Microfacies and Depositional Environmental Studies of Lockhart Formation of Chhangla Gali Area, Hazara Basin, Pakistan.

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ABSTRACT:

The Paleocene Lockhart Formation of Hazara Basin Lesser Himalayas of Pakistan was deposited in the package of shelf carbonates after the second disconformity transgression of Tethys. Three hundred thirteen (313) thin sections were prepared and stained for petrography from this section. The measured Chhangla Galli section is about 60 m thick of Lockhart Formation in Hazara Basin. Nine microfacies Mudstones, Rotaliidae Wackstones / Packstones, Miscelaneidae Wackstones / Packstones, Bioclastic Wackstone / Packstone, and Algal Wackstones / Packstones have been established and geochemically analyzed. The study shows that this formation deposited in shallow marine subtidal to the tidal marine environment of deposition environment of a carbonate platform (inner to mid ramp). The study includes biostratigraphy and micropaleontology of Paleocene carbonates of the Chhangla Gali section. Twenty-three (23) representative samples selected for major and trace elements (Ca, Mg, Sr, Mn, Fe and Na) analysis of the carbonates are reflected diagenetic and depositional environment. Ten (10) samples analyzed for stable isotopes variation in Carbon and Oxygen of the carbonate shows the water temperature.

Keywords: Lockhart Formation; Microfacies; Hazara Basin; Diagenesis; Depositional Environment

INTRODUCTION:

This paper interprets microfacies' depositional environment, lateral and vertical variation, and depositional modal. Paleocene-Eocene shelf carbonates have been found in Azad Kashmir, Hazara, Salt Range, and Kohat. Former stratigraphers found that Paleocene Lockhart limestone in Hazara

Hazara trough changed into a shallow marine environment. Other areas have similar depositional environments and diagenetic histories (Akhtar and But, 1999; But, Sonnenfeld and Cross, 1993).

Paleocene carbonates (Lockhart formation) of the studied area are dominated by rotalidae, miscellaneidae, algae, bioclasts, and other benthic foraminifera. Low-energy environments deposit fine-grained sediments. Lockhart Formation samples were scattered. The Lockhart Formation in this part of Field has four carbonate ramp systems. Subtidal, intertidal, restricted intertidal, and supratidal environments form a regressive sequence. According to organisms and sedimentary processes, the paleoecology of Paleocene carbonates is discussed. Hangu formation, composed of sandstones, siltstones, and carbonaceous shales, represents transgressive marine cycle in Hazara Basin and other areas. Hazara and Kashmir's deposition scatters benthic foraminifera, marine environment indicators. Paleoecology, paleoenvironment, and sedimentary structures in Paleocene carbonates were used to determine the benthic foraminifers' depositional environment (Malik, 2014; Luterbackher, 1970; Abramovich et al., 2002; Hottinger et al., 1962, 1974, 1993, 1997, 1999, 2000; Kerans, 1995; Scuta, 1997; Adams, 1970 and 1989; Hallock, 1983, 1984; Hallock and Glen, 1986; Kerans and Fitchen, 1995; Harney et al., 1999 and Kirsch, 2006). Specific genera and foraminiferal assemblages identify paleoenvironments from lagoon to deep sea (Reiss and Hottinger, 1984). Modern benthic foraminifera distributions help identify paleoceanographic variations in intermediate and deep water movement.

Microfacies

The microfacies of the Lockhart Formation have been carried out according to modern and recent works such as Flugel (2004), Dunham (1962) and Folk (1962). In addition, based on benthic foraminifera microfacies have been documented. The following microfacies are established and interpreted.

1- Rotalidae Wakestone / Packstone

a. Rotaliidae Bioclastic Wakestone / Packstone
b. Rotaliidae Miscelinidea Wakestone / Packstone

2- Bioclastic Mudstone /Wakestone / Packstone

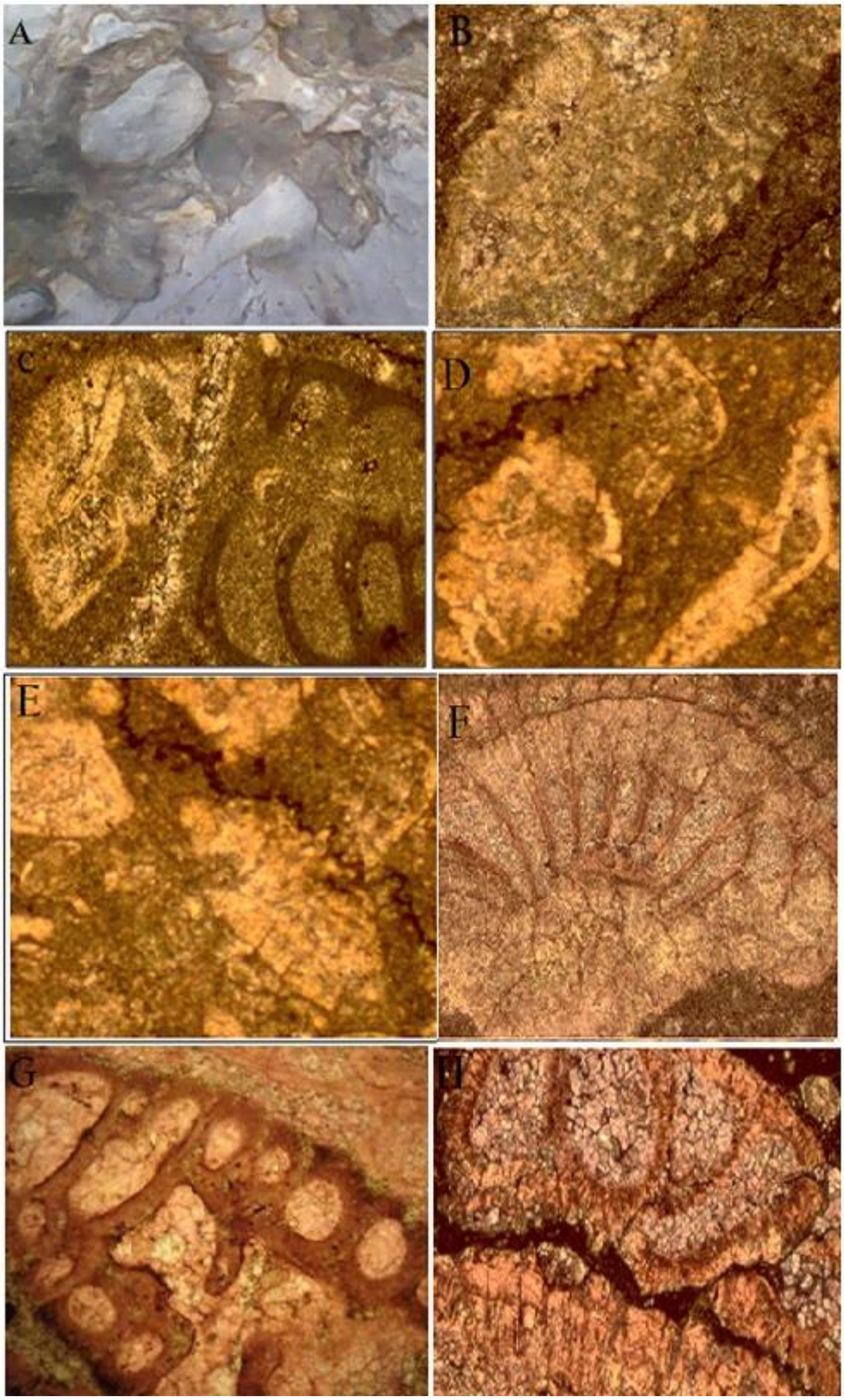
a. Bioclastic Miscelinidea Wakestone / Packstone

3- Algal Wackestones /Packstone

a. Algal Bioclastic Wakestone / Packstone
b. Algal Rotaliidae Wakestone / Packstone

4- Miscelinidea Mudstone Wackestones / Packstone

a. Miscelinidea Bioclastic Wakestone / Packstone



Wackstones (Rotaliidae)

Rotaliidae wackstones/packstones dominate the Lockhart Formation. Less than half of all six sections have Rtaliidae wackstones/packstones. 35% 76 in Khiara Galli, 55% in Chhagngla Galli, 26% in Gammanwan section, 60% in Jabbri section, 25% in Muzaffarabad, Neelum valley Azad

Kashmir, 72% in Fouji cement section. Modern Rotalids are found in brackish and open marine environments (Nombel et al. 1995, Col et al. 1995). Rotaliids form between 20 and 45m deep (Reiss and Hottinger, 1984). Lockhartia deposited in 25 to 26m in lower intertidal deposition of lagoon environment in shoal/barrier (inner ramp) bar while rotaliids deposited in 20 to 45m, 40 to 48m in red sea, 5 to 25m (Hottinger, 1980) intertidal to shoal or barrier bar environment up to 5m depth (Luterbackher, 1970). Abbott (1997) reported Rotalia wenganuiensis and Notorotalia zeolandica in 2.5 to 26m of Eastern New Zealand shelf. Hottinger (1980) found Rotalia in the Red Sea, Persian Gulf, and South China Sea at depths of 40 to 80m. Rotalia, Lockhartia, and Sakesria dominate this microfacies. Few Lockhartia, Rotalia, and Sakesria works are insufficient to draw the environment. Lockhartia and Rotalia deposit in the lagoon's deeper side. Most samples contain unidentified benthics, including Rotaliidae. Lockhartia and Sakesria are related, per Hynes (1981). Hattinger (1980) reported 5 to 25m depths for the Miocene Rotaliid bearing delta front platform, its slopes, and the depth difference between the Miocene and Recent. Luterbacher (1970) found Rotalia in muddy beach bay deposits, protected platforms (up to 5m) and open shelf deposits (up to 35m) in Spain's Paleocene Ager formations. Rotaliidae wackstones and packstones have many skeletal grains. High-energy reef material with Rotaliids has low diversity, according to Cole et al. (1995). Micrite dominates low-energy conditions. More than 48% of this microfacies is composed of Sakesaria, Lockhartia, and Rotaliids, with subordinate Miscellanea Miscella, Discocyclina, Millliolids, Algae, and planktons, and very little Pseudophragmina, Ranikothalia, and Eocenica Eonolaria. Bioclastic wackstones and packstones are formed from these samples. Rotaliidae are found with Operculina, gastropods, Assilinids, Textularia, Ostracod parts, Echinoids spines, and Plecypode fragments in the remaining samples. Samples contained few plankton. In some cases, planktons were absent and sparsely distributed in lagoon fauna. Based on microfacies data, most samples are deposited in outer lagoon to bars/shoals while this microfacies is intertidal to barrier shoal (inner ramp). Rtaliidae wackstones/packstones are deposited in lagoons, channels, and subtidal environments (inner ramp). It has two submicrofacies.

Bioclastic Wackstones (Rotaliidae):

Lockhartia, Rotalia, and Sakesaria are deposited in equal or greater amounts than bioclasts in Rotaliidae Bioclastic Wackstone / Packstones submicrofacies. Rotaliidae are found in muddy beach-bay deposits with Miscellanca Miscella, Milliolids, Discocyclina, Asslilina, Operaculina, Textularia, and Globigerina. Discocyclina, Assilina, Planktons, Milliolids and smaller benthic foraminifer with traces of Operculina, Gastropods, Textularia, Ostracod parts, Echinoids spines and Plecypode fragments were deposited in open shelf (20 to 35m). Several samples contained planktons. Rotalia and Operculina have shallow foreslopes (Saliawan, 1983). Rotalidae and

Milliolids in Kirkak Oil Field carbonates of Iraq as shelf edge, bank margin, lagoonal, and mudflat deposits (Majid & Veiger, 1986). Millliolids (Miliolina and Quinqueloculina) in this microfacies is normal salinity lagoon and reef environment (Hallock & Glemn, 1986). LI & Jones (1997) found Quinquloculina in the Grand Canyon's inner and outer lagoons. Milliolids are hypersaline bottom-dwellers (Hottinger, 1974). Milioline carbonate rocks have been deposited in beach, tidal flat, lagoon, or reef environments, according to several documents.

Wackstones (Miscelaneidae):

2% of two sections have Rotaliidae Miscellaneidae wackstones/packstones. Lockhartia and Miscellanea in samples indicate a warm shallow environment of deposition, and Milliolids with Rotalia indicate clear water (Hynes, 1981). Rotaliidae is associated with Miscellanca Miscella with very little Discocyclina, Asslilina, Operaculina, Milliolids, Textularia, planktons, and other smaller benthics in muddy beach-bay deposits or open shelf (depth 20 to 35m). Rotaliidae is deposited equal to or more than Miscelaneidae in this submicrofacies and has subordinate algae with same amount of Discocyclina, Ostracodes, Milliolids, Gastropods, Pseudohatigerina, Pseudophragmina, planktons, etc. This submicrofacies ranged from inner intertidal ramps to outer lagoon to barrier/shoals.

Mudstone/Wackstone/Packstones:

This work describes Hazara Basin microfacies. This bioclastic microfacies is characterised by the predominance of bioclasts and the low amount of micrite in the studied sections. 32% of six sections contain benthic foraminifers and other fauna in bioclastic mudstone/wackstones/packstones. Bioclastic mudstones make up 7% of six sections: 4% in Khiara Galli, 9% in Chhagngla Galli, 8% in Gammanwan, 2% in Jabbri, 10% in Muzaffarabad Neelum valley, and 6% in Fouji Cement Factory. The Hangue formation's splintery surface grades into thinly bedded limestone. Some sections have pyrite nodules. Broken, abraded, and neomorphosed fossil fragments show mid-ramp settings or calm water. Tucker & Wright (1990) say that mudstones are the precursors of micrite ads. Wilson (1982) and Flugel (1982) interpreted micritic/mud deposition in hypersaline tidal ponds. Most bioclastic mudstones are based on skeletal grains deposited in shallower water. The ferroan-to-non-ferroan neomorphic spot grades. They have mudstone-like groundmass. Spine fossils are longitudinal or transverse. Few calcite veins contain ferroan sparite. This formation was deposited after Hangue Formation's transgression. Intertidal shallow marine environments have vertical to inclined burrows. Bioclastic mudstone samples were compared to shallow water microfacies to determine that they formed in the inner lagoon in less than 5m of water. Open-marine Bioclastic mudstones contain few planktonic foraminifers.

Millliolids (Quinqueloculines, Miliolines) are found in inner lagoon or landward outer lagoon bioclastic mudstone samples (Li & Jones, 1997). Lockhartia, Rotalia, Miscellanea Miscella, Ostracodes, Discocyclina, Enularia Eocenica, and planktons are found in bioclastic mudstones. These were likely deposited at low water level in shallower depth than other microfacies in the lagoon offshore. Bioclastic mudstones indicate sea level rise/fall.

Bioclastic wackstones/packstones are present in 32% of Chhangla Galli samples, 39% of Ghumanwan samples, 18% of Jabri samples, 23% of Fauji cement samples, 55% of Neelum valley Azad Kashmir Muzaffarabad samples, 39% of Khaira gali samples, and 32% overall in the six sections. Warmick & Shakoor (1988) suggested the Paleocene carbontes' submarine high environment. Foraminiferas and other microfossils identified in sections (Flugel 2004, Tucker & wright, 1990). This formation consists of fine to medium-grained, nodular, and light to dark grey foraminiferal limestone and bituminous carbonates. Larger benthic foraminifera in Lockhart Limestone at Shah Alla Ditta were deposited in shallow to deep water of inner to middle shelf environment (Khattak, 2017). Malik and Ahmed (2014) found two Paleocene carbonate sections in Northern Pakistan's Kohat-Potwar Sub-Basin in shallow shelf open water (inner and outer shelf). Lockhart Formation's larger benthic foraminifera indicate shallow shelf deposition. Waves drive planktons. Ranikothalia and Operculina deposited 10 to 40m deep (Hottinger, 1983). High-energy spar-bounded packstones form in the upper foreshore, according to Luterbackher (1970) and James (1984). Textularia indicates shallow water (Cushman, 1954). Assilina lives in shallow marine environments, per Lehmann (1970). Discocyclina, Milliolids, Textularia, Pseudohatigerina, Ostracodes, and algae dominate these microfacies. Paleoecology of major skeletal grains, including parts of the reef environment due to Milliolids and other formas. Millliolids are the only hypersaline bottom-dwellers (Hottinger, 1974). Normal saline modern reefs may deposit abundant to common Millliolids in restricted platform areas from 12 to 20m depth showing shoal- reef depositional environment. Milliolids with Dacycladaccans show restricted bank interior deposition. It's possible that the material was transported closer to wave turbulence or currents. These microfacies are less than 5m deep compared to others. Discocyclina and Enularia Eocenica are found in the foreslope at 5-12m and lens-shaped at 12-30m (Luterbacher, 1970). Plankton means open water. Textularia deposited in fore-bank platform, per Luterbacher (1970). They're shallow, high-energy environments (Hallock &Glemn, 1986). Discocyclina is a restricted fore-reef deposit (Henson, 1950). Flat discoidal disccyclina have deposited in the foreslope at 5-12m and lens-shaped disccyclina at 12-30m (Luterbacher, 1970). Discocyclina in Tertiary carbonates of Iraq's foreslope and shelf edge bank margin (Majid & Weizer, 1986). Oriented grains indicate deposition environment. Other submicrofacies bioclasts are from fore-bank to slope or subtidal environments, but Ostracodes is lagoonal. In Chhangla Galli samples, Discocyclina and Opercolina with Assilinids are 5 to 12m deep, while in Jabri and Gammanwan it may be 20m.

Miscelaneidae Wackstones and Packstones:

Submicrofacies Two Lockhart Formation sections contain Miscellaneidae wackstone. Bioclasts are evenly distributed with Miscellaneidae in 2% of the studied area representing shallow to deep inner to middle shelf water. This submicrofacies contains nodular, light to dark grey foraminiferal carbonates. Lockhart Limestone at Shah Alla Ditta is in shallow to deep, inner to middle shelf water (Khattak, 2017). Paleocene carbonates from Northern Pakistan's Kohat-Potwar Sub-Basin were deposited in shallow shelf open water, according to Malik and Ahmed (2014). (Inner and outer shelf). Thin sections showed planktons.

Packstone Algal:

Algal wackstone/packstone is Lockhart Formation's third most abundant microfacies. It's the first time algal wackstones/packstones have been found in 13% of samples (green and red algae). Lteria, Neomaris, Dacycladaceans, etc. contain green algae. Recent green algae are limited to shallow warm and tropical water, according to Johnsan 1981 and Wilson, 1975, and Dodd and Stanton, 1981. Algae live in 20 to 50% to 60% saline water on mud (Macket, 1972) and sand bottoms (Flugel, 1982, Wray, 1978). (Wilson, 1975). Calcareous algae have been found from blow to low tides to 100m depths (Dodd and Stanton, 1981), but are most abundant from 3 to 5m depth. 13% of study samples have this microfacies. Due to low representation, Jabri's algae facies cannot establish. In Khaira Galli, 5%, 2% in Chhangla Galli, 32% in Ghumanwan, 8% in Fauji Cement, and 5% in Muzaffarabad are related. Johnsan (1961) says algae can live in 10m to 12m of water, Wilson (1975) says 12m to 15m, and Flugel (1982) says 20m to 30m in subtidal shallow water. Green algae and Dacycladacean are abundant in shallow, protected lagoonal environments, according to Wray, 1978 and Egenhoff et al., (1999). Green algae microfacies are abundant in tropical to near-tropical warm shallow water less than 10m deep. Ovulates and Furcoporella have the same ecology in Caribbean and Pacific reefs and lagoons, especially Florida's 8m inner shelf and Bahama's 15m back-reef lagoon (Tucker & Whright, 1990). Enos (1983) found Chypina in a bay and lagoon. Bold and Wynne, 1978, discuss Paleocene cymopolia from the Gulf of Maxico and Caribbean. Hiddle, 1979 documented C.barbata sp. in NW Puert River. Neomeris and Acieularia are shallow water representatives, per Fritch, 1971; Pol and Chatterji, 1978. Based on allochens and bioturbation, this microfacies is thought to be lagoonal. Broken, unbroken rare to common. Most Milliolidae samples indicate shallow water or a landward lagoon area. Vertical and horizontal mottling in some samples indicates subtidal deposition. Other papers suggest this microfacies is deposited in subtidal, lagoonal, and shallow water. Coralline algae are found in tropical, temperate, and polar regions in intertidal to 200m depths. These are in lagoons, bays, reefs, offshore banks, and open shelves (Adey & Madntyre, 1973; Bosellinit Ginsburg, 1971). Adey and Macintyre suggest coralline algae (corals) are primarily tropical to subtropical (1973). Red algae and foraminifera are dominant. Halimeda (Halimedaceae) fragments. Corallines have warty, encrusting, fructose growth. Thin crusts form these morphologies (up to 1 mm thick).

Bioclastic Wackstone:

Submicrofacility 8% of Lockhart Formation samples contain algal bioclastic Wakestone/Packstone. Other sections have minimal algae. Submicrofacies algae contain discocyclina, Miscellaneidae, Miliolids, and Nummulitidae. Sarkar (2017) found algal wackstone packstone microfacies in Paleocene-Eocene carbonates in Meghalaya, India. The palaeoecological middle-ramp gradient is characterised by an increase in algae dominance, thinning coralline plants, and flattening foraminiferal shells. The paleoenvironments of larger foraminifera and coralline algae in Prang limestones vary from shallow in high energy shoal to moderate energy inner ramp to mid ramp (Jauhri, 2016). Green algae and coralline algae are found in Paleocene limestone with benthic foraminifera.

Wackstone Rotaliids:

Submicrofacility 3% of Lockhart Formation samples contain algal Rotalidae wakestone/packstone. Miscelaneidae and Rotaliidae are abrasion-resistant and globular in this submicrofacies. Globular forams represent shallow water, while flatter forams represent deep water (Hollinger and Dreher. 1977). Thanatian Lakodong Formation has a transgression below. These foraminiferal-algal (rotaliid) are found on a shallow subtidal ramp and deposited at 20-40m depth in a lagoon (Jauhri et al., 2006). Green algae and Dacycladacean are abundant in shallow, protected lagoonal environments, while Lockhartia and Rotalia are found in deeper lagoons. Green algae microfacies are abundant in tropical to near-tropical warm shallow water less than 10m deep.

Wackstones and packstones (Miscelaneidae)

More than 5% of all five sections are Miscelaneidae wackstones and packstones. Miscelaneidae wackstones and packstones are found in Khaira Galli, Chhangla Galli, Ghumanwan, Jabri, and Muzaffarabad. Figure shows micrite-filled samples Flatter Miscelaneidae lived deeper than spheroid forms (Hottinger & Dreher, 1977). Miscelaneidae can be replaced by Assilina. Hottinger (1974) calls their fore-bank distribution reef facies-shoals. Miscellanea miscella in SBZ4 to SBZ5 in shallow water (50 to 80m and 30 to 130m) suggests a wider range of environments. Serra-Kiel et al (2009). Broken parts create a low-energy depositional environment. Miscellaneids are the deepest skeletal grains observed (Hottinger 1983). Miscellaneidae wackstones and packstones represent deeper Paleocene benthic foraminifers' deposition. Miscellanea ornamentation and thick walls represent SBZ4 to SBZ5 in shallow benthic zones. Kuss and Kippig (1989) reported that Miscelanea Miscella is restricted to SBZ4, but Http://inger (2009) said this is too small and not applicable until further study. Miscelanea, Ranikothaia, and Algae with rare discocyclina represent fore-reef and back-reef environments. Miscellaneous means shallow water (Hootinger, 1983; Ghose. 1976; Reis and Hottinger, 1984). Imraz (2013) found two Paleocene Miscellaneina species in shallow benthic zones of the Indus basin (SBZ3). Miscellanea and Ranikothalia with subordinate algae were deposited in shallow benthic zones, according to Ali et al. (2013). Paleocene Miscellanea sp. and Ranikothalia sp. dominate shallow benthic zones of inner ramp facies of Lockhart Formation in salt range (Ahmad, 2013). Pelagic carbonates deposited on the open seaside contain rotalines and abundant plankton, but in the Lockhart formation, they are rare or absent. During a wavy storm, some samples show graded bedding (bioturbation). These wackstones and packstones with micrite and sparite matrix contain abraded formainiferas. At low wave or current, micrite settled. Miscelaneidae wackstones are deposited in back shoal environments or subtidal fore-bank to bank shallow marine environments, while Miscelaneidae packstones are deposited in fore-back shoal back to bank or subtidal reef flat environments. Discocyclina is found in the open ocean. Without changing fabrics, some samples show compaction (stylolitization). High energy reef (bank) materials with Rotaliids have low diversity compared to low energy back-reef/lagoons with subordinate Milliolids. This study found low bank fauna diversity. Warvick & Shakoor (1988) say photic zone topographic highs are important. Khaira Galli, Chhangla Galli, Fouji Cement, and Muzaffarabad have bioclastic wackstone and packstone dominantly Discocyclina. Discocyclina is found in shallow open marine environments between 5-12 and 12-30m. Miscella, Opercolina, and Milliolidae are found in half of the brackage abrasion microfacies (milioline and quinqueloculina). Miscelaneidae wackstones and packstones live in fore-back bank-to-bank inner ramp facies.

Miscelaneidae Wackstones and Packstones:

Submicrofacies 4% of two sections contain Miscellanea miscella with subordinate Opercalina, Assilina, Ranikotalia, Lockhartia, Rotalia, Milliolidae and Discocyclina. Pseudophragmina, Pseudohatigerina, and Ostracodes are rare. Miscellanea miscella and Opercalina show abrasion, poor sorting, and broken under thin-section. During storms, forebank grains may be transported over the bank towards the lagoon. Miscellanea miscella, Operculina, Ranikotalia, and traces of Lockhartia and Rotalia sediment in 25% of subtidal samples. Some fauna are found across the bedding. Hazara, Azad Kashmir, and Sulaman Range have Paleocene Miscelanea and Operculina without Nummulites (Akhtar and But, 2000). Miscella with Opercolina and Milliolidae (milioline and quinqueloculina) occur in half of this microfacies. Miscelaneidae bioclastic wackstones and packstones are deposited in subtidal ramp facies. Miscellanea Miscella's dense ornamentation and thick walls are associated with Discocuclina and Ranikothalia. Top of Lockhart Formation in upper Indus basin Imraz indicates hydrocarbon bearing (2013). Operculina is subordinate to this microfacies from 50 to 80m depth (Luterbacher, 1970). According to Hallock (1984), Operculina-ammonoids occur at 20-30m. Operculina inhabits Louisiana's Ansela Butte reef sublittoral zones (Squires & Sachs, 1957). Lockhart Limestone has a shallow to open marine, inner to middle shelf depositional environment (Khattak, 2017 and Malik and Ahmed, 2014). Paleocene carbonates of the Indus basin were deposited in SBZ4 and 5. (2013).

Bioclasts in microfacies and submicrofacies indicate that the studied sections were deposited in a shallow marine shoal to lagoon (subtidal) environment. With changing sea level, different fauna depths range from 5 to 50m. So it's 50m deep.

Variation vertical

In the studied microfacies, six sections are vertically distributed and interpreted 60% of samples are subtidal. In this study, foraminiferas (i-g lagoon shallow deposition) were found in the upper section. Lockhart Formation microfacies vertical distribution and interpreted environment are discussed below. Some samples are intertidal to subtidal. These subtidal environments are lagoon (inner, mid, and outer), shoal, back shoal, fore shoal to shoal, channels, open marine, and offshore. Inner, mid, and outer lagoons have 48.2% Rotalidae and 12% Algal microfacies. Algal microfacies are mostly green algae with some red corals. 14% of Miscelanidae microfacies are back shoal to shoal and environment with channel and storm deposit. Fore shoal to shoal, channel, and storm deposit environments represent 16% of Bioclastic microfacies. Subtidal deposits in the studied sections lack cyclicity. Read (1990) says this environment has shallowing upward cyclicity trends. Enos (1983) noted cyclicity or sequences in restricted environments. Random facies transitions characterise this subtidal lagoonal environment. In vertical or leteral facies pattern. Transgression and progradation patterns are complex. Subtidal deposits show no visible cyclicity, according to Steinhauff and Walker (1995). (Saller, 1996). Applying experience and special measures reveals subtidal depth changes. Scinclair et al. (1998) noted shallowing and deepening trends in French Alps foraminifers' assemblages.

In the studied sections, the depositional environment has shallowed upward in two ways using ecological data. Lockhart's sedimentation bottom Location and deformation after deposition cause formation variations. Lockhart Formation deposition began with Rotalidae wackstones/packstones or Miscelanidae wackstones/packstones and sometimes Bioclastic mudstone/wackstones/packstones and Algae wackstones/packstones. Vertical deposition varies as follows.

1. Rotalidae wackstones/packstones overlain by Bioclastic mudstone shows mid-lagoon to deep open marine environment. Rotalidae wackstones deposited in shallow water may become buried by rising sea levels. Mudstone deposited in LK, LC, LJ, LG, LM, and LF sections LC section bioclastic mudstones overlain by Rotalidae wackstones/packstones.

2. In sections LK, LC, LG, LJ, LM and LF Rotalidae wackstones/packstones are deposited before Bioclastic mudstones and sometimes before Algal wackstones/packstones. In LC and LG sections, bioclastic mudstones followed Rotalidae wackstones/packstones. These are the most common environments in the above sections.

3. Rotalidae wackstones/packstones overlain by Algal microfacies and submicrofacies (lagoon) Green algae represent deposition from (inner to outer) lagoon environment in LK, LC, LG, LF and LM sections. Rotalidae wackstones and packstones are deposited in deeper water than Algal wackstones and packstones. Inner to outer lagoon algal wackstones/packstones are overlain by Rotalidae wackstones/packstones in LK, LC, LG, LF, and LM sections. LF, LM, and LK had green algae. LC, LK, LG, and LM sections had red algae. Red algae make these beds outer lagoon. Rotalidae wackstones/packstones overlain by Miscelanidae wackstones/packstones (inner to outer lagoon) in LK, LC, LG, LJ, LM and LF sections

4. Bioclastic mudstones (deep open marine) overlain by packstones (fore shoal) in LC, LF, and LM sections LC, LG, LF, and LM sections have bioclastic wackstones/packstones (fore shoal) overlain by bioclastic mudstones (open marine) Bioclastic mudstones contain broken Operculina and Rotalia, Discocyclina, Pseudohatigerina, Pseudophragmina. Bioclastic wackstones/packstones (fore shoal) contain Discocyclina, Textularia, Miscellanea Miscella, Sakesaria, Lockhartia, Rotalia, Pseudohatigerina, Pseudophragmina, Operculina, Broyozoans, Bivalve, algae, and planktons. Algal wackstones (green algae) and Bioclastic mudstones containing mililids are lagoon environment, while red algae wackstones and Bioclastic mudstones are open marine environment.

5. In LK, LG, and LM sections, bioclastic mudstones were deposited before wackstones/packstones. In Khaira Galli sections, bioclastic mudstones followed bioclastic wackstones/packstones.

6. Bioclastic mudstones wackstones / packstones (fore shoal) are overlain by Miscelanidae wackstones / packstones (back shoal) in sections LK, LC, LG, LJ, and LM. In sections LG, LM, and LF, Bioclastic wackstones / packstones. Milliolids make Bioclastic wackstones/packstones shallower than Miscelanidae wackstones/packstones.

7. Bioclastic wackstones (fore shoal) are overlain by Rotalidae wackstones (inner to mid lagoon) in LK, LC, LG, LJ, LM, and LF sections. Microfacies and submicrofacies of Rotalidae wackstones/packstones (inner to mid lagoon) overlain by Bioclastic wackstones/packstones (fore

shoal) have been documented in LC, LG, LK, LJ, LM and LF sections. In LC, LG, LF, and LK sections, bioclastic wackstones/packstones (fore-shoal) are overlain by algal wackstones/packstones (inner to outer lagoon). LK, LC, LG, and LF sections have Algal wackstones/packstones (inner to outer lagoon) overlain by Bioclastic wackstones/packstones (open marine/fore shoal).

8. Miscelanidae wackstones/packstones (normal marine shoal) are overlain by Rotalidae wackstones/packstones (slightly deeper part of lagoon), which are overlain by Bioclastic wackstones/packstones (deep open marine/lagoon) in parts of Lockhart Formation LK, LC, LG, L J and LF. Miscelanidae wackstones/packstones (shoal to open marine/ fore-shoal) are repeatedly overlain by Biolistic wackstones/packstones (deeper subtidal (fore-shoal) environment). Lockhart Formation LG, LJ, and LF show these changes.

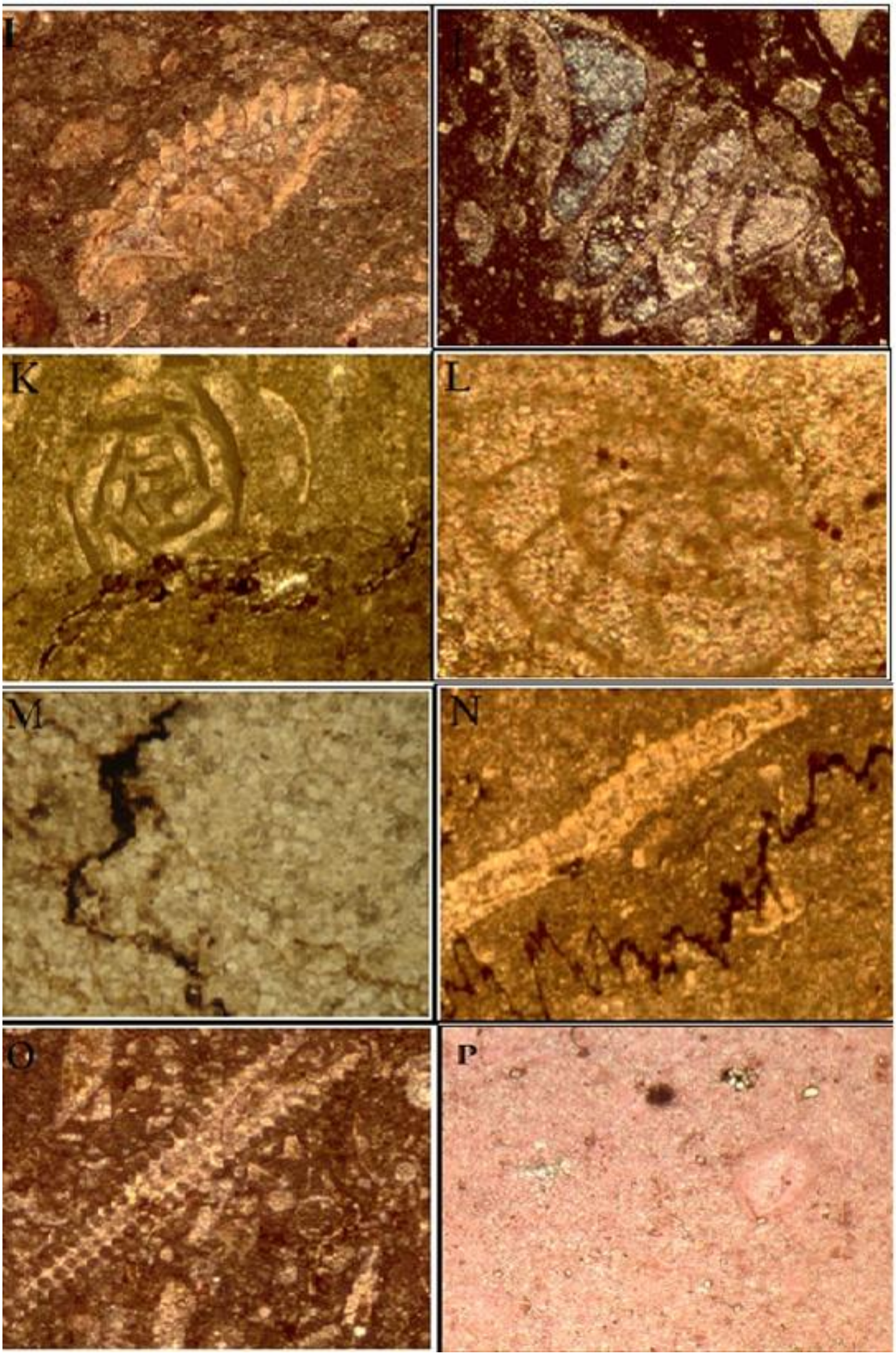
9. The last but normally found some sections as LG and LF Miscelanidae wackstones / packstones were deposited before Bioclastic mudstones wackstones / packstones and some times before Algal wackstones / packstones in LF and LG sections. Bioclastic mudstones / wackstones / packstones deposited before the Miscelanidae wackstones / packstones in LK, LC, LJ, LG and LM sections Algal wackstones / packstones microfacies in LK, LC, LG and LF sections. Bioclastic mudstones were deposited after the Miscelanidae wackstones / packstones microfacies in LG section. Bioclastic mudstones were deposited before the Rotalidae wackstones / packstones microfacies in LC sections. In LC and LG sections, bioclastic mudstones followed Rotalidae wackstones/packstones. Bioclastic mudstones were deposited before the Bioclastic wackstones / packstones microfacies in LC, LF and LM sections. After Bioclastic wackstones/packstones microfacies in Khaira Galli LC, LG, and LM sections, bioclastic mudstones were deposited.

10. Miscelanidae wackstones/packstones are overlain by Algal wackstones/packstones microfacies and submicrofacies (green Algal) that are covered by Bioclastic wackstones/packstones (deeper part of lagoon). LC, LG, and LF sections have Algal wackstones/packstones (outer lagoon) before Miscelanidae wackstones/packstones (back shoal). Algal wackstones/packstones (open marine shoal) microfacies and submicrofacies are overlain by Miscelanidae wackstones/packstones in LC, LG, and LF sections. It is observed that Bioclastic wackstones / packstones microfacies and submicrofacies (open marine shoal) are overlained by the Miscelanidae wackstones / packstones microfacies and submicrofacies in the part of LK, LC, LJ and LG sections. Miscelanidae wackstones / packstones are depsited under Bioclastic Mudstone/ wackstones / packstones shows back shoal to outer lagoon/ deep open marine environment in LK, LC, LG, LF and LM sections. Bioclastic Mudstone (deep open marine) overlain by Miscelanidae wackstones / packstones (back shoal) fallowed upward by Algal or Bioclastic wackstones / packstones in the sequence of LG section only. Deeper than Rotalidae and Algal wackstones/packstones.

Discocyclina, Brayozoan, and Operculina decrease in Lockhart Formation. Early deposition deepens due to Discocyclina, Lepidocyclina, and Eunularia Eocenica. All studied sections note this. In LK section Miscelanidae packstones are overlaid by Bioclastic wackstones/packstones, followed by Miscelanidae wackstones/packstones and Algal wackstones/packstones at the top of bed bearing dacycladacean algae. Miscelanidae packstones appear within 15ft at top Rotalidae wackstones is laying. Hangue formation underlies bioclastic Mudstone layer. Miscelanidae packstones with Bioclastic wackstone shows shoal (open marine) environment followed by Algal and Rotalidae packstones. All sections studied had shallowing biotic changes. At the top of LF section, Rotalidae wackstones/packstones bed found. LG and LM found bioclastic Mudstone and wackstones/packstones with Miliolids and Lockhartia at the bed's top.

Second, biotic changes cause some microfacies in a thick bed to shallow vertically. Miscelanidae wackstones/packstones, Rotalidae wackstones/packstones, and Algal wackstones/packstones overlapped in LK, LC, LJ, LG, LF, and LM sections. Thin sections repeat. Rotalidae wackstones/packstones are found in LK, LG, and LC sections. In LK, LC, and LG sections, bioclastic wackstones/packstones are overlain by bioclastic mudstones. Algae are subordinate bioclasts in some sections, with Algal wackstones/packstones microfacies and submicrofacies.

Green and red algae with few corals make up algal microfacies. This upward shallowing is seen in lagoons (subtidal). A bed shows the different microfacies and different environment of deposition because of the presence of bioclasts (equal measure of different species) represents deep marine fauna such as discocyclina, miscellanea miscella, brayozoa, textularia, etc. The bottom of these beds is bioclastic, indicating a shoal, subtidal environment. Microfacies repetition and water depth fluctuation (environmental change) indicate a cyclic model possibly related to transgressive/regressive phases. Green algae or Milliolid bioclastic wackstones and packstones represent restricted conditions at the top of cycles. These cycles with green algae or Milliolid on microfacies have no subaerial features (Gomez-Perez et al., 1998). In such cases, the cycles lead in the inner ramp, they say. Based on the above, several incomplete and complete regressive depositional cycles can be predicted. They're thought to be caused by rapid transgresses fallow during slow offlap. The Lockhart Formation contains a range of inferred environments based on stratigraphic relationships and vertical variation, as well as an idealized composite sequence of microfacies and environmental variation. The Hangue Formation is a deeper water deposit, and the Patala Formation contains shale with Lockhart microfossils.



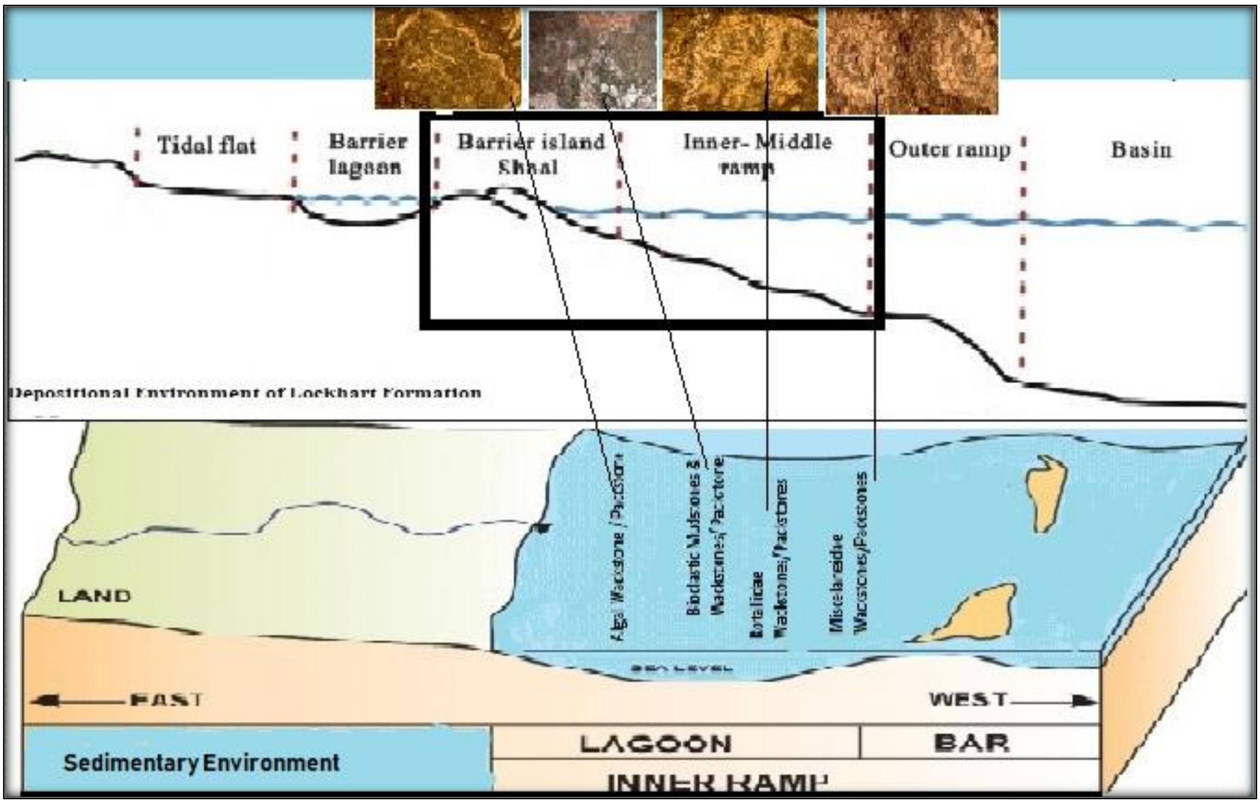
Depositional Model

A view of distributed micfrofacies and interpretation of environment in the studied sections are established and that Lockhart Formation within the studied areas is mostly shallow plateform carbonates. A simple modal represents the environment of deposition of Lockhart Formation in a period of time within. The microfacies are part of the ramp and referred to inner ramp (Burchette and Wright, 1992). There is not peritidal side deposition and mid and outer ramp are not exposed in shallowest sides. It is concluded that the Paleocene carbonates were deposited above or below fair weather wave base. A homoclinal type (Read, 1982, 1985, 1998) ramp towards the north-east is seen. Based on the north-east of the study area in the Hazara Kashmir syntax and nortern Kohat Potohar platue the Lockhart Formation is indicated by shallow water carbonates. According to several outhers the presence of rich skeletal grains such as Rotaliidae, Miscelaneidae with algae, Ranikothalia, bioclasts and some plankton indicative that this formation is suggesting shallowing in ramp. It is noted that homoclinal ramp are caused of underthrusted continental crust in foreland basin (Read, 1985). It is already that the study area is scattered from Muzaffarabd Azad Kashmir to Hazara and Salt Range area and surrounded by Main Boundary Thrust (MBT), Main Punjal Thrust (MPT), Main Central Thrust (MCT) and Salt Range Thrust (SRT) within the Lesser Himalayan zone. These ramps are expanded due to deformation in the fold thrust belt. Accrding to geochemical data and Memoir 12 (Shah, 1977), the carbonates are humid in a subtropical settings. While bank and shoals are occurred around pre-existing highs that the submarine highs were be present at the time of formation of Lockhart Formation in the LK, LC, LM and LF areas. From these sections it may say that the results at that time the under lying Hangue (Paleocene) and Kawagarh (Ctretaceous) Formations. It is noted that some Nummulitidae fauna with discocyclina and bioclasts are present in some section but highs are found. The larger foraminifera are deposited in subtidal to intertidal, lagoonal environment are so highs as compare to to previous deposited carbonates. Over all Rotaliidae family is More than 48% in palecne carbonates are deposited in subtidal to intertidal (lagoonal) environment and these are the important suppliers of carbonate factory. Wackstones are more widely scattered than mudstones and packstones in all sections mud supported wackstone and packstones are scattered in two sections LK and LC. Diagenetic activities and abrasions are affected very rarely though styloltes and neomorphism have traced in sections. The presense of milliolids and some bioclasts are lagoonal and restricted environment. The microfacies are Rotaliidae Wakestone / Packstone and submicrofacies Rotaliidae Bioclastic Wakestone / Packstone and Rotaliidae Miscelaneidae Wakestone / Packstone are the dominant abundant in all the sections proves that the environment of Paleocene carbonates ranges subtidal to intertidal (inner ramp). The absence of intraclasts is indicating inner ramp deposition. The second abundant microfacies are Bioclastic Mudstones Wakestone / Packstone and submicrofacies Bioclastic Miscelaneidae Wakestone / Packstone which indicate Fore-shoal to Shoal, barrier/ back barrier (inner to outer ramp) environments in the studied sections. The third microfacies is Algal Wackestones /Packstone with submicrofacies Algal Bioclastic Wakestone / Packstone and Algal Rotaliidae Wakestone / Packstone shows shoal (Lagoonal) inner ramp) environment of deposition. Foraminifera and the green algae constituents are identified in this formation represent lagoonal environment. The fourth microfacies Miscelaneidae Wackestones / Packstone and submicrofacies Miscelaneidae Bioclastic Wakestone / Packstone are found in two sections. These microfacies are indicated Subtidal (inner ramp) environmental deposition. Several litratures are considered as important factors about sedimentation, energy and other aspects of ramp (Wrey, 1978; Hallock, 1985; Hallock and Glenn, 1986; Harney et al., 1999, Fujita and Hallock, 1999; Tucker, 1990). Tucker (1990) has noted that no micritization by algae in windward confined areas. The presense of skeletal grains (foraminifera) in Lockhart Formation of the study area a fully ramp environments are explained. The absence of micrite envelop indicates that the ramp develop in a windward-protected direction.

Model Deposit

A view of distributed microfacies and interpretation of environment in the studied sections are established, and Lockhart Formation is mostly shallow plateform carbonates. A simple modal represents the Lockhart Formation deposition environment in Fig. Figure shows that microfacies are an inner ramp (Burchette and Wright, 1992). Peritidal side deposition and mid and outer ramp exposure are absent in shallowest sides. Paleocene carbonates were deposited above or below wave base. A north-eastward ramp is homoclinal (Read, 1982, 1985, 1998) Lockhart Formation shallow water carbonates are found in Hazara Kashmir syntax and northern Kohat Potohar plateau. According to others, the presence of Rotaliidae, Miscelaneidae with algae, Ranikothalia, bioclasts, and some plankton suggests ramp shallowing. Underthrusted continental crust in foreland basin causes homoclinal ramps (Read, 1985). The study area stretches from Muzaffarabd Azad Kashmir to Hazara and Salt Range and is surrounded by the Main Boundary Thrust (MBT), Main Punjal Thrust (MPT), Main Central Thrust (MCT), and Salt Range Thrust (SRT) in the Lesser Himalayan zone. The fold thrust belt deforms these ramps. Subtropical carbonates are humid, according to geochemical data and Memoir 12 (Shah, 1977). While banks and shoals form around pre-existing highs, submarine highs were present during Lockhart Formation formation in the LK, LC, LM, and LF areas. These sections show the underlying Hangue (Paleocene) and Kawagarh (Cretaceous) Formations. Some sections have Nummulitidae fauna with discocyclina and bioclasts but highs. Larger foraminifera are deposited in subtidal to intertidal, lagoonal environments more than carbonates. Rotaliidae Palecne carbonates are deposited in subtidal to intertidal (lagoonal) environments, which are important carbonate factory suppliers. Wackstones are more widespread than mudstones and packstones. LK and LC have mud-supported wackstone and packstones. Diagenetic activities and abrasions are rarely affected, but styloltes and neomorphism are. Lagoonal and restricted environments have milliolids and bioclasts. Rotaliidae Wakestone/Packstone and submicrofacies Rotaliidae Bioclastic Wakestone/Packstone and Rotaliidae Miscelaneidae

Wakestone/Packstone are abundant in all sections, proving that Paleocene carbonates were subtidal to intertidal (inner ramp). Intraclast-free ramps indicate inner deposition. Bioclastic Mudstones Wakestone/Packstone and submicrofacies Bioclastic Miscelaneidae Wakestone/Packstone indicate Fore-shoal to Shoal, barrier/back barrier (inner to outer ramp) environments in the studied sections. The third microfacies is Algal Wackestones/Packstone with submicrofacies Algal Bioclastic Wakestone/Packstone and Algal Rotaliidae Wakestone/Packstone. Foraminifera and green algae indicate a lagoonal environment. The fourth microfacies Miscelaneidae Wackestones / Packstone is in two sections. Indicated microfacies Subtidal environmental deposit. Several litratures discuss sedimentation, energy, and other ramp issues (Wrey, 1978; Hallock, 1985; Hallock and Glenn, 1986; Harney et al., 1999, Fujita and Hallock, 1999; Tucker, 1990). Tucker (1990) found no micritization in windward confines. Lockhart's foraminifera explaining the study area and ramp environments. Lack of micrite envelope indicates windward-protected ramp development.



Generalized depositional modal of Paleocene carbonates.

Geochemistry

For Geochemistry, 23 representative rock samples were selected from each microfacies of four different sections to find trace elements (Ca, Mg, Sr, Mn, Fe and Na) in the depositional and diagenetic realms. More than three samples were selected from each microfacies of Hazara Basin for chemical test and two samples from each microfacies for stable isotopes analysis of every section. Samples have been prepared using Robinson's (1980) method in the soluble carbonate fraction to determine Sr, Mn, Fe, Na, Mg and Ca. In addition, C^{13} and O^{18} stable isotopes tests have been conducted to interpret the diagenesis, temperature and environment of deposition. Each element varies in every microfacies, providing an environment of deposition (Fig. 4). This is based on the inferences that petrographic studies have indicated the presence of the effect of dedolomitization could be made. However, its impact must have resulted in a change in the geochemistry of the studied samples.

Major and Minor Elements

Strontium Sr;

Sr concentration in modern tropical carbonate deposits ranges from 8000 to 10000 ppm (Milliman, 1974), while carbonates of recent temperate range from 1642 to 5007 ppm (Adabi and Rao, 1991). Sr contents vary along carbonates due to carbonates mineralogy. Sr increases with the increase of aragonite and decrease aragonite with increasing calcite. Sr directly depends on water temperature. Sr ranges from 4.55 to 39.23 ppm and means 26.17 ppm in samples of Lockhart Formation (Fig. 4). Sr values indicate diagenesis when aragonite is replaced by calcite. According to the analysis, these show shallow Sr values, which means there is low aragonite. Calcite or Mg-calcite may occur in the samples of shallow warm water subtropical carbonates.

Sodium Na;

In recent tropical environments, Na ranges from 1500 to 2700 ppm (≈2500ppm). Content of Na is related to salinity, bio-fractionation, mineralogy, water depth and kinetics. Na concentration in the limestone of Lockhart Formation ranges from 2800 to 5300 ppm (Fig. 4). If the values of Na are lower than modern water aragonite counterpart, then the low concentration of sodium show recrystallization of carbonate during buried marine setting, which will cause the loss of sodium from carbonate. But here, Na values are higher than modern water aragonite mean to lower the Sr. The importance of Sr and Na indicates most samples of limestone lying or within warm-water subtropical aragonite field for Lockhart formation.

Manganese Mn and Iron Fe;

The Mn and Fe data concentration shows more than 20 ppm contents. Recent warm water contains aragonite, Mn, and Fe contents of less than 20 ppm (Milliman, 1974). Mn concentration in the limestone of Lockhart Formation’s samples ranges from 38ppm to 549 ppm as in Fig. (4). The Sr-Mn values indicate that some samples lay in the aragonite area. A low concentration of Mn shows original aragonite mineralogy, but high concentrations show calcite mineralogy. Fe concentration in samples of Lockhart Formation ranges from 227 to 9650 ppm with a mean of 3300ppm. The higher Fe values indicate calcite minerals.

Magnesium Mg;

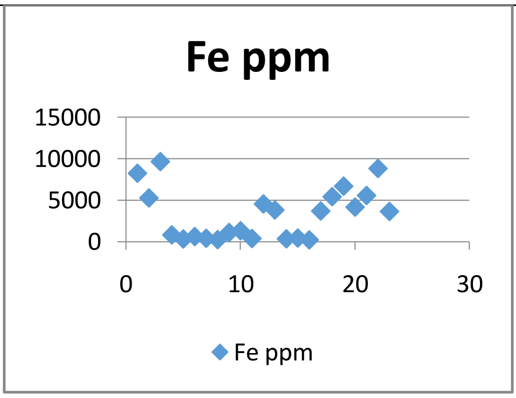
Mg content in aragonite and low Mg calcite is less than 1% where, whereas it varies from 0.11% to 3.2% in high Mg calcite in modern tropical bulk carbonates, while Mg content in aragonite and low Mg calcite is 0.12% to 0.54% and 1.86% to 2.34% in high Mg calcite in modern temperate carbonates (Rao, 1996). Mg concentration in Lockhart Formation ranges between 2175ppm to 20900 ppm (0.21% - 2.09 %) in the limestone samples. Mg values show high Mg calcite in tropical bulk carbonates. The studied skeletal carbonates are dominantly composed of foraminifera and green algae, etc. Foraminifera has mixed mineralogy (mostly high Mg and low Mg calcite), whereas green algae are aragonite in composition. As such, the Mg content (0.11 to 0.993%, mean 0.43%) is most likely a reflection of a mixture of this initial mineralogy.

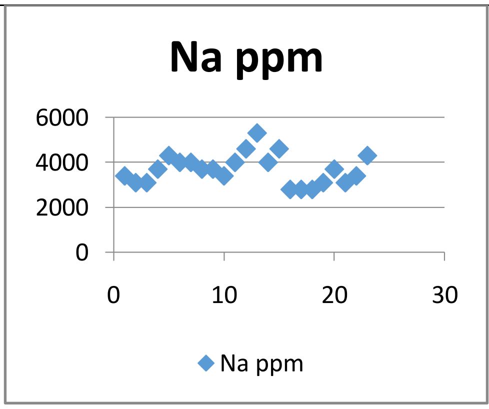
Calcium Ca;

The values of Ca concentration in the Lockhart Formationare falling from 0.38% to 2.105 % in samples (Fig. 4). Ca and Mg content in the samples are ranged from 19500ppm to 25500 ppm. According to Rao (1996), Ca content ranges from 29.2 to 40 % high, with an average of 37.4 % and 33.5 to 39.8 %, with a mean of 36.8 % in bulk carbonates of brachiopods and Bryozoans.

Insoluble Residue Solution I. R. S.;

Values of concentrations of IRS in the Lockhart Formation fall between 0.282g to 0.038g and mean = 0.11g in samples (Fig.5).





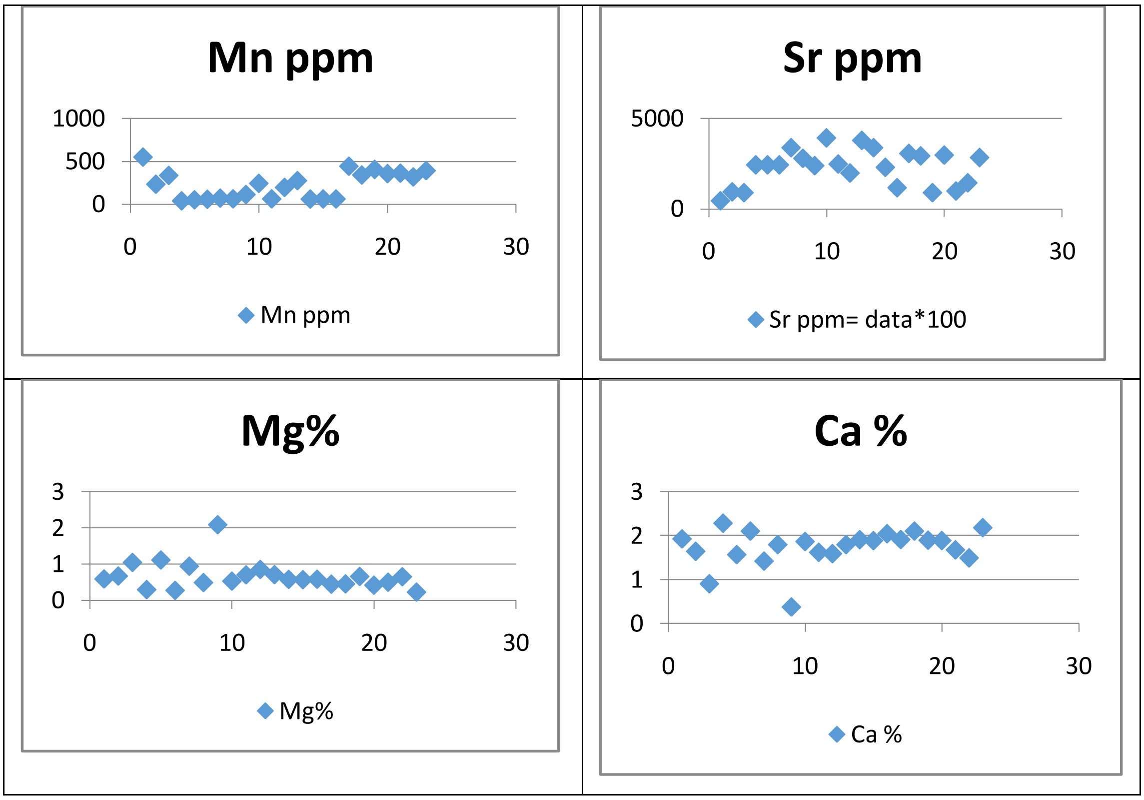


Fig. 4 shows Fe, Na, Mn, Sr, Mg, and Ca concentrations in carbonate rock samples.

Isotopes of Carbon and Oxygen

C^{13} and O^{18} stable isotope tests have been applied to interpret the diagenesis and temperature of the environment of deposition. Each element varies in every microfacies as the geochemical out puts isotopic of carbonate rocks depend on the isotopic exchange process since deposition and the depositional environment (e.g, Land and Epstein, 1970). The values of $\delta^{13}C$ in carbonates are linked to the amount of change and cause of CO_2 caused by the oxidation of organic carbon entered in pore water at the time of cementation and recrystallization (Maliva and Dickson, 1997). Carbon isotopes are less receptive to temperature alters. The lower values of $\delta^{13}C$ in Lockhart limestone correlated to the modern carbonate sediments may be associated with the pressure of CO2 and may propose the merging of $\delta^{13}C$ washed-out carbon. The ratio ranges from 2.12 to 2.93 in C^{13} and -6.36 to -7.44 in O^{18} of the given samples in Fig.5. As such, they provide additional information about the nature of changes that may occur in carbonate rocks. For this purpose, ten limestone and dolomitic limestone were analyzed following Mc Crea, (1950) method. The results discussed below, however, should be treated with caution.

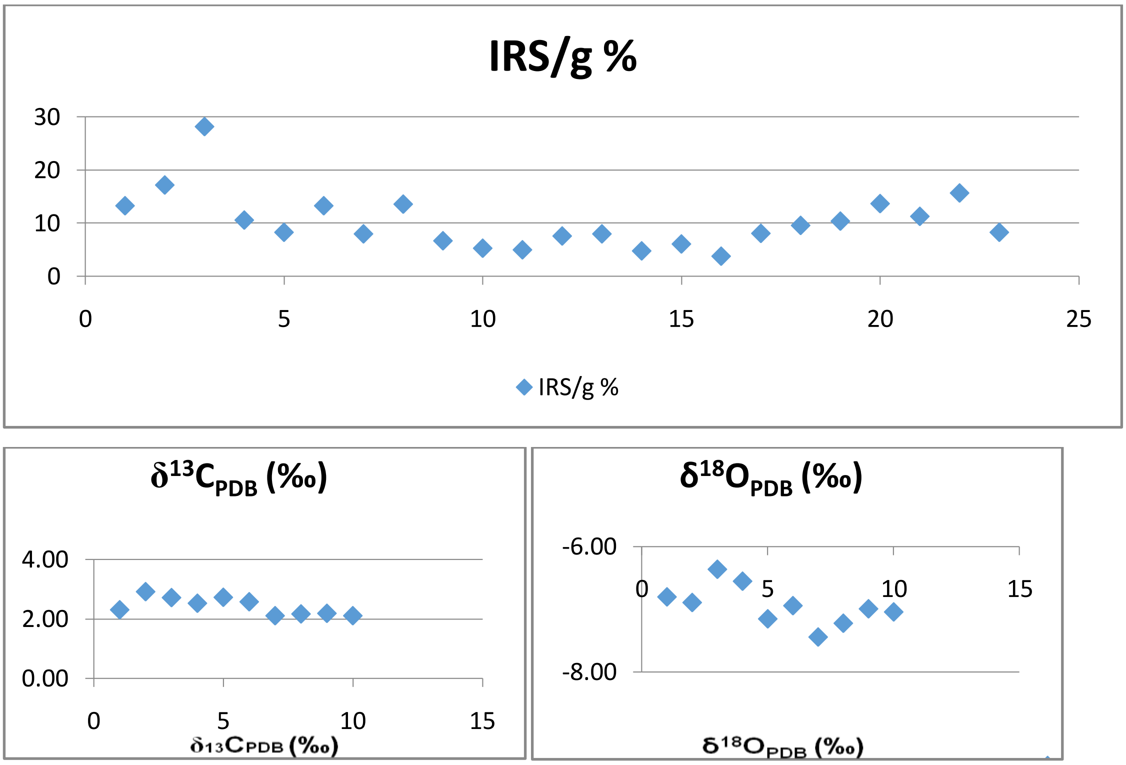


Fig. 5. Showing IRS (g) %,**δ18OPDB (‰);δ13CPDB (‰)** concentration in carbonate rock samples.

Discussion and Conclusion

Calcareous, clayey and shall limestones of Lockhart Formation have established standard microfacies, the environment of deposition and digenesis and suggested organic carbon maturation and preservation. The lower part is thickly bedded with Hague sandstones with marls, and the upper part is mostly thinly bedded limestones subordinate with Patala shales and marl intercalations. Three hundred thirteen samples were selected for petrography from 60m thick Changla Galli section, Hazara. Four main microfacies and submicrofacies Rotaliidae Wackstone/Packstone, Miscelaneidae Wackstone/Packstone, Bioclastic Mudstone/ Wackstones/Packstonesand Algal Wackstones/Packstoneshave established and geochemically analyzed. Based on the data, it is suggested that the sedimentation of Lockhart Formation was started from (Lagoon-shoal environment) shallow marine subtidal to the tidal marine environment (inner to mid ramp) and diagenetic environment. According to Lockhart limestone's chemical and isotopic analysis, this formation was deposited in a Lagoon-shoal climate, and the values of $\delta^{18}O$ and $\delta^{13}C$ show constantly through seawater after being applied and compared to other limestones. Oxygen and carbon (C/O) fraction is the reflection of depletion of heavier isotopes of oxygen and carbon consequences to late stage crystallization, an influx of fresh water and formation of carbonate cement during progressive diagenesis. It is estimated that the temperature of the Lockhart Formation ranges from 26.00 to 35 °C. The study will be fruitful in hydrocarbon discovery and helpful for future research. It will also be beneficial to find out about depositional and diagenetic environments. This formation has shown oil and gas bearing deposits in the Kohat Potwar region. Subthrust (MBT) packages in Hazara and Kashmir areas also possibly contain hydrocarbon.

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