REWORKED DINOFLAGELLATE CYSTS FROM THE SIWALIK GROUP OF CHANDIGARH AND HIMACHAL PRADESH

R. K. SAXENA AND SAMIR SARKAR

Birbal Sahni Institute of Palaeobotany, 53, University Road, Lucknow-226 007

ABSTRACT

Eight genera and twelve species of dinoflagellate cysts recovered from the five Siwalik sequences, one in Chandigarh and four in Himachal Pradesh, have been recorded. These cysts have been considered as reworked and reasons for such conclusion have been discussed. A fluviatile environment of deposition has been suggested for these sediments. The source of the cysts has been traced in the Subathu Formation (Eocene) developed in the east and north-east of the areas of study. This has been inferred from the close resemblance of these cysts with those recorded earlier from the Subathu Formation and from the then-prevailing palaeogeographic conditions which were ideal for the derivation of Subathu sediments of the east and north-east and their redeposition at the sites of present study.

INTRODUCTION

Encounter with reworked palynomorphs of older age in younger sediments is common in palynological studies. Common rock types containing reworked palynomorphs are shale, siltstone, sandstone, limestone, marl, etc. as they are made up of material derived from pre-existing rocks whereas peat, lignite and coal are generally *in situ* deposits and, therefore, are by and large devoid of reworked fossils.

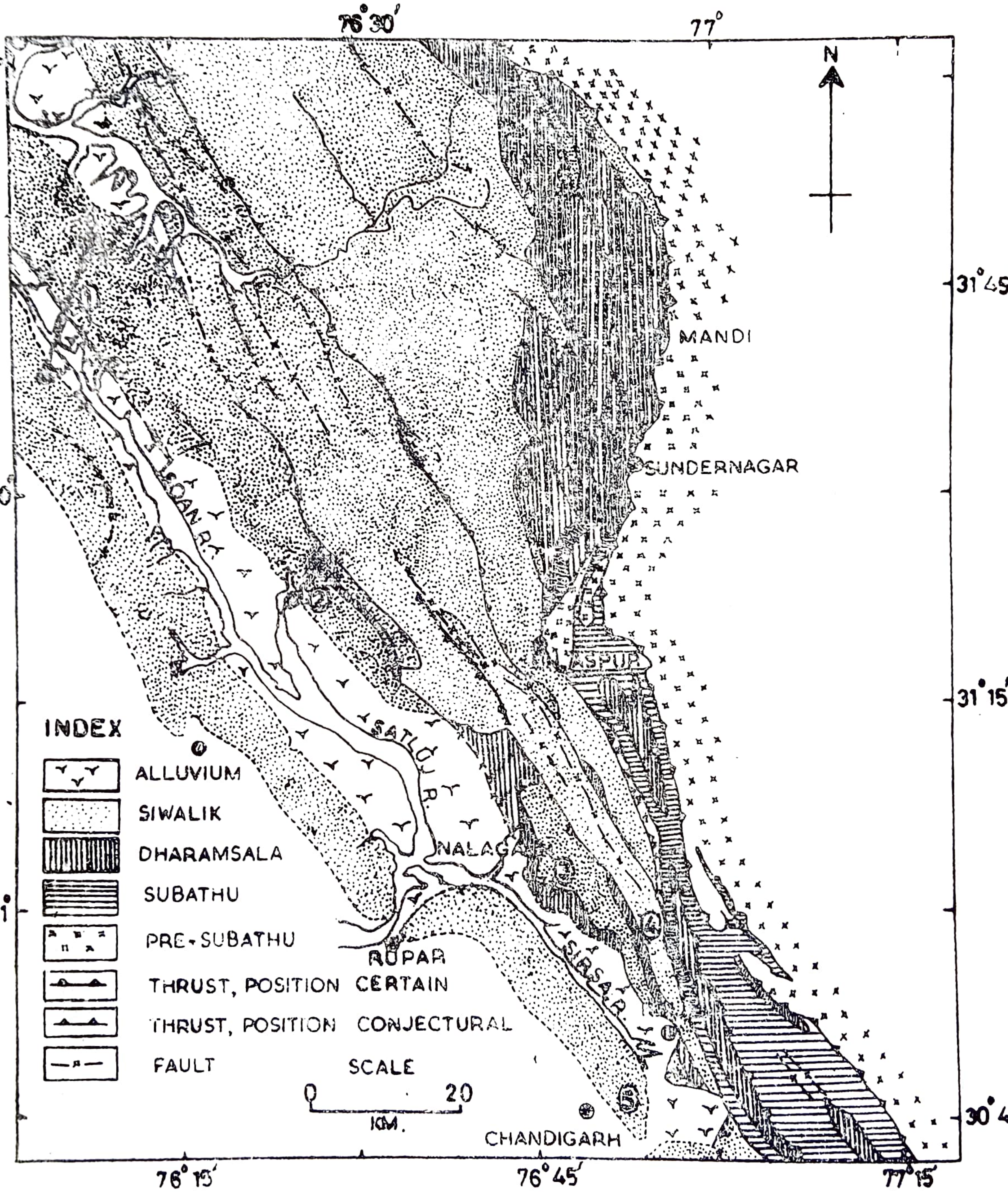
In India, reworked palynomorphs have been recorded by Potonié and Sah (1960, Permian palynotaxa from Mio-Pliocene sediments), Dev (1961, Permian palynotaxa from Upper Jurassic sediments), Venkatachala (1970, Permian palynotaxa from Upper Jurassic sediments), Sah and Kar (1970, Cretaceous palynotaxa from Eocene sediments), Banerjee, Misra and Koshal (1973, Permian palynotaxa from Miocene-Pliocene sediments), Salujha, Rehman and Kindra (1973, Permian palynotaxa from Miocene sediments), Jain, Sah and Singh (1975, Permian palynotaxa from Cretaceous sediments), Dutta (1978, 1979, Permian palynotaxa from Cretaceous and Miocene sediments), Saxena (1979, Cretaceous palynotaxa from Palaeocene sediments), Kar (1980, Permian palynotaxa from Miocene sediments) and Kar and Saxena (1981, Permian and Cretaceous palynotaxa from Eocene sediments).

Reworked palynomorphs from Siwalik Group—Like other Indian sediments, there are some records of reworked palynotaxa from the Siwalik Group too. Nandi (1972) published Middle Siwalik palynoflora from the Mohand (East) field in Saharanpur district of Uttar Pradesh. This assemblage, besides having typical Neogene taxa, consists of *Klukisporites, Concavissimisporites* and *Tsugaepollenites* which are characteristic of Mesozoic, hence may be reworked. Mathur (1973) described a Lower Siwalik palynoflora from Tharukhola-Chepang, north-east of Nepalgange, Nepal. Of this assemblage, *Contignisporites* spp. A and B may be reworked Mesozoic spores. Dutta (1980) recorded some reworked Permian miospores from the Siwalik equivalent rocks of Kameng district, Arunachal Pradesh. Dutta and Singh (1980) recovered an interesting palynoflora from the Siwalik sequence developed in Kameng district of Arunachal Pradesh. From the lower part (Unit D) they recorded typically Permian palynomorphs while from the middle

Geophytology, **13**(2) : 202-213, 1983.

(Units C + B) and upper (Unit A) parts they recovered a mixture of Permian, Eocene and Miocene palynomorphs. The occurrence of Permian and Eocene palynomorphs is due to reworking.

Recently, Singh and Saxena (1980, 1981), Saxena and Singh (1980, 1982a), Saxena, Sarkar and Singh (in press), Singh and Sarkar (in press) and Sarkar (MS.) studied palynofloras from the various Siwalik sequences in Chandigarh and Himachal Pradesh (Map-1). In these assemblages, the authors observed the occu-



Map 1. Geological map of a part of north-western India showing the locations of the areas of investigation (modified after Karunakaran & Ranga Rao, 1979). 1. Gagret-Bharwain section; 2. Bhakra Nangal section; 3. Nalagarh; 4. Ramshahr; 5. Chandigarh.

rrence of a few possibly reworked dinoflagellate cysts. These palynomorphs are comparatively poorly preserved than those of the original assemblages. Presence of such marine elements in fresh water Siwalik sediments is very interesting. A brief account of these palynomorphs is given below :

REWORKED DINOFLAGELLATE ASSEMBLAGE

Genus—**Cleistosphaeridium** Davey, Downie, Sarjeant & Williams, 1966

Cleistosphaeridium diversispinosum Davey, Downie, Sarjeant & Williams, 1966
Pl. 1, Fig. 3.

Remarks—The present specimens possess almost similar size range as those described by Davey, Downie, Sarjeant & Williams (1966) from the London Clay of England, but the variations in processes are comparatively less in the present case.

Previous record—Davey *et al.* (1966, London Clay, White Cliff Bay, Enborne and Sheppey); Khanna (1978) and Sarkar (1982, Subathu Formation, Eocene, Himachal Pradesh, India).

Cleistosphaeridium disjunctum Davey, Downie, Sarjeant & Williams, 1966
Pl. 1, Fig. 6

Remarks—This specimen possesses similar size as the specimens recovered from the Subathu Formation in Banethi-Bagthan area of Himachal Pradesh (Sarkar, 1982).

Previous record—Davey *et al.* (1966, London Clay, White Cliff Bay, Enborne); Khanna (1978) and Sarkar (1982, Subathu Formation, Eocene, Himachal Pradesh, India).

Genus—**Hystrichosphaeridium** Deflandre, 1937 emend. Davey & Williams, *in* Davey *et al.*, 1966

Hystrichosphaeridium tubiferum (Ehrenberg, 1838) Deflandre, 1937 emend. Davey & Williams *in* Davey *et al.*, 1966
Pl. 1, Fig. 5

Previous record—Conrad (1941) and Lejeune Carpentier (1970, Maestrichtian of Belgium); Cookson (1953, doubtful Tertiaries of Victoria, Australia); Górka (1963, Turonian to Maestrichtian of Poland); Rossignol (1964, Pleistocene of Israel, presumably reworked); Stanley (1965) and Drugg (1967, Maestrichtian to Palaeocene strata of U. S. A.) McIntyre and Wilson (1966) and Wilson (1967, doubtful attributions from the undifferentiated formations of Antarctica in Erratics); Baldis (1966, doubtful attributions from the undifferentiated formations of Tierra del Fuego, Argentina); Davey and Williams *in* Davey *et al.* (1966) and Downie, Hussain and Williams (1971, Lower Eocene of Hampshire and London basins); Zaitneff (1967, Maestrichtian of U. S. A.); DeConinck (1967, 1968, 1972) and Gruas Cavagnetto (1968, Lower Eocene of Belgium); Wilson (1968, Palaeocene to Lower Eocene of New Zealand); Archangelsky (1969, undifferentiated Eocene of Argentina); Davey and Verdier (1971, Albian of Paris Basin), Gruas Cavagnetto (1971, Lower-Middle Eocene of northern France); Eaton (1976, Lower Eocene Isle of Wight, southern England); Khanna (1978) and Sarkar (1982, Subathu Formation, Eocene, Himachal Pradesh, India).

Hystrichosphaeridium sp.
Pl. 1, Fig. 10

Description—Chorate cysts, central body subspherical. Endophragm and periphragm closely appressed in between the processes; endophragm smooth, periphragm faintly granulose. Processes intratabular, tubiform, hollow, distally open and expanded and of similar shape and size; distal margin of processes denticulate. Sulcal processes slender, Archeopyle apical in position. Paratabulation indistinct.

Dimensions—Size of the central body : 35—40 μm, length of the processes : 15—22 μm, width of the processes : 2—3 μm.

Genus—**Homotryblium** Davey & Williams *in* Davey *et al.*, 1966

Homotryblium tenuispinosum Davey & Williams *in* Davey *et al.*, 1966
Pl. 1, Fig. 7.

Previous record—Davey and Williams *in* Davey *et al.* (1966, London Clay, southern England); Downie, Hussain and Williams (1971, Palaeogene of southeast England); Caro (1973, Lower Eocene of northern Spain); Eaton (1976, Lower, Middle and Upper Eocene, Bracklesham Beds); Khanna (1978) and Sarkar, (1982, Subathu Formation, Eocene, Himachal Pradesh, India).

Homotryblium plectilum Drugg & Loeblich, 1967
Pl. 1, Figs. 8, 13, 14

Previous record—Agelopoulos (1964, 1967, Upper Eocene of North Germany); Drugg and Loeblich (1967, Oligocene, Glenden Limestone, U. S. A.); Dutta and Jain (1980, Upper Eocene of Meghalaya, India); Sarkar (1982, Subathu Formation, Eocene, Himachal Pradesh, India).

Genus—**Operculodinium** Wall, 1967

Operculodinium centrocarpum (Deflandre & Cookson, 1955) Wall, 1967
Pl 1, Fig. 4

Previous record—Cookson (1953, as *Hystrichosphaeridium* sp. a and sp. b, undifferentiated Oligocene and Middle Miocene of Victoria, Australia); Deflandre and Cookson (1955, Middle Miocene of Victoria, Australia); Maier (1959) and Gerlach (1961, Middle to Upper Oligocene and Middle to Upper Miocene of North Germany); Brosius (1963, Upper Oligocene of North Germany); Morgenroth (1966, Lower Eocene of Belgium and North Germany); Agelopoulos (1967, doubtful attribution from Upper Eocene of North Germany); Drugg (1967, Lower Palaeocene-Danian of California, U.S.A.); Wall (1967, Pleistocene of Carribean Sea); Wall and Dale (1968, Pleistocene of Norfolls); DeConinck (1968) and Gruas-Cavagnetto (1968, Lower Eocene of Belgium); Davey (1969, Upper Cretaceous-Senonian of Natal, South Africa); Gruas-Cavagnetto (1970, Middle and Upper Eocene of the Hampshire Basin in southern England), Gruas-Cavagnetto (1971, Middle Eocene of northern France).

Genus—**Hystrichokolpoma** Klumpp, 1953 emend. Williams & Downie *in* Davey *et al.*, 1966

Hystrichokolpoma salacium Eaton, 1976
Pl. 1, Fig. 11

Previous record—BALTES (1969, as *Hystrichokolpoma eisenacki*, possibly undifferentiated Eocene of Rumania); EATON (1976, Lower, Middle and Upper Eocene of southern England); DUTTA AND JAIN (1980, Middle Eocene of Meghalaya, India); SARKAR (1982, Subathu Formation, Eocene, Himachal Pradesh, India).

Genus—**Spiniferites** Mantell, 1850 emend. Sarjeant, 1970

Spiniferites membranaceus (Rossignol, 1964) Sarjeant, 1970
Pl. 1, Fig. 1

Previous record—ROSSIGNOL (1964, Pleistocene of eastern Mediterranean); DAVEY AND WILLIAMS *in* DAVEY *et al.* (1966, London Clay, Eocene); WALL (1967, Pleistocene of Carribean Sea); SARKAR (1982, Subathu Formation, Eocene, Himachal Pradesh, India).

Spiniferites sp.
Pl. 1, Fig. 2

Description—Chorate cyst; central body subspherical. Endophragm and periphragm closely appressed except beneath the processes and parasutural ridges, wall between the processes granulose. Processes small, slender, solid, bifurcated or trifurcated at tips. Archeopyle precingular. Paratabulation not very distinct.

Dimensions—Size of the central body : 46 × 40 μm, length of the processes : 5—12 μm, width of the processes : 2—3 μm.

Remarks—Only a single specimen of this type has been found.

Genus—**Thalassiphora** Eisenack & Gocht, 1960 emend. Gocht, 1968

Thalassiphora sp. cf. **T. velata** (Deflandre & Cookson, 1955) Eisenack & Gocht, 1960
Pl. 1, Figs. 12, 15

Description—Cavate cysts. Endocyst oval and pericyst subspherical. Endophragm and periphragm widely separated. Wall faintly granulose, fibro-reticulate; endophragm thicker than periphragm. Archeopyle position not clear but appearing to be precingular.

Dimensions—Overall size: 80—94 × 64—67 μm, size of the central body : 55—66 × 45—48 μm.

Remarks—The preservation of the specimens is poor but the overall appearance and organization of the cyst body compares with *Thalassiphora velata* described by DEFLANDRE AND COOKSON (1955) from the Lower Tertiary sediments of Australia.

Genus—**Areoligera** Lejeune-Carpentier, 1938 emend. Williams & Downie *in* Davey *et al.*, 1966

cf. **Areoligera** sp.
Pl. 1, Fig. 9

Description—Chorate cyst; central body lenticular. Body wall made up of autophragm only, which being faintly granulose in between the processes. Processes penta-tabular and distally branched forming arcuate processes groups; mid-dorsal and mid-ventral surfaces lacking processes. Archeopyle appearing to be apical. Paratabulation indistinct.

Dimensions—Size of the central body : 38 μm, length of the processes : 20—30 μm, width of the processes : 2—5 μm.

Remarks—Only a single specimen of this type has been recorded from the Upper Siwalik of the Chandigarh area. Bad preservation precluded its identification upto specific level.

DISCUSSION

The dinoflagellate cysts described in the preceding pages consist of 8 genera and 12 species. These cysts commonly occur in the marine and brackish water sediments all over the world and their presence in the well accepted fresh water sediments of the Siwalik Group is unusual.

When we first noticed such forms in the Upper Siwalik palynoflora from near Chandigarh (SAXENA & SINGH, 1980, 1982a), we thought them to be the contamination either in field or in laboratory. To check this, the samples were properly cleaned to remove all extraneous matter and then remacerated, but same results were obtained. Later, similar forms were recovered in other assemblages too, viz., (i) Upper Siwalik palynoflora from the Gagret-Bharwain Road section in Una district, Himachal Pradesh (SINGH & SAXENA, 1980, 1981); (ii) Lower, Middle and Upper Siwalik palynofloras from the Bhakra-Nangal area in Bilaspur district, Himachal Pradesh (SAXENA, SARKAR & SINGH, in press); (iii) Lower Siwalik palynoflora from Nalagarh in Solan district, Himachal Pradesh (SARKAR MS.); and (iv) Lower and Middle Siwalik palynofloras from subsurface sediments of Ramshahr well in Solan district, Himachal Pradesh (SINGH & SARKAR, in press). The recovery of such cysts even after all precautions and repeated maceration of samples from various areas ruled out any possibility of their being contaminations.

The next question which puzzled us was that whether these cysts were a part of original assemblage or reworked. To determine this, various parameters suggested by earlier workers were considered. WILSON (1964) published a paper on the recycling, stratigraphic leakage and faulty techniques in palynology. He mentioned that the recycling of the palynofossils may be recognized in the following type of assemblages : (i) assemblages consisting of fossils of more than one geological age; (ii) assemblages consisting of fossils with different biological stain reactions, (iii) assemblages consisting of fossils showing differential preservation; (iv) assemblages consisting only of fossils recognized to be geologically older than the rocks in which they occur; and (v) assemblages of marine fossils preserved in fresh water sediments. WILSON (1965) used the stain technique to differentiate reworked Mississippian fossils in Pennsylvanian sediments from Ti Valley, Pittsburg County, Oklahoma. VAN GIJZEL (1967a) suggested the use of fluorescence microscopy to detect reworked fossils in sediments. However, he clearly mentioned that acritarchs, hystrichosphaerids and dinoflagellates, due to their different chemical nature, show no colour change with the increasing geological age (VAN GIJZEL, *loc. cit.*). They react differently upon fossilization processes in comparison with fossil exines (VAN GIJZEL, 1967b). This method is, therefore, not reliable for recognizing dinoflagellate cysts of various ages.

Keeping in view the above points, the present dinoflagellate assemblage was carefully studied, as mentioned below :

(i) *Preservation*—It has been observed that the preservation of the dinoflagellate cysts is comparatively poor, sometimes extremely poor precluding their identification upto specific level, in contrast with the good preservation of the associated spore-pollen assemblage. Such differential preservation separates these cysts from the rest of the mioflora and suggests them to be reworked.

(ii) *Poor representation*—It is a general experience that wherever we recover dinoflagellate cysts in an assemblage we get them in considerable number. But in all the assemblages studied here, these cysts show exceedingly poor representation and not even a single species could come in the percentage count. Such poor recovery of these cysts in the assemblages studied is an unusual feature and indicates that these may not be a part of the original assemblage and might have been derived from the source rocks along with the sediments and then redeposited.

(iii) *Age and stratigraphical distribution*—It has been noticed that all the dinoflagellate cysts recorded here have already been reported from the Eocene sediments of the various parts of the world indicating their wide distribution during that period of earth's history. Although some of these species range upto Plio-Pleistocene, the others, viz. *Cleistosphaeridium diversispinosum*, *C. disjunctum*, *Homotryblium tenuispinosum*, *H. plectilum* (one record from Oligocene, Glendon Formation, U.S.A., Drugg & Loeblich, 1967) and *Hystrichokolpoma salacium*, are restricted upto Eocene and do not extend into younger sediments. The occurrence of such species in Siwalik, even in the Upper Siwalik (Plio-Pleistocene) sediments is difficult to explain except by the process of reworking.

(iv) *Differential stain reaction*—The macerated residue containing these cysts was stained with Safranin and the slides were prepared in the usual manner. Observation of these slides reveals that the dinoflagellate cysts generally accept less stain in comparison to the spores-pollen. The differential stain reaction points out that the dinoflagellate cysts may be of different age than that of other fossils.

(v) *Marine forms in fresh water sediments*—The Siwalik Group is a widely accepted sequence of fresh water sediments. There is no positive evidence to indicate the marine or brackish water origin of these sediments. Occurrence of marine dinoflagellate cysts in these sediments may therefore be attributed to reworking.

The above discussion explains that the present dinoflagellate assemblages fulfil all the conditions of reworked assemblage mentioned by Wilson (1964) and there remains no doubt in their being reworked.

Environment of deposition

It was well accepted, till late, that the Siwalik Group is constituted by fresh water sediments, mainly because of the profuse occurrence of the vertebrate land fauna, the total absence of marine megafossils and other evidences, such as—cross-bedding in the sandstones and red, ferruginous nature of the Lower Siwalik. But in 1958, Ghosh recovered some spores and pollen grains from the Lower Siwalik sediments of Jawalamukhi which suggest warm and humid climate in close proximity to the sea (Talukdar, 1982). Recently, palynologists of the K.D. Malviya Institute of Petroleum Exploration have obtained some microfossils of undoubted marine origin in the Lower Siwalik sediments but whether these forms are reworked or are indigenous to the host sediments is yet to be ascertained (Talukdar, *op. cit.*, p. 110). The occurrence of such fossils in Lower Siwalik sediments created doubt as to their being entirely of fresh water origin.

In the present assemblages too, we found the fossils of undoubted marine origin but, as explained earlier, all of them are reworked and, as such, do not have any bearing on the depositional environment of he sediments in which they occur. The remaining fossils which constitute the original assemblage contain no elements of positively marine origin. Instead, pollen grains of Potamogetonaceae, although less in number, have been recorded from the Upper Siwalik sediments of Gagret-Bharwain Road section, Himachal Pradesh (SINGH & SAXENA, 1981) and Upper Siwalik sediments of Hoshiarpur-Una Road section, Himachal Pradesh (SAXENA & SINGH, 1982b), which indicate exclusively fresh water conditions. It is therefore reasonable to deduce the fresh water environment of deposition for all the Siwalik sequences studied here and any type of marine influence therein is ruled out.

SOURCE AREA/FORMATION—It has already been mentioned that all the species of dinoflagellate cysts recorded here occur in the Eocene sediments of various parts of the world and some of them do not extend beyond Eocene. It seems, therefore, reasonable that these forms might have come from the nearby developed Eocene sediments. Not far away from all the sections of the present study, Subathu Formation (Eocene) is very extensively developed. The palynology of this formation has been studied in detail by KHANNA (1978) and SARKAR (1982). It is noteworthy that all the present dinoflagellate species are common to the Subathu assemblage, and it is almost impossible to differentiate the present forms from those of the Subathu assemblage except for the comparatively poor preservation of the former. The similarity in the two assemblages is such that a palynologist not aware of the fact that these cysts are recovered from the Siwalik Group, may consider them to be derived from the Subathu Formation. Occurrence of such forms indicates that these might have been derived from the Subathu sediments developed in the east and north-east (Map 1).

The palaeogeography of the area, as reconstructed by the earlier workers, during the Siwalik sedimentation also supports the above contention. It is accepted that the depositional site for the Siwalik sediments was provided by a foredeep, formed due to the rising of the Himalayan chain along its southern margin. The general slope of the area can be envisaged towards the foredeep. It is, therefore, likely that the bulk of the material accumulated there must have come from the highland area in the east and north-east made up mainly of Subathu Formation, though some of the material must have come also from the southern side through drainage water as indicated by the palynofloral evidences (LUKOSE, 1969, SAXENA & SINGH, 1982a). In the light of the close similarity of the present dinoflagellate cysts with those of the Subathu Formation and the then-prevailing ideal palaeogeographic conditions for their derivation from the Subathu Formation and redeposition in Siwalik Group, it can safely be deduced that the Subathu Formation developed in the east and northeast would have been their source.

CONCLUSION

The dinoflagellate assemblages recovered from the various levels of the five Siwalik sequences consisting of 8 genera and 12 species, were considered reworked because : (a) their preservation was comparatively poorer than that of the remaining palynofossils; (b) their representation in all the assemblages studied was extremely poor and even a single species did not appear in the percentage count; (c) all the cysts widely occur in the Eocene sediments and most of them do not extend beyond Eocene; (d) they showed differential stain reaction as compared to the rest of the palynoflora; and (e) they were of undoubted marine origin and were recovered from the fresh water sediments.

The environment of deposition of all the sequences studied here is interpreted as fluviatile, and since the dinoflagellate cysts recovered herein are very similar to those recorded earlier from the Subathu Formation the source of these and also of the sediments containing them has been traced in the Subathu Formation developed in the east and north-east of the areas of present study.

REFERENCES

Agelopoulos, J. (1964). *Hystrichostrogylon membraniphorum* n. g. n. sp. aus dem Heiligenhafener Kieselton (Eozän) : *N. Jb. Geol. Paläontol. Monatsh.* : 673-675.

Agelopoulos, J. (1967). Hystrichosphäiren, Dinoflagellaten und Foraminiferen aus dem eozänen Kieselton von Heiligenhafen, Holstein. *Diss. Erlang. Gr. Doktors Nat. Math. natur. Fakultät der Eberhard- Karls-Universitat zu Tubingen* : 1-74.

Archangelsky, S. (1969). Sobre el paleomicroplancton del Terciario Inferior de Rio Turbio, Provincia de Santa Cruz : *Ameghiniana*, **5** : 406-416.

Baldis, E. D. P. De (1966). Microplankton del Terciario de Tierra del Fuego. *Ameghiniana*, **4**(7): 219-228.

Baltes, N. (1969). Distribution stratigraphique des dinoflagellés et des acritarches Tertiares en Roumanie. *Proc. Ist. Planktonic Conf. Geneva*, **1** : 26-45.

Banerjee, D., Misra, C. M. & Koshal, V. N. (1973). Palynology of the Tertiary subcrops of Upper Assam. *Palaeobotanist* **20**(1) : 1-6.

Brosius, M. (1963). Plankton aus dem nordhessischen Kasseler Meeressand (Oberoligozän). *Deutsch. Geol. Gesell. Zeitschr*, **114**(1) : 32-56.

Caro, Y. (1973). Contribution à la connaissance des dinoflagellés, du Paléocéne—Eocène inférieur des Pyrenées Espagnoles. *Rev. Espanola Micropaleont.* **5**(3) : 329-372.

Conrad, W. (1941). Notes protistologiques XIX. Quelques microfossiles des silex Crétacés. *Belg. Mus. Royal Hist. Nat. Bull.*, **17** : 1-10.

Cookson, I. C. (1953). Record of the occurrence of *Botryococcus braunii*, *Pediastrum* and the Hystrichosphaerideae in Cainozoic deposits of Australia. *Nat. Mus. Melbourne. Mem.*, **18** : 107-123.

Davey, R. J. (1969). Some dinoflagellate cysts from the Upper Cretaceous of northern Natal, S. Africa, *Palaeontol. Afr.* **12** : 1-23.

Davey, R. J., Downie, C., Sarjeant, W. A. S. & Williams, G. L. (1966). Studies on Mesozoic and Cainozoic dinoflagellate cysts. *British Mus. (Nat. Hist.) Bull. Geology, Suppl.*, **3** : 1-248.

Davey, R. J. & Verdier, J. P. (1971). An investigation of microplankton assemblages from the Albian of the Paris Basin : *Koninkl. Nederland. Akad. Wetensch. Verh., Afd. Natuurk., Eerste. Reeks*, **26** : 1-58.

DeConinck, J. (1967). Hystrichosphereen en Dinoflagellaten. *In* Het. fossielpounded leperiaan van Merelbeke, by Moorkens *et al.* (1967). *Natuurt. Tijdschr.*, **48** : 202-227.

De Coninck, J. (1969). Dinophyceae et Acritarcha de l'yprésien du sondage de Kallo. *Belg. Inst. Royal. Sci. Nat. Mem.*, **161** : 1-67.

De Coninck, J (1972). Application stratigraphique des microfossiles organiques dans 1. Yprésien du bassin Belg. *Bull. Soc. Belg. Geol. paleont. Hydrol.*, **81** (1-2) : 1-11.

Deflandre, G. (1937). Microfossiles des silex Crétacés. Pt. 2. Flagellés incertae sedis Hystrichosphaeridés, Sarcodines, Organismes divers. *Annal. paleontologie*, **26** : 51-103.

Deflandre, G. & Cookson, I. C. (1955). Fossil microplankton from Australian late Mesozoic and Tertiary sediments. *Aust. J. Marine Freshwater Res.*, **6**(2) : 242-313.

Dev, S. (1961). The fossil flora of the Jabalpur Series-3. Spores and pollen grains. *Palaeobotanist*, **8**(1-2) : 43-56.

Downie, C., Hussain, M. A. & Williams, G. L. (1971). Dinoflagellate cyst and acritarch associations in the Palaeogene of South-east England. *Geoscience Man*, **3** : 29-35.

Drugg, W. S. (1967). Palynology of the Upper Moreno Formation (late Cretaceous-Paleocene) Escarpado Canyon, California *Palaeontographica* **B**, **120** : 1-71.

Drugg, W. S. & Loeblich, A. R., Jr. (1967). Some Eocene and Oligocene phytoplankton from the Gulf Coast, U. S. A. *Tulane Studies Geology*, **5** : 181-194.

Dutta, S. K. (1973). A note on the significance of the discovery of Gondwana palynomorphs in the rocks of Assam, Nagaland and Meghalaya. *Geophytology*, **8**(1) : 131.

Dutta, S. K. (1979). Recycled Permian palynomorphs in Upper Cretaceous rocks of Jaintia Hills, Meghalaya. *Geophytology*, **8**(2) : 250-251.

DUTTA, S. K. (1980). Palynostratigraphy of the sedimentary formations of he Arunachal Pradesh-2. Palynology of the Siwalik equivalent rocks of Kameng district. *Geophytology*, **10**(1-2) : 5-13.

DUTTA, S. K. & JAIN, K. P. (1980). Geology and palynology of the area around Lumshnong, Jaintia Hills. Meghalaya, India. *Biol. Mem.*, **5**(1) : 56-81.

DUTTA, S. K. & SINGH, H. P. (1980). Palynostratigraphy of sedimentary formations in Arunachal Pradesh-1. Palynology of Siwalik rocks of the Lesser Himalayas, Kameng district. *Proc. IVth Internat. Palynol. Conf., Lucknow*, **2** : 617-626.

EATON, G. L. (1976). Dinoflagellate cysts from the Bracklesham Beds (Eocene) of the Isle of Wight, Southern England. *British Mus. (Nat. Hist.) Bull. Geology*, **26**(6) : 227-332.

EHRENBERG, C. G. (1838). Über das Massenverhaltnis der jetzt lebenden Kieselinfusorien und über eine neues Infusorien Conglomerat als Polierschiefer von Jastraba in Ungarn. *Abh. Acad. Wiss. Berlin*, **1843** : 61-63.

EISENACK, A. & GOCHT, H. (1960). Neue Namen für einige Hystrichosphären der Bernsteinformation Östpreussens. *N. Jb. Geol. Paläontol. Monatsh.*, **11** : 511-518.

GERLACH, E. (1961). Mikrofossilien aus dem Oligozän und Miozän Nordwestdeutschlands, unter besonderer. Berücksichtigung der Hystrichosphaerideen und Dinoflagellaten. *N. Jb. Geol. Paläontol. Abh.*, **112**(2) : 143-228.

GOCHT, H. (1968). Zur Morphologie und Ontogenie von *Thalassiphora* (Dinoflagellata). *Palaeontographica* A, **129** : 149-156.

GORKA, H. (1963). Coccolithoforidés, Dinoflagellés, Hystrichosphaeridés, et microfossiles incertae sedis du Crétacé supérieur de Pologne. *Acta. palaeont. Polonica*, **8** : 1-10.

GRUAS-CAVAGNETTO, C. (1968). Étude palynologique des divers gisements du Sparnacien du bassin de Paris. *Soc. Géol. France Mém. N. S.*, **47**(110) : 1-144.

GRUAS-CAVAGNETTO, C. (1970). Apercu sur la; microflore et le microplancton du Paleogene anglais. *c. r. Somm. Seianc. Soc. geol. Fr. Paris*, **1** : 19-21.

GRUAS-CAVAGNETTO, C. (1971). Presence de microplancton et de pollens dans le Lutetien du bassin de Paris. *c. r. Somm. Seanc. Soc. geol. Fr.* **3** : 172-174.

HABIB, D. (1971). Dinoflagellate stratigraphy across the Miocene Pliocene boundary. Tabiano stratotype section. *Proc. IInd Planktonic Conf. Rome*, **1** : 591-598.

HABIB, D. (1972). Dinoflagellate stratigraphy leg 11, Deep Sea Drilling project, *in* Hollister, C. D., *Ewing, J. I. et al. Initial reports of the Deep Sea Drilling Project*, **11**(10) : 367-425.

JAIN, K. P., SAH, S. C. D. & SINGH, R. Y. (1975). Fossil dinoflagellates across Maestrichtian-Danian boundary in Lower Assam, India *Palaeobotanist*, **22**(1) : 1-18.

KAR, R. K. (1980). Permian miospores in the Miocene sediments of Kutch, Gujarat. *Geophytology*, **10**(1-2) 171-173.

KAR, R. K. & SAXENA, R. K. (1981). Palynological investigation of a bore core near Rataria, southern Kutch, Gujarat. *Geophytology*, **11**(2) : 103-124.

KARUNAKARAN, C. & RANGA RAO, A. (1979). Status of exploration for hydrocarbons in the Himalayan region—contributions to stratigraphy and structure. *Geol. Surv. India, Misc. Publ.* **41** : 1-66.

KHANNA, A. K. (1977). Stratigraphy and palynology of the Subathu Formation of the Punjab Basin, India. (Unpublished) *Ph. D. thesis, Lucknow University, Lucknow.*

KHANNA, A. K. (1978). Subathus—stratigraphic status and nomenclature. *Him. Geol.*, **8** : 209-223.

KLUMPP, B. (1953). Beitrag zur Kenntnis der Mikrofossilien des mittleren und oberen Eozän. *Palaeontographica*, **103** : 377-406.

LEJEUNE-CARPENTIER, M., (1938). L'étude microscopique des silex (sixième note) *Areoligera:* nouveau genre d'Hystrichosphaeridée. *Soc. Géol. Belgique Annales*, **62** : 163-174.

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

MAIER, D. (1959). Plankton Untersuchungen in tertiären und quartären marinen sedimenten. Ein Beitrag zur systematik Stratigraphie und Okologie der coccolithophorideen, Dinoflagellaten und Hystrichosphaerideen. Von Oligozan bis zum Pleistozan. *N. Jb. Geol. Palaont. Abh.*, **107** : 278-340.

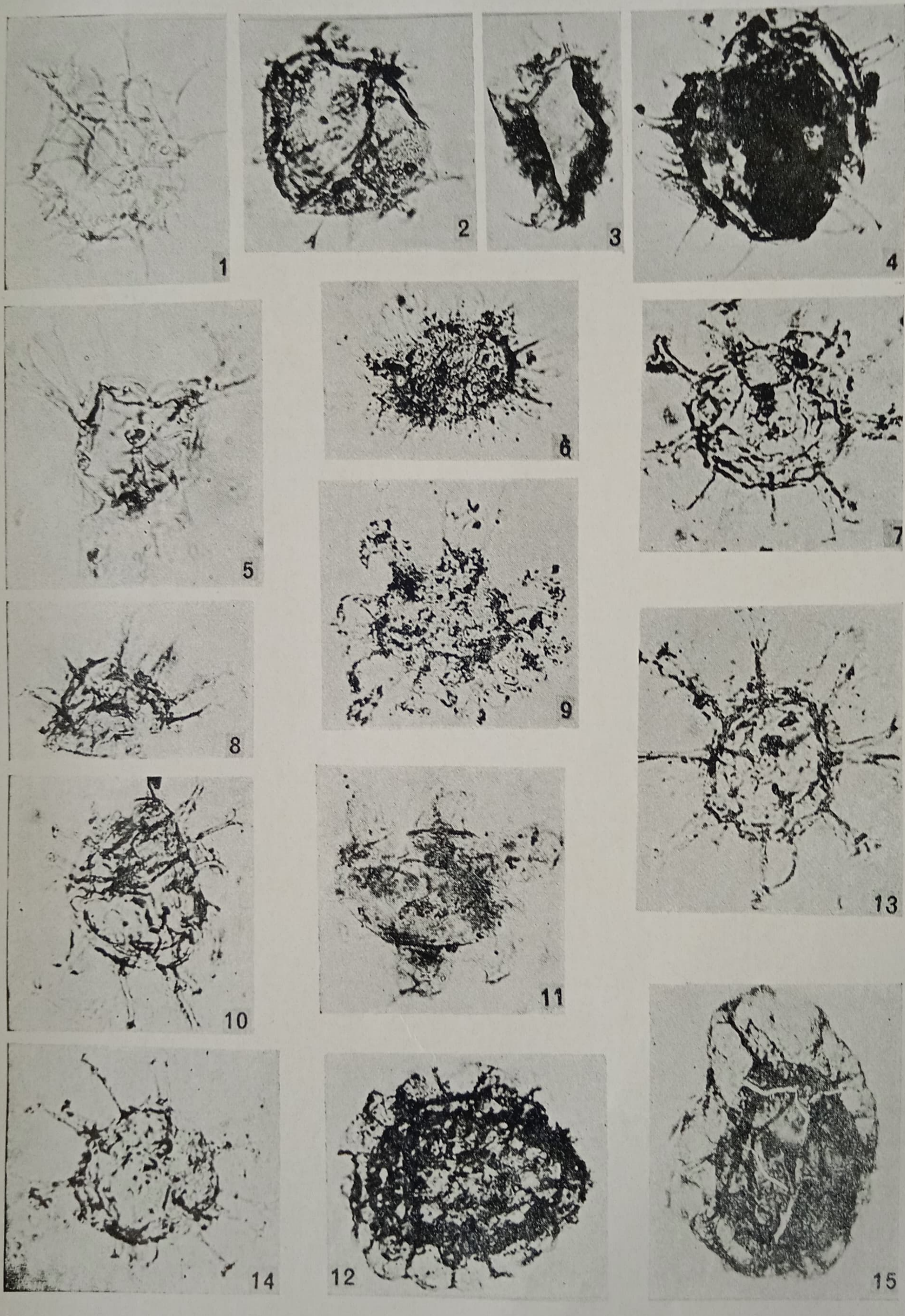
MANTELL, G. A. (1850). *A pictorial atlas of fossil remains, consisting of coloured illustrations selected from Parkinson's "Organic remains of a former world" and Artis's "Antediluvian phytology"*—Bohn. London.

MATHUR, K. (1973). Studies in the palaeoflora of the Himalayan foot hills-2. On the palynoflora in the Lower Siwalik sediments of Nepal. *J. Palynol.*, **8** : 54-62.

MC INTYRE, D. J. & WILSON, G. J. (1966). Preliminary palynology of some Antarctic Tertiary erratics. *New Zealand Jour. Bot.*, **4**(3) : 315-321.

MORGENROTH, P. (1966). Mikrofossilien und Konkretionen des nordwest-europäischen Untereozäns. *Palaeontographica* B, **119** : 1-53.

NANDI, B. (1972). Some observations on the microflora of Middle Siwalik sediments of Mohand (East) field, Himachal Pradesh. *Proc. Semin. Paleopalynol. Indian Stratigr.*, : 375-383.
POTONIÉ, R. & SAH, S. C. D. (1960). *Sporae dispersae* of the lignites from Cannanore beach of the Malabar Coast of India. *Palaeobotanist*, **7** : 121-135.
ROSSIGNOL, M. (1964). Hystrichosphères du Quaternaire en Méditerranée orientale, dans les sédiments Pleistocènes et les boues marines actuelles. *Rev. Micropaléont.* **7** : 83-99.
SAH, S. C. D. & KAR, R. K. (1970). Palynology of the Laki sediments in Kutch-3. Pollen from the bore holes around Jhulrai, Baranda and Panandhro. *Palaeobotanist*, **18**(2) : 127-142.
SALUJHA, S. K., REHMAN, K. & KINDRA, G. S. (1973). Distinction between the Bhuban and Bokabil sediments on the southern edge of Shillong Plateau based on palynofossil assemblage. *Bull. Oil Nat. Gas Commn.* **10**(1-2) : 109-117.
SARJEANT, W. A. S. (1970). The genus *Spiniferites* Mantell, 1850 (Dinophyceae), *Grana*, **10** : 74-78.
SARKAR, S. (1982). Contribution to the palynology of Tertiary sediments of Himachal Pradesh. India. (unpublished). *Ph. D. thesis, Lucknow University, Lucknow.*
SARKAR, S. (MS). A palynoflora from the Siwalik sediments of Nalagarh area, Himachal Pradesh, India.
SAXENA, R. K. (1979). Reworked Cretaceous spores and pollen grains from the Matanomadh Formation (Palaeocene), Kutch, India. *Palaeobotanist*, **26**(2) : 167-174.
SAXENA, R. K., SARKAR, S. & SINGH, H. P. (in press). Palynological investigation of the Siwalik sediments of Bhakra-Nangal area, Himachal Pradesh. *Geophytology.*
SAXENA, R. K. & SINGH, H. P. (1980). Occurrence of palynofossils from the Pinjor Formation (Upper Siwalik) exposed near Chandigarh. *Curr. Sci.*, **49**(12) : 479-480.
SAXENA, R. K. & SINGH, H. P. (1982a). Palynology of the Pinjor Formation (Upper Siwalik) exposed near Chandigarh, India. *Palaeobotanist*, **30**(3) : 325-339.
SAXENA, R. K. & SINGH, H. P. (1982b). Palynological investigation of the Upper Siwalik sediments exposed along Hoshiarpur-Una Road section in Punjab and Himachal Pradesh. *Geophytology*, **12**(2) : 287-306.
SINGH, H. P. & SARKAR, S. (in press). Palynological investigation of Ramshahr well no. 1, Himachal Pradesh, India. *Palaeobotanist.*
SINGH, H. P. &. SAXENA, R. K. (1980). Upper Siwalik palynoflora from Gagret-Bharwain Road section, Himachal Pradesh. *Geophytology.* **10**(1-2) : 278-279.
SINGH, H. P. & SAXENA, R. K. (1981). Palynology of the Upper Siwalik sediments in Una district, Himachal Pradesh. *Geophytology*, **11**(2) : 173-181.
STANLEY, E. A. (1965). Upper Cretaceous and Palaeocene plant microfossils and Palaeocene dinoflagellates and hystrichosphaerids from north-western South Dakota. *Bull. Am. Paleont.*, **49**(222) : 179-378.
TALUKDAR, S. N. (1982). Palynology in oil exploration. *Palaeobotanist*, **30**(1) : 101-119.
VAN GIJZEL, P. (1967a). Palynology and fluorescence microscopy. *Rev Palaeobot. Palynol.*, **2**(1-4) : 49-79.
VAN GIJZEL, P. (1967b). Autofluorescence of fossil pollen and spores with special reference to age determination and coalification. *Leid. Geol. Mededel*, **39**.
VENKATACHALA, B. S. (1970). Palynology of the Mesozoic sediments of Kutch, W. India. 7. Reworked Permian pollen from the Upper Jurassic sediments—A discussion, *Palaeobotanist*, **18**(1) : 45-49.
WALL, D. (1967). Fossil microplankton in deep sea cores from the Caribbean Sea. *Palaeontology*, **10** : 95-123.
WALL, D. & DALE, B. (1968). Quaternary calcareous dinoflagellates (Calciodinellideae) and their natural affinities. *J. Palaeont.*, **42** : 1395-1408.
WILSON, G. J. (1967). Some new species of Lower Tertiary dinoflagellate from McMurdo Sound, Antarctica. *New Zealand Jour. Bot.*, **5**(1) : 57-83.
WILSON, G. J. (1968). Palynology of some Lower Tertiary coal measures in the Waihao District, south Canterbury, New Zealand. *New Zealand Jour. Bot.*, **6** : 56-62.
WILSON, L. R. (1964). Recycling, stratigraphic leakage and faulty techniques in palynology. *Grana Palynol.*, **5**(3) : 425-436.
WILSON, L. R. (1965). Palynological age determination of a rock section in Ti Valley, Pittsburg County, Oklahoma. *Okl. Geol. Notes*, **25**(1) : 11-18.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

EXPLANATION OF PLATE I

(All photomicrographs are *ca* ×500. The coordinates of specimens in slides refer to the stage of Olympus microscope no. 208125).

1. *Spiniferites membranaceus* (Rossignol) Sarjeant; Slide no. 6198, coordinates 8.4 × 116.8.
2. *Spiniferites sp.*; Slide no. 6194, coordinates 11.5 × 89.5.
3. *Cleistosphaeridium diversispinosum* Davey, Downie, Sarjeant & Williams; Slide no. 6891, coordinates 13.2 × 83.8.
4. *Operculodinium centrocarpum* (Deflandre & Cookson) Wall; Slide no. 6289, coordinates 4.5 × 109.6.
5. *Hystrichosphaeridium tubiferum* (Ehrenberg) Deflandre emend. Davey & Williams *in* Davey, Downie, Sarjeant & Williams ; Slide no. 6189, coordinates 7.5 × 109.5.
6. *Cleistosphaeridium disjunctum* Davey, Downie, Sarjeant & Williams; Slide no. 6289, coordinates 20 × 83.
7. *Homotryblium tenuispinosum* Davey & Williams *in* Davey, Downie, Sarjeant & Williams; Slide no. 6881, coordinates 7.5 × 109.5.

8,13,14. *Homotryblium plectilum* Drugg & Loeblich; Slide nos. 6882, coordinates 7 × 110.9, showing the epitractal archeopyle; 6884, coordinates 16.5 × 113; 6884, coordinates 9 × 115.

9. cf *Areoligera* sp.; Slide no. 6871, coordinates 18.9 × 105.

10. *Hystrichosphaeridium* sp.; Slide no. 6882, coordinates 5 × 104.5.

11. *Hystrichokolpoma salacium* Eaton; Slide no. 6289, coordinates 13.1 × 102.3.

12,15. *Thalassiphora* sp. cf. *T. velata* (Deflandre & Cookson) Eisenack & Gocht; Slide no. 6892, coordinates 18.4 × 74.6; Slide no. 6892, coordinates 15 × 97.8.