Palaeobotanist 50 (2001) : 267-286
0031-0174/2001/267-286 $2.00

Palynology of the Late Pliocene sediments of Pinjor Formation, Haryana, India

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(Received 8 June 2001; revised version accepted 21 May 2002)

ABSTRACT

Rao MR & Patnaik R 2001. Palynology of the Late Pliocene sediments of Pinjor Formation, Haryana, India. Palaeobotanist 50 (2 & 3) : 267-286.

Present study highlights the palynoassemblage consisting of algal and fungal remains, pteridophytic spores, gymnosperm and angiosperm pollen recovered from the Pinjor Formation exposed at Nadah, Panchkula, Haryana. The assemblage is dominated by pollen of gymnosperms and angiosperms followed by pteridophytic spores. Algal remains assignable to the Zygnemataceae (*Spirogyra, Mougeotia* and *Zygnema*), fungal spores (*Polyadosporites* and *Frasnacritetrus*), pteridophytic spores *Lycopodiumsporites (Lycopodium), Pteridacidites* (*Pteris*) and *Striatriletes (Ceratopteris)*, gymnosperm pollen *Pinuspollenites* (*Pinus*), *Piceapollenites (Picea)* and *Abiespollenites (Abies)* have been recorded. Angiosperm pollen are mainly represented by *Pinjoriapollis (Magnolia), Retitrescolpites, Graminidites, Chenopodipollis* and *Malvacearumpollis*. On the basis of their affinities with the modern equivalents, a warm and humid tropical-subtropical climate has been inferred for the Pinjor Formation. The presence of *Spirogyra, Mougeotia, Zygnema, Lycopodium, Ceratopteris,* fungal spores (*Polyadosporites* spp.) and angiosperm pollen (*Malvacearumpollis*) collectively suggest the existence of moist and swampy depositional environment. The presence of grass pollen (Poaceae) indicates the existence of herbaceous flora. The significant drop in grass pollen coinciding with the good proportion of ferns in the middle part of the Pinjor Formation suggests that the vegetation was changed from dry to mainly wet and marshy grassland. Based on the overall palynofloral assemblage, a wet grassland with open and mixed flora during the Pinjor sedimentation has been inferred. The temperate elements viz., *Abies, Pinus* and *Picea* appear to be derived from the near by upland areas of the rising Himalaya.

Key-words—Palynology, Palaeoecology, Pinjor Formation, Late Pliocene, Upper Siwalik, Haryana, India.

भारत के हरियाणा प्रान्त के पिन्जोर शैलसमूह के अन्तिम प्लायोसीन अवसादों का परागाणुविज्ञान

मुलागलापल्ली रामचन्द्र राव एवं राजीव पटनायक

सारांश

प्रस्तुत अध्ययन में हरियाणा के पंचकूला क्षेत्र के नादाह में अवस्थित कवकीय एवं शैवालीय अवशेषों और टेरिडोफ़ाइटी जीवाणुओं, अनावृतबीजी तथा आवृतबीजी परागकणों से युक्त परागाणु समुच्चय का विवेचन अभिप्रेत है। समुच्चय में अनावृतबीजी तथा आवृतबीजी परागकणों की प्रधानता है, तत्पश्चात् टेरिडोफ़ाइटी जीवाणु आते हैं। ज़ाइग्मीटेसी (*स्पाइरोगाइरा माउजिओपेटिया* एवं *ज़ाइग्नीमा*) कवकीय बीजाणुओं (*पॉलीएडोस्पोराइटीज़* एवं *फ्रैस्नाक्राइटेट्रस*), *टेरिडोसाइडाइटी*

बीजाणुओं लाइकोपोडियमस्पोराइटीज़ (लाइकोपोडियम), टेरिडासाइडाइटीज़ (टेरिस) एवं *स्ट्रायाट्रायलिटीज़ (सीरेटॉप्टेरिस)*, अनावृतबीजी परागकणों *पाइनसपोलेनाइटीज़ (पाइनस), पाइसियापोलेनाइटीज़ (पाइसिया)* एवं *एबीज़पोलेनाइटीज़ (एबीज़)* से सन्दर्भनीय शैवालीय अवशेष भी अंकित किए गए हैं। आवृतबीजी परागकण मुख्य रूप से *पिन्जोरियापॉलिस (मैग्नोलिया), रेटिट्रेसकॉलपाइटीज़, ग्रैमाइनाइडाइटीज़, चीनोपोडीपोलिस* तथा *माल्वेसीरम्पोलिस* द्वारा निरूपित हैं। आधुनिक समतुल्यों के साथ इनकी बन्धुता के आधार पर पिंजोर शैलसमूह हेतु एक ऊष्ण तथा आर्द्र ऊष्णकटिबन्धीय-उपोष्णकटिबन्धीय जलवायु का अनुमान किया गया है। *स्पाइरोगाइरा, माउजिओटिया, ज़ाइग्नीमा, लाइकोपोडियम, सीरेटॉप्टेरिस,* कवकीय बीजाणुओं तथा आवृतबीजी परागकणों *(माल्वेसीरम्पोलिस)* की संयुक्त उपस्थिति नम तथा अनूपीय निक्षेपणीय पर्यावरण की उपस्थिति प्रस्तावित करती है। घास परागकणों (पोएसी) की उपस्थिति शाकमय वनस्पति जगत की प्राप्ति का संकेत करती है। पिंजोर शैलसमूह के मध्य भाग में फ़र्न के अच्छे अनुपात में होने तथा घास परागकणों में उल्लेखनीय कमी से प्रस्तावित होता है कि इस समय वनस्पति जगत शुष्क से मुख्यतः आर्द्र तथा कच्छ युक्त घास भूमि में परिवर्तित हो गया। समग्र परागाणु वनस्पतिजात समुच्चय के आधार पर पिंजोर अवसादन के दौरान एक विवृत आर्द्र घास भूमि तथा सम्मिश्र वनस्पतिजात का अनुमान किया गया है। शीतोष्ण तत्त्व, जैसे *एबीज़, पाइनस* तथा *पाइसिया* सम्भवतः अग्रायित हिमालय के ऊपरी क्षेत्रों के पास से लिए गए होंगे।

संकेत शब्द—परागाणुविज्ञान, पिंजोर शैलसमूह, अन्तिम पेलियोसीन, उपरि शिवालिक, हरियाणा, भारत।

INTRODUCTION

THE Siwalik Group of rocks forms an important succession in the Tertiary strata of the Indian subcontinent. These continental deposits were laid down in the foredeep on the southern side of the rising Himalaya all along the sub-Himalayan range of India, Nepal and Pakistan. The Group has been divided into Lower, Middle and Upper Siwaliks on the basis of lithology. These were further subdivided into Kamlial, Chinji, Nagri, Dhokpathan, Tatrot, Pinjor and Boulder Conglomerate formations. They are best exposed in Potwar Plateau, Pakistan where most of the type sections of the Siwalik Group but the type sections of the Pinjor and Boulder Conglomerate formations (the middle and the Upper part of the Siwalik subgroup) are best exposed in the vicinity of Chandigarh in India (Pilgrim, 1910, 1913; Gill, 1951). The Siwalik group in general is composed of sandstones, grits, conglomerates, pseudoconglomerates, clays, silts, etc. These fluvial sediments representing age from Middle Miocene to Early Pleistocene (18.4 m.y. to 0. 22 m.y., Johnson *et al.*, 1985; Ranga Rao *et al.*, 1985).

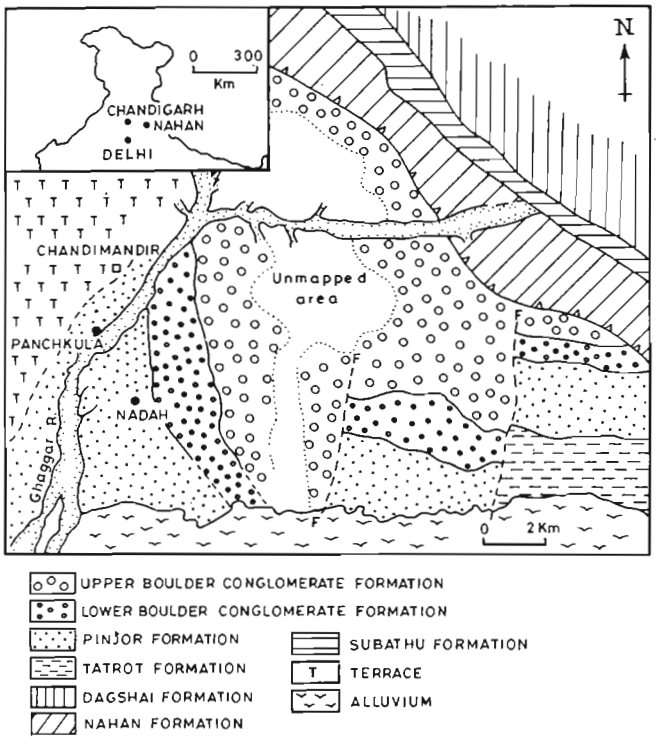

Fig. 1—Geological map showing the Nadah area, Panchkula, Haryana (modified after Kumar & Tandon, 1985).

The Upper Siwaliks in general and Pinjor Formation in particular is very well exposed in the vicinity of Chandigarh (Fig. 1) and are characterized by red, grey mudstones and sandstones. It is sandwiched between the lower Tatrot and upper Boulder Conglomerate formations. These deposits have been extensively studied for sedimentological features (Tandon & Kumar, 1984a; Kumar & Tandon, 1985), fossil fauna (Sahni & Khan, 1959; Nanda, 1973; Raghavan, 1990; Patnaik, 1995, 1997; Patnaik & Schleich, 1998) and Charophyte flora (Bhatia, 1999), Palynoflora (Saxena & Singh, 1980, 1981, 1982a, b; Singh & Saxena, 1980, 1984; Saxena, 1996, 2000), Mathur (1984); Saxena & Bhattacharyya (1987) and Phadtare *et al.* (1994), magnetostratigraphy (Tandon *et al.*, 1984; Azzaroli & Napoleone, 1982; Ranga Rao *et al.*, 1995) and dating of tuffaceous mudstone (Tandon & Kumar, 1984b; Mehta *et al.*, 1993).

The Nadah locality, which has yielded the present flora lies in the Pinjor Formation exposed about 100 meters above the base of the section. The maximum thickness of the section is about 2.5 m but it varies laterally (Fig. 2). Lithologically, the fossiliferous horizon at Nadah is a part of the bluish grey mudstone facies of Kumar and Tandon (1985) contain

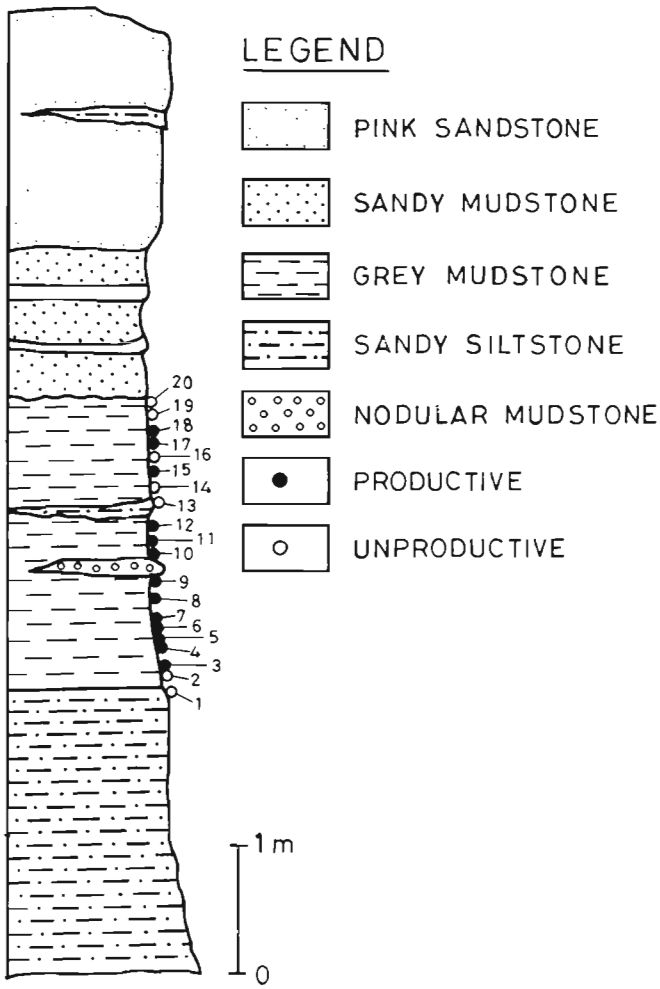

Fig. 2—Litholog of the sampled profile of Pinjor Formation exposed in Nadah section, Panchkula, Haryana.

ferruginous and calcareous nodules, molluscan shells, bioturbation and capped by around 15 cm thick nodular calcium carbonate band indicating presence of shallow seasonal pool of limited aerial extent. In this area, Pinjor Formation conformably overlies the Tatrot Formation characterized by dominant red and grey mudstones and sandstones. Transition between the Tatrot and Pinjor formations is marked by the presence of grey tuffaceous mudstone of 2.14 m.y. (Mehta *et al.*, 1993). In up section, the Pinjor Formation overlain by the Lower Boulder conglomerate Formation. Azzaroli and Napoleone (1982) placed the Nadah section within the Matuyama Epoch spanning between 2.48 and 0.73 m.y. Based on rock magnetic studies, Sargode *et al.* (2001) opined that the Pinjor Formation could also of Pleistocene age. By integrating the data on fission track dating of the tuffaceous mudstone, palaeomagnetic reversals and rodent assemblages, Patnaik (1997) considered the Nadah deposits of Late Pliocene age (around 1.8 to 2 m.y.).

MATERIAL AND METHODS

The samples were collected from the Pinjor Formation, Upper Siwalik exposed at Nadah, Panchkula, Haryana. Out of 20 samples were collected from the grey mudstone facies, 12 samples yielded palynofossils. Samples were treated with HCL and HF followed by 5% solution of KOH. The slides were prepared in polyvinyl alcohol and mounted in Canada balsam. The material, slides and negatives have been deposited in the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow.

PALYNOLOGY

The palynoflora recorded from the Pinjor Formation (Nadah section) consists of 28 genera and 37 species of algal and fungal remains, pteridophytic spores, gymnosperm and angiosperm pollen. Of these, 3 genera and 4 species belong to algal remains, 2 genera and 2 species to fungal remains, 4 genera and 8 species to pteridophytic spores, 7 genera and 9 species to gymnosperm pollen and 12 genera and 14 species to angiosperm pollen. Besides, some cuticles and tracheids have also been recorded.

LIST OF PALYNOTAXA

Taxa with an asterisk (*) mark have been either described or commented in the text.

Algal remains

*Zygospore of *Spirogyra* type- A (Pl. 1.7)
*Zygospore of *Spirogyra* type- B (Pl. 1.8)
*Zygospore of *Zygnema* (Pl. 1.9)
* Zygospore of *Mougeotia* (Pl. 1.11-12)

Fungal remains

**Polyadosporites nadahensis* sp. nov. (Pl. 1.14-16)
**Polyadosporites siwalikus* sp. nov. (Pl. 3.6, 9)
**Frasnacritetrus* sp. A (Pl. 3.7)
**Frasnacritetrus* sp. B (Pl. 3.8)
*Fungal spore type-A (Pl. 2.18)
*Fungal spore type-B (Pl. 2.19)

Pteridophytic spores

**Lycopodiumsporites nadahensis* sp. nov. (Pl. 1.1-2)
**Lycopodiumsporites* sp. A (Pl. 2.1-2)
**Lycopodiumsporites* sp. B (Pl. 3.1)
**Lycopodiumsporites* sp. C (Pl. 3.4)
**Pteridacidites chandigarhensis* sp. nov. (Pl. 1.3-4)
**Leptolepidites* sp. (Pl. 2.3)
Striatriletes susannae van der Hammen emend. Kar 1979
S. sinuosus Rao & Singh 1987
*Spore-type (Pl. 1.5-6)

Gymnosperm pollen

Inaperturopollenites punctatus Saxena & Bhattacharyya, 1987
**Cycadopites* sp. (Pl. 3.12)

Laricoidites magnus Potonié 1958
Podocarpidites meghalayaensis Rao 1986
Pinuspollenites foveolatus Rao 1986
**Pinuspollenites nadahensis* sp. nov (Pl. 2.7-8)
**Pinuspollenites chandigarhensis* sp. nov (Pl. 2.12-14)
**Piceapollenites* sp. (Pl. 3.5)
Abiespollenites surmaensis Rao1986

Angiosperm pollen

Verrualetes assamicus Singh and Saxena, 1984
**Liliacidites* sp. (Pl. 3.2)
**Palmidites* sp. (Pl. 3.10)
**Nymphaeacidites* sp. (Pl. 1.13)
Iridacidites warkalliensis Ramanujam 1987
Pinjoriapollis lanceolatus Saxena & Singh 1981
**Retitrescolpites* sp. (Pl. 2.9)
**Jacobipollenites* sp. (Pl. 2.6)
**Psilodiporites* sp. (Pl. 3.11)
Malvacearumpollis bakonyensis Nagy 1962
M. grandis Sah 1967
**Malvacearumpollis* sp. (Pl. 2.15-16)
**Graminidites siwalikus* sp. nov. (Pl. 1.18-20)
Chenopodipollis mioceneca Kar & Jain 1981
*Pollen tetrad type-A (Pl. 1.13)
*Pollen tetrad type-B (Pl. 1.20)

SYSTEMATIC DESCRIPTION

SPIROGYRA zygospore type-A

Pl. 1.7

Remarks—Several specimens closely comparable to the zygospores of *Spirogyra* have been recovered. The specimens are oval to rounded-elliptical in outline. Size range 75-100 x 45-55 µm. Each specimen is characterized by longitudinal furrow. The walls are 3 µm thick with multiple folds, laevigate.

Affinity—Zygnemataceae (van Geel, 1976).

SPIROGYRA zygospore type-B

Pl. 1.8

Remarks—Zygospores are oval-ellipsoidal in outline. Size range 65-80 x 45-60 µm. The walls are 3 µm thick with wavy blunt folds, scrobiculate ornamentation.

Affinity—Zygnemataceae (van Geel, 1976).

ZYGNEMA zygospore

Pl. 1.9

Remarks—Zygospores are quadrate in shape, most of them are crumpled. Size range 70-95 x 68-93 µm. A circular depression present in the center of the angles. The retuse angles 2-5 µm in diameter. The walls are 3-4 µm thick , laevigate to finely scabrate ornamentation.

Affinity—Zygospores closely compare with those of extant genus *Zygnema* of Zygnemataceae (Randhawa, 1959).

MOUGEOTIA zygospore

Pl. 1.11-12

Remarks—Zygospores are more or less circular in shape. Size range 63-70 x 60-65 µm. The retuse angles are 2-10 µm in diameter. The walls are 2.5 µm thick, laevigate to finely scabrate. Depression present in the center of the angles.

Affinity—Zygnemataceae.

Genus—POLYPODISPORITES van der Hammen, 1954 emend. Takahashi, 1991

Type Species—POLYPODISPORITES SUESCAE van der Hammen, 1954

POLYADOSPORITES NADAHENSIS sp. nov

Pl. 1.14-16

Holotype—Pl. 1.14, size 90 x 65 µm, Slide No. BSIP 12611.

PLATE 1 →

(All photomicrographs are enlarged ca. x 500. Coordinates of the specimens refer to the stage of the BH2 Olympus microscope no. 217267)

1-2. *Lycopodiumsporites nadahensis* sp. nov., Slide No. BSIP 12604, coordinates, 19.5 x 150.0 (Holotype); 12605, coordinates 21.6 x 154.9.
3-4. *Pteridacidites chandigarhensis* sp. nov Slide No. BSIP 12506, coordinates 17.3 x 146.2; 12607, coordinates 9.5 x 138.5 (Holotype).
5, 6. Spore type, Slide No. BSIP 12606, coordinates 9.5 x 138.5.
7 *Spirogyra* zygospore type – A, Slide No. BSIP 12608, coordinates 8.5 x 167.5.
8. *Spirogyra* zygospore type- B, Slide No. BSIP 12609, coordinates 8.5 x 156.6.
9. *Zygnema* zygospore, Slide No. BSIP 12610, coordinates 15.5 x 153.5.
10, 11 *Mougeotia* zygospore, Slide No. BSIP 12607, coordinates 7.0 x 146.5; 12609, coordinates 3.0 x 151.0.
12. Pollen tetrad type-A, Slide No. BSIP 12605, coordinates 22.0 x 151.0.
13. *Nymphaeacidites* sp., Slide No. BSIP 12608, coordinates 5.5 x 141.0.
14-16. *Polyadosporites nadahensis* sp. nov. Slide No. BSIP 12611, coordinates 11.0 x 163.5 (Holotype); 12612, coordinates 9.0 x 136.0; 12613, coordinates 8.0 x 131.0.
17 Pollen tetrad type-B, Slide No. BSIP 12605, coordinates 3.5 x 151.0.
18-20. *Graminidites siwalikus* sp. nov. Slide No. BSIP 12604, coordinates 11.4 x 148.0 (Holotype); 12614, coordinates 6.0 x 140.0; 12605, coordinates 22.0 x 151.0.

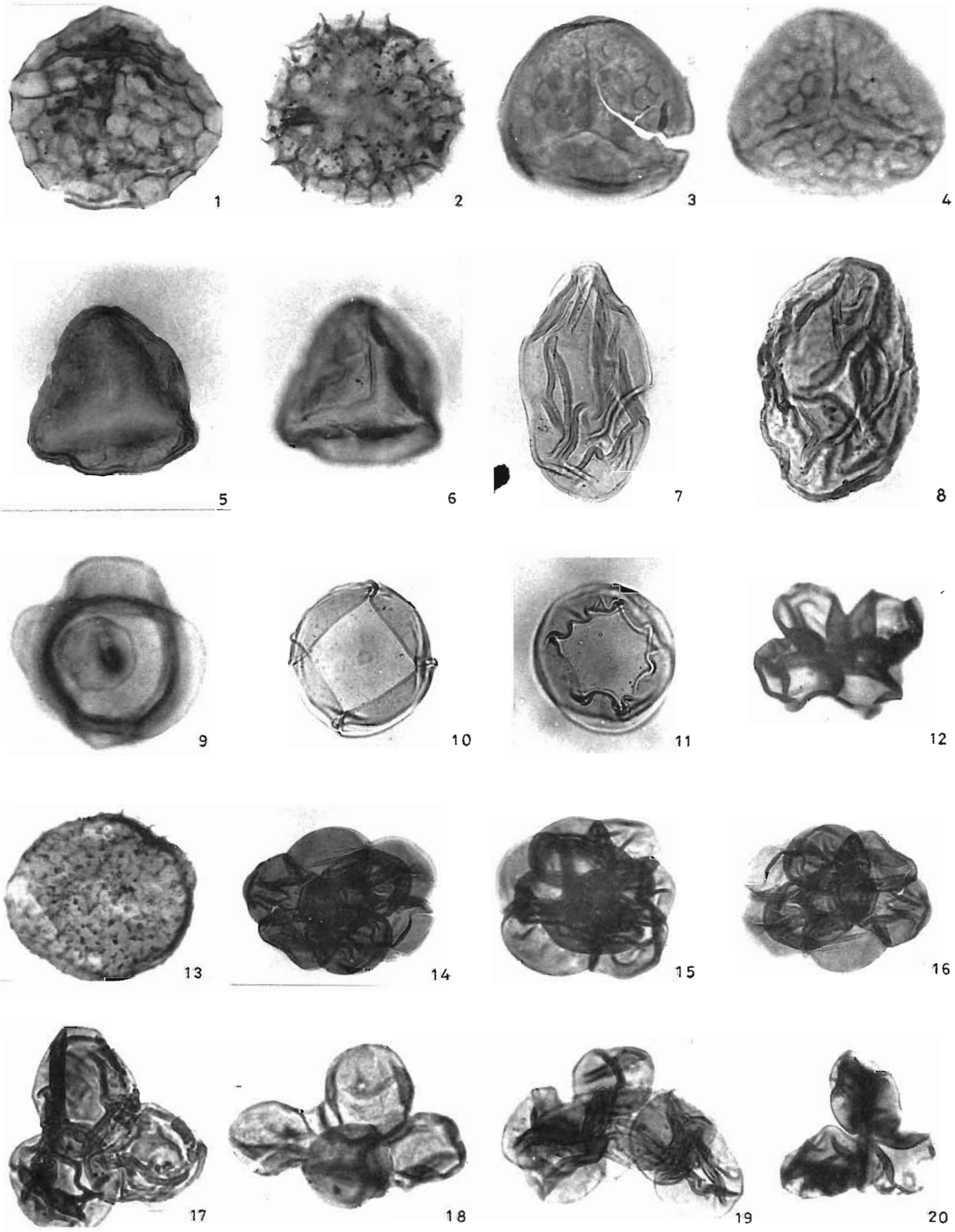

PLATE 1

Type Locality, Horizon and Age—Nadah, Panchkula, Haryana, Upper Siwalik, Pinjor Formation, Late Pliocene.

Diagnosis and Description—Fungal spore colonies composed of number of cells, 16-20 in number. Overall size range 90-130 x 65-90 µm. Inaperturate. Individual cells more or less subspherical in shape, variation in overall shape and size, size range 35-42 x 28-33 µm. Wall 1 µm thick, perforated, surface showing finely pitted reticulate ornamentation.

Comparison—*Polyadosporites nadahensis* sp. nov. is closely comparable with the type species *P. suescae* van der Hammen (1954) by its general characters but the latter is differentiated by its smaller size (40-55 µm) and psilate wall.

POLYADOSPORITES SIWALIKUS sp. nov.

Pl. 3.6, 9

Holotype—Pl. 3.6, size. 127 x 112 µm, Slide No. BSIP 12620.

Type Locality, Horizon and Age—Nadah, Panchkula, Haryana, Upper Siwalik, Pinjor Formation, Late Pliocene.

Diagnosis and Description—Fungal spores composed of number of individual subspherical cells, cells inapeturate. Size range 127-145 x 112-120 µm . Cell wall thin, septa connecting to 2 or 3 cells, 1-2 µm thick, smooth.

Comparison—*Polyadosporites siwalikus* sp. nov is distinguished from *Polyadosporites nadahensis* sp. nov. by its bigger size and psilate wall.

Genus—FRASNACRITETRUS Taugourdeau, 1968 emend. Saxena & Sarkar, 1986

Type Species—FRASNACRITETRUS JOSETTAE Taugourdeau, 1968

FRASNACRITETRUS sp. A

Pl. 3.7

Description—Fungal conidia with three processes. Main body rectangular in shape, unicellular, longitudinally septate. Surface finely conate, evenly distributed all over the body. Processes arise from one end of the body, tubular, wide at the base and gradually tapering towards the apices, nonseptate, wall processes smooth.

Length of conidia—127 µm.

Size of the body—35 x 25 µm.

Size of the processes—92 µm.

Comparison—The present species closely resembles with the *Frasnacritetrus conatus* Saxena and Sarkar (1986) by its conate wall but the latter is differentiated in having 4 processes.

FRASNACRITETRUS sp. B

Pl. 3.8

Description—Fungal conidia with four processes. Main body subrectangular, longitudinally septate. Surface verrucate, verrucae very small, closely placed. Processes arise from one end of the body, tubular, transversely septate, 3-4 septa present in each processes, wall smooth.

Length of conidia—140 µm.

Size of the body—30 x 21 µm.

Size of the processes—110-113 x 4 µm.

Comparison—The present species is closely comparable with the type species *Frasnacritetrus josettae* Taugourdeau (1968) by its shape and general organization but differs in having verrucate body wall.

FUNGAL SPORE -type A

Pl. 2.18

Description—Fungal spore sub-circular with broad appendage. Size 85 x 95 µm. Appendage tubular, coiled, length 65-80 µm. Inaperturate, wall thin, laevigate associated with folds.

Affinity—Spores of *Glomus* (Pirozynski *et al.*, 1988).

PLATE 2 →

(All photomicrographs are enlarged ca. x 500. Coordinates of the specimens refer to the stage of the BH2 Olympus microscope no. 217267)

1-2. *Lycopodiumsporites* sp. A Slide No. BSIP 12615, coordinates 7.8 x 162.0.
3. *Leptolepidites* sp., Slide No. BSIP 12611, coordinates 19.5 x 139.0.
4. *Abiespollenites surmaensis* Rao, 1986, Slide No. BSIP 12616, coordinates 14.0 x 135.3.
5. *Striatriletes sinuosus* Rao & Singh, 1987, Slide No. BSIP 12615, coordinates 18.5 x 150.0.
6. *Jacobipollenites* sp. Slide No. BSIP 12606, coordinates 17.0 x 154.0.
7-8. *Pinuspollenites nadahensis* sp. nov. Slide No. BSIP 12617, coordinates 19.0 x 149.0 (Holotype).
9. *Retitrescolpites* sp. Slide No. BSIP 12618, coordinates 17.4 x 149.5
10. *Podocarpidites meghalayaensis* Rao, 1986 Slide No. BSIP 12609, coordinates 8.4 x 140.0.
11 *Pinuspollenites foveolatus* Rao, 1986, Slide No. BSIP 12608, coordinates 13.2 x 167.5.
12-14. *Pinuspollenites chandigarhensis* sp. nov. Slide No. BSIP 12609, coordinates 13.2 x 167.5; 12607, coordinates 6.0 x 134.0 (Holotype); 12606, coordinates 9.7 x 145.0.
15-16. *Malvacearumpollis* sp. Slide No. BSIP 12607, coordinates 9.5 x 132.0.
17 *Malvacearumpollis grandis* Sah, 1967, Slide No. BSIP 12607, coordinates 16.4 x 161.5.
18-19. Fungal spores of *Glomus*, Slide No. BSIP 12609, coordinates 8.5 x 147.0; 12619, coordinates 5.5 x 159.0.

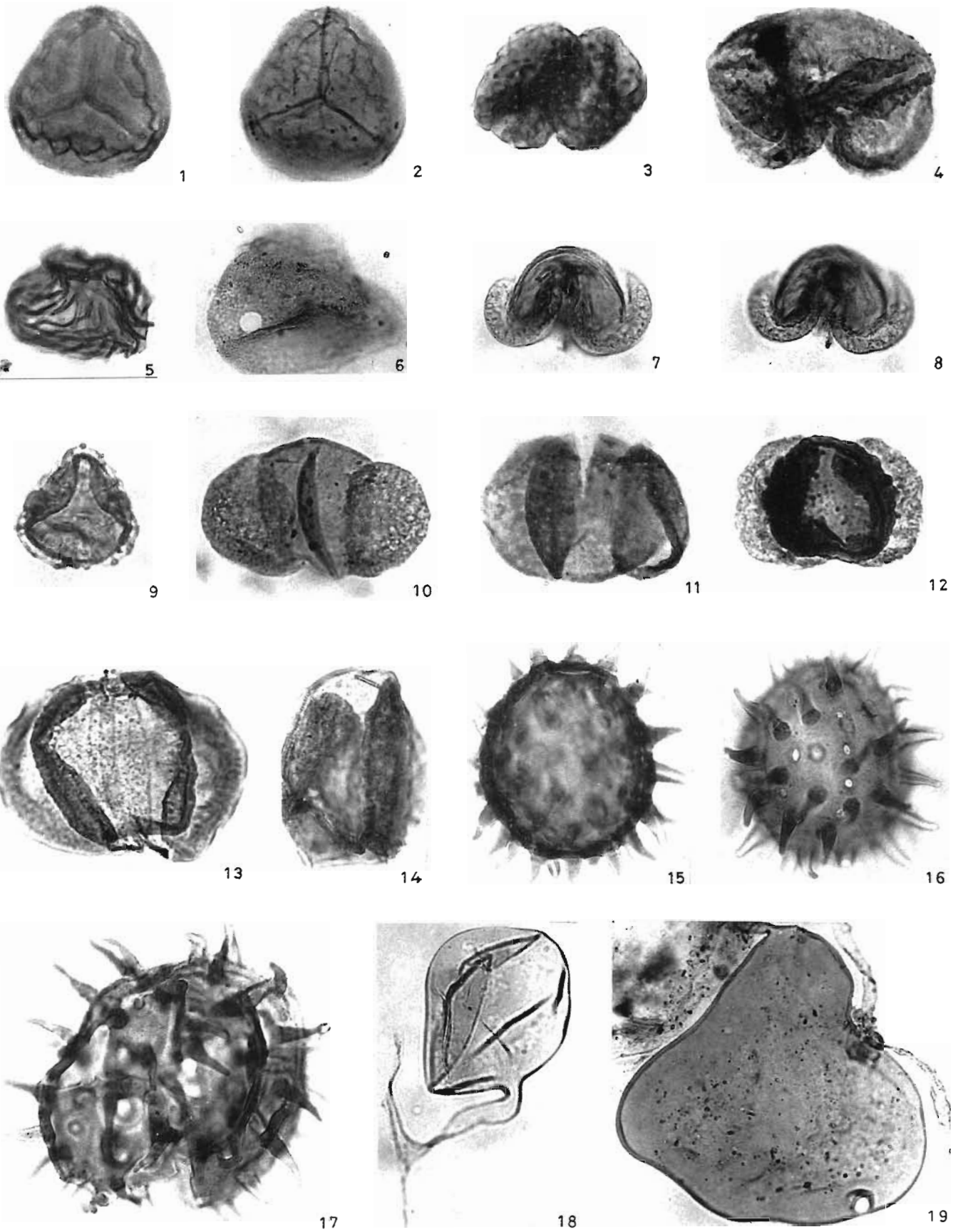

PLATE 2

FUNGAL SPORE type-B

Pl. 2.19

Description—Fungal spore sub-circular with broad appendage. Size 110 x 100 µm. Appendage tubular, coiled, 60 µm long, 4-6 µm wide. Pore present on one side, 4 µm diameter, surrounded by thickening, wall smooth.

Affinity—Spores of *Glomus* (Pirozynski *et al.*, 1988).

Genus—LYCOPODIUMSPORITES (Thiergart, 1938) Delcourt & Sprumont, 1955

Type Species—LYCOPODIUMSPORITES AGATHOECUS (Potonié) Delcourt & Sprumont, 1955

LYCOPODIUMSPORITES NADAHENSIS sp. nov.

Pl. 1.1-2

Holotype—Pl. 1.1, Size 100 µm, Slide No. BSIP 12604.

Type Locality, Horizon and Age—Nadah, Panchkula, Haryana, Upper Siwalik, Pinjor Formation, Late Pliocene.

Diagnosis and Description—Miospores sub-circular in proximal view. Size range 100-118 µm. Trilete, rays indistinct due to heavy reticulation. Exine 1 µm thick, proximal surface psilate while distal surface showing distinct broad reticulate ornamentation, mesh size variable, meshes filled with grana.

Comparison—The present species is distinguished from all the recorded species of *Lycopodiumsporites* from Tertiary sediments of India in having extraordinary size and broad reticulate ornamentation.

Affinity—Lycopodiaceae.

LYCOPODIUMSPORITES sp. A

Pl. 2.1-2

Description—Miospores sub-triangular in proximal view, interapical margins concave, apices broadly rounded. Size range 78-83 x 70-75 µm. Trilete, trilete rays sinuous, raised, reaching almost to the apices. Exine thin, proximal surface smooth. Distal surface showing distinct reticulate ornamentation, meshes big in the centre and small towards apices.

Affinity—Lycopodiaceae.

LYCOPODIUMSPORITES sp. B

Pl. 3.1

Description—Miospore sub-circular in proximal view. Size 150 x 140 µm, Trilete, indistinct due to heavy ornamentation. Exine 3 µm thick. Proximal surface smooth, distal surface showing distinct reticulate ornamentation, meshes 15-25 µm wide, meshes filled with grana. Thin cingulum present around the miospore.

Affinity—Lycopodiaceae.

LYCOPODIUMSPORITES sp. C

Pl. 3.4

Description—Miospore sub-triangular in proximal view, margins concave, apices broadly rounded. Size 110 x 105 µm. Trilete, rays thickened at the centre and narrow towards apices, reaching almost reaching to the equator. Exine 4 µm thick, proximal surface smooth and distal surface showing distinct broad reticulate ornamentation, meshes 10-30 µm wide.

Affinity—Lycopodiaceae.

Genus—PTERIDACIDITES Sah, 1967

Type Species—PTERIDACIDITES AFRICANUS Sah, 1967

PTERIDACIDITES CHANDIGARHENSIS sp. nov.

Pl. 1.3-4

Holotype—Pl. 1.4, Size 95 x 100 µm, Slide No. BSIP 12607.

Type Locality, Horizon and Age—Nadah, Panchkula, Haryana, Upper Siwalik, Pinjor Formation, Late Pliocene.

Diagnosis and Description—Miospores subtriangular with cingulum in proximal view, apices broadly rounded. Size range 93-105 x 85-95 µm. Trilete, open, reaching almost to the

PLATE 3

(All photomicrographs are enlarged ca. x 500. Coordinates of the specimens refer to the stage of the BH2 Olympus microscope no. 217267)

1. *Lycopodiumsporites* sp. B Slide No. BSIP 12616, coordinates 9.0 x 137.4.
2. *Liliacidites* sp. Slide No. BSIP 12607, coordinates 19.5 x 147.0.
3. *Laricoidites magnus* Potonié, 1958. Slide No. BSIP 12607, coordinates 5.0 x 133.0.
4. *Lycopodiumsporites* sp. C, Slide No. BSIP 12607, coordinates 5.5 x 154.3.
5. *Piceapollenites* sp. Slide No. BSIP 12609, coordinates 10.5 x 145.0.
6, 9. *Polyadosporites siwalikus* sp. nov. Slide No. BSIP 12620, coordinates 5.0 x 155.5 (Holotype); 12621, coordinates 19.0 x 166.0.
7. *Frasnacritetrus* sp. A., Slide No. BSIP 12607, coordinates 5.7 x 141.5.
8. *Frasnacritetrus* sp. B., Slide No. BSIP 12622, coordinates 15.0 x 140.7.
10. *Palmidites* sp. Slide No. BSIP 12609, coordinates 10.4 x 157.0.
11. *Psilodiporites* sp. Slide No. BSIP 12623, coordinates 5.0 x 142.0.
12. *Cycadopites* sp. Slide No. BSIP 12604, coordinates 12.0 x 151.4.
13. Angiosperm tracheid, Slide No. BSIP 12624, coordinates 11.0 x 167.0.

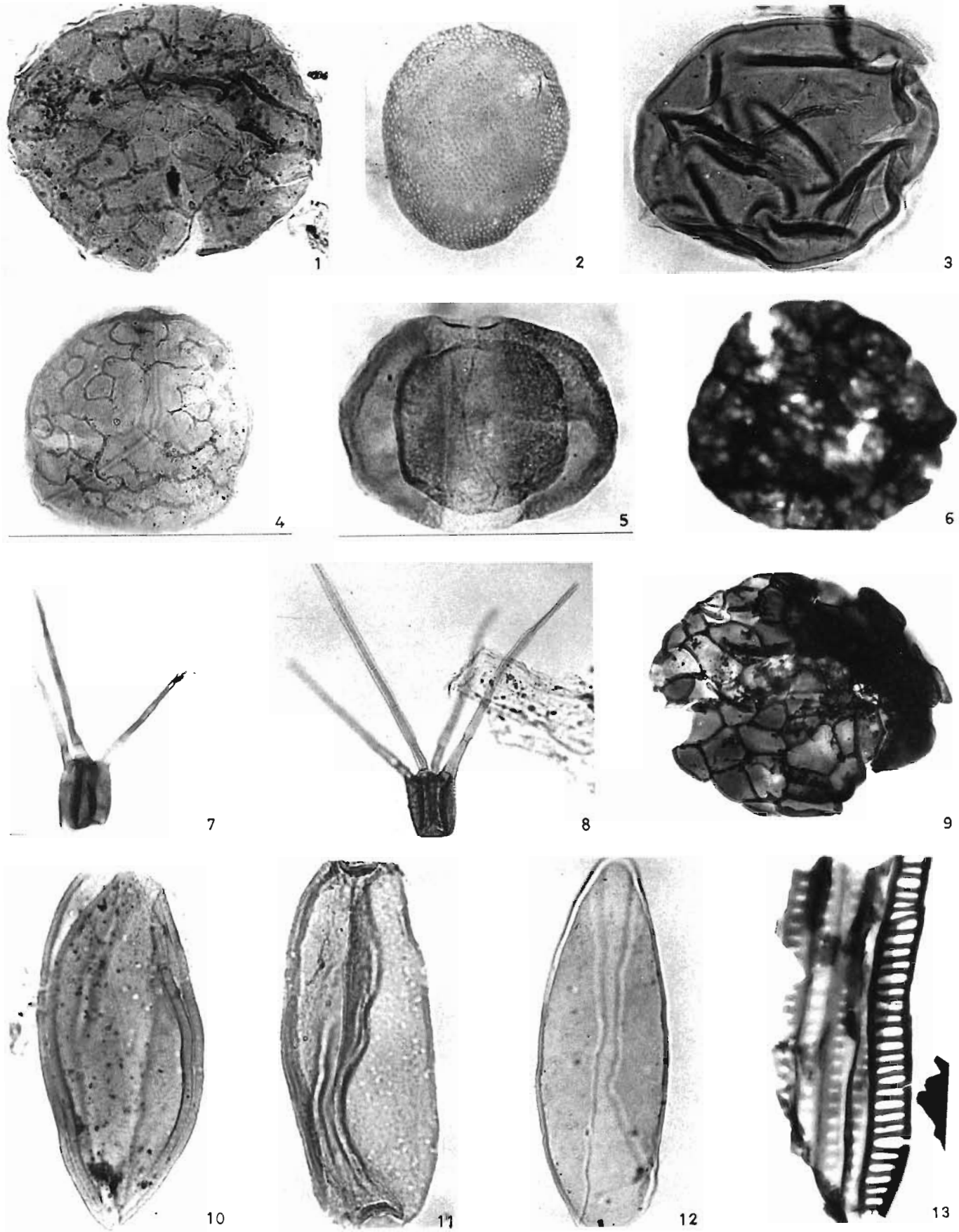

PLATE 3

apices. Exine 1-2 μm thick, proximal surface smooth, distally verrucate, verrucae coalesce to form distinct broad reticulate ornamentation.

Comparison—*Pteridacidites chandigarhensis* sp. nov. is comparable with the type species *Pteridacidites africanus* Sah (1967) by its general characters but the latter is distinguished in its smaller size (53-81 μm), thicker exine and ornamented with fairly large reniform and rounded verrucae. *Pteridacidites rarus* Sah (1967) is distinct by its more or less circular shape, broader cingulum and in possessing few and large warts. *P. vermiverrucatus* Sah (1967) differs from the present species in having inter-ray area wholly covered by a small rounded verrucae fused to form a warm-like appearance.

Genus—LEPTOLEPIDITES Couper, 1953

Type Species—LEPTOLEPIDITES VERRUCUS Couper, 1953

LEPTOLEPIDITES sp.

Pl. 2.3

Description—Miospore subtriangular in proximal view. Size 60 x 45 μm. Trilete rays indistinct due to heavy ornamentation. Exine thin, verrucate, verrucae very closely placed. Distal surface showing negative reticulate ornamentation.

SPORE-TYPE

Pl. 1.5-6

Description—Miospore sub-triangular in proximal view, apices broadly rounded, interapical margins concave. Size 83 x 78 μm. Trilete, open, reaching almost to the apices thickening along the rays. Exine 2 μm thick. Proximal surface smooth and distal surface showing distinct reticulate ornamentation.

Affinity—Lycopodiaceae.

Genus—CYCADOPITES Wodehouse, 1933

Type Species—CYCADOPITES FOLLICULARIS Wilson & Webster, 1946

CYCADOPITES sp.

Pl. 3.12

Description—Pollen grain oval-elongate in polar view. Size 120 x 64 μm. Monosulcate, sulcus broad at the margin, 15-30 μm wide, and narrow in the center. Exine 3 μm thick, sexine and nexine not differentiated, laevigate ornamentation.

Affinity—Cycadaceae.

Genus—PINUSPOLLENITES Raatz, 1937

Type Species—PINUSPOLLENITES LABDACUS (Potonié) Raatz, 1937

PINUSPOLLENITES NADAHENSIS sp. nov.

Pl. 2.7-8

Holotype—Pl., 2.7, Size 77 x 50 μm, Slide No. BSIP 12617.

Type Locality, Horizon and Age—Nadah, Panchkula, Haryana, Upper Siwalik, Pinjor Formation, Late Pliocene.

Diagnosis and Description—Pollen grains bisaccate. Size range 70-77 x 45-55 μm. Central body more or less circular, size range 45-52 x 40-45 μm, margin wavy, thickened in the middle part, up to 4 μm thick, thinning towards the sacci, 1-2 μm thick, central part sunken. Sacci diploxylonoid type, bean-shaped, size range 35-42 x 28-32 μm. marginal crest developed. Surface showing distinct broad reticulate ornamentation.

Comparison—The present species is closely comparable with the type species *Pinuspollenites labdacus* Potonié (1958) by its general organization but the latter is distinguished in having bigger sacci and larger than central body. *Pinuspollenites foveolatus* Rao (1986) is distinct in having smaller size (41-48 x 33-47.5) and foveo-reticulate ornamentation.

Affinity—Pinaceae.

PINUSPOLLENITES CHANDIGARHENSIS sp. nov

Pl. 2.12-14

Holotype—Pl. 2.13, Size, 122 x 87 μm, Slide No. BSIP 12607.

Type Locality, Horizon and Age—Nadah, Panchkula, Haryana, Upper Siwalik, Pinjor Formation.

Diagnosis and Description—Pollen grains bisaccate, size range 90-122 x 60-87 μm. Central body sub-circular to quadrangular in shape, margin wavy, dark brown in colour, size range 75-88 x 58-70 μm, central body bigger than sacci, crest well developed, very thick in the middle and narrow in the attachment of sacci. Sacci kidney-shaped, size range 73-88 x 35-58 μm, ornamented with small meshes, marginal crest developed.

Comparison—*Pinuspollenites chandigarhensis* sp. nov. is distinguished from the *P. nadahensis* sp. nov. by its bigger size and well developed crest on the central body.

Affinity—Pinaceae.

Genus—PICEAPOLLENITES Potonié 1931

Type Species—PICEAPOLLENITES ALATUS Potonié, 1931

PICEAPOLLENITES sp.

Pl. 3.5

Description—Pollen grains bisaccate, oval-elongate in outline. Size range 125-132 x 90-96 μm. Central body sub-circular in shape, size range 90-93 x 80-83 μm, microreticulate. Sacci very closely placed leaving no space in between, hemispherical

in shape, size range 88-92 x 40-45 µm, ornamented with small meshes, marginal crest developed, crest gradually thinning to the wings though thickened in the middle.

Comparison—*Piceapollenites alatus* Potonié (1931) differs from the present species in having smaller size (70 µm) and coarser reticulum of the central body.

Affinity—Pinaceae.

Genus—LILIACIDITES Couper, 1953

Type Species—LILIACIDITES KAITANGATAENSIS Couper, 1953

LILIACIDITES sp.

Pl. 3.2

Description—Pollen grain oval in polar view. Size 110 x 90 µm. Monosulcate, sulcus broad and wide. Exine thin, perforated, distinct reticulate ornamentation.

Comparison—*Liliacidites* sp. compares well with *Liliacidites kaitangataensis* Couper (1953) in its general characters but the latter can be distinguished by its differential ornamentation pattern of the reticulate exine (lumina 5 µm at the equator and 1 µm at poles). *Liliacidites baculatus* Venkatachala & Kar (1969) differs in having funnel-shaped sulcus and intrabaculate exine. *Liliacidites keralaensis* Rao (1990) is different in having thicker exine (3.5 µm) and smaller size.

Affinity—Liliaceae.

Genus—PALMIDITES Couper, 1953

Type Species—PALMIDITES MAXIMUS Couper, 1953

PALMIDITES sp.

Pl. 3.10

Description—Pollen grain oval-elongate in polar view. Size 120 x 47 µm. Monocolpate, colpus very long, broad in the middle and narrow at the apex. Exine 7 µm thick, sexine and nexine differentiated, sexine 4 µm thick, perforated, nexine 3 µm thick, smooth, surface showing finely scrobiculate ornamentation.

Affinity—Arecaceae.

Genus—NYMPHAEACIDITES Sah, 1967

Type Species—NYMPHAEACIDITES TYPICUS Sah, 1967

NYMPHAEACIDITES sp.

Pl. 1.13

Description—Pollen grain sub-circular in shape. Size 92 x 82 µm. 1-aperturate, aperture large, operculate, exine 5 µm thick, sexine and nexine not differentiated, sexine provided with sparsely placed spines, spines thin, 6 µm long.

Comparison—*Nymphaeacidites* sp. is differs from *N. typicus* Sah (1967) in having comparatively larger size and absence of suprategellar baculoid processes.

Affinity—Nymphaeaceae.

Genus—RETITRESCOLPITES Sah, 1967

Type Species—RETITRESCOLPITES TYPICUS Sah, 1967

RETITRESCOLPITES sp.

Pl. 2.9

Description—Pollen grain sub-triangular in polar view, apices broadly rounded. Size 60 x 55 µm. Tricolporoidate. Exine 6 µm thick, tectate. Sexine 5 µm thick, pilate, sparsely placed, nexine 1 µm thick, smooth. Distal surface showing distinct broad reticulate ornamentation.

Comparison—The present species is closely comparable with the type species *Retitrescolpites typicus* Sah, 1967 by its retipilate exine but the latter is distinguished in having closely placed pila and thick reticulum.

Affinity—Oleaceae.

Genus—JACOBIPOLLENITES Ramanujam, 1966

Type Species—JACOBIPOLLENITES MAGNIFICUS Ramanujm, 1966

JACOBIPOLLENITES sp.

Pl. 2.6

Description—Pollen grain sub-circular in polar view. Size 72 µm. Monoporate, pore wall thin, 10 µm in diameter. Exine thin, finely reticulate ornamentation.

Comparison—*Jacobipollenites* sp. is closely comparable with *J. magnificus* Ramanujam (1966) by its general characters but the latter distinguished in having coarser reticulum.

Affinity—Sparganiaceae.

Genus—PSILADIPORITES Varma & Rawat emend. Venkatachala & Rawat, 1972

Type Species—PSILADIPORITES HAMMENII Varma & Rawat, 1963

PSILADIPORITES sp.

Pl. 3.11

Description—Pollen grain oval-cylindrical in polar view. Size 120 x 70 µm. Diporate, 15 µm diameter, pore margin thickened, 5 µm thick. Exine 6 µm thick, sexine and nexine differentiated, sexine 2 µm thick, smooth, nexine 4 µm thick, finely scrobiculate ornamentation.

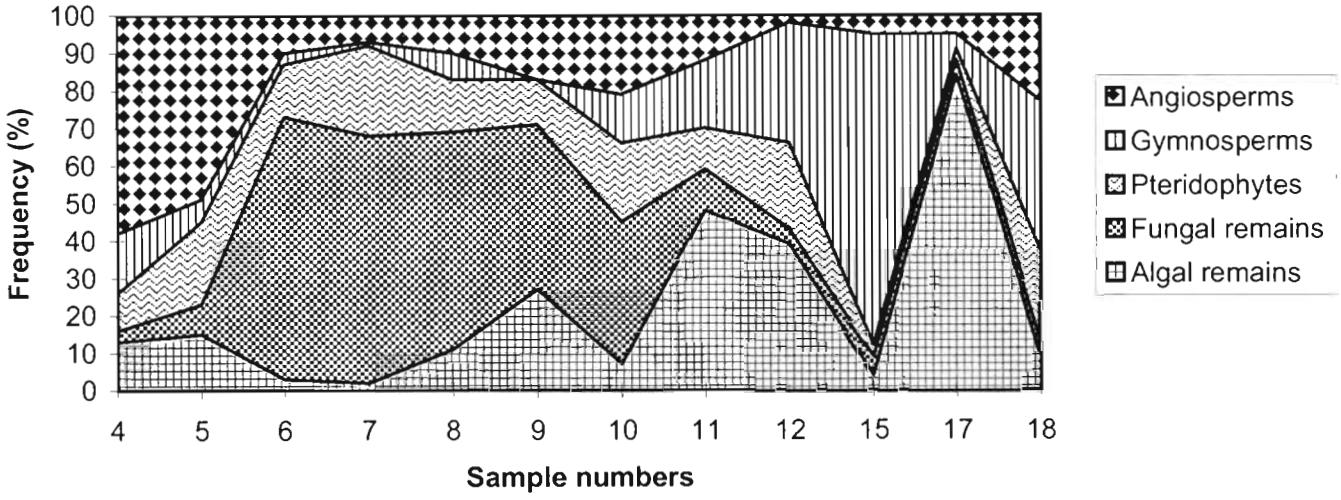

Fig. 3—Representation of different plant groups of Nadah area, Panchkula, Haryana.

Genus—MALVACEARUMPOLLIS Nagy, 1962

Type Species—MALVACEARUMPOLLIS BAKONYENSIS Nagy, 1962

MALVACEARUMPOLLIS sp.

Pl. 2.15-16

Description—Pollen grains sub-circular. Size range 90-100 µm excluding processes. Polyporate, pores more than 12 in number. Exine 6 µm thick, sexine and nexine well differentiated, sexine beset with numerous suprategillar spines, fairly long spines, broad and bulbous base and narrow at the tips, nexine 1 µm thick, smooth. Spines are many, 15-20 µm long, 6-10 µm wide, in between the processes finely fitted reticulate ornamentation.

Comparison—Malvacearumpollis sp. closely comparable with the type species *Malvacearumpollis bakonyensis* Nagy (1962) by its general characters but the former is distinguished in having many spines (more than 12) and very bulging bases (bases 6-10 µm). *M. grandis* Sah (1967) is very much larger size (115-139 µm) and many pores.

Affinity—Malvaceae.

Genus—GRAMINIDITES Cookson, 1947

Type Species—GRAMINIDITES MEDIA Cookson, 1947

GRAMINIDITES SIWALIKUS sp. nov.

Pl. 1.18-20

Holotype—Pl. 1.18, Size 110 x 83 µm, Slide No. BSIP 12604.

Type Locality, Horizon and Age—Nadah, Panchkula, Haryana, Upper Siwalik, Pinjor Formation, Late Pliocene.

Diagnosis and Description—Pollen grains in clusters, generally 4-15 in number, connected with 2 or more septa. Size range 70-115 x 70-98 µm. Individual grains sub-triangular to sub-circular in polar view. Size range 40-48 x 32-45 µm . Monoporate, pore surrounded by thick annulus. Exine 2 to 2.5 µm thick, surface showing finely foveo-reticulate ornamentation.

Comparison—The present species is closely comparable with the type species by its porate nature but differs from *Graminidites media* and *G. subreticulata* Cookson (1947) in distinct reticulate ornamentation. *Graminidites assamicus* Sah & Dutta (1968) is distinct by its oval-elliptical shape and ornamentation psilate to faintly structured. *Graminidites chandigarhensis* Saxena & Singh (1982a) is different in having laevigate exine. *G. congoensis* Sah, 1967 is distinct from the present species in having larger size (60-76 µm).

Affinity—Poaceae.

Fig. 4—Possible affinities of palynomorphs recognised in the assemblages and present day distribution.

Family	Fossil Taxa	Modern equivalents	Preferable habitat	Distribution/ Climate
Zygnemataceae	----------	*Zygnema, Spirogyra Mougeotia*	Commonly found in freshwater of small ponds or temporary pools in wet areas	Cosmopolitan
Lycopodiaceae	*Lycopodiumsporites* spp.	*Lycopodium*	Terrestrial or epiphytes	Cosmopolitan absent in arid areas
Parkeriaceae	*Striatriletes* spp.	*Ceratopteris*	Grow in a variety of aquatic habitats including lakes, ponds, rivers, open swamps and ditches	Widespread distribution though largely confined to warmer regions tropical-subtropical
Pteridaceae	*Pteridacidites chandigarhensis*	*Pteris*	Terrestrial	Worldwide distribution though largely confined to warmer regions, tropical-subtropical
Schizaeaceae	*Leptolepidites* sp.	*Schizaea*	Mostly moist forest	Tropical-subtropical
Arecaceae	*Palmidites* sp.	----------	----------	Tropical-subtropical
Cycadaceae	*Cycadopites* sp.	*Cycas*	Prefers dry places	Tropical-subtropical
Podocarpaceae	*Podocarpidites meghalayaensis*	*Podocarpus*	Plants of mesic forest conditions	Mostly in tropical to warm or occasionally in cool temperate regions.
Pinaceae	*Pinuspollenites* spp. *Piceapollenites* sp. *Abiespollenites surmaensis*	*Pinus, Picea, Abies*	Trees of generally poor acidic and either wet or rocky habitats	Widely distributed throughout the temperate parts
Liliaceae	*Liliacidites* sp.	----------	Mostly herbs, terrestrial	Cosmopolitan
Iridaceae	*Iridacidites warkalliensis*	*Watsonia*	----------	Tropical to temperate
Magnoliaceae	*Pinjoriapollis lanceolatus*	*Magnolia*	Trees and shrubs	Temperate to terrestrial
Oleaceae	*Retitrescolpites* sp.	----------	----------	Cosmopolitan
Poaceae	*Graminidites siwalikus*	----------	Almost every type of habitat frequently forming a part of a forest undergrowth in wet or dry places	Widely distributed in all regions of the world.
Malvaceae	*Malvacearumpollis* spp.	*Hibiscus*	Terrestrial	Tropical and temperate
Nymphaeaceae	*Nymphaeacidites* sp.	*Nymphaea*	Aquatic plant	Warm parts of India
Chenopodiaceae	*Chenopodipollis mioceneca*	*Chenopodium*	----------	Tropical-temperate
Sparganiaceae	*Jacobipollenites* sp.	*Sparganium*	Aquatic	Temperate

POLLEN TETRAD type- A

Pl. 1.13

Description—Pollen grain in tetrad stage, sub-circular in polar view. Size 72 x 85 µm. Individual grains oval-subcircular in shape. Size 40 x 35 µm. Monosulcate, sulcus showing simple cohesion in a tetrad. Exine thin, finely punctate ornamentation.

POLLEN TETRAD type-B

Pl 1.20

Description—Pollen grain in tetrad stage, sub-triangular in polar view. Size 98 x 93 µm. Individual grains sub-circular in shape, size 57 x 52 µm. Monosulcate, sulcus wide, long and associated with folds. Exine 4 µm thick, sexine and nexine differentiated. Surface showing finely fitted reticulate ornamentation.

PALYNOFLORAL ANALYSIS

The palynoassemblage recovered from the Pinjor Formation consists of algal and fungal remains, pteridophytic spores, gymnosperm and angiosperm pollen. Of these *Polyadosporites nadahensis*, *P. siwalikus*, *Lycopodiumsporites nadahensis*, *Pinuspollenites nadahensis*, *P. chandigarhensis* and *Graminidites siwalikus* have been proposed as new species.

The gymnosperm pollen is dominant over angiosperm pollen and pteridophytic spores. The frequency of algal remains (zygospores of Zygnemataceae) are low in the lower part of the section and increases in the up section whereas the fungal remains show high frequency in the lower part and progressively decreases towards the top. The frequency of pteridophytic spores especially *Lycopodiumsporites* is dominant in the lower and upper part of the section and decreases at the top of the section. Gymnosperm pollen represented by Pinaceae (*Pinus*) are dominant at the top of the section whereas reverse is the case with the angiosperm pollen (Fig. 3). The possible modern affinities of palynomorphs recognized in the assemblage and their ecological interpretations are given in Fig. 4.

PALYNOSTRATIGRAPHIC ZONATION

Quantitative analysis has been done on the basis of frequencies of palynotaxa in a count of 100 specimens or more specimens per sample and percentage of each palynotaxon or group of palynotaxa was calculated. Percentage frequencies of the selected palynotaxa were plotted under four categories, namely, rare (1-5%), common (6-10%), abundant (11-20%) and predominant (above 20%) (Fig. 5).

Vertical distribution of the palynotaxa clearly indicates that the studied sequence (Pinjor Formation) has been divided into two palynozones –the lower Zone-1 and the upper Zone-2. Recognition of these zones is based on the first (FAD) and last appearance (LAD) of various palynotaxa and their maximum development, decline, restricted occurrence and absence. A description of zones is discussed below:

The characteristic palynotaxa to the lower Zon-1 are *Polyadosporites* spp., *Lycopodiumsporites* spp., *Pinjoriapollis lanceolatus* and *Graminidites siwalikus*. The frequency of zygnemataceous spores (*Spirogyra, Zygnema* and *Mougeotia*) is rare to common in the lower part of the section and increases from abundant to predominant at the top of the section. On the other hand, the percentage frequency of *Polyadopsorites* spp., *Lycopodiumsporites* spp., *Pinjoriapollis lanceolatus* and *Graminidites siwalikus* is abundant to predominant in the lower part of the section and decreases at the top of the section. *Laricoidites magnus* and *Inaperturopollenites punctatus* are restricted to this zone.

The characteristic feature of Zone-2 is that the *Pinuspollenites* spp. are dominant to predominant in the upper part of the zone. The increased frequency of *Graminidites siwalikus* has been observed at the top of the section. *Abiespollenites, Piceapollenites, Retitrescolpites* and *Chenopodipollis* are restricted to this zone. *Striatriletes* spp. and *Malvacearumpollis* spp. occurring in both the zones of the section (Fig. 5).

PALYNOFLORAL COMPARISON

A comparison of the present assemblage with the known Upper Siwalik assemblages from India and Nepal is discussed below:

Nandi (1975) reported a rich palynoflora from the Siwalik sequence exposed in Jwalamukhi area, Chamba District, Himachal Pradesh and utilized the same in palynostratigraphic zonation. On the basis of qualitative analysis of spore-pollen, she divided the Siwalik sequence into four zones, viz., I-IV, of these Zone- IV represents the upper most part of the middle and upper Siwalik. This zone has poor representation of *Cyathidites, Alsophilidites, Leptolepidites, Podocarpidites, Pinuspollenites, Monoporopollenites, Alnipollenites* and *Tetradomonoporites*. Of these, *Podocarpidites, Pinuspollenites*, *Monoporopollenites* (Poaceae) are common to both the assemblages. The comparative study reveals that the dominant elements *Pinuspollenites* and *Monoporopollenites* (Poaceae) are present in both the assemblages showing close resemblance to them.

Singh and Saxena (1981) recorded fungal remains, gymnosperm and angiosperm pollen grains from the Gagret-Barwain Road section, Una District, Himachal Pradesh. The common genera between the two assemblages are *Pinuspollenites, Laricoidites, Verrualetes* and *Graminidites*. The above comparison reveals that the palynoassemblage recorded by Singh and Saxena (1981) is broadly comparable to the present assemblage.

	EOCENE–PLIOCENE												AGE
	PLIOCENE–PLEISTOCENE												FORMATION
	ZONE 1							ZONE 2					ZONES
	4	5	6	7	8	9	10	11	12	15	17	18	SAMPLE NUMBERS
	○	□	□	□		■	□	●	■		●	□	Spirogyra A
	□	○				○	□	○	■		●	□	Spirogrya B
								○	○		□		Mougeotia
	□			□		□	□		□				Zygnema
	□		●	●	●	●	■			□	□		Fungal body A
	□	○	○	■	○	■	●						Fungal body B
										□	●	□	Fungal type
			□					□					Frasnacritetrus sp.
	○	■	■	●	■	■	●	○	■			■	Lycopodiumsporites spp
		□						□	□	□	□	□	Pteridacidites sp.
	□	□		□	□			□					Striatriletes susannae
	□	□											Laricoidites major
									□		□		Podocarpidites sp.
	■	□	□		○		■	■	●	●		●	Pinuspollenites spp.
									□				Piceapollenites sp
				□					□			○	Abiespollenites sp.
		□	□	□	□	□							Inaperturopollenites punctatus
	■	■	□	○		■	○	○			□		Pinjoriapollis lanceolatus
										□			Retitrescolpites sp.
						□	□	□	□			□	Malvacearumpollis spp.
										□			Chenopodipollis mioceneca
	●	●	□	●			□	□	□	□		●	Graminidites spp.

Rare □ 1-5% Common ○ 6-10% Abundant ■ 11-20% Predominant ● Above 20%

Fig. 5—Palynostratigraphic zonation in the Pinjor Formation, Panchkula, Haryana.

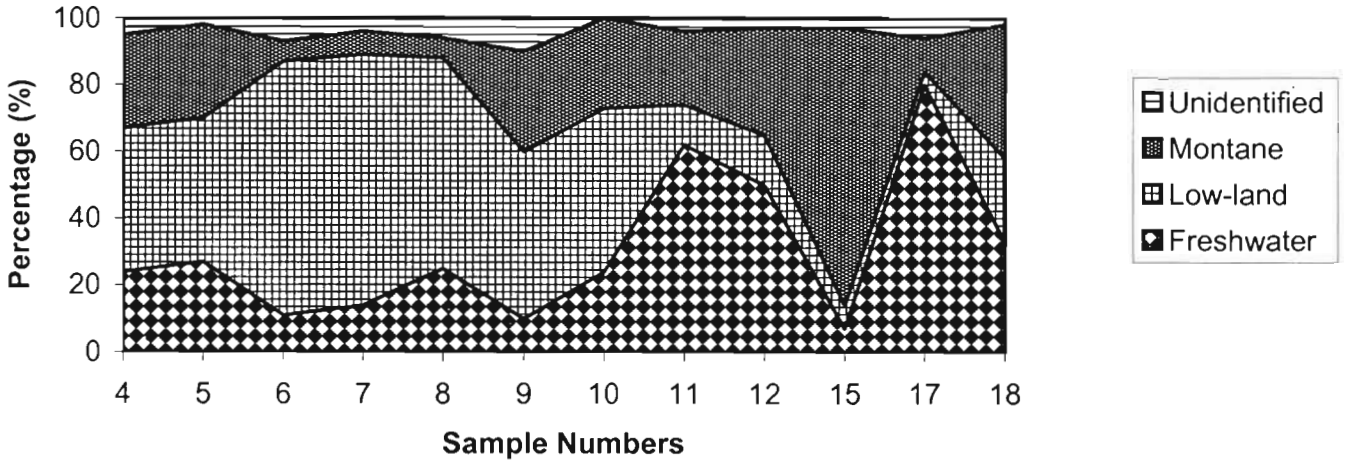

Fig. 6—Percentage of palynotaxa belong to various ecological groups, Pinjor Formation, Haryana.

Saxena and Singh (1982a) recovered palynofossils from the Upper Siwalik sediments exposed along Hoshiarpur-Una Road section, Himachal Pradesh. The common genera between the two assemblages are *Pinuspollenites, Abiespollenites, Laricoidites, Inaperturopollenites, Verrualetes* and *Graminidites*. The palynoassemblage described by Saxena and Singh (1982a) is broadly comparable.

Saxena and Singh (1982b) recorded palynoassemblage from the Pinjor Formation (Upper Siwalik) exposed near Chandigarh, India. The assemblage recorded by them are: *Cyathidites, Lygodiumsporites, Todisporites, Striatriletes, Podocarpidites, Pinuspollenites, Cedripites, Laricoidites, Araucariacites, Retiinaperturites, Palmidites, Psilamonocolpites, Pinjoriapollis, Liliacidites, Favitricolporites, Graminidites* and *Triporites*. Of these, *Striatriletes, Laricoidites, Podocarpidites, Pinuspollenites, Liliacidites* and *Graminidites* are common to both the assemblages. The above comparison indicates that the assemblage recorded by Saxena and Singh (1982b) closely resembles with the present assemblage.

Saxena *et al.* (1984) studied the entire Siwalik sequence exposed along Bhakra-Nangal Road section. The palynoflora recovered from Upper Siwalik are very poor and the genera common to both the assemblages are *Striatriletes, Pinuspollenites* and *Graminidites*. A critical study of the two palynoassemblages reveal that the assemblage recorded by Saxena *et al.* (1984) is broadly comparable with the present one.

Mathur (1984) reported palynoflora from the Upper Siwalik sediments exposed in Malnu-Salwana traverse. The common taxa between the assemblages are *Pinuspollenites, Piceapollenites, Chenopodipollis* and *Graminidites* (Poaceae). The important genera like *Spirogyra, Mougeotia, Zygnema, Polyadosporites* and *Lycopodiumsporites* are not recorded by Mathur (1984), hence, both are not comparable.

Saxena and Bhattacharyya (1987) recorded fungal spores, gymnosperm and angiosperm pollen from the Upper Siwalik sediments exposed along Kala-Amb–Nahan Road section, Sirmaur District, Himachal Pradesh. *Laricoidites, Inaperturopollenites, Pinuspollenites, Pinjoriapollis* and *Monoporopollenites* (Poaceae) are common to both the assemblages. The gymnosperms referable to *Laricoidites, Inaperturopollenites* and *Pinuspollenites* are most dominant element of the assemblage and the same have been recorded from the present study, hence both are broadly comparable.

Phadtare *et al.* (1994) recovered algal and fungal remains, pteridophytic spores, gymnosperm and angiosperm pollen from the Upper Siwalik (Tatrot-Pinjor) sequence of Haripur Khol area, Sirmaur District, Himachal Pradesh. The common genera between the two assemblages are *Pteridacidites, Lycopodiumsporites, Striatriletes, Pinuspollenites Abiespollenites, Graminidites, Chenopodipollis* and *Malvacearumpollis*. According to their study the reduction in *Pinus* pollen and absence of *Ceratopteris, Lycopodium, Chenopodium* have been observed in the Pinjor Formation but reverse is the case in the present study, hence, both the assemblages are not closely comparable.

Saxena *et al.* (1987) recorded fungal remains, pteridophytic spores, gymnosperm and angiosperm pollen from Upper Siwalik (Tatrot-Pinjor) sequence exposed along the Masol-Kiratpur Road, Haryana. The Pinjor palynoassemblage is dominated by gymnospermous pollen (*Laricoidites, Inaperturopollenites* and *Pinuspollenites)*. The pteridophytic spores are represented by *Osmundacidites* and *Striatriletes* and angiospermous pollen are represented by *Verrualetes, Pinjoriapollis* and *Cupuliferoipollenites*. The present study has recorded all except *Osmundacidites* and *Cupuliferoipollenites*. The above comparison indicates that the assemblage recorded from Pinjor Formation by Saxena *et al.*, 1987 is broadly comparable with the present one.

Sarkar (1990) recorded palynofossils from Surai Khola of western Nepal and the significant elements of the palynoflora are *Botryococcus*, zygospores of *Zygnema* and *Mougeotia*, *Pediastrum*, *Striatriletes*, *Lycopodiumsporites*, *Monoporopollenites*, *Malvacearumpollis* and *Polyadopollenites*. Except *Botryococcus*, *Pediastrum* and *Polyadopollenites* all the other genera recorded from the present study, hence, the two assemblages are closely comparable.

PALAEOECOLOGICAL INTERPRETATION

The distribution pattern of spores and pollen grains in the Pinjor Formation (Nadah section) clearly indicates the temporal changes in the environment of deposition from the older to younger horizons. The lower part of the section exhibits the presence of aquatic elements viz., *Striatriletes* (*Ceratopteris*) and *Jacobipollenites* (*Sparganium*) that are known to be of freshwater environment. The upper part of the section seems to represent stagnant shallow freshwater conditions in view of the high incidence of zygospores belonging to Zygnemataceae (*Spirogyra*, *Zygnema* and *Mougeotia*). It seems likely that a lowland topography supported the growth of ferns and other herbaceous angiosperms (Poaceae). In the up section the occurrence of algal remains, and pteridophytic spores belong to Lycopodiaceae (*Lycopodium*) gradually decreased and replaced by taxa belonging to upland (*Pinus*, *Picea* and *Abies*) forest communities. The palynofloral population continued from the preceding section shows a remarkable drop in grass pollen and increase the frequency of the spores of *Lycopodium* collectively indicate the wet climate. The presence of *Striatriletes* (*Ceratopteris*) further supports the existence of marshy muddy condition. The highest percentage of Pinaceae (*Pinus*) pollen in the upper part of the section indicates the possibility of the closeness of temperate vegetation belt.

PALAEOCLIMATE

The Pinjor (Nadah area) palynoassemblage contains algal and fungal remains, pteridophytic spores, gymnosperm and angiosperm pollen. The assemblage has been studied and compared with the modern families and found they are comparable to 18 families. Of these, 5 families restricted to tropical-subtropical, 3 families to tropical to temperate, 4 families to temperate and 6 families are cosmopolitan in distribution (Fig. 4). The pteridophytic spores generally favour moist and shady habitat. *Ceratopteris*, a genus represented by *Striatriletes*, is a water fern growing in tropical region. The presence of fungal spores is indicative of warm and humid condition. The overall vegetational pattern indicates, a tropical - subtropical humid climate during the sedimentation of the Pinjor Formation. The temperate flora belonging to Magnoliaceae (*Magnolia*) and Pinaceae (*Pinus*) appear to be transported from the upland areas in the north.

ENVIRONMENT OF DEPOSITION

Palynological data were thoroughly scrutinized and ecologically significant taxa were selected and seggregated for identifying various habitats. Ecological analysis of Pinjor Formation (Nadah area) identifies habitats including low-land, freshwater swamp and water edge and montane elements mentioned below:

Low-land elements—*Polyadosporites, Frasnacritetrus, Retitrescolpites, Graminidites* and *Malvacearumpollis.*

Freshwater elements—*Spirogyra, Zygnema, Mougeotia, Lycopodiumsporites, Pteridacidites, Striatriletes, Nymphaeacidites* and *Jacobipollenites.*

Montane elements—*Cycadopites, Laricoidites, Inaperturopollenites, Podocarpidites, Pinuspollenites, Abiespollenites* and *Piceapollenites*

The ecological interpretation of recovered spore-pollen reveals that the freshwater forms are dominant over the low-land and montane elements. The percentage frequency of freshwater elements (*Spirogyra, Zygnema, Mougeotia, Nymphaea*) is low in the lower part of the section and progressively increases at the top of the section but reverse is the case with the low-land elements. The montane elements belonging to Pinaceae are predominant at the top of the section (Fig. 6).

The presence of zygospores of Zygnemataceae is indicative of stagnant shallow and more or less mesotrophic freshwater habitat (van Geel, 1976; van Geel & van der Hammen, 1978). The presence of the fossil Chara *Lamprothamnium* (i. e., *L. papulosum* and *L. succintum)* in the Pinjor Formation suggests that the grey mudstone bed must have been laid down in an oligo-mesohaline environment (Bhatia, 1999). The presence of *Nymphaea* pollen further corroborates the prevalence of lacustrine habitat. A diverse microvertebrate assemblage recovered by (Patnaik & Schleich, 1998) suggest the presence of pond and pond bank communities.

The high incidence of algal and fungal remains, fern spores (*Lycopodium*) and grass pollen indicates that the prevailing flora was mainly of wet, open and mixed nature. The presence of many chlamydospores of *Glomus* reflect the paucity of endomycorrhizal plants and repeated occurrence in these sediments, linked with allochthonous elements representing grassland (Berch & Warner, 1985; Wilson, 1965). The significant drop in grasses pollen coinciding with the good proportion of ferns (*Lycopodium*) and Chenopodiaceae pollen reveal that the flora was changed from dry to mainly wet and marshy grass land. The top most part of the succession exhibits reappearance of graminaceous pollen along with bisaccate pollen, collectively indicate the drier condition during the latter period. The presence of Chenopodiaceae along with

the other members of ferns shows that at few places, these plants were thriving for a short period. The gymnosperm pollen possibly were derived from the high mountains nearby in the north. So it may be inferred that the depositional environment of the Pinjor Formation particularly in Panchkula area was deposited in a wet and marshy with open and mixed grassland flora.

CONCLUSIONS

1. The palynoassemblage recovered from the Pinjor Formation (Late Pliocene) is well diversified and contains algal and fungal remains, pteridophytic spores, gymnosperm and angiosperm pollen.
2. *Polyadosporites nadahensis, P. siwalikus, Lycopodiumsporites nadahensis, Pteridacidites chandigarhensis, Pinuspollenites nadahensis, P. chandigarhensis* and *Graminidites siwalikus* have been newly proposed.
3. Qualitative and quantitative analyses reveal that the gymnosperm pollen is dominant over angiosperm pollen followed by pteridophytic spores.
4. Stratigraphic distribution of palynoflora revealed that the Pinjor Formation can be divided into lower Zone-1 and the upper Zone-2.
5. On the basis of affinity with modern families, a tropical-subtropical humid climate has been interpreted during the sedimentation of the Pinjor Formation.
6. The assemblage represents a mixture of ecological groups such as low-land, freshwater swamp and water edge, montane and back-mangrove elements.
7. The Pinjor Formation was deposited in a wet and marshy grassland with open and mixed flora.

Acknowledgements—*The authors are thankful to Prof. C.G.K. Ramanujam, Osmania University, Hyderabad for help in the identification of some fungal and pteridophytic spores and valuable suggestions during the preparation of the manuscript.*

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