Journal of
Earth Science & Climatic Change

Mukherjee, J Earth Sci Clim Change 2015, 6:9
DOI: 10.4172/2157-7617.1000307

Research Article Open Access

Palyno-petrographical Study of the Siwalik Rocks of Some Areas of Arunachal Pradesh, North-Eastern India to Understand Palaeo-climatic Evolution of this Region

Mainak Mukherjee*

University of Calcutta, West Bengal-700073, India

Abstract

The palynological assemblages within the Siwalik shale rock samples from some areas of Arunachal Pradesh is studied to determine the palaeoclimatic condition. The petrographic study of the Shales also taken as the supportive to the determined palaeoclimate by the study of Palynological assemblages of 32 species and 30 genera taken separately from three distinct Siwalik strata, upper, middle and lower, collected from open exposures of Itanagar Banderdewa Roadside, Julu Village, and Pinjoli area of Arunachal Pradesh. The Palyno-petrographic study overall suggests that, during the lower siwalik, the region was highly coastal influenced with a dominating Tropical, humid climate. During the middle Siwalik, coastal influence was lowered, which shows coastline getting wiped out, and the temperature condition of Tropical- Sub-tropical climate. Upper Siwalik shows a further decreased coastal influence, with mainly a sub-tropical climate with an indication of temperate condition, which is indicative and supportive for the Pleistocene Glaciation in the global geological history.

Keywords: Arunachal; Palynology; Paleoclimatology; Siwalik

Introduction

The area of study includes some areas adjacent to Itanagar-Banderdewa Road and some areas of Julu village of Papumpare district where Upper and Middle Siwalik stratas are exposed respectively. The area of study also includes Pinjoli sector of West Kameng district where Lower Siwalik bedding have exposures. Both of these two districts are situated in the western part of Arunachal Pradesh, North-East India (Figure 1). The Siwalik rocks are underlain by Gondwana sequence which mainly comprises of carbonaceous shale, sandstone and coal with plant fossil. The Gondwana sequence is separated from the Lower Siwalik by Main Boundary Fault or MBF. Due to the MBF, Gondwana rocks are sometimes found overlying the Siwalik strata. The Siwalik strata are classified into three groups Lower, Middle, and Upper. The Lower Siwalik is essentially composed of well indurated sandstone, shale and siltstone, and abundant plant fossils. It is then further separated by a fault with the Middle Siwalik strata. The Middle siwalik is composed of weakly indurated sandstone with concretions, shale, siltstone and conglomerate, and abundant plant fossils. Middle and Lower Siwalik are separated by another fault. Lower Siwalik strata comprise mainly sandstone, claystone/shale and boulder beds/ gravel beds, and abundant plant fossils especially petrified and carbonized wood. Assam alluvia or the quaternary deposits cover the whole Siwalik stratigraphy. Assam alluvia are separated from the Siwalik essentially by Main Frontal Thrust or MFT. Due to this MFT Siwalik strata in a number of exposures are found to overlie the quaternary deposits. The generalized stratigraphic sequence of the Kameng Dist., in which the major part of the studied area lies, is shown in Table 1.

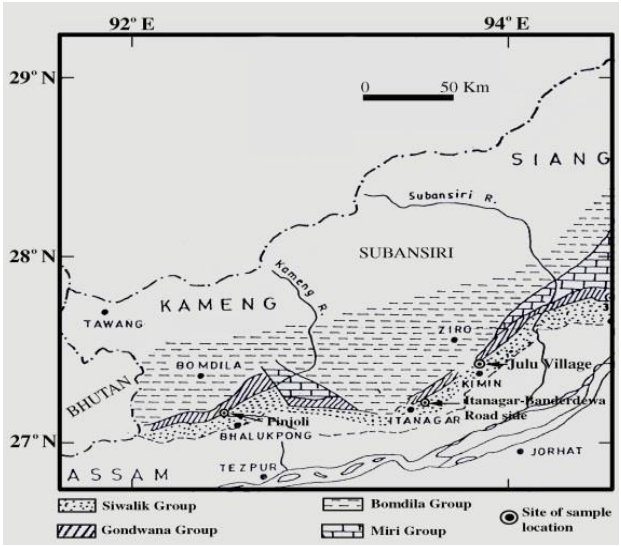

Figure 1: Map of part of Arunachal Pradesh showing locations of sample collection.

Previous work

A Miocene palynoassemblage was recorded from the Siwalik rocks of lesser Himalayas of Kameng district by Dutta and Singh [1]. The assemblage also contains reworked palynomorphs of Palaeozoic and Eocene age. Dutta [2] also recovered palynomorphs from the Siwalik rocks of Kameng district. The palynoassemblage recorded from the Tertiary sediments in Arunachal Pradesh by Srivastava and Bhattacharya, largely shows the overwhelming presence of angiosperm pollen viz., Lakiapollis, Neocourperipollis, Arecipites, pteridophytic spores viz., Todisporites, Cyathidites, Striatriletes and Crassoretitriletes. At some sections presence of dinoflagellate and acritarchs indicate marine intercalation in the area during early Tertiary. This palynoassemblage also contains reworked Permian palynomorphs. The palynological

***Corresponding author:** Mainak Mukherjee, University of Calcutta, West Bengal-700073, India, Tel: 033 2241 0071; E-mail: mmukherjee131187@gmail.com

Received September 07, 2015; **Accepted** September 21, 2015; **Published** September 31, 2015

Citation: Mukherjee M (2015) Palyno-petrographical Study of the Siwalik Rocks of Some Areas of Arunachal Pradesh, North-Eastern India to Understand Palaeo-climatic Evolution of this Region. J Earth Sci Clim Change. 6: 307. doi:10.4172/2157-7617.1000307

NORTH	
Gondwana	carbonaceous shale, sandstone and coal with plant fossils.
MBF	
Lower Siwalik	Well indurated sandstone, shale and silt-stone, abundant plant fossils.
Fault	
Middle Siwalik	Weakly indurate sandstone with concretions, shale, siltstone and conglomerate; abundant plant fossils.
Fault	
Upper Siwalik	Sand rock, claystone/shale and boulder beds/ gravel beds. abundant plant fossils especially petrified and carbonized wood
Main Frontal Fault	
SOUTH	Assam alluvia/ quaternary deposits

Table 1: Generalized lithotectonic sequence in the Ka-meng district, Arunachal Pradesh.

assemblages comprising angiosperm pollen, pteridophytic spores, fungal remains, gymnosperm pollen, dinoflagellate cysts, acritarchs and reworked Permian morphs have been reported from the Siwalik sediments ex-posed in Kameng, Subansiri and Siang districts by Singh and Saxena [3]. Khan, has recovered a palynoassemblage from the Upper Siwalik [4] sediments of Kimin Formation (Upper Pliocene-Lower Pleistocene), exposed at the road cutting section of Papumpare district, contain abundance of fungal remains followed by angiosperm pollen grains and pteridophytic spores and complete absence of gymnosperm pollen grains. This palynoassemblage indicates the prevalence of warm humid, tropical- sub tropical climate with occasional near shore condition during Upper Pliocene-Lower Pleistocene in the area [5].

Objective of Present Work

The objective of the present work is to study and understand the depositional environment and palaeogeography of the said area of Arunachal Pradesh during tertiary period by the palynological assemblage analysis and petrographical study as well of the collected rock samples of Siwalik shales.

Petrography

Lower Siwalik: It is a dark-colored, extremely fine grained rock composed of, in order of approximately decreasing abundance of sericite, clay, quartz, feldspar, iron oxide, biotite and chlorite. The most significant textural feature is the segregation of sericite-biotite-chlorite rich thin elongate patches (Figures 2-5). Sporadically through the rock; in such segregated patches there is distinct preferred orientation of micas along a particular direction, however, haphazard criss-cross pattern of orientation of sericite within the clay-rich part of the rock is also common. Both sericite and biotite (pleochroic from pale yellow to greenish brown) occur in the patchy segregations as thin elongate grains, occasionally forming bunches. Chlorite, apart from forming thin laths occurs also as medium sized subsequent flakes [6]. Iron oxides occur both as highly irregular brown limonitic grains as well as subhedral to anhedral equant to slightly elongate grains. Rarely thin rim of aggregates of biotite occur around black iron oxide grains. Iron ox-ide is more concentrated along the cracks. Sericite occurs within the clay commonly as sporadic needles [7].

Middle siwalik: The mineralogical composition and order of abundance is same here as in the Lower Siwalik samples. It is also a fine-grained rock, but the grain size is coarser than the Lower Siwalik samples (Figure 6).

Upper Siwalik: The mineralogical composition is mainly like the previous samples sporadic and medium sized, angular hornblende

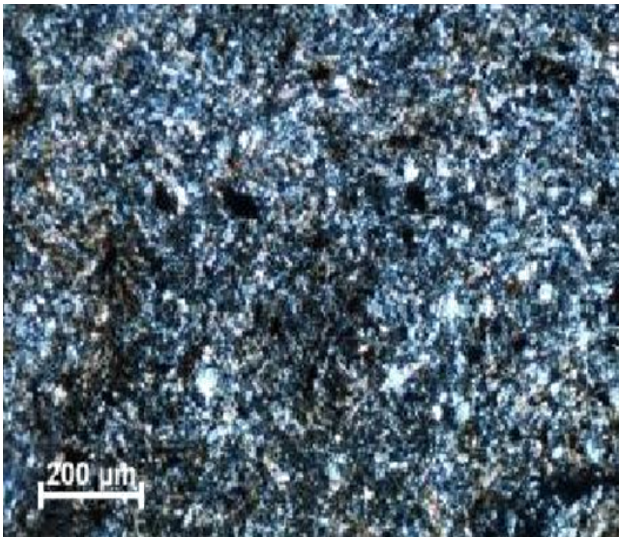

Figure 2: Photomicrograph of Lower Siwalik shales showing the very fine grain-size. (sample P16).

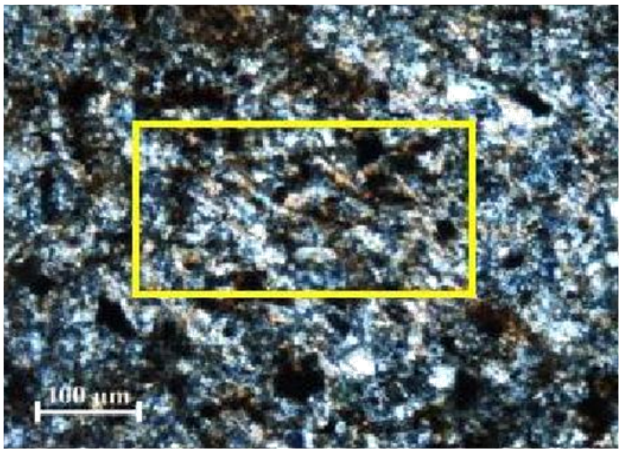

Figure 3: Photomicrograph of Lower Siwalik shales showing the very fine grain-size. Note preferred orientation of serici needles. Plane (sample P4).

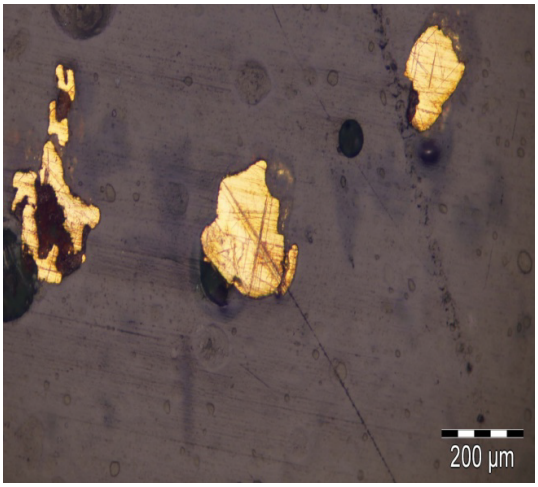

Figure 4: Photomicrograph of Lower Siwalik shales showing the very fine grain-size. Sericite needles showing criss-cross arrangement within the clay matrix. Crossed (Sample P4).

(strongly pleochroic from pale green to bluish green) thin lenticles of brown limonite occasionally show preferred orientation (Figure 7) through the fine-grained matrix [8]. The overall size of the matrix is similar to lower Siwalik. But the significant feature is the occurance of coarser clasts of quartz throughout the slide within the extremely fine grained matrix. The bluish colour of amphibole grain is due to high concentration of Na in its crystal structure. This in turn indicates high pressure metamorphism of the source rock/ provenance from where it is derived (Figure 8).

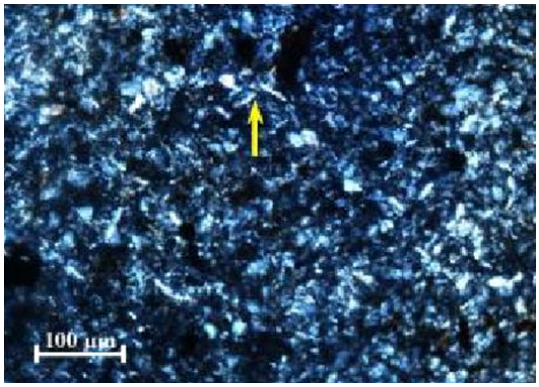

Figure 5: Photomicrograph of Lower Siwalik shales showing the very fine grain-size. Note a bit coarser grain-size than Lower Siwalik Shale and also criss-cross arrangement of sericite laths. Crossed (Sample JU 3A).

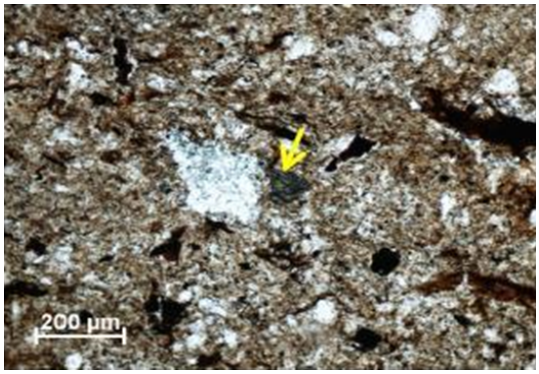

Figure 6: Photomicrograph of Upper Siwalik shales. Note presence of quartz clasts within the matrix. The arrow indicates an angular hornblende clast. Plane (Sample IB 7/4).

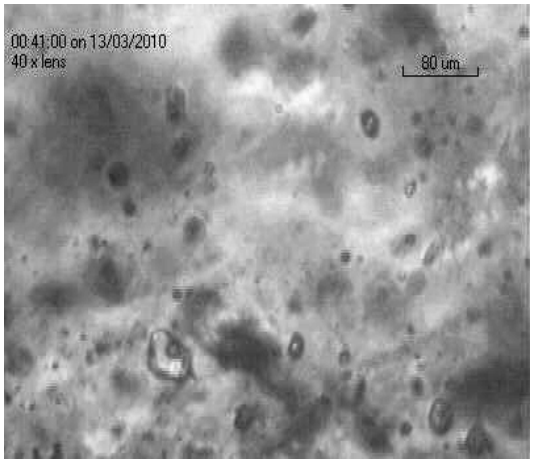

Figure 7: Photomicrograph of Upper Siwalik shales. Stringers of limonite occur filling up the cracks in the rock. Plane (Sample IB 7/8).

Palynology

Sample collection

The samples were collected from the exposures of Siwalik Shales from Pinjoli area of West Kameng Dist. and Itanagar-Banderdewa Roadside and Julu Village of Papumpare Dist. of Arunachal Pradesh, N-E India. These are exposure samples, not the drilled one [9,10].

Methodology

For Palynological study usual maceration technique has been adopted for recovery of palynomorphs with particular caution to avoid contamination. Each sample weighing 10 gm. was treated with 10% aqueous solution of HCL to dissolve carbonates, if any, washed thoroughly with distilled water followed by 40% HF treatment for 24 hours to remove all the silica contents. The HF-free samples were then treated with concentrated HNO_3 for few hours to few days depending on the maturation status of the samples. After thorough washing the samples were treated with 5-10% KOH (to dissolve the humic matters), sieved, washed with distilled water and dried partially. The samples were then suspended in a heavy liquid of KI-CdI2 mixture adjusted to a specific gravity of 2.3. To the supernatant liquid, five times distilled water was added and then few drops of 10% glacial acetic acid were added and kept for overnight, centrifuged, washed and finally preserved in distilled water or 50% glycerin. Fine slides (5.0 cm X 2.2 cm) were prepared and preserved by cover glass for study under biological microscope. The best-preserved forms were photo-graphed and studied through Image Analyzer for detailed morphologic character analysis including measurement. Each of the bioforms is stored in a hard disk of computer. The pre-pared slides are stored in the repository of palaeobotany- palynology laboratory section of the Department of Botany, University of Calcutta.

Palynological characters

The total number of Genus recovered is 30. And the total number of species recovered is 32, of which 15 are fungal spores, 8 are pteridophytes,

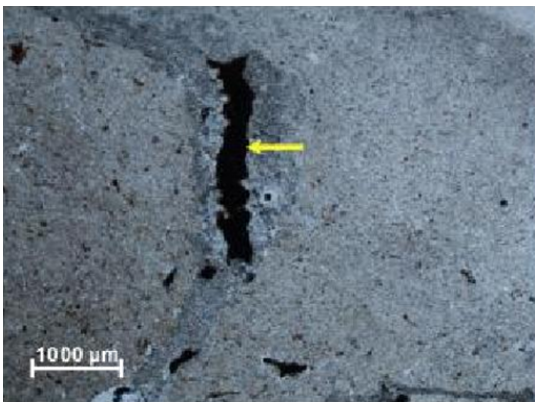

Figure 8: Photomicrograph of Upper Siwalik shales Showing the fracture filling irregular elongate black opaque iron oxide. Plane (IB 7/8).

and 9 are angiosperms. The description of each individual Palynotaxa is given below.

The Description of the Microspores Present

Fungi

1. Genus- Colligerites Jain and Kar

Species- Colligerites kutchensis (Kar and Saxena) Jain and Kar

Description- spores multicellular, coiled, cells generally smaller, rounded in central region and bigger, Rectangular in outer region. Spore wall mostly levigate, some-times granulose. Pore may be present or absent in each cell.

2. Genus- Inapertisporites Van der Hammen ex Rouse

Species- Inapertisporites sp.

Description- Spores unicellular, sub-spheroidal to ellipsoidal, sizes between + 9-54 µm X 9-36 µm; light to dark brown in colour, in aperturate, without any folds, spore wall + 1-1.5 µm thick, psilate.

3. Genus- Monoporisporites Van der Hammen

Species- Monoporisporites sp.

Description- Spores unicellular, spherical to subspherical, ellipsoidal or obovate, sizes between + 6 X 4- 27 X 15 µm, dark brown in colour, monoporate, pore towards one side, simple, without folds. Spore wall + 1-1.5 µm thick, distinctly 2-layered, psilate.

4. Genus- Quilonia Jain and Gupta

Species- Quilonia sp.

Description- Body multicellular, filamentous, exine thick, margin undulated, Apical and Basal portions narrow, central [section] wide. Basal stalk prominent with one or two rectangular thick-walled cells; apical cell mostly in-complete, curved, central portion broad, elongate. With irregularly shaped furrow-like suture, inside the filament at different places occur one-four small, circular, ostiolate bodies.

5. Genus- Dicellaesporites Elsik

Species- Dicellaesporites sp.

Description- Spores two-celled, uniseptate, uniseriate, inaperturate, 12 µm long, 4-5.5 µm broad, slightly constricted at joining of two cells, free ends rounded; cells apparently dissimilar, one clearly larger, longer than the broad, blackish blown; other cell small, broader than long, 3 µm elements, wall ca 0.5 m thick and relatively lighter in colour; septum transverse, prominent, 1 µm broad.

6. Genus- Dyadosporites Van der Hammen

Species- Dyadosporites sp.

Description- Fungal spores bilocular, elliptical, central septum simple, cell wall psilate to finely punctuate, pore at apex of each cell, sizes between 31-42 µm X 12-16 µm.

7. Genus- Desmidiospora Thaxter

Species- Desmidiospora willoughbyi (Bradley) Ethridge, Brown and Elsik

Description- Sporangia thick-walled and flattened in the plane of the substratum, circular, 8-22 µm diameter, to irregularly elliptical, up to as much as 22 µm long. Sporangia more or less deeply lobed, the lobes being separated by distinctive narrow invaginations, many of which have a characteristic circular enlargement at the proximal ends. In larger sporangia these invaginations commonly occur in radial sets of two or three length, each shorted invaginations being be-tween two next longer invaginations. Sporangia smooth or papillate, some having the persistent, thickened zoospore cyst, 2.5-3.5 µm diameter, ad germ tube. Many have clearly defined, circular exit pore.2-2.5 µm in diameter. Zoospores and rhizoidal axis unknown.

8. Genus- Exesisporites Elsik

Species- Exesisporites sp.

Description- Unicellular, aseptate, psilate, monoporate fungal spores of circular outline with lenticular to spherical in shape. The centrally located pore in most specimens is surrounded by a dark circular patch which is interpreted as a thickened wall. This polar area is occasionally found free of the spore. Spores 17-30 µm in diameter in polar view.

9. Genus- Fractisporonites Clarke

Species- Fractisporonites sp.

Description- Fungal spores uniseriate, fragments consist of four to many rectangular to square cells, 16-28 µm high, 25-30µm diameter. Overall dimensions 25-30 X 150-230 µm, sides generally parallel.

10. Genus- Hypoxylonites Elsik

Species- Hypoxylonites sp.

Description- Oval to elongate, aseptate, bilateral, psilate fungal spores bearing an elongate scar, slit or furrow. At the level of transmitted light microscopy, at least one species is faintly sculptured. The elongate furrow is parallel to this axis and can be of various lengths. Apices rounded to pointed; usually of similar shape but some species have an attachment scar at one end; apices can also be thickened or otherwise modified. The spore wall in most specimens is generally rigid.

11. Genus- Hypoxylonites Elsik

Species- Hypoxylonites gulfensis Elsik

Description- Bilateral, reniform, aseptate, psilate fungal spores with a longitudinal furrow generally ½ or less of the length of the straight or concave side of the spore.

Overall size 7-10 X 25-32 um. Spore wall 0.25-0.5 um or slightly thicker, thickening to a maximum of 1.5 um over the ends of the spore in a few specimens; not thickened in other specimen: Aperture a narrow furrow with rounded ends. Ends of spore sub-pointed or narrowly rounded.

12. Genus- Multicellites gen. nov.

Species- Multicellites sp.

Description- Multicellate, uniserial, inaperturate fungal spores; number of cells three to many; terminal cells usually smooth, of medium thickness, usually thinner than the septa (or septal base).

13. Genus- Scolecosporites Lange and Smith

Species- Scolecosporites sp.

Description- Scoleco- phragmospore of length 15-30 X the breadth, the outline of walls and septa ladder-like.

14. Genus- Scleroderma Persoon

Species- Scleroderma echinosporites Rouse

Description- Spores small, circular in outline, with no obvious openings or pores in the wall. Ornamentation consists of fine spines radiating out from the wall. These cover the spore except at one place, which presumably was the place of attachment of the sterigma. The wall also seems coarsely punctuate, with, thin areas more or less scattered onto the surface, size range 11-15um.

15. Genus- Phragmothyrites Edwards

Species- Phragmothyrites sp.

Description- Fossil forms belonging to the Microthyriaceae, the exact position of which is uncertain, but which appear to be most closely related to Phragmothyrium as defined by Von Hohnel. No free hyphae, ascostromata sub-circular- circular, dimidiate, non-ostiolate; hyphae radially arranged, interconnected to form pseudopar-enchymatous cells; central cells + squarish sub cicular, outer cells elongated, may be setose atmargin and thickened. Cells with or without pore, generally cells in the middle region are more porate than outer ones.

Pteridophyta

1. Genus- Polypodiaceaesporites Thiergart

Species- Polypodiaceaesporites sp.

Description- Spore bean shaped, 54 um, monolete, exine 2um thick, exo-exinous layer very thin, exinelaevigate and weakly infrastructured.

2. Genus- Cyathidites Couper

Species - Cyathidites sp.

Description- Free anisopolar, trilete, laesurae distinct, long, spores triangular to sub-triangular, apices very broadly rounded and sides concave in polar view. Exine psi-late, 1.5 um thick, size ranges from 31-(35)-45 um.

3. Genus- Lygodiumsporites Potonie, Thomson and Thiergarte emend

Species- Lygodiumsporites sp.

Description- Spores sub-triangular size range 55-60 um, trilete distinct, extendint upto two-thirds the radius; exine laeviogate.

4. Genus- Deltoidospora

Species- Deltoidospora sp.

Description- Trilete spore. Outline triangular with straight to convex sides in polar view. Laesurae distinct and long, exceeding 2/3 of the radius of the spore, Exine two-layered; surface of exine psilate and kyrtomes develop along the laesuraea. Size is 32.0 X 25.0um.

5. Genus- Polypodisporites

Species- Polypodisporites sp.

Description- Trilete, roundly triangular, cingulated spore with concave sides. Y mark distict; aesuraea reaching the edge of the inner body, narrow and surrounded by exinal thickenings. Exine psilate; cingulum about 6.0 um side and psilate. Size is 35 um.

6. Genus- Pteridacidites

Species- Pteridacidites sp.

Description- Trilete cingulated spore. Contour triangular with rounded corners and slightly concave sides. Y mark dis-tinct; laesuraea thin and prominent, reaching upto the end of the spore body, but not entering the cingulum. Spore body covered, proximal and distal side with generally large polyangular, flat topped verrucae. Cingulum psilate and 4.0-6.0 um wide. Size is about 31.0-33.5uum.

7. Genus- Lycopodiumsporites Thiergart ex Delcount and Spurmont

Species- Lycopodiumsporites sp.

Description- Spores triangular, 22-35uum, trilete distinct, rays extending upto three fourths of the radius; reticulate, proximal muri ill-developed, do not anastomose to form regular meshes, distal muri form a regular reticulum. Exine 2-3um thick.

8. Genus-Gleichenidites Ross

Species- Gleichenidites sp.

Description- Miospore triangular or sub-triangular, apices rounded, sides concave, size 27um-29.5um, trilete, Y-mark slender but distinct, rays extending more than 2/3rd of the spore radius, lip thin, ends pointed. Exine 1.5um-2um thick, surface laevigate. Distal face provided with three arcuate folds and proximal intertidal thickenings.

Angiosperm

1. Genus- Palmaepollenites (Potonie) ex Potonie

Species- Palmaepollenites sp.

Description- Pollen grains bilateral, elliptical, 45uum in size, ends and bordered by thick exine, + 1.5 um thick, psilate.

2. Genus- Cupuliferoidaepollenites

Species- Cupuliferoidaepollenites sp.

Description- Tricolpate pollen grain, outline sub-circular in polar view; colpi narrow and long almost reach-ing the poles and are uniform width. Exine over 1.0 um thick, two layered; nexine is thicker than sexine; surface of exine psilate, size is about 15.0 um in diameter.

3. Genus- Betulaepollenites

Species- Betulaepollenites sp.

Description- Triporate pollen grain, outline small and triangular. Exine thin and psilate. It is characterized by the presence of arci connecting all the three pores and running nearer the equator and away from the poles. Size is 22.0 um.

4. Genus- Graminidites Cookson

Species- Graminidites media Cookson

Description- Pollen grains sub-spheroidal to sub-triangular, sides convex to slightly rounded, trilobite, poles somewhat flattened to rounded, 36-38um X 40um in size. Monoporate, pore rounded + 4 um in diameter, aspidate with thick annulus. Exine thin, surface granulate.

5. Genus- Dicolpopollis

Species- Dicolpopollis sp.

Description- Dicolpate pollen grains. Amb barrel shaped, biconvex in polar view. Colpi short, about 5.0 um deep and wide. Exine thn, about 1.0 um thick, atectate, psilate to chagrenate, size variable, small to medium. Size varies from 25.0-47.0um X 20.0-25.0um. verrucate with some scabrae.

6. Genus- Liliacidites Couper

Species- Liliacidites sp.

Description- Pollen grains elongate, ellipsoidal, monosulcate, 50 X 25um in size. Sulcus as the pollen length, open at both ends and of uniform width. Exine upto 1 um thick, tectate, surface reticulate.

7. Genus- Quercoidites

Species- Quercoidites sp.

Description- Pollen grains spheroidal in shape, 30 X 25.5um in size, tricolpate. Exine 1.5-2.0um thick, sculpture.

8. Genus- Araliaceoipollenites Potonie ex Potonie

Species- Araliaceoipollenites sp.

Description- Pollen grains oval in shape, tricolporate, 21 X 20um in size, colpi long, narrow, extending from one margin to other. Pores distinct, lalongate. Exine 2.5um thick unequal thickening of the exine in the margin, intrami-croreticulate.

9. Genus- Rhoipites Wodehouse

Species- Rhoipites sp.

Description- Pollen grains spheroidal, tricolporate, pore lalongate. Exine less than 1um in thickness, two-Layered, surface very finely ornamented.

Recovered Palynotaxa	Nearest living Relative		Siwalik (Arunachal Pradesh)		Habit	Climate/Environment
		Lower	Middle	Upper		
FUNGI						
Inapertisporites sp	Fungi imperfecti	_	+	+	Thallo-phyta	Tropical, Humid
Monoporisporites sp	Fungi imperfecti, amerosporae	+	+	_	Thallo- phyta	Tropical, Humid
Quilonia sp	Fungi imperfecti, phragmosporae	_	_	+	Thal- lophyta	Tropical, Humid
Dicellaesporites sp	Fungi imperfecti	_	+	_	Thal- lophyta	Tropical, Humid
Dyadosporites sp	Fungi imperfecti	_	_	+	Thal- lophyta	Tropical, Humid
Desmidiospora willoughbyi	Fungi imperfecti, amerosporae	_	_	+	Thal- lophyta	Tropical, Humid
Exesisporites sp	Fungi imperfecti	_	_	+	Thal- lophyta	Tropical, Humid
Fractisporonites sp	Fungi imperfecti, phragmosporae	_	+	_	Thal- lophyta	Tropical, Humid
Hypoxylonites sp	Fungi imperfecti, amerosporae	+	+	+	Thal- lophyta	Tropical, Humid
Hypoxylonites gulfensis	Fungi imperfecti, amerosporae	_	+	_	Thal- lophyta	Tropical, Humid
Multicellites sp	Fungi imperfecti, phragmosporae	_	+	_	Thal- lophyta	Tropical, Humid
Scolecosporites sp	Fungi imperfecti, phragmosporae	_	_	+	Thal- lophyta	Tropical, Humid
Scleroderma echi- nosporites	Basidiomycetes, sclerodermatales	_	+	_	Thal- lophyta	Tropical, Humid
Phragmothyrites sp	Ascomycetes, Microtyriale	_	+	+	Thal- lophyta	Tropical, Humid
Colligerites kutch- ensis	Fungi imperfecti, helicosporae	+	_	_	Thal- lophyta	Tropical, Humid
PTERIDOPHYTES						
Polypodiaceaespo- rites sp.	Polipodiacaea	+	+	+	Herb	Tropical-Subtropical
Cyathidites sp.	Cyatheaeae	_	+	+	Herb	Tropical-Subtropical
Lygodiumsporites sp.	Lygodium of Schizeaceae	+	_	_	Herb	Tropical-Subtropical
Deltoidospora sp.	Lindsaeaceae	_	+	_	Herb	Tropical-Subtropical
Polypodiisporites sp.	Denstaedtiaceae	+	+	+	Herb	Tropical- Temperate
Pteridacidites sp.	Pteridaceae	_	+	+	Herb	Tropical-Subtropical
Lycopodiumsporites sp.	Lycopodium	+	_	_	Herb	Tropical-Subtropical
Gleichenidites sp.	Gleichaeniaceae	+	_	_	Herb	Tropical-Subtropical
ANGIOSPERMS						
Palmaepollenites sp.	Arecaceae	+	+	+	Tree	Tropical- Subtropical
Cupuliferoidaepol- lenites sp.	Cupuliferae Fagaceae	+	_	_	Tree	Temperate
Betulaepollenites sp.	Betulaceae	_	_	+	Tree	Temperate
Graminidites media	Poaceae	+	+	+	Grass	Cosmopolitan
Dicolpopolis sp.	Calamus, palmae	_	+	+	Tree	Tropical- Subtropical
Liliacidites sp.	Liliacae	_	_	+	Herb	Cosmopolitan
Quercoidites sp.	Fagaceae	_	_	+	Herb	Subtropical Temperate
Araliaceoipol- lenites sp.	Araliaceae	+	_	+	Herb	Tropical
Rhoipites sp.	Anacardiaceae	+	+	_	Herb	Temperate

Table 2: The chart for palynotaxa recovered from various Strata and the palaeo-environmental analysis with reference to their nearest living relatives and habit.

Environmental Analysis

The Palaeo-environment can be concluded from the systematic analysis of the percentile distribution of the palynomorphs in the Upper, Middle and Lower Siwalik strata.

Conclusion

Although the systematic and quantitative analysis of the palynotaxa recovered (Table 2) shows that the predominance of fungal spores over angiosperms and pteridophytes all over the Lower and Middle Siwalik (Figures 9 and 10). However, a slight decrease in frequency of fungal elements has been observed in Middle Siwalik than that of Lower Siwalik sediments. In contrast to Lower and Middle Siwalik sediments, the sediments of Upper Siwalik age show the dominance of angiosperms over fungal spores and pteridophytes (Figure 11) [11-15]. The palynoassemblages of Lower Siwalik sediments suggest that the overall climatic conditions during the Lower Siwalik was mostly Tropical and humid. However, presence (~18% total) of Cupuliferodaepollenites sp. and Polypodiisporites sp. indicates towards a slight influence of temperate climate (Figure 12). Cosmopolitan Graminidites sp. was present as usual. A major percentage of Palmae indicates that the region was mainly coastal. The thallophytes dominated all over. In Middle Siwalik, frequency of recovery of palm pollen grains of Dicolpopolis sp. and Palmaepollenites sp. Decreased (Figure 12) than that of Lower Siwalik sediments. This indicates that the coastal influence is lowered during the Middle Siwalik times. The pteridophytes, which grow in the tropical to sub-tropical condition, dominate the pteridophytic assemblage. So the overall climatic condition during Middle Siwalik was mostly tropical to Subtropical with a lowered coastal influence. Frequency of Palmae has been reduced in The Upper Siwalik sediments than Lower and Middle Siwalik sediments indicating a lesser influence of coastal environment in the Upper Siwalik. A reduced recovery of thallophytes indicates a less humid condition (Figure 11).

That means the coastline moved further away during Upper Siwalik and as effect humidity decreased [16]. And the presences of mainly Tropical to Sub-tropical taxas are dominating. But there is a

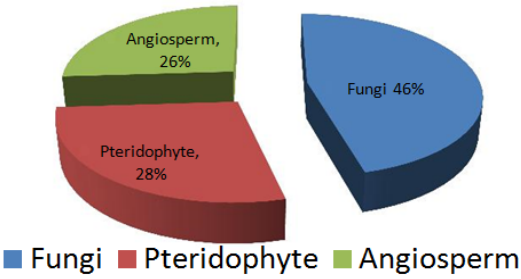

Figure 9: Frequency of recovery of palynotaxa from lower siwalik sediments.

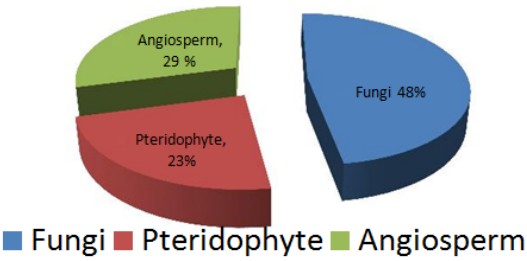

Figure 10: Frequency of recovery of palynotaxa from middle siwalik sediments.

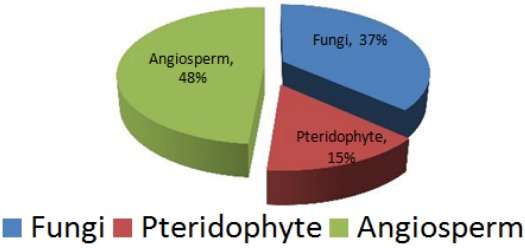

Figure 11: Frequency of recovery of palynotaxa from upper siwalik sediments.

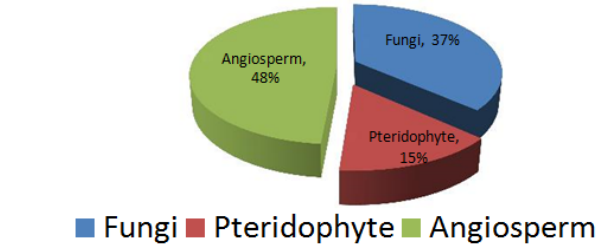

Figure 12: Abundance comparison of Individual Taxa during Lower, Middle and Upper Siwalik.

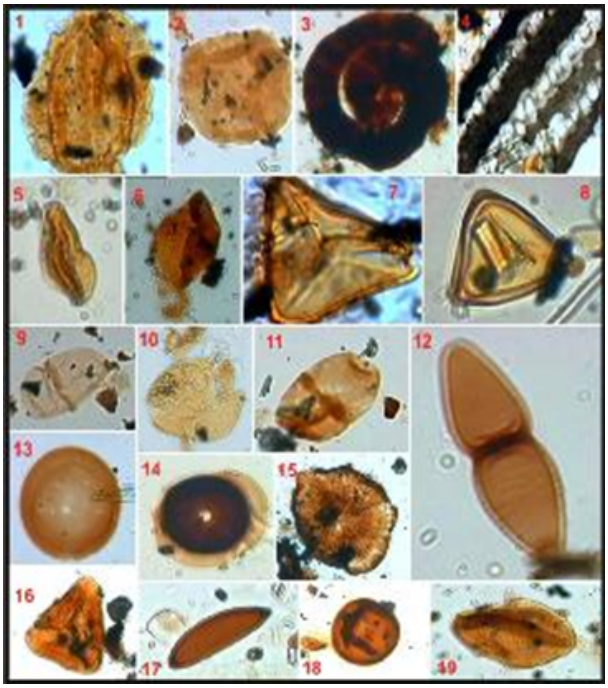

Figure 13: PLATE-I (Magnification is 600X, if mentioned otherwise along with the names of the species). *1. Araliaceaepollenites sp., 2. Betulaepollenites sp., 3. Colligerites kutchensis (350X), 4.* Grass cuticle, *5 & 6. Cufuliferoidaepollenites sp (350X), 7. Cyathidites sp., 8. Deltoidospora sp (350X), 9. Dicellaesporites sp, 10. Dicolpopolis sp (350X), 11 &12.Dyadosporites sp., 13 & 14.Exesisporites sp., 15.Phragmothyrites sp. (350X), 16. Gleicheniidites sp. (350X), 17.Hypoxylonites gulfensis (350X), 18.Inapertisporites sp (350X), 19.Liliacidites sp. (350X).*

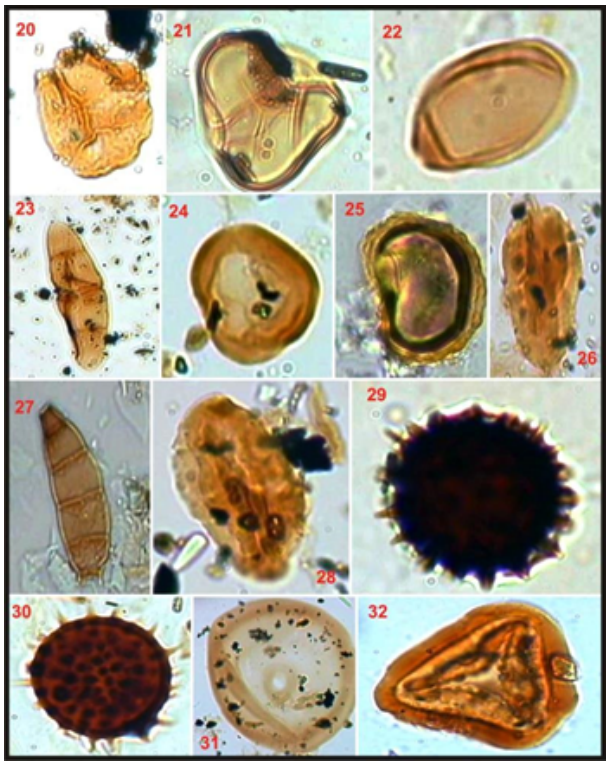

Figure 14: PLATE II (Magnification is 600X, if mentioned otherwise along with the names of the species). *20. Lycopodiumsporites sp (350X), 21. Lygodiumsporites sp(350X) 22.Monoporisporites sp 23.Multicellites sp.(350X) 24.Palmaepollenites sp. 25. Polypodisporites sp.(350X), 26. Quer-coidites sp. 27. Quilonia sp, 28. Rhoipites sp. 29 & 30. Scleroderma echinosporites 31.Monoporisporites sp. 32.Pteridacidites sp.*

major percentage (~20% total) of Sub-tropical to Temperate condition favouring Queroidites sp. and Betulaepollenites sp. (Figure 12) Angiosperms indicates that the climatic condition was mainly Sub-tropical to temperate during Upper Siwalik. The large percentage of fungal spores during all over the Siwalik, however, does indicate the high rate of deposition. Petrographic study also indicates to a coastal vicinity influence (Figures 13 and 14).

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