Palynology of Middle Siwalik sediments (Late Miocene) from Bagh Rao, Uttar Pradesh

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Sarkar S, Bhattacharya Ananta P & Singh HP 1994. Palynology of Middle Siwalik sediments (Late Miocene) from Bagh Rao, Uttar Pradesh. *Palaeobotanist* **42**(2) : 199-209.

A Late Miocene palynofloral assemblage, recovered from the Siwalik sediments exposed at Bagh Rao in Uttar Pradesh, has been studied. It contains a variety of spores, pollen grains and algal and fungal remains. Based on palynofloral analysis two distinct palynological zones A and B are established. The presence of *Botryococcus*, *Pediastrum*, *Zygnema*, *Azolla* and *Nymphea* indicates fresh water environment during the deposition of Zone A sediments. Zone B lacks the presence of aquatic elements. However, it shows the abundance of montane elements, viz., *Pinus*, *Podocarpus* and *Tsuga* in addition to the pollen of Poaceae, Asteraceae and *Acacia*. The sediments of Zone B appear to have been deposited in much drier conditions than that of Zone A. The overall palaeobotanical evidences point out the prevalence of low land rainforests under warm humid climate in the area of investigation.

Key-words—Palynology, Freshwater elements, Montane elements, Middle Siwalik, Late Miocene (India).

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साराँश

उत्तर प्रदेश में बाघ राव से मध्य शिवालिक अवसादों (अनन्तिम मध्यनूतन) का परागाणविक अध्ययन

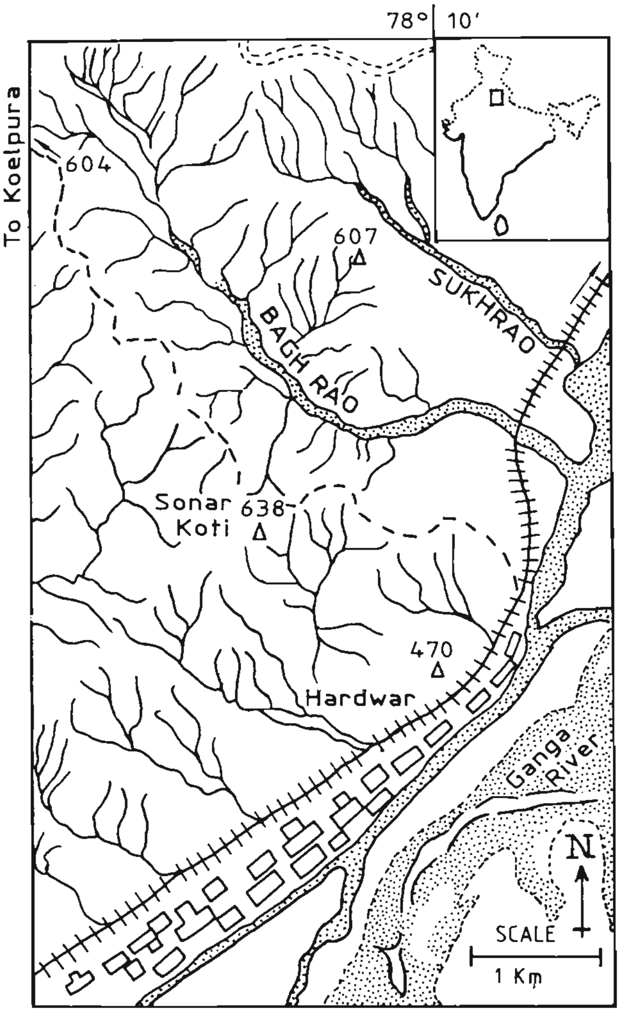
समीर सरकार, अनन्त प्रसाद भट्टाचार्य एवं हरपाल सिंह

उत्तर प्रदेश में बाघ राव के आस-पास विगोपित शिवालिक अवसादों से उपलब्ध अनंतिम मध्यनूतन परागाणविक समुच्चय में विद्यमान कई प्रकार के बीजाणु, परागकण एवं शैवालीय अवशेषों का अध्ययन किया गया है। परागाणविक विश्लेषण के आधार पर दो स्पष्ट मंडल– ए. एवं बी., प्रस्तावित किये गये हैं। ***बॉट्रीओकॉकस, पेडिआस्ट्रम, जिग्नीमा, अँज़ोला*** एवं ***निम्फ़िआ*** की उपस्थिति से मंडल-ए. के निक्षेपण के समय स्वच्छ जलीय वातावरण इंगित होता है। मंडल-बी में जलीय अवयव अनुपस्थित हैं। तथापि, इसमें पर्वतीय अवयवों जैसे ***पाइनस, पोडोकार्पस*** एवं ***सूगा*** तथा पोएसी, एस्टेरेसी एवं ***अकेशिया*** के परागकणों की बाहुल्यता है। अध्ययन से व्यक्त होता है कि मंडल-बी के अवसाद मंडल-ए. की अपेक्षाकृत अधिक शुष्कतर परिस्थितियों में निक्षेपित हुए थे। समग्र रूप से पुरावनस्पतिक प्रमाणों से इस क्षेत्र में उष्ण-नम जलवायु में विकसित निम्नभूमि वाले वर्षा-वनों की उपस्थिति व्यक्त होती है।

THE Siwalik Group (Miocene-Pliocene) of rocks form an important succession in the Tertiary strata of the Indian subcontinent. These continental deposits were laid down in the fore deep on the southern side of the rising Himalaya all along the sub-Himalayan range of India, Nepal and Pakistan. The Siwalik sediments attracted the attention of palaeontologists because of their rich vertebrate fauna.

However, palynological information available from these sediments is very scanty as most of the investigated samples from these areas have been found to be barren or with very few palynofossils (Badgley & Behrensmeyer, 1980; Ranga Rao *et al.*, 1981). During palynological investigation of the Lower Tertiary formations of north-western Himalaya, the present author's have processed few Siwalik samples containing well-preserved palynofossils of Late Miocene at Bagh Rao, northern India (Text-figure 1). Considering its potential to reveal palaeoclimatic and palaeoecological information in the sub-Himalayan region during the Neogene Period a detailed palynological study of this area was undertaken.

Therefore, the present study is aimed to record palynofossils from the Middle Siwalik sediments (Late Miocene) exposed at Bagh Rao and also to evaluate their bearing on palaeofloristics, palaeoclimate, and palaeoenvironments. Available contemporary palynological data has also been used to assist in identification of stratigraphically and ecologically significant palynotaxa.



Text-figure 1—Shows the location of Bagh Rao locality, Dehradun District, Uttar Pradesh, India.

GEOLOGICAL SETTING

Middle and Upper Siwalik sediments are exposed at Mohand (30°11'N: 70°55'E) in the Saharanpur District, Uttar Pradesh. The rocks are folded into an anticline with its axis aligning in NW-SE direction. The south-eastern limb is better exposed in the Bagh Rao area. The dip of the rocks varies from 25°-45° and at places it is much steeper. The Middle Siwalik lithology is generally represented by grey to greenish grey, thick bedded, friable, poorly sorted and fine to coarse-grained sandstone. The occurrence of leaf-impressions on clay partings, petrified tree trunks and pockets of lignites has been reported in some horizons (Sinha, 1970). The Upper Siwalik sediments are represented by conglomerates. Generally the conglomerates are loose, although at times quite hard due to secondary enrichment by carbonate. The location of productive samples has been shown in Text-figure 2.

MATERIAL AND METHODS

The material for the present study was collected from the Siwalik sequence exposed along the Bagh Rao near Hardwar. The samples consist of clay, siltstone, silty shale and carbonaceous shale which occur as thin intercalations in the thick sequence of sandstone. Of the 17 samples macerated, only 7 samples yielded rich palynoassemblages. The palynofossils were recovered from the samples by employing the conventional technique of maceration. HCl, HF, HNO3 and KOH reagents were used to complete the process. Palynofossils have been recorded only from thin intercalated clay partings between the thick sandstones. This situation is quite normal with the Siwalik strata. In case of poorly yielding samples heavy liquid floatation technique using Potassium-Cadmium-Iodide solution was employed for better recovery of palynofossils. Slides were prepared in polyvinyl alcohol and mounted in Canada balsam. Three hundred palynofossils per sample were counted for quantitative analysis.

LIST OF PALYNOFOSSILS RECORDED

A check-list containing well known palynotaxa but without description has been given. Selected palynofossils have been commented upon, wherever necessary. Palynotaxa are arranged alphabetically with in the categories, viz., algal and fungal remains, pteridophytic spores, gymnospermous and angiospermous pollen and *Incertae sedis*.

A. Algal remains

1. *Botryococcus braunii* Kützing 1840 (Pl. 1, fig. 8)
2. *Pediastrum compactum* Singh & Khanna 1978 (Pl. 1, fig. 2)
3. *Spirogyra* zygospore (Pl. 1, fig. 10)

Remarks—Several specimens closely comparable to the zygospores of *Spirogyra* have been recovered. The specimens are ellipsoidal in outline with a size-range from 80 × 100 to 95 × 110 μm. Each specimen is characterised by having a longitudinal furrow. The wall is very thin with laevigate to infrapunctate ornamentation.

4. *Zygnema* zygospore (Pl. 1, fig. 5)

Remarks—Zygospores are quadrate, most of them are crumpled, with size range from 55-65 to 100-115 μm. The walls are very thin and finely pitted. A circular depression with a very hyaline wall has been noticed in most of the specimens. These zygospores closely compare with those of extant genus *Zygnema* of Zygnemaceae (Randhawa, 1959).

B. Fungal remains

5. *Callimothallus assamicus* Kar, Singh & Sah 1970
6. *Inapertisporites circularis* Sheffy & Dilcher 1971
7. *Inapertisporites ovalis* Sheffy & Dilcher 1971
8. *Multicellaesporites* sp.
9. *Notothyrites amorphus* Kar & Saxena 1976
10. *Phragmothyrites eocaenica* Edwards 1922

C. Pteridophytic spores

11. *Azolla* microspores (Pl. 1, fig. 9)

Remarks—Only a few microspores of the genus *Azolla* have been studied. They are mostly embedded in the spongy massula. Massulae are circular to subcircular with size varying from 130 to 140 μm. Microspores possess a distinct trilete mark with laesurae extending up to the equator.

12. *Azolla* megaspore Type-1 (Pl. 1, fig. 13)

Remarks—The present specimen has long conical column. Perispore is slightly lamellated and the upper part is foveolate. The oval-shaped megaspore has a trilete mark with thick and sinuous laesurae. Megaspore wall has fove. late ornamentation. Floats are spongy in nature. These specimens are comparable with *Azolla vellus* (Dijkstra) Jain & Hall 1969 except in having smaller size range. Megaspore length varies from 200 to 250 μm including the float.

13. *Azolla* megaspore Type-2 (Pl. 2, fig. 19)

Remarks—Several specimens of *Azolla* megaspore Type-2 have been recorded in the present assemblage but most of them are broken. Megaspores with the float have been found rarely. The perispore surface has an even texture and appears foveolate uniformly. Some small excrescences are present on the lower side. Triradiate crests are prominent. Floats are nine in number, arranged in two rows, three larger ones are present at the apical side whereas six smaller ones are present below them. Few verrucae have also been noticed on the floats. The present megaspore specimens resemble those of modern *Azolla nilotica*.

14. *Cheilanthoidspora mioceneca* Kar & Jain 1981 (Pl. 1, fig. 6)
15. *Cyathidites australis* Couper 1953
16. *Foveosporites canalis* Balme 1957 (Pl. 2, fig. 1)
17. *Intrapunctisporis intrapunctis* Krutzsch 1959 (Pl. 2, fig. 21)
18. *Leptolepidites verrucatus* Couper 1953 (Pl. 2, fig. 2)
19. *Leptolepidites* sp. (Pl. 2, fig. 3)
20. *Lycopodiumsporites parvireticulatus* Sah & Dutta 1966 (Pl. 1, fig. 11)
21. *Lycopodiumsporites* sp. (Pl. 1, fig. 4)

Remarks—The specimens ascribed to *Lycopodiumsporites* sp. are very similar to those described as *Lycopodium amnotidites* by Hopkins (1969) from the Eocene Kitsilano Formation of British Columbia, Canada. Reticulations are well-developed on the distal surface and equatorial areas of the proximal surface.

22. *Lygodiumsporites eocenicus* Dutta & Sah 1970 (Pl. 2, fig. 16)
23. *Monolites* sp. (Pl. 2, fig. 6)
24. *Osmundacidites* sp.
25. *Polypodiaceasporites* sp. (Pl. 1, fig. 1)

Remarks—These specimens are very similar to those described by Sah (1967) from the Miocene sediments of Burundi as *Polypodiaceaesporites* sp. except in having scabrate ornamentation pattern.

26. *Polypodiisporites ornatus* Sah 1967 (Pl. 1, fig. 3).
27. *Pteridacidites* sp. (Pl. 2, fig. 4)
28. *Striatriletes multicostatus* Kar & Saxena 1981 (Pl. 2, fig. 17)
29. *Striatriletes paucicostatus* Kar 1985
30. *Striatriletes susannae* (Van der Hammen) Kar 1979 (Pl. 3, fig. 5)
31. *Trilites* sp. (Pl. 1, fig. 12)

Remarks—Only a few specimens have been recorded in this assemblage. Morphologically these specimens closely compare with osmundaceous miospores. Sah (1967) has recorded *Triletes morleyi* Couper 1953 from Rusizi Valley, Burundi, which is very similar except in having verrucose ornamentation and a smaller size. The present specimens range from 150-160 μm in diameter.

D. Gymnospermous pollen

32. *Abiespollenites cognatus* Kar 1985 (Pl. 2, fig. 23)
33. *Cedripites miocenicus* Krutzsch 1971 (Pl. 2, fig. 10)
34. *Pinuspollenites crestus* Kar 1985 (Pl. 2, fig. 11)
35. *Podocarpidites khasiensis* Dutta & Sah 1970 (Pl. 2, fig. 7)
36. *Tsugaepollenites velatus* Kar 1985 (Pl. 2, fig. 15)

E. Angiospermous pollen

37. *Compositoipollenites serratus* Sah 1967
38. *Dicotetradites* sp. (Pl. 2, fig. 13)
39. *Granustephanocolpites* sp.
40. *Impatiensidites brevicolpus* Sah 1967 (Pl. 2, fig. 22)
41. *Jacobipollenites magnificus* Ramanujam 1966
42. *Liliacidites perforatus* Pocknall 1982
43. *Liliacidites* sp.
44. *Malvacearumpollis grandis* Sah 1967
45. *Malvacearumpollis* sp. A (Pl. 2, fig. 18)

46. *Malvacearumpollis* sp. B (Pl. 2, fig. 12).

Remarks—In these specimens pores are not very clearly visible. Morphological characters show more affinity towards the family Convolvulaceae rather than Malvaceae.

47. *Monoporopollenites gramineoides* Meyer 1956

48. *Monosulcites* sp. (Pl. 3, fig. 10)

49. *Nympheacidites* sp.

50. *Nyssapollenites thompsonianus* Traverse 1955

51 *Polycolpites pedaliaceoides* Sah 1967 (Pl. 2, fig. 8)

52. *Tricolpites* sp. (Pl. 2, fig. 14)

F. Incertae-sedis

53. Spore Type-1 (Pl. 2, fig. 14)

Description—Miospore subtriangular, size 45 × 75 µm. Trilete, Y-rays prominent, laesurae thin, sinuous, bordered by thick labrum. Exine 3 µm thick, ornamentation granulose, ill-developed meshes observed on the distal surface.

Remarks—Only a single specimen has been recovered.

54. Spore Type-2 (Pl. 2, fig. 5)

Description—Miospore oval-shaped, inaperturate, size range 42 to 47 µm in diameter, peripheral region transparent, about 4 µm thick. Exine thin, ornamentation curvimurate, coarse-meshes about 5 to 6 µm in diameter, low projecting papillae observed on the corners of rectangular meshes.

Remarks—The overall morphology indicates a bryophytic affinity for these miospores.

55. Angiosperm pollen Type-1 (Pl. 2, fig. 24)

Description—Pollen grain oval-shaped, size 38 × 58 µm. Tricolpate, colpi long, extending more than 2/3 of the longer axis. Exine thin, ornamentation very finely granulose, appearing finely reticulate under low magnification

56. Angiosperm pollen Type-2 (Pl. 1, fig. 7)

Description—Pollen grains oval-shaped, size range 64 × 80 µm. Polyporate, 5 pores clearly visible. Exine very thin, ornamentation finely granulose, grana simulating reticulate pattern.

DISCUSSION

Palynofloral composition

The Bagh Rao palynoflora consists of pteridophytic spores, gymnospermous and angiospermous pollen grains, and algal and fungal remains. In all, 43 genera and 56 species have been recorded. A few forms have been described under *Incertae sedis*. Pteridophytic spores and algal remains generally predominate as compared to gymnospermous and angiospermous pollen grains. A few miospores with bryophytic affinity have also been recorded.

The algal forms represented by four genera, viz., *Botryococcus, Pediastrum, Zygnema* and *Spirogyra* are found in the lower horizon of the stratigraphic sequence. Among these, zygospores of the members of Zygnemaceae are most common, whereas the colonial alga *Pediastrum* of the family Hydrodictyaceae and *Botryococcus* of family Xanthophyceae are relatively less represented. Qualitative representation of the fungal palynofossils is noteworthy throughout the whole sequence, though their numerical occurrence is rather low. Among the fungal remains microthyriaceous members are well represented by *Phragmothyrites eocaenica, Callimothallus assamicus* and *Notothyrites amorphus.*

Several trilete miospores having close affinity with those of the bryophytic spores of Ricciaceae have been encountered. Pteridophytic spores represented by 14 genera and 19 species constitute one of the most important botanical group in this assemblage. Palynofossils assignable to the following eight families—Cyatheaceae, Schizaeaceae, Parkeriaceae, Polypodiaceae, Lycopodiaceae, Osmundaceae, Adiantaceae, and Azollaceae have been identified. Gymnosperm pollen grains are represented by only two families, viz., Pinaceae and Podocarpaceae. The Bagh Rao assemblage contains 12 genera and 15 species of angiospermous pollen grains.

PLATE 1 →

(All photomicrographs are magnified Ca × 500, unless otherwise mentioned)

1. *Polypodiaceaesporites* sp.; Slide no. BSIP 8435. Coordinates 57.5 × 96.
2. *Pediastrum compactum* Singh & Khanna; Slide no. BSIP 8435, coordinates 28 × 101.5.
3. *Polypodiisporites ornatus* Sah; Slide no. BSIP 8436; coordinates 36 × 99.9.
4. *Lycopodiumsporites* sp.; Slide no. BSIP 8434, coordinates 50 × 108.
5. Zygospore of *Zygnema*; Slide no. BSIP 8436; coordinates 38.5 × 101.5.
6. *Cheilanthoidspora mioceneca* Kar & Jain; Slide no. BSIP 8436, coordinates 28.4 × 107.5.
7. Angiosperm pollen Type-2; Slide no. BSIP 8436, coordinates 61 × 97.5.
8. *Botryococcus braunii* Kützing.; Slide no. BSIP 8446, coordinates 47 × 96.5.
9. *Azolla* microspores; Slide no. BSIP 8435, coordinates 45.2 × 99.
10. Zygospore of *Spirogyra*; Slide no. BSIP 8437, coordinates 53 × 96.
11. *Lycopodiumsporites parvireticulatus* Sah & Dutta; Slide no. BSIP 8445, coordinates 38.2 × 108.
12. *Triletes* sp.; Slide no. BSIP 8435, coordinates 62.5 × 100.5.
13. *Azolla* megaspore Type-1; Slide no. BSIP 8435, coordinates 29 × 108.8.

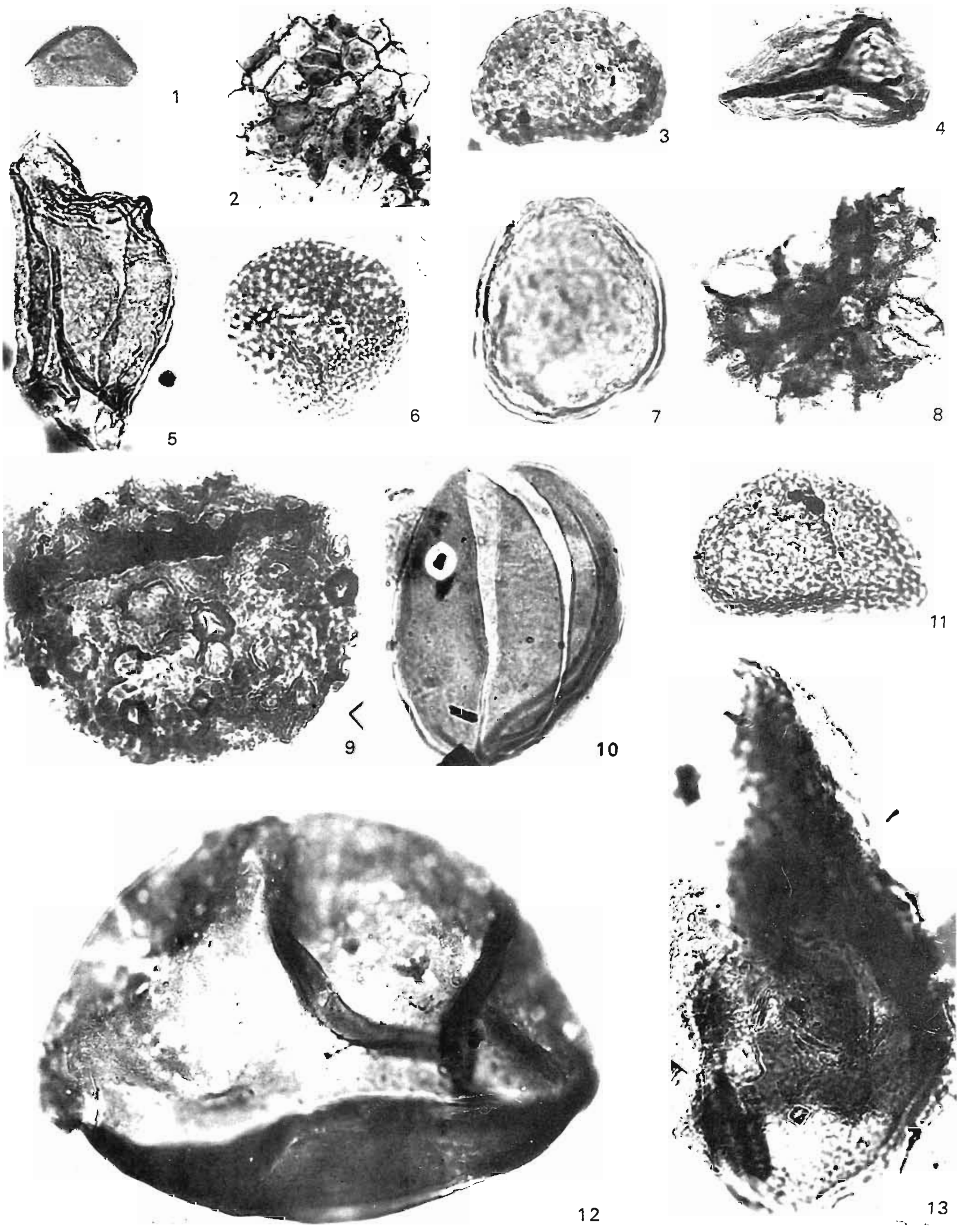


PLATE 1

Out of these, 3 genera and 4 species belong to monocotyledons and 9 genera and 11 species to dicotyledons. Angiosperm families, viz., Asteraceae, Malvaceae, Balsaminaceae, Cruciferae, Pedaliaceae, Lentibulariaceae and Nympheaceae are dicotyledonous, whereas Sparganiaceae, Poaceae and Liliaceae are monocotyledonous.

Quantitative representation of spores-pollen of different botanical groups in the assemblage is as follows: pteridophytic spores 39 per cent, gymnospermous pollen 25 per cent, angiospermous pollen grains 20 per cent and algal and fungal remains 16 per cent. Among the pteridophytic spores some of the significant forms are *Striatriletes* spp. (33%), *Lycopodiumsporites* spp. (15%), *Polypodiaceasporites* sp. (12%), and *Azolla* megaspores and microspores (11%). *Tsugaepollenites velatus* (55%) is the most common element among the gymnospermous pollen grains. The other genera *Pinuspollenites* and *Abiespollenites* have 24 per cent and 20 per cent representation respectively. Among the angiosperm pollen grains *Monoporopollenites* (23%) and *Malvacearumpollis* (20%) are the most common, while the percentage of other genera are generally less than 8 per cent.

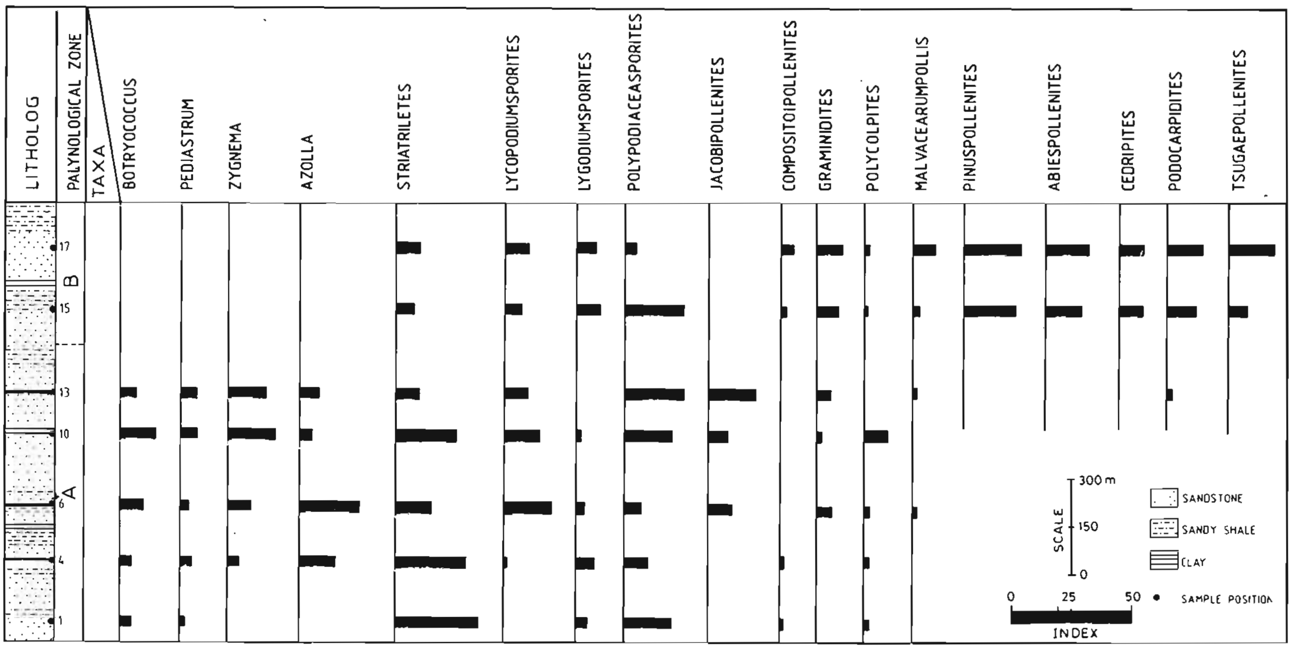
Distributional analysis of the Bagh Rao palynoflora reveals the presence of two palynological zones A and B (Text-figure 2) in the Middle Siwalik sequence. Dominance of pteridophytic elements has been noticed in the basal part of the palynological Zone A. Angiospermous pollen grains, although conspicuous by their presence, are much less in quantity. Gymnospermous pollen grains are infrequently represented in this palynological zone. *Striatriletes* spp. are the most common palynofossils of this assemblage zone. Abundant occurrence of *Botryococcus* and *Pediastrum* in some horizon is noteworthy. The other common genera in this palynological zone are *Lycopodiumsporites, Polypodiisporites, Azolla* micro-and megaspores, zygospores of *Zygnema, Jacobipollenites, Liliacidites* and *Nympheacidites*.

Pinuspollenites and *Tsugaepollenites* are the most significant elements of Zone B. Some of the other genera abundantly present in this Zone are *Abiespollenites, Monoporopollenites, Malvacearumpollis, Lycopodiumsporites, Striatriletes* and *Polypodiaceasporites*. The frequency of *Striatriletes* is low in comparison to that in the palynological Zone A. The algal elements are completely absent in this zone. A marked palynofloral change has been noticed in the upper part of the sequence which is 225 metre thick. Cold loving upland elements, viz., *Pinuspollenites, Tsugaepollenites* and *Abiespollenites* are copiously represented in this horizon.

Several palynotaxa, viz., *Jacobipollenites magnificus, Impatiensidites brevicolpus, Polycolpites pedaliaceoides, Compositoipollenites serratus, Malvacearumpollis grandis* and microspores of *Azolla* have been recorded for the first time from Middle Siwalik sediments. The known botanical affinities of some of the significant Bagh Rao palynofossils and their preferable habitats are given in Table 1.

Palynofloral comparison

The present palynoflora has been compared with other Middle Siwalik palynofloral assemblages recorded



Text-figure 2—Showing the percentage of significant palynofossils in the Bagh Rao Siwalik sequence and palynological zonation.

Table 1—Botanical affinities of recorded palynofossils and their preferable habitat and distribution

Palynofossils	Modern comparable taxa	Preferable habitat	Distribution
Botryococcus	*Botryococcus* (Xanthophyceae)	Freshwater planktonic algae	Cosmopolitan
Pediastrum	*Pediastrum* (Hydrodictyaceae)	Abundant in freshwater plankton and also occur commonly in ponds and ditches amongst other water plants	Cosmopolitan
Spirogyra and *Zygnema*	*Spirogyra* and *Zygnema* (Zygnemaceae)	Commonly found in fresh-water of small ponds or temporary pools in wet areas	Cosmopolitan
Callimothallus Phragmothyrites and *Notothyrites*	Ascostromata of Microthyriaceae	—	Tropical regions
Azolla micro- and megaspores	*Azolla* (Azollaceae)	Free floating, occur on surface of ponds or in slough of rivers	World wide in distribution, warm temperate or tropical
Cyathidites	Cyatheaceae	Mostly occur in the under-growth of moist forests, often in ravines, some species prefer open habitats even swamps	Mostly concentrated in tropics, most numerous in montane to alpine vegetation
Foveosporites, Lycopodiumsporites and *Cheilanthoid - spora*	*Lygodium* (Lycopodiaceae)	Terrestrial or epiphytic	Cosmopolitan, absent in arid areas
Lygodiumsporites	*Lygodium* (Schizeaceae)	Terrestrial ferns with creeping habits	Tropical and warm temperate
Monolites, Polypodiaceasporites and *Polypodiisporites*	Polypodiaceae	Usually terrestrial or epiphytic, sometimes epilithic. Many prefer even wet forests at low to middle elevation	Predominantly tropical-subtropical
Osmundacidites and *Trilites*	*Osmunda* (Osmundaceae)	Terrestrial	Cosmopolitan, greatest concentration of species in east and southeast Asia, absent in cold and arid areas
Striatriletes	*Ceratopteris* (Parkeriaceae)	Grow in a variety of aquatic or wet habitats such as lakes, ponds, rivers, open swamp and ditches	Widespread through the tropics of both hemispheres
Pteridacidites	Adiantaceae	Terrestrial or rupestral ferns	World wide in distribution, though largely confined to warmer regions
Abiespollenites, Cedripites, Pinuspollenites, and *Tsugaepollenites*	*Abies, Cedrus, Pinus* and *Tsuga* (Pinaceae)	Trees of generally poor acidic and either wet or rocky habitats	Widely distributed throughout the temperate parts of both old and new world
Podocarpidites	*Podocarpus* (Podocarpaceae)	Plants of mesic forest conditions	Mostly in tropical to warm or occasionally in cool temperate regions
Compositoipollenites	Asteraceae	Mostly herbaceous plants occur in almost every conceivable situation	Widely distributed in both hemispheres
Monoporopollenites	Poaceae	Almost every type of habitat frequently forming a part of forest undergrowth in wet or dry places	Widely distributed in all regions of the world where plant can survive
Liliacidites	Liliaceae	Terrestrial, mostly herbs	Cosmopolitan
Malvacearumpollis	Malvaceae	Terrestrial	Tropical and temperate
Nymphaeacidites	*Nymphaea* (Nymphaeaceae)	Aquatic plant, grow in shallow water	Warmer parts of India and many other countries
Polycolpites	Pedaliaceae	Terrestrial	Mostly in tropical regions
Jacobipollenites	*Sparganium* (Sparganiaceae)	Aquatic plants	Temperate

from India and Nepal in order to evaluate its palynological status. Middle Siwalik sediments in most of the investigated areas (Text-figure 3) have yielded palynofossils of low diversity dominated by bisaccate pollen and polypodiaceous spores. Palynofloral assemblages recorded by Banerjee (1968), Nandi (1972, 1975), Saxena *et al.* (1984) and Singh and Sarkar (1984) compare very well with those encountered in the present investigation. Several palynotaxa are in common between these assemblages. The Raxaul Middle Siwalik palynofloral assemblage (Lukose, 1969) is also closely comparable to those palynofossils recovered from the Bagh Rao in their dominance of *Pinus* pollen and pteridophytic spores. However, the absence of angiosperm pollen of Myricaceae, Juglandaceae and Moraceae in these sediments is noteworthy. This may be due to the fact that the sediments might have been derived from two different geographic regions.

Middle Siwalik palynofloral assemblages recorded from Chepang-Chinji section, east of Nepal Ganj (Mathur,

Text-figure 3—The areas of comparative palynological study—**A**, Kutwalta-Chiani (Mathur, 1984); **B**, Bararta-Dagwani; Malnu-Salwana (Mathur, 1984); **C**, Bhakra-Nangal (Banerjee, 1968; Saxena *et al.*, 1984); Ramshahr (Singh & Sarkar, 1984); **D**, Jawalamukhi (Nandi, 1975); **E**, Puranpur (Mathur, 1984); **F**, Mohand (Nandi, 1972); **G**, Raxaul (Lukose, 1969); **H**, Chepang-Chinji (Mathur, 1984); **I**, Surai khola (Sarkar, 1990) are shown.

PLATE 2 →

(All photomicrographs are magnified ca × 500, unless otherwise mentioned)

1. *Foveosporites canalis* Balmae; Slide no. BSIP 8435; coordinates 14 × 42.
2. *Leptolepidites verrucatus* Couper; Slide no. BSIP 8432; coordinates 96 × 33.5.
3. *Leptolepidites* sp.; Slide no. BSIP 8433; coordinates 27 × 109.
4. *Pteridacidites* sp.; Slide no. BSIP 8438; coordinates 44.5 × 104.5.
5. Spore Type-2; Slide no. BSIP 8434; coordinates 35.8 × 94.5.
6. *Monolites* sp.; Slide no. BSIP 8449; coordinates 48 × 101.
7. *Podocarpidites khasiensis* Dutta & Sah; Slide no. BSIP 8430; coordinates 52 × 105.5.
8. *Polycolpites pedaliaceoides* Sah; Slide no. BSIP 8435; coordinates 53.2 × 103.
9. Spore Type-1; Slide no. BSIP 8435, coordinates 42.5 × 95.5.
10. *Cedripites miocenicus* Krutzsch; Slide no. BSIP 8436; coordinates 43 × 98.
11. *Pinuspollenites crestus* Kar; Slide no. BSIP 8430; coordinates 66 × 99.
12. *Malvacearumpollis* sp. B.; Slide no. BSIP 8434, coordinates 65 × 110.5.
13. *Dicotetradites* sp.; Slide no. BSIP 8439; coordinates 65 × 110.5.
14. *Tricolpites* sp.; Slide no. BSIP 8445; coordinates 41 × 99.
15. *Tsugaepollenites velatus* Kar; Slide no. BSIP 8430; coordinates 55 × 108.5
16. *Lygodiumsporites eocenicus* Dutta & Sah; Slide no. BSIP 8440; coordinates 36 × 99.9.
17. *Striatriletes multicostatus* Kar & Saxena; Slide no. BSIP 8441; coordinates 53 × 96.
18. *Malvacearumpollis* sp. A.; Slide no. BSIP 8434; coordinates 48.2 × 101.6.
19. *Azolla* megaspore Type-2 (Ca × 250); Slide no. BSIP 8435; coordinates 47 × 99.5.
20. *Monosulcites* sp.; Slide no. BSIP 8442; coordinates 37 × 106.
21. *Intrapunctisporis intrapunctis* Krutzsch; Slide no. BSIP 8431; coordinates 50.5 × 98.9.
22. *Impatiensidites brevicolpus* Sah; Slide no. BSIP 8436; coordinates 51 × 101.8.
23. *Abiespollenites cognatus* Kar; Slide no. BSIP 8436; coordinates 54.5 × 101.5.
24. Angiosperm pollen Type-1; Slide no. BSIP 8442; coordinates 43.5 × 105.5.

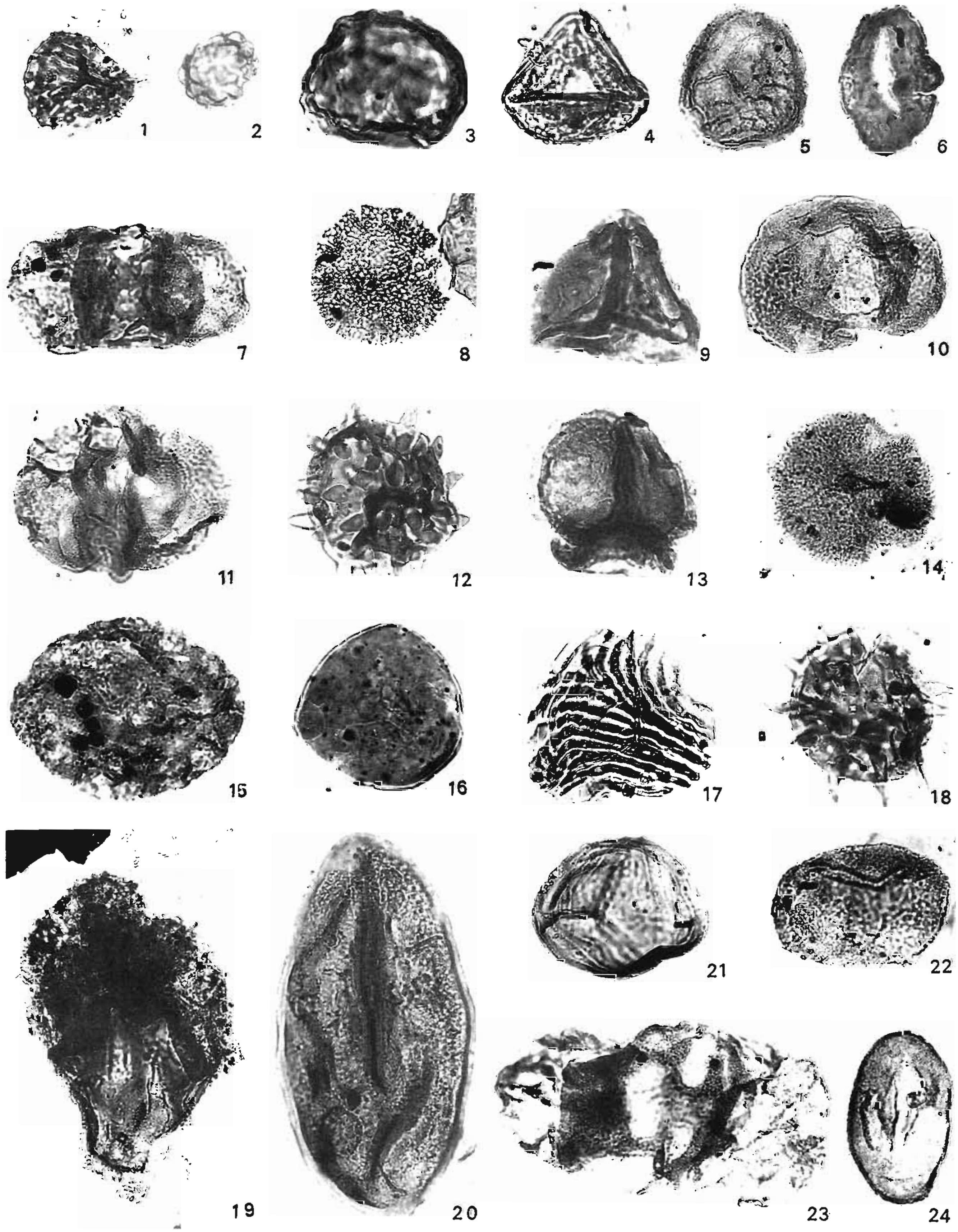


PLATE 2

1984) and Surai Khola area (Sarkar, 1990) of Nepal show similarity in palynofloral composition in the dominance of pollen genera *Pinus, Cedrus, Podocarpus,* and pteridophytic spores of *Striatriletes, Polypodiaceaesporites,* etc.

Palaeoecology and palaeoenvironment

The distributional pattern of spores and pollen grains in the Bagh Rao sequence clearly identifies changes in the environment of deposition from the older to younger horizons. The Lower part of Zone A exhibits the presence of mostly aquatic elements, viz., *Azolla, Ceratopteris, Nymphea, Sparganium* which are known to inhabit freshwater environment. The older part of Zone A seems to represent stagnant shallow freshwater conditions in view of the high incidence of Zygospores of *Zygnema* and *Spirogyra.* It seems likely that a lowland topography supported the growth of ferns and other herbaceous angiosperms. In the younger horizons of the profile the frequency of occurrence of algal remains and pteridophytic spores gradually dropped and latter it was replaced by taxa belonging to upland forest communities. Here the pollen grains of Asteraceae and Poaceae are represented in high percentages. The presence of increased upland elements in the upper part of the Bagh Rao sequence indicates relatively a drier environment of deposition. The absence of any aquatic elements in this horizon also supports this view.

The palynofloral evidences have also been examined to reconstruct the palaeoclimatic conditions during the deposition of Bagh Rao Siwalik sequence. The recovered spore/pollen data is rather inadequate for any precise palaeoclimatic conclusion, hence megafossil records (Varma, 1968; Prasad, 1993) from the Bagh Rao and its adjoining areas have been taken into consideration for a meaningful interpretation. Varma (1968) described a few leaf-impressions, viz., *Meliaceaephyllum mahogonites* (Meliaceae), *Diospyros embryopterisites* (Ebenaceae). *Eucalyptophyllum raoi* (Myrtaceae) and *Croton* cf. *C. tegelis* (Euphorbiaceae) from Bagh Rao. Recently, Prasad (1993) recorded the presence of leaf-impressions from Latita Rao and Kharkhari area near Bagh Rao which includes seven species belonging to seven genera of four dicot families, viz., *Ziziphus tertiarus* (Rhamnaceae), *Cassia prefistula* (Fabaceae), *Pongamia mioglabra, Dalbergia siwalica* and *Albizzia siwalica* (Fabaceae), *Myrsine siwalica* (Myrsinaceae) and *Homonoya miocenicum* (Euphorbiaceae).

The Bagh Rao palynofloral assemblage (Table 1) comprises palynotaxa having affinities with those families which are distributed mainly in the tropical and subtropical region, excepting some gymnosperms. Based on the available palaeobotanical evidences (both micro- and mega) from the Middle Siwalik of Bagh Rao, a lowland rain forest type vegetation is envisaged. It is also envisaged that a warm and humid climate prevailed during the sedimentation of the older horizons and subsequently it was more or less dry in the younger horizons. The fluctuation in the abundance of the aquatic and montane elements may be due to the available humidity and rainfall. In the younger horizons the sharp increase in the occurrence of Asteraceae, Poaceae and Mimosaceae probably indicates a shift towards arid climate. Palaeontological and sedimentological data (Varishat *et al.*, 1978; Gaur *et al.*, 1978) provide cogent support to these observations.

The Siwalik sediments in this area lack faunal and chronological control (Kumar *et al.*, 1991). Therefore, it is very difficult to date these sediments precisely with the help of available inadequate palynofossil data. However, the overall palynofloral association throws some light on the age of Middle Siwalik sediments from Bagh Rao when considered in conjunction with earlier data. Earlier studies in the Himalayan foot-hills (Banerjee, 1968; Nandi, 1972, 1975; Saxena & Singh, 1980, 1982a, 1982b; Singh & Saxena, 1980; Mathur, 1984) show that bisaccate pollen grains belonging to Pinaceae, viz., *Pinus* and *Abies* attained dominance only after the mid-Miocene orogeny of the Himalaya. Therefore, the high incidence of *Pinuspollenites* and *Abiespollenites* belonging to the family Pinaceae in the present material strongly suggests that the age of the Middle Siwalik sediments may pertain to Late Miocene. Additionally high incidence of pollen genera, viz., *Malvacearumpollis, Compositoipollenites, Monoporopollenites* and *Polyadopollenites* alongwith gymnospermous taxa also provide logical support for a Late Miocene age.

REFERENCES

Badgley C & Behrensmeyer AK 1980. Palaeoecology of Middle Siwalik sediments and faunas, northern Pakistan. *Palaeogeogr Palaeoclimat. Palaeoecol.* **30** : 133-155.

Banerjee D 1968. Siwalik microflora from Punjab, India. *Rev. Palaeobot. Palynol.* **6** : 171-176.

Couper RA 1953. Upper Mesozoic and Cainozoic spores and pollen grains from New Zealand. *Bull. N.Z. geol. Surv. Palaeont.* **22** : 1-77.

Fritsch FE 1935. *The structure and reproduction of the algae,* vol. **1**. Cambridge Univ. Press, Great Britain.

Gaur R, Sabhlok AK, Chopra SRK & Suneja IJ 1978. A palaeoenvironmental study of the Siwalik Formation in parts of Bilaspur District (Himachal Pradesh). *Man Environm.* **2** : 69-71.

Hopkins WZ Jr 1969. Palynology of the Eocene Kitsilano Formation, south-west British Columbia. *Can. J. Bot.* **47** : 1101-1131.

Jain RK & Hall JW 1969. A contribution to the early fossil record of the Salviniaceae. *Am. J. Bot.* **56** : 527-539.

Kramer KU, Green PS & Gotze E (Editors) 1991 Pteridophytes and gymnosperms, Vol. **1**. *In* Kubitzki K (Editor)—*The families and genera of vascular plants* : 1-104. Narosa Publishing House, Delhi.

Kumar R, Ghosh SK, Virdi NS & Phadtare NR 1991. Excursion guide, The Siwalik Foreland Basin, Dehradun-Nahan Sector : *Spec. Publ.* : 1-61 Wadia Institute of Himalayan Geology, Dehradun.

Lukose NG 1969. Microfossils from the Middle Siwalik of Bihar, India. *J. Palynol.* **4**(2) : 107-112.

Mathur YK 1984. Cenozoic palynofossils, vegetation, ecology and climate of the north and north-western sub-Himalayan region, India *In* White RO *et al* .(Editors)—*The evolution of the East Asian environment* **2** : 504-551. Centre of Asian studies occasional papers and monographs no. 59, Univ. of Hong-Kong.

Nandi B 1972. Some observations on the microflora of Middle Siwalik sediments of Mohand (East) field, Himachal Pradesh. *Proc. Sem. Palaeopalynol. Indian Stratigr., Calcutta* : 375-383.

Nandi B 1975. Palynostratigraphy of the Siwalik Group of Punjab. *Him. Geol.* **5** : 411-423.

Potonié R 1931. Zur Mikraskopie der Braunkohlen *Braunkohle* **30** : 554-556. Halle.

Potonié R 1934. Zur Mikrabotanik der Kohlen und ihren *Ver Wandten. Arbeiten aus dem inst. fur Palaeobot. Petrog. Brens tiene* : 1-210.

Potonié R 1956. Synopsis der Gattungen der *Sporae dispersae* 1. Teil : Sporites. *Beih. geol. Jb* **23** : 1-103.

Prasad M 1994. Angiospermous leaf remains from the Siwalik sediments of Hardwar, Uttar Pradesh and their bearing on palaeoclimate and phytogeography. *Him. Geol.* **14** : 83-94.

Randhawa MS 1959. *Zygnemaceae.* I.C.A.R. Monograph on algae. Indian Council of Agricultural Research, New Delhi.

Ranga Rao A, Khan KN, Venkatachala BS & Sastri VV 1971. Neogene/Quaternary boundary and the Siwalik. *In* Sastry MVA *et al.* (Editors)—*Proc Field Conference. Neogene/Quaternary Boundary, India, 1979* : 131-141. Geological Survey of India, Calcutta.

Sah SCD 1967. Palynology of an Upper Neogene profile from Rusizi Valley (Burundi). *Annls. Mus. r. Afr. Cent.* ser. 8°, *Sci. geol.* 1-173.

Sarkar Samir 1990. Siwalik pollen succession from Surai Khola of western Nepal and its reflection on palaeoecology. *In* Jain KP & Tiwari RS (Editors)—*Proc. Symp. Vistas in Indian Palaeobotany, Palaeobotanist* **38** : 319-324.

Saxena RK & Singh HP 1980. Occurrence of palynofossils from the Pinjor Formation (Upper Siwalik) exposed near Chandigarh. *Curr Sci.* **49**(12) : 479-480.

Saxena RK & Singh HP 1982a. Palynology of the Pinjor Formation (Upper Siwalik) exposed near Chandigarh, India. *Palaeobotanist* **30**(3) : 325-339.

Saxena RK & Singh HP 1982b. Palynological investigation of the Upper Siwalik sediments exposed along Hoshiarpur-Una Road Section in Punjab and Himachal Pradesh. *Geophytology* **12** 287-306.

Saxena RK, Sarkar Samir & Singh HP 1984. Palynological investigation of Siwalik sediments of Bhakra Nangal area, Himachal Pradesh. *Geophytology* **14**(2) : 178-198.

Singh HP & Sarkar Samir 1984. Palynological investigations of Ramashahr Well-1, Himachal Pradesh, India. *Palaeobotanist* **32**(2) : 91-112.

Singh HP & Saxena RK 1980. Upper Siwalik palynoflora from Gagret-Bharwain Road section, Himachal Pradesh. *Geophytology* **19**(2) : 278-279.

Singh HP & Saxena RK 1981. Palynology of the Upper Siwalik sediments in the Una District, Himachal Pradesh. *Geophytology* **11**(2) : 171-179.

Sinha RN. 1970. Heavy mineral investigations in the Siwalik of Mohand, district Saharanpur, Uttar Pradesh, India. *J. geol. Soc. India* **11**(2) : 163-177.

Varma CP 1968. On a collection of leaf-impressions from Hardwar beds (Siwalik Formation). *J. palaeont. Soc. India* **5-9** 83-88.

Varishat RN, Gaur R & Chopra SRK 1978. Community structure of Middle Siwalik vertebrates from Haritalyangar (H. P.), India. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **23** : 131-140.

Willis JC 1973. *A dictionary of the flowering plants and ferns.* Cambridge Univ. Press, London.