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RECORDS OF THE OCCURRENCE OF *BOTRYOCOCCUS BRAUNII*, *PEDIASTRUM* AND THE HYSTRICHOSPHAERIDEAE IN CAINOZOIC DEPOSITS OF AUSTRALIA

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Plates I-II

SUMMARY

Several occurrences of *Botryococcus braunii* in Australian deposits ranging from Tertiary to Quaternary have been recorded.

Pediastrum boryanum has been isolated from two Tertiary localities, one in Victoria and one in South Australia.

Eleven distinct types of the Hystrichosphaerideae, representing four genera known from European deposits, have been identified.

A new species, referred to *Cannosphaeropsis* O. Wetzel, has been described.

The palaeoecological importance of these microfossils and the distribution of the Hystrichosphaerideae have been considered.

INTRODUCTION

Botryococcus and the *Hystrichosphaerideae* have been known for some considerable time as fossil components of peats and older deposits in Europe and Britain, but neither they nor *Pediastrum* has previously been recorded from Australian Cainozoic strata.

Their occurrence in Australian beds of this period was first noted during a pollen analysis. They were found in residues which resulted from the treatment of certain Tertiary clays and sandstones with hydrofluoric acid followed either by Schultze's solution and alkali or chlorination-acetolysis mixtures. Since then new occurrences in widely separated beds of different ages have come to light. These discoveries, however, have been quite fortuitous and as such provide only limited information regarding the age and distribution of all three types of microfossils. Unfortunately a more detailed and systematic investigation is not possible at present. It has therefore been decided to record the findings as they stand in the hope that they may be of some palaeoecological and micropalaeontological interest.

(1) *Botryococcus braunii* Kützing
(Plate 1, figs. 1-6)

(i) *Historical Record*

So much has been written recently regarding the structure and geological occurrence of *Botryococcus braunii* that only brief reference to both aspects need be given here.

The structure of the living colonies and the individual cells of which they are composed has been exhaustively dealt with by Blackburn (1936) and Frémy and Dangeard (1938).

Temperley (1936) and Harris (1938) have both expressed considered opinions regarding the synonomy and geological history of *B. braunii,* and in 1944 Dulhunty discussed the origin of the Australian boghead or Kerosene Shale in New South Wales. As the result of these and other investigations, it is now generally believed that an alga identical with the living *B. braunii* has existed from the Ordovician onwards and was responsible for the production of localized deposits of boghead coal in various countries.

(ii) *Structure and Occurrence*

B. braunii is a cosmopolitan colonial alga which usually inhabits freshwater lakes and ponds. Sometimes, as in the lagoons of the Coorong along the south-eastern coast of South Australia (Dulhunty 1944) and in certain lakes in Russia, it lives in salt and brackish water.

The colonies are generally spherical or nearly so and vary in size according to the number of daughter colonies which remain attached to one another. This attachment is effected by means of definite strands as is shown in plate I, fig. 3.

The individual cells, themselves, are pear-shaped. Each lies in a thin cup-shaped thimble of cuticular nature which in turn is surrounded by a thick fatty cup open at the distal end. The cell in this region is covered by a cap composed of cellulose and pectic substances.

Cell divisions take place in longitudinal directions at right angles to one another. After a division, each daughter cell secretes a new thimble and cup within the parent wall. Thus the cells of a colony are primarily grouped in pairs and, as the number of cells and cell groups increases, a definite skeletal framework is gradually built up.

This framework is of a fatty nature and extremely resistant to decay. Very often it retains its original form in the fossil condition, empty cups in pairs or larger groups such as fours, sixes or eights being clearly visible. It is the preservation of such features in colonies isolated from the various deposits, to be cited, that has permitted their identification with *B. braunii.*

The fossil colonies vary considerably in size from small individuals about 10μ in diameter to large compound groups with diameters of about 100μ. The length of the cells ranges from 5-15μ.

Different races of *Botryococcus* such as those distinguished by Blackburn (1936) have not been recognized.

(iii) *Cainozoic Distribution*

New South Wales:

Warlands Creek seven miles north-east from Murrundi. Clay and sandy wash beneath Tertiary basalt. Age: Probably Oligocene-Miocene. Portion of Dr. J. Dulhunty's coal sample 176—remaining fraction Nat. Mus. Melb. No. P 15584. *Botryococcus braunii* abundant. Pollen content low, a few winged pollen grains observed.

Victoria:

Lal Lal near Ballarat (Thomas and Baragwanath 1950). Geol. Surv. of Vic., bores 60 and 62. Carbonaceous clays. Age: ? Oligocene. Bore 60, at 69 ft., Geol. Surv. Vic. No. 11907. *Botryococcus* moderately abundant. Pollen content high, mainly winged grains of the Podocarpaceae. *Nothofagus* sp. *b* and *N.* sp. *c* observed (Cookson 1946).

Bore 60, at 67 ft., Geol. Surv. Vic. No. 11908. *Botryococcus* abundant. Pollen content high, includes *Araucariacites australis* varieties of winged podocarpaceous types and *Nothofagus* sp. *b*.

Bore 62, at 246 ft., Geol. Surv. Vic. No. 11909. *Botryococcus* sparse. Pollen content high, includes winged types and *Nothofagus* sp. *b, N.* sp. *c, N.* sp. *d,* and *N.* sp. *e.*

Anglesea. Coastal cliff near mouth of the Anglesea River. Black carbonaceous sandstone. Age: Oligocene (Singleton 1941, p. 13). *Botryococcus* sparse, pollen content high, includes *Araucariacites australis,* a number of distinct podocarpaceous types, *Nothofagus* sp. *b,* N. sp. *c,* N. sp. *f,* and several types of Hystrichosphaerids.

Werona, near Campbelltown. Carbonaceous clay under newer basalt. Age: Late Tertiary (Harris and Thomas 1948). Geol. Surv. Vic. No. 11906. *Botryococcus* moderately abundant. *Pediastrum* very infrequent. Pollen content very low.

Stony Creek Basin near Daylesford. Dark shale. Age: ?Middle Pliocene (Coulson 1950). Nat. Mus. Melb. No. P 15583. *Botryococcus* moderately abundant. Pollen content only moderate, several podocarpaceous types observed.

South Ecklin, 12 miles from Terang. Peat. Age: Quaternary. Geol. Surv. Vic. No. 11910. *Botryococcus* moderately abundant. Pollen content negligible. Unidentified, thick-walled, pointed hairs (plate I, fig. 18) moderately numerous.

Moyne River, right bank, 0·6 mile slightly E. of N. of Rosebrook Bridge; military map, Port Fairy sheet 1942, grid reference 202,719, Western Victoria. Clay resting on marine shell bed. Quaternary. Nat. Mus. Melb. No. P 15586. *Botryococcus* present but not abundant. Pollen content moderate; spheroidal cribellate pollen grains 29-39μ in diameter (average 33·5μ) are conspicuous (plate I, fig. 17). These have more than fifty pores and thus can be safely referred to the Chenopodiaceae (Faegri and Iverson, 1950, p. 147). Shells of *Hystrichosphaera furcata* moderately numerous.

South Australia:

Cootabarlow, east of Lake Frome. S.A. Dept. of Mines. Bore at 471-493 ft. Carbonaceous shale. Age: ?Early Tertiary. Nat. Mus. Vic. No. P 15585. *Botryococcus* very abundant accompanied by *Pediastrum.* Pollen grains rare.

Western Australia:

Shannon River, south coast Western Australia. Lignite. Age Tertiary. Geol. Dept. Univ. W.A. No. 40. *Botryococcus* abundant. Pollen content moderate.

(2) *Pediastrum boryanum* (Turp.) Menegh.
(Plate I, Figs. 7-11)

Only three references to the fossil occurrence of *Pediastrum* have been found. These are the report by Davis (1916) of its presence in the Eocene Green River Shales of U.S.A., the mention by Blackburn (1936) of well-preserved colonies in preparations of lake mud after treatment with 10% potash, and the record by Iversen (1936) of its occurrences as a secondary constituent in unweathered boulder-clay from North Jutland. In none of these cases were illustrations and descriptive notes of the fossil species provided.

Pediastrum is a cosmopolitan green alga frequently found amongst plankton in freshwater lakes and ponds. The colonies have the form of minute stellate plates composed of a single layer of regularly arranged cells four to one hundred and twenty-eight in number. The marginal cells of a colony differ from the internal cells in having one, two, or three more or less prominent processes.

Colonies agreeing with the general features of *Pediastrum* are associated in moderate numbers with *Botryococcus braunii* in the carbonaceous shale from the Cootabarlow bore at 471-493 ft. They are remarkably well preserved and even after the drastic action of Schulze's solution, several, almost entire, colonies have been seen. Fragmentary remains of *Pediastrum* occur very sparsely in the clay from Werona.

The colonies observed have had diameters ranging from 42-143μ (processes included) and have been composed of from eight (plate I, fig. 7) to approximately 60 cells (plate I, fig. 11). In them a central cell is usually evident around which the remaining cells are concentrically arranged. The width of the cells is from 13-18μ. Each marginal cell has two rather horn-like processes, 8-13μ long, with truncate ends. The cell walls are usually distinctly granular, but in the specimen shown in plate I, fig. 8, the surface appears to have been almost smooth.

The fossil colonies agree most closely with those of *P. boryanum* of the section *Diactinium* A. Br. (Lindau and Melchoir 1930, p. 149). In this species, as in the fossil, the individual cells are closely united and not separated by perforations as they are in *P. duplex* Meyers of the same section. There is further agreement as regards the paired marginal processes, the number of cells of which the colonies are composed and the granular nature of the cell walls. It is in view of this close similarity that the fossil *Pediastrum* has been identified with the living species *P. boryanum.* In this connection West's record (1909) of *B. boryanum* in the littoral algal flora of the Yan Yean Reservoir near Melbourne is of some interest.

3. *Hystrichosphaerideae*

General Account

The Hystrichosphaerideae comprise a variety of obscure unicellular marine microfossils of uncertain affinities. All consist of a more or less spherical or ovoid body or shell which is variously ornamented with branched or unbranched spine-like or tubular appendages. Their membranes are resistant to strong acids and remain in good condition after chlorination and acetolysis.

The microfossils included in this group have had a long geological history. They have been recorded from rocks as far back as the Upper Cambrian* and are of frequent occurrence in European marine strata from the Jurassic period onwards. Forms similar or very close to the Hystrichosphaerideae have been occa-

*A. Eisenack *Senckenbergiana* 32, p. 194.

sionally mentioned in present day plankton. (Deflandre, 1947, p. 13, Pastiels, 1948, p. 48).

The identity of the Hystrichosphaerids has been much discussed (Deflandre 1947, Pastiels 1948, etc.). Ehrenberg (1836) believed them to be the zygospore cases of *Xanthidium,* a living genus of the Desmidiaceae. Since then, they have been variously thought to be eggs of planktonic crustacea, cysts, radiolaria of the group Collosphaerida, remains of organisms related to the Dinoflagellates and spores.

In 1933 O. Wetzel removed Ehrenberg's species from *Xanthidium* to *Hystrichosphaera* and at the same time created other new genera and species. Subsequently Deflandre (1937) redefined the limits of Hystrichosphaera by including in it only those species in which the shells are subdivided into polygonal fields and equatorial plates. Those species with unsegmented membranes were classified as *Hystrichosphaeridium.*

The occurrence of the Hystrichosphaerideae in Australian Tertiary deposits demonstrates how widespread their past distribution must have been, although this is not surprising since they are members of the plankton. The age of the Australian deposits in which they have been located ranges from Oligocene to Quaternary. Several of the genera known from European horizons have been recognized. Both generic and specific determinations have, however, been hampered by lack of literature on the one hand (Wetzel's paper (1933) for example has not been seen) and by an insufficient number of examples of some of the types on the other. At a later date a more detailed investigation may be possible.

Australian Cainozoic Occurrences

Victoria:

Anglesea (see p. 109). Type locality of the Anglesean stage. Age: Oligocene. Hystrichosphaerids are associated with *Botryococcus* and a number of pollen types.

Gellibrand River. About $\frac{3}{4}$ mile south-east of Point Ronald, at the river mouth. Poorly fossiliferous carbonaceous sandy shale which is lithologically similar to the black sandstone at Anglesea (Baker 1944, 1953). Age: ?Oligocene. Several types of Hystrichosphaerids observed. Pollen content moderate, includes *Araucariacites australis* and a few podocarpaceous types. All references in this paper to the Gellibrand River allude to this locality.

Balcombe Bay. Type locality of the Balcombian series. (Singleton 1941, p. 27.) Grey shelly clay rich in foraminifera. Age:

Miocene. Several varieties of Hystrichosphaerids occur. Pollen content very low, includes *Araucariacites australis.*

Nelson Bore. Bore put down near the south-western end of the bridge over the Glenelg River at Nelson. Carbonaceous shaley layer in micaceous sandstone at 6192 ft. Age: ?Tertiary. Hystrichosphaerids sparse. Pollen content low.

Moyne River (see p. 110). *Hystrichosphaera furcata* present, pollen content moderate.

Western Australia:

Perth Bore. Bore put down in Government House grounds, Perth, at 81-82 ft. Grey marine clay. Age: ?Tertiary. Hystrichosphaerids sparingly present. Pollen grains sparse.

Description of Types

1. *Hystrichosphaera furcata* (Ehrenberg) O. Wetzel.
(Plate I, Figs. 13-17)

Origin of type: Cretaceous flints of Delitzsch in Saxony. Other records include Cretaceous flints of the Paris basin (Deflandre 1937), Eocene of Belgium (Pastiels 1948) and the Miocene rock salt deposit near Cracow (Kirchheimer 1950).

The Australian examples of *Hystrichosphaera furcata* are spherical shells 26-55μ in diameter which are ornamented with a number of radiating bi- or tri-furcate appendages 7-18μ long. The overall diameter of the specimens ranges from 39-96μ.

The membrane of the shell is smooth or finely granular (plate I, fig. 15), a variation that is in conformity with the European representatives of this species (Deflandre 1937, p. 15). It is marked out into rectangular or hexagonal fields by usually clearly defined sutures at the junction of which the appendages are situated (plate I, figs. 13, 15).

Occurrence: Sediments at Anglesea, Gellibrand River, Balcombe Bay, Moyne River, and Perth, the ages of which range from Oligocene to Quaternary.

2. *Hystrichosphaeridium tubiferum* (Ehrenb.) Deflandre . .
(Plate 2, fig. 24)

Origin of type: Cretaceous flint, Delitzsch, Saxony. Other occurrences include Cretaceous of Paris Basin (Deflandre), Cretaceous of England, and Eocene of Belgium (Pastiels).

The general appearance of the much-flattened shell shown in fig. 24 bears sufficient resemblance to *Hystrichospaeridium tubi-*

ferum for its inclusion in this species. It measures 68 x 42μ, is oval in outline, and shows the insertion of seven (possibly eight) radially disposed, tubular appendages about 34μ long. These have cup-shaped ends with fringed edges. The shell-membrane is granular.

Occurrence: Nelson Bore at depth of 6192 ft.

Comments: According to Deflandre (1937) *Hystrichosphaeridium tubiferum* is a variable species. Apparently the shell may be either spherical or ellipsoidal and the appendages may vary considerably in number and length. The small number, at most eight, in the Australian example is exceptional but not sufficiently far from Wetzel's minimum (Deflandre 1937, p. 21) of ten to remove it from *H. tubiferum.*

3. *Hystrichosphaeridium truncigerum* Deflandre
(Plate II, figs. 21-23)

Origin of type: Cretaceous flints and shingles of the Paris Basin.

Several specimens have been observed which very closely resemble *Hystrichosphaeridium truncigerum.* These are more or less spherical shells about 50-70μ in diameter (not counting appendages) with radially arranged appendages of varying widths. Usually the larger appendages are of even width and their ends are truncate, but sometimes, as in the example shown in plate II, figs. 21, 22, they widen distally and are more vase-like. Their width varies from 3-23μ and their length from 10-27μ. The walls of the appendages are traversed by slender fibrils which run from apex to base at which point they radiate out into the shell. The main fibrils are connected together by delicate transverse and oblique strieae. The membrane of the shell appears to be granular.

Occurrence: Sediments near Gellibrand River and Anglesea.

Comments: The reference of such forms to *Hystrichosphaeridium truncigerum* seems justified, although their shells are larger than those of the French examples and the small appendages appear to be less numerous. They agree, however, with these, in the occurrence of tubular appendages of different widths and truncate form, and the presence in their walls of delicate fibrils.

4. *Hystrichosphaeridium geometricum* Pastiels
(Plate II, fig. 25)

Origin of type: Eocene argillites, Ypres, Belgium.

A number of examples of *Hystrichosphaeridium geometricum* have been isolated from the deposit near the mouth of the Gellibrand River. All show the polygonal form, the short, simple or forked, spiny appendages and the smooth surface, typical of this species. The diameter of the shell (not counting appendages) ranges from 44-60μ and the length of the appendages from 5-15μ. Both measurements approximately closely to those of the Belgian examples.

The identity of this type is clearly evident when fig. 25 of this paper is compared with fig. 8 on plate 4 of Pastiel's publication (1948).

Hystrichosphaeridium spp.
(Plate II, figs. 26-30)

The two specimens shown in figures 26, 28 are possible representatives of the group of the Hystrichosphaerids typified by *Hystrichosphaeridium hirsutum* (Ehr.), *H. spinosum* White, and *H. pseudohystrichodinium* Defl. (see (Lejeune-Carpentier 1941). Both seem nearer to *H. pseudohystrichodinium* than to either of the other two species but differ from all three in having a large opening or "pylome" at one end of the shell. For this reason, their reference to the Radiolaria may have to be considered. *H.* sp. *a.* shown in optical section and surface view in figs. 26, 27 was isolated from the type Balcombian deposit at Balcombe Bay. It is a large ellipsoidal shell 75 x 83μ (not counting appendages) with numerous stiff, slender, radiating appendages. These are 13-18μ long and are inserted by means of fine "stilts" either separately or in pairs on the surface of the shell. Towards one end of the shell there is an angular opening or "pylome".

H. sp. *b.* The shell shown in fig. 28 was isolated from the Anglesea sandstone. It is smaller (44 x 55μ) than that of *H.* sp. *a,* is roughly ovoid, and slightly concave at the narrower end. The appendages are numerous, slender and stiff, about 10-23μ long, shorter and incurved at the concave end. The surface of the shell is rather coarsely granular. There is a relatively large opening near the wider end of the shell.

H. sp. *c.* This is a still smaller form with the same type of appendage. The shell (figs. 29, 30) has a diameter of about 31μ and the rather stiff appendages about 13μ long have slightly flattened tips and are inserted on the shell by means of short, slender "stilt-like" filaments. At about the middle of the convex surface there is a relatively broad funnel-like outgrowth. The surface of the shell is very finely granular.

This type was isolated from the sandstone near the mouth of the Gellibrand River.

Hystrichosphaeridium cf. *hirsutum* (Ehr.) Defl. (1937)
(Plate 1, fig. 20)

The shells included under this heading are more or less spherical, about 26-44μ in diameter (not counting appendages) with numerous, radially arranged, filiform, flexuous appendages from 5-15μ long. The overall diameters range from 41-60μ. The surface of the shell is granular.

Occurrence: Tertiary clay at Werona, Victoria.

Comments: This microfossil is rather common at this locality. It is not unlike the figure of *Hystrichosphaeridium* cf. *hirsutum* given by Deflandre (1947, fig. 15). However, since the deposit in which it occurs is of freshwater origin, I prefer to leave such questions as its identity and occurrence in the deposit, that is whether it is a primary or secondary constituent, completely open for the present.

Micrhystridium cf. *reticulatum* Deflandre
(Plate II, figs. 31, 32)

Origin of type: Cretaceous flint and shingle of the Paris basin.

The genus *Micrhystridium* as defined by Deflandre includes small globular Hystrichosphaerids with diameters of less than 20μ.

The specimen illustrated in figs. 31, 32 comes under this category and agrees closely with Deflandre's species *M. reticulatum*.

It is a spherical shell 18μ in diameter with radiating appendages of about 5μ, the overall diameter being 27μ. It bears a wide-meshed reticulum at the angles of which the appendages are situated. The appendages are straight and narrow gradually towards minute truncate apices. The surface of the shell is granular.

Occurrence: Sediments near the mouth of Gellibrand River.

Comment: This example bears a great resemblance to the single specimen upon which *M. reticulatum* was based. The only feature in which the two specimens disagree is the texture of the shell-membrane, which is smooth in the French example, granular in the Australian.

Micrhystridium cf. *ambiguum* Deflandre
(Plate II, fig. 33)

Origin of type: Cretaceous flints of Paris Basin.

The shell is spherical 20μ in diameter with numerous closely placed radiating appendages about 7μ long. The overall diameter is 30μ. Most of the appendages are terminally forked and the branches recurved. The surface of the shell is slightly granular.

Occurrence: Oligocene sandstone near Anglesea.

Comments: Only one shell of this type has been seen. It does not agree exactly with *H. ambiguum* in which the appendages are shorter relative to the diameter of the shell than in the Anglesea specimen. It is distinct from *M. reticulatum* Deflandre in the absence of a surface reticulum.

Micrhystridium sp.

(Plate II, fig. 34)

The shell is more or less spherical 13-19μ in diameter (not counting appendages), with fine, rather stiff, radially arranged appendages, 3-5μ long. The apices of the appendages are slightly flattened and occasionally forked. The surface of the shell is smooth.

Occurrence: Gellibrand River, Victoria.

Cannosphaeropsis cf. *caulleryi* Deflandre

(Plate II, figs. 35-40)

Shells that are comparable with *Cannosphaeropsis caulleryi* as figured by Deflandre are relatively numerous in the bed near the Gellibrand River. Usually they are rather crumpled, folded or fragmentary.

The shell itself is somewhat ovoid, 43-74μ in diameter and invested by an outer delicate net-like envelope of unequal mesh formed by the branching and anastomosis of the fine radially arranged stems which link it to the central shell. Minute spines (Plate II, fig. 40) are sometimes present on the outer edges of the "net". The overall diameter ranges from 67-115μ. The surface of the shell is finely granular.

Occurrence: Oligocene sandstone near the mouth of the Gellibrand River and Anglesea.

Comments: This type has been referred to *Cannasphaeropsis* rather than to *Membranilarnax* O. Wetzel which to some extent it resembles, on account of the radial arrangement of the branched stems which support the covering network. In some species, at least, of *Membranilarnax* the axial "stems" are restricted to an equatorial zone.

Of the six species of *Cannasphaeropsis* that have been described the descriptions of only two—*C. utinensis* O. Wetzel and *C. reticulensis* Pastiels have been available. However, figures of all have been considered, and it is on the basis of the resemblance between the Australian shell and the one of *C. caulleryi* figured by Deflandre (1947, fig. 54) that the present tentative reference to this species has been made.

It should perhaps be mentioned that the example illustrated in plate II, fig. 36, of this paper has a coarser net than most of the other specimens and possibly approaches more closely to *C. reticulensis* Pastiels than they do.

Cannosphaeropsis urnaformis n. sp.

(Plate II, fig. 41-43)

The type specimen of *Cannosphaeropsis urnaformis,* shown in surface view and optical section in plate II, figs. 41, 42, is a smooth ovoid shell 44 x 55μ with approximately twelve short, broad, radially arranged vase-shaped appendages. The latter measure about 20μ across the base and about 30μ across the rim and are 15-18μ long. The walls of the appendages are much perforated, the holes frequently extending from the rim to the prominent annular thickening present at the point of junction of an appendage with the shell-membrane. The rim is entire and slightly fluted. The appendages of this specimen are free from one another. A second example, however, suggests that they may not have always been so, since two of its appendages (plate II, fig. 43) are definitely attached to one another by a short and delicate strand.

The surface of the shell is finely granular.

Occurrence: Oligocene sandstone, Anglesea, Victoria.

Comments: This type has been classified with *Cannosphaeropsis* rather than with the species of *Hystrichosphaeridium* with tubular appendages, on account of the perforated character of the appendages and the probability that these were connected together by delicate strands or tubes. The general resemblance of *C. urnaformis* to one of the figured specimens of *H. salpingophorum* Deflandre (Pastiels 1948, plate III, fig. 7) has been noticed but the walls of the vase-shaped appendages of this and other examples of *H. salpingophorum* are entire.

Some of the large appendages of *Cannosphaeropsis aemula,* judging from Deflandre's drawing* (1947, fig. 5), are also vase-shaped and perforated distally, and thus rather like those of *C. urnaformis.* They are connected to one another and to other more slender, forked branches which occur by long, loose, wavy, narrow connecting tubes. The appendages of *C. urnaformis,* on the contrary, are all alike, they are completely perforated and if they were connected it seems probable that the strands between them were short and extremely delicate.

*A description of this species has not been seen.

Palæoecology

Of the three microfossil types considered in this paper *Botryococcus braunii* is of least importance in any palæoecological study since it can live in either salt or fresh water. On the other hand *Pediastrum* being a freshwater alga and the Hystrichosphaerideae being components of the marine plankton are more valuable indices in this respect. Thus the occurrence of *Pediastrum* with *Botryococcus* in the Cootabarlow shale and Werona clay confirms that both are freshwater lake deposits. In contrast the association of Hystrichophaerids with *Botryococcus* in the Anglesea sandstone and Moyne River clay indicates that these deposits accumulated in or near salt water, but since *Botryococcus* is present, at no great distance from a marine shore-line.

The pollen content in both cases throws some light on the type of vegetation growing in the vicinity of these particular accumulating sediments. One of the most frequently recurring pollen-grains in the Moyne River deposit is one referable to the Chenopodiaceae. Its presence is suggestive of the probable existence of nearby coastal or salt-marsh formations, that is, conditions possibly somewhat similar to those prevailing, at present, along the south-eastern coast of South Australia. Erdtman (1943, p. 82) writes as follows, "Plants belonging to this family are often characteristic of salt marshes and the occurrence of *Chenopodiaceae* pollen in marsh peat and certain sediments may be an indication of changes in the shore-line, etc."

The pollen content of the Anglesea sandstone is high and varied, and includes a number of tree pollen grains. It would seem therefore that a forest was not far removed from the accumulating sediments.

The lithological agreement existing between the sandstone beds near the mouth of the Gellibrand River and at Anglesea has already been mentioned (p. 112). The microfossil content of the two deposits is also closely similar but not exactly so. *Botryococcus* has not been observed in the Gellibrand River sandstone, whereas it has been consistently present, although in rather small numbers, at Anglesea. Several types of *Hystrichosphaerids,* for example *Hystrichosphaera furcata, Hystrichosphaeridium truncigerum* and *Cannosphaeropsis* cf. *caulleryi* are common to both, but the number of individuals seems higher at Gellibrand River than at Anglesea. The pollen content of the former deposit is correspondingly lower than that of the latter. Whether these facts suggest that the conditions of sedimentation were slightly different in the two areas can only be decided after a more comprehensive examination of the two deposits has been made.

When using microfossils such as the Hystrichosphaerideae for palæoecological purposes it must be remembered that these and other types may be transferred from older to younger deposits. Iversen (1936) has reported the secondary occurrence of *Pediastrum,* "Hystrix", and Tertiary pollen grains in boulder clay from North Jutland, and Kirchheimer (1950) has suggested the possibility that microfossils from the Miocene Salt deposit at Wieliczka were washed into the developing deposit from the underlying Cretaceous beds.

In this connection, reference to the occurrence of the microfossil described here as *?Hystrichosphaeridium* cf. *hisutum* (Ehr.) Defl. from the Tertiary clay at Werona seems relevant. If this type were to be accepted as a member of the Hystrichosphaerideae its presence in this fresh-water deposit could only be explaind on the assumption that it was a secondary derivative from some older deposit.

Distribution of the Hystrichosphaerideae

Much has still to be learnt concerning the vertical range of the individual types of the Hystrichosphaerideae. The present investigation has been neither sufficiently comprehensive nor precise to add much to the knowledge already available. However, it has shown that the group as a whole was well represented in southern waters during the Tertiary period and, if the identifications are correct (about some of them there is little doubt), has demonstrated the cosmopolitan nature of such species as the following:

Hystrichosphaera furcata is known from European Cretaceous, Eocene and Miocene deposits. Its range in the Australian beds so far examined is from Oligocene to Quaternary.

Hystrichosphaeridium tubiferum which is common in the Cretaceous of Britain and Europe, and also occurs in several European Eocene deposits, has been isolated from a Victorian sediment of uncertain age.

Hystrichosphaeridium truncigerum. Known from Cretaceous flints of the Paris Basin, occurs in Victorian strata regarded as belonging to the Oligocene period.

Hystrichosphaeridium geometricum recorded only from Eocene beds in Belgium, also occurs in one of the Victorian deposits believed to be of Oligocene age.

Cannosphaeropsis caulleryi with which one of the Victorian Oligocene types has been compared, was originally described from French Jurassic marls.

The Hystrichosphaerid population of the Australian Tertiary rocks is actually greater than is indicated by this account. Several varieties more difficult to place systematically have been purposely omitted.

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EXPLANATION OF PLATES

The photographs are the work of I. Cookson. All the figures are from untouched negatives.

Plate 1

Figs. 1, 2. *Botryococcus braunii*—A large colony in surface view and optical section. Werona, Victoria. x 800. P 15650*.
Fig. 3. *B. braunii*—A small colony showing connecting strands between daughter colonies. Lal Lal, bore 60 at 187 ft., Victoria. x 800. P 15655.
Fig. 4. *B. braunii*—A large group of loosely connected daughter colonies. Warlands Creek, New South Wales. x 600. P 15633.
Fig. 5. *B. braunii*—Anglesea, Victoria. x 400. P 15634.
Fig. 6. *B. braunii*—Side view of a four-celled group showing two of the cups. Warlands Creek. x 800.
Fig. 7. *Pediastrum boryanum*—An eight-celled colony. Cootabarlow Bore, South Australia. x 400. P 15646.
Figs. 8, 9. *P. boryanum*—Two sixteen-celled colonies. Cootabarlow. x 400. Fig. 8, P 15647.
Fig. 10. *P. boryanum*—A thirty-two-celled colony. Cootabarlow. x 400. P 15648.
Fig. 11. *P. boryanum*—An approximately sixty-four-celled colony. Cootabarlow. x 400. P 15649.
Fig. 12. *P. boryanum*—Marginal cells. Cootabarlow. x 800. P 15647.
Figs. 13, 14. *Hystrichosphaera furcata*—Surface view and optical section of a shell. Balcombe Bay, Victoria. x 400. P 15654.
Fig. 15. Portion of a shell of *H. furcata*. Gellibrand River, Victoria. x 400. P 15639.
Fig. 16. *H. furcata*. Anglesea, Victoria. x 400.
Fig. 17. *H. furcata*. Moyne River, Victoria. x 400. P 15652.
Fig. 18. A thick-walled hair from peat at South Ecklin, Victoria. x 400. P 15644.
Fig. 19. A cribellate pollen grain of chenopodiaceous type. Moyne River. x 600. P 15653.
Fig. 20. *?Hystrichosphaeridium* cf. *hirsutum* (Ehr.) Defl. Werona, Victoria. x 400. P 15651.

Plate II

Figs. 21, 22. *Hystrichosphaeridium truncigerum* in surface view and optical section. Gellibrand River. x 400. P 15639.
Fig. 23. Another shell of *H. truncigerum* showing a small appendage at *S.* Gellibrand River. x 400. P 15640.
Fig. 24. *Hystrichosphaeridium tubiferum.* Nelson Bore at 6192 ft., Victoria. x 400. P 15645.

*References so given are the registered numbers in the palaeontological collection of the National Museum.

Fig. 25. *Hystrichosphaeridium geometricum*. Gellibrand River. x 400. P 15640.

Figs. 26, 27. *Hystrichosphaeridium* sp. *a*.—Surface view and optical section. Balcombe Bay. x 400. P 15654.

Fig. 28. *H.* sp. *b*. Anglesea. x 400.

Figs. 29, 30. *H.* sp. *c*. Gellibrand River. x 400. P 15641.

Figs. 31, 32. *Micrhystridium* cf. *reticulatum*—Surface view and optical section of the same specimen. Gellibrand River. x 400.

Fig. 33. *M.* cf. *ambiguum*. Anglesea. x 400. P 15635.

Fig. 34. *Micrhystridium* sp. Gellibrand River. x 400. P 15642.

Fig. 35. *Cannosphaeropsis* cf. *caulleryi*. Gellibrand River. x 400. P 15643.

Fig. 36. *C.* cf. *caulleryi*. Another specimen from the Gellibrand River. x 400. P 15643.

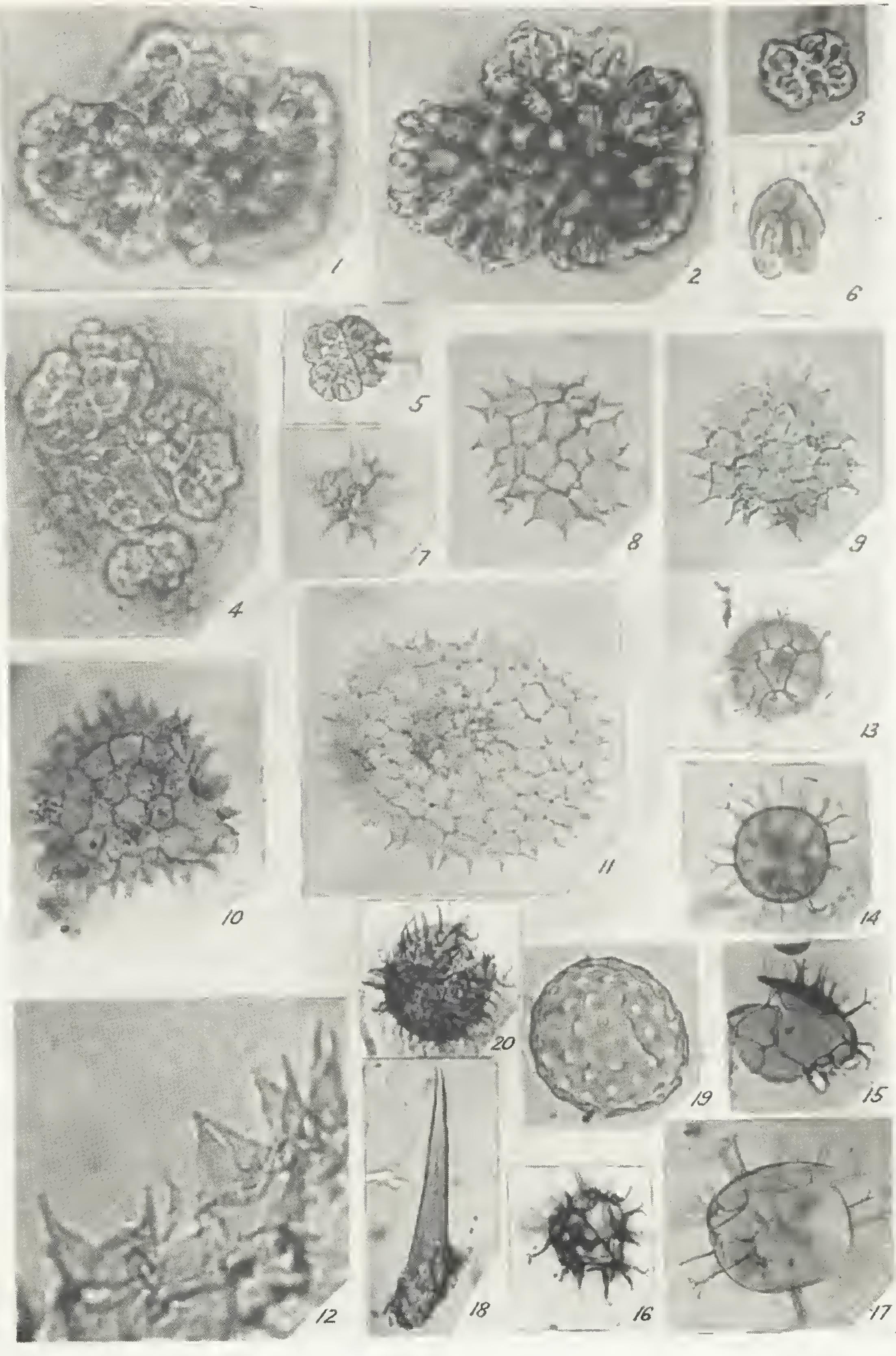
Fig. 37. *C.* cf. *caulleryi*. Anglesea. x 400. P 15636.

Figs. 38, 39. *C.* cf. *caulleryi*. Gellibrand River. x 400. P 15639.

Fig. 40. *C.* cf. *caulleryi*. Portion of outer network. x 800.

Figs. 41, 42. *Cannosphaeropsis urnaformis* n. sp. Surface view and optical section of the same specimen. x 400. P 15637.

Fig. 43. *C. urnaformis*. Portion of the shell of a second specimen showing the linking of two vase-shaped, perforated appendages by a short connecting strand. Anglesea. x 600. P 15638.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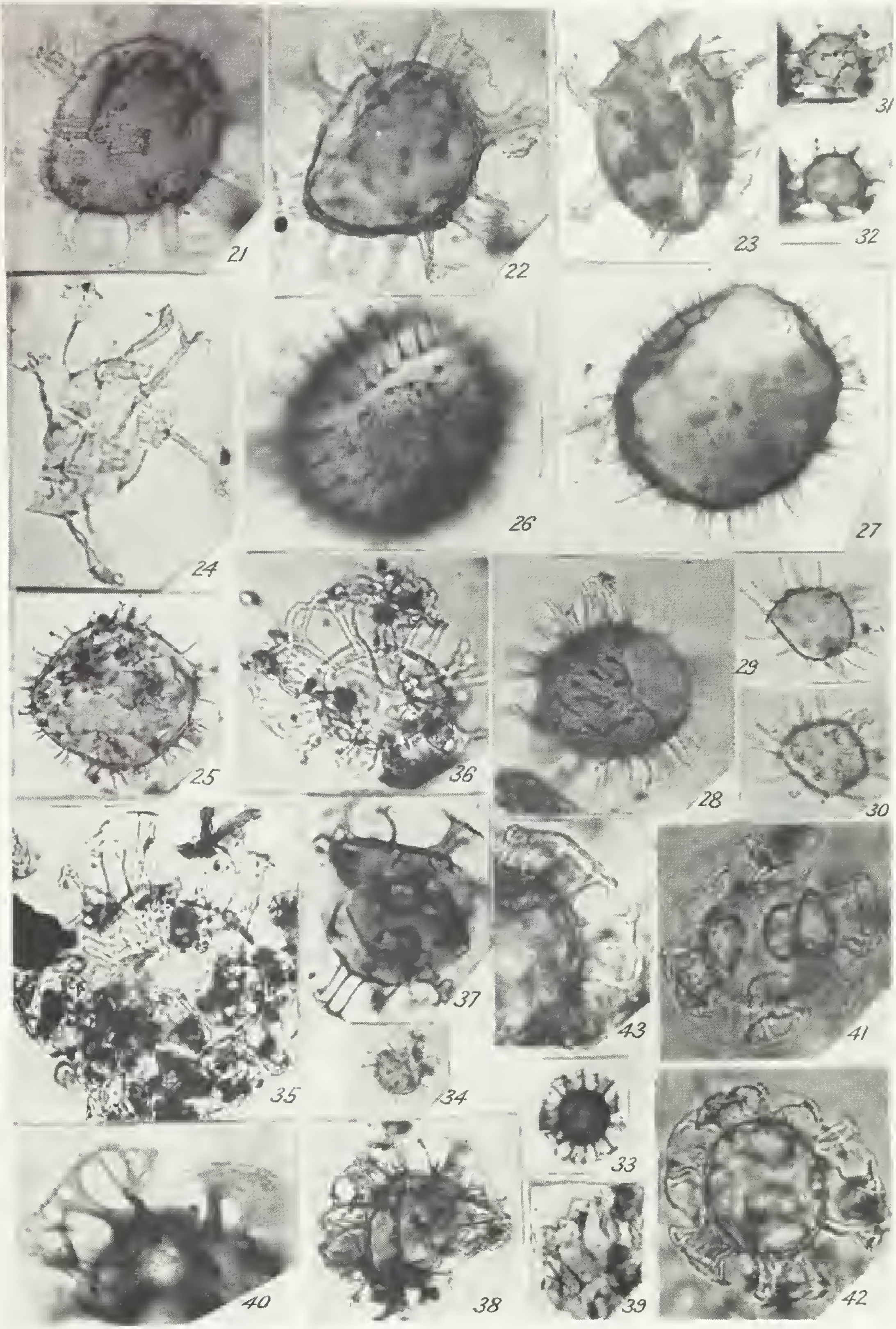
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