belt at the southern

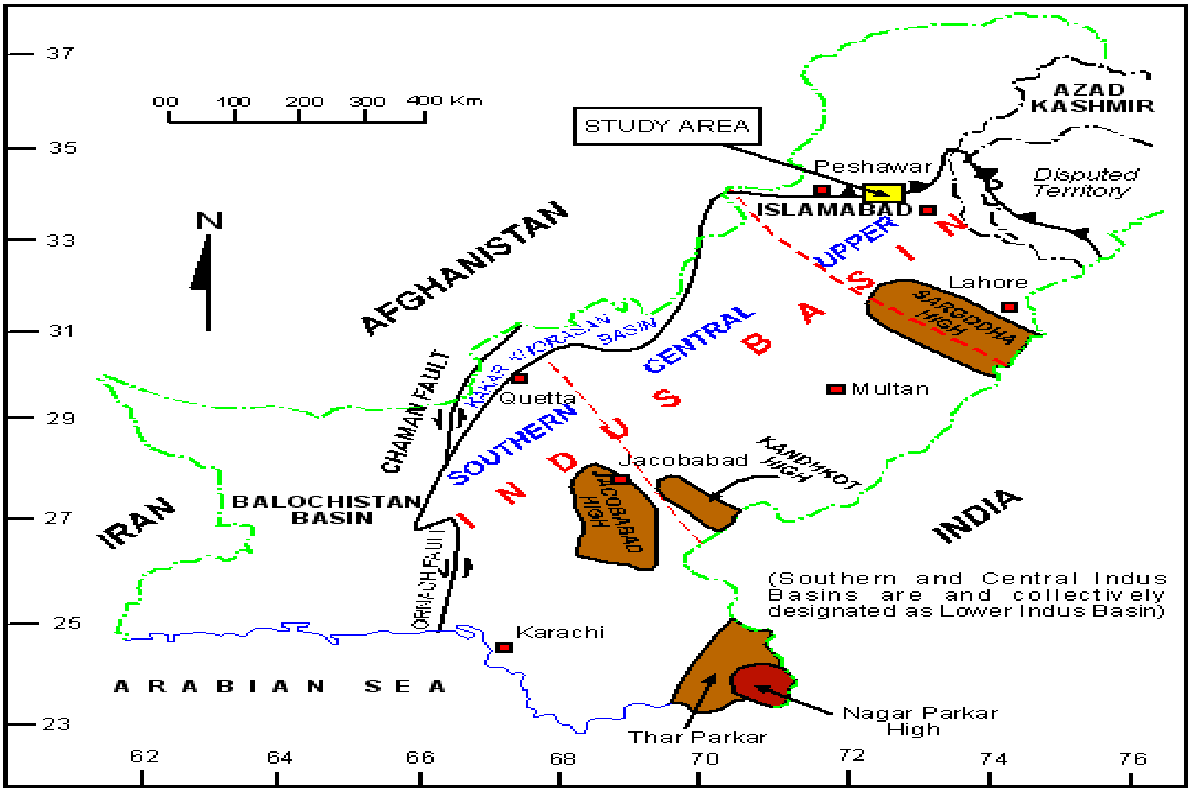


Figure 1: Generalized Map & Location of Study Area

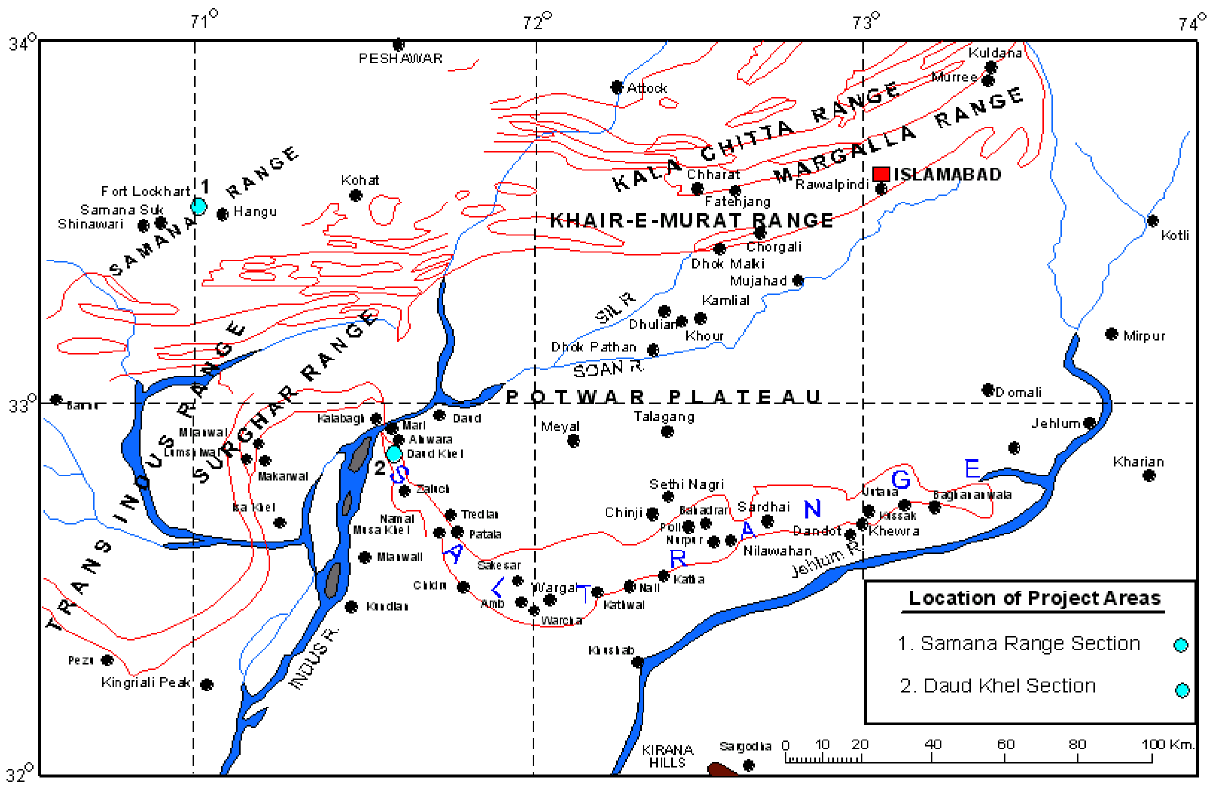


Figure 2: Location Map of Study Area Showing Two Principal Sections

boundary of Lesser Himalayas. It is constituted by a number of north dipping thrusts and south verging tight isoclinals to overturned folds [18]. The southern margin of Himalayan collision zone in Pakistan is represented by Salt Range, Potwar Plateau and Kohat Plateau. It is an active fold-thrust belt which is bounded by MBT in north and Main Frontal Thrust (MFT) in the south. The Salt Range and Potwar Plateau are bounded in the east by the left lateral, strike- slip Jhelum Fault. The western boundary of Potwar Plateau is not very sharp. In the northern part of Potwar Plateau the EW trending thrusts extend westwards to Shakardara area in Kohat Plateau while Kala Bagh Fault in the southern parts marks the western boundary of Potwar Plateau and cis-Indus Salt Range. The structural style in the Upper Indus Basin of Pakistan generated multiple petroleum prospects [19]. These structures resulted by compression tectonics at the foreland margin, basement uplift in the platform areas and extensional tectonics. Structurally, the Upper Indus Basin may be classified into Potwar Plateau/ Eocene Salt Zone, Bannu Depression, Main Boundary Thrust and the Kohat Plateau [19] (Figure-3).

3. STRATIGRAPHY

The rocks of Paleocene age are widely distributed and exposed in the Potwar-Kohar areas of upper

Indus Basin of Pakistan. These rocks are classified as Hangu Formation, Lockhart Limestone and Patala Formation. Apart from carbonate and siliciclastic rocks coal, laterite, iron ore and bauxite are also found within the Paleocene sedimentary sequence[20]. A comparison of Tertiary sedimentary rocks of Kohat and Potwar Sub-basins is shown in Figure-4.

3.1.1. Hangu Formation

“Hangu Shale” and “Hangu Sandstone” [21] from the Kohat area has been assigned by the Stratigraphic Committee of Pakistan (1973) as Hangu Formation. The type locality is situated south of Fort Lockhart Limestone (Lat: 33° 33′ 44″ N, Long: 71° 44′ E) and Dhak Pass (Lat: 32° 40′ N, Long: 71° 44′ E) in the Salt Range which are the main sections where Hangu Formation is well exposed. In the Kohat area Hangu Formation consists of white, light gray and reddish brown sandstone with gray colored shale intercalations

and rarely conglomerate lenses. In the Salt Range and Trans Indus Ranges this formation is comprised of dark gray sandstone, carbonaceous shale and some nodular argillaceous limestone. At places carbonaceous content increases and forms coal seams. The base of this formation is characterized by a 2-3m thick bed of ferruginous and pisolitic sandstone while to the western parts i.e. Kala Chitta, Nizampur and Hazara areas it contains Iron Ore. This formation unconformably overlies the various Paleozoic and Mesozoic rocks in differe

nt parts of Potwar and Kohat basin. The age of the formation has been assigned as an early Paleocene on the basis of micro-paleontological fossil assemblages.

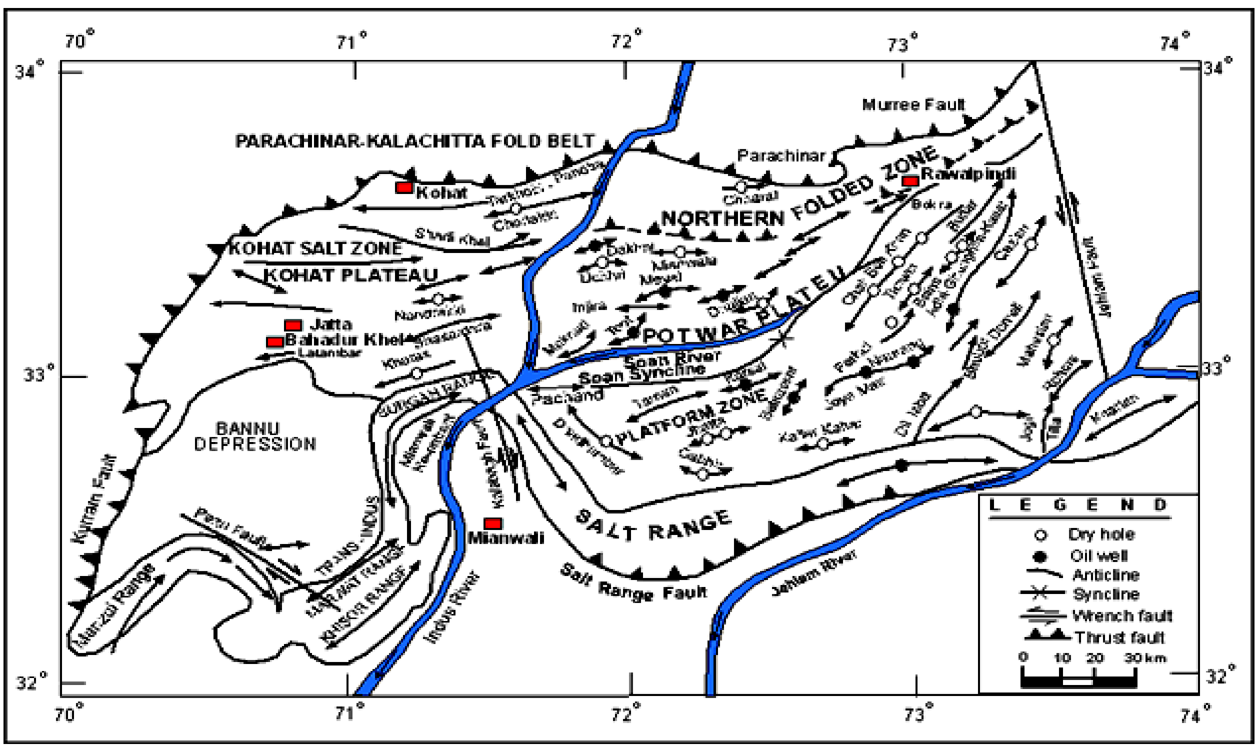


Figure 3: Tectonic Map of Kohat-Potwar Area

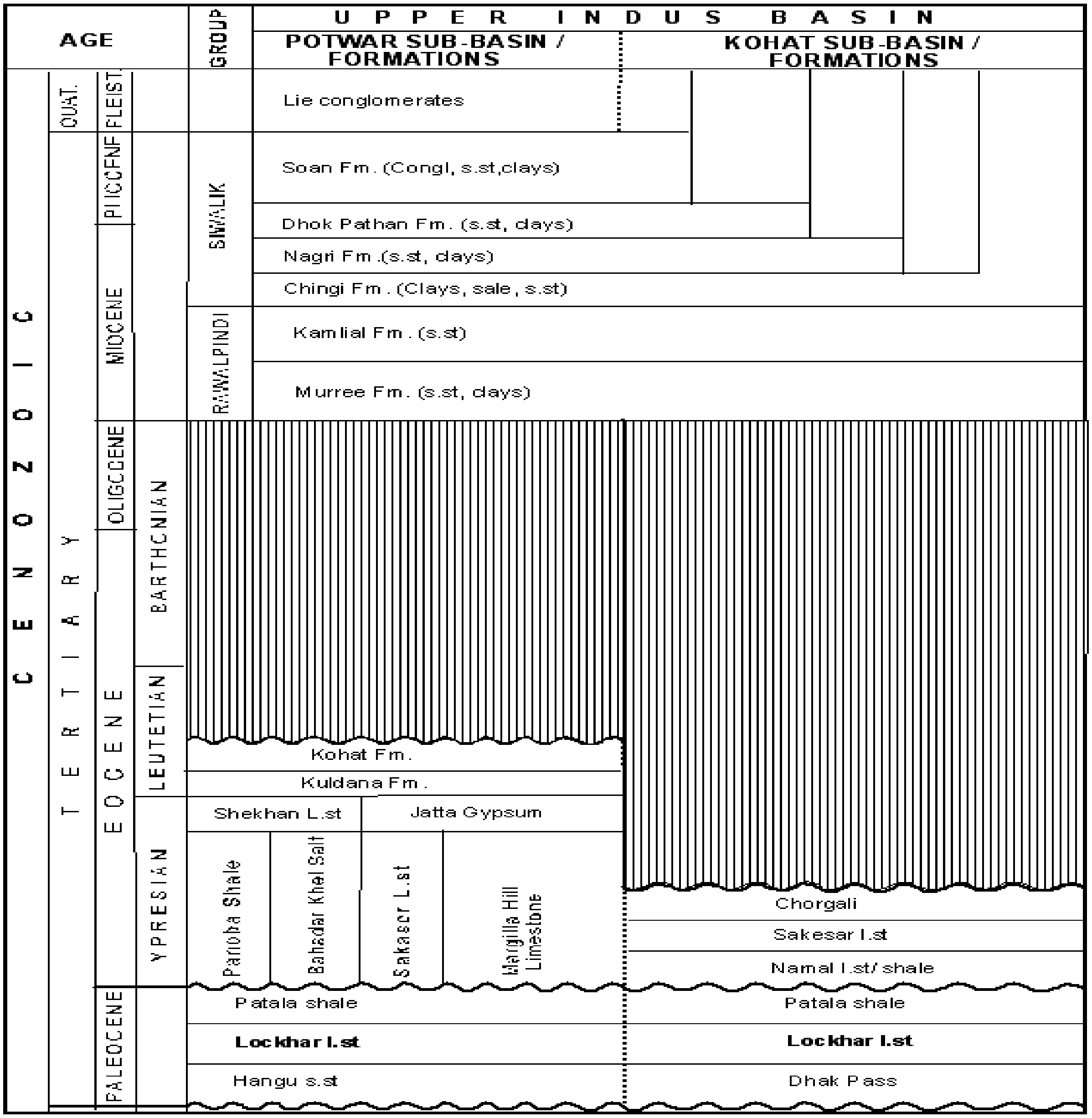


Figure 4: Chart of Tertiary Sedimentary Sequence in Kohat- Potwar Area (Late Paleocene age throughout its extent except for Hazara area where it extends to Early Eocene) [20]

3.1.2. Lockhart Limestone

The term "Lockhart Limestone" is introduced [21] for a Paleocene limestone unit in the Kohat area. In the Samana range, a section exposed near Fort Lockhart Limestone (Lat. 33° 26' N: Long. 70° 30' E) has been designated as type locality of the limestone.

In the Salt Range and Trans-Indus Ranges Lockhart Limestone is comprised of grey to light grey, medium bedded, nodular with minor amounts of grey marl and bluish grey calcareous shale in the lower part. However, in the Kohat area is grey to medium grey, medium to thick-bedded, massive, rubbly and brecciated in places while the basal part dark grey to bluish grey and flaggy. In the Hazara and Kala Chitta areas, the limestone is dark grey and black in colour and contains intercalations of marl and shale and generally gives off bituminous odor on a fresh surface. It is well-developed throughout Kohat Potwar areas. The limestone conformably and transitionally overlies and underlies the Hangu Formation and the Patala Formation respectively. The limestone contains abundant foraminifers , corals, mollusks, echinoids and algae etc. On the basis of micro-fossils assemblages' Paleocene age for Lockhart Limestone has been assigned.

3.1.3. Patala Formation

The term Patala was introduced by Davies and Pinfold [22] for the Patala Shale and formalized by the Stratigraphic

Committee of Pakistan. The formation extends largely in the Kohat-Potwar and Hazara areas. In the type section it gives good exposures in the Salt Range (Lat: 32^o 40$^/$ N, Long: 71^o 49$^/$ E). The Patala Formation is mainly comprised of shale and marl with subordinate limestone and sandstone. The shale is dark greenish gray, carbonaceous and calcareous, selenitic and marcasite nodules bearing. Lithologically, the formation shows some variations from place to place. The upper part of Patala Formation is characterized by yellowish brown and calcareous sandstone. Coal seams of economic worth are present at some localities i.e. Dandot area. In Kohat area it is represented by dark gray shale which is occasionally carbonaceous with intercalate argillaceous limestone beds. The shale is greenish brown to buff in color with inter-bedded nodular limestone in Hazara area. While in the Kala Chitta Range the formation is characterized by light brown and gray marl with thin inter-beds of limestone. Its thickness varies from 20-180 m from place to place in Potwar-Kohar sedimentary basins. Patala Formation conformably overlies the Lockhart Limestone. It is highly fossiliferous and contains abundant foraminifera, mollusks and ostracodes. This formation has been assigned as a Late Paleocene Age throughout its extent except for Hazara area where it stretches to Early Eocene [20].

4. METHODOLOGY

The Paleocene carbonate rocks of Lockhart Limestone in the Kohat-Potwar sub-basins of northern Pakistan presents exceptionally well exposed outcrops of high relief for studies. Therefore, sedimentological studies of two principal and conformable sections of Samana Range Section Daud Khel Section have been slected. The aim of research is to quantitatively characterize the startal geometry and lithofacies distribution of Paleocene carbonate platform by using combination of conventional field studies and laboratory analysis.The field studies of these sections includes geological mapping, preparation of sedimentary log, detailed section measurement, samples collection and sedimentological/ petrographic studies of rock samples.The total vertical thickness measured for the Lockhart Limestone in Saman Range Section is 46 meters and Daud Khel Section is 44 meters. The rock samples from distinct litho-facies were collected for petrographic studies and loboratory analysis. The petrographic analysis was performed to determine carbonate components, microfacies and diagenesis. Both unstained and stained thin scetions were used for sedimentological and diagenetic studies. The data obtained from the field and laboratory studies have been combined to construct facies description, depositional environment and diagenetic evolution. Photomicrographs have taken for illustration and description of micofacies characterization and depositional environments and diagenetic overprints. Field observations along with micoscopic features have used to interpret depositional environments of each microfacies assemblage. The micoscopic features include minerology, composition, biogentic grains morphology , orientation, size and identification. For facies analysis the parametres were based on Wilson [23] (SMF) and Flügal [24] (new models of SMF). Classification of Dunham [25] was employed for limestone facies classification. Sea level changes was revealed by the the field observations and petrographic results. The sea level fluctuation curve was constructed using microfacies modeling technique described by Spencer [26].

5. SEDIMENTOLOGY

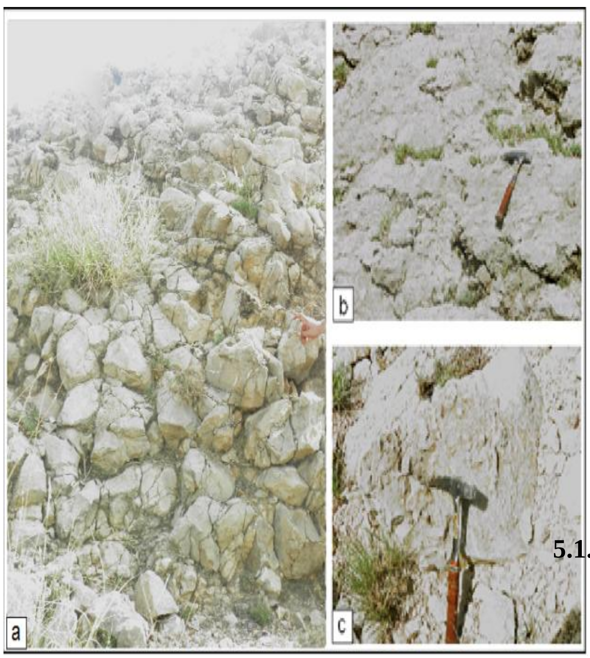
The sedimentological studies of carbonate rocks of Daud Khel Section and Samana Range Section will help to develop inner platform/ lagoons, platform margin and slope settings for which platform evolution was mainly controlled by organic productivity, environmental changes, sea level fluctuations and active synsedimentary tectonics. The results could be analogous to a number of carbonate platforms with similar settings in which carbonate platform growth was greatly influenced by synsedimentary tectonics and other factors.

5.1. Daud Khel Section

The Daud Khel Section is located at 32^0 50$^/$ 25.3$^{//}$ N, 71^0 36$^/$ 56.1$^{//}$ E and 25 km NE from Mianwali City on Mianwali-Bannu road. Further, 4 km toward east un-mettaled road leads to access the main outcrops of the study area. This section is also the quarry area for laterite, limestone, fire clay etc. (Figure-5a). In this section the Lockhart Limestone is about 44 meters thick and makes lower unconformable contact with the Hangu Formation. The overlaying Patala Formation though pinches out considerably but conformably lying over Lockhart Limestone. In the Daud Khel Section the Lockhart Limestone is characterized by mainly nodular and massive at the lower stratigraphic level while thickly bedded nodular limestone in the upper stratigraphic level (Figure- 5b).

The thickness of individual bed is about 2 to 2.5 meters with total thickness of this limestone unit is more than 10 meters. This nodular bedded limestone is underlain by planner bedded limestone without prominent nodular structure development. These nodules are of small (few cm to 10 cm), medium (10-20 cm) and large (more than 20 cm) sized with almost sub-rounded to rounded shapes. These different nodular structured limestone may form

Figure 5: a) Excavation Work of Laterite ore of Hungu Formation **b)** Photograph showing thickly bedded limestone of Lockhart Limestone composed of small nodules composed of small nodules.



5.1.1.1.

Figure 6: Fractured and Brecciated Nodular Limestone

isolated to semi interconnected limestone mounds and/ or heaps at the lower strata-graphic levels of Lockhart Limestone and then overlain by less nodular to nodular massive bedded limestone.

The limestone of lower part is mainly comprised of micritic to large fossiliferous limestone with well preserved corals, alveolina, intraclasts and limestone breccias. This limestone is light yellow, brown and pink coloured on the weathered surface while off-white to cream, buff and light gray colored on the fresh surface (Figure 6a). The well preserved limestone breccias size varying from 1 cm to 6 cm and show synsedimentary tectonics and may be interlinked with tectonic controlled carbonate platform development (Figure-6,b&c). Intensive fracturing at certain levels is well pronounced with calcite filled veins and pockets of calcite fillings. Large reworked limestone clasts followed by brecciated zone in upper stratigraphic levels shows a tectonic controlled carbonate platform development (Figure-7).

Figure7: Photograph showing carbonate platform slope deposits mainly comprised of large reworked limestone clasts (Arrowed).

5.1.1. Microfacies Analysis & Environmental Interpretation

5.1.1.1 DKMF-1. Benthic Foraminiferal Wackstone:

Petrographic studies reveal that the bioclastic grains are about 20 -25% (Figure 8a). The skeletal allochems of this facies are mainly benthic foraminira (5-7%), mollusks (3-10%), echinoderms (2-5%) and algae (2-3%). The fine micritic matrix is about 30-35%. The mollusks fragments are generally replaced by non-ferroan sparry calcite cement. The pelagic foraminifera i.e. globigerina is also less commonly present. The matrix as well as allochems is generally replaced by dolomite crystals. Sometimes due to the dolomitization the primary internal fabrics of bioclasts as well structures have been obliterated. Fracture related dolomitization is commonly observed where fractured rocks are dolomitized.

5.1.1.2. DKMF-2. Dasycladean Algal – Foraminiferal Wackstone-Packstone

This microfacies is comprised of 10-25% bioclasts. The bioclasts are dasycladean green algae 2-7%, gastropods, pelecypods, milliolids, Lockhartia, bivalve shell fragments, and broken bioclastic fragments with mostly micritic envelopments. Matrix as well as bioclasts is partially replaced by dolomite. (Figure 8b). Grains are poorly sorted. Geopetal structure is also present in few bioclasts.

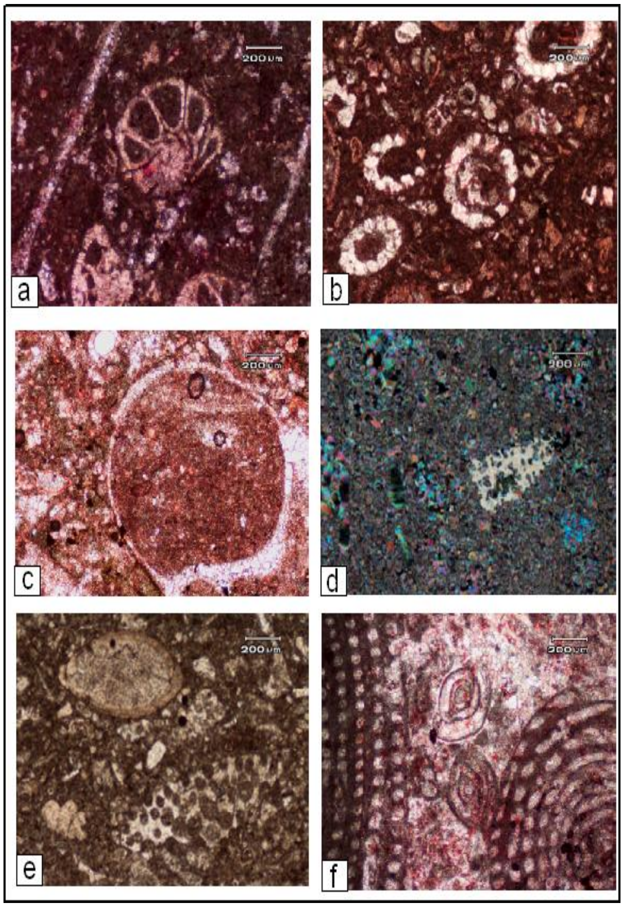


Figure 8: a) The photomicrograph showing large benthic foraminiferal wackstone and development of two fractures and saddle dolomite. Few pelagic foraminifera can also be clearly seen (DKMF-1). **b)** The photomicrograph showing green algal wackstone-packstone fabrics. Also note poorly sorted and broken bioclastic grains (DKMF-2). **c)** Photomicrograph showing rounded limestone intraclast the outer boundary of which has been replaced by calcite. (DKMF-3). **d)** The Photomicrograph showing bioclastic mudstone. Note that the bioclasts have been completely replaced by neomorphic calcite. (DKMF-4). **e)** Photomicrograph showing bryozoa (lower left corner), Ostracod (upper left corner) and broken bioclastic fragments typical showing platform slope setting (DKMF-5). **f)** Photomicrograph showing large benthic foraminifera: Alveoloina, Milliolid with less commonly dolomite and iron minerals in the benthic foraminiferal packstone microfacies. (DKMF-6)

5.1.1.3. DKMF-3. Intraclast Bioclastic

Wackstone-Packstone or Limestone Breccia

Petrographically, this microfacies is comprised of large rounded to sub rounded intraclasts which are cemented with equigranular sparry calcite. The allochems i.e. Globigernia, benthoic foraminifera, serpulid tubes, Lockhertia, Brachiopods and Plecypods are severely broken and disorganized. (Figure 8c). The matrix material is less commonly dolomitized with microcrystalline dolomite fabrics. The fracture related dolomite has been observed at few places.

5.1.1.4. DKMF-4: Bioclastic Mudstone

This microfacies assemblage is comprised of almost small uniformly sized nodular limestone. This limestone also makes lower startigraphic levels of Lockhart Limestone in the Daud Khel section. It is gray colored on the fresh surface and contains no visible microfossils visually. The petrographic studies show that this microfacies is mainly composed of mudstone with rarely reworked and broken bioclasts (1-5%) (Figure 8d). The mudstone as well as bioclasts shows replacement with sparry calcite cement and resulted into only the unrecognizable internal texture; and only ghosts of bioclasts show their presence. The microcrystalline dolomitization may have significantly obliterated primary sedimentary fabrics of the rocks. The dolomitization sometime exceeds more than 50%.

5.1.1.5. DKMF-5: Bryozoan Foraminiferal Wackstone-

Packstone Petrographically, this microfacies is comprised of 20-45% bioclasts, intraclasts and less commonly sliliciclastsic grains (Figure 8e). These are mainly Bryozoas, broken coral fragments, benthonic foraminifera i.e. milliolids, lockhartia etc., globegirina, bivalve shells i.e. pelecypods, crionoids and broken bioclatic fragments. The bioclasts are moderately to poorly sorted and randomly oriented. Sometime the allochems are tightly packed and make sutured and pointed contacts with each others. The dolomitization is less commonly present or completely absent. Low amplitude stylolites are commonly present with concentrations of clay minerals and/or organic matter along them. Iron is scattered within the rock mass in the form of dark brown cubic crystals which may be pyrite or magnetite. Various types of fractures are present, where in smaller fractures are filled with microcrystalline sparry calcite while larger fractures have been filled with coarse blocky calcite. Very rarely euhedral to subhedral dolomite crystals are accumulated along the fractures boundaries. Some fractures have been displaced by the development of later fractures. Few fractures are filled with fine micritic material which is termed as fissure fractures. Moldic porosity is commonly developed within the allochems which are sometime filled up with dark brown colored organic matter. Circumgrannular cement around the allochems as well as granular cavity filling cement is present.

Cementation may occur at almost any stage of digenesis. Circumgrannular cement is characterized by cement rims around grains consisting of equidimentional crystals forming the first generation of pore-filling cements. This cement type develops in meteoric pheratic environment [27]. Granular cement is characterized by small pore filling calcite crystals of approximately equal size without a preferred orientation and no substrate control.

This cement characteristically develops in meteoric-vadose, meteoric-phereatic and burial environment [27].

5.1.1.6. KMF-6: Large Benthic Foraminiferal – Alveolinid Wackstone-Packstone

Petrographically, this microfacies is comprised of more than 45% bioclasts with selective bioclasts variety. These are mainly comprised of wholly preserved benthic foraminifera including alveolina, milliolid with red algal fragments and broken bioclasts. The intergrannular space or primary porosity is filled with equigrannular calcite cement. The matrix material is negligible or absent. Few grains are tightly packed and making sutured and pointed contacts with each other showing the effect of mechanical compaction. The benthonic foraminifera are of small medium and larger size with no preferred orientation and distribution with in rock fabric. (Figure 8f) No pelagic foraminifera have been identified. A few scattered pyrite crystals with dark brown to black insoluble residues (probably organic matter) are also present.

Interpretation: The microfacies assemblages of Daud Khel section show deposition in a wide range of inner platform, lagoon and slope settings. The present lagoon sediments have been described as composed of a wide range of carbonate sands and carbonate mud [28, 27]. These lagoonal sediments are characteristically comprised of current rippled and cross bedded sandy deposits. However, in study area the rocks of this microfacies are typically nodular structured. The deposition of lagoonal sediments in hypersaline conditions with the development of effective barrier. This facies probably shows deposition in sub-tidal environment under the reducing conditions. The dark grey color is due to presence of organic matter and opaque minerals. The environment in which lagoonal facies deposited was probably less agitated. Consequently, this facies has been interpreted as deposited in lagoonal environment above the fair weather wave base at the depth from 5-10 meters. Similar, facies have also been reported from the Paleocene age Dunghan Formation of Upper Indus Basin [29].

The varying size of benthic foraminifera from smaller to larger size with commonly milliolids indicate that deposition has taken place in semi restricted to restricted shelf lagoon. The absence of matrix material as well as commonly occurrence of blocky cement indicates occasional inters connection with open marine high energy regime. A similar facies assemblage with imperforated foraminifera as well as perforated foraminifera has been reported from the inner ramp of the Miocene sediments of the Central Apennines [30], from early Oligocene deposits of the Lower Inn Valley [31], Oligo-Miocene Asmari Formation in SW Iran [32] and Middle Miocene Horu Formation SE Turkey [33].

Dasycladean green algae "Helimeda" has a segmented skeleton that grow rapidly and disintegrates freely. It is significantly producer of allochthonous fragments in tropoical shallow marine environment [34] and never found preserved completely. The porous segments of algae are light and readily transported therefore are broken. Helimeda is essentially a warm, shallow water marine algae with a wide range of its latitudinal and depth distribution [35]. It is most abundant in the tropical carbonate environment with commonly at depths from 1-50m [36]. Modern dasycladean algae has been described commonly occur in tropical and subtropical environment but are also found in temperate water i-e the Mediteranean Sea [27]. Its distribution is controlled by water temperature (warm water mostly 20 degrees), substrate (sand and mud), salinity (normal marine to hypersaline and brackish water), water energy (subtidal) and depth (below low tide down to about 30m., commonly less than 5m).

The breccias are characterized by abundant angular clasts (more than 50%). The breccias result from sedimentary and tectonic process and develop down slop by large thrusts connected with gravitational sliding e.g. mega derbies flow deposits [37]. They are formed on a broad range of slope angles and contain coarse grain as well as fine grained breccias resulted by catastrophic collapse of high angle over steepened carbonate platform margins.

Low diversity of bioclasts and commonly replacement of mudstone with sparry calcite cement indicate a shallow water inner shelf lagoon with freshwater recharge from the attached continental areas. The well preserved lockhteria, nummulites, alveolina and ranikothalia show their in-situ preservation. Moreover, these forms originally show deposition in shallow ramp setting and then transported into deeper ramp environment with depth from 70 -100 meters as proposed from the Dungan Formation of same age from the lower Indus basin [29].

The general characteristic features as massive bedding often with significantly thick beds, irregular top surfaces, no preferred depositional fabrics, poor sorting, random or chaotic clastic fabrics, densely clasts packing with sutured and pointed contacts and matrix supported limestone fabrics has been described as related to carbonate platform slope setting [27]. The depositional mechanism specifically related to debris flow deposits with shallow and/or deep water limestone sheets deposited in proximal or distal position of platform depending upon the position of the source areas. According to this interpretation this microfacies assemblages may be related to upper carbonate platform slope with high hydrodynamic conditions which have developed at the expense of tectonic subsidence and sea level fluctuations.

The sediments filled fractures found in this microfacies has been interpreted as fissure fills. The carbonate rocks are often affected by destructive processes leading to opening and filling of various sized fissures, voids and veins. The initiation, development and sedimentary filling of fissures can take place in a variety of environments. These fissures may be influenced by various processes such as karst solutions in subaerial and vadose settings, solutions in phreatic and mixing zones between fresh water and saline waters and processes operate in shallow and deep marine setting [27]. Synsedimentary fissures develop by down slope sliding and slumping of early cemented slope deposits on uncemented interbeds as a result of earthquakes or seismic shocks [38]. Shallow marine lagoonal carbonates can be affected by dessication and shrinkage leading to formation of dikes [39]. The tectonic fissures are related to block

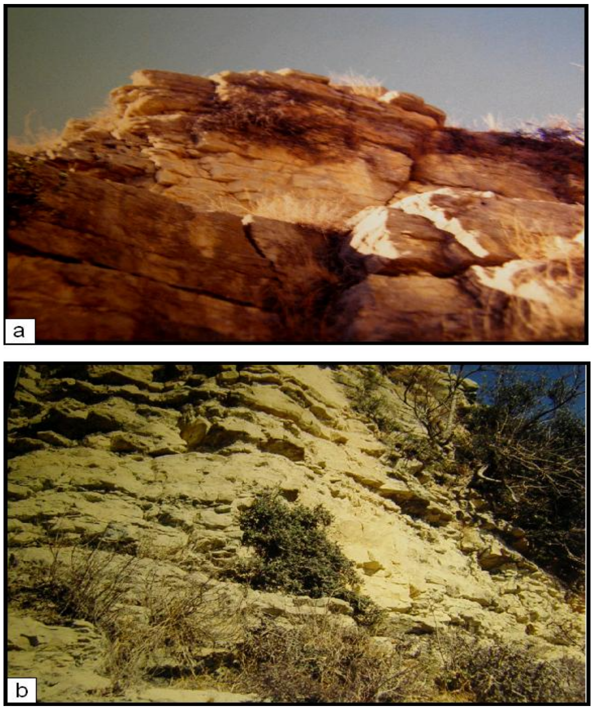


Figure-9: Thin and Thickly Bedded Limestone

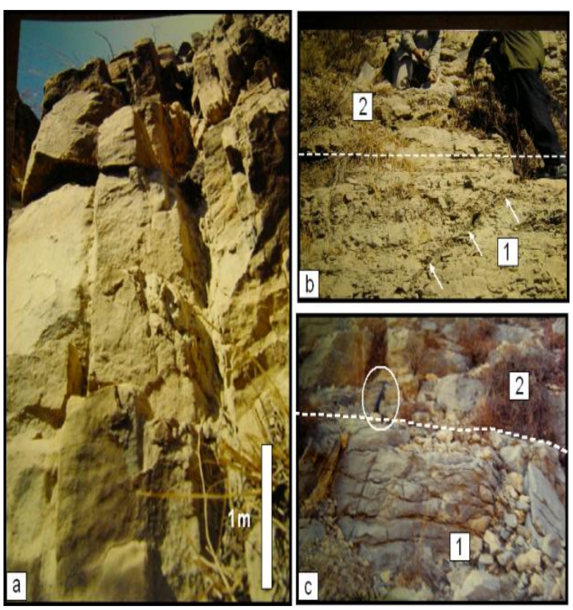


Figure-10: Massive and Lenticular Limestone Beds

faulting and rifting. Cement is the material that precipitates chemically in the pores of sediments.

5.2. Samana Range Section

The Lockhart Limestone of Samana Range Section is exposed near Fort Lockhart (lat. 33° 26' N: long. 70° 30' E). Fort Lockhart is about 30km North-West of Hangu Town and connected with Hangu-Samana road. The lithology of Hangu Formation is mainly composed of sandstone with grey shale intercalations in the upper part. The sandstone is white, light grey and reddish brown and is dark rusty brown on weathered surface. The formation is fine to coarse grained and medium to thick bedded and at some places it is conglomeratic. Its contact with Lockhart Limestone is conformable.

The Samana Range has also been designated as type locality of the Lockhart Limestone. The limestone, in the area, is grey to light grey, medium to thick-bedded, massive. The upper part of limestone is thickly bedded overlain by thin and parallel bedded limestone(Figure 9).The middle part of limestone is alternately medium and thinly bedded limestone. The limestone at places is massive (Figures 10). The thickness of individual bed ranges from 30-75cms. This peculiarity of Lockhart Limestone is less commonly observed in Daud Khel section. The lower part of Lockhart Limestone in the area is dark grey to bluish grey and flaggy. It also contains minor amounts of grey marl and bluish grey calcareous shale and thinly bedded intercalated with marl in the lower part and brecciated in places shown at stratigraphic level-1 which is overlain by medium bedded limestone sequence at level-2. The Lockhart Limestone is mainly composed of bedded limestone. The bedding geometry ranges from thin, medium and thickly bedded and is lenticular. The limestone is gray coloured on fresh surface while dark gray colored on fresh surface and with intercalated variegated colored clays, marl and siltstone. The limestone is micritic with less commonly macrofossils preserved in rock outcrops. Calcite veins, fracturing and brecciation of limestone is commonly present in limestone. Karren structures and dissolution potholes have been developed on weathering surfaces at certain stratigraphic levels. The Patala Formation is conformably and transitionally overlies the Lockhart Limestone. The shale is dark greenish grey, in place carbonaceous and calcareous, and the limestone is white to light grey and nodular. The section of exposed outcrop was measured 46 meters approximately and more than 53 rock samples were collected for sedimentological studies and microfacies analysis. On the basis of field observations, Lockhart Limestone may be divided into different lithological units of bedding thickness, nodularity, intensity of dolomitization and shale intervals etc.

5.2.1. Microfacies Analysis & Environmental Interpretation

5.2.1.1. SMF1. Bioclastic Wackstone-Packstone

The microfacies is classified as bioclastic wackstone to packstone. The bioclasts are about 25% and mainly consist of Lockhartia sp., brachiopods, planktonic forams and other broken shell fragments. Grains internal parts are replaced by spar while outer boundary of the grain is preserved. A few calcite veins are present which are filled by spar and ferroan calcite cement. Dolomite rhombs are also present (Figure 11a).

5.2.1.2. SMF2. Benthic Foraminiferal Packstone

The main bioclasts are about 23% and mainly consist benthic foraminifera i.e. lockhartia., mollusks, brachiopods, broken shell fragments and planktonic forams. Calcite veins are present which are filled by spar and ferroan calcite cement. Well crystallized zoned dolomite crystals (light brown color) are present. (Figure 11d)

5.2.1.3. SMF3. Benthic Plankton Foraminiferal Wackstone-Packstone

The microfacies is classified as benthic planktonic foraminiferal wackstone-packstone. The bioclasts are about 25% and mainly consist of Mollusks, broken fragments along with ghosts and planktonic forams. Calcite veins are less commonly present which are filled by spar and ferroan calcite cement. Dolomite rhomb is also present (Figure 11b).

5.2.1.4. SMF4. Planktonic Foraminiferal Wackstone

The facie is classified as bioclastic wackstone to packstone. Bioclasts are about 24% and mainly consist of planktonic forams, mollusks, broken fragments along with some ghosts. Calcite veins are present which are filled by spar and ferroan calcite cement. Cement is mainly of spar and ferroan calcite. Dolomite rhombs are also present. At places this microfacies assemblage is dominated by glauconitic and phosphate grains (Figure 11e and f).

Interpretation: Within the stratigraphic section of 46 meter thickness the individual units in the Lockhart Limestone are about in the order of 10’s to 100’s of cms thick and exhibits rapid vertical and lateral facies changes. Significant irregularities in water depth of shallow water have produced changes in carbonate deposition in Samana Section. Relatively deep water sedimentation tends to be more uniform at certain stratigraphic levels with shale intercalations and that of large scale cross stratification. These cross bedding geometries contaminated by glauconite and phosphate are abundant in upper stratigraphic levels of section. In comparison micrite abundance with pelagic fauna is increased in the lower part with reworked benthic community. The Lockhart Limestone of this particular section show ample evidence of accumulation in intertidal to shallow marine realm.

Disarticulated abraded bioclasts abundant in micrites and biosparite in lower middle part of the section are mixed with glauconite and phosphatic grains along with siliciclastic. The lower stratigraphic section also shows pervasive dolomitization while upper part affected by very sparce or non dolomitization diagentic process. Small coated grains including ooids and pisoids are fairly common constituents of individual beds and are more abundant in middle-upper part. Oosparite facies are much more common than oomicrite and intercalated with pelmicrite laminae. This relationship indicates lateral proximity of deposits of two diverse depositional environments i.e. high energy represented by oosparite and low energy pelmicrite[40]. Such rapid vertical and lateral facies change show shallow marine carbonate deposits [41] and reported from Morgan Creek Limestone, Texas. These ooids are rounded, discrete as well as closely attached, well sorted and show a range of internal structure from radial to concentric. Ooids with radial and/ or concentric internal structures are most likely composed of high magnesium calcite [42]. Ooids seems to be very rapidly dolomitized allochem whereas micrite matrix is less affected by dolomitization. This relationship show that carbonate comprising of ooids was first altered to coarse calcite mosaic and then dolomite replaced the pseudospar [41].

Glauconite and terrigenous material has also significance in Lockhart Limestone of Samana Section (Figure 12f). The laminated limestone with intercalated greenish shale is of glauconitic composition with sand sized glauconite pellets along with silts sized siliciclastic grains and phosphoritized bioclats. The intergrannular space between glauconite grains filled with coarse sparry calcite indicated that glauconite must have precipitated prior to cementation. Brecciated limestone comprised mainly of fossil fragments, glauconite pellets, matrix and most significantly sparry calcite cement indicate that these deposits must have been partly cemented prior to erosion which channelized to deeper part of the carbonate platform with high angle of repose. Such carbonate channels underlain by reefal limestone have been described as deposited in high angle carbonate platform of Osmaniye-Bahce sub-basin SE Turkey [43]. In oxic water the iron is in oxic state and cannot easily entre the calcite lattice [45] whereas ferrous iron is present in reducing environment and can easily entre the calcite lattice.

Dolomitization occur after glauconitization and phosphoritization, cementation or may be said as late stage diagentic phenomenon as latter are replacing the earlier ones. As for as the origin and depositional environment of glauconite are concerned, it has been described as sub-oxic, partly reducing environment for the formation of Oligocene-Miocene glauconite [46]. The author described that closed/ restricted conditions are necessary for the formation of glauconite and these occur only in impermeable sediments i-e shale and would not be met in highly permeable coarse grained deposits that show resemblance in our case study where green glauconitic limestone unit intercalated with shale.

6. DISCUSSION

Tertiary carbonate rocks have been proven reservoir rocks because they contain potential hydrocarbon reserves while late Jurassic to erly Cretaceous black shales are considered important source rocks in Upper Indus Basin of Pakistan [19]. Early Paleocene is the time of wide spread carbonate platform development and thick carbonates of Lockhart Limestone onlapped the longstanding Langrial Horst [47]. In the Tethyan realm during early Paleogene the less preservation or absence of coral reef has been described as caused either by burial under sediments in active tectonic zones or poorly development in tropics [48]. The Paleocene carbonate

platform dominated several coral reefs thrived along the western border of Indian subcontinent while more dominent fauna comprised of Ranikothalia and Miscellananea. However, our studies revealed that true in-situe coral reefs poorly developed in northern Pakistan. However some reworked corals occurence may be due to active tectonics during early Paleocene carbonate platform development as noted in Daud Khel section in the form of thick breccia deposits. In some areas like Pyrenees Basin Spain extensive coral reef forming fauna florished in Tethyan realm [49].

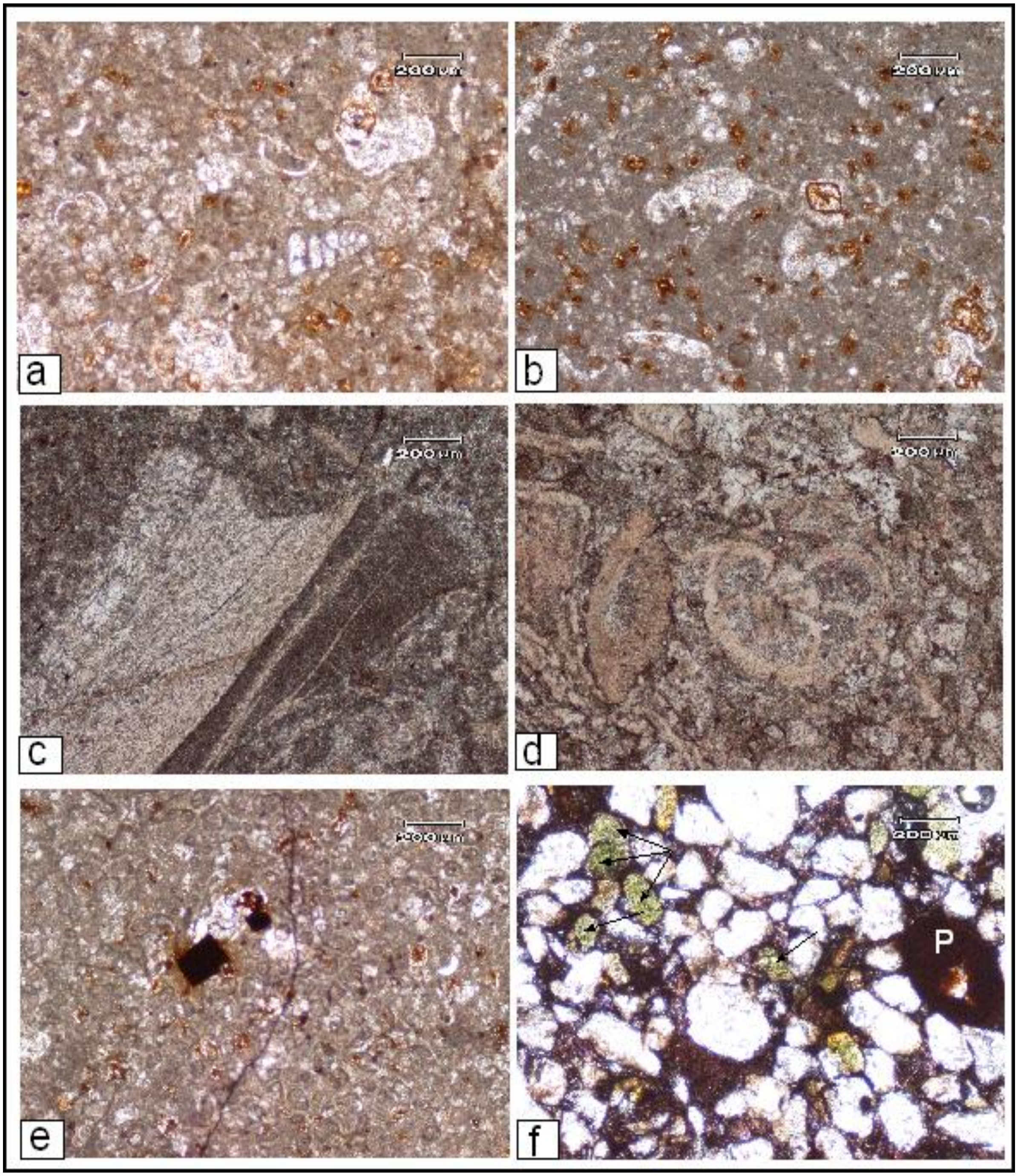


Figure-11: a) Photomicrograph showing bioclastic wackstone-packstone of SMF-1. **b)** Photomicrograph showing pelagic foraminiferal wackstone-Packstone. Some zoned dolomite crystals may clearly be seen SMF-2. **c)** Photomicrograph showing large reworked and broken brachiopod shell fragment. **d)** Photomicrograph showing large foraminiferal packstone microfacies belonging to SMF-3. **e)** Photomicrograph showing small planktonic foraminiferal wackstone microfacies with late stage pyrite crystal. Few allochems are partially dolomitized (SMF-4). **f)** Photomicrograph showing glauconite grains (arrowed), phosphate replaced grain (p) and siliciclastic grains (quartz).

According to the studies conducted by Scheibner and Speijer [50] during the Stage-1 corals and encrusting coralline algae thrived at platform margins while inner platform was dominated by Milliolids, Rotaliids and green algae Helimeda. But in our case study the larger foraminifera more extensively florished as compared to coral reef during this time interval. The next stage of platform evolution marks transitional P/E boundary and described to be characterised by occurence of first larger foraminiferal shoals comprised of Miscellanea and Ranikothalia while coralgal reef facies apart from scarce coral debris are absent as observed in the upper most stratigraphic part of Daud Khel section. The reason is that this part of carbonate platform already dominated over reef building fauna during this time interval of platform evolution at this paleo-lattitude [50]. The final stage of carbonate plaform development shows turnover of second stage larger foraminifera dominated carbonates to Aleveolinids and Nummulitides dominated platform sediments. This last stage may be subdivided on the basis of paleobathymetric distribution into inner platform to outer platform/ slope transect with respect to faunal distribution in respective part of above mentioned platform subdivision. The last evolutinary stage in our study area is characterised by red coralline algae with large benthic formaminifera (Daud Khel section) in inner platform to platform margin while planktonic foraminifera dominated carbonates along with some reworked small forams in slope setting (Samana Range section).

From the above discussion it may be concluded that three stages of Paleocene carbonate platform evolution in Tethyan realm may be extended to the northen Pakistan with some minor variations due to local tectonics and small scale sea level variaions.

The carbonates of Lockhart Limestone show three major depositional settings as; 1) peritidal facies belt. 2) shallow subtidal facies belt and 3) deep subtidal facies belt. The peritidal facies belt that makes intertidal and supratidal depositional environment was influenced by submergence and partly emersion. The zone of supratidal environment continously affected by storm conditions and siliciclastic input as observed in Daud Khel. Stressed conditions prevailed during deposition in this particular area which may be reflected by restricted fauna i-e gastropods, Miliolids, fenestral texture, dolomite and siliciclastic grains. Under these stressed conditions like high salinity rate, high sedimentation (storms, input from continental areas) deposition took place in tidal flats or ‘ponds’. The facies assemblages characteristically of low diversity fauna i-e benthic foraminifera, or gastropod assemblages indicate restricted subtidal environments. The dominated forminiferal assemblages in this facies belt are mainly Milliolids which show unfavorable life conditions for many benthic organisms due to fluctuationg salinity and/ or decresed oxygen content. The sediments deposited under these environmental conditions are mainly comprised of completely preserved rounded and micritised grains. In open marine shallow subtidal environment the microfacies types particularly include abundant and high diversity faunal association like calcareous green algae and benthic foraminifers associated with corals, coralline algae, some gastropods and planktonic foraminifera. Such characterization reflect well oxigenated , photic and normal sea water salinity. Moreover, intraclasts and peloids additionally indicate increased hydrodynamic conditions as compared to restricted shallow water subtidal environment. Deep subtidal facies associations include restricted and open marine deep water environment. Typical microfacies of deep water environment are comprised of abundant planktonic forminifera, calcispheres or assemblages of small oppotunistics benthic foraminifers of Samana Range section of the study area. Although in few microfacies planktonic foraminifera and flora is partially associated with dolomitic matrix material, they do not indicate typically pelagic and hemi-pelagic conditions. However, the occurence of glauconitic and phosphatic grains indicate deep marine water circulation.

7. CONCLUSIONS

Following conclusions have been drawn from the research work of the two principal sections i-e Daud Khel and Samana Range in Kohat Potwar sub-basins.:

i. Paleocene Lockhart Limestone gives good outcrops for studies and is predominantly composed of nodular limestone with subordinate intercalated shale, marl and siltstone.
ii. The limestone is comprised of mainly rich benthic foraminiferal assemblages along with less commonly pelagic and planktonic foraminiferal associations.
iii. The foraminifera include: gastropods, pelecypods, lockhartia, nummulites, assilina, miscellanea, mollusks, green algae helimeda, red algae, globigerina and broken bioclats.
iv. The microfacies assemblages and environmental interpretation revealed that Lockhart Limestone deposited in three carbonate platform settings of inner platform/ lagoons, platform margin and slope setting under normal marine conditions.
v. The typical platform margin insitu coral reef could not establish within Lockhart Limestone may be due to the reasons of environmental conditions and tectonics instability and therefore reef building fauna could not establish. Although reworked coral contributed significantly during limestone deposition.
vi. The tectonic breccias and large reworked limestone clasts embedded in Lockhart Limestone show that carbonate platform evolution was greatly influenced by synsedimentary tectonics.
vii. The analytical studies of these microfacies lead towards the inference that the Lockhart Limestone was deposited in the open marine environments of shallow shelf (Inner and outer shelf).

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