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Paleogene biostratigraphy of Tattapani, Kotli Azad Kashmir, northwest sub-Himalayas, Pakistan

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Abstract

The detailed study of the Paleogene rocks near Tattapani yields 10 age diagnostic benthic larger foraminiferal species. These benthonic foraminiferal species include Operculina patalensis DAVIES and PINFOLD, Miscellanea miscella (d'ARCHIAC and HAIME), Nummulites atacicus (LEYMERIE), Nummulites mamillatus (FICHTEL and MOLL), Assilina subspinosa DAVIES and PINFOLD, Lockhartia tipperi (DAVIES) and Lockhartia conditi (NUTTALL). The analyses of benthic foraminifers suggest that the deposition of the Paleogene sequence occurred in warm and shallow marine environments.

1. Introduction

The Tattapani section lies along the eastern limb of the Hazara-Kashmir Syntaxis, about sixteen km northeast of Kotli Azad Kashmir at Survey of Pakistan toposheet number 43 G/14. It occurs between the longitude 73^0 $50^/$ $35^{//}$ E and latitude 33^0 $33^/$ $51^{//}$ N (Fig. 1). The rocks range in age from Precambrian to Recent forming the sub-Himalayas of Neotethys Ocean (Table 1). However, this study deals with the Lower Tertiary sequence exposed in the Tattapani area Kotli, Azad Kashmir (Figs. 2 and 3). This area belongs to eastern Tethyan region and was classic for the tropical to sub-tropical marine and transitional sedimentary deposition. The Paleogene sedimentary units of the study area (Table 1; Fig. 2) are characterized by the development of foraminiferal assemblages.

Table 1. Stratigraphic succession of Tattapani, Kotli, Azad Kashmir, Pakistan.

Age	Formation
Recent	Alluvium
-----------Unconformity-----------	
Miocene	Murree Formation
-----------Unconformity-----------	
Middle Eocene	Kuldana Formation
Early Eocene	Chor Gali Formation
Early Eocene	Margala Hill Limestone
Late Paleocene	Patala Formation
Early Paleocene	Hangu Formation
-----------Unconformity-----------	
Cambrian	Abbottabad Formation
Precambrian	Dogra Formation

The foraminiferas have an important role in biostratigraphic studies. In comparison to most other organisms the amount and distribution of foraminiferal data in the study area are vast (Fig. 2) and the environment of deposition varies from marine to transitional. In Kotli Azad Kashmir, the Tattapani area lies in the Sub-Himalayas of Pakistan. The Cambrian to Eocene rock sequence is folded and imbricated in the Sub-Himalayas. The regional Tattapani–Karaila anticline extends from northwest to southeast. The Cambrian Abbottabad Formation lies in the core and the Paleocene to Eocene rock sequence along the limbs of the anticline. The Paleogene rock sequence is well exposed in the northern limb of anticline near Tattapani area (Ashraf et al., 1983). The Paleogene rock sequence includes the Hangu Formation, Patala Formation, Margala Hill Limestone, Chor Gali Formation and Kuldana Formation. The Early Paleocene Hangu Formation unconformably overlies the Abbottabad Formation and shows the unconformable sharp contact with the overlying Patala Formation. The Patala to Murree Formations show transitional contact relationship. The earlier geologists worked on stratigraphy and tectonics of the area. The geology and stratigraphy of this region was originally introduced by Verchere (1867) and Lydker (1883) as "Nummulitic Limestone" to the Paleogene strata. The latter accounts are present in studies made by Wadia (1928) who described the Tertiaries of Kashmir as "Subathu" of Eocene age alongwith Miocene Murree and Miocene-Pleistocene Siwalik Group. He correlated the Tertiaries of the Jammu hills to the corresponding rocks of the Kumaon, Simla Himalayas, western Punjab, Kashmir Himalayas and northern part of Potwar. He placed the unconformity between the Eocene Chhart and Subathu strata and the Lower Miocene Lower Murree and Dagshai in Kashmir and Simla Himalayas.

Wells and Gingerich (1987) initially interpreted the paleo-environments of the Paleogene strata of Kamroti area, Kotli Azad Kashmir. They have correlated the Paleogene strata with Muzaffarabad, Hazara, Kohat, Kala Chitta, Kalakot and Jammu regions. The A to J units of the Paleogene strata are denoted by them comparing with the Subathu Formation at Kamroti. All the geological work in the area is mainly on the structure, tectonics and stratigraphy. It is evident that the present research is the first comprehensive contribution in the new direction related to the biostratigraphic study of the Paleogene rocks of Neotethys Ocean in Tattapani, Kotli area (Figs. 1 and 2; Table 1).

2. Biostratigraphy of the Paleogene sequence

The Paleogene sequence of Tattapani area is geologically investigated for benthic larger and smaller foraminifers (Plates 1–12; Fig. 2). For this purpose 45 rock samples are collected from the section. The distribution of the 45 rock samples includes 2, 14, 27 and 8 from Hangu Formation, Patala Formation, Margala Hill Limestone, Chor Gali Formation and Kuldana Formation respectively (Fig. 2). Samples are mainly from limestones. We prepared thin section slides for the micropalaeontological studies. The foraminiferal species are good index fossils for age determination of the rock units because these are restricted in stratigraphic ranges (Fig. 2, Plates 1–12). These species are quite common in the equivalent geological deposits of northern Pakistan and other parts of the world. This is the good criteria for the regional and inter-regional correlation of the strata using the age diagnostic species of foraminifers**.**

The geology of the Paleogene sequence of Tattapani is exposed in the axial portion of the Hazara-Kashmir Syntaxis (Figs. 1 and 2; Table 1). It is an elliptical dome and elongated parallel to the regional northeast – southwest strike. The south side of the dome is breached by a major thrust fault and its crest is highly undulatory. The Cambrian Abbottabad Formation lies in the core of the dome and the Paleogene strata along the limbs. The area remained uplifted before and after the deposition of the Paleogene sequence. The unconformity lies between the Early Paleocene Hangu Formation and the Cambrian Abbottabad Formation. The Paleogene sequence in the study area includes the Hangu Formation, the Patala Formation, the Margala Hill Limestone, the Chor Gali Formation and the Kuldana Formation (Table 1; Fig. 2). The detailed biostratigraphy of the area is presented as follows:

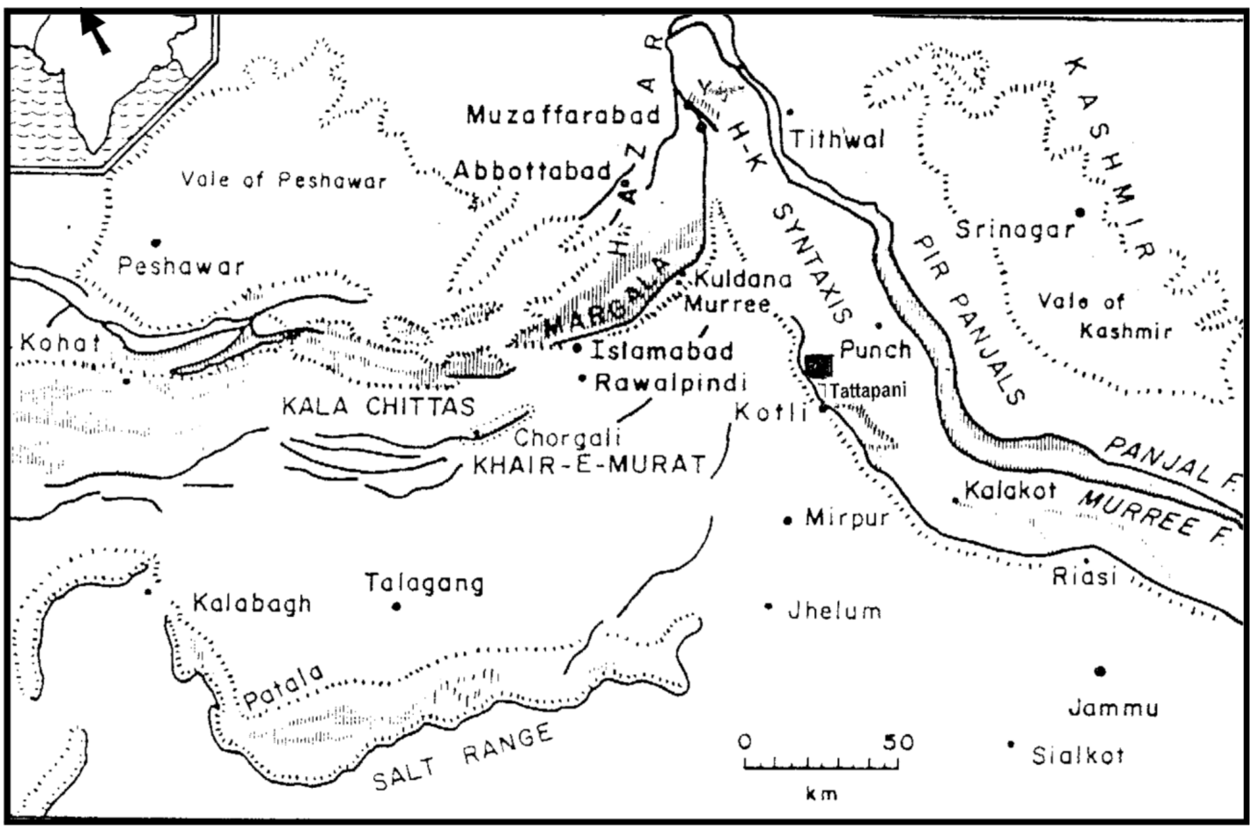
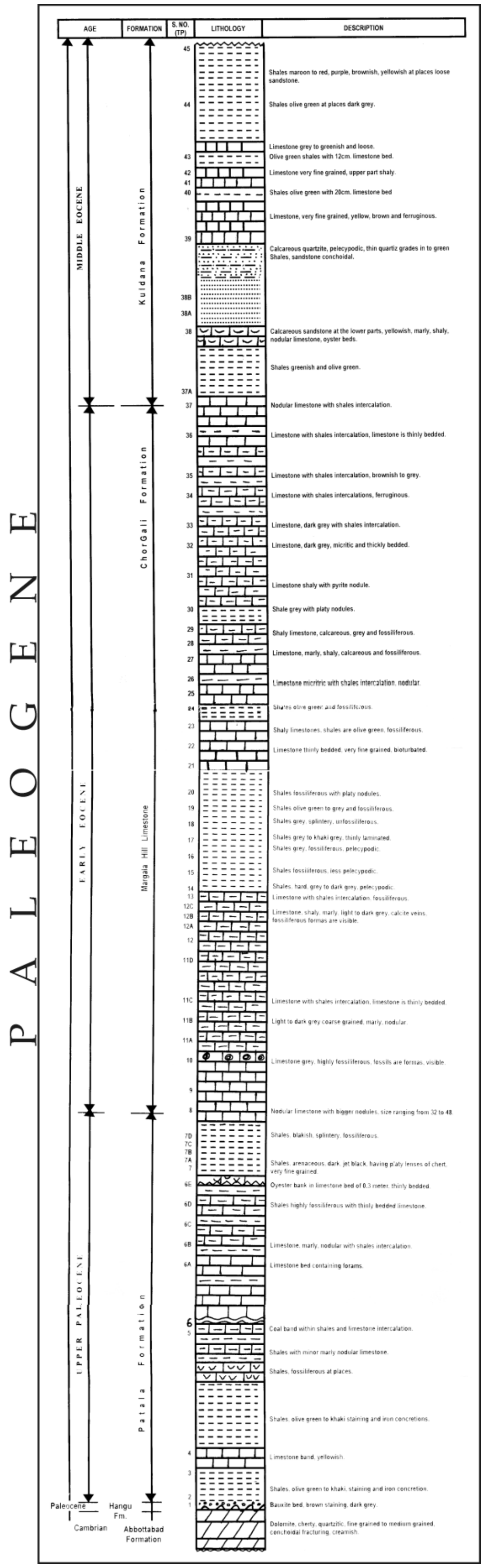


Fig. 1. Location map of Tattapani area, Kotli Azad Kashmir (modified after Wells and Gingerich, 1987).


PALEOGENE
AGE
FORMATION
S. NO. (TP)
LITHOLOGY
DESCRIPTION
MIDDLE EOCENE
EARLY EOCENE
UPPER PALEOCENE
Kuldana Formation
ChorGali Formation
Margala Hill Limestone
Patala Formation
Paleocene
Cambrian
Hangu Fm.
Abbottabad Formation
Shales maroon to red, purple, brownish, yellowish at places loose sandstone.
Shales olive green at places dark grey.
Limestone grey to greenish and loose.
Olive green shales with 12cm. limestone bed.
Limestone very fine grained, upper part shaly.
Shales olive green with 20cm. limestone bed
Limestone, very fine grained, yellow, brown and ferruginous.
Calcareous quartzite, pelecypodic, thin quartiz grades in to green Shales, sandstone conchoidal.
Calcareous sandstone at the lower parts, yellowish, marly, shaly, nodular limestone, oyster beds.
Shales greenish and olive green.
Nodular limestone with shales intercalation.
Limestone with shales intercalation, limestone is thinly bedded.
Limestone with shales intercalation, brownish to grey.
Limestone with shales intercalations, ferruginous.
Limestone, dark grey with shales intercalation.
Limestone, dark grey, micritic and thickly bedded.
Limestone shaly with pyrite nodule.
Shale grey with platy nodules.
Shaly limestone, calcareous, grey and fossiliferous.
Limestone, marly, shaly, calcareous and fossiliferous.
Limestone micritric with shales intercalation. nodular.
Shales olive green and fossiliferous.
Shaly limestones. shales are olive green. fossiliferous.
Limestone thinly bedded. very fine grained. bioturbated.
Shales fossiliferous with platy nodules.
Shales olive green to grey and fossiliferous.
Shales grey. splintery. unfossiliferous.
Shales grey to khaki grey. thinly laminated.
Shales grey. fossiliferous. pelecypodic.
Shales fossiliferous. less pelecypodic.
Shales. hard. grey to dark grey. pelecypodic.
Limestone with shales intercalation. fossiliferous.
Limestone. shaly. marly. light to dark grey. calcite veins. fossiliferous formas are visible.
Limestone with shales intercalation. limestone is thinly bedded.
Light to dark grey coarse grained. marly. nodular.
Limestone grey. highly fossiliferous. fossils are formas. visible.
Nodular limestone with bigger nodules. size ranging from 32 to 48.
Shales. blakish. splintery. fossiliferous.
Shales. arenaceous. dark. jet black. having platy lenses of chert. very fine grained.
Oyester bank in limestone bed of 0.3 meter. thinly bedded.
Shales highly fossiliferous with thinly bedded limestone.
Limestone. marly. nodular with shales intercalation.
Limestone bed containing forams.
Coal band within shales and limestone intercalation.
Shales with minor marly nodular limestone.
Shales. fossiliferous at places.
Shales. olive green to khaki staining and iron concretions.
Limestone band. yellowish.
Shales. olive green to khaki. staining and iron concretion.
Bauxite bed. brown staining. dark grey.
Dolomite. cherty. quartzitic. fine grained to medium grained. conchoidal fracturing. creamish.

3. Patala Formation

In Tattapani area of Azad Kashmir, the Patala Formation consists of khaki, dark grey to black shales with subordinate interbedded limestone. Shales are generally silty and splintery. The shale represents a prominent olive green colour. The limestone is greyish yellow, mainly nodular with marly intercalation, medium to thick bedded and massive. It has a permeable nature in general so do not produce mud in the rainy season. These are much cleaved and have a tendency to splinter rather than split. The shale bands within Margala Hill Limestone of khaki colour differs from shale of Patala Formation by having forams of much larger size (4–8 mm) and khaki coloured shale of the Kuldana Formation are generally associated with purple and grey coloured shale.

The Patala Formation grades into the Margala Hill Limestone. The formation is 24 m in the area. The Lockhart Limestone is missing in the area between the Hangu and Patala Formations. The Patala formation contains the following benthonic foraminiferal microfossils. *Lockhartia haimei* (DAVIES), *Lockhartia conditi* (NUTTALL), *Lockhartia tipperi* (DAVIES), *Operculina patalensis* DAVIES and PINFOLD, *Miscellanea miscella* (d' ARCHIAC and HAIME). This microfaunal assemblage confirms the Late Paleocene age for the Patala Formation.

4. Margala hill limestone

The Margala Hill Limestone primarily comprises of nodular limestone. The limestone is light grey to dark grey, weathers dull to brownish grey, fine to medium grained, thick bedded, massive nodular and nodules vary from 2 to 22 cm in diameter. The limestone gives fetid smell from the freshly broken surfaces. Prominent joints, fractures and slicken side surfaces occur in the lower part of the section. The lower limestone units of the formation are highly fossiliferous, contains abundant foraminifers of larger size, from 4 to 8 mm and are visible with the naked eye. This is a distinguishing characteristic of the unit. Similar situation prevails elsewhere in the other areas. The lithology of formation does not represent any marked deviation. The nodular aspects of the Margala Hill Limestone is the result of the differential compaction of the limestone and intervening argillaceous material which surrounds the nodules, pointing out the sedimentary origin. The diagenetic fabrics of Margala Hill Limestone are produced with effects of chemical compaction, pressure solution and mechanical compaction. It is a massive unit in the area and shows cliffy behavior. The thickness of the formation is 47m. The unit differs from overlying Chor Gali Formation by having non flaggy/platy habit.

The cumulative study of the thin sections has indicated the occurrence of the following foraminifers (Fig. 2; Plates 1–12): *Nummulites atacicus* (LEYMERIE), *Nummulites mamillatus* (FICHTEL and MOLL), *Assilina granulosa* d'ARCHAC, *Assilina spinosa* (DAVIES and PINFOLD), *Assilina laminosa* (GILL), *Assilina subspinosa* (DAVIES and PINFOLD), *Operculina patalensis* DAVIES and PINFOLD, *Lockhartia tipperi* (DAVIES) and *Lockhartia conditi* (NUTTALL). This microfossil assemblage indicates the Early Eocene age for the Margala Hill Limestone.

5. Chor Gali Formation

The Chor Gali Formation generally consists of limestone, marly limestone, argillaceous limestone, marl and subordinate shale. The limestone is rarely massive and generally shows a flaggy/platy habit. The flaggy habit is probably due to the increasing marly intercalations. The limestone weather into creamy light yellow and light grey colours. The freshly broken surfaces are light grey. The Margala Hill Limestone passes upwards with a gradual change of lithology into the Chor Gali Formation. However, the presence of larger foraminifera helps in its identification in the field. Occasionally these limestones of the formation weather to a chalky appearance. The marls of unit are generally in very light shades from khaki to grey. There is a significant increase in the argillaceous content towards the upper part of the formation which may range from argillaceous limestone to calcareous mudstone. The rock unit is generally thin bedded and less dense in nature and light to medium grey in colour, so visibly devoid of any fossils. The formation is occasionally found to be intensely folded, sheared and brecciated due to its less competent nature. It is fine grained at places, shows secondary calcite veins and gives bituminous smell from the freshly broken surfaces. Some of the beds are nodular and argillaceous. The shales are greenish grey, splintery and alternate with flaggy limestone. The shales are soft and calcareous.

The diagenetic fabric of the rock unit is produced by the chemical compaction and pressure dissolution, which are very important burial processes. Apart from producing a range of dissolution textures, this result in the dissolution of grains and sediments, and this may be a significant source of lime for burial cementation. Pressure dissolution arises from the increased solubility of material at grain contacts and long sediment interfaces as a result of applied stress.

The Chor Gali Formation consists of alternating beds of hard limestone and platy limestone within the shale sequence. Bedding planes are developed in platy limestone. These are mostly destroyed by bioturbation.

It appears that hard layers were selectively cemented earlier and eventually mechanical and chemical compaction affected the less cemented layers to produce platy limestone and bedding planes. This indicates that cementation of sediment was taking place periodically during shallow burial beneath the seafloor. Topographically, the formation generally forms slopes and low cliffs.

The formation comprises of limestone and shale. It may be inferred from the sedimentation of the area that the influx of clay material with carbonates formed the sediments for Chor Gali Formation. The green clays are quite water deposits, in lagoon or bay mud.

Bioturbation of the shales probably represents a marshy shore at the back of a lagoon. The actual shore line must have been an almost insignificant emergence of wet mud under a salt marsh or mangrove swamp. As neither there is any obvious change in grain size to indicate a shoreline nor in the manner of supply of sediment (Wells, 1984) and (Wells et. al., 1987). The energy of incoming waves must have been expanded on the off-shore sand bar and finally dissipated in crossing the back-bar lagoon or bay and entering the vegetation. Presence of a number of species of larger foraminifera is suggestive of the fact that the Chor Gali Formation was deposited in a shallow shelf environment. The formation conformably overlies the Margala Hill Limestone. The intervening greenish marl demarcates the boundary. The formation is overlain conformably by Kuldana Formation. The contact between the Chor Gali Formation and the Kuldana Formation is gradational.

The Chor Gali Formation is fossiliferous particularly in the lower part. It contains foraminifers, ostracods and mollusks. The foraminifera have been studied in detail from the formation. Their preservation is poor in many parts of the unit. The following foraminifers are reported from the lithobiosection of Tattapani area (Table 3; Plates 1–12). *Assilina granulosa* (d'ARCHIAC), *Assilina subspinosa* (DAVIES and PINFOLD), *Assilina laminosa* GILL, *Nummulites atacicus* (LEYMERIE), *Nummulites mamillatus* (FICHTEL and MOLL), *Lockhartia conditi* (NUTTALL) and *Lockhartia tipperi* (DAVIES). On the basis of these microfossils assemblage a Lower Eocene age is assigned to the Chor Gali Formation.

6. Kuldana Formation

The Kuldana Formation dominantly comprises of multi-coloured shale, clay, marl, limestone, siltstone, mudstone and sandstone. The shale and clay are purple, red, buff, green, greenish grey, crimson, maroon and pale grey to brownish grey. These are generally arenaceous whitish or violet bentonitic. Marl is grey to greenish grey, compact, thinly laminated and arenaceous. At places, these marls are leached and produce vuggy structures.

The limestone is grey, marly, argillaceous, brecciated and fine grained. These are highly weathered and burrowed. The sandstone is embedded at different levels. These beds are composed almost entirely of distinctive, iron-stained and calcareous granules. These sandstones contain lithic grains or fragments of quartzite, chert, sandstone and limestone. Most calcareous granules have matrix of small calcite rhombs. The granules are clearly recrystallized and degraded. Most granules have concentric rings of hematite. The features suggest that the granules are reworked soil nodules that grew under arid or semi arid conditions in calcareous soil. Rendzina soil profiles are typical feature of the Kuldana Formation (Wells, 1983). These profiles have a very dark brown horizon that passes down into a zone of nodular calcite. In some cases nodules collapse to form a solid layer. Rendzina soil primarily indicates a calcareous substrate. These are common under grasslands on marl and limestone in humid to semi-arid climates.

The red colouration of the clays of the formation is result of oxidation. Nacrite is relatively rare mineral occurring for the most part in association with metallic ores. The formation is generally calcareous at the base and arenaceous towards the top. The Kuldana Formation with abundant clays indicates a condition of standing water in the immediate areas and high local environmental diversity with nearness to sea. The purple clays indicate a relatively high water table. The overlying marine beds with limestone and marl suggest that base level was rising. The presence of an aquatic fauna indicates that the rivers of the area were perennial rather than ephemeral (Wells, 1983).

The Kuldana Formation represents a varied lithology consisting of marl, siltstone, limestone and oyster beds, which are interpreted to be deposited as white marls with commonly leached features are deposited as marsh, lake, or lagoon limestone. Some of the leached white marls have rough and irregular, solution pitted features, as a result of exposure and baking in the sun. Limestone/ bioclast, wackestone commonly gastropodal in thin sections are brackish water deposits.

Carbonates, particularly with purple and violet hue, show an extensive evidence of iron staining. They occur as nodules with unusual networks of curvilinear cracks. These are produced by soil forming processes, particularly those working in marshy conditions.

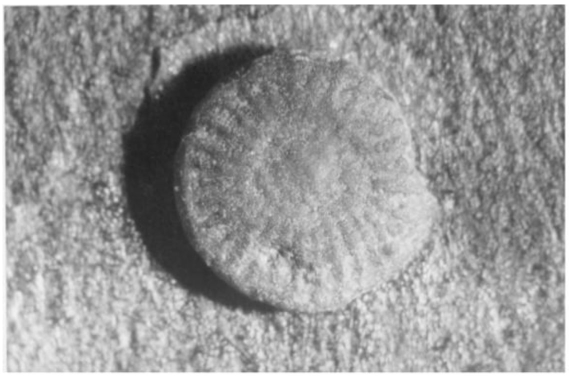


Plate 1. Horizontal view of *Operculina patalensis* DAVIES and PINFOLD, Patala Formation, Fig. 2; TP 13; field of view 600μm.

Plate 2. Horizontal view of *Operculina patalensis* DAVIES and PINFOLD, Patala Formation, Fig. 2; TP 8C; field of view 600μm.

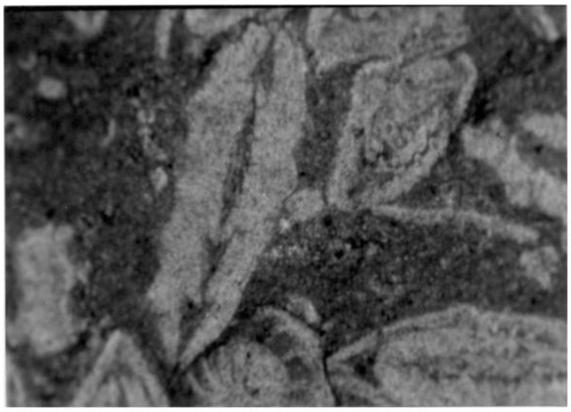


Plate 3. Vertical view of *Assilina subspinosa* DAVIES and PINFOLD, Patala Formation, Fig. 2; TP 8C; field of view 600μm.

Plate 4. Vertical view of *Nummulites atacicus* (LEYMERIE), Margala Hill Limestone, Fig. 2; TP 8C; field of view 600μm.

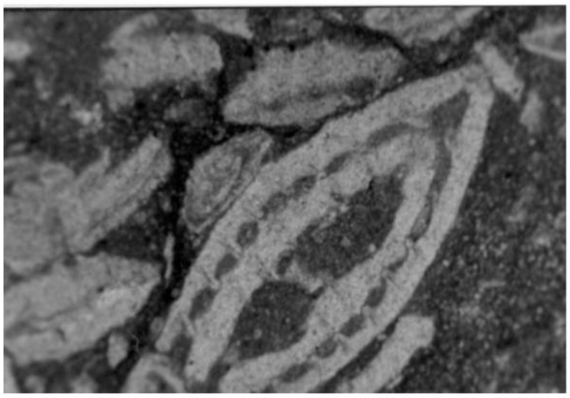


Plate 5. Vertical view of *Nummulites atacicus* (LEYMERIE), Margala Hill Limestone, Fig. 2; TP 8C; field of view 600μm.

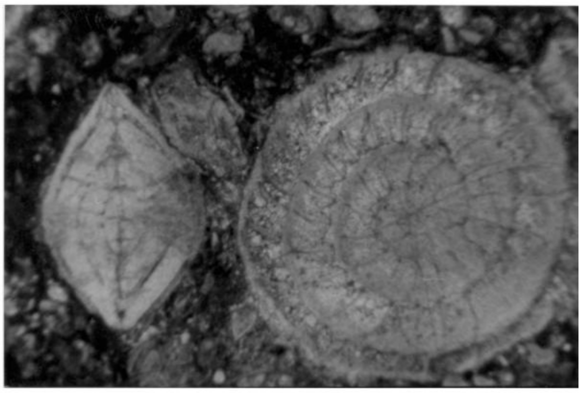


Plate 6.Right horizontal and left vertical view of *Nummulites mamillatus* (FICHTEL and MOLL), Margala Hill Limestone, Fig. 2; TP 16B; field of view 600μm.

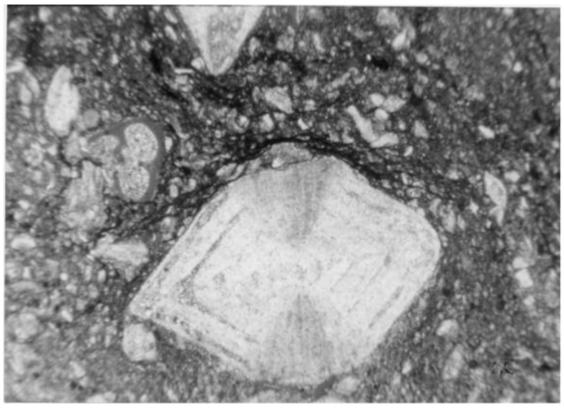


Plate 7. Vertical view of *Nummulites mamillatus* (FICHTEL and MOLL) showing characteristic umbonal pillars and thick wall Margala Hill Limestone, Fig. 2; TP 14; field of view 600µm.

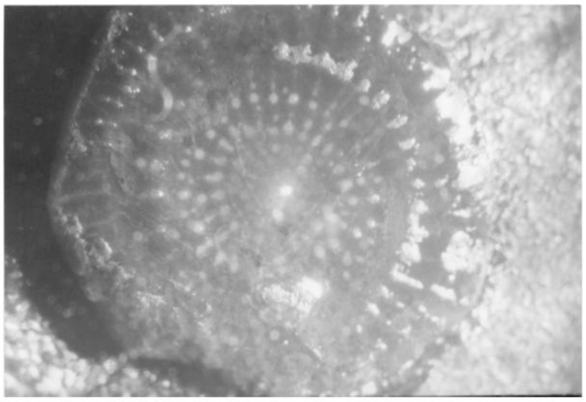


Plate 8. Horizontal view of *Assilina granulosa* (d' ARCHIAC) Margala Hill Limestone, Fig. 2; TP 8; field of view 600µm.

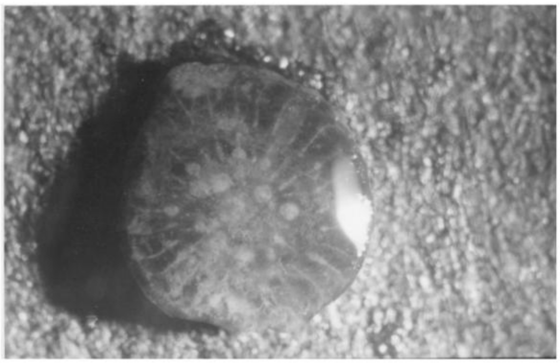


Plate 9. Horizontal view of *Assilina granulosa* (d' ARCHIAC) Margala Hill Limestone, Fig. 2; TP 12C; field of view 600µm.

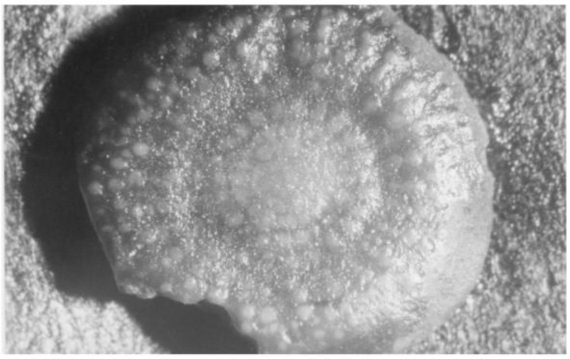


Plate 10. Horizontal view of *Assilina subspinosa* DAVIES and PINFOLD, Margala Hill Limestone, Fig. 2; TP 14; field of view 600µm.

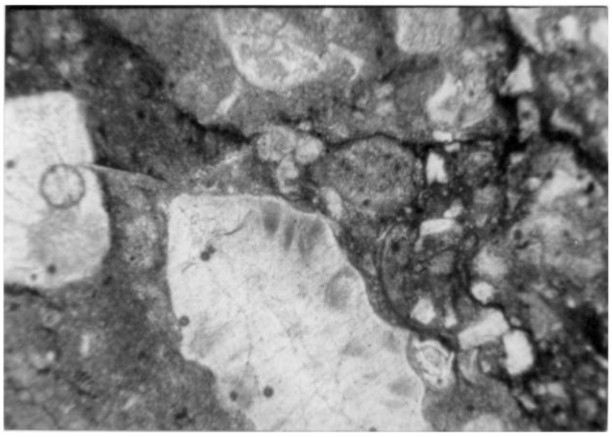


Plate 11. Vertical view of *Assilina subspinosa* DAVIES and PINFOLD showing spinose outline which is the external expression of pillars Piercing the shell, Margala Hill Limestone, Fig. 2; TP 12C; field of view 600µm.

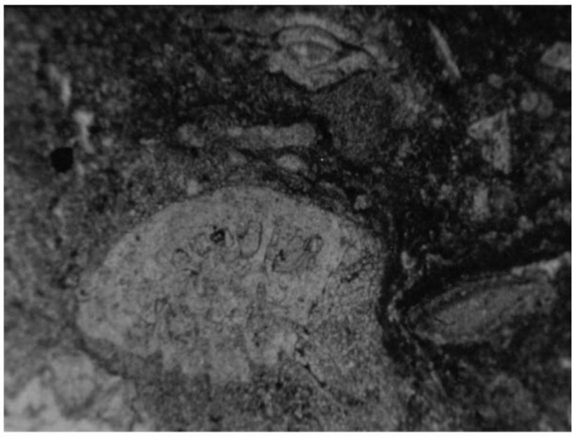


Plate 12. Vertical view of *Lochartia tipperi* (DAVIES), Margala Hill Limestone, Fig. 2; TP 8C; field of view 600µm.

One or more thin beds of broken shells accompany oyster beds at the top of the Kuldana Formation. Because oysters are sessile and cannot tolerate rapid sedimentation in very muddy water, the sequence is believed to represent slow sedimentation under brackish water. Coarse intraclastic limestone/ rudstone/ floatstone and dolomite in sandstone, siltstone and clays are caused by high energy conditions or by reworking of clasts formed by mud cracking or evaporate dissolution under lower energy conditions. On shore clays, completely pedogenized and apparently representing very slow sedimentation until the earliest Himalayan molasse was swept into the foreland basin.

The Kuldana formation is the last stratigraphic unit of the Paleogene sequence in the area, however it has gradational contact with the overlying Miocene Murree Formation. Foraminifera have been identified (Fig. 2; Plates, 1–12) from this formation which include: *Assilina granulosa* (d'ARHIAC), *Assilina sp.*, *Nummulites atacicus* (LEYMERIE), *Nummulites mamillatus* (FICHTEL and MOLL), *Nummulites sp. Quinqueloculina sp.* and other miliolids. On the basis of above mentioned faunal assemblage the Middle Eocene age is assigned to the Kuldana Formation.

7. Discussion and Conclusions

The start of initial collision of the Indian Plate and the Ladakh Island Arc in the Maastrchtian to Early Paleocene, a major regressive cycle occurred in the area (Baig et al., 1991). The regressive cycle of Neotethys Ocean occurred due to pre-Paleocene tectonic uplift in the area (Russel and Zhai, 1987). This regressive cycle deposited the basal part of the Early Paleocene Hangu Formation.

The laterite/ bauxite of the lower part of the Hangu Formation deposited during tropical to subtropical conditions whereas the sandstones, siltstones, carbonaceous shales and coal seams of the upper part of the Hangu Formation deposited under restricted shallow marine to lagoonal environments.

The second transgressive cycle of Neotethys ocean deposited shallow marine shelf carbonate and shale sequence during the Late Paleocene to Early Eocene. The formations which deposited during second transgressive cycle include the Patala Formation, the Margala Hill Limestone and the Chor Gali Formation.

The shallow shelf carbonate deposition of the nodular Margala Hill Limestone continued in the Early Eocene time. The presence of dark shales and fossiliferous limestones that accumulated in slight higher energy water has a basinal configuration across the Paleocene-Eocene boundary.

The pre-existing paleogeographic setting of the basin has been changed after the deposition of the Margala Hill Limestone when a trend of younging of units towards the south has been observed during the Early Eocene. The flaggy limestone of the Chor Gali Formation comprises near shore deposits and shows a single regression in the Early Eocene marked southward shift in the basinal configuration that left the land dry during Middle Eocene fluctuations of the shoreline to the north and to the west.

In Middle Eocene, the Kuldana Formation deposited under transitional environment. This indicates the closing of the Neotethys ocean and strengthening the argument of the southward shift of the paleogeographic setting and the development of the Hazara- Kashmir foreland basin which marks the end of the Paleogene deposition in the area. The Middle Eocene is the time of main Himalayan collision in northern Pakistan and the formation of Hazara-Kashmir foreland basin (Baig, 1991). The Himalayan molasse initiated deposition as Murree Formation during Middle Eocene in Azad Kashmir and Miocene in the Hazara area. This indicates that the Himalayan molasse of the Murree Formation is time transgressive unit.

The occurrence of abundant foraminiferal fauna laterally and vertically in the succession from Paleogene made it possible to study the several age diagnostic species. The Paleogene strata consists mainly of larger benthic foraminiferal genera such as *Operculina, Miscellanea, Lockhartia, Assilina* and *Nummulites* (Fig. 2. Plates, 1–12).

The Paleocene-Eocene Boundary is placed by the disappearance of *Operculina patalensis* (DAVIES and PINFOLD) and *Miscellanea miscella* (d'ARCHIAC and HAIME) and the appearance of *Nummulites atacicus* (LEYMERIE) and *Nummulites mamillatus* (FICHTEL and MOLL) in the upper part of the Patala Formation and basal part of the Margala Hill Limestone respectively. In Tattapani area, the whole succession from Late Paleocene to Middle Eocene was deposited by single cycle of transgression and regression of Neotethys Ocean before the initiation of Himalayan molasse during the Middle Eocene to Miocene Himalayan collision.

Acknowledgement

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