

# SOME FOSSIL SPECIES OF *PEDIASTRUM* AND THEIR PALAEOECOLOGICAL SIGNIFICANCE IN THE SUBATHU FORMATION OF HIMACHAL PRADESH

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## ABSTRACT

Seven new species of the genus *Pediastrum* Meyen, 1829 have been described from the Subathu Formation (Upper Palaeocene-Eocene), Punjab Basin, Himachal Pradesh. Significance of the morphological characters used for the delimitation of different species has been discussed with a note on the distribution of fossil *Pediastrum* in the Indian sediments. Comments on the palaeoecological significance of the genus have also been made which highlight its importance in different conditions of deposition.

## INTRODUCTION

THE present paper deals with the morphological study of seven new species of the genus *Pediastrum* Meyen, 1829 recovered from the sediments of Subathu Formation (Upper Palaeocene-Eocene), Punjab Basin, Himachal Pradesh. The sediments of Subathu Formation outcrop along the Kalka-Simla Highway. The present specimens of *Pediastrum* have been recovered from the suites of sediments exposed at Jabli, Dharampur and Kumarhatti. Palaeoecological significance of the genus has also been described.

The newly proposed species are *P. compactum* sp. nov., *P. wilsonii* sp. nov., *P. indicum* sp. nov., *P. pallidus* sp. nov., *P. angulatus* sp. nov., *P. magnus* sp. nov. and *P. diffusus* sp. nov. The genus *Pediastrum* as a whole has a simple morphological organization. It is easily identifiable by its characteristic disc-shaped coenobia which consist of 8-64 to 128-256 coenocytes. The coenocytes are arranged in a concentric manner and consist of inner and marginal coenocytes. The inner coenocytes are either closely packed or have intervening spaces. For taxonomic study of the species, the important morphographic characters are — (i) presence or absence of the central coenocyte, (ii) shape and relative size of the inner and marginal coenocytes, (iii) shape, size and number of processes on the marginal coenocytes.

The genus *Pediastrum* consists of free floating green algal forms which inhabit fresh water ponds or lakes and are cosmo-

politan in distribution. In fossil condition, however, information about the distribution of the genus *Pediastrum* is rather scanty. Earlier workers recorded *Pediastrum* mostly from Pleistocene deposits. However, in 1953, Wilson and Hoffmeister described four new species of *Pediastrum* from the Tertiary sequence (Eocene) of southern Sumatra. The species are *P. kajaites* Wilson & Hoffmeister, *P. paleogeneites* Wilson & Hoffmeister, *P. bifidites* Wilson & Hoffmeister and *P. delicatites* Wilson & Hoffmeister. In the same year Cookson (1953) reported the occurrence of *P. boryanum* from the Early Tertiary shales of Australia. The living forms of *Pediastrum* do not inhabit the marine environment, so Cookson (1953) pointed out that the sediments of Cootabarlow shale and Werona clay, in which specimens of *P. boryanum* and *Botryococcus* were identified, belong to fresh water lake deposits. She did not attach any palaeoecological significance to the genus *Botryococcus* because it is known to inhabit both brackish and fresh water habitats. Matsuoka and Hase (1977) have studied fossil *Pediastrum* from the Pleistocene of Central Japan reporting a new variety. Evitt (1963) recorded *Pediastrum* from the marine sediments of Pakistan (Lower Cretaceous) and California (Upper Cretaceous) and questioned the palaeoecological significance of *Pediastrum* as solely an indicator of fresh water environment. Similar observations were made by Stanley (1965) and Singh *et al.* (1973). To explain the presence of *Pediastrum* in the marine assemblages, various arguments have been put forward. Firstly, it is very likely that

some species of fossil *Pediastrum* might have been adapted to brackish or marine conditions of life in the past. Secondly, it is very much possible that *Pediastrum* thriving in fresh water habitats around or near shore conditions might have been transported to their present place of burial through some water channels connecting the two different environmental habitats. In that event it was postulated by Singh *et al.* (1973) that the presence of *Pediastrum* particularly in association with marine assemblages could be used as an indicator of near shore conditions.

Mathur (1963, 1964, 1965) has reported the occurrence of *Pediastrum* in the marine assemblage of the Subathu Formation, Himachal Pradesh surmising subtropical to tropical climate and Middle to Upper Eocene age. Subsequently Salujha *et al.* (1969) have also figured specimens referable to the genus *Pediastrum* in a hystrichosphaerid rich assemblage from the Subathu Formation indicating Lower Eocene age. Unfortunately, morphological study of the specimens assigned to the genus *Pediastrum* has not been done in detail by the above mentioned authors. Misra (1974) has reported the occurrence of *Pediastrum* spp. from the cores, cuttings and outcrop samples from various parts of the country. He has identified *Pediastrum* spp. from Lower Jurassic to Plio-Pleistocene rock sequences. He also states in the abstract of his yet unpublished paper that many specimens have been assigned to some new species of *Pediastrum*.

*Diagnosis* — Coenobium double layered, 65-118  $\mu$  in diameter, coenocytes arranged in compact rings; marginal coenocytes 30 or more, triangular, 10-16  $\mu$  long and 5-9  $\mu$  broad, each coenocyte enlarging into a single attenuating process with a rounded tip; inner coenocytes bigger in size and more in number, exact number indeterminable.

*Description* — Colonial alga, coenobium a double layered plate having inner coenocytes as well as marginal coenocytes. Coenocytes arranged in compact rings, number of rings indeterminable, perforations absent. Marginal coenocytes 30 or more in number, triangular in shape, longer than broad, measuring 10 to 16  $\mu$  in length and 5 to 9  $\mu$  in width, head of the each triangular coenocyte enlarging to form a single attenuating, fairly long, tipped process, 3 to 10  $\mu$  in length and 1 to 3  $\mu$  in breadth at the base. Inner coenocytes numerous, exact number indeterminable, appearing bigger in size as compared to marginal coenocytes, walls of the inner coenocytes collapsing, membrane appearing lacerated.

*Comparison* — *Pediastrum compactum* sp. nov. is closely comparable to *P. paleogeneites* Wilson & Hoffmeister in having double layered plate of coenocytes but it differs from the latter by its larger triangular marginal coenocytes, the processes of which are slightly attenuating to stumpy in contrast to the linear and pointed ones in *P. paleogeneites*. Rest of the fossil species described under *Pediastrum* have a single layered plate of coenocytes and hence are not comparable.

Division — CHLOROPHYTA  
Class — CHLOROPHYCEAE  
Order — CHLOROCOCCALES  
Family — HYDRODICTYACEAE

Genus — *Pediastrum* Meyen, 1829

*Pediastrum compactum* sp. nov.

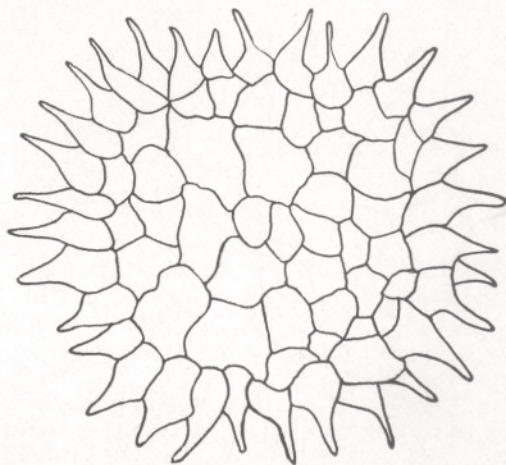
Pl. 1, figs. 1-3; Text-fig. 1

*Holotype* — Pl. 1, fig. 1; size 79  $\times$  69  $\mu$ .  
Slide no. KS125/2/1540.

*Isotype* — Pl. 1, fig. 2.

*Locus Typicus* — Jabli-Kumarhatti, Solon District, Himachal Pradesh, India.

*Stratum Typicum* — Subathu Formation, Simla Hills, (Upper Palaeocene to Eocene) Punjab Basin, India.



TEXT-FIG. 1 — *Pediastrum compactum* sp. nov.

*Remarks* — Some of the specimens of *P. compactum* show perforations on the coenobia in surface view which may be due to the effect of some kind of mineralization. The walls of the inner coenocytes are usually disintegrated or collapsed so it becomes difficult to determine the exact size and shape of the inner coenocytes. It also seems difficult to mark the presence or absence of the central coenocyte.

*Pediastrum wilsonii* sp. nov.

Pl. 1, figs. 6-7; Text-fig. 2

*Holotype* — Pl. 1, fig. 6; size  $75 \times 69 \mu$ . Slide no. K1/1/1811.

*Isotype* — Pl. 1, fig. 7.

*Locus Typicus* — Jabli-Kumarhatti, Solon District, Himachal Pradesh, India.

*Stratum Typicum* — Subathu Formation, Simla Hills (Upper Palaeocene to Eocene), Punjab Basin, India.

*Diagnosis* — Coenobium single layered,  $56-80 \mu$  in diameter, coenocytes arrangement 11, 5; central coenocyte absent; marginal coenocytes longer than broad with two long processes; inner coenocytes larger and polygonal in surface view.

*Description* — Coenobium consisting of a single layered plate of coenocytes usually 16 in number, arranged in two compact rings, outer ring having 11 pear-shaped marginal coenocytes and inner ring having 5 polygonal inner coenocytes. Central coenocyte absent. Marginal coenocytes longer than broad ( $12-19 \mu$  long &  $10-16 \mu$  broad), deeply invagi-

nated at the base, each counterpart looking more or less like a pear; processes 2,  $3-7 \mu$  long and  $1-2 \mu$  broad at the base with a tip at the rear end. Inner coenocytes polygonal,  $12-21 \mu$  in diameter, usually larger than the marginal coenocytes; perforations absent, wall pitted.

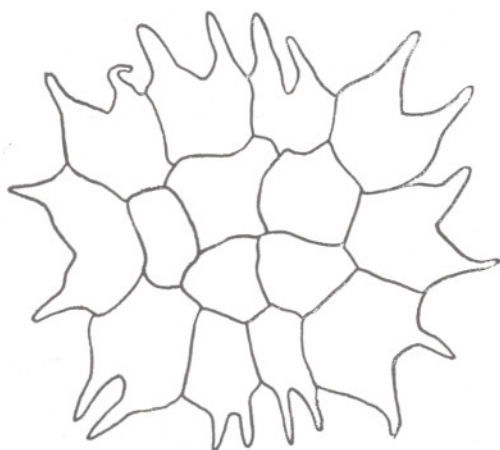
*Comparison* — *Pediastrum bifidites* Wilson & Hoffmeister and *P. diffusus* sp. nov. have a central coenocyte which is followed by a ring of small inner coenocytes and in this character both the species are distinct from *P. wilsonii* sp. nov. *P. compactum* sp. nov. and *P. paleogeneites* Wilson & Hoffmeister have double layered coenobia and a single process at each marginal coenocyte besides having other distinct morphological characters which do not compare with *P. wilsonii*. The presence of a central coenocyte in *P. indicum* sp. nov., *P. pallidus* sp. nov., *P. angulatus* sp. nov. and *P. magnus* sp. nov. is the main character by virtue of which these species can be readily distinguished from *P. wilsonii*. *P. kajaites* Wilson & Hoffmeister and *P. delicatites* are very different in having distinct shape and arrangement of coenocytes.

*Pediastrum indicum* sp. nov.

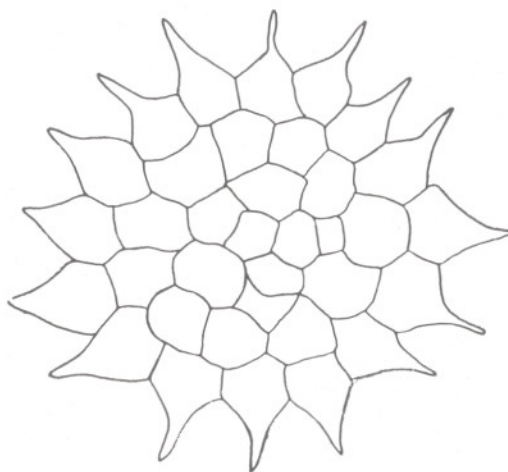
Pl. 1, fig. 12; Text-fig. 3

*Holotype* — Pl. 1, fig. 12; size  $91 \times 89 \mu$ . Slide no. KS136/3/1540.

*Locus Typicus* — Jabli-Kumarhatti, Solon District, Himachal Pradesh, India.



TEXT-FIG. 2 — *Pediastrum wilsonii* sp. nov.



TEXT-FIG. 3 — *Pediastrum indicum* sp. nov.

*Stratum Typicum* — Subathu Formation, Simla Hills (Upper Palaeocene to Eocene), Punjab Basin, India.

*Diagnosis* — Coenobium single layered, usually less than  $92\ \mu$  in diameter; marginal coenocytes pentangular, longer than broad, tipped with a single process; inner coenocytes polygonal with  $\pm$  equal sides; central coenocyte present.

*Description* — Coenobium a single layered plate of coenocytes, 29 or more in number, arranged in compact rings, outer ring differentiated into marginal coenocytes and the inner rings into inner coenocytes; perforations absent. Marginal coenocytes pentangular, longer than broad, usually with a single process measuring  $5-6\ \mu$  in length and  $1-2\ \mu$  in breadth at the base. Inner coenocytes polygonal ( $12-15\ \mu$ ) having almost equal sides; wall pitted. Central coenocyte present.

*Comparison* — Coenobia are double layered in *P. compactum* sp. nov. and *P. paleogeneites* Wilson & Hoffmeister and hence differ in organization. In *P. wilsonii* sp. nov., the coenocytes are arranged in the order of 11, 5, marginal coenocytes have two long processes and the central coenocyte is distinctly absent. *P. bifidites* Wilson & Hoffmeister is different by having two processes on the peripheral part of each marginal coenocyte whereas it is only one in *P. indicum* sp. nov.

*Pediastrum pallidus* sp. nov.

Pl. 1, figs. 4, 5; Text-fig. 4

*Holotype* — Pl. 1, fig. 4; size  $76 \times 71\ \mu$ . Slide no. KS111/3/1540.

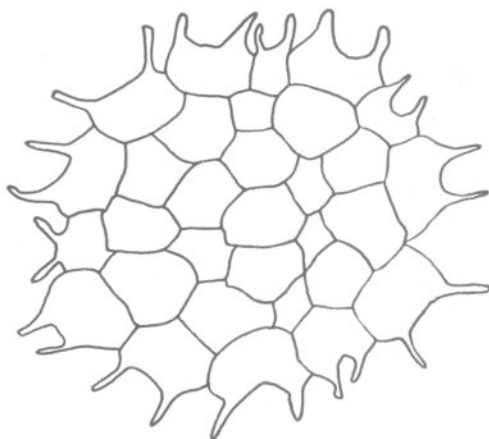
*Isotype* — Pl. 1, fig. 5.

*Locus Typicus* — Jabli-Kumarhatti, Solon District, Himachal Pradesh, India.

*Stratum Typicum* — Subathu Formation, Simla Hills (Upper Palaeocene to Eocene), Punjab Basin, India.

*Diagnosis* — Coenobium single layered,  $83-126\ \mu$  in diameter, coenocytes arranged in rings, marginal coenocytes broader than high with 2 short processes; inner coenocytes polygonal with unequal sides, central coenocyte present.

*Description* — Coenobium consisting of a single plate of coenocytes usually 30 in number, arranged in compact rings, perforations absent. Marginal coenocytes broader than high, appearing pear-shaped because of in-



TEXT-FIG. 4 — *Pediastrum pallidus* sp. nov.

vaginated base, processes two, usually short and stumpy. Inner coenocytes polygonal, sides unequal, wall pitted. Central coenocyte present.

*Comparison* — *Pediastrum bifidites* Wilson & Hoffmeister has half the number of coenocytes, hexangular inner coenocytes with  $\pm$  equal sides and spine-like two processes arising from the outer angles of the coenocytes. *P. compactum* sp. nov. and *P. paleogeneites* Wilson & Hoffmeister are distinct by having double layered coenobia and a single stumpy process on each marginal coenocyte. In *P. wilsonii* sp. nov. and *P. indicum* sp. nov., marginal coenocytes are longer than broad and have two long processes in the former and a single process in the latter case.

*Pediastrum angulatus* sp. nov.

Pl. 1, figs. 8, 9; Text-fig. 5

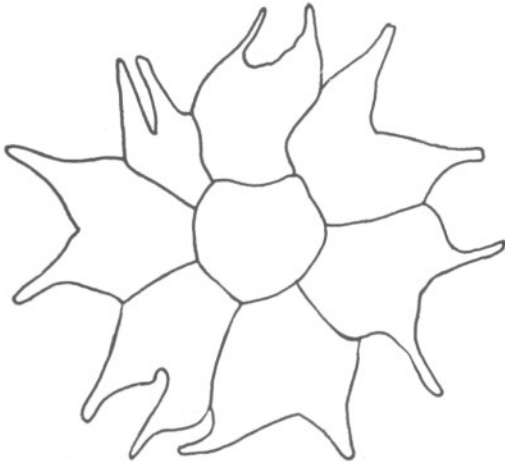
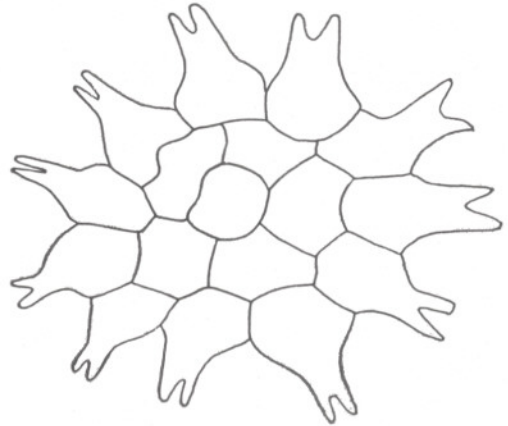
*Holotype* — Pl. 1, fig. 8; size  $58 \times 56\ \mu$ . Slide no. KS26/1/1540.

*Isotype* — Pl. 1, fig. 9.

*Locus Typicus* — Jabli-Kumarhatti, Solon District, Himachal Pradesh, India.

*Stratum Typicum* — Subathu Formation, Simla Hills (Upper Palaeocene to Eocene), Punjab Basin, India.

*Diagnosis* — Coenobium single layered,  $50-60\ \mu$  in diameter, coenocytes arrangement 7,1; marginal coenocytes longer than broad, hexagonal, having two processes, inner coenocytes absent; central coenocyte present.

TEXT-FIG. 5 — *Pediastrum angulatus* sp. nov.TEXT-FIG. 6 — *Pediastrum magnus* sp. nov.

*Description* — Coenobium a single plate of coenocytes, usually 8 in number, arranged in a compact ring of 7 marginal coenocytes and a single central coenocyte; perforations absent. Marginal coenocytes hexagonal longer than broad, outer wall usually invaginated, height of marginal coenocyte 11-15  $\mu$ ; membranes pitted; processes two, arising from the sharply defined angles of the marginal coenocytes, 6-8  $\mu$  in length and 2-3  $\mu$  in breadth. Central coenocyte present.

*Comparison* — The present species is very distinct from all other known species of *Pediastrum* by the absence of inner coenocytes. Also the processes arise from the sharply defined angles of the hexagonal marginal coenocytes. By virtue of these characters *P. angulatus* is distinguished from the known species of fossil *Pediastrum*.

*Pediastrum magnus* sp. nov.

Pl. 1, figs. 10,11; Text-fig. 6

*Holotype* — Pl. 1, fig. 10; size 75  $\times$  60  $\mu$ . Slide no. KS107/3/1540.

*Isotype* — Pl. 1, fig. 11.

*Locus Typicus* — Jabli-Kumarhatti, Solon District, Himachal Pradesh, India.

*Stratum Typicum* — Subathu Formation, Simla Hills (Upper Palaeocene to Eocene), Punjab Basin, India.

*Diagnosis* — Coenobium single layered,  $\pm$  75  $\mu$  in diameter, coenocytes arrangement 11, 5, 1; marginal coenocytes flask-shaped,

each having two terminal processes; inner coenocytes polygonal with unequal sides; central coenocyte present.

*Description* — Coenobium consisting of a single plate of coenocytes, usually 17 in number, arranged in compact rings, perforations absent. Marginal coenocytes 11 in number, flask-shaped, 18  $\mu$  long and 12  $\mu$  broad, membranes pitted, processes 2, 5  $\mu$  long and 1.5  $\mu$  broad at the base. Inner coenocytes 5 in number, polygonal in shape with unequal sides, wall pitted. Central coenocyte present.

*Comparison* — *P. magnus* sp. nov. is not comparable to any of the known species by having flask-shaped marginal coenocytes.

*Remarks* — Examination of the specimens referable to the present species shows that shape of the marginal coenocytes exactly resembles that of a flask excepting in having two small processes which arise from the neck of the flask. Sometimes the neck of the marginal coenocyte is not preserved and so the coenocytes appear  $\pm$  circular bodies with a pin-head like spot on the peripheral ends.

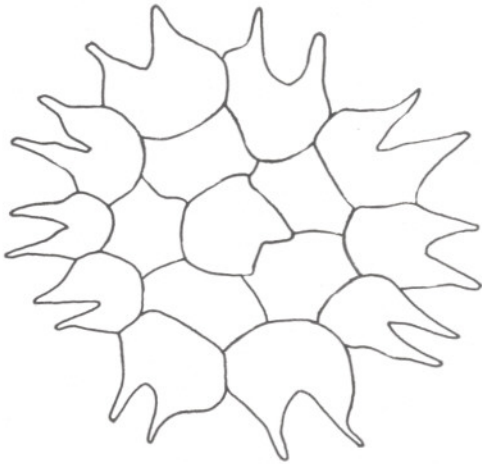
*Pediastrum diffusus* sp. nov.

Pl. 1, figs. 13-17; Text-fig. 7

*Holotype* — Pl. 1, fig. 17; size 80  $\times$  68  $\mu$ . Slide no. KS125/2/1540.

*Isotype* — Pl. 1, fig. 14.

*Locus Typicus* — Jabli-Kumarhatti, Solon District, Himachal Pradesh, India.



TEXT-FIG. 7 — *Pediatrum diffusus* sp. nov.

*Stratum Typicum* — Subathu Formation, Simla Hills (Upper Palaeocene to Eocene), Punjab Basin, India.

*Diagnosis* — Coenobium single layered, 62-93  $\mu$  in diameter; coenocyte arrangement 10, 5, 1; marginal coenocytes higher than broad, each coenocyte with two processes, each process arising from the obtuse angles; inner coenocytes  $\pm$  polygonal, central coenocyte present.

*Description* — Coenobium a single plate of coenocytes usually arranged in 3 compact rings in the order of 10, 5, 1; perforations absent. Marginal coenocytes higher than broad, looking more or less pear-shaped due to invagination in the outer wall; processes 2, 3-7  $\mu$  in length and 1-2  $\mu$  in breadth at the base, each process arising from the outward angles. Inner coenocytes polygonal to hexagonal, sides unequal. Central coenocyte present, walls pitted.

*Comparison* — In the coenocytic arrangement, *Pediatrum diffusus* sp. nov. closely compares with *P. magnus* in having similar organization of the coenobium but the latter is distinct by virtue of its characteristic flask-shaped marginal coenocytes. *P. angulatus* sp. nov. does not compare with the present species because of its smaller size, 7, 1 order of coenocytic arrangement and by the absence of inner coenocytes. Marginal coenocytes in *P. pallidus* sp. nov. are broader than high and hence it is not comparable. *P. indicum* sp. nov. is distinct by the presence of a single process instead of two as in

the case of *P. diffusus*. In *P. wilsonii* sp. nov., inner coenocytes are larger than the marginal coenocytes and the central coenocyte is absent. *P. compactum* sp. nov. and *P. paleogeneites* are different by having double layered coenobium.

#### DISCUSSION

During the course of present study of the genus *Pediatrum* some important morphological trends have been observed. The taxonomic significance of these trends has been evaluated. To compile this information, morphological variations as observed in the fossil species of *Pediatrum* both from India and abroad have been considered. Broadly speaking (i) the coenobia of *Pediatrum* can be grouped under a single layered coenobium or a double layered coenobium, (ii) the central coenocyte may be present or absent, (iii) the inner coenocytes may be arranged compactly or have perforations of variable shape and size, (iv) the size of the inner coenocytes may be smaller, larger or equal to the size of marginal coenocytes, and (v) the size, shape and number of processes on the marginal coenocytes may be related to the dimensions and shape of the marginal coenocytes.

It has been observed that most of the species described under *Pediatrum* have a single layered coenobium with the exception of *P. paleogeneites* and *P. compactum* which are double layered excluding the area of marginal coenocytes. From this it can be inferred that the structural organization relating to the arrangement of single layered plates may perhaps represent one line of evolution and the introduction of complexity in morphological characters as it appears in *P. paleogeneites* and *P. compactum* may perhaps represent another.

The presence or absence of the central coenocyte has been considered to be an important morphological character for the identification of different species. It is very likely that two different evolutionary trends may be represented each with a set of such species which possess the central coenocyte in contrast to those which are without it.

*Pediatrum kajaites* and *P. delicatites* are distinct by the absence of central coenocyte and at the same time have perforations of triangular to variable shape in surface view.

The presence of perforations associated with the inner coenocytes of the above mentioned two species is rather very striking. Also, it seems likely that the forms having perforations in association with the inner coenocytes are better suited for floatation and assimilation of solutes and minerals.

Shape, size and number of inner coenocytes in a concentric ring of the coenobium prove to be extremely useful in delimiting various species. The relationship of these characters is worked out in comparison to the similar characters represented by the marginal coenocytes. Number of coenocytes remains fairly constant in different concentric rings and hence is a useful morphological character for taxonomic purposes. In some species, viz., *P. wilsonii* the inner coenocytes are larger in size as compared to the marginal coenocytes while in others, e.g. *P. magnus* inner coenocytes are polygonal in shape whereas the marginal coenocytes are flask-shaped. Hence, evaluation of all these characters helps a lot in proper understanding of the morphological limits of the species.

Amongst all the morpho-characters discussed so far, reference to the marginal coenocytes together with their processes is most important. Shape and size of the marginal coenocytes is exceedingly variable. They

may be hexagonal to flask-shaped in shape and may have 1-2 processes in number which are small to long and sharp to blunt. They may arise from acute to obtuse angle of the coenocytes excepting when they are pear to flask-shaped. Thus shape, size and number of the marginal coenocytes together with the variety exhibited by the processes constitute dependable characters for speciation of the genus. Different combination of all the above mentioned characters result in the recognition of a wide variety of species assignable to the genus *Pediastrum*.

Distribution and palaeoecological significance of this algal form has already been discussed. It is reiterated that the occurrence of *Pediastrum* in two different environment of depositions, i.e. fresh water to marine habitat has to be evaluated differently. Its association with continental assemblages offers little difficulty in deciphering the fresh water conditions of deposition. However, when it occurs along with the hystrichosphaerid dominated marine assemblages, the palaeoecological significance of *Pediastrum* goes to jeopardy. It has been argued earlier in the text that in such events *Pediastrum* may be considered as a derived element from the near shore fresh water channels or connections which might have existed along the coast line.

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## EXPLANATION OF PLATE

(All photographs.  $\times 500$  and are from unretouched negatives)

## PLATE 1

1-3. *Pediastrum compactum* sp. nov., slide nos. KS125/2/1540, KS125/2/1540, KS125/1/1540.

4, 5. *P. pallidus* sp. nov., slide nos. KS111/3/1540, K1/1/1540.

6, 7. *P. wilsoni* sp. nov., slide nos. K1/1/1811, KS125/1/1540.

8, 9. *P. angulatus* sp. nov., slide nos. KS26/1/1540, KS26/1/1540.

10, 11. *P. magnus* sp. nov., slide nos. KS107/3/1540, KS107/1/1540.

12. *P. indicum* sp. nov., slide no. KS136/3/1540.

13-17. *P. diffusus* sp. nov., slide nos. KS125/2/1540, KS125/4/1540, KS125/4/1540, KS125/2/1540, KS125/4/1540.



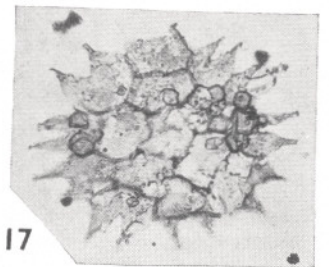
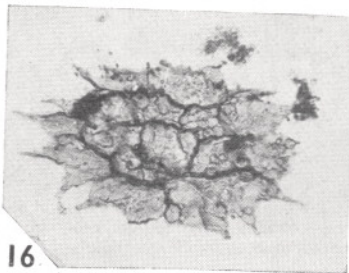
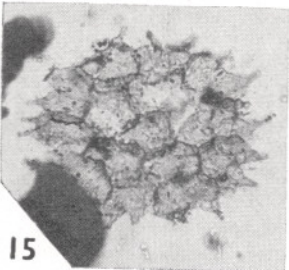
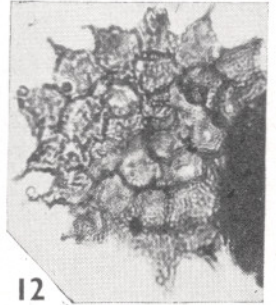
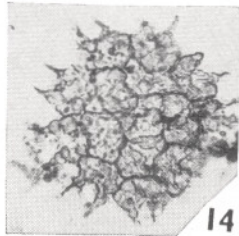
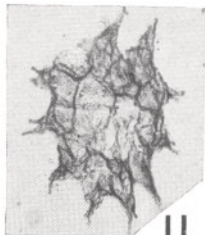
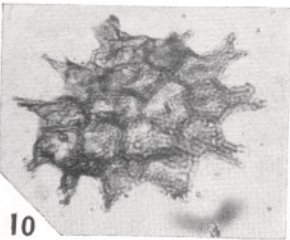
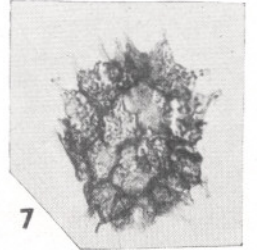
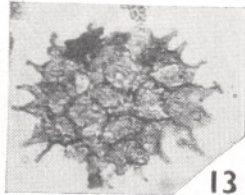
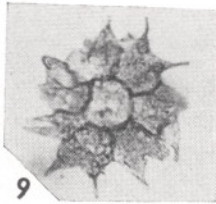
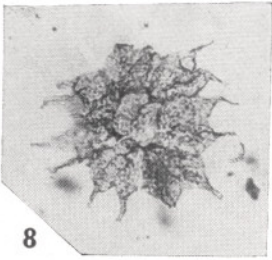
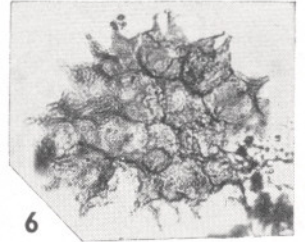
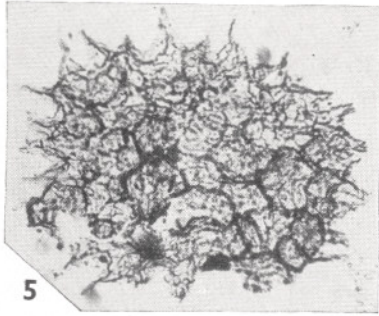
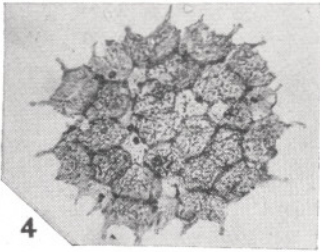
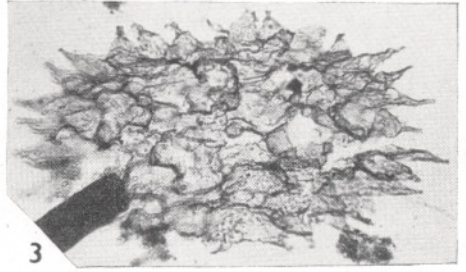
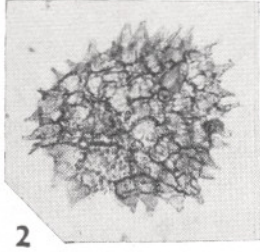
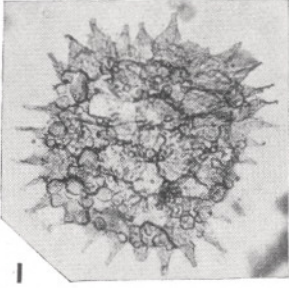


PLATE 1