

Dinoflagellate Cysts in Recent Marine Sediments from Tasmania, Australia

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Abstract

Thirty-four cyst types capable of seeding plankton dinoflagellate populations have been identified in Tasmanian estuarine sediments. The most common cysts were those of *Gonyaulax grindleyi*, *G. spinifera*, *Gymnodinium catenatum*, *Gyrodinium* sp., *Polykrikos schwartzii*, *Protoperidinium conicum*, *P. pentagonum*, *P. subinermis*, *Scrippsiella* spp. and *Zygabikodinium lenticulatum*. Also common were ovoid to spherical *Alexandrium tamarense*-like cysts, which lack distinctive taxonomic features and mucilaginous covering. These latter cysts could only be identified by incubation experiments, which produced living cells of *Scrippsiella* (2 spp.), *Gyrodinium* sp. and *Alexandrium* cf. *excavatum*. While Tasmanian dinoflagellate cyst assemblages resemble those of New South Wales, Australia, and New Zealand, one notable difference is the cyst of the toxic dinoflagellate *Gymnodinium catenatum* which appears to be confined to south-eastern Tasmania.

Introduction

More than sixty species of marine plankton dinoflagellates produce a resistant resting cyst (hypnozygote) as part of their sexual life cycle (Dale 1983). Cysts formed in the plankton settle to the bottom and, when conditions are suitable, can germinate to seed motile, vegetative populations in the water column. Sporopollenin cyst walls can persist in the sediments, thereby providing an integrated record over time of the cyst-producing dinoflagellates. Fossilized 'dinocysts' are known from sedimentary deposits as far back as the Triassic (230 million years ago) and are extensively studied in the field of oil exploration. Surveys of these microfossils in sediments from across the mainland of Australia and Papua New Guinea have been carried out by, for example, Deflandre and Cookson (1955) (Mesozoic and Tertiary), Helby *et al.* (1987) (Mesozoic) and McMinn (1987, 1989) (Pleistocene). Information on Recent dinoflagellate cyst assemblages (*i.e.* from the last 100 years) from the Australasian region is found in studies by Baldwin (1987), Bint (1988) and McMinn (1990).

Some thirty out of the total of 1500 extant dinoflagellate species produce potent toxins that can find their way through shellfish to humans, causing gastrointestinal and neurological symptoms (paralytic shellfish poisoning, PSP). In estuaries of south-eastern Tasmania, Australia, the dinoflagellate *Gymnodinium catenatum* Graham has been responsible for a number of human poisonings. Blooms of this species were most extensive during summer/autumn 1986, leading to the temporary closure of up to fifteen shellfish farms (Hallegraef and Sumner 1986). *G. catenatum* produces a brown, spherical, resting cyst with microreticulate ornamentation (Anderson *et al.* 1988; Hallegraef *et al.* 1988b). Preliminary results (Hallegraef *et al.* 1989) showed that these cysts are widespread throughout the area affected by shellfish toxicity, but their Tasmania-wide distribution was not yet known. In the present study, we describe the species composition, abundance and distribution of Recent marine dinoflagellate cysts from coastal estuaries around Tasmania.

Material and Methods

Sediment sampling

Surface sediments were collected from 11 estuarine sites in Tasmania (Table I and Fig. 1). The choice of sampling sites was based on local hydrography, depth contours and sediment characteristics. Undisturbed, duplicate, sediment cores (10–20 cm long, 4.5 cm diameter) were obtained with a modified Craib corer (Craib 1965) and were stored in the dark at 4 °C until further examination.

Sediment preparation

The top 6–10 cm of sediment core was carefully extruded from the coring tube and mixed with filtered seawater to obtain a watery slurry. Subsamples (5–10 ml) were sonicated for 2 min (Braun Labsonic homogenizer, intermediate probe, 100 watts) to dislodge detritus particles. The sample was then screened through a 90 µm sieve and collected on to a 20 µm sieve and the remaining fraction was panned to remove denser sand grains and larger detritus particles. Sediment samples with low cyst concentrations were further concentrated by density gradient centrifugation using Ludox TM (Dupont Nemours) (Blanco 1986). Subsamples (1 ml) were counted in Sedgewick-Rafter chambers using a Zeiss light microscope and, where possible, a total number of at least 200 cysts were counted.

Microscopy

Cysts were photographed with a Zeiss Standard, Olympus Vanox or Zeiss Axioplan light microscope using bright field, phase contrast or differential interference contrast illumination. Cleaned cyst samples were dehydrated in increasing concentrations of acetone, collected on Nuclepore filters (2 µm) and critical-point dried from liquid CO₂. Portions of these

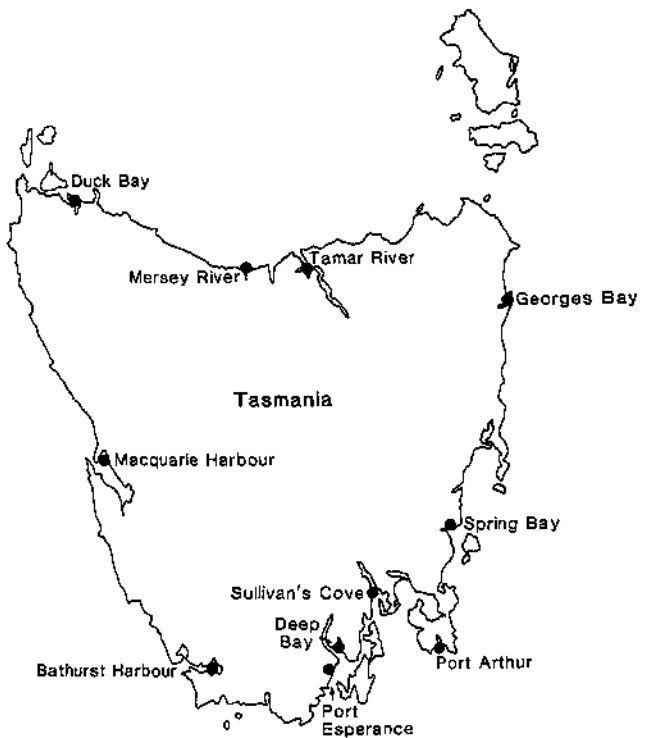
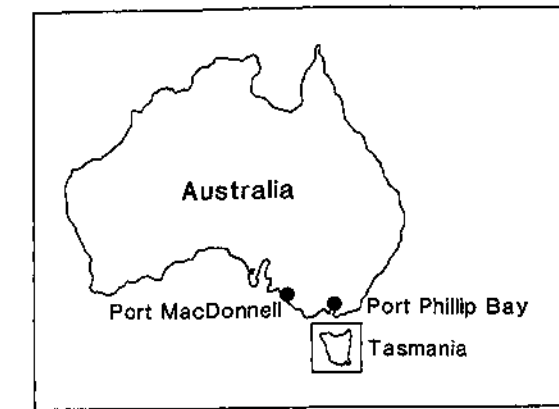


Fig. 1. Map of Australia (inset) showing the location of Tasmania and the sites where sediments were collected.

filters were mounted on aluminium stubs, sputter-coated with platinum and examined with a Philips 515 scanning electron microscope (SEM).

Table. I. Sites in Tasmania where sediments were collected and analysed for cysts.

Locality	Water depth (m)	Sampling date	Sediment type
1 Port Esperance	20	27 January 1988	brown mud/silt
2 Deep Bay (Huon River)	14	1 December 1987	black mud with shell grit
3 Sullivan's Cove (Derwent River)	8	22 June 1987	black mud
4 Port Arthur	13	13 October 1987	fine, black to grey mud
5 Spring Bay	18	27 August 1987	fine brown silt
6 Georges Bay	8	11 September 1987	fine brown mud
7 Tamar River	10	10 September 1987	fine brown mud
8 Mersey River	18	24 September 1987	fine brown mud
9 Duck Bay	4	24 September 1987	fine black mud
10 Macquarie Harbour	9	23 September 1987	brown mud
11 Bathurst Harbour	5	27 October 1987	brown silt with coarse mineral sand black mud with coarse organic detritus

Cyst germination experiments

Following sonication and size-fractionation, selected cyst types were isolated by micropipette under a Nikon Diaphot inverted microscope and then washed twice in filtered seawater. Individual cysts were placed into tissue culture wells containing 2 ml of 75% filtered seawater with nutrients added according to medium GPM of Loeblich (1975). Cysts were incubated at 17.5 °C at a light intensity of 80 $\mu\text{E m}^{-2} \text{s}^{-1}$ (12 h light: 12 h dark) and were examined regularly for germination.

Results

Systematics

Palaeontologists and biologists often use different names for the life history stages of the same dinoflagellate. Since the early 1960s germination experiments with Recent dinoflagellate cysts have been establishing cyst/theca relationships (Wall and Dale 1968, Lewis *et al.* 1984). In the present study, we use the biological names of species, where possible, with palaeontological synonyms indicated in brackets. In the following cyst descriptions we provide

- (1) references to illustrations in the literature;
- (2) a brief characterisation of Tasmanian specimens; and
- (3) an indication of the known distribution in the Australasian region.

Family Gonyaulacaceae

Gonyaulax grindleyi Reinecke Figs 2a–d
 Synonym: *Protoceratium reticulatum* Claparède *et* Lachmann

[Palaeontological taxon: *Operculodinium centrocarpum* (Deflandre *et* Cookson) Wall]

Wall and Dale 1968, figs 19–20; Matsuoka 1985b, plate 7, figs 1–6.

Spherical to ovoidal cyst (27 to 30 μm diameter) with numerous randomly oriented processes (up to 12 μm long) (Fig. 2a). These processes are erect, slender to stout, and have variable morphology (compare Figs 2b and 2c). The proximal part of the process shaft is somewhat expanded and has a strand-like appearance. The distal part of the process is closed and may be bifid, many-branched or flared (Fig. 2d). Some cysts had unusually wide and sometimes partially fused processes (Fig. 2c), which have not been reported previously. The precingular archeopyle is mid-dorsally placed and trapezoidal in outline.

This was the most abundant cyst type at many Tasmanian sites examined. None was successfully germinated. This species is also common in Recent and Pleistocene (100 000 years old) marine sediments from New South Wales, Australia (McMinn 1989, 1990), and in Recent marine sediments from New Zealand (Baldwin 1987). It is also known from the Miocene (20 million years old) of Victoria (Deflandre and Cookson 1955).

Gonyaulax spinifera (Claparède *et* Lachmann) Diesing

Cultures belonging to this dinoflagellate can produce different cyst types, presumably in response to different environmental conditions (Taylor and Gaines 1989). Four types were encountered in Tasmanian sediments, of which only *Spiniferites membranaceus* and *Spiniferites mirabilis* were easily identifiable.

[Palaeontological taxon: *Spiniferites membranaceus* (Rossignol) Sarjeant] Figs 3a–c

Reid 1974, figs 28–30.

Highly variable, spherical to ovoidal cyst (38 to 42 μm long, 35 to 38 μm wide), with membranous processes particularly at the antapical and paracingulum regions (Fig. 3b). These processes are generally trifurcate with bifid tips (Fig. 3c). The archeopyle is approximately trapezoidal in outline (Fig. 3b).

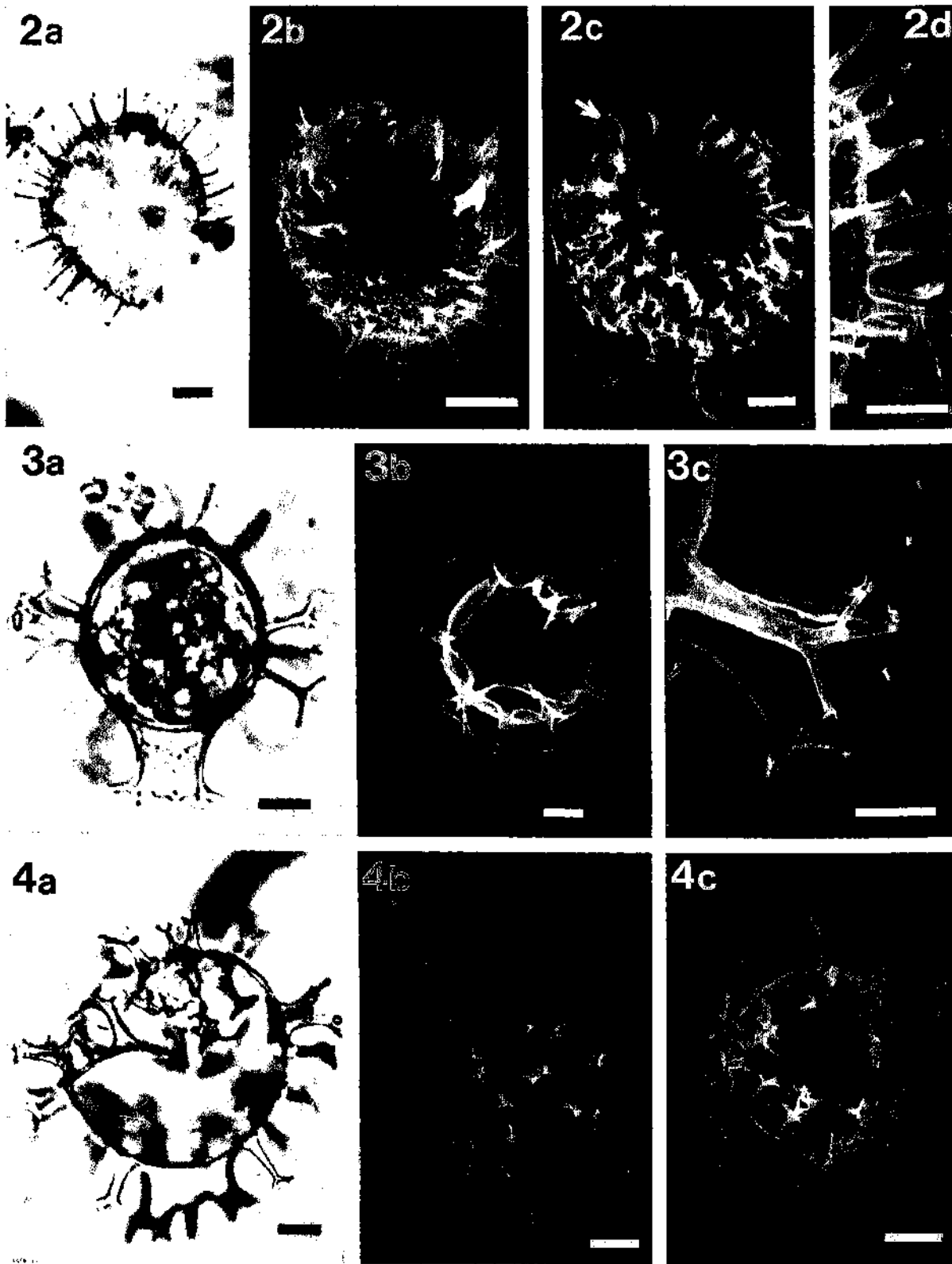
This cyst type was widespread and common at all Tasmanian sites examined. None were successfully germinated. It is also known from Recent sediments from New South Wales (McMinn 1989, 1990).

[Palaeontological taxon: *Spiniferites mirabilis* (Rossignol) Sarjeant] Figs 4a–c

Wall and Dale 1968, plate 1, fig. 10.

Large, spherical to ovoidal cyst (60 μm long, 52 to 58 μm wide) with indistinct tabulation (Fig. 4b). The processes are tubular and conical, branching into fairly broad distal tips with Y-shaped extremities (Fig. 4b). The distinctive antapical flange consists of the sutural lists of plate 1^{'''} drawn out into a tubular process that splits into a number of small tubular extensions similar to those elsewhere on the cyst surface. The archeopyle is precingular (Fig. 4c).

This cyst type was common in southeast Tasmanian sediments; none had contents, therefore germination experiments could not be carried out. It is also known from Recent and Pleistocene marine sediments from New South Wales (McMinn 1989, 1990) and from Recent marine sediments from New Zealand (Baldwin 1987).



Figs 2-4. Gonyaulacoid dinoflagellates.

Fig. 2. Cyst of *Gonyaulax grindleyi*. Fig. 2a. LM. Cyst showing numerous randomly oriented processes; Port Esperance. Fig. 2b, c. SEM. Cysts showing variation in process morphology; Sullivan's Cove. Fig. 2c. SEM. Atypical cyst type with short, unusually wide and partially fused processes (arrow). Fig. 2d. SEM. Detail of processes showing the many-branched or flared terminations. Fig. 3, 4. Cysts of *Gonyaulax spinifera*. Fig. 3. Palaeontological taxon *Spiniferites membranaceus*. Fig. 3a. LM. Cyst showing cell contents; Spring Bay. Fig. 3b. SEM. Dorsal view of cyst showing the precingular archeopyle, distinct paratabulation and flange-like antapical process; Sullivan's Cove. Fig. 3c. SEM. Detail of furcate processes with bifid tips. Fig. 4. Palaeontological taxon *Spiniferites mirabilis*. Fig. 4a. LM. Empty cyst from Deep Bay. Fig. 4b. SEM. Ventral view of cyst showing the tubular, conical processes with branched tips and the indistinct paratabulation; Sullivan's Cove. Fig. 4c. SEM. Dorsal view of cyst with precingular archeopyle; Sullivan's Cove.

All scale bars 10 µm, except Fig. 2d (5 µm).

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Gonyaulax scrippsae Kofoid Fig 5
[Palaeontological taxon: *Spiniferites bulloideus* (De-
flandre *et* Cookson) Sarjeant]

Reid 1974, figs 17–19.

Ovoidal cyst (35–40 µm long, 30–35 µm wide) with simple, relatively long, processes which are trifurcate with distinct bifid tips. The junction of plates 4'' and 1''' has a characteristic geminal process with well developed columnar stems which expand into trumpet-shaped or multifurcate tips. A dorsal precingular archeopyle is present. There is confusion in the literature as to the circumscription of *Spiniferites bulloideus* (compare Harland 1983 and Reid 1974); our specimens agree with Reid's (1974) interpretation of this taxon. McMinn (1990) reported *S. bulloideus* as the most abundant *Spiniferites* species from New South Wales, Australia.

This cyst was present at three sites on the east and north coasts of Tasmania. None was successfully germinated.

Gonyaulax sp. 1 Figs 6a, b

Elongate to ovoidal cyst (40 to 46 µm long, 30 to 34 µm wide) with the epicyst generally more conical than the hypocyst. The cyst is tabulate with the reflected plate areas delimited by low ridges. The processes vary in morphology from conical to tapering, and terminate in bifid or trifid, closed tips. The dorsal precingular archeopyle (Fig. 6b) is often distinctly pentagonal in outline.

This cyst species differs from *Spiniferites bulloideus* by its larger size, elongated shape and absence of a geminal process. It resembles *Spiniferites bentori* (Rosignol) Wall *et* Dale except for the conspicuous absence of an apical boss, and compares favourably with *Spiniferites* cf. *elongatus* Reid of Harland and Sharp (1986; figs 9–16). A similar taxon has been recorded from New South Wales estuaries (McMinn 1990, plate 2, figs 10, 14). This cyst was widespread in Tasmanian marine sediments. None was successfully germinated.

Alexandrium cf. *tamarensis* (Lebour) Balech Fig. 7

Anderson and Wall 1978, figs 22–33; Dale 1977, figs 1a–c; Fukuyo 1985, figs 2o–p.

Elongate, ellipsoidal cyst (35–40 µm long) with rounded ends. The cyst wall is thick and covered with an amorphous, transparent, mucilaginous substance which may incorporate fine detrital particles. The cyst contains pale or colourless starch granules, light-brown lipid globules, and one or two bright-orange accumulation bodies.

In Tasmania, two specimens were found in Mersey River sediments; none were successfully germinated. Similar cysts have now been recorded in the Australian region from Port Phillip Bay, Melbourne associated with a bloom of *Alexandrium catenella* (Whedon *et* Kofoid) Balech and from Port MacDonnell, South Australia, associated with a bloom of *A. cf. tamarensis* (Figs 8 and 9; see Hallegraef *et al.*, 1988b; unpublished). A detailed taxonomic account of *Alexandrium* species in the Australian region will be published elsewhere.

Alexandrium cf. *excavatum* (Braarud) Balech *et* Tangen Figs 10a–e

Spherical cyst (28–30 µm diameter), with clear yellowish contents and an indistinct accumulation body (Fig. 10a). This cyst type was successfully isolated and cultured from Tamar estuary sediments and similar spherical cysts were found in Georges Bay sediments. Germination occurs through a small breach in the cell wall (Fig. 10b) and results in small (25 µm diameter) dinoflagellate cells with thecae with well-defined shoulders (Fig. 10c), a ventral pore in the first apical plate (Fig. 10d), and a concave antapical region (Fig. 10e). They correspond with the description of *Alexandrium excavatum* (sensu Balech 1985, fig. 21). This spherical cyst type is distinct from the oval mucoid cyst described for this species by Dale (1977). A similar spherical cyst has been described for *Alexandrium* (*Protogonyaulax*) *affine* (Inoue *et* Fukuyo) Balech by Fukuyo *et al.* (1985).

Family Peridiniaceae

Scrippsiella trochoidea (Stein) Loeblich III

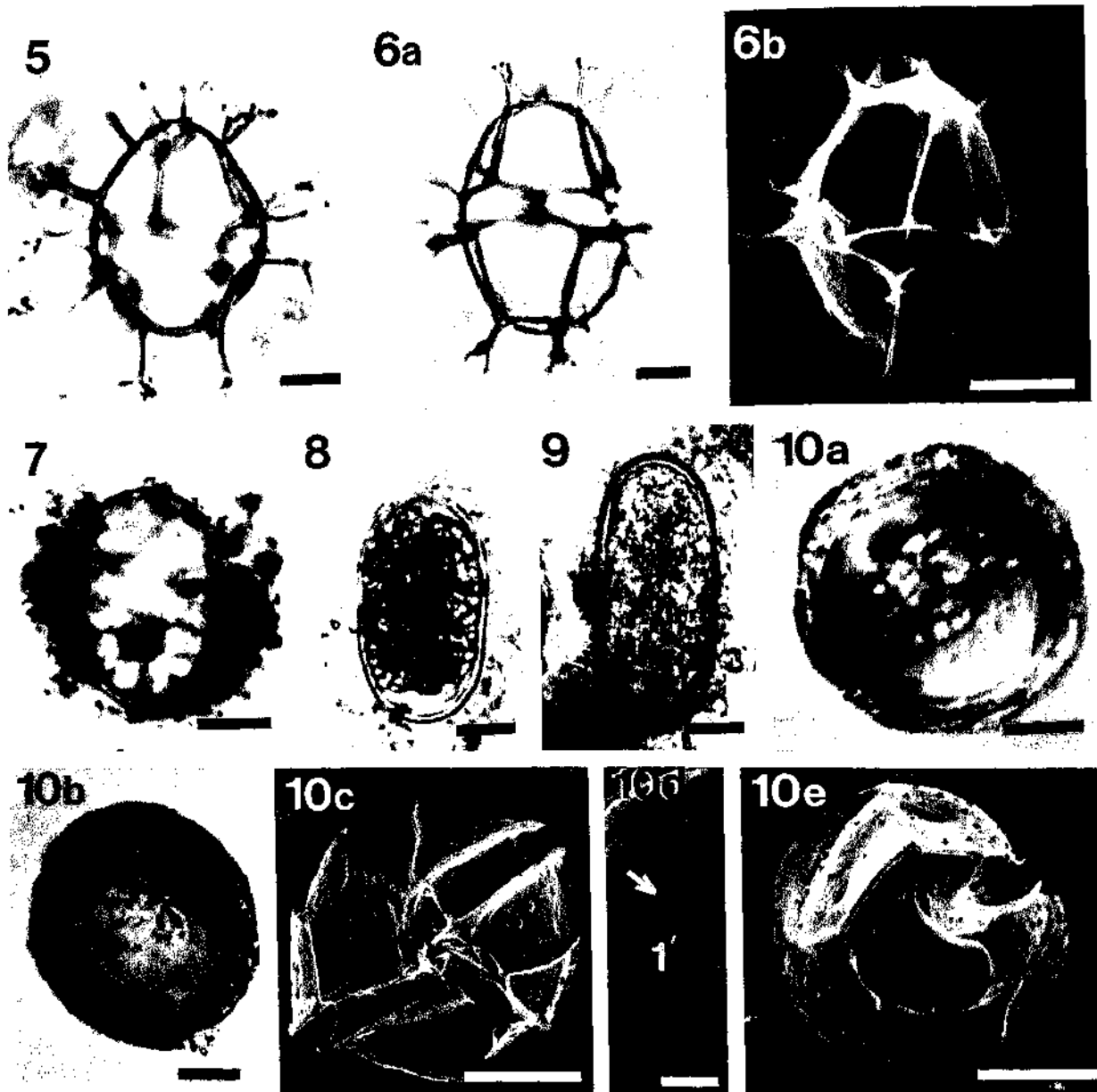
Figs 11a–f

Synonym: *Peridinium trochoideum* (Stein) Lemmermann

Wall *et al.*, 1970, figs 1–10

Highly variable ovoid to spherical (Figs 11a–c), dark greyish-coloured cyst (33 to 40 µm long) covered by more than fifty calcareous spines up to 10 µm long. These spines have expanded hexagonal bases which overlap on the cyst body (Fig. 11d). The spine shafts consist of crystalline rods which terminate in blunt, capitate or pointed ends (Fig. 11d). A thecophytic archeopyle (Matsuoka 1985a) is present in the epicyst and a bright red accumulation body is often visible.

One cyst was successfully germinated to produce a typical *Scrippsiella trochoidea* motile cell identical to those in the local plankton (Fig. 11f). This calcareous cyst was widespread and common in all Tasmanian sediments, where it co-occurred with the following non-calcareous cyst types.

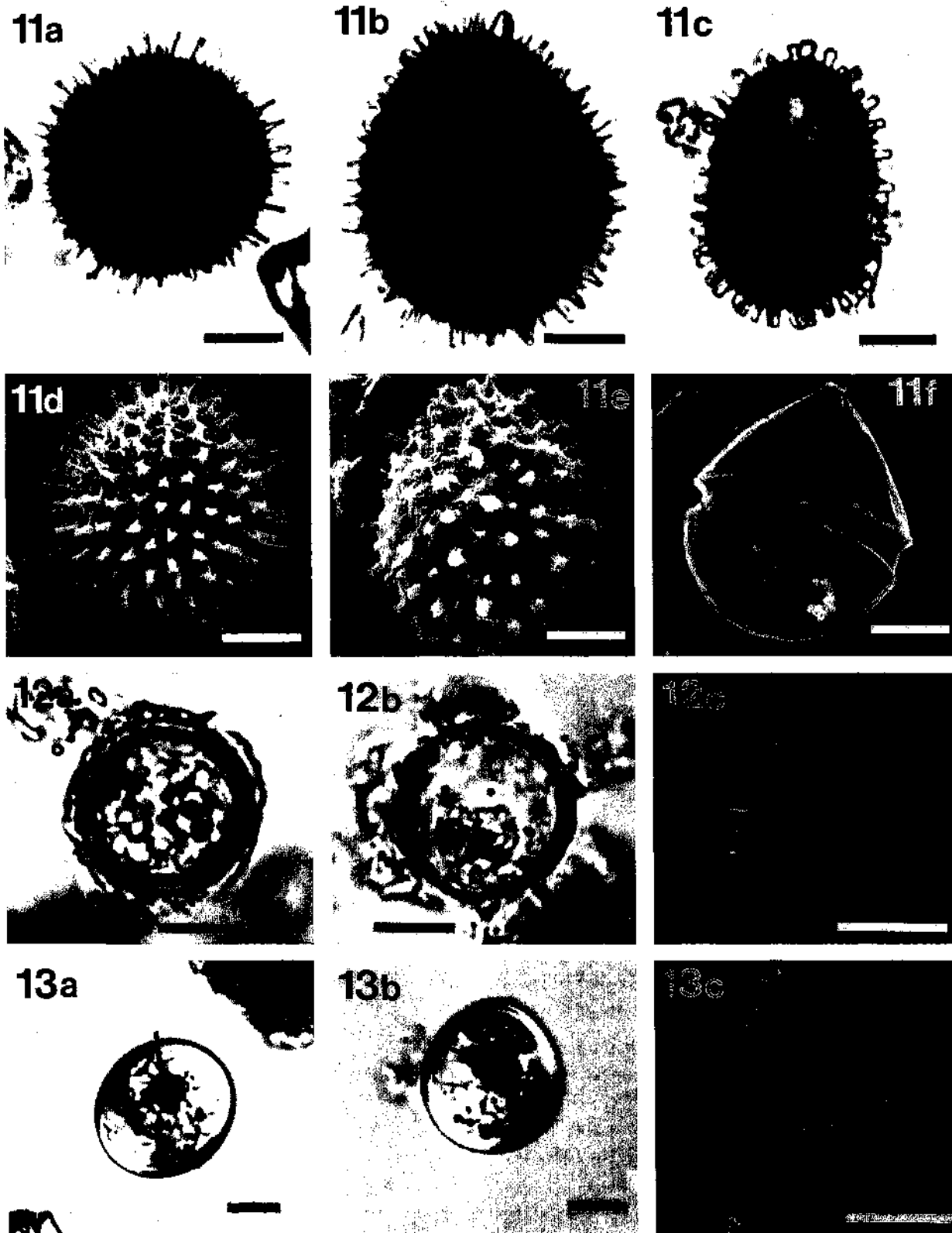


Figs 5–10. Gonyaulacoid dinoflagellates.

Fig. 5. LM. Cyst of *Gonyaulax scrippsae* showing characteristic geminal process with well-developed columnar stems; Port Arthur. Fig. 6. *Gonyaulax* sp. 1. Fig. 6a. LM. Dorsal view of cyst showing ovoid, elongate shape and well defined paratabulation; Spring Bay. Fig. 6b. SEM. Dorsal view of cyst showing the roughly trapezoidal precingular archeopyle and granular appearance of cyst wall. Note absence of apical boss; Spring Bay. Fig. 7. LM. Mucoid cyst of *Alexandrium* cf. *tamarensis* group from the Mersey River. Fig. 8. Cyst from sediments of Port Phillip Bay, Victoria, associated with mixed blooms of *Alexandrium catenella* and *Alexandrium fundyense*. Fig. 9. LM. Cylindrical cyst from a plankton sample from Port MacDonnell, South Australia, associated with a bloom of *Alexandrium* cf. *tamarensis*. Fig. 10. *Alexandrium* cf. *excavatum*. Fig. 10a. Cyst from the Tamar River, showing cell contents. Fig. 10b. Same cyst as in Fig. 10a following germination. Note breach in cyst wall through which excystment occurred (arrow). Fig. 10c. SEM. Ventral view of motile dinoflagellate cell cultured from the cyst shown in Fig. 10a. Fig. 10d. SEM. Detail of first apical plate, which touches the apical pore complex, and which has a ventral pore (arrow). Fig. 10e. SEM. Antapical view of dinoflagellate cell from the same culture. All scale bars 10 μ m, except Fig. 10d (5 μ m).

Figs 11–13. *Scripsiella* spp.

Fig. 11. *S. trochoidea*/Figs 11a–c. LM. Calcareous cysts showing variation in size, shape and process morphology; Port Arthur. Fig. 11d. SEM. Cyst showing crystalline processes with overlapping hexagonal bases; Port Arthur. Fig. 11e. SEM. Cyst with short blunt processes; Port Arthur. Fig. 11f. SEM. Typical motile form of *S. trochoidea* from the Derwent River. Fig. 12. *Scripsiella* sp. 1. Fig. 12a. LM. Cyst showing irregular granular material covering the cyst wall; Port Arthur. Fig.



12b. LM. Empty cyst showing clear cyst wall; Port Arthur. Fig. 12c. SEM. Ventral view of small, motile *Scrippsiella*-like dinoflagellate cell cultured from this cyst-type. Fig. 13. *Scrippsiella* sp. 2. Figs 13a, b. LM. Intact cysts showing the bright-red accumulation body, (arrows) and smooth non-mucoid cyst wall; Duck Bay. Fig. 13c. SEM. Motile *Scrippsiella*-like dinoflagellate cell cultured from this cyst type. All scale bars 10 μ m.

Scrippsiella sp. 1

Figs 12a–c

Spherical cysts (20–25 µm diameter) with pale contents and pale-orange accumulation body sometimes present. The cyst wall is clear (Fig. 12b) and is often covered with irregular, granular material (Fig. 12a), which may represent rudimentary calcification or mucilage.

This cyst was common in most Tasmanian sediments. Four specimens were successfully germinated into viable *Scrippsiella*-like cultures (Fig. 12c). Previously, a similar clear cyst type was described from uni-algal *Scrippsiella trochoidea* cultures (Braarud 1958, plate II, fig. f.; Wall *et al.* 1970, fig. 3; Watanabe *et al.* 1982, fig. 26).

Scrippsiella sp. 2

Figs 13a–c

Subspherical to ovoid cysts (20–25 µm diameter) with clear contents and a bright, ruby-red accumulation body (Figs 13a, b). The cyst wall is relatively thin and clear (Figs 13a, b), with germination occurring through a slit-like archeopyle. Three specimens were successfully germinated into viable *Scrippsiella*-like cultures (Fig. 13c).

This was the dominant cyst type at Duck Bay (> 70% of total cysts) and was also found at Georges Bay.

Protoperidinium conicum (Gran) Balech Figs 14a–c
[Palaeontological taxon: *Selenopemphix quanta* (Bradford) Matsuoka]

Matsuoka 1985b, plate 11.

Ovoidal to kidney-shaped, apically/antapically compressed, spinose cyst (32 to 52 µm diameter) with offset intercalary archeopyle (Fig. 14b). The cyst wall is smooth and ornamented by several parallel rows of moderately long (up to 15 µm) needle-shaped spines (Fig. 14a). Two rows of spines outline the girdle zone.

This was the most common *Protoperidinium* cyst type in Tasmanian sediments. Three specimens were germinated to produce typical *P. conicum* cells (Fig. 14c). This species is also known from Recent and Pleistocene sediments from New South Wales (McMinn

1987, 1989) and from Recent sediments from New Zealand (Baldwin 1987).

Protoperidinium pentagonum (Gran) Balech Fig. 15
[Palaeontological taxon: *Trinovantedinium capitatum* Reid]

Matsuoka 1985b, plate 9, 10.

Pentagonal, dorso-ventrally compressed, colourless cyst of peridinioid shape (69 to 72 µm long). This cyst is covered by short, rigid, needle-shaped processes, often with capitate solid tips. The broad hexagonal archeopyle is formed by the loss of the 2a paraplate. The epicyst has an apical boss and the hypocyst has two antapical horns of variable morphology.

This was the second most abundant and widespread *Protoperidinium* cyst type in Tasmanian sediments, and is also known from Recent sediments from New South Wales (McMinn 1990) and New Zealand (Baldwin 1987). None was successfully germinated.

Protoperidinium subinerme (Paulsen) Loeblich III

Figs 16a–c

[Palaeontological taxon: *Selenopemphix alticinctum* (Bradford) Matsuoka]

Matsuoka 1982, plate 1, figs 5, 8.

Ovoidal to kidney-shaped (Fig. 16c), light brown cyst (40 to 51 µm diameter) with smooth surface and no spines. The apically/antapically compressed cyst has a deeply excavated girdle (Fig. 16b) and an offset, standard "hexa", intercalary archeopyle (Fig. 16a). This cyst type is different from the round brown cyst described for *Protoperidinium subinerme* by Lewis *et al.* (1984).

This was the third most abundant and widespread *Protoperidinium* cyst type in Tasmanian sediments. It is also known from New Zealand (Baldwin 1987). None was successfully germinated.

Protoperidinium cf. avellana (Meunier) Balech

Fig. 17

[Palaeontological taxon: *Brigantedinium cariacense* (Wall) Reid]

Figs 14–24. Peridinioid dinoflagellate cysts.

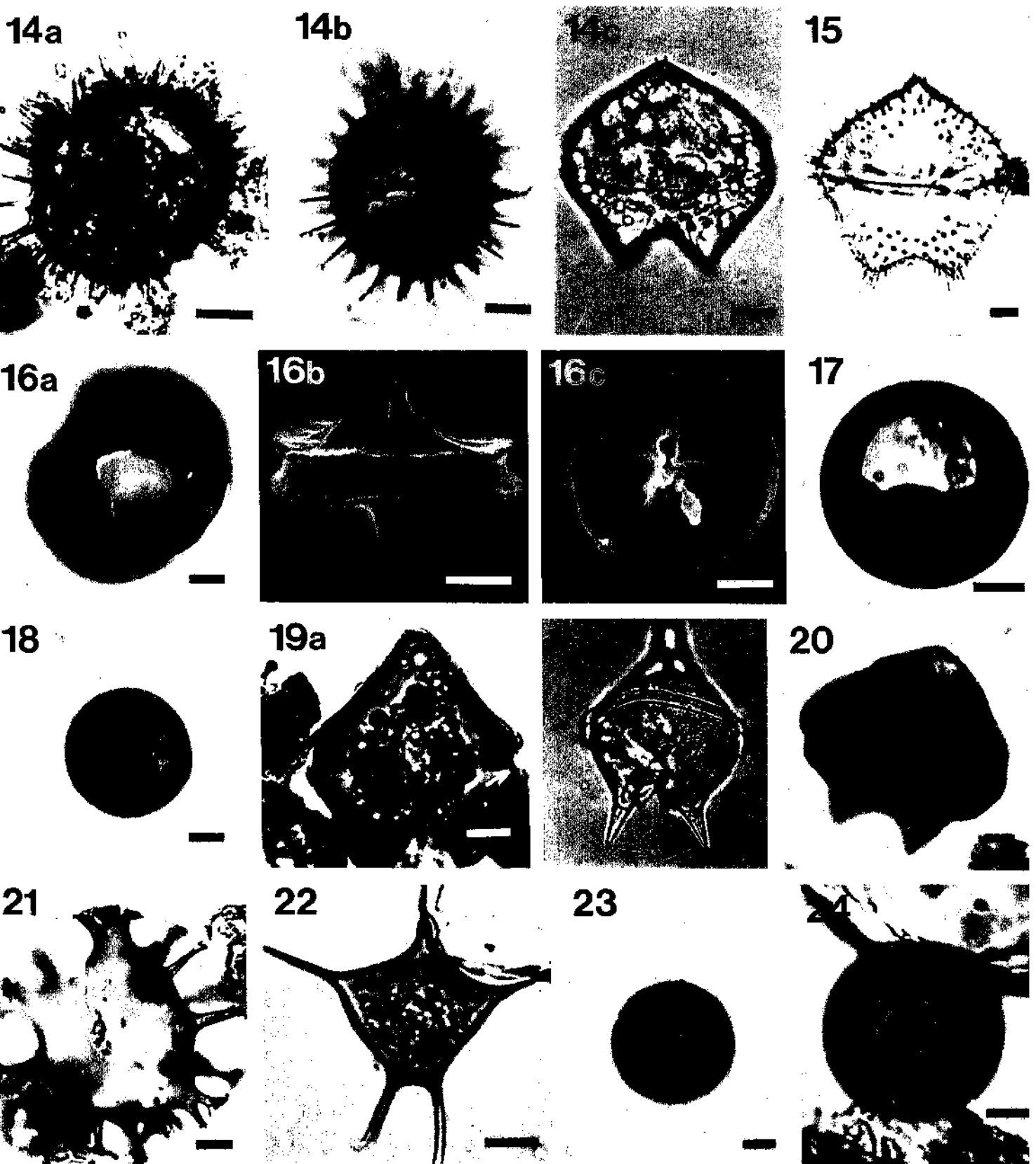
Fig. 14. *Protoperidinium conicum*. Fig. 14a. LM. Cyst with dark, globular contents and needle-shaped spines; Port Arthur. Fig. 14b. LM. Empty cyst showing the offset, intercalary archeopyle; Port Arthur. Fig. 14c. LM. Motile dinoflagellate cell germinated from this cyst type. Fig. 15. LM. Pentagonal, dorso-ventrally compressed, spinose cyst of *Protoperidinium pentagonum*; Port Esperance. Fig. 16. *Protoperidinium subinerme*. Fig. 16a. LM. Cyst showing the offset, intercalary archeopyle; Port Esperance. Fig. 16b. SEM. Lateral view of apically/antapically compressed cyst showing the deeply excavated girdle. Fig. 16c. SEM. Apical view of cyst showing the ovoidal to kidney-shaped outline and intact operculum (op). Fig. 17. LM. Cyst of *Protoperidinium cf. avellana* with laterally elongate, symmetrical archeopyle; Georges Bay. Fig. 18. LM. Cyst of *Protoperidinium cf. punctulatum* showing the large, asymmetrical archeopyle; Sullivan's Cove. Fig. 19. *Protoperidinium oblongum*. Fig. 19a. LM. Cyst showing unusual girdle inflection (arrow); Port Arthur. Fig. 19b. LM. Motile dinoflagellate cell with two longitudinal flagella (arrows),

14a

16a

18

21



germinated from this cyst type. Fig. 20. LM. Cyst of *Protoperidinium leonis* with epicystal shoulders and hypocystal horns; Mersey River. Fig. 21. LM. Cyst of *Protoperidinium divaricatum* showing hollow, tubular processes with multifurcate extensions; Georges Bay. Fig. 22. LM. Stellate cyst of *Protoperidinium compressum*; Sullivan's Cove. Fig. 23. LM. Cyst of *Protoperidinium* cf. *denticulatum* with hexagonal, laterally elongated archeopyle; Sullivan's Cove. Fig. 24. LM. Cyst of *Protoperidinium* sp. 1 showing the lunate, two intercalary plate, archeopyle; Port Esperance. All scale bars 10 μ m.

Harland 1982, plate 38, figs 4–9, text fig. 7b.

Brown spherical cyst (40 to 43 μm diameter) with smooth surface. The distinctive intercalary archeopyle is laterally elongate and symmetrical, and reflects the loss of paraplate 2a.

This cyst type was common at Georges Bay (east coast of Tasmania) but was rare elsewhere. It is also known from Port Hacking, New South Wales (Dale and Hallegraef, unpublished data). None was successfully germinated.

Protoperidinium cf. *punctulatum* (Paulsen) Balech Fig. 18

Harland 1982, text fig. 17; Harland 1983, plate 47, fig. 1.

Brown spherical cyst (34 to 45 μm diameter) with large, asymmetrical, intercalary archeopyle formed by the loss of paraplate 2a. The asymmetrical archeopyle distinguishes this cyst type from those of *P. denticulatum* (Gran et Braarud) Balech and *P. avellana*.

This cyst type was encountered at four sites scattered along the Tasmanian coast; none was successfully germinated.

Protoperidinium oblongum (Aurivillius) Balech Figs 19a, b
[Palaeontological taxon: *Votadinium calvum* Reid]

Wall and Dale 1968, plate 1, figs 22–29.

Smooth, light brown, dorso-ventrally compressed cyst (55 to 62 μm long) with rounded apices and without spines. A clear girdle inflection (Fig. 19a), which is unusual for this cyst type, could be seen on most specimens. The broad and large archeopyle appears to reach the apex of the cyst on the dorsal surface, thus giving the cyst a truncate appearance.

This cyst type was widespread in Tasmanian sediments. Two specimens were successfully germinated to yield pinkish, longitudinally biflagellate cells (planomeiocytes) with typical *P. oblongum* morphology (Fig. 19b).

Protoperidinium leonis (Pavillard) Balech Fig. 20
[Palaeontological taxon: *Quinquecuspis concretum* (Reid) Harland]

Lewis et al. 1984, plate 2, fig. 3.

Roughly pentagonal, light brown cyst (68 to 85 μm long) with smooth or somewhat granular surface. The epicyst may be conical or have shoulders, while the hypocyst carries two horns of variable morphology. The archeopyle is roughly trapezoidal in outline.

Thus far this species has been found only at two sites on the north coast of Tasmania. It is also known from Recent and Pleistocene sediments from New South Wales (McMinn 1989, 1990) and from Recent sediments from New Zealand (Baldwin 1987). None was successfully germinated.

Protoperidinium divaricatum (Meunier) Balech Fig. 21
[Palaeontological taxon: *Xandarodinium xanthum* Reid]

Matsuoka 1982, plate 1, fig. 4.

Elliptical to peridinioid shaped cyst (46–50 μm diameter) with irregular outline formed by the extension of the wall into hollow tubular processes. These processes open to the internal cavity of the cyst body and are terminated by multifurcate extensions, which are closed distally. This cyst is a characteristic opaque, pale brown which readily distinguishes it from spinose gonyaulacoid cysts which are generally colourless.

This species was only found in Georges Bay (East Tasmania) sediments. None had contents, therefore germination experiments could not be carried out.

Protoperidinium compressum (Abé) Balech Fig. 22
[Palaeontological taxon: *Stelladinium stellatum* (Wall) Reid]

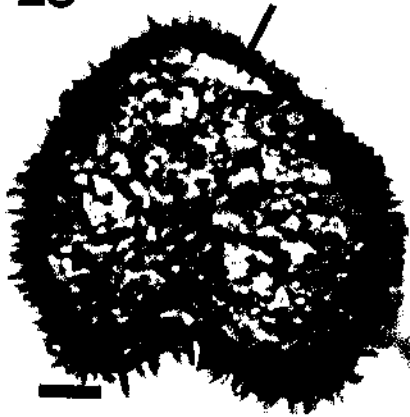
Harland 1982, plate 39, fig. 12; Matsuoka 1982, plate 1, fig. 1.

Figs 25–31. Peridinioid dinoflagellate cysts.

Fig. 25. LM. Heart-shaped cyst of *Protoperidinium claudicans*, showing the subapical archeopyle that truncates the apex (arrow); Spring Bay. Fig. 26. LM. Cyst of *Protoperidinium conicoides* with distinctive, large, trapezoidal archeopyle; Sullivan's Cove. Fig. 27. LM. Cyst of *Protoperidinium* cf. *minutum* showing the numerous slender, curved spines; Georges Bay. Fig. 28. *Protoperidinium* sp. 2. Fig. 28a. LM. Discoid cyst showing the slightly asymmetrical, sub-circular outline; Tamar River. Fig. 28b. LM. Same cyst showing the concave shape in lateral view. Fig. 29. *Protoperidinium* cf. *americanum*. Fig. 29a. LM. Cyst from Port Arthur showing the irregular folds of the outer membrane (arrow). Fig. 29b. LM. Same cyst showing granular inner wall and clover-shaped arrangement of the opercular paraplates (arrows). Fig. 30. *Zygabikodinium lenticulatum*. Fig. 30a. LM. Apical view of lenticular, brown cyst; Port Arthur. Fig. 30b. LM. Lateral view of motile dinoflagellate cell germinated from this cyst type. Fig. 31. *Diplopelta parva*. Fig. 31a. LM. Cyst with numerous non-tabular spines; Port Arthur. Fig. 31b. LM. Cyst showing polygonal, apical archeopyle and attached operculum; Spring Bay. Fig. 31c. LM. Motile dinoflagellate cell germinated from this cyst type.

All scale bars 10 μm .

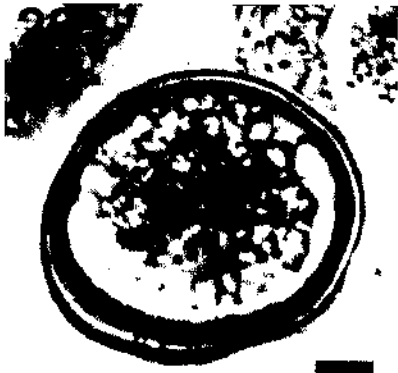
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26



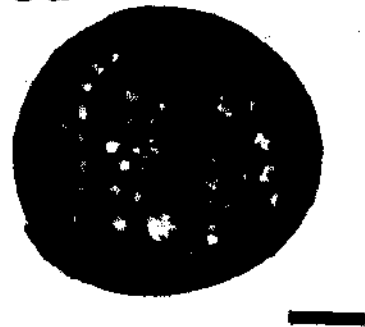
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29a



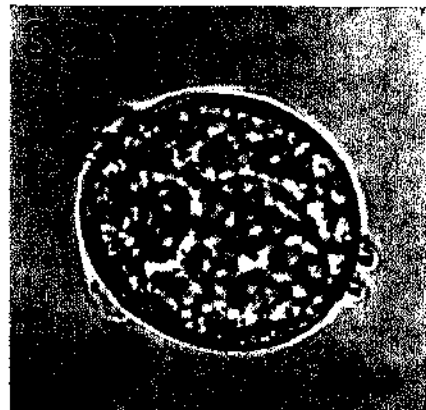
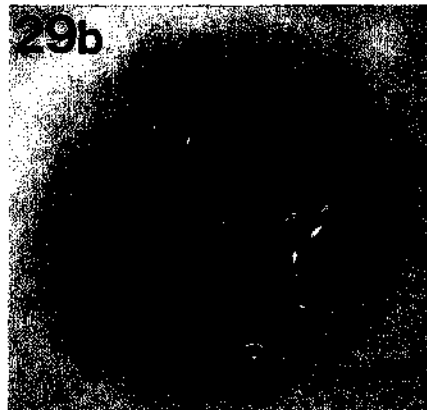
30a



28b



29b



31a



31b



Dorso-ventrally compressed cyst (34 μm long, excluding horns) with unique stellate morphology. The cyst wall is smooth and the epicyst is smaller than the hypocyst. The cyst carries one apical, two antapical and two lateral horns, which are long (up to 20 μm), solid and needle-shaped. A two-paraplate, intercalary archeopyle is present.

This species was only found at two Tasmanian sites, and is also known from Recent sediments from New South Wales (McMinn 1990) and New Zealand (Baldwin 1987). None was successfully germinated.

Protoperidinium cf. *denticulatum* (Gran et Braarud) Balech Fig. 23

Harland 1982, text fig. 7a.

Brown spherical cyst (40–43 μm diameter) with a hexagonal, laterally elongated archeopyle formed by the loss of the 2a intercalary paraplate.

This cyst was found only at Spring Bay and in the Tamar estuary. None was successfully germinated.

Protoperidinium sp. 1 Fig. 24

Brown, spherical cyst (36 to 38 μm diameter) with very long, lunate-shaped, symmetrical archeopyle, possibly formed by the loss of the two intercalary paraplates 1a and 2a [not one intercalary paraplate as described for *P. denticulatum* by Harland 1982].

This cyst type was only found at two sites in south east Tasmania. One specimen was successfully germinated to produce a two-celled chain closely resembling the dinoflagellate *P. denticulatum*.

Protoperidinium claudicans (Paulsen) Balech Fig. 25 [Palaeontological taxon: *Votadinium spinosum* Reid]

Wall and Dale 1968, plate 2, figs 1–2.

Heart-shaped cyst (57 μm long) with numerous short-pointed spines (2–4 μm long). The archeopyle is formed by the loss of a 2a intercalary paraplate, which is subapical in position and truncates the apex.

This species was only found at Spring Bay. It is also known from Port River, Adelaide, South Australia (Dale and Hallegraef, unpublished data). None was successfully germinated.

Protoperidinium conicoides (Paulsen) Balech Fig. 26 [Palaeontological taxon: *Brigantedinium simplex* (Wall) Reid]

Wall and Dale 1968, plate 2, fig. 29.

Brown spherical cyst (35 to 40 μm diameter) with smooth or granular surface. The distinctive large intercalary archeopyle is trapezoidal in outline and may be composed of 1 or 2 intercalary paraplates.

This cold-water cyst type was only found at two Tasmanian sites and is also known from New Zealand (Baldwin 1987). None was successfully germinated.

Protoperidinium cf. *minutum* (Kofoid) Loeblich Fig. 27

Fukuyo et al. 1977, figs 2a, b.

Spherical, purple-brown cyst (23–28 μm diameter) with numerous slender, curved spines. This cyst type resembles *Operculodinium centrocarpum* but differs in its size, colour and possession of an intercalary archeopyle. This cyst is distinct from that described for this species by Wall and Dale (1968) (plate 4, figs 6–7).

Only two specimens were found in Georges Bay sediments; none had contents, therefore germination experiments could not be carried out.

Protoperidinium sp. 2 Figs 28a, b

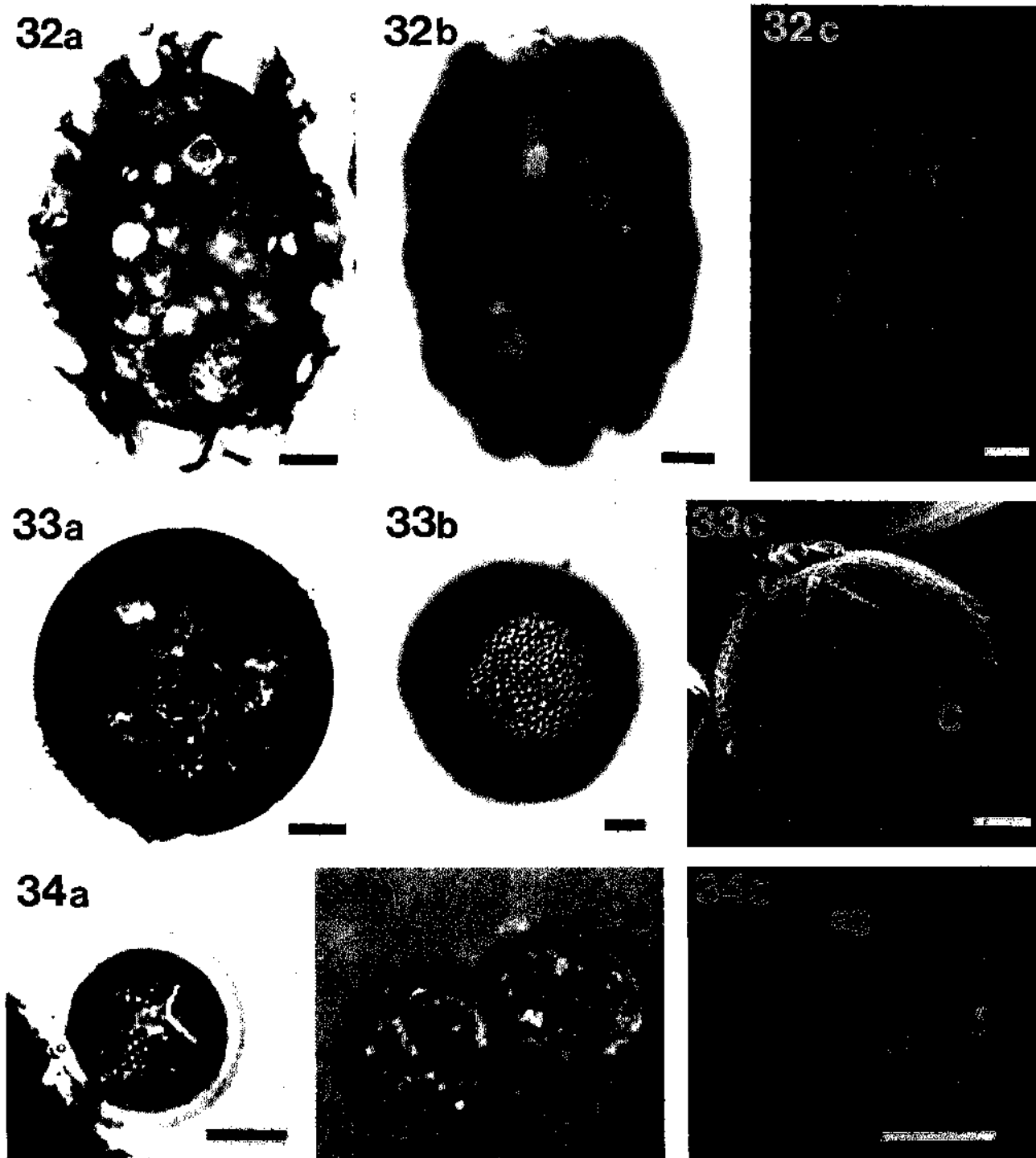
Pale purple-brown, discoid, cap-shaped cyst (57 μm long, 51 μm wide, 40 μm high). Seen from above it appears to be almost circular (Fig. 28a), although it can be slightly asymmetrical; in lateral view it is concave to bean-shaped (Fig. 28b). No accumulation body has been observed in this clear, non-mucoid cyst.

Seven specimens were found in the Tamar estuary, four of which were successfully germinated to produce colourless peridinioid cells resembling *Protoperidinium achromatum* (Levander) Balech. This cyst type has not been described previously in the literature of either Recent or fossil dinoflagellates.

Protoperidinium americanum (Gran et Braarud) Balech Figs 29a, b

Matsuoka 1987 a, Plate 17; Dale 1976, plate 1, fig. 16.

Spherical (30–35 μm diameter) light-brown cyst with a coarse, granular cyst wall (Fig. 29b), and a loosely attached, folded, membranous outer layer (Fig. 29a). The archeopyle is formed by the loss of 3 paraplates (Fig. 29b) which remained attached to the cyst wall in all specimens examined. To date, *P. americanum* is the only dinoflagellate known to produce a cloverleaf-shaped, 3 plate archeopyle (Dale, personal communication).



Figs 32–34. Gymnodinium dinoflagellates.

Fig. 32. *Polykrikos schwartzii*. Fig. 32a. LM. Ovoidal cyst with globular contents and distally flaring processes; Port Arthur. Fig. 32b. LM. Surface detail of cyst showing complex reticulate network of processes; Port Arthur. Fig. 32c. SEM. Detail of reticulate network of fibrous processes. Fig. 33. *Gymnodinium catenatum*. Fig. 33a. LM. Spherical cyst showing cell contents with characteristic large globules; Port Arthur. Fig. 33b. LM. Empty cyst showing microreticulate surface markings; Sullivan's Cove. Fig. 33c. SEM. Cyst showing microreticulate surface markings and para-cingulum (c); Sullivan's Cove. Fig. 34. *Gymnodinium* sp. 1. Fig. 34a. LM. Empty cyst showing microreticulate surface markings, similar to *G. catenatum*; Port Arthur. Fig. 34b. LM. Two-celled dinoflagellate chain germinated from this cyst type. Fig. 34c. SEM. Ventral view of cyst showing surface markings including the para-cingulum (c) and the para-apical groove (paracrobases) (ag); Port Arthur. All scale bars 10 μ m.

This cyst type was found in low numbers at three sites on the east coast of Tasmania. One specimen was successfully germinated to produce a peridinioid dinoflagellate. This cyst type has been illustrated from the Trondheimsfjord, Norway (Dale 1976) and from North Japan (Matsuoka 1987 a), but it has not been recorded previously from the Australasian region.

Zygabikodinium lenticulatum (Paulsen) Loeblich *et* Loeblich Figs 30a, b
Synonym: *Diplopetopsis minor* (Paulsen) Pavillard
[Palaeontological taxon: *Dubridinium caperatum* Reid]

Wall and Dale 1968, plate 2, figs 19, 20; Reid 1977, plate 4, figs 38–41.

Lenticular, brown cyst (Fig. 30a) (34 to 41 μm diameter) with microgranulate surface and reflections of the tabulation of girdle and apical pore complex clearly visible. A chasmic archeopyle is present in the epicyst.

In plankton samples from Tasmanian waters we have often found this cyst still enclosed within the dinoflagellate theca. This cyst type is widespread in Tasmanian sediments and is also known from New Zealand (Baldwin 1987). Three specimens were germinated to produce typical pale-pink *Zygabikodinium* cells (Fig. 30b) with large pusules and prominent sulcal lists.

Diplopetta parva (Abé) Matsuoka Figs 31a–c
Synonym: *Dissodium parvum* Abé

Matsuoka 1987 b, p. 438, fig. 5.

Brown, spherical cyst (27–30 μm diameter) covered with numerous spines, which are nontabular, hollow and distally pointed (Fig. 31a). A polygonal, apical archeopyle is present (Fig. 31b).

This cyst type was widespread in Tasmanian sediments and common at Georges Bay, Spring Bay and Port Arthur. Three specimens were germinated to produce colourless, spherical *Diplopetta* cells (Fig. 31c).

Family Gymnodiniaceae

Polykrikos schwartzii Bütschli Figs 32a–c

Matsuoka 1987 a, plate 15.

Elongated, ovoidal, green-brown cyst (80 to 100 μm long, 50–70 μm wide) with an irregular, nearly circular, tremic archeopyle (Matsuoka 1985 a). The processes are fibrous and flare distally (Fig. 32a) to form a reticulate structure (Fig. 32b). The outer cyst membrane may be microgranulate or microreticulate.

This cyst type was widespread and common in Tasmanian sediments, and is also known from Port Hacking, New South Wales (Dale and Hallegraef, unpublished data) and from New Zealand (Baldwin 1987). One specimen was successfully germinated to confirm its identification.

Gymnodinium catenatum Graham Figs 33a–c

Anderson *et al.* 1988, figs 7–13; Hallegraef *et al.* 1988 b, fig. 6.

Dark reddish-brown, spherical cyst (43 to 55 μm diameter) with globular contents (Fig. 33a), prominent red accumulation body and microreticulate surface markings that reflect the pattern of amphiesmal vesicles on the motile dinoflagellate cell (Fig. 33b). Markings reflecting the girdle, sulcus and apical groove are also visible (Fig. 33c) and an irregularly developed chasmic archeopyle is present.

This cyst type is known from Recent marine sediments from Tasmania, Spain and Japan, and has been recorded from fossil sediments from the Baltic Sea (Nordberg and Bergsten 1988). It was not detected in a survey of Recent sediments along the entire east coast of mainland Australia (McMinn, personal communication). In Tasmania, it was found in the Derwent and Huon estuaries, Spring Bay and Georges Bay. These cysts have been successfully germinated to produce vegetative cells, which divide to form chains (Blackburn *et al.* 1989).

Gymnodinium sp. 1 Figs 34a–c

This cyst type is similar to *Gymnodinium catenatum* except for its smaller size (17 to 22 μm diameter) and pale purple-brown colour.

It was found in low numbers at Spring Bay, Georges Bay and Deep Bay but was common at Port Arthur. Two specimens were successfully germinated to produce small (17 μm diameter) two-cell chains (Fig. 34b) resembling *Gymnodinium catenatum*. Chains of similarly small (17 μm) *G. catenatum* cells have also been reported from North-West Spain (Fraga and Sanchez 1985). This cyst type has not previously been described from either Recent or fossil sediments.

Gyrodinium sp. 1 Figs 35a–f

Pear-shaped, rhomboidal to spherical cyst (33 μm long, 26 μm wide) with yellowish contents and an inconspicuous accumulation body. The cyst wall is clear, thick and often covered with detrital particles.

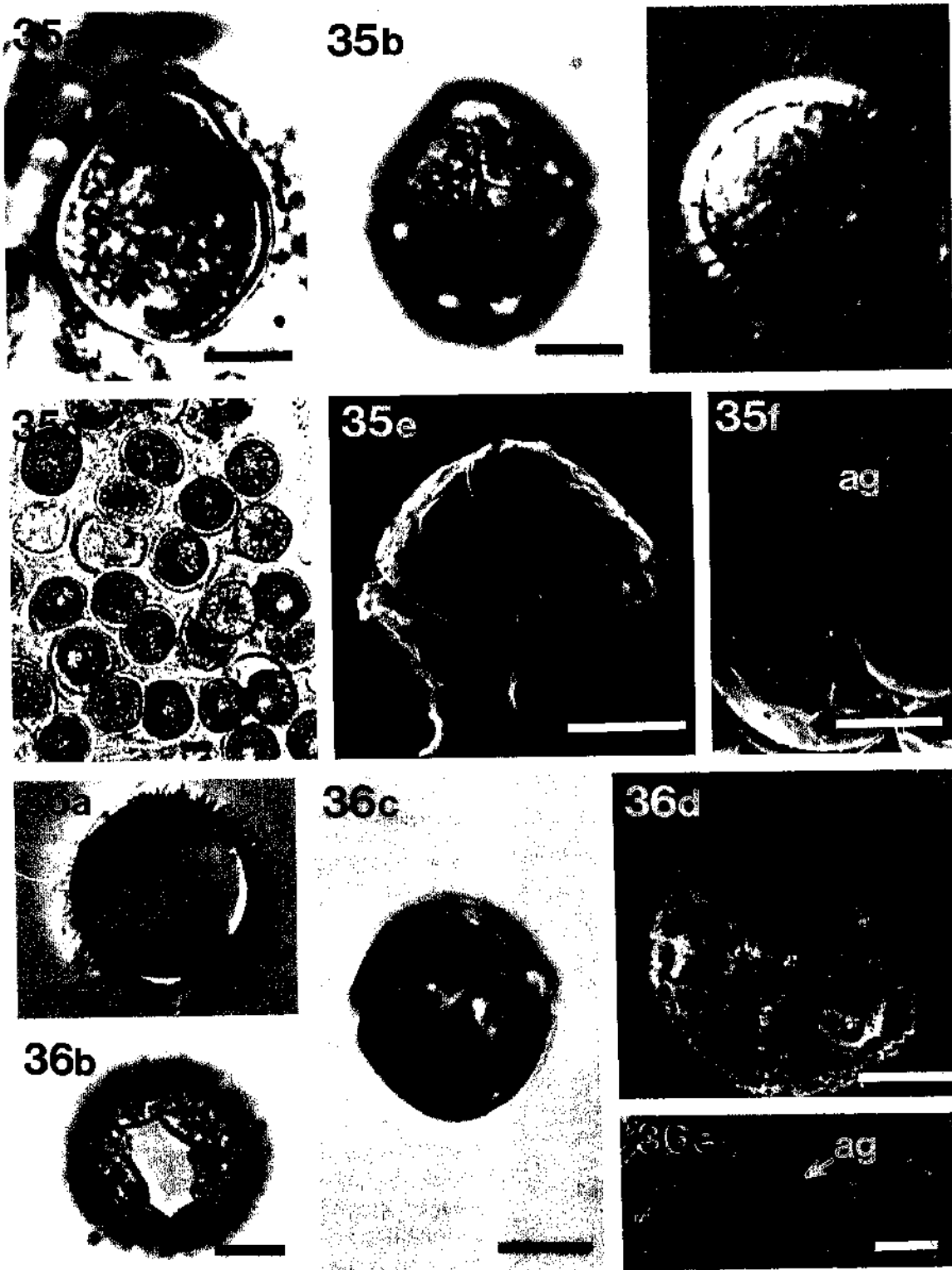


Fig. 35. *Gyrodinium* sp. 1.

Fig. 35a. LM. Cyst showing rhomboidal outline and thick wall covered with detrital particles; Port Arthur. Fig. 35b. LM. Ventral view of motile dinoflagellate cultured from this cyst type. Fig. 35c. LM. Cyst or resting stage produced in nutrient deficient culture, showing columnar outer covering. Fig. 35d. LM. Group of cysts from culture showing variability in shape. Fig. 35e. SEM. Ventral view of motile dinoflagellate cell showing girdle displacement. Fig. 35f. SEM. Detail of horse-shoe shaped apical groove (ag) on top of the motile dinoflagellate cell. Fig. 36. *Woloszynskia* sp. 1. Fig. 36a. LM. Cyst showing the closely packed, short spines and excystment opening with the margins pushed outward (arrow); Port Arthur. Fig. 36b. LM. Same cyst showing irregularly shaped excystment opening. Fig. 36c. LM. Ventral view of the motile dinoflagellate cultured from the cyst in Fig. 36a. Fig. 36d. SEM. Cultured dinoflagellate showing typical *Woloszynskia* amphiesmal pattern. Fig. 36e. SEM. Detail of apex of dinoflagellate cell, showing the short, raised, slit-like apical groove (ag). All scale bars 10 μ m, except Fig. 35f (5 μ m) and Fig. 36e (1 μ m).

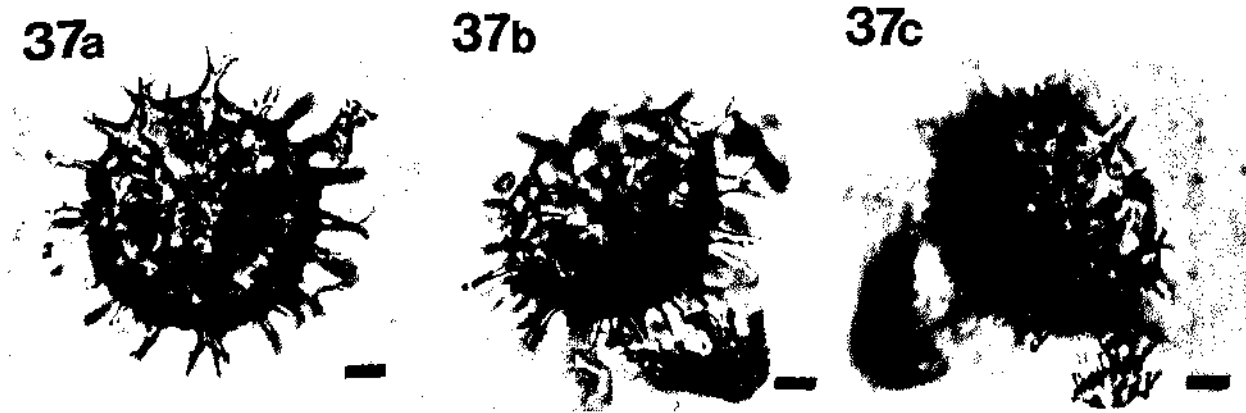


Fig. 37. *Cobricosphaeridium giganteum*.
Figs 37a, b, c. LM. Large, spherical cysts with long, tapered, pointed or branched spines; Port Esperance.

This cyst was widespread in Tasmanian sediments. Three specimens were germinated into greenish-brown *Gyrodinium* cells (25–30 μm length) (Figs 35b, e, f) with large horse-shoe shaped apical grooves. One culture, upon incubation in nutrient deficient medium, produced abundant cysts with columnar outer covering and highly variable morphology (Figs 35c, d). It is not yet clear whether these latter cysts, which are different from those observed in Tasmanian sediments, represent vegetative or sexual resting stages. This cyst type is similar, but not identical, to that described for *Gyrodinium uncatenum* Hulbert (Coats *et al.* 1984).

Woloszynskia sp. 1

Figs 36a–c

Spherical (25 μm diameter), yellowish cyst covered by a large number of densely packed short spines (Fig. 36a). Excystment occurs through an irregular breach (Fig. 36b) with the margins of the opening pushed outwards (Fig. 36a).

This cyst was found in low numbers at Port Arthur. One specimen was germinated to produce a small (15–20 μm diameter), green-brown dinoflagellate with displaced girdle and characteristic *Woloszynskia* amphiesmal pattern (Fig. 36d) (Netzel and Dürr 1984). The apex has a short (2–3 μm), straight, slit-like apical groove (Fig. 36e). This cyst type differs from those described for five freshwater species of *Woloszynskia* (Von Stosch 1973).

Miscellaneous

Cobricosphaeridium giganteum McMinn Figs 37a–c
McMinn 1990, plate 4, figs 1–12.

Large (60 μm diameter), spherical spinose cyst covered by long (20–25 μm), tapered spines with pointed or completely branched terminations.

In the present work, two cysts were found in Port Esperance. This is the first record of this species since its type description from Tuggerah Lakes, New South Wales (McMinn 1990). Germination experiments with material from Tuggerah Lakes suggest that this “cyst” has no dinoflagellate affinities but instead is the egg stage of a small crustacean animal (Hallegraeff and McMinn, unpublished). The only other known members of this genus were described from fossil freshwater sediments (Holocene) from Victoria, Australia (Harland and Sarjeant 1970).

Discussion

Species composition of Tasmanian dinoflagellate cyst assemblages

Thirty-four cyst types were identified from estuarine Tasmanian sediments (Table II), eight of which are new (*Alexandrium* cf. *excavatum*, *Scrippsiella* spp. (2), *Protoperidinium* spp. (2), *Gymnodinium* sp. 1, *Gyrodinium* sp. 1 and *Woloszynskia* sp. 1). The most common species, in order of decreasing abundance, were *Gonyaulax grindleyi* (cyst taxon *Operculodinium centrocarpum*), *G. spinifera* (cyst forms *Spiniferites membranaceus* and *S. mirabilis*), *Scrippsiella* spp., *Protoperidinium conicum*, *P. subinerne*, *Gymnodinium catenatum*, *Zygabikodinium lenticulatum* and *Polykrikos schwartzii*.

The Tasmanian species composition is broadly similar to that of New South Wales, Australia, and New Zealand. McMinn (1990) used palynological methods (hydrofluoric acid treatment) to investigate Recent dinocyst assemblages from six New South Wales estuaries. Twenty cyst types were identified, of which *Lingulodinium hemicystum* McMinn (similar to *L. machaerophorum* (Deflandre *et* Cookson) Wall, cyst of *Gonyaulax polyedra*, but with an epicystal archeopyle), *Spiniferites mirabilis*, *S. bulloideus*, *S. ramosus*

Table II. Dinoflagellate cyst species in Tasmanian estuaries. These are compared with cysts from New South Wales, Australia (McMinn 1988, 1989) and New Zealand (Baldwin 1987).

Cyst species	Fig.	Sampling site										NSW	NZ	
		Port Esperance	Deep Bay	Sullivan's Cove	Port Arthur	Spring Bay	Georges Bay	Tamar River	Mersey River	Duck Bay	Macquarie Harbour			Bathurst Harbour
<i>Gonyaulax grindleyi</i>	2	+	+	+	+	+	+	+	+		+	+	+	+
<i>Spiniferites membranaceus</i>	3	+	+	+	+	+	+	+	+	+			+	
<i>Spiniferites mirabilis</i>	4	+	+	+		+	+						+	
<i>Gonyaulax scrippsae</i>	5				+	+	+							
<i>Gonyaulax</i> sp. 1	6	+	+	+	+	+	+	+	+					
<i>Alexandrium</i> cf. <i>tamarense</i>	7								+					
<i>Alexandrium</i> cf. <i>excavatum</i>	10								+					
<i>Scripsiella trochoidea</i>	11	+	+	+	+	+	+	+	+	+	+			
<i>Scripsiella</i> sp. 1	12		+	+	+	+	+	+	+	+				
<i>Scripsiella</i> sp. 2	13									+				
<i>Protoperidinium conicum</i>	14	+	+	+	+	+	+	+					+	+
<i>Protoperidinium pentagonum</i>	15	+		+	+	+	+	+					+	+
<i>Protoperidinium subinerme</i>	16	+	+	+	+	+	+	+	+				+	+
<i>Protoperidinium</i> cf. <i>avellana</i>	17				+		+	+						
<i>Protoperidinium</i> cf. <i>punctulatum</i>	18			+				+	+				+	
<i>Protoperidinium oblongum</i>	19				+	+	+	+	+				+	+
<i>Protoperidinium leonis</i>	20						+	+	+				+	
<i>Protoperidinium divaricatum</i>	21						+							
<i>Protoperidinium compressum</i>	22			+		+							+	
<i>Protoperidinium</i> cf. <i>denticulatum</i>	23						+	+						
<i>Protoperidinium</i> sp. 1	24	+			+									
<i>Protoperidinium claudicans</i>	25					+								
<i>Protoperidinium conicoides</i>	26			+	+								+	
<i>Protoperidinium</i> cf. <i>minutum</i>	27						+							
<i>Protoperidinium</i> sp. 2	28							+						
<i>Protoperidinium americanum</i>	29				+	+	+							
<i>Zygabikodinium lenticulatum</i>	30	+		+	+	+	+	+	+					+
<i>Diplopelta parva</i>	31	+			+	+	+	+						
<i>Polykrikos schwartzii</i>	32	+	+	+	+	+	+	+	+		+	+	+	+
<i>Gymnodinium catenatum</i>	33	+	+	+	+	+	+							
<i>Gymnodinium</i> sp. 1	34		+		+	+	+							
<i>Gyrodinium</i> sp. 1	35	+	+	+	+	+	+	+						
<i>Woloszynskia</i> sp. 1	36				+									

and *Protoperidinium* spp. were the most abundant. Baldwin (1987) used gentle preparation techniques, similar to those in the present study, in a survey of Recent dinoflagellate cysts from Marlborough Sounds, New Zealand. Seventeen cyst types were identified, of which *Gonyaulax spinifera*, *Gonyaulax grindleyi*, *Protoperidinium subinerme* and *Protoperidinium leonis* were the most common. We did not detect the cyst types, *Spiniferites hyperacanthus* (Deflandre et Cookson) Reid or the warm-water species *Lingulodinium hemicystum* and *Tuberculodinium vancampoeae* (Rossignol) Wall (cyst of *Pyrophacus steinii* var. *vancampoeae*) in Tasmanian sediments, although McMinn (1990) found them in New South Wales sediments. Recent Tasmanian dinocyst assemblages also resemble those of the Northern Hemisphere (Dale 1983, Harland 1983, Matsuoka 1987a), except for the near

absence of typical cold-water species such as *Bitectatodinium tepikiense* Wilson (cyst form of *Gonyaulax spinifera*).

Whereas some species (such as *Operculodinium centrocarpum*, *Spiniferites bulloideus*, *S. mirabilis*, *S. ramosus*, *Protoperidinium conicum* and *P. leonis*) have remained unchanged in New South Wales estuaries from the Pleistocene till present, others such as the cold-water species *Bitectatodinium tepikiense* or the tropical species *Polysphaeridium zoharyi* (Rossignol) Bujak *et al.* (cyst of *Pyrodinium bahamense*) are known from the Pleistocene of Australia but are absent from Recent sediments (McMinn 1987, 1989). Compared to Australian microfossil assemblages (e. g. Deflandre and Cookson 1955, Helby *et al.* 1987) Recent Australian dinocyst populations show an apparent reduced species diversity.

Table III. Relative Abundance of Major Cyst Types (% of total cysts).

Site	Port Esperance	Deep Bay	Sullivan's Cove	Port Arthur	Spring Bay	Georges Bay	Tamar River	Mersey River	Duck Bay	Macquarie Harbour*	Bathurst Harbour*
<i>Gonyaulax grindleyi</i>	76	83	65	2	6	26	5	15	—	(2)	(1)
<i>Gonyaulax spinifera</i> group	12	10	14	8	21	20	35	18	3	—	—
<i>Proto-peridinium</i> spp.	4	1	4	9	11	15	10	14	11	(3)	(2)
<i>Scrippsiella</i> spp. (calcareous)	4	1	2	14	12	8	17	41	14	(1)	(1)
<i>Alexandrium tamarense</i> — like cysts	—	<1	6	43	34	12	25	7	72	—	—
<i>Gymnodinium catenatum</i>	1	3	7	9	1	3	—	—	—	—	—
Others (mainly <i>Diplopelta</i> , <i>Polykrikos</i> , and <i>Zygabikodinium</i>)	3	2	2	15	15	16	8	5	—	(4)	(2)
Total number of cysts counted	252	457	287	223	208	202	204	201	70	10	6

* Figures in parentheses indicate number of cysts rather than percentages.

Other cysts

A most unexpected finding in the present work was the abundance of colourless, fragile, ovoid to spherical *Alexandrium tamarense*-like cysts, 20 to 30 µm diameter, but often lacking a distinct mucilaginous covering. These morphologically indistinctive cysts, with clear contents and occasionally pale orange or red accumulation bodies, could only be identified by germination experiments. This produced living cells belonging to three very different dinoflagellate taxa, including *Alexandrium* cf. *excavatum*, *Scrippsiella* (2 spp.) and a *Gyrodinium* sp. In some samples (e.g. Duck Bay) this cyst category accounted for up to 70% of the total number of cysts (Table III); using destructive palynological methods, they would have gone unrecognised.

Relationship between cysts and plankton dinoflagellates

Out of the total number of 1500 extant species of plankton dinoflagellates, only some 60 marine and 15 freshwater species are known to produce zygotic resting cysts. Comparison between species composition of plankton dinoflagellates in Tasmanian waters (unpublished data) and dinoflagellate cysts in Tasmanian sediments (Table II) reveals large discrepancies. Abundant plankton genera such as *Ceratium* and *Dinophysis* never produce cysts, the cyst-producing red tide dinoflagellate *Gymnodinium catenatum* clearly is under-represented in the cyst record (up to 9% of total cysts), while *Proto-peridinium* (15%), *Gonyaulax spinifera* (35%) and especially *G. grindleyi* (up to 80%) are over-represented in the sediments (Table III).

The cysts of heterotrophic *Proto-peridinium* spp., which can be abundant in the proximity of open ocean environments (Bint 1988), were never abundant in Tasmanian estuaries. The dominance of *Gonyaulax grindleyi* cysts especially in the sediments from the Derwent and Huon estuaries may be related to specific organic growth factors derived from land-runoff but may also be related to eutrophication from urban development. McMinn (1990) recorded a similar dominance of *G. grindleyi* (up to 90% of total cysts) from Sydney Harbour sediments, and Dale (personal communication) has documented increasing *G. grindleyi* abundance during recent eutrophication of the Oslofjord, Norway.

Cysts of toxic dinoflagellates

In Tasmanian waters, the micro-reticulate cyst of the toxic dinoflagellate *Gymnodinium catenatum* was confined to sediments from the Huon and Derwent estuaries (Fig. 1). A few empty cyst walls have also been recorded from Spring Bay and Georges Bay, but no motile dinoflagellates or shellfish toxicity have ever been detected in these latter areas. This cyst type, which can withstand palynological treatment (Anderson *et al.* 1988), was absent from the entire east coast of mainland Australia and is also unknown from New Zealand; it has never been observed in fossil Australian sediments (McMinn, personal communication). This cyst distribution has fuelled speculation that *G. catenatum* may have been introduced into Tasmanian waters through cyst stages contained in the ballast tank sediments of Japanese woodchip cargo vessels (Hallegraeff *et al.* 1988 a).

The present work also records for the first time the occurrence of mucoid cysts of toxic and non-toxic *Alexandrium* species in the Australasian region, from the Tamar estuary and Mersey River in Tasmania and from the neighbouring Australian mainland harbours Port Phillip Bay (Melbourne) and Port MacDonnell, South Australia. Cyst surveys provide a relatively cheap and easy way of mapping areas with potential shellfish toxicity problems.

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