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Lithofacies and Palaeoenvironmental Reconstruction of the Tertiary Rocks of Changki Valley, Mokokchung District, Nagaland, Northeast India

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Abstract: The Changki Valley with its spectacularly developed Tertiary sequences, occupies the innermost part of belt of Schuppen towards northeast. The study area comprise the coal bearing Tikak Parbat Formation of the Barail Group, the newly identified Changki Formation and Tipam Sandstone Formation of the Tipam Group. Based on lithology (grain-size), sedimentary structures, geometry, fossil contents and palaeocurrents altogether, 9 (nine) lithofacies have been identified in the study area. The entire assemblage of facies characteristics of Tertiary rocks of Changki Valley suggests a gradual change in depositional environments from a prograding Shore-line through transgressive estuarine phase to fluvial conditions in response to the tectonic impulses during early to middle Eocene, Late Oligocene and Middle Miocene respectively.
Keywords: The Tertiary rocks of Changki Valley, Mokokchung District, Nagaland- Facies analysis, Palaeoenvironmental reconstruction.

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Introduction

The area investigated covers nearly 125 square kilometres bounded between North parallels of 94^0 20’ and 94^0 30’ East meridians of 26^0 24’ and 26^0 30’ of the Topographic Sheet No.83 G/7 of Survey of India. It includes areas lying near Changki, Longnak, Chungliyimsen, Atuphu, Mangkolemba and Mongchen Villages of Changkikong Range in the Mokokchung District, Nagaland (Figure 1).

Geomorphic Features

The Changki valley flanked between two sub-parallel strike ranges–the Changkikong to the east and Japukong to the west, presents an immature geomorphic character. The outer Japukong range attains an average elevation of 750 meters, whereas the inner Changkikong range has an average elevation of 1000 meters. The entire area is dissected by three prominent northwest flowing streams namely, Tsusemsa, Longnak and Tsujenyongnalas. The Longnaknala forms the main drainage system and divides the area approximately into two halves. It assumes the name of Tsuing River in the lower reaches which in turn joins the Desai River, an important tributary of Brahmaputra River.

Parameters of Sedimentary Facies

During recent years, the study of primary sedimentary structures together with lateral and vertical facies change of litho-units has gained much more importance for the reconstruction of depositional environment. Although, Johnnes Walther (1984) first recognised the changes of lithofacies in space and time as a sensitive depositional environment indicator (Middleton, 1973), it is the study of recent depositional environments (Reineck and Singh, 1980) which further enhances the utility of above concept in understanding ancient sedimentary records. The first systematic consideration to this was given by Visher (1965); LeBlanc (1972) and Selly (1976).

Selly (1970, 1976) reviews five parameters for clastic sedimentary rocks namely-bed geometry, lithologic composition including grain size, primary sedimentary structures, palaeocurrent patterns and biogenic remains if any, as diagnostic characters of environments of deposition.

Geometry

The general shape of sedimentary facies is a valuable criterion in distinguishing depositional environment. Useful data on shape of a sedimentary facies are given by LeBlanc (1972) and Allen (1982). Since the different litho-units of Tertiary rocks in the Changki Valley are exposed at different vertical sections, it has been sometimes possible to build up a three-dimensional or two dimensional plan view of their component facies.

Lithology and Grain–Size

The mineralogical composition of siliciclastic rocks is helpful in distinguishing the type of source rocks (provenance), mechanism of transportation and ultimately the depositional environment. Many attempts have been made to interpret depositional environments on the basis of granolumetric analysis, but there are conflicting evidences regarding its effectiveness and reliability (Selley, 1976; Pettijohn, 1975; Friedman and Sanders, 1978; Walton, Stephens and Shawa, 1980).

The Tertiary sediments of Changkivalley, in general, exhibit a range of mineralogical composition from quartzosearenite (Tikak Parbat Formation), lithic arenite (Changki Formation) to feldspathic-lithic arenite (Tipam Sandstone Formation). The grain size also shows a similar variable trend from very fine to very coarse and conglomeratic, even within respective Formations.

Sedimentary Structures

Primary sedimentary structures, such as cross-beddings ripple marks etc. in the sedimentary rocks are important in view of understanding palaeohydraulics of depositional processes (Allen, 1982). In the study area, the variation in the dimension of cross- beddings and nature of ripple marks together with other minor structures in the siliciclastics are of much use in the interpretation of depositional processes.

Palaeocurrent Patterns

Selly (1978), has given different palaeocurrent models for specific to general environments and their utility in environment reconstruction. The large areal as well as vertical spread of primary sedimentary structures within each litho-unit of study area is of great help in deciphering the palaeocurrent directions as well as the depositional environments.

Biogenic Structures / Fossils

The importance of trace fossils is well understood by Frey (1975) and other workers in interpreting the depositional environments of sedimentary rocks. They give vital information in terms of water depth, salinity, energy level, oxygenation etc. and they are especially valuable where body fossils are absent. The sedimentary column in the study area is totally devoid of body fossils and hence attempts were made to search for trace fossils. Sporadic occurrence of trace fossils were recorded and used in interpreting the depositional environments. Recovery of silicified wood fossils from Changki Formation has further substantiated the environmental interpretations.

Primary Sedimentary Structures

A number of primary sedimentary structures of variable scale and geometry were recognised in the Tertiary sediments of the study area. These structures may be conveniently grouped into seven morphotypes namely, bedding, lamination, ripples/ dunes, cross- stratification, channels, pillow like scour marks and contemporaneously deformed bedding including load balls, slump structures, bioturbation etc.

Bedding

The Tertiary succession in the area display all variations of bed thickness ranging between 1cm and 2m (very thin to thick bedding after Campell, 1967). On an average thickness of beds in Tikak Parbat, Changki and Tipam Sandstone Formations ranges between 0.35-2.0m, 0.25-3.0m and 0.15-2.5m respectively. In vertical profile sections, a systemstic upward decrease as well as increase in bed thickness was recorded. Features like flaser bedding and graded bedding are also present, the later being restricted mostly to theChangki Formation (Plate 3.4a) At places, Lag gravel deposits and also coarse to very coarse grained sandstones containing isolated pebbles and even cobbles, display massive bedded character.

Lamination

Sedimentation units less than 10mm in thickness comprise the laminated structures. These are moderately common in almost all Formations studied. Two main types of laminated structures were recognised, namely plane bed and parallel / wavy laminations (Plates 2, 3 &13).

Ripples/ Dunes

Both asymmetrical and Symmetrical ripple marks were observed in the Tertiary sediments of the study area. The lingoid small ripples (Plate 4) and sinuous, bifurcating wave ripples with ripple index ranging from 4 to 5 are commonly associated with calcareous sandstones of Tipam Sandstone Formation. Both current and wave modified ripples are prevalent in TikakParbat andTipam Sandstone Formations. Well preserved straight crested dunes (L=2.75m, H=0.4m) with succession of tidal bundles containing reactivation surfaces were also recorded from Tikak Parbat Formation (Pate 2).

Cross–Stratification

The most commonly occurring cross–stratification include planar-tabular, planar–wedge and trough-lenticular types after McKee and Weir (1953). They contain reactivation as well as laterally extensive master surfaces (Plates 2, 5, 14, 15). At places, concentration of pebbles and granules along the foreset laminae was also encountered. The average dip of foreset laminae is 15^0 , 10^0 and 8^0 in Tikak Parbat, Changki and Tipam Sandstone Formations respectively.

Channels

Erosional sedimentary structures , measuring approximately 0.5 meters across ; concave up in cross section and showing cross cutting relationship to underlying sediments , were recognised as channels . These are usually infilled with coarser sediments than that below or adjacent, and there is commonly a basal conglomeratic layer. Cross- bedded sandstones infill most of these channels. Such channel structures are fairly common in Changki Formation (Plate 6) in this Formation, lateral accretion surfaces giving large scale (epsilon) cross-stratification were also observed across a small channel (Plate 11).

Pillow-Like Scour Marks

These are commonly associated with Tikak Parbat Formation. Unlike other scour marks, these show rather indistinct orientation. At first sight they look more like load structures but occurrence of pillow like scour marks together with flute marks (Plate 7) indicate their current origin due to scouring (Reineck and Singh, 1980).

Contemporaneously Deformed Bedding

Load balls, slump structures (Plate 13), deformed cross-bedding (Plate 5) and bioturbation are some of the sedimentary structures which were formed within the Tertiary sediments of the study area due to deformation following their deposition or concurrent with that and before consolidation. These are mostly confined to Tipam Sandstones and Changki Formation.

Recognition of Lithofacies

The tertiary succession in the study area has been divided into three Formations, namely Tikak Parbat Formation Changki Formation and Tipam Sandstone Formation. These are mostly dominated by interbedded medium to fine sandstones-shale-coal, conglomerate very coarse to medium sandstones-mud and very coarse to fine calcareous and non-calcareous sandstones-shale sequences respectively. This entire assemblage may be divided into nine types including three each from the respective Formations. Following Miall, (1990), these lithofacies were assigned specific codes, namely SlfSc, SpSt & C in respect of Tikak Parbat Formation, GpGt, Sp & fl in respect of Changki Formation and Sprfl , Spr & PSr in respect of Tipam Sandstone Formation. The characteristic features of these lithofacies are presented in tables 1, 2 and 3.

SlfSc

This facies includes fine to coarse grained cross laminated sandstones and siltstone alternations . The former is characterised by very low-angle planar cross-stratifications, arranged into truncated sets. Symmetrical wave ripples, pillow-like scour marks, burrow marks and interbedded lenses of very coarse sand and granules are some of the typical structures which are commonly associated with this facies. Layers showing rich concentration of opaque heavy minerals are not very uncommon. On weathering such layers display colours typically of limonite. The thickness of this lithofacies varies from 2 to 7 meters in which, thickness of individual beds of sandstones and siltstone varies approximately between (0.01-0.60 m and 0.01-0.10 m) respectively. In general this facies exhibits a coarsening upward sequence with an erosional top. On an average, it constitutes approximately 49% of the total sections measured for Tikak Parbat Formation. The overall geometry of this facies corresponds to that of linear or shoestring type.

SpSt

This facies is composed of thickly bedded , medium to coarse grained, wedge-shaped multistoried sand bodies (Plate 8). The thickness of individual bed varies between 1 and 2 meters. Occurrence of trough cross bedding with trough depths averaging to 25cm. (range 10-40 cm) is a common feature. Here, sets are composed of well- sorted medium sand . A few of the coarser sets contain granules and pebbles concentrated at their base. Occurrence of shale pebbles and flaser bedding is not very uncommon. The most characteristic feature of this facies is the occurrence of straight crested dunes (L=2.75m, H=0.4m) with succession of tidal bundles containing reactivation surfaces (Plate 2). On an average, this facies constitutes 35 percent of the total section measured for Tikak Parbat.

C

This facies is characterised by coal and carbonaceous shale alternations. The coal occurs in the form of discontinuous seams ranging in thickness from 0.15 to 1.5 meters. On weathering this coal is easily disintegrated into finer and yellowish encrustation emanating unpleasant sulphur smell. Occurrence of framboidal pyrite is also not very uncommon. The associated carbonaceous shale contains ill-defined impressions of partly carbonised plant remains. Except for laminated structures and lenticular bedding, no other sedimentary structures were observed in this facies (Plate 10) On an average it constitutes approximately 16% of total section measured for Tikak Parbat Formation.

GpGt

This facies consists of laterally impersistent layers of moderately sorted, sub-angular to rounded cobles and pebbles (Plate 1) of variously coloured cherts, sandstones, shales, coal along with sub-ordinate schist, basic and ultrabasic rocks. Medium to large scale trough cross-stratification with trough depths averaging 35cm is more pronounced than graded bedding .Troughs are regularly stacked on top of each other with an upward decrease in depth. Pebble imbrications are not very uncommon; fragments of fossilised tree trunks are commonly associated with this facies. On an average, it constitutes approximately 57% of total sections measured for Changki Formation. This facies usually occurs as wedge or lens–shaped bodies within the facies succession. It commonly occurs with a channelled base and sharp/ gradational top.

Sp

This facies consists of highly cross-bedded, medium to coarse grained, moderate to well sorted multistoried sand bodies. This cross-bedded sandstone infill the channels measuring approximately 0.5 meters across. Within this cross-bedded channel sandstone there occurs larger-scale epsilon cross-bedding associated with lateral accretion surfaces (Plate 11) Concentration of granules and pebbles at the base of coarser sets generates pebble-lined surfaces. The base is usually channelled and gradational with fl and GpGt respectively (Plate 6) while the top of the facies is often bioturbated . The thickness of beds and cross–sets varies between 40 to 300 cm. and 15 to 60 cm respectively. On an average, it constitutes approximately 38% of the total sections measured for Changki Formation. Occurrence of silicified wood fossils is not very uncommon in this facies.

Fl

It occurs as wedge shaped bodies comprising finely laminated and rippled fine sand-silt-mud alternations (Plate 6, 12). The thickness of this facies varies from 5 to 150cm. It is commonly associated with thin (0.5 to 1.5 cm) iron encrustations. Bioturbation structures are not very uncommon in this facies. It also contains small to a very small fragments of silicified wood fossils. This facies constitutes approximately 5% of the total sections measured for Changki Formation.

Sprfl

This facies includes contemporaneously deformed plane laminated sandstones and mudstones. Penecontemporaneously deformed structures are more pronounced towards northeastern part, where this facies attains its maximum thickness of approximately 45 meters (plate 13). The intensity of such syn-sedimentary deformations decreases towards southeast where this facies is little developed (maximum thickness 15 meters) (Plate 3). On an average it constitutes approximately 48% of the total sections measured for Tipam Sandstone Formation.

Spr

This facies is composed of channelled, thickly cross-bedded, medium, very coarse grained, may be pebbly multistoried sandstones. These sandstones display loosely cemented false bedded (Plate 14) as well as hard and compact, well-bedded character (Plate 15) occupying the southeastern and northeastern parts of the area respectively. The thickness of cross bedded units varies from 10 to 25cm. Clay lined surfaces are commonly associated with the cross-beddings. Sole marks are not very uncommon. It constitutes approximately 49.5% of the total sections measured for Tipam Sandstone Formation. Deformed cross-bedded units containing cobble and pebble size shale fragments are common towards the northeastern part of the area (Plate 5).

PSr

This facies consists of fine to coarse grained cross-laminated calcareous sandstones. In the northeastern part of the area, near Khar, the finer counterpart of the facies is well developed. Here, it attains a maximum thickness of 3.5 meters containing lingoid small ripples and sinuous bifurcating wave ripples in ascending order. Some of the beds display only plane lamination. The coarser component of this facies occupies the southwestern part of the area where it attains a maximum thickness of 5 meters. Here, plane laminated as well as cross-laminated/ cross-bedded units are well developed. On average, this facies constitutes approximately 3% of the total sections measured for Tipam Sandstone Formation.

Reconstruction of Paleoenvironments

The palaeo-environmental interpretations of the ancient sedimentary deposits require thorough understanding of modern sedimentary processes and their products. In the past three decades, much attention has been paid on the study of modern sedimentary processes , both normal and catastrophic and their resultant facies mosaic in space and time (Reading, 1978; Hubert and Hyde, 1982). The normal sedimentary processes which may persist for a long period of time, are climatic changes, pelagic sedimentation, organic growth, water chemistry and diagenesis , tidal and fluvial currents. The catastrophic processes, on the other hand, occur instantaneously and include storm surges, floods, earthquakes, volcanism and tectonic movements. The relative distinction between these processes in the depositional facies, however, depends on the preservation or fossilisation potential of deposits (Goldring, 1965). Thus, the first and foremost requirement for the study of ancient sedimentary deposits calls for the development of a regional framework of 'multistoried' sand bodies on the basis of lithology, geometry, internal organisation, paaleocurrents and facies. This is usually succeeded by the palaeogeographic reconstructions depicting the locations and orientations of different sub-environments leading ultimately to a suitable conceptual model.

As mentioned earlier, the present area of investigation forms the northern part of a collision belt, popularly known as Indo-Burma Ranges (IBR). According to Bally (175, 1981) such collision belts are bounded by fold-thrust zones which he called Ampferer, Alpine type, or A-

Subduction boundaries to distinguish them from the better known Benioff or B-Subduction Zones whereoceanic lithosphere is being subducted. A-and B-subduction zones bound compressional megasutures (Bally and Snelson, 1980), which are wide mobile realms that include orogenic belts and sedimentary basins and show extensive folding, thrusting and igneous activity. On the other hand, the 'suture', which are boundaries between two collided continents or between an arc and a continent, reflects only the juxtaposition of two differing Continental palaeogeographic realms (Mitchell and Reading, 1978). Associated with the continental collision, there occurs remnant basin (Graham *et al.*, 1975) with enormous input of sediments from collision orogen. The 'Bay of Bengal' one of the best known modern example lies on the southern margin of the present orogenic belt. The 'Bay of Bengal' owe its origin due to oblique subduction and subsequent collision between India, Central and East Burmese (Myanmar) continental blocks sometimes during Late Cretaceous- Eocene Period (Acharyya, 1986).

Major sedimentary basins develop between fold thrust belts and the craton over which the mountain belt is thrust. Such basins called 'Foreland' basins after Dickinson, 1974 and Beaumont, 1981. Foreland basins are asymmetrical, and deepest near to the fold thrust belt. They migrate towards the foreland and have resulted from the downward flexuring of the lithosphere by the overriding fold-thrust belt (Beaumont, 1981), the evolution of the foreland basins being coupled to that of its adjacent mountain belt. Lateral migration of the fold-thrust belt accounts for the progressive overriding and disruption of some foreland basins. Since sedimentation is directly related to tectonics (Krumbein and Sloss, 1963), the evolution of the fold belt may be determined by an examination of the sedimentary succession (Hayward, 1984). Facies patterns are controlled not only by sedimentary input from the contrasting source areas of the fold thrust belt and the foreland but also by transverse lineaments in the basement which strongly affect local facies pattern and may divide the foreland basin into separate sub-basins. Traditionally, sediments of foreland basins have been considered as continental molasse but they may include deep marine, shallow marine, deltaic or continentalfacies (Mitchell and Reading, 1978). In the present investigation a gradual shift of the depositional environments i.e., Shallow marine → Estuarine →Fluvial in response to tectonic impulses has been envisaged for the deposition of coal bearing Barails (= Petrofacies I); Changki Formation (Petrofacies II) and Tipam Sandstone Formation (= Petrofacies III) respectively. The different sub-environments for the above three Petrofacies are described in the following sub–sections.

Supratidal Marsh-Intertidal–Front Bars / Shoreface Complexes

The intertidal zone is the main part of a tidal flat located near the margin of a gently dipping sea coast, next to the land. It falls under the marked influence of tidal rhythms together with sufficient sediment supply through rivers and mild wave actions. Within intertidal zone, tidal channels with their meandering and landward branching patterns, cause extensive reworking following lateral migration of their courses (Reineck and Singh, 1973). The intertidal deposits are associated landward with coastal plain, swamps / marshes etc. While towards the sea these are associated with shore-face like deposits. Normally, the tidal flat sediment bodies are elongated parallel to the shore- line but in the bights they may show semi-circular, or trumpet-shaped pattern depending upon the shape of the bight (Reineck and Singh, 1973). The fining landward sequences characterise the tidal flat deposits, however, associated coarsening upward sequences may be attributed to progradingshoreface deposits (Leeder, 1982) or front bars with ridge and runnel system (Reineck and Cheng, 1978). Among the primary sedimentary structures, planar, herringbone cross-bedding, megaripple bedding, flaser and lenticular bedding, inter layered sand / mud bedding, tidal bedding with thin clay partings, reactivation surfaces, interference ripples, mud pebbles, burrows and/ or shell fragments are important. However, a comparison of tidal flat deposits of modern as well as ancient has clearly revealed a great variation in their lithology and contained sedimentary structures , although, in general they exhibit a similar look (Reineck, 1979). In the present case, the distribution of depositional sub- environments and the facies associations are comparable to some extent with the present day Jade Bay of Germany (Reineck, 1970). Based on the following characters, the coal bearing Barails (Petrofacies I) have been assigned to Supratidal-intertidal-shoreface complexes.

1. Elongated sediment body parallel to shore line , comprising SlfSc (interlayered sand / mud sequences), SpSt (multistoried sandstone with mud clast and pebbles concentrated along foreset laminae) and C(coal- carbonaceous shales)
2. Fining and coarsening upward sequences related to tidal flat and progradingshoreface deposits respectively.
3. Presence of very low – angle planar cross stratifications arranged into truncated sets showing concentration of opaque heavy minerals along laminae in SlfSc.
4. Occurrence of through cross- bedding with trough depths averaging to 25cm , shale pebbles , flaser bedding , occasional herringbone cross-bedding, tidal bundles containing re-activation surfaces within moderately to well sorted medium grained lithofacies SpSt.
5. Presence of coal seams associated with carbonaceous shales containing framboidal pyrite . Laminated and lenticular beddings are common in this lithofacies C.
6. Burrow marks are common in almost all the lithofacies.
7. Bimodal and polymodal palaeocurrent patterns.
8. Typical litho facies associations- SlfSc, SpSt and C, comparable to shoreface, tidal channel bars-sandflat, and paralic swamp deposits respectively.

Mesotidal Coast- Estuarine Channel Complexes

A typical mesotidal coast (tidal range 2-4 m) consists of a broad funnel shaped estuary which passes upstream into tidally influenced meandering channels before reaching the fluvial dominated river channel. Prominent features of sand deposition include flood- and ebb-tidal deltas and transverse bars (Boothroyd, 1978).In an estuarine setting, subsidence and/or intense tidal activity play the vital role in controlling the distribution pattern of different facies. The varied and commonly bipolar palaeocurrents, abundance of hetrolithicfacies and the association of marine suite of trace fossils with abundant plant debris are some of the diagnostic features of estuarine deposits. Extremely rapid and local facies variations, vertically and laterally, are a striking feature of the association. Seaward progradation of the ebb-tidal delta produces a coarsening upward sequence in which bioturbated shelf sands are overlain by well sorted sands with trough cross- bedding, ripple lamination and parallel lamination produced by interaction between tidal currents and wave processes (Elliot, 1978). This sequence may be truncated by the estuary channel as progradation continues and the erosion surface is overlain by a variable fining–uowards sequence with the general trend: lag deposit → tidally–dominated channel facies→ tidal flat facies as described by Greer (1975) from Ossabaw Sound, Georgia Coast, USA. The Petrofacies II corresponding to the Changki Formation bears similarity to some extend with the deposits of Georgia Coast, USA, the salient features being:-

1. Typical hetrolithic facies association comprising large channel like scours, filled with extra- and intra-formational conglomerates (GpGt), multistoried, flat- bedded, planar/ trough cross bedded sandstones with pebble line surface (Sp) and interlaminated mud with fine ripple laminated sandstone (fl)

2. Overall bimodal / polymodalpalaeocurrent directions except for the occasional unidirectional patterns in GpGt .
3. Coarsening as well as fining upward sequence corresponding toprogradational ebb-tidal and estuary channel deposits respectively.
4. Occurrence of well sorted sand with trough cross-bedding, large scale epsilon cross-bedding due to lateral accretion of channel, reactivation surfaces, bioturbation and flaser cross-bedding in Sp.
5. Association of fossil wood with all the three lithofacies types.
6. Conspicuous wedge–shaped geometry of the deposit with tapering end towards north.
7. Well rounded ,well-polished, shiny grain surfaces with sporadic V-shaped pits as revealed by SEM studies.

Channel Islands-Sandflat Complexes

Channel Islands, also called braid bars and channel bars, are characteristic features of braided rivers. The braided patterns in rivers results from a complex interaction of sediment supply and water discharge (Collinson, 1978). During low water discharge, different types of bars develop causing split in the flow at several co-existing scales .Rivers especially with curved channels display attached bars which grade into transverse bars downstream .Sandflats, the composite bodies built up from accretion of transverse bars, develop from a nucleus produced by the emergence of a sector of a cross channel bar (Cant and Walker, 1978). They occur in both mid-channel and marginal positions and have been variously called as ‘mid-channel bars’ and ‘side bars’ (Collinson, 1970). Sand flats do not posses any slip face rather they gradually descend into flanking channels. The accretion on the sand flats of cross-channel bars with strongly skewed crest lines leads to tabular sets of cross-bedding oriented at quite high angles to the downstream direction (probable bimodal distribution e.g. Cant and Walker, 1978). The pattern of cross-bedding of different scales, types and orientations contrast with the unimodal pattern generated by the migration of dunes and lingoid bars (a variety of transverse bars) in the channel areas between sand flats. The shifting of the channels and flats through time lead to a complex fining upward sequence, the coarse and fine being the two end members. The boundary between coarse grained sediments and the underlying finer grained sediments of an older cycle is very irregular and marked with scour and fill structures. The grain-size gradually decreases upward. In vertical sequences, the pebbly sediments are overlain by more sandy and muddy deposits leading to an upward fining sequence beginning with pebbly unit and passing through medium sandstone with ripple-megaripple bedding–fine sand with small ripple, may be partly climbing ripple lamination and ending with horizontal mud layers (Reineck and Singh, 1973). The topmost mud layers usually exhibit mud cracks, rill marks and rain drop imprints. Penecontemporaneous deformation structures are commonly found associated with channel bar sediments.

In the present context, the lithofacies associations together with contained sedimentary structures and other features resemble channel bar and associated deposits of Brahmaputra River as described by Coleman, (1969). The salient features of Tipam Sandstone Formation (=Petrofacies III) are outlined as below:

1. The typically staking up pattern of various lithofacies , the pebbly multistoried thickly cross-bedded unit (Spr) followed by rippled medium to fine grained calcareous sandstone (PSr) which is in turn overlain by contemporaneously deformed plane laminated shales and alternating fine sand and mudstones (Sprfl).
2. A distinct fining upward sequence.

3. Highly planar cross-bedded, channelled sandstone of Spr, lingoid ripple in PSr and overturned cross-bedding, load and ball structure, feebly bioturbatedSprfl, besides other characteristic sedimentary structures.
4. The bi-directional palaeocurrent System representing accretionary product of cross-channel bars on sand flats.
5. Sheet- like geometry of the deposit.
6. Moderately sorted nature of sediments with indications of upward improvement.
7. Angular to sub-rounded quartz and feldspar grains.

Tectonic Settings and Depositional History

The entire assemblage of facies characteristics of Tertiary rocks of Changki Valley suggests a gradual change in depositional environments from a prograding shore-line through trangressive estuarine phase to fluvial conditions in response to the three tectonic impulses during Early- Middle Eocene, Late Oligocene and Middle Miocene respectively. The Early-Middle Eocene Period witnessed the collision of Naga-Chin Arakan Island arc located towards East within the oceanic domain of India and Myanmar, with the Central Burmese (Myanmar) block (Acharyya, 1990). The signatures of tectonic impulses were recorded in the obductingophiolitecomplexes.

The sedimentation kept pace with tectonism and the ongoing Eocene-Oligocene sedimentation continued uninterrupted in the inner parts of the Assam- Bengal basin, west of the Naga-Chin–Arakan Island arc. Sediments were supplied from both the newly uplifted ophioliteterrane as well as the Himalaya and Trans–Himalaya located towards east and north respectively. Flooded by sediments, the Assam-Bengal basin became progressively shallower and sediments coarsened upwards due to obvious reasons. The shore-line witnessed progradation and mangrove swamps/marshes developed on land near the coastal region. Under this favourable condition, the coal bearing Barails (Tikak Parbat Formation) were deposited during Oligocene Period. The detailed lithofacies as well as petrofacies analyses indicate that the deposition of Barail rocks took place in a supratidal – intertidal–shoreface complexes under relatively high to moderate energy condition with intermittent storm activities (Figure 2).

The Late Oligocene witnessed the second tectonic impulse, possibly due to collision of north and northeast prolongation of the Indian sub-continent with the Himalayan micro-continent to the north and the Central Burma (Myanmar) micro-continent to the east respectively. The sediments of Naga–Chin–Arakan=basin (a northern part of Assam-Bengal basin) were folded, partly thrusted and its major parts, including the youngest Tikak Parbat,were uplifted in the form of a fold-thrust belt. Foreland basins developed to the west. In the marginal parts of Assam–Bengal basin this Late Oligocene movement caused a prominent break in sedimentation. After a gap of time, sedimentation continued within the foreland basins with the initiation of a transgressive phase as evidenced by the thick column polymictic to oligomictic conglomerate-very coarse to medium grained lithic sandstone sequences of Changki Formation. The deposition of Changki Formation took place in various environments of an embayed shore-line (estuarine and mesotidal coast complexes) of early mature or late youth stage, in a temperate humid climate with high rainfall (Figure 3).

The supply of detritus was maintained through the river (s) draining nearby Barail, ophiolite plus associated sedimentary cover as well as the Himalaya, Trans-Himalaya and Mishmi Hills towards east and north respectively. With the progressive out pouring of sediments, the basin became shallower which in turn gave place to fluvial regime of sedimentation.

During Middle Miocene, a severe impact of Himalaya Orogeny caused the antecedent Brahmaputra River to shift and follow the tectonic course (Prakash and Kumar, 1991). It is envisaged that the same Brahmaputra River is responsible for the deposition of Tipam sandstone. The out pouring of sediments from the newly uplifted mountainous regions led the Brahmaputra River to become braided and deposit its load over Changki Formation through lateral migration of braided channels (Figure 4).

The successive later tectonic impulses resulted in lateral migration of foreland basins towards west whose contained sediments were later disposed off along the western margin of present day Nagaland state in the form of Belt of Schuppen possibly during penultimate stage of continental suturing (Acharyya, 1986).

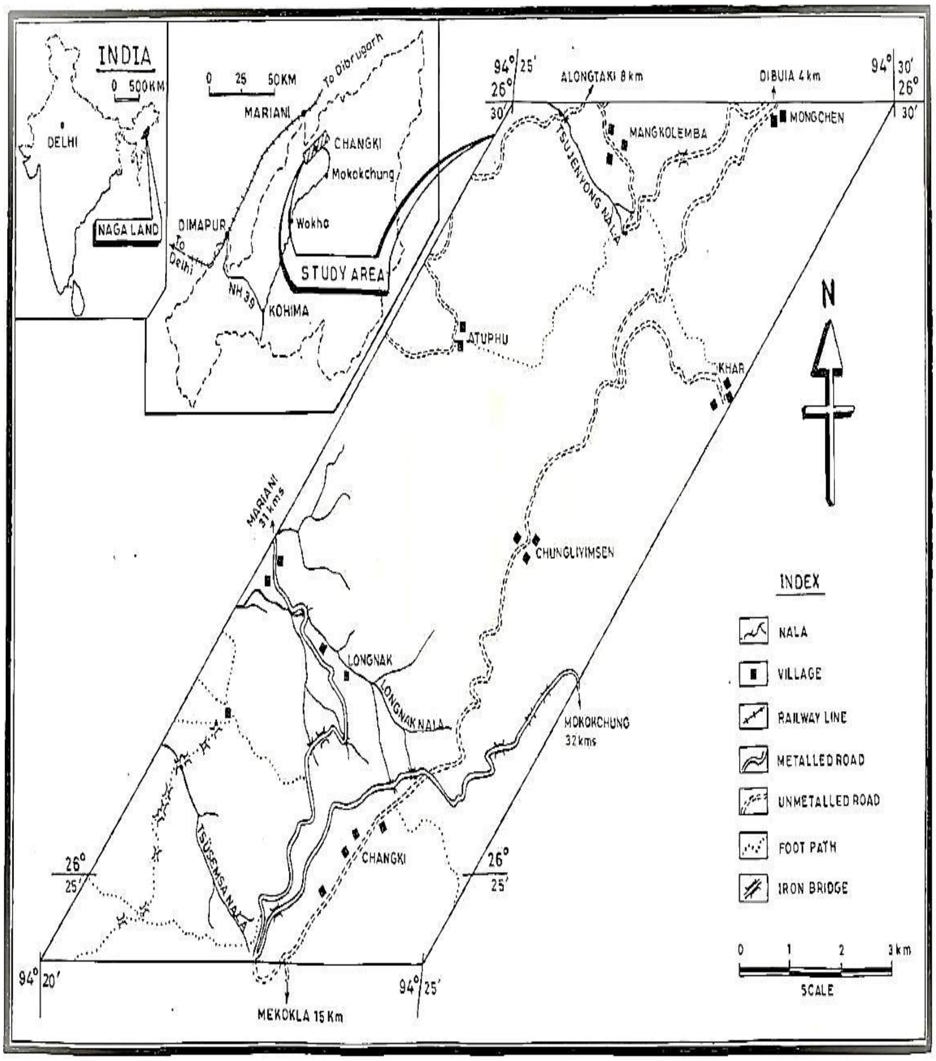

Fig.1: Location map of the area.

Table 1 :	Summary of Characteristic features of different Lithofaces of Barail group, measured along Vertical Profile Section		
Symbols Used :	**r -rare,**	**c - common,**	**a - abundent.**
	I : Tsusema Nala Section		
	Spst	**SlfSC**	**C**
Lithofacies percent	43	43	14
Bed Base			
Erosive	c	-	-
Sharp, Planer	-	a	a
Channel	a	-	-
Bed Top			
Erosive	-	c	c
Sharp, Planer	a	-	-
Channel	-	a	r
Bed Geometry			
Sheet	c	a	c
Lenses	a	r	-
Shoe string/Prism	-	-	-
Structures			
Parallel/Wavy laminations	r	a	a
Grain fall and sand flow laminations	-	-	-
Plane bed laminations	-	a	c
Planar cross beds	c	a	-
Trough cross beds	c	-	-
Herringbone cross bedding	r	r	-
Graded bedding	-	-	-
Reactivation surface	c	c	-
Flaser bedding	c	c	r
Granule rich tabular cross bedding	-	-	-
Symmetric-wave modified current ripples	-	-	-
Asymmetrical ripples	-	a	-
Granular or sand ripples	r	-	-
Deflection lags	-	-	-
Texture			
Mean size (M_z)	26.63 Ø	3.31 Ø	Coal & Mud
Standard deviation (σ_I)	0.50 Ø	0.63 Ø	-
Skewness (SK_I)	0.21 Ø	0.16 Ø	-
Kurtosis (K_G)	1.64 Ø	1.22 Ø	-
Pebble	c	-	-
Granule	c	r	-
Bed thickness (cms)	upto 200	1-7	>1-2

Contd.

	II : 3 Km South-West of Longnak		
	Spst	**SlfSC**	**C**
Lithofacies percent	50	33	17
Bed Base			
Erosive	c	-	-
Sharp, Planer	-	a	a
Channel	a	-	-
Bed Top			
Erosive	-	c	r
Sharp, Planer	c	c	c
Channel	a	-	-
Bed Geometry			
Sheet	-	c	c
Lenses	a	r	-
Shoe string/Prism	-	-	-
Structures			
Parallel/Wavy laminations	-	c	c
Grain fall and sand flow laminations	-	-	-
Plane bed laminations	-	a	c
Planar cross beds	c	a	-
Trough cross beds	c	-	-
Herringbone cross bedding	r	r	-
Graded bedding	-	-	-
Reactivation surface	c	r	-
Flaser bedding	r	r	c
Granule rich tabular cross bedding	r	-	-
Symmetric-wave modified current ripples	r	-	-
Asymmertrical ripples	r	c	-
Granular or sand ripples	-	-	-
Deflection lags	-	-	-
Texture			
Mean size (M_z)	26.63 Ø	2.40 Ø	Coal & Mud
Standard deviation (σ_I)	0.50 Ø	0.83 Ø	-
Skewness (SK_I)	0.19 Ø	0.10 Ø	-
Kurtosis (K_G)	1.14 Ø	1.92 Ø	-
Pebble	a	-	-
Granule	a	-	-
Bed thickness (cms)	150-200	1-7	1-3

III : 1.5 Km South-East of Mangkolemba			
	Spst	**SlfSC**	**C**
Lithofacies percent	44.5	11	44.5
Bed Base			
Erosive	c	-	-
Sharp, Planer	-	a	a
Channel	a	-	-
Bed Top			
Erosive	-	c	-
Sharp, Planer	c	c	c
Channel	-	-	-
Bed Geometry			
Sheet	-	c	c
Lenses	c	-	-
Shoe string/Prism	-	-	-
Structures			
Parallel/Wavy laminations	-	c	c
Grain fall and sand flow laminations	-	-	-
Plane bed laminations	-	a	c
Planar cross beds	c	a	-
Trough cross beds	c	-	-
Herringbone cross bedding	r	r	-
Graded bedding	-	-	-
Reactivation surface	c	r	-
Flaser bedding	c	c	c
Granule rich tabular cross bedding	a	-	-
Symmetric-wave modified current ripples	r	r	-
Asymmertrical ripples	-	c	-
Granular or sand ripples	r	-	-
Deflection lags	-	-	-
Texture			
Mean size (M_z)	2.42 Ø	2.84 Ø	Coal & Mud
Standard deviation (σ_I)	0.76 Ø	0.70 Ø	-
Skewness (SK_I)	0.19 Ø	0.16 Ø	-
Kurtosis (K_G)	1.14 Ø	1.52 Ø	-
Pebble	c		-
Granule	c		-
Bed thickness (cms)	50-110	1-3	>2

Table 2 :	Summary of Characteristic feature of different Lithofaces of Changki formation, measured along Vertical Profile Section		
Symbols Used :	**r -rare,**	**c - common,**	**a - abundent.**
	I : 4 Km South-West of Changki (along approach road)		
	GpGT	**Sp**	**fl**
Lithofacies percent	50	25	-
Bed Base			
Erosive	a	r	-
Sharp, Planer	-	c	c
Channel	a	c	-
Bed Top			
Erosive	-	r	a
Sharp, Planer	a	c	r
Channel	-	c	c
Bed Geometry			
Sheet	-	-	-
Lenses	a	r	r
Shoe string/Prism	-	c	r
Structures			
Parallel/Wavy laminations	-	-	c
Grain fall and sand flow laminations	-	-	-
Plane bed laminations	r	r	r
Planar cross beds	-	a	r
Trough cross beds	a	c	-
Herringbone cross bedding	-	-	-
Graded bedding	r	-	-
Reactivation surface	c	c	-
Flaser bedding	-	c	c
Granule rich tabular cross bedding	-	r	-
Symmetric-wave modified current ripples	-	-	-
Asymmertrical ripples	-	-	c
Granular or sand ripples	-	-	-
Deflection lags	-	-	-
Texture			
Mean size (M_z)	0.47 Ø	2.27 Ø	2.58 Ø
Standard deviation (σ_I)	0.43 Ø	0.69 Ø	0.51 Ø
Skewness (SK_I)	0.27 Ø	0.13 Ø	0.35 Ø
Kurtosis (K_G)	0.89 Ø	1.34 Ø	1.36 Ø
Pebble	a	r	-
Granule	a	c	-
Bed thickness (cms)	40-300	30-320	<1-5

	II : 3 Km South-West of Changki Along Approach Road	
	GpGT	**Sp**
Lithofacies percent	54	46
Bed Base		
Erosive	a	c
Sharp, Planer	-	r
Channel	c	c
Bed Top		
Erosive	-	c
Sharp, Planer	a	r
Channel	-	c
Bed Geometry		
Sheet	-	-
Lenses	a	r
Shoe string/Prism	-	c
Structures		
Parallel/Wavy laminations	-	-
Grain fall and land flow laminations	-	-
Plane bed laminations	-	r
Planar cross beds	-	c
Trough cross beds	a	-
Herringbone cross bedding	-	-
Graded bedding	r	-
Reactivation surface	c	c
Flaser bedding	-	r
Granule rich tabular cross bedding	-	c
Symmetric-wave modified current ripples	-	-
Asymmertrical ripples	-	-
Granular or sand ripples	-	-
Deflection lags	-	-
Texture		
Mean size (M_z)	0.47 Ø	2.27 Ø
Standard deviation (σ_I)	0.49 Ø	0.69 Ø
Skewness (SK_I)	0.27 Ø	0.13 Ø
Kurtosis (K_G)	1.89 Ø	1.34 Ø
Pebble	a	r
Granule	a	c
Bed thickness (cms)	40-250	30-310

III : 2 Km South-West of Chankgi (along approach road)			
	GpGT	**Sp**	**fl**
Lithofacies percent	33	47	20
Bed Base			
Erosive	a	c	-
Sharp, Planer	-	c	a
Channel	a	c	-
Bed Top			
Erosive	-	r	a
Sharp, Planer	a	c	r
Channel	-	c	r
Bed Geometry			
Sheet	-	-	-
Lenses	a	r	r
Shoe string/Prism	r	c	c
Structures			
Parallel/Wavy laminations	-	-	a
Grain fall and land flow laminations	-	-	-
Plane bed laminations	-	c	a
Planar cross beds	r	a	-
Trough cross beds	a	c	-
Herringbone cross bedding	-	r	-
Graded bedding	r	-	-
Reactivation surface	c	c	-
Flaser bedding	-	r	c
Granule rich tabular cross bedding	-	c	-
Symmetric-wave modified current ripples	-	-	-
Asymmertrical ripples	-	-	-
Granular or sand ripples	-	-	-
Deflection lags	-	-	-
Texture			
Mean size (M_z)	0.47 Ø	2.27 Ø	2.58 Ø
Standard deviation (σ_I)	0.49 Ø	0..69 Ø	0.51 Ø
Skewness (SK_I)	0.27 Ø	0.13 Ø	0.31 Ø
Kurtosis (K_G)	0.89 Ø	1.34 Ø	1.36 Ø
Pebble	a	c	-
Granule	a	c	-
Bed thickness (cms)	40-200	30-300	<1-4

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IV : 6.1 Km North-East of Changki (Along Approach Road)		
	GpGT	**Sp**
Lithofacies percent	50	50
Bed Base		
Erosive	a	-
Sharp, Planer	-	c
Channel	c	r
Bed Top		
Erosive	-	c
Sharp, Planer	c	r
Channel	-	c
Bed Geometry		
Sheet	-	-
Lenses	a	-
Shoe string/Prism	-	c
Structures		
Parallel/Wavy laminations	-	-
Grain fall and sand flow laminations	-	-
Plane bed laminations	-	r
Planar cross beds	-	a
Trough cross beds	a	-
Herringbone cross bedding	-	-
Graded bedding	r	-
Reactivation surface	c	r
Flaser bedding	-	r
Granule rich tabular cross bedding	r	c
Symmetric-wave modified current ripples	-	-
Asymmertrical ripples	-	-
Granular or sand ripples	-	-
Deflection lags	-	-
Texture		
Mean size (M_z)	0.53 Ø	2.27 Ø
Standard deviation (σ_I)	0.66 Ø	0.69 Ø
Skewness (SK_I)	0.09 Ø	0.13 Ø
Kurtosis (K_G)	1.23 Ø	1.34 Ø
Pebble	a	r
Granule	a	c
Bed thickness (cms)	50-100	60-150

Table 3. Summary Of Characteristic Feature of Different Lithofaces of Changki Formation, measured along Vertical Profile Section

Symbols Used:	**r -rare,**	**c - common,**	**a - abundent.**
	I : 1.5 Km North-East of Changki (Along Approach Road)		
	Sprfl	**Spr**	**PSr**
Lithofacies percent	10	60	30
Bed Base			
Erosive	-	r	-
Sharp, Planer	a	c	a
Channel	-	c	-
Bed Top			
Erosive	c	-	-
Sharp, Planer	r	r	a
Channel	-	c	-
Bed Geometry			
Sheet	c	r	c
Lenses	-	c	-
Shoe string/Prism	-	-	-
Structures			
Parallel/Wavy laminations	c	-	r
Grain fall and sand flow laminations	-	-	-
Plane bed laminations	c	-	r
Planar cross beds	r	a	c
Trough cross beds	-	c	-
Herringbone cross bedding	-	-	-
Graded bedding	-	-	-
Reactivation surface	r	r	-
Flaser bedding	c	c	-
Granule rich tabular cross bedding	-	r	-
Symmetric-wave modified current ripples	-	-	r
Asymmertrical ripples	-	c	a
Granular or sand ripples	-	-	-
Deflection lags	-	-	-
Texture			
Mean size (M_z)	2.51 Ø	2.20 Ø	2.56 Ø
Standard deviation (σ_I)	0.69 Ø	0.43 Ø	0.74 Ø
Skewness (SK_I)	0.27 Ø	0.00 Ø	0.14 Ø
Kurtosis (K_G)	0.94 Ø	1.30 Ø	1.18 Ø
Pebble	-	r	-
Granule	-	r	-
Bed thickness (cms)	>1-5	10-150	50-180

II : 4.5 Km North-East of Changki		
	Spfl	**Spr**
Lithofacies percent	57	43
Bed Base		
Erosive	-	c
Sharp, Planer	a	r
Channel	-	-
Bed Top		
Erosive	r	-
Sharp, Planer	c	a
Channel	-	r
Bed Geometry		
Sheet	r	c
Lenses	-	-
Shoe string/Prism	-	-
Structures		
Parallel/Wavy laminations	r	-
Grain fall and sand flow laminations	-	-
Plane bed laminations	c	-
Planar cross beds	-	a
Trough cross beds	-	c
Herringbone cross bedding	-	-
Graded bedding	-	-
Reactivation surface	r	r
Flaser bedding	c	c
Granule rich tabular cross bedding	-	r
Symmetric-wave modified current ripples	-	-
Asymmertrical ripples	c	c
Granular or sand ripples	-	-
Deflection lags	-	-
Texture		
Mean size (M_z)	2.51 Ø	2.20 Ø
Standard deviation (σ_I)	0.69 Ø	0.43 Ø
Skewness (SK_I)	0.27 Ø	0.00 Ø
Kurtosis (K_G)	0.94 Ø	1.13 Ø
Pebble	-	-
Granule	-	r
Bed thickness (cms)	<1-5	10-150

III : 3 Km East of Chankgi		
	Spfl	**Spr**
Lithofacies percent	50	50
Bed Base		
Erosive	-	r
Sharp, Planer	c	c
Channel	-	r
Bed Top		
Erosive	c	-
Sharp, Planer	r	a
Channel	-	-
Bed Geometry		
Sheet	c	r
Lenses	-	-
Shoe string/Prism	-	-
Structures		
Parallel/Wavy laminations	r	r
Grain fall and sand flow laminations	-	-
Plane bed laminations	a	r
Planar cross beds	r	a
Trough cross beds	-	-
Herringbone cross bedding	-	-
Graded bedding	-	-
Reactivation surface	-	r
Flaser bedding	r	c
Granule rich tabular cross bedding	-	r
Symmetric-wave modified current ripples	-	r
Asymmertrical ripples	-	a
Granular or sand ripples	-	-
Deflection lags	-	-
Texture		
Mean size (M_z)	2.51 Ø	2.20 Ø
Standard deviation (σ_I)	0.69 Ø	0.43 Ø
Skewness (SK_I)	0.27 Ø	0.00 Ø
Kurtosis (K_G)	0.94 Ø	1.13 Ø
Pebble	-	-
Granule	-	-
Bed thickness (cms)	<1-5	10-150

Iv : 3.5 Km South-West of Mongchen		
	Spfl	**Spr**
Lithofacies percent	50	50
Bed Base		
Erosive	-	r
Sharp, Planer	c	c
Channel	-	r
Bed Top		
Erosive	c	-
Sharp, Planer	r	c
Channel	r	r
Bed Geometry		
Sheet	r	c
Lenses	-	-
Shoe string/Prism	-	-
Structures		
Parallel/Wavy laminations	-	-
Grain fall and sand flow laminations	-	-
Plane bed laminations	a	r
Planar cross beds	r	a
Trough cross beds	-	-
Herringbone cross bedding	-	-
Graded bedding	-	-
Reactivation surface	-	r
Flaser bedding	c	r
Granule rich tabular cross bedding	-	r
Symmetric-wave modified current ripples	-	-
Asymmertrical ripples	c	c
Granular or sand ripples	-	-
Deflection lags	-	-
Texture		
Mean size (M_z)	2.51 Ø	2.20 Ø
Standard deviation (σ_I)	0.69 Ø	0.43 Ø
Skewness (SK_I)	0.27 Ø	0.00 Ø
Kurtosis (K_G)	0.94 Ø	1.13 Ø
Pebble	-	r
Granule	-	r
Bed thickness (cms)	<1-5	10-150

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Plate 1

Plate 2

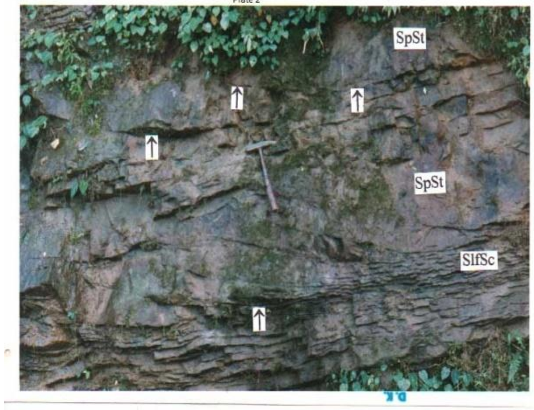

Plate 3

Plate 4

Plate 5

Palte 6

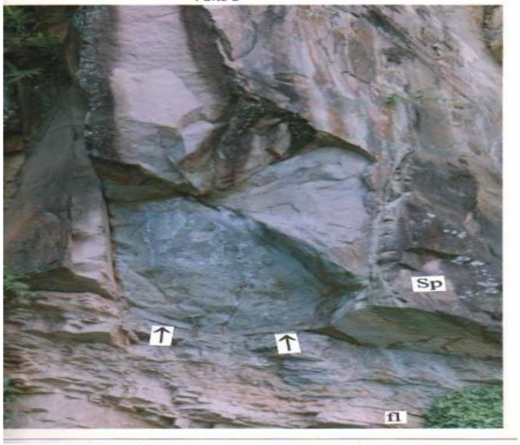

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Plate 7

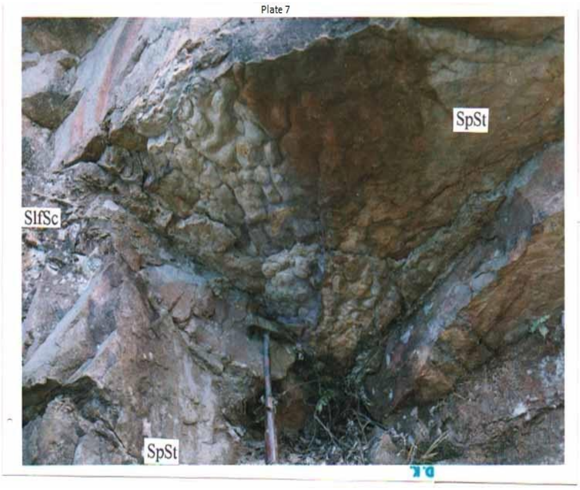

Plate 8

Plate 10

Plate 11

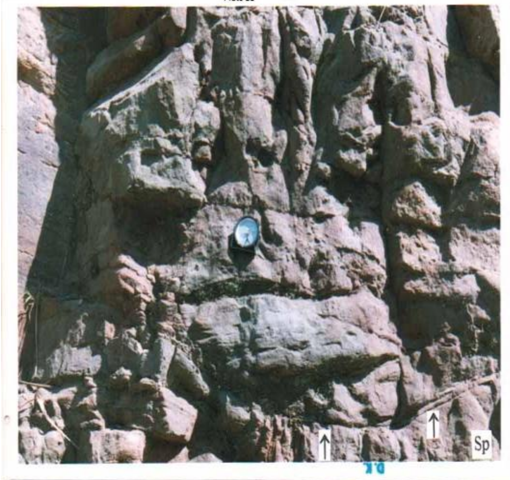

Plate 12

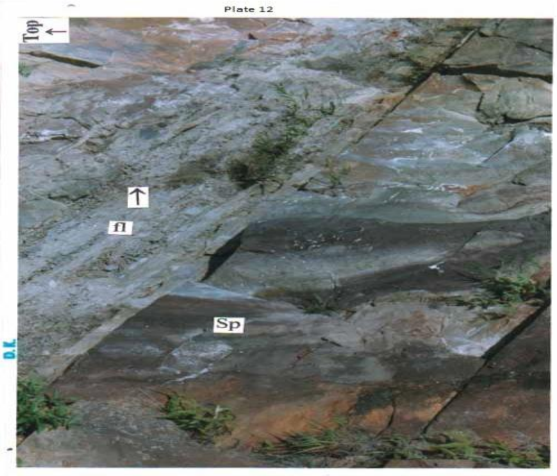

Plate 13

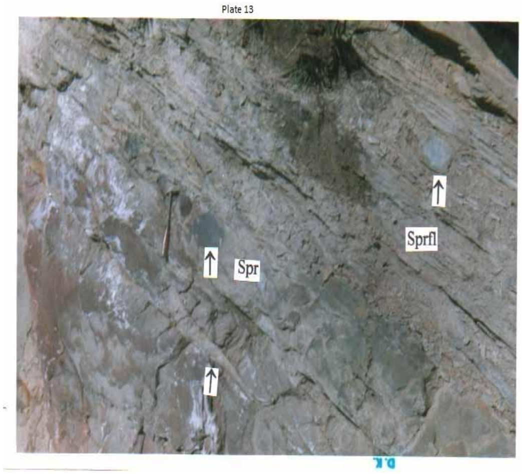

Plate 14

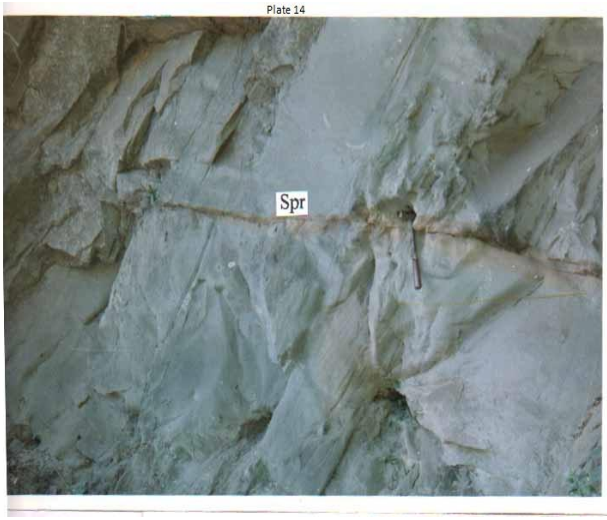

Plate 15

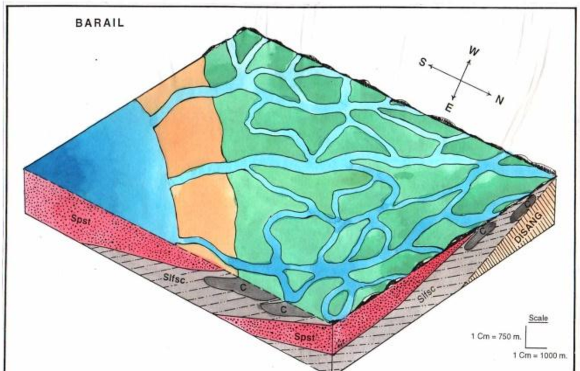

Fig. 2 : Conceptual model for the deposition of Barail Group, Changki valley, Nagaland.

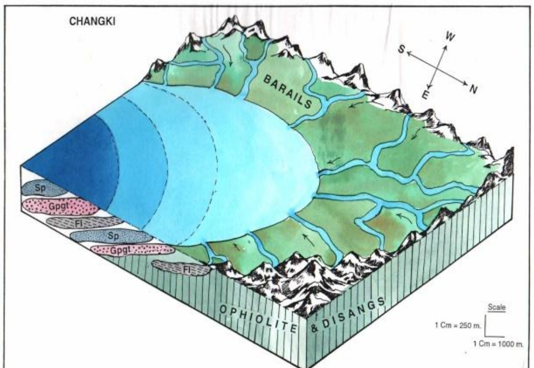

Fig. 3 : Conceptual model for the deposition of Changki Formation, Changki valley, Nagaland.

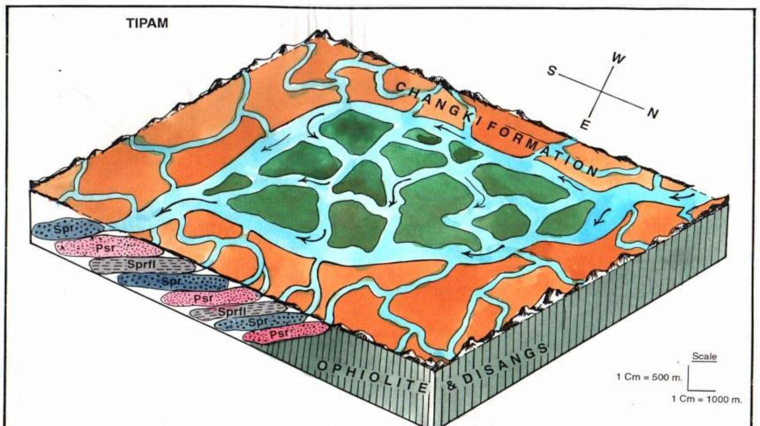

Fig. 4 : Conceptual model for the deposition of Tipam Sandstone Formation, Changki valley, Nagaland.

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