International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

Petrographic Analysis of the Early Tertiary Subathu Formation rocks from the Kalakot Area, western Himalayan Foreland Basin, India

Dr. Sanjay Karlupia

Associate Professor, Govt. MAM College, Jammu, India

Abstract: ***The megascopic and microscopic investigations of the Early Tertiary sediments of the Subathu Formation identified nine facies exhibiting cyclic arrangements in the Subathu Formation in Jammu area, with top of the formation showing tidal cyclicity in the form of alternating thick marl and thin limestone laminae. The abundance of pyrite framboids indicate strongly reducing conditions and their early diagenetic origin in the presence of adequate amounts of iron and sulphur. Small phosphate nodules probably formed just beneath the sediment-water interface.The high ash contents of carbonaceous shales and coals and euxinic conditions probably causing high sulphur content was due to the intermittent sedimentation.The benthic foraminiferal assemblage present in the lime-mudstone indicates a sub tidal bathymetry falling. The lime-mudstone was deposited in low-energy conditions in a turbid lagoon. The presence of mud cracks reveals shallowing of the basin and exposure of the sediments.The coarse-grained limestone with full of oyster shells indicates high-energy conditions. Mixed fresh and brackish water fauna indicate an estuary or outer tidal-flat, suggesting infrequent flooding during high wind-tides under prolonged exposure originated purple shale in supratidal zone.***

1. Introduction

The Himalayan Foreland Basin (HFB) originated due to the collisional tectonics between the Indian and the Eurasian plates, with the initial phase of collision having taken place c. 50 Ma ago.The collision became more intense during the Eocene, causing the egress and shifting of the deformation front towards the south, leading to the formation of the peripheral foredeep (foreland basin). The peneplanation of the egressed parts supplied the sediments which accumulated in the foreland basin as Subathu Formation. The present investigation comprises detailed field studies as well as megascopic and microscopic analyses of the Early Tertiary sediments of the Subathu Formation to ascertain the depositional environment.

2. Regional Geology

The basement of Cenozoic rock in the HFB is of the Sirban Limestone Formation which occurs as inliers unconformably overlain by the Subathu Formation.The Eocene Subathu Formation is in turn followed by the Murree Group and Siwalik Group with no major hiatus.The Stratigraphic sequence of the Tertiary rocks is given in the table (Table 1):

Table 1: Stratigraphic sequence of Tertiaries

Group	Formation	Age
	Upper Siwalik Subgroup	Middle Miocene
Siwalik	Middle Siwalik Subgroup	to Pleistocene
Group	Lower Siwalik Subgroup	
Murree	Upper Murree Formation	Middle Eocene to
Group	Lower Murree Formation	Lower Miocene
	Subathu Formation	Late Paleocene to Eocene
^^^^^^	Unconformity/ Thrust?	^^^^^^^^^^^^^^^^^^^^^^^^^^
	Sirban Limestone	Proterozoic

The Proterozoic dolomitic limestone forming the basement is known in the literature as Sirban limestone or Great Limestone.The rocks occurring in this formation are dark grey, pink yellow or whitish in colour and consist of thick beds of massive dolomitic limestones interbedded with chert bands of variable thickness. These dolomitic limestones vary widely between the two end members viz: dolosparites and dolomicrites and also show many micro structural features like microvugs, micro veins, etc. The sedimentary structures are thin beddings, ripple marks, desiccation cracks and stromatolites.

The chert Breccia is a sedimentary breccia which occurs above the Sirban limestone and below the Subathu formation at Kalakot. This represents rapid sedimentation, probably along an escarpment or in the fault zone. The age assignment for the chert breccia is difficult but certainly it is older than Eocene and younger than Sirban Limestone. The chert breccia is composed of angular fragments of chert and limestone cemented by calcareous and siliceous cement. The breccia is of intraformational type, having disintegrated and decomposed fragments of Sirban Limestone arranged in a bedded form. The thickness of the chert breccia is about 6 to 10 m in Kalakot area.

The Subathu Formation, named after the Subathu town near Dharampur (district Solan, H.P.), consist of a basal pisolitic laterite overlain by a thick succession of green, grey and red shales associated with impure limestones. Presence of the laterite rocks at the base of the succession indicates a prolonged phase of tropical erosion and peneplanation prior to the commencement of the Palaeogene marine transgression (Kumar, 1982).

Nummulitic facies (similar to the Subathu type area) of Eocene is met within a number of inliers exposed in the Murree zone lying to the south of the Pir Panjal range. The most important of these inliers occur as a narrow rim bordering the outcrop of Sirban Limestone, exposed as the core of an anticline near Reasi (Wadia, 1983).

In Kalakot and adjoining areas, the rocks of the Subathu Formation overlie the Sirban Limestone. The contact is unconformable and marked by the occurrence of residual deposits and chert breccia. The Subathu Formation has

ISSN: 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

yielded a rich assemblage of large foraminifera that includes *Nummulites*, *Ranikothalia*, *Lockhartia*, *Dictyconides*and*Assilina* indicating a Late Palaeocene to Middle Eocene age of the formation.

An unconformity is marked between Eocene and Murree rocks throughout Kohat and Potwar Plateau in Pakistan in the form of conglomerate containing *alveolina* limestone fragments (Pascoe, 1964). However many later workers (Ranga Rao, 1971, Mehta and Jolly, 1989) recorded Middle Eocene and Oligocene vertebrates from the base of the Murree Group (Figure 1).

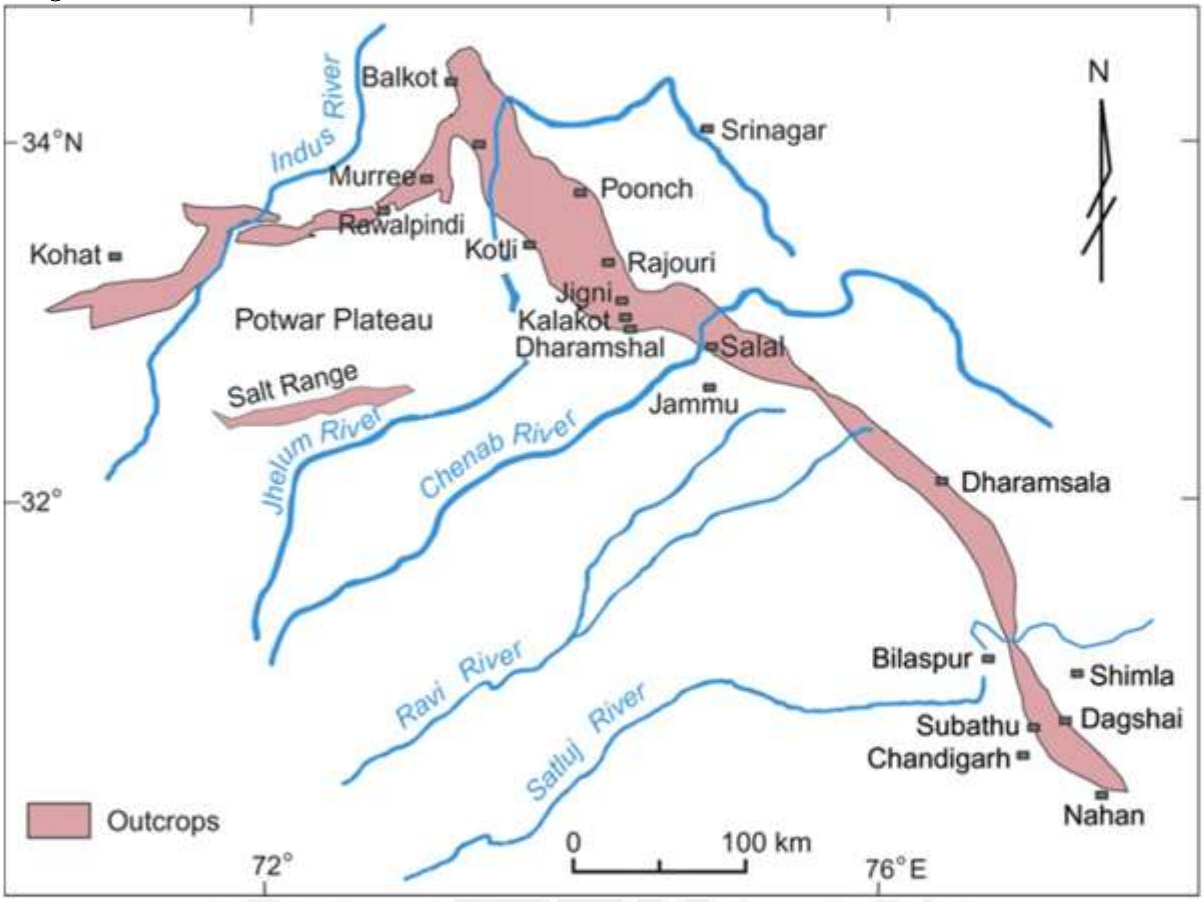

Figure 1: Map shows distribution of the Tertiary sequences and important locations in the western Himalayan foreland Basin (modified after Singh, 2013)

Singh (1973) considered the Subathu Formation to be a Group and divided it into four Formations: the Jangalgali, Beragua, Kalakot and Arnas Formations. The Jangalgali Formation represents the unconformity unit between the Sirban Limestone and rest of the Subathu Formation. It is appropriate to keep these rocks as Subathu Formation (so classified in the type area and suggested by Wells and Gingerich, 1987) due to their limited horizontal and vertical extension and make the Beragua, Kalakot and Arnas Formations of Singh (1973) as members in ascending order. Singh (1973) made four zones in this formation based on Ypresian and Lutetian aged foraminifers. *Ranikothallianuttalli*, recovered from the top of the Beragua Member indicates a Thanetian age. Palaeomagnetic data discovered by Klootwijk et.al. (1986) fixes the boundary between the Subathu Formation and overlying Murree Group at 46 Ma.

The overlying Murree Group is dominated by sandstones, mudstones and intraformational conglomerates. The Murree rocks contain plant fossils (Sabal Major) and bivalves. Their age span is from Middle Eocene to Early Miocene. Vertebrate fossils indicating an age range of Middle Eocene to Oligocene have been reported from Kalakot area in Jammu region (Sahni and Khare, 1973; Ranga Rao and Obergfell, 1973).

The termination of the Murree sedimentation in the Early Miocene coincided with the most violent episode in mountain building on the northern borders of India (Krishnan, 1982). The narrow depression (the fore deep) widened formed in front of the rising mountain, Himalaya and the sediments deposited in this fore deep resulted into Siwalik Group.

Siwalik rocks forming the foot hills in the outer part of the Himalaya are a part of the Sub- Himalayan zone. The Siwalik Group has a great thickness of detrital rocks such as sandstone, mudstone, claystone and conglomerate, measuring 4000 to 5200 m. in thickness. Although local breaks exist here and there, from the beginning of the Middle Miocene to the Lower Pleistocene, the whole thickness is one, connected and complete sequence deposited without a significant break.

3. Methodology

The methodology included the field and laboratory works. Detailed measurement of thickness of beds was carried out of different sections between Kalakot and Akhnoor. Individual facies were measured and demarcated in the profile. The collection of samples was done on the basis of lithological variations. The grain size variation and sedimentary structures were studied in the field. Precautions were taken to avoid contamination or mixing of the samples. Each samples thus collected was stored in a polythene bag and secured with the help of rubber bands. The name of locality, section and the sample numbers were noted on the label and recorded in the field diary. The type of contact and nature of the unconformity with overlying and underlying rock formation were recorded. The azimuth and angle of the beds were also measured in the field. Field photographs were also taken of different sedimentary structures and exposures of different rock sections.

The thickness of beds and their stratigraphic order measured in the field were drawn in the lithostratigraphic columns.The thin sections were studied for petrographic details. During microscopic investigations, grain size and shape and grain to cement and grain to grain relationship of thin sections were determined. The relative proportions of quartz, feldspar, rock fragments, mica, iron minerals and cement/matrix were determined and type of rock fragments identified. Field photographs were used for description of sedimentary structures and exposures of sandstone and mudstone beds.

4. Results

4.1 Lithology

Base of the Subathu Formation contains coal seams, black carbonaceous shales, thinly laminated pyritic carbonaceous shales. Large part of the Subathu Formation consists of succession of green shales, oyster-bearing limestones, conglomeratic limestones, argillaceous limestones and in upper part thin layers of green shales intercalated with argillaceous and oyster-bearing limestones. The upper most part of the formation consists of a succession of laminated limestone, yellow shale and layers of limestone, pink marl and purple shale in alternations. (Figure 2).

Carbonaceous shale and coal occur above the silty shale and the thickness of this shale is about 18 m. at Kalakot. This includes three coal bands of about 3 m. thicknesses. At Kalakot, two coal seams of about 2 m. thicknesses occur. In the basal part hard black silty shale is present which grades upward to thinly laminated clay shale (thickness of individual laminae is 5 mm.). Diagenetic pyrite, phosphate nodules, calcite and dolomite are also present in the shales.

Green and greenish yellow shales are laminated, hard and fissile (1- 2 mm. thick laminae). Shales are rich in clay minerals. The shales are impregnated with calcareousmatter, including patches of calcite and dolomite. These shales consist of nodules and elongated mud balls. At some places, thin streaks of coal are present in green shales whereas phosphatic nodules with thin concentric pyrite layers are present in greenish-yellow shale.

Argillaceous limestone occurs in bedded form with 20- 30 cm. thick beds. This limestone contains fossils of foraminifers and lamellibranches composed of calcite and dolomite and are classified as lime mudstone (Dunham, 1962). The pellets and welded faecal pellets are common.

Conglomeratic limestone occurs above the argillaceous limestone with erosional contact. The limestone shows up to 2 m. thick fining upward carbonate sequences. This limestone is clast supported and contains limestone clasts of 15- 20 cm. diameter in basal part and 2- 10 cm. diameter in the upper part of the beds. The clasts are enclosed in argillaceous lime mud that contains micrite crystals of both calcite and dolomite. The pebbles are poor in fossil content but laminated argillaceous lime mud is rich in fossils.

Oyster limestones with abundant oyster shells along the lamina planes occur above the lag deposits. The conglomeratic limestone facies grades upward in laminated limestone that is full of large and small foraminifers terminating into oyster rich limestone. Yellow shale is platy with individual lamina thickness of 2- 4 mm. Calcite is present as patches in the laminated yellow mud shale. Laminated limestone is grey in colour having thin bands alternate with mud flasers. It occurs in association with greenish-yellow and yellow shale. Finely laminated grey limestone is hard and unfossiliferous. The dolomitic limestone is clay free.

White limestone with intercalated pink marl is found in the upper most part of the Subathu Formation. The thickness of beds is in centimeters in the lower part while thickness decreases to millimeters in the upper part. Marl bands are comparatively thicker than that of the limestone bands. The marl is composed of silt and clay with calcite. The limestone is composed of sparry calcite and dolomitic crystals. Upper surfaces of the marl preserve mud cracks.The purple shale is flaggy with lamina thickness of 4- 6 mm. This shale is a mud shale having clay and silt in sub equal amounts. Hematite is the iron oxide imparting red pigmentation to this shale.

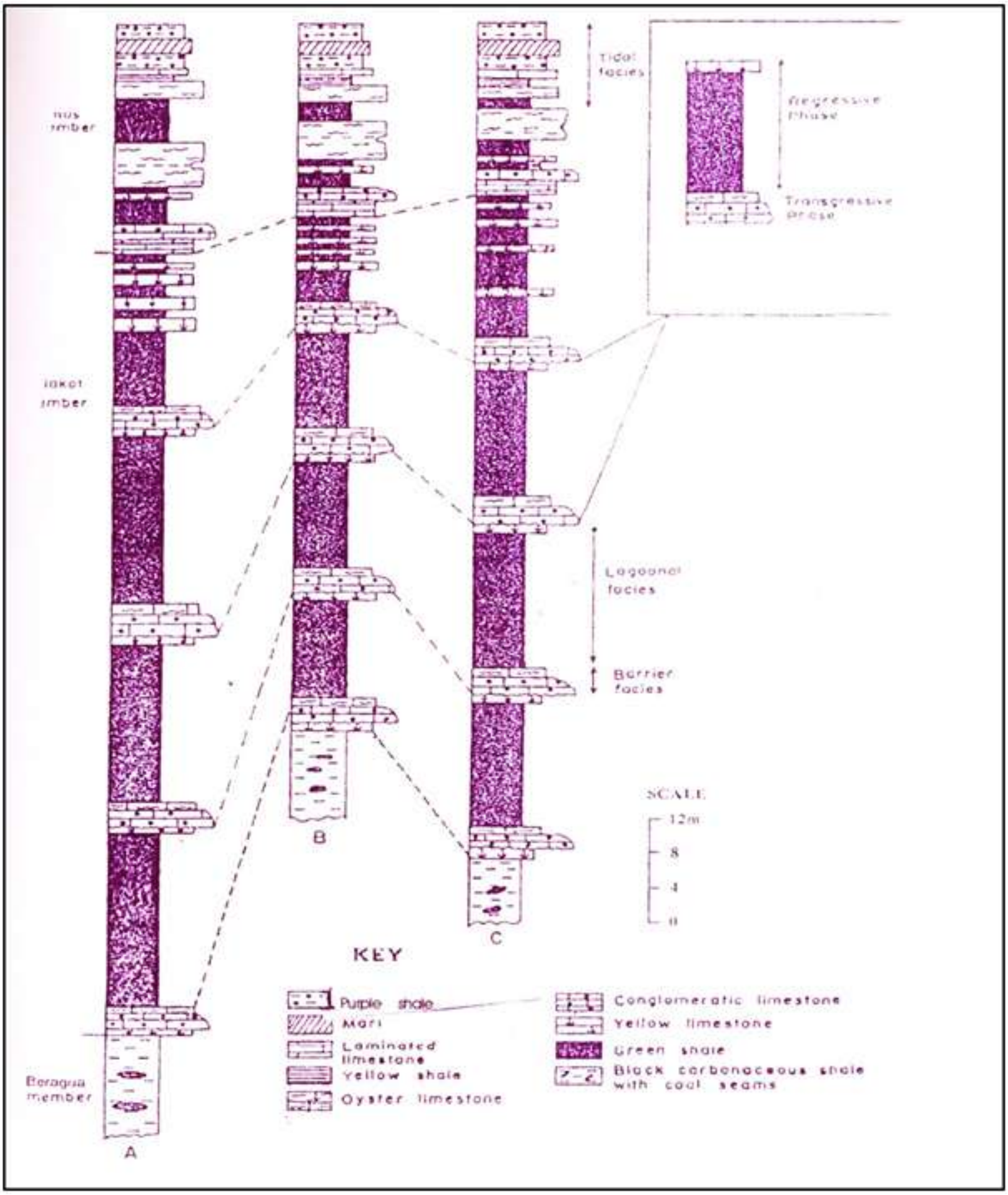

Figure 2: Lithological profile of the Subathu Formation.

4.2 Petrography

Petrographic study broadly reveals texture and mineral composition of the rocks. The Subathu sequences of the study area are composed of shales, limestones, siltstones, fine- to coarse-grained sandstones, calcareous mudstones, mudstones and claystones. The rock samples of Cenozoic sequences have been studied megascopically as well as under microscope. During microscopic investigation, attention has been focused on grain size, shape and grain to cement and grain to grain relationship. The relative proportion of quartz, feldspar, rock fragments, mica, iron minerals and cement/matrix were determined and type of rock fragments identified. Various lithofaciesof the Subathu sequences are discussed below:

4.2.1 Yellow Limestone

The limestone is composed of calcite and dolomite and is classified as lime-mudstone following Dunham (1962). Shallow water forams have been reported by Singh (1980) from this bed. The dolomite grains are present in planar-s to planar-e shape within micriteorthochem.

4.2.2 Conglomeratic Limestone

The cobbles are composed of planar-s and planar-e crystals of calcite and dolomite in micriteorthochem. *Assilinagranulosa* and other foraminifers have been reported from the conglomeratic limestone bed by Singh (1980). Following the Dunham's (1962) petrographic classification this limestone is a wackestone.

4.2.3 Oyster Limestone

Petrographic study of this limestone shows well developed dolomite crystals cemented with calcite cement. At places, some big dolomite crystals of 50 um size are present. The fossil shells are composed of both dolomite and calcite crystals. This limestone can be classified as wackestone. The foraminifers are also present in this limestone which are composed of both calcite and dolomite crystals.

4.2.4 Green and Greenish Yellow Shales

Petrographic study shows scattered calcite and dolomite crystals embedded in argillaceous matrix. These shales reveal the presence of chlorite, illite and kaolinite. The chlorite is dominating mineral whereas kaolinite is present in traces. The green colour might be because of the presence of chlorite. Both these shales contain mud balls of elongated shapes.

4.2.5Yellow Shales

Yellow shale can be classified as mud-shale that is composed of clay and silt fraction. The silt size quartz grains are scattered all along the clay matrix. The clay minerals are mainly illite and chlorite with dominance of illite. Calcite is present in patches in the laminated yellow mud shale. Septarian nodules are also present having elliptical shape.

4.2.6 Greyish Green Limestone

Planar-e to planar-s crystals of dolomite and calcite are present with the size of 0.1 mm. to 0.4 mm. along with argillaceous cement.

4.2.7Purple Shale

Petrographic study of this shale shows that silt size quartz grains are embedded in clay matrix. Calcite and dolomite crystals are also present in the fabric.

4.2.8 Marl

The white band of the marl is composed of sparry calcite and dolomite crystals occurring in calcite cement. The marl is composed of silt and clay cemented with calcite. Some of the laminations got destroyed because of bioturbation whereas upper surface of the marl preserve mud cracks.

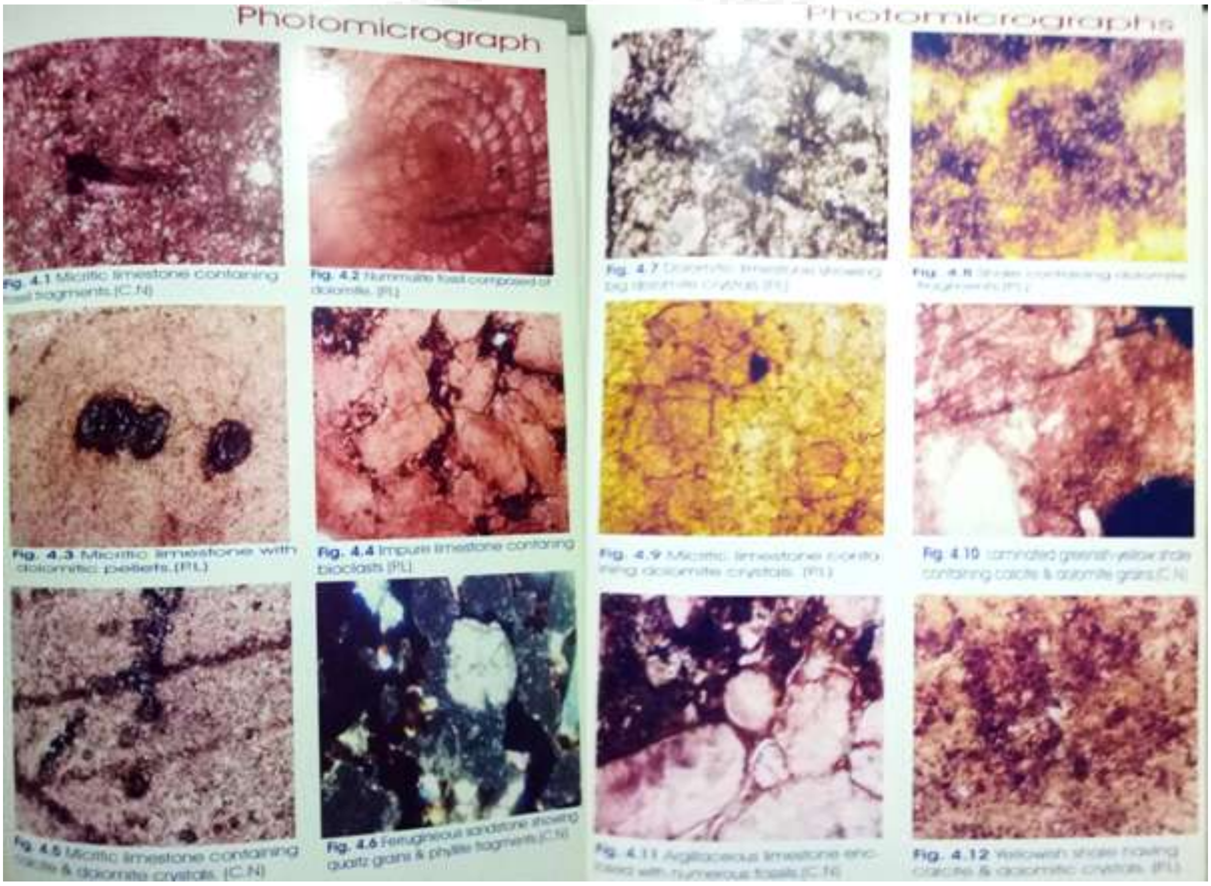

Figure 3: Photomicrograph showing the various lithofacies of the Subathu Formation

5. Discussion

The depositional history, concluded on various lines of evidence, of the Subathu Formationis detailed below. Nine facies exhibiting cyclic arrangements in the Subathu Formation in Jammu area have been recognized. The top of this formation shows tidal cyclicity in the form of alternating thick marl and thin limestone laminae.

Parallel and even lamination suggests that sedimentation occurs in quiet water, where currents were too weak to sculpt the bottom and where clay and only the finest silt are transported (Potter et. al., 1980). Finely laminated shale indicates their deposition in a quiet water environment. The suspended clay was supplied during episodic flooding while finely laminated; clay shale was deposited in calm water in a lake or lagoon. During early diagenesis, iron diffusion from the organic-rich anoxic sediment into the bacterial cavity results iron sulphide including framboids precipitation

(Bennett et.al., 1990). The Pyrite framboids (nodules), cubed crystals and thin layers indicate strongly reducing conditions and their early diagenetic origin in the presence of adequate amounts of iron and sulphur. Small phosphate nodules probably formed just beneath the sediment-water interface. Carbonates and pyrites are product of diagenetic processes in the argillaceous rocks (Singh and Muller, 1983). Patches of calcite and dolomite within the shale again represent diagenetic pore water crystallization.

The high ash contents of carbonaceous shales and coals and euxinic conditions probably causing high sulphur content was due to the intermittent sedimentation. Singh and Singh (1995) have concluded that coals of the Subathu Formation originated from a forest moor in a limno-telmatic condition from undisturbed peat. Further, they have suggested that the bandwidth, semifusinite ratio and very high vitrinite content are indicative of their deposition in foreland basin. The organic matter supplied from the adjoining swamps was deposited in the partially or wholly enclosed water bodies and subsequent sedimentation buried the peats so produced.

Shale layers contain 10 to 20 cm. long ellipsoid mud balls. The extent and duration of rolling about the major axes with currents determine the form of balls (Hall and Fritz, 1984; Kale and Awasthi, 1993). Balls that are free to roll and bounce for long distances develop high sphericity, whereas those subjected to rolling action on a slope become ellipsoidal (Stanley, 1969). The occurrence of the ellipsoidal mud balls with doming of the adjacent shale layers suggests their formation along slope may be in littoral zone.

Phosphorite nodules and crusts form today in marine environments of high productivity, such as those associated with upwelling of cold, nutrient-rich marine waters on continental slopes and outer shelves (Damasion and Moore, 1980; McLane, 1995). The phosphorite nodules formed on either continental slope or outer shelf and few centimeters of burial in anaerobic condition developed early diagenetic pyrite layers in these nodules.
The lime-mudstone was deposited in low-energy conditions in a turbid lagoon. The presence of mud cracks reveals shallowing of the basin and exposure of the sediments. Lagoonal sediments are typically pelloidal, comprising of faecal pellets generated by mud ingestors and grains micritized by endolithic microorganisms (Reid et.al., 1992). The occurrence of faecal pellets indicates their preservation in lagoons or bays. Bullen and Sibley (1984) concluded that echinoderms, coralline algae and foraminifers are dolomitised with fabric retention, although the dolomite crystals become somewhat coarser than original high-Mg calcite crystals. The subhedral and euhedral dolomite crystals indicate the presence of several small crystals of a calcite precursor.

The benthic foraminiferal assemblage present in the lime-mudstone indicates a sub tidal bathymetry falling in zone III of Boucot (1981), except for Rotalia which indicates a dominantly inner sub littoral environment (Singh and Andotra 2000). Structures like Imbrichnus are created by animal's movement in a shallow marine environment with slightly lowered salinity (Hallam, 1970). Thalassinoids are considered to be feeding-dwelling burrows made by crustaceans in shallow marine environment (Glaessner, 1947; Muller, 1970; Ager and Wallace, 1970). The trace fossils of Scolithos assemblage developed in shallow marine environments in the littoral or sub tidal zone (Singh and Andotra 2000). Bioturbation seems largely responsible for destruction of the laminae and beds.

A landward migration of the barrier leaves behind an erosional surface generated in the upper foreshore region and there may occur a thin intraclastic breccia/conglomerate derived from erosion of lagoonal sediment (Tucker, 1990). The conglomeratic limestone having erosional contact with the underlying yellow limestone and containing black elliptical gravels and skeletal debris represents a wash over deposit formed during the landward migration of the barrier. This limestone facies was deposited as transgressive lags through the reworking of lagoonal and beach sediments.

As per Wilson facies scheme (1975) limestone breccia consist of debris derived from the platform deposit on fore slope and are associated with slumping. In the present case, the gravels are large, lying with their longer axis parallel to the bedding plane and devoid of slump structure indicating their deposition on shore face and not on fore slopes. Storm cuts may forms by cross-island scouring resulting from over wash from the lagoon side after the storm pass and an inlet channel forms along tide-dominated coasts (Oertel et. al., 1991). The extensive development of the conglomeratic limestone at some locations may be due to the presence of tidal inlets rather than storm cuts, which connect the lagoon with the open sea through a barrier bar. The faunal association present in this facies falls in zone III of Baucot (1981), suggesting sub tidal conditions.

Mid ramp zone is dominated by storms where graded beds and HCS are recognized (Aigner, 1984; Burchett, 1987). The graded unit containing small foraminifers to large foraminifers and oyster shells is storm deposited along the mid ramp zone which is cyclic as well episodic. Wave ripples and shallow marine fauna with distal shelf mud distinguishes shelf storm with analogous turbidite (Aigner and Reineck, 1982). The wave ripples with symmetrical and rounded crests indicate shallow water sedimentation and shelf-storm. The oyster present in this lithofacies fall in the zone I of Boucot (1981) indicating an intertidal setting. The preservation of HCS at some locations is due to the storm activity during oyster limestone sedimentation.

The coarse-grained limestone with full of oyster shells indicates high-energy conditions. The origin of euhedral and subhedral crystals of dolomite seems to be related to the early diagenetic processes under a low temperature range. The oyster shells wholly composed of calcite reveal that they have retained the original mineralogy whereas foraminifers dolomitised during diagenesis.

Yellow colour of the shale is related to its deposition in weakly oxidizing condition. The presence of silt size quartz grains within the clay indicate derivation of silt from land and may indicate progradation or regression of the sea or the approach of an estuary or delta or progradation of a beach or barrier. The presence of chlorite suggests a source rich in phyllite and schist from the Kohistan or Ladakh arcs. Calcite and septarian nodules with septa of pure calcite were formed during diagenesis. The laminated shales formed in weakly oxidizing conditions within the intertidal zone, which was exposed after the storm.

One of the most characteristic features of peritidal carbonates is fine–scale lamination, especially in the intertidal zone (Wright, 1990). The millimeter thick laminae of the grey limestone probably developed in the intertidal zone. Mixed tidal flats are characterized by flaser bedding, wavy bedding and lenticular bedding (Reineck, 1960). Mud flasers again suggest tidal sedimentation during the limestone deposition. The desiccation cracks indicate sufficient exposure to these limestones between the two high tides.

The hardness of the limestone is mainly because of the dolomitic composition and lesser content of argillaceous impurity. The arenaceous size of the crystals indicates a high-energy environment of deposition in intertidal zone. Cloudiness of the centers arises from mineral relicts of the calcite precursor, inclusions and empty or fluid filled micro cavities (Tucker, 1990). The cloudiness of the centers in the dolomite crystals suggests alteration of a calcite precursor during early diagenetic stage and their presence as relicts.

Some laminations in carbonates may result from deposition by semi-diurnal tides in tidal flats (Wright, 1990). The effect of wave tide with diurnal variation has been interpreted by Defant (1961) from Persian Gulf and Indonesian Island, and Duncan and Wells (1992) from Mississippian Berea Formation of Northern Ohio. The sedimentation of this facies took place through wave tides with diurnal variation in its intensity in intertidal zone. The source of the clastic material in the marl is presumed to be from the continent.

The increase in the silt content suggests additional river influx from adjoining land. An oxidizing setting is revealed by the presence of hematite. The source of clay minerals was same as in the case of other shales and the presence of sepiolite reveals low-salinity conditions and an influx of fresh water. Mixed fresh and brackish water fauna indicate an estuary or outer tidal-flat. In short, infrequent flooding during high wind-tides under prolonged exposure originated purple shale in supratidal zone. Wells and Gingrich (1987) regarded these ossiferous beds as on-shore pedogenised clays representing slow sedimentation in Kotly area (Pakistan) whereas Srivastava and Kumar (1996) interpreted them in Kalakot locality as silty clay stone deposited in fluvio-deltaic conditions.

References

[1] **Ager, D.V. and Wallace, P. 1970.** The distribution and significance of trace fossils in the uppermost Jurassic rocks of the Boulonnais, northern France. In: *Trace Fossils* (ed. T.P Crime and J.C. Harper). *Geol. Jour. Spec. Issue.***3**: 1-18.

[2] **Aigner, T. 1984.** Dynamic stratigraphy of epicontinental carbonates, Upper Muschelkalk (M. Triassic), South German Basin. *Neues Jb. Geol. Palaeont. Abh.***16**: 127-159.

[3] **Aigner, T. and Reineck, H.E. 1982.**Proximality trends in modern storms sands from the Helegoland Bight (North Sea) and its implications for basin analysis. *SenkenbergMarit.***14**: 183-215.

[4] **Bennet, R.H., Brine, N.R. Hulbert, M.H. 1990.** Determinants of clay and shale microfabric signatures: processes and mechanisms. In: Microstructure of fine-grained sediments from Mud to shale (eds. R.H. Bennet, W.R. Bryant and M.H. Hulbert). *Front.Sediment. Geol., Springer-Verlag.* 5-32.

[5] **Boucot, A.J. 1981.** Principles of benthonic marine palaeocology. *Academic Press, NewYork.* 106.

[6] **Bullen, S.B. and Sibley D.F. 1984.** Dolomite selectivity and mimic replacement. *Geology.***12**: 655-658.

[7] **Burchette, T.P. 1987.** Carbonate-barrier shorelines during the basal Carboniferous transgression: the Lower Limestone Shale Group, South Wales and western England. In: *European Dinantian Environments* (eds. J. Miller, A.E. Adams and V.P. Wright). John Wiley. 239-263.

[8] **Damaison, G.T. and Moore, G.T. 1980.** Anoxic environments and oil source genesis. *Amer. Assoc. Petrol. Geol. Bull.***64**: 1179-1209.

[9] **Defant, A. 1961.** Physical Oceanography. Pergamon, New York. **2**: 598.

[10] **Duncan, P.W. and Wells, N.A. 1992.** The Mississippian Berea sandstone at Bedford in northern Ohio. Tidal cyclicity, syndepositional deformation and major boundary surfaces. *Northeast. Geol.***14**: 15-28.

[11] **Dunham, R.J. 1962.** Classification of carbonate rocks according to depositional texture. In: Classification of carbonate rocks (ed. W.E. Ham.) *Mem. Ass. Petrol. Geol.***1**: 108-112.

[12] **Glassner, M.F. 1947.** Decapod Crustacea (Callianassidae) from the Eocene of Victoria. *Royal Soc. Victoria Proc.***59**: 1-7.

[13] **Hall, A.M. and Fritz, W.J. 1984.**Armored mud balls from Carbetta and Sapelo barrier islands, Georgia. *Jour. Sed. Petrol.***54**: 831-835.

[14] **Hallam, A. 1970.**Gyrochorte and other trace fossils in the Forest Marble (Bathonian) of Doreset, England. In: Trace Fossils (eds. T.P. Crimes and J.C. Harper). *Geol. Jour. Spec.Issue.***3**: 189-200.

[15] **Kale, V.S. and Awasthi, A. 1993.** Morphology and formation of armored mud balls on Revadanda Beach, Western India. *Jour. Sed. Petrol.***63**: 809-813.

[16] **Klootwijl, C.T., Sharma, M.L., Berger, G., Baradat, J. and Lacharpagne, J.C. 1986.** Rotational over thrusting of the Northwestern Himalaya: further palaeomagnetic evidence from the Riasi Thrust sheet, Jammu foot-hills, India. *Earth Planet Sci. Lett.***80**: 375-393.

[17] **Krishnan, M.S. 1982.** Geology of India and Burma. **Sixth** Edition. 482.

[18] **Kumar, R. 1982.** Fundamentals of Historical Geology and Stratigraphy of India. **Fourth** reprint.

[19] **McLane, M. 1995.***Sedimentology. Oxford University Press.***423.**

[20] **Muller, A. 1970.**UberIchnia Von typ*Ophiomorpho* and *Thallassionides* (Vestigainvertebratorum, Crustacea): *Deutsch. Akad. Wise. Berlin, Montasber.***12**: 775-787.

[21] **Mehta, S.K. and Jolly, A. 1989.** Leptomeryx and Oligocene *artiodectyl* from the Lower Murree of Sial Sui (Kalakot Tehsil) District Rajouri, J&K State. *Curr. Sci.* **58**: 675-677.
[22] **Oertel, G.F., Henry, V.J. and Foyle, A.M. 1991.** Implications of tide-dominated lagoonal processes on the preservation of buried channels on a sediment-starved continental shelf. In: Shelf Sand and Sandstone Bodies (eds. D.J.P. Swift, G.F. Oertel, R.W. Tillman and J.A. Thorne). *Spec. Publ. Int. Assoc. Sed.* **14**: 379-393.
[23] **Potter, P.E., Mayanard, J.B. and Pryor, A.W. 1980.** Sedimentology of Shale. *Springer-Verlag, New York.* 310.
[24] **Pascoe, E.H. 1964.** A manual of India and Burma (**3rd. Ed.**) New Delhi.
[25] **Ranga Rao, A. 1971.** New mammals from Murree (Kalakot zone) as the Himalayan foothills near Kalakot, Jammu and Kashmir state, India. *Jour. Geol. Soc. India.* **12(2)**: 125-134.
[26] **Ranga Rao, A. and Obergfell, F.A. 1973.** *Harchyusasiaticus,* new species of an upper Eocene tapiroid from Kalakot. India. Oil Nat. Gas Comm., *Special paper* **3**: 1-8.
[27] **Reid, R.P., Macintyre, I.G. and Post P.E. 1992.** Micritized skeletal grains in northern Belize lagoon: a major source of Mg-calcite mud. *Jour. Sed. Petrol.* **62**: 145-156.
[28] **Reineck, H.E. 1960.** UberZeitlucken in rezentenflachseesedimenten. *Geol. Rundschau.* **49**: 149-161.
[29] **Sahni, A. and Khare, S.K. 1973.** Additional Eocene mammals from the Subathu Formation of Jammu and Kashmir. *Jour. Pal. Soc. India.* **17**: 31-49.
[30] **Singh, P.1973.** Geology of the Subathu Group of Jammu and Kashmir state. *Him. Geol.* **3**: 284-294.
[31] **Singh, P. 1980.** The Subathu Group of India. Professional paper no.1, *Nav JyotiScientific Publ. Lucknow, India.* (Proffesional Paper) 1: 1-92.
[32] **Singh, B.P. and Singh, H. 1995.** Evidence of tidal influence in the Murree Group of rocks of the Jammu Himalaya, India. In tidal signature in modern and ancient sediments. (Eds. B.W. Flemming and A. Bartholoma). *Spec. Publ. Int. Ars. Sediments.* **24**: 343-351.
[33] **Singer, A. and Muller, G. 1983.** Diagenesis in argillaceous sediments. In: Diagenesis in Sediment and Sedimentary Rocks, Developments in sedimentology. 25 B (eds. G. Larsen and G.V. Chilingar). *Elsevier.* 115-212.
[34] **Singh, B.P. and Andotra, D.S. 2000.** Barrier-lagoon and tidal cycles in Palaeocene to Middle Eocene Subathu Formation, NW Himalaya, India. *Tert. Res.* **20.**
[35] **Srivastava, R. and Kumar, K. 1996.** Taphonomy and palaeoenvironment of the Middle Eocene rodent localities of northwestern Himalaya, India. *Palaeog. Palaeocl. Palaeoec.* **122**: 185-211.
[36] **Stanley, D.J. 1969.** Armored mud balls in an intertidal environment. *Jour. Geol.* 77: 683-696.
[37] **Tucker, M.E. 1990.** Coastal and offshore environments. In: Carbonate Sedimentology (eds. M.E. Tucker and V.P. Wright). *Blackwell Scientific Publ.* 101-127.
[38] **Wadia, D.N. 1983.** Geology of India, Fourth Edition, *Sixth Reprint.* Chapter **XX**: 335.
[39] **Wells, N.A. and Gingerich, P.D. 1987.** Palaeoenvironmental interpretation of Palaeogene strata near Kotli, Azad Kashmir, N.E. Pakistan, Kashmir. *Jour. Geol.* **5**: 23-41.
[40] **Wright, V.P. 1990.** Peritidal carbonates. In: Carbonate Sedimentology (eds. M.E. Tucker and V.P. Wright). *Blackwell Scientific Publ.* 137-164.