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Palynology of the Lachman Crags Member, Santa Marta Formation (Upper Cretaceous) of north-west James Ross Island

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Abstract: Palynomorph assemblages from the Lachman Crags Member of the Santa Marta Formation, north-west James Ross Island, Antarctic Peninsula are described. By basis of comparison with other Southern Hemisphere localities, particularly southern Australia, an early Santonian–early Campanian age is indicated. The results broadly corroborate previous stratigraphical interpretations based on macrofaunal evidence, although the presence of a significant thickness of Santonian strata, not previously recognized, is suggested. The dinoflagellate cyst floras allow the recognition of the local equivalents of the Australian *Odontochitina porifera, Isabelidinium cretaceum, Nelsoniella aceras* and *Xenikoon australis* Interval Zones. Some recycling of mid Cretaceous (and possibly Late Jurassic) taxa is also indicated. The miospore flora is composed of relatively long-ranging species, although the local appearance of certain taxa may be of stratigraphical significance. Ranges recorded support previous interpretations of heterochroneity in Southern Hemisphere floras. The palynoflora comprises 76 dinoflagellate cyst, 40 miospore and 7 acritarch, prasinophyte and chlorophyte taxa. Six undescribed species of dinoflagellate cyst are recorded and placed in open nomenclature.

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Introduction

The studies of Dettmann & Thomson (1987), Olivero & Palamarczuk (1987) and Askin (1988) have shown the stratigraphical value of palynological studies in the James Ross Island area. This paper presents the results of a preliminary palynological study of three sections through the Lachman Crags Member of the Santa Marta Formation in the north-west of the island (Fig. 1). The principal aim of the study was to use palynology to make a contribution to the development of an integrated lithostratigraphical and biostratigraphical scheme, necessary to understand the geological history of this area of unique geological importance (see Crame *et al.* 1991).

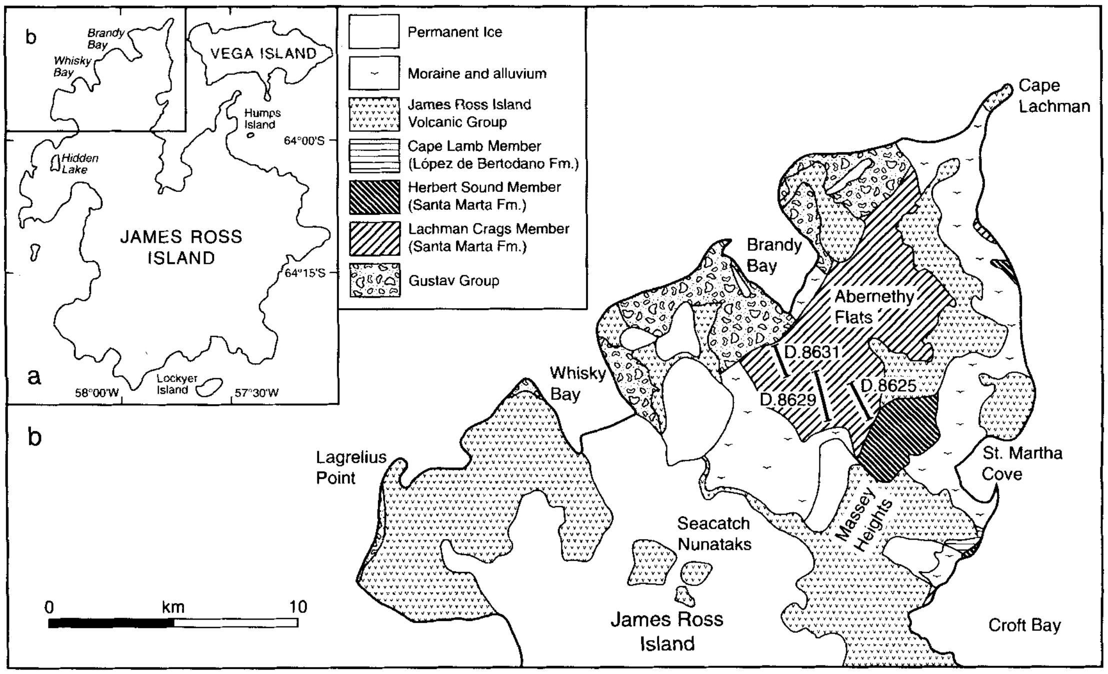

Fig. 1. Locality and sketch lithostratigraphical map of north-west James Ross Island (adapted from Crame *et al.* 1991), showing location of the sections investigated.

Lithostratigraphy and depositional setting

The Santa Marta Formation was defined by Olivero *et al.* (1986). It comprises interbedded sandstones, silt-stones, mudstones, accretionary lapilli, with rare conglomerates and coquinas and abundant early diagenetic concretions (Crame *et al.* 1991). The formation was originally divided into three informal members, Alpha, Beta and Gamma (Olivero *et al.* 1986). Crame *et al.* (1991) have since established three formal members within the formation; the lower Lachman Crags Member and upper Herbert Sound Member, which crop out in north-west James Ross Island, and the Rabot Member which is exposed in the south-west of the island. The precise stratigraphical relationships between the Rabot Member and the Lachman Crags and Herbert Sound members are not clear, although Crame *et al.* (1991) considered the Rabot Member a partial distal equivalent of the other two. The Santa Marta Formation is *c.* 1100 m thick in its type area (Crame *et al.* 1991).

In this work only material from the Lachman Crags Member was studied. Crame *et al.* (1991) considered the member to be equivalent to the Alpha and Beta members of Olivero *et al.* (1986) and approximately equivalent to Facies Association 1 of Pirrie (1989). It is interpreted as a sub-storm wave base, mid to outer shelf deposit (Pirrie 1989, Crame *et al.* 1991).

Previous biostratigraphical studies

The Lachman Crags Member is richly fossiliferous and has yielded abundant infaunal molluscs (Crame *et al.* 1991), ammonites (Olivero 1984, 1988, Olivero *et al.* 1986), belemnites (Doyle 1990) and inoceramid bivalves (Crame 1983). Crame *et al.* (1991) provided a review of the work completed on the macrofauna to date and indicated the stratigraphical distribution of the principal fossil groups reported from the Santa Marta Formation. They concluded that the age suggested by the macrofauna has strong Campanian affinities, although the presence of certain taxa, notably the *Inoceramus neocaledonicus* form group and *Baculites baileyi,* may indicate that the lower levels of the formation may be of latest Santonian age (Crame 1983, Crame *et al.* 1991).

Dettmann & Thomson (1987) described the palynomorphs from three spot samples from the Santa Marta Formation in north-west James Ross Island. Sample D.3030.3 from the back of Brandy Bay yielded an assemblage including the dinoflagellate cyst taxa *Chatangiella tripartita, Manumiella ? cretacea, M. lata, Odontochitina porifera* and *Xenascus australensis* and a diverse spore-pollen assemblage dominated by long ranging cryptogam spores, with common gymnosperm and rare angiosperm pollen. A Campanian–Santonian age was suggested with an associated macrofauna strongly indicative of a Campanian age (Dettmann & Thomson 1987). Two further samples, 8540 and 8665 from the east side of Lachman Crags, yielded an algal flora including *Isabelidinium* spp., *Maduradinium pentagonum, Nelsoniella* spp. and *Xenikoon australis* together with an abundant terrestrially-derived assemblage including a diverse angiosperm pollen flora. A Campanian age was suggested for the flora.

Sections and material studied

This paper is an account of palynomorph assemblages from 19 samples from the Lachman Crags Member (Santa Marta Formation) of north-west James Ross Island, (Fig. 1). Schematic logs of the sections investigated showing sample positions are given in Fig. 2, together with the distribution of stratigraphically significant dinoflagellate cyst taxa. The stratigraphical distribution of palynomorph taxa is presented in Fig. 3 and selected dinoflagellate cyst taxa are illustrated on Figs 4 & 5. The samples were taken from three stratigraphically consecutive sections (D.8631, D.8629 and D. 8625) in the area to the south of Abernethy Flats (Fig. 1). The base of the formation and its boundary with the underlying Hidden Lake Formation is not exposed there. A diverse molluscan macrofauna including ammonites, belemnites and inoceramid bivalves, probably indicative of a Campanian age, was recorded from the studied sections (M.R.A. Thomson, personal communication 1987).

Samples were prepared at the British Geological Survey, Keyworth using standard palynological preparation techniques. Yields were variable, usually consisting of a sparse to moderately rich assemblage of palynomorphs, degraded palynomorphs and structured plant tissue, and none required prolonged oxidation. Preservation varied from good to fair.

Stratigraphical palynology

The sample from the lowermost Santa Marta Formation, D.8631.10 (see Fig. 2), yielded an abundant and diverse palynoflora. The microplankton component of the assemblages was dominated by *Isabelidinium* cf. *belfastense* with other capsulate peridinoids; *Chatangiella victoriensis, C. tripartita, Isabelidinium* cf. *microarmum, Isabelidinium* spp. and *I. cooksoniae* present. *Odontochitina cribropoda* (Fig. 5a), *O. operculata* and *O. porifera* were also recorded in a dinoflagellate cyst flora which comprises 33 taxa (Fig. 3). This assemblage is comparable to those reported from early Santonian strata from Australia and appears to equate to the *Odontochitina porifera* Interval Zone of Helby *et al.* (1987). The index species of this zone has a first occurrence within the early Santonian of the latter region and significant numbers of taxa are present in both areas. Marshall (1984) described a dinoflagellate cyst suite closely similar to the James Ross Island assemblage from early Santonian strata of the Perth Basin, Australia. The first appearance of *O. porifera* also occurs in the Santonian of New Zealand (Riding *et al.* 1992). The presence of *Prolixosphaeridium parvispinum, P.* cf. *inequiornatum* and *Odontochitina singhii* within the assemblage from sample D.8631.10 probably represents recycling of mid-Cretaceous (Aptian–Albian) strata (cf. Morgan 1980, Helby *et al.* 1987).

The terrestrially-derived palynoflora is relatively diverse with subequal proportions of cryptogam spores and gymnosperm pollen with subordinate angiosperm pollen. The flora largely comprises long-ranging taxa of limited stratigraphical value. The local first occurrence of *Dacrycarpites australiensis* may, however, prove to be of some value. Dettmann & Thomson (1987) recorded this taxon from strata (sample D.3122.3) considered to be of Campanian–Maastrichtian age on Vega Island.

The local first occurrence of *M. ? cretacea* was recorded *c.* 60 m above the base of the Santa Marta Formation (Figs 2 & 3) in a diverse dinoflagellate cyst assemblage including common capsulate peridinoids, *Cassiculosphaeridia* sp. I, *Heterosphaeridium heteracanthum* and common *Manumiella lata* (Fig. 4n & o). Other taxa present include *Amphidiadema denticulata* (Fig. 4g), *Cyclonephelium* spp., *Microdinium* sp. and *Xenascus australensis*. This assemblage compares closely to mid–late Santonian floras of Australia. The first occurrence of *M ? cretacea* marks the base of the *Isabelidinium cretaceum* Interval Zone of Helby *et al.* (1987), whereas *A. denticulata* and *Isabelidinium belfastense* are confined to the zone in Australia (Helby *et al.* 1987). Marshall (1984) recorded an association including *M. ? cretacea* and *M. lata* in mid Santonian strata of the Perth Basin, Australia. Davey (1978) reported an association of *M. ? cretacea, Chatangiella tripartita* and *O. porifera* from the Cape Basin, off south-western Africa, from strata lacking independent faunal control, but underlying levels containing Campanian–Maastrichtian foraminifera and inoceramids (McLachlan & Pieterse 1978). Wilson (1984) suggested that *M. ? cretacea* appears in Campanian strata in New Zealand although recent recalibration of the New Zealand stage with the International time scale (Edwards *et al.* 1988) suggests a closer alignment of ranges of taxa within Australasia. The assemblage recorded from James Ross Island is similar to those recorded from southern Australia, New Zealand and the South Atlantic, but is markedly different from those recorded from northern Australia (north of a present day latitude 20°S) where the predominance of peridinacean forms is much reduced (Helby *et al.* 1987, McMinn 1988). The assemblage recorded here is closely similar to that reported by Dettmann & Thomson (1987) from a sample from the back of Brandy Bay (sample D.3030.3).

The top of the *Isabelidinium cretaceum* Interval Zone in Australia is marked by the incoming of the index taxon of the overlying *Nelsoniella aceras* Interval Zone. *Nelsoniella aceras* (Fig. 4 a & b) appears in sample D.8629.34 on James Ross Island (Figs 2 & 3); indicating that a relatively thick sequence (*c.* 300 m) of strata could be assigned to the *Isabelidinium cretaceum* Zone (Fig. 2). A number of local events within the palynoflora (particularly the dinoflagellate cyst suite) may, however, be of value in increasing biostratigraphical resolution. Samples from the lower part of the zone are characterized by the presence of common *M. lata* and *Hexagonifera glabra* and the presence of

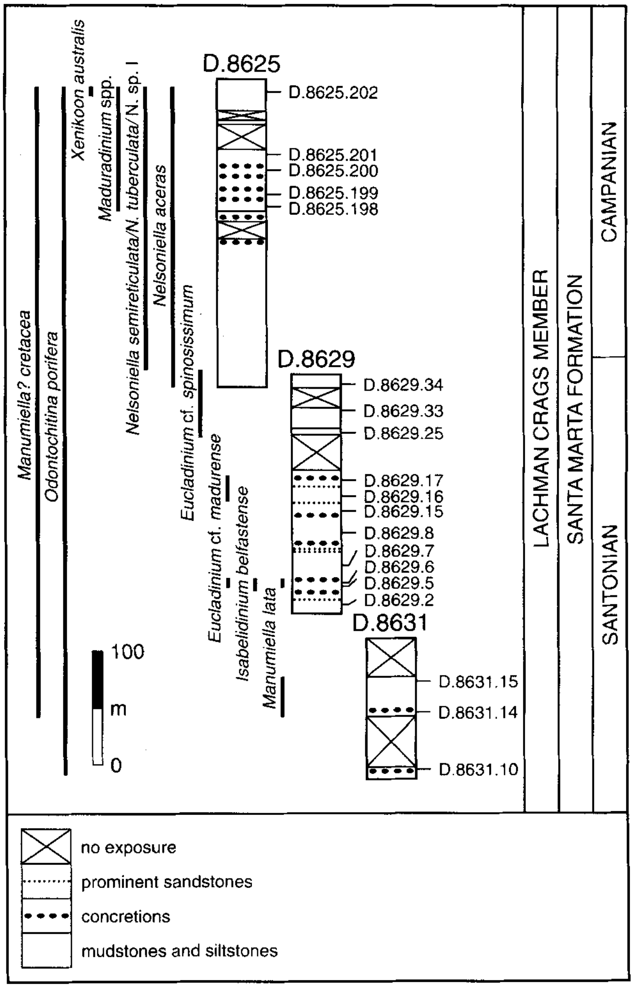

Fig. 2. Sketch logs of sections investigated within the Lachman Crags Member, Santa Marta Formation, north-west James Ross Island, together with sample positions. Ranges of stratigraphically important dinoflagellate cyst taxa from sections studied are also shown.

Canninginopsis sp. I. (Fig. 5g & h). Higher in the sequence there is a marked increase in the percentages of *Trithyrodinium vermiculatum* and *Eucladinium* cf. *madurense* (Fig. 4 j–l), together with the local first occurrences of *Isabelidinium belfastense sensu stricto* (Fig. 4m) and *Eucladinium* cf. *spinosissimum*; *Odontochitina* sp. I (Fig. 5f) is common and *Odontochitina* sp. II (Fig. 5b) is restricted to this zone. *Manumiella ? cretacea* is sporadically present throughout this interval. The occurrence of single specimens of *Scriniodinium ?* cf. *ceratophorum sensu* Helby *et al.* 1988 may represent minor recycling of Upper Jurassic strata or the continued reworking of mid-Cretaceous strata; this taxon is common, along with other allochthonous forms, in samples from the Gustav Group (Keating *et al.* 1992).

The miospore flora is relatively conservative throughout the presumed mid–late Santonian interval, commonly comprising sub equal amounts of gymnosperm pollen and pteridophytic spores with subordinate angiosperm pollen. The local first a

Dinoflagellate Cysts / Samples	D.8631.10	D.8631.14	D.8631.15	D.8629.2	D.8629.5	D.8629.6	D.8629.7	D.8629.8	D.8629.15	D.8629.16	D.8629.17	D.8629.25	D.8629.33	D.8629.34	D.8625.198	D.8625.199	D.8625.200	D.8625.201	D.8625.202
Oligiosphaeridium complex	●					●	●			●			●		●				●
Cassiculosphaeridia sp. I	●	●	●																
Spiniferites ramosus	●	●	●	●		●	●	●	●	●	●			●		●			
Pterodinium cingulatum	●		●	●															
Odontochitina costata		●	●						●	●									
Diconodinium psilatum	●	●		●								●	●		●	●			
Odontochitina operculata	●	●	●			●		●	●	●	●		●			●	●	●	
Isabelidinium acuminatum	●																		
Circulodinium distinctum longispinatum	●	●	●			●													●
Circulodinium distinctum distinctum	●		●		●	●				●									
Heterosphaeridium heteracantum	●	●	●	●		●	●		●	●	●	●	●	●	●	●		●	
Cyclonophelium compactum	●	●																	
Callaiosphaeridium asymmetricum	●							●		●									
Isabelidinium glabrum						●													
Tanyosphaeridium isocalumum	●																		
Heterosphaeridium sp.	●	●	●	●		●	●		●	●	●	●	●	●	●				
Canningia scabrosa	●	●																	
Canningia sp. I		●																	
Trithyrodinium suspectum	●	●	●																
Circulodinium distinctum ssp. indet.	●	●		●		●	●		●	●		●	●	●	●	●	●	●	●
Odontochitina cribropoda	●	●	●	●	●	●	●	●	●	●	●								
Palaeohystrichophora infusorioides	●	●								●	●	●	●						
Isabelidiniun cooksoniae	●	●				●												●	●
Odontochitina porifera	●	●	●	●		●			●	●			●	●				●	●
Hexagonifera glabra	●								●	●		●							
Isabelidinium cf. *microarmum*	●					●													
Chatangiella victoriensis	●	●	●																
Chatangiella tripartita	●		●						●										
Isabelidinium spp.	●	●	●	●						●									
Prolixosohaeridium parvispinum	●																		
Odontochitina singhii	●																		
Dinogymnium euclaensis	●																		
Spinidinium echinoideum rhombicum	●	●																	
Prolixosphaeridium cf. *inequiornatum*	●																		
Isabelidinium cf. *belfastense*	●	●	●	●		●		●	●	●									
Manumiella lata		●	●				●												
Chatangiella serratula		●	●							●									
Canninginopsis colliveri		●											●		●				
Dinogymnium nelsonense		●				●				●									
Hystrichosphaeridium paracostatum		●																	
Manumiella ?cretacea		●	●			●	●		●				●						
Canninginopsis sp. I.		●	●																
Tenua hystrix		●	●																
Xenascus australensis		●																	
Microdinium sp.		●																	
Amphidiadema denticulata			●	●					●	●									
Heslertonia striata			●																
Heterosphaeridium difficule			●			●													
Heterosphaeridium conjunctum			●																
Cleistosphaeridium armatum				●															
*Scriniodinium ?*cf. *ceratophorum*				●															
Oligosphaeridium pulcherrimum						●									●			●	●
Lejeunacysta sp.						●									●	●	●		●
Eucladinium cf. *madurense*						●						●	●						
Dinogymnium westralium						●		●											
Isabelidinium belfastense						●			●	●									
Chatangiella cf. *multispinosa*									●										
Trithyrodinium vermiculatum									●	●	●	●							●
Exochosphaeridium phragmites										●	●		●						
Odontochitina sp. I										●		●							
Amphidiadema rectangularis										●									
Odontochitina sp. II										●	●								
Eucladinium cf. *spinosissimum*												●	●	●					
Nelsoniella aceras														●	●				●
Nelsoniella semreticulata													●		●	●			●
Nelsoniella sp. I													●		●	●	●	●	●
Spinidinium lanterna															●	●	●		
Maduradinium sp. I															●	●		●	●
Maduradinium pentagonum															●			●	●
Nelsoniella tuberculata															●		●	●	●
Palaeocystodinium rhomboides															●	●			
?Spinidinium sp.															●		●	●	●
Subtilisphaera ?ventriosa																●			
Spinidinium echinodeum																●		●	
Australisphaera verrucosa																	●		
Alterbidinium minus																			●
Xenikoon australis																			●

b

Pollen and Spores / Samples	D.8631.10	D.8631.14	D.8631.15	D.8629.2	D.8629.5	D.8629.6	D.8629.7	D.8629.8	D.8629.15	D.8629.16	D.8629.17	D.8629.25	D.8629.33	D.8629.34	D.8625.198	D.8625.199	D.8625.200	D.8625.201	D.8625.202
Alisporites similis	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●
Angiosperm pollen (undifferentiated)	●	●	●	●		●	●			●	●	●	●	●	●	●	●	●	●
Bisaccate spp. (undifferentiated)	●	●	●			●				●				●		●			●
Ceratosporites equalis	●	●	●	●		●	●		●	●	●	●	●	●	●	●		●	●
Cyathidites minor	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Cyathidites punctatus	●	●	●			●	●		●			●	●						●
Gleicheniidites circinidites	●	●	●	●		●				●	●	●	●	●	●	●	●	●	●
Inaperturopollenites spp.	●												●		●			●	●
Klukistporites scaberis										●									●
Leptolepidites verrucatus	●		●	●		●					●					●		●	●
Microcachryidites antarcticus	●	●	●			●		●		●	●		●		●	●	●		●
Osmundacidites wellmannii	●	●											●		●				●
Perotriletes majus	●	●	●														●	●	●
Phyllocladidites mawsonii										●			●						●
Podocarpites ellipticus	●	●	●			●	●			●		●	●		●		●		●
Retitriletes austroclavatidites	●		●	●				●		●			●			●			●
Clavifera triplex				●										●				●	
Densoisporites velatus																		●	
Lygisterpollenites balmei																		●	
Araucariacites australis	●	●	●			●				●		●	●	●	●	●			
Cyathidites australis	●	●	●			●						●	●			●			
Perotriletes laceratus	●	●											●						
Triletes tuberculiformis	●					●								●					
Laevigatosporites ovatus	●		●						●	●		●							
Cyatheacidites archangelskii											●								
Foramanisporis dailyi											●								
Alisporites grandis	●					●				●									
Microcachryidites sp.	●					●				●									
Biretisporites spectabilis	●					●		●											
Cyatheacidites annalatus						●													
Baculatisporites comaumensis	●			●															
Dacrycarpites australiensis	●	●	●																
Foveogleicheniidites confussus	●	●																	
Aequitriradites spinulosus	●																		
Foraminisporis asymmetricus	●																		
Ischyosporites volkheimeri	●																		
Neoraistrickia truncata	●																		
Podosporites microsaccatus	●																		
Triporoletes simplex	●																		

c

Acritarchs/Prasinophytes/ Chlorophytes / Samples	D.8631.10	D.8631.14	D.8631.15	D.8629.2	D.8629.5	D.8629.6	D.8629.7	D.8629.8	D.8629.15	D.8629.16	D.8629.17	D.8629.25	D.8629.33	D.8629.34	D.8625.198	D.8625.199	D.8625.200	D.8625.201	D.8625.202
Cyclopsiella spp.		●	●		●								●					●	
Palambages Form A.			●			●				●		●	●	●	●				●
Micrhystridium spp.	●	●	●			●									●				
Tasmanites spp.						●									●	●			●
Palambages Form C.						●													

Fig. 3. Distribution of palynomorphs from the Lachman Crags Member, Santa Marta Formation, north-west James Ross Island, arranged in order of first occurrence. **a.** dinoflagellate cysts; **b.** pollen and spores; **c.** acritarchs, chlorophyte and prasinophyte algae.

occurrence of *Phyllocladidites mawsonii* occurs within this interval. This species was recorded by Dettmann & Thomson (1987) from strata they considered to be Santonian–Campanian in age from James Ross Island (samples D.3030.3, 8665 and 8540, in the area behind Brandy Bay and east of Lachman Crags respectively). It is the index species of the *Phyllocladidites mawsonii* Oppel Zone of Helby *et al.* (1987), who recorded the first appearance of this taxon in the Turonian of Australia. Raine (1984) recorded a similar inception of this species in New Zealand. Also of interest are the rare occurrences of the probable gleicheniaceous fern spore *Clavifera triplex*. Askin (1989, 1990) suggested this species had a Maastrichtian–Danian range in the Antarctic Peninsula. It has previously been recorded from Cenomanian strata of Bathurst Island (Burger 1976), from Cenomanian strata of Australia (Morgan 1980) and was considered indicative of a Turonian–early Santonian age in Australia by Dettmann & Playford (1969). Raine (1984) reported a first occurrence of this taxon from Piripauan (Campanian) strata in New Zealand. The angiosperm pollen component includes *Clavatipollenites hughesii, Peninsulapollis gilli, Proteacidites* spp., *Liliacidites* spp. and rare specimens of *Nothofagidites* spp.

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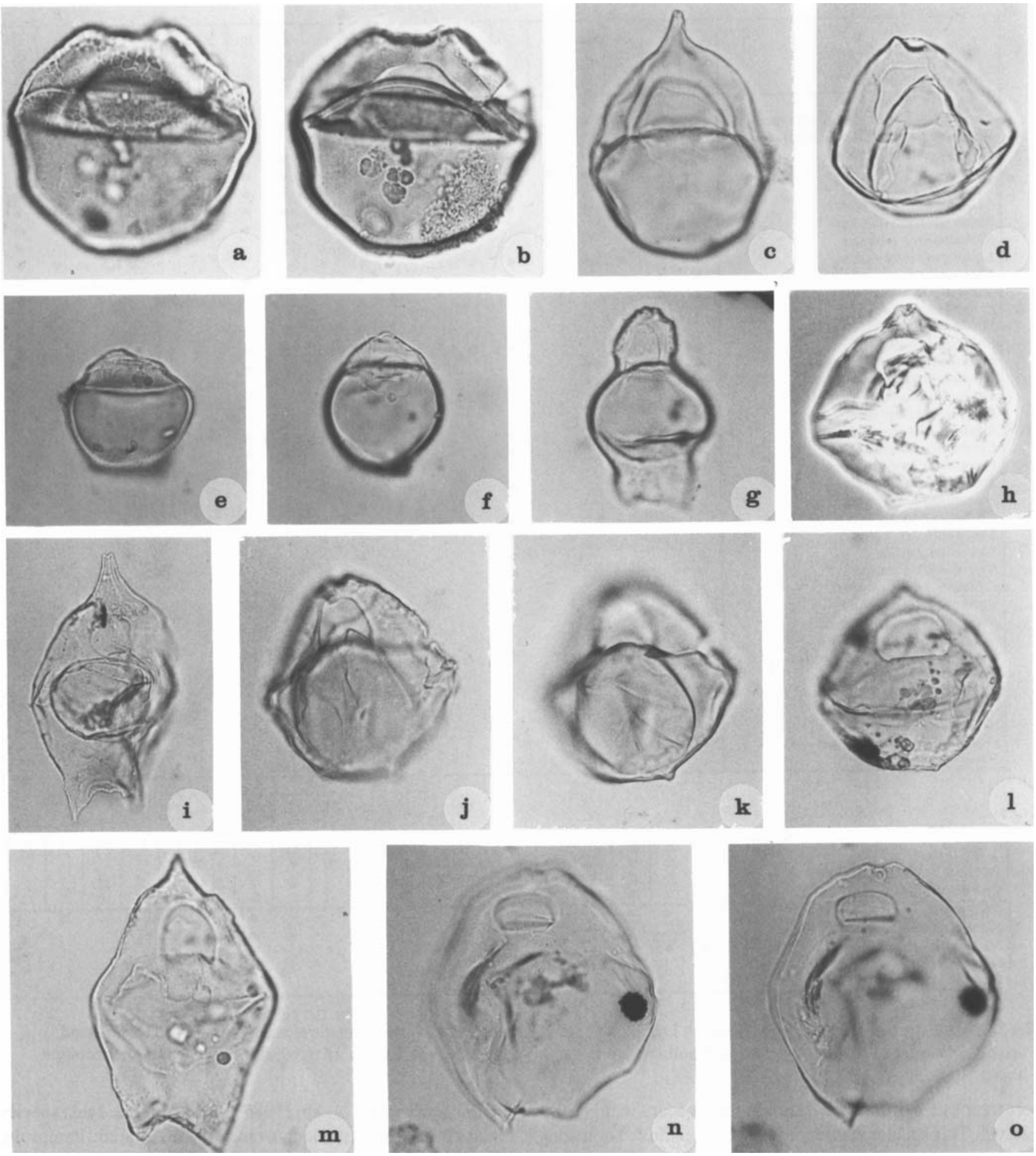

Fig. 4. Dinoflagellate cysts from the Lachman Crags Member, Santa Marta Formation, north-west James Ross Island. All photomicrographs taken in plain transmitted light and enlarged to x 500 unless otherwise stated. **a. b.** *Nelsoniella aceras* Cookson & Eisenack 1960. Ventral view. **a.** high focus, **b.** low focus. D.8625.202/1, S/46 x 400. **c.** *Nelsoniella tuberculata* Cookson & Eisenack 1960. Dorsal view, median focus. D.8625.198/1, H64/3, x 400. **d.** *Nelsoniella* sp. I. Oblique dorsal view, high focus. D.8625.198/1, N66. **e. f.** *Xenikoon australis* Cookson & Eisenack 1960. Both specimens in dorsal focus. **e.** D.8625.202/2, O63. **f.** D.8625.202/2, O67/4. **g.** *Amphidiadema denticulata* Cookson & Eisenack 1960. Dorsal view, high focus. D.8629.16/4, F52, x 400. **h.** *Isabelidinium acuminatum* (Cookson & Eisenack 1958) Stover & Evitt 1978. D.8631.10/3, X47/2. Taken using phase contrast. **i.** *Isabelidinium glabrum* (Cookson & Eisenack 1969) Lentin & Williams 1977. Dorsal view, median focus. D.8629.6/1, Q47/2, x 400. **j.–l.** *Eucladinium* cf. *madurense* (Cookson & Eisenack 1970) Stover & Evitt 1978. Dorsal view. **j.** high focus, **k.** low focus. D.8629.25/1, M56/2. **l.** Dorsal view, median/low focus. D.8629.25/1, P44/1. **m.** *Isabelidinium belfastense* (Cookson & Eisenack 1960) Lentin & Williams 1977. Dorsal view, median focus. D.8629.16/2, K62/1. **n. o.** *Manumiella lata* (Cookson & Eisenack 1968) Bujak & Davies 1983. Dorsal view. **n.** high focus, **o.** low focus. D.8631.14/2, P66/4.

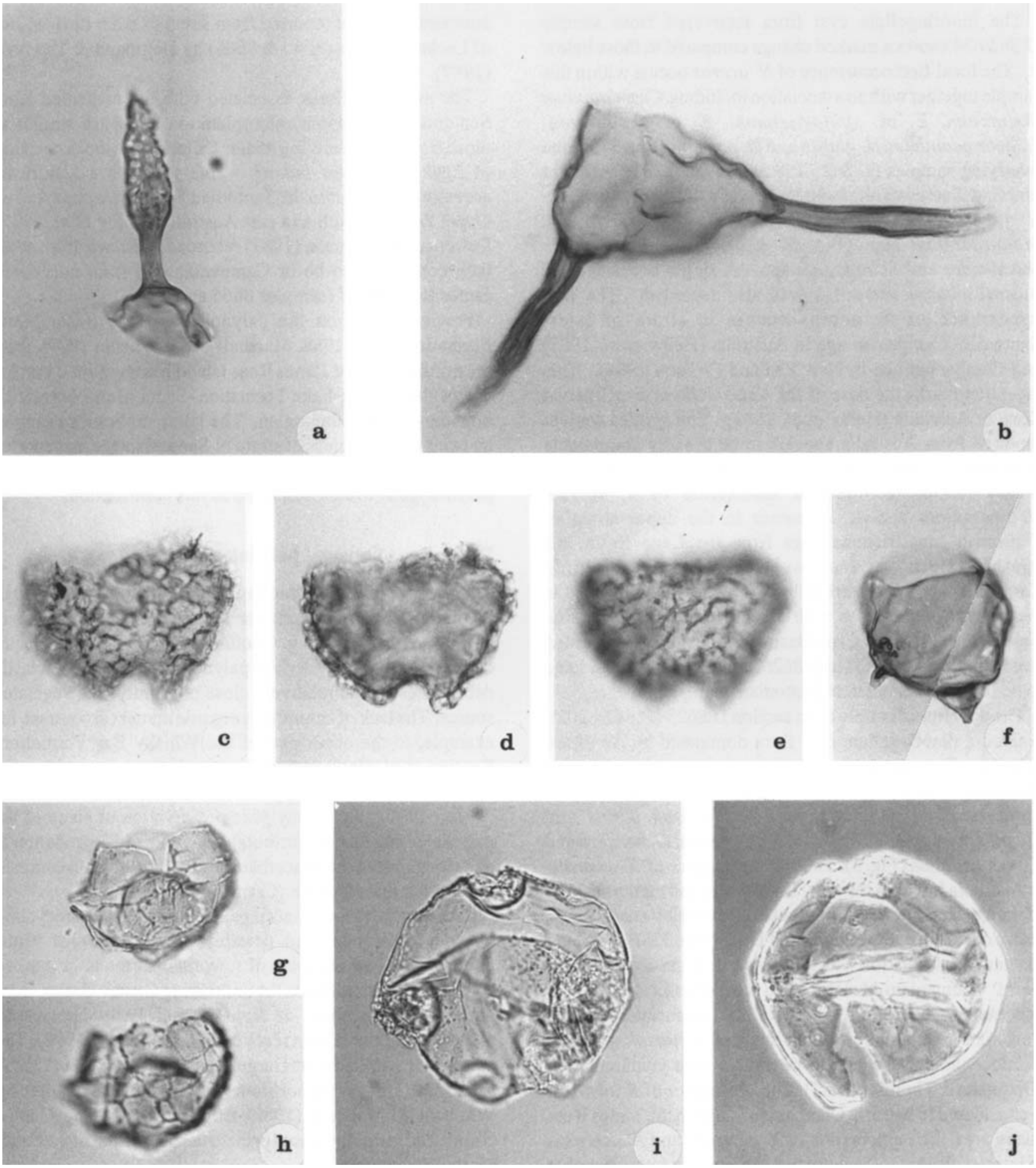

Fig. 5. Dinoflagellate cysts from the Lachman Crags Member, Santa Marta Formation of north-west James Ross Island. All photomicrographs taken in plain transmitted light and enlarged to x 500 unless otherwise stated. **a.** *Odontochitina cribropoda* Deflandre & Cookson 1955. An isolated operculum. D.8631.1/3, J46/3, x 300. **b.** *Odontochitina* sp. II. D.8629.16/2, F43/1. **c.-e.** *Canningia* sp. I. High to low focus sequence. D.8631.15/1, Q50/1. **f.** *Odontochitina* sp. I. Composite photomicrograph. D.8629.16/4, H63/3. **g. h.** *Canninginopsis* sp. I. **g.** high focus, **h.** low focus. D.8631.14/2, Q62. **i. j.** *Maduradinium* sp. I. **i.** D.8625.198/1, G60. **j.** D.8625.198/1, R60. Taken with phase contrast.

The dinoflagellate cyst flora recovered from sample D.8629.34 shows a marked change compared to those below it. The local first occurrence of *N. aceras* occurs within this sample together with an association including *Circulodinium distinctum*, *E.* cf. *spinosissimum*, *E.* cf. *madurense*, *H. heteracanthum*, *H. glabra* and *O. porifera* (Fig. 3). In the overlying samples (D.8625.198 and D.8625.201) a diverse dinoflagellate cyst suite includes *N. aceras*, *N. semireticulata*, *N. tuberculata* (Fig. 4c), *Nelsoniella* sp. I (Fig. 4d), *Maduradinium* spp. (Fig. 5i & j), *Palaeocystodinium rhomboides* and *Spinidinium* spp. A single occurrence of *Australisphaera verrucosa* was also recorded. The first appearance of *N. aceras* occurs in strata of latest Santonian–Campanian age in Australia (Helby *et al.* 1987) and Campanian age in New Zealand (Wilson 1984). This inception marks the base of the *Nelsoniella aceras* Interval Zone in Australia (Helby *et al.* 1987). The species content reported from Australia appears to be broadly comparable with that recorded from the James Ross Island material. Davey (1978) recorded an association of *N. aceras*, *N. tuberculata* and *A. verrucosa* in the upper strata of "Turonian–Maastrichtian" age from the Cape Basin, off south-western Africa, overlying strata yielding Campanian–early Maastrichtian planktonic foraminifera. On the basis of comparison with assemblages from Australia, New Zealand and the Cape Basin the assemblages recorded from samples D.8629.34 to D.8625.201 (Fig. 2) are considered to be indicative of a latest Santonian–Campanian age.

The uppermost sample from section D.8625 (D.8625.202), yielded a dinoflagellate cyst flora dominated by *Xenikoon australis* (Fig. 4e & f) and *N. aceras* in an association including *N. semireticulata*, *N. tuberculata*, *Nelsoniella* sp. I, *Maduradinium pentagonum*, *Alterbidinium minus* and *Spinidinium* spp. together with *C. distinctum*, *O. porifera* and *T. vermiculatum* (Fig. 3). The first appearance of *X. australis* in Australia is within the early Campanian and marks the base of the *Xenikoon australis* Interval Zone of Helby *et al.* (1987). It also occurs in cores 10 and 11 of DSDP Site 328B, Falkland Plateau, in association with *N. aceras*, in strata considered to be of Campanian–Maastrichtian age (Harris 1977). The occurrence in core 7 (of DSDP Site 328B) associated with the Turonian–Coniacian marker species *Conosphaeridium striatoconus* may be due to downhole core contamination (Dettmann & Thomson 1987). The appearance of *X. australis* is considered to be early Campanian in age in the James Ross Island area. The association of *X. australis* and *N. aceras* is of interest. In Australia these two taxa are not found together (Helby *et al.* 1987), leading Riding *et al.* (1992) to suggest that the above assemblage may be equivalent to an earliest *Xenikoon australis* Zone age. It appears likely that the reports of *Nelsoniella* spp. from stratigraphically higher levels within the James Ross Island area (Askin 1988, Sumner 1992) are a consequence of recycling rather than indicating an extended range of this taxon within the Antarctic Peninsula area. The palynoflora recorded from D.8625.202 in this paper is closely comparable to that reported from samples from the east side of Lachman Crags (8540 & 8665) by Dettmann & Thomson (1987).

The miospore floras associated with the presumed latest Santonian–Campanian microplankton suite are similar to those from the underlying strata. Of interest is the occurrence of *Lygistepollenites balmei*. This taxon is a significant accessory form within the Santonian *Tricolpites apoxyexinus* Oppel Zone of south and east Australia (Helby *et al.* 1987). Dettmann & Thomson (1987) recorded *L. balmei* from strata they considered to be of Campanian age from north-west James Ross Island (samples 8665 and 8540).

Previous work on the palynology of the Santa Marta Formation (Piper 1988, Marshall 1988, Whelan 1989), from the northern part of James Ross Island has suggested that the age of the Hidden Lake Formation–Santa Marta Formation boundary is early Santonian. The latter studies also suggest an extensive thickness of strata of Santonian age, as reported herein, and corroborate the order and value of many of the palynological events described in this contribution.

Palaeoenvironmental palynology

The predominance of dinoflagellate cysts in relatively high diversity and low dominance suites indicates a "normal" marine environment (e.g. Goodman 1979). The presence of common terrestrially-derived palynomorphs and phytoclastic debris attest to the relatively close proximity of a vegetated source. The lack of amorphous organic matter (in contrast, for example, to the upper part of the Whisky Bay Formation; Keating *et al.* 1992) indicates normal circulation within the site of deposition and upper levels of the sediment column (Tyson 1987). Relatively poor preservation of some of the palynomorphs may be attributable to biogenic degredation in an oxic environment, exacerbated by the bioturbation common throughout the sequence (Crame *et al.* 1991).

Rare allochthonous dinoflagellate cysts attest to recycling of mid-Cretaceous (and possibly Upper Jurassic) strata, although the low numbers of reworked forms is in marked contrast to the yields from the underlying Gustav Group, from which large numbers of Jurassic and Early Cretaceous palynomorphs have been recovered (Keating *et al.* 1992). The paucity of reworked forms largely confirms the view of Crame *et al.* (1991) that syndepositional deformation, as reported by Whitham & Marshall (1988) from the underlying Gustav Group, had virtually ceased prior to the deposition of the Santa Marta Formation.

Provincialism

The dinoflagellate cyst suite is comparable to those recorded from southern Australia, New Zealand and the South Atlantic and suggests the development of a Santonian–Campanian southern circumpolar, high palaeo-latitude flora; the *Isabelidinium* cyst flora of Dettmann & Thomson (1987). The

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relatively low numbers of taxa endemic to the Antarctic area during this interval suggests a continuity with the preceding Aptian-Turonian floras (Keating *et al.* 1992) which are similarly comparable with their Austral counterparts. Later Cretaceous (late Campanian–Maastrichtian) and Tertiary floras (see Askin 1988, Wrenn & Hart 1988, Smith 1992), by contrast appear to include a greater number of endemic forms and may indicate an isolation of the Antarctic Peninsula from Austral influences during the latest Cretaceous and Tertiary.

The spore-pollen flora also comprises elements previously reported from Australia and New Zealand. Askin (1988, 1989, 1990), Dettmann (1986), Dettmann & Jarzen (1988) and Dettmann & Thomson (1987) have previously demonstrated considerable heterochroneity in Southern Hemisphere terrestrially-derived palynofloras. The results presented here broadly support the previous interpretations; the only major difference is the presence of *Clavifera triplex* in strata considered to be of Santonian–Campanian age. Askin (1989, 1990) previously recorded this taxon from Maastrichtian–Danian strata within the James Ross Island area.

Conclusions

The dinoflagellate cyst floras proved to be similar to those reported from other areas within the Southern Hemisphere and successive floral events common to the region provide the basis of ages suggested for the samples from James Ross Island. The Australian zonation scheme of Helby *et al.* (1987), in particular, proved to be readily applicable to the area studied. The palynoflora reported in this paper is considered to be strongly indicative of an early Santonian–Campanian age and suggests the presence of a thick (*c.* 300 m) section of strata of Santonian age (Fig. 2). There is some discrepancy between the ages suggested by the macrofauna and the palynology, principally the dinoflagellate cyst flora. The macrofossil biostratigraphy is generally indicative of a Campanian age for the Lachman Crags Member (see Crame *et al.* 1991). Some elements of the molluscan fauna may be supportive of a latest Santonian age for the lower part of the section (Crame 1983, Crame *et al.* 1991), but the palynomorph assemblage from the lowest sample is closely comparable with those reported from the early Santonian of southern Australia. The presence of distinctive heteromorph ammonites, probably indicative of an early Campanian age, concentrated *c.* 250–450 m from the base of the formation (Olivero 1988, Crame *et al.* 1991) may, however, provide some corroborative evidence for the interpretation presented here.

The miospore floras are composed of relatively long ranging taxa of limited stratigraphical value. However, the current work does provide a framework within which further studies of the development of the flora of the Antarctic Peninsula and heterochroneity within the Southern Hemisphere flora may be calibrated. The first appearance of *P. mawsonii* within strata of Santonian age may be of stratigraphical value, Dettmann & Thomson (1987) having previously reported this taxon from the Santa Marta Formation on James Ross Island (samples D.3030.3, 8665 and 8540). The occurrence of *C. triplex* in Santonian and Campanian strata is the oldest reported from the area.

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Appendix I. List of taxa

Alphabetical listing of palynomorph taxa from the Lachman Crags Member of the Santa Marta Formation under probable botanical affinities. The assignment of dinoflagellate cyst taxa follows Lentin & Williams (1989).

* denotes probable reworked taxa.

Dinoflagellate cysts

Alterbidinium minus (Alberti 1959) Lentin & Williams 1985
Amphidiadema rectangularis (Cookson & Eisenack 1962) Lentin & Williams 1976
Amphidiadema denticulata Cookson & Eisenack 1960 Fig. 4 g
Australisphaera verrucosa Davey 1978
Callaiosphaeridium asymmetricum (Deflandre & Courtville 1939) Davey & Williams 1966
Canningia scabrosa Cookson & Eisenack 1970
Canningia sp. I[1] Fig. 5 c–e
Canninginopsis colliveri (Cookson & Eisenack 1960) Backhouse 1988
Canninginopsis sp. I[2] Fig. 5 g & h

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Cassiculosphaeridia sp. I Keating *et al.* 1992 Fig. 6c &d
Chatangiella cf. *multispinosa* (Cookson & Eisenack 1970) Lentin & Williams 1976
Chatangiella serratula (Cookson & Eisenack 1958) Lentin & Williams 1976
Chatangiella tripartita (Cookson & Eisenack 1960) Lentin & Williams 1976
Chantangiella victoriensis (Cookson & Manum 1964) Lentin & Williams 1976
Circulodinium distinctum subsp. *distinctum* (Deflandre & Cookson 1955) Jansonius 1986
Circulodinium distinctum subsp. *longispinatum* (Davey 1978) Jansonius 1986
Cleistosphaeridium armatum (Deflandre 1937) Davey 1969
Conosphaeridium striatoconus (Deflandre & Cookson 1955) Cookson & Eisenack 1969
Cribroperidinium cooksoniae Norvick 1976
Cyclonephelium compactum Deflandre & Cookson 1955
Diconodinium pusillum Singh 1971
Dinogymnium euclaense Cookson & Eisenack 1970
Dinogymnium nelsonense (Cookson 1956) Evitt *et al.* 1967
Dinogymnium westralium (Cookson & Eisenack 1958) Evitt *et al.* 1967
Eucladinium cf. *madurense* (Cookson & Eisenack 1970) Stover & Evitt 1978 Fig. 4 j–l
Eucladinium cf. *spinosissimum* (Cookson & Eisenack 1970) Stover & Evitt 1978
Exochosphaeridium phragmites Davey *et al.* 1966
Heslertonia striata (Cookson & Eisenack 1960) Norvick 1976
Heterosphaeridium conjunctum Cookson & Eisenack 1968
Heterosphaeridium difficile (Manum & Cookson 1964) Ioannides 1986
Heterosphaeridium ? heteracanthum (Deflandre & Cookson 1955) Eisenack & Kjellström 1971
Heterosphaeridium sp.
Hexagonifera glabra Cookson & Eisenack 1961
Hystrichosphaeridium paracostatum Cookson & Eisenack 1974
Isabelidinium acuminatum (Cookson & Eisenack 1958) Stover & Evitt 1978 Fig. 4 h
Isabelidinium belfastense (Cookson & Eisenack 1961) Lentin & Williams 1976 Fig. 4 m
Isabelidinium cf. *belfastense* (Cookson & Eisenack 1961) Lentin & Williams 1976
Isabelidinium cooksoniae (Alberti 1959) Lentin & Williams 1976
Isabelidinium glabrum (Cookson & Eisenack 1969) Lentin & Williams 1976 Fig. 4 i
Isabelidinium cf. *microarmum* (McIntyre 1975) Lentin & Williams 1976
Isabelidinium thomasii (Cookson & Eisenack 1961) Lentin & Williams 1976
Isabelidinium spp.
Kiokansium polypes (Cookson & Eisenack 1962) Below 1982
Lejeunecysta sp.
Maduradinium pentagonum Cookson & Eisenack 1970
Maduradinium sp. I[3] Fig. 5 i & j
Manumiella ? cretacea (Cookson 1956) Bujak & Davies 1983
Manumiella lata (Cookson & Eisenack 1968) Bujak & Davies 1983 Fig. 4 n & o
Microdinium sp.
Nelsoniella aceras Cookson & Eisenack 1960 Fig. 4 a & b
Nelsoniella semireticulata Cookson & Eisenack 1960
Nelsoniella tuberculata Cookson & Eisenack 1960 Fig. 4 c
Nelsoniella sp. I[4] Fig. 4 d
Odontochitina costata Alberti 1961
Odontochitina cribropoda Deflandre & Cookson 1955 Fig. 5 a
Odontochitina operculata (O. Wetzel 1933) Deflandre & Cookson 1955
Odontochitina porifera Cookson 1956
Odontochitina singhii Morgan 1980 *
Odontochitina sp. I[5] Fig. 5 f
Odontochitina sp. II[6] Fig. 5 b
Oligosphaeridium complex (White 1842) Davey & Williams 1966
Oligosphaeridium pulcherrimum (Deflandre & Cookson 1955) Davey & Williams 1966
Palaeocystodinium ? rhomboides (O. Wetzel 1933) Lentin & Williams 1973
Palaeohystrichophora infusorioides Deflandre 1935
Palaeotetradinium silicorum Deflandre 1936
Prolixosphaeridium cf. *inequiornatum* Stover & Helby 1987 *
Prolixosphaeridium parvispinum (Deflandre 1937) Davey *et al.* 1969 *
Pterodinium cingulatum (O. Wetzel 1933) Below 1981
Scriniodinium ? cf. *ceratophorum* Cookson & Eisenack 1960 *sensu* Helby *et al.* 1988 *
Spinidinium echinoideum (Cookson & Eisenack 1960) Lentin & Williams 1976
Spinidinium echinoideum subsp. *rhombicum* (Cookson & Eisenack 1974) Lentin & Williams 1977
Spinidinium lanterna Cookson & Eisenack 1970
Spinidinium spp.
Spiniferites ramosus (Ehrenberg 1838) Loeblich & Loeblich 1966
Subtilisphaera ? ventriosa (Alberti 1959) Jain & Millopied 1973
Tanyosphaeridium isocalamus (Deflandre & Cookson 1955) Davey & Williams 1966
Tenua hystrix Eisenack 1958
Trithyrodinium suspectum (Manum & Cookson 1964) Davey 1969
Trithyrodinium vermiculatum (Cookson & Eisenack 1961) Lentin & Williams 1976
Xenascus australensis Cookson & Eisenack 1969
Xenikoon australis Cookson & Eisenack 1960 Fig. 4 e & f

Cryptogam spores

Aequitriradites spinulosus (Cookson & Dettmann 1958) Cookson & Dettmann 1961
Baculatisporites comaumensis (Cookson 1953) Potonié 1956
Biretisporites spectabilis Dettmann 1963
Ceratosporites equalis Cookson & Dettmann 1958
Cyatheacidites annulatus Cookson 1947 ex Potonié 1956
Cyatheacidites archangelskii Dettmann 1986
Cyathidites australis Couper 1953
Cyathidites minor Couper 1953
Cyathidites punctatus (Delcourt & Sprumont 1955) Delcourt *et al.* 1963
Clavifera triplex (Bolchovitina 1953) Bolchovitina 1956
Densoisporites velatus Weyland & Krieger 1953
Foraminisporis asymmetricus (Cookson & Dettmann 1958) Dettmann 1963
Foraminisporis dailyi (Cookson & Dettmann 1958) Dettmann 1963
Foveogleicheniidites confussus (Hedlund 1966) Burger 1976
Gleicheniidites circinidites (Cookson 1953) Dettmann 1963

Ischyosporites volkheimeri Filatoff 1975
Klukisporites scaberis (Cookson & Dettmann 1958) Dettmann 1963
Laevigatosporites ovatus Wilson & Webster 1946
Leptolepidites verrucatus Couper 1953
Neoraistrickia truncata (Cookson 1953) Potonié 1956
Osmundacidites wellmannii Couper 1953
Perotriletes majus (Cookson & Dettmann 1958) Evans 1970
Perotriletes laceratus (Norris 1968) Dettmann *in* Dettmann & Thomson 1987
Retitriletes austroclavatidites (Cookson 1953) Döring *et al.* 1963
Stereisporites antiquasporites (Wilson & Webster 1946) Dettmann 1963
Trilites tuberculiformis Cookson 1947
Triporoletes simplex (Cookson & Dettmann 1958) Playford 1971

Gymnosperm pollen

Alisporites grandis (Cookson 1953) Dettmann 1963
Alisporites similis (Balme 1957) Dettmann 1963
Araucariacites australis Cookson 1947
Dacrycarpites australiensis Cookson & Pike 1953
Inaperturopollenites spp.
Lygistepollenites balmei (Cookson 1957) Stover & Evans 1973
Microcachryidites antarcticus Cookson 1947
Microcachryidites sp.
Phyllocladidites mawsonii Cookson 1947 ex Couper 1953
Podocarpidites ellipticus Cookson 1947
Podosporites microsaccatus (Couper 1953) Dettmann 1963
Vitreisporites pallidus (Reissinger 1950) Nilsson 1958

Angiosperm pollen

Clavatipollenites spp.
Liliacidites spp.
Nothofagidites spp.
Peninsulapollis spp.
Proteacidites spp.

Acritarchs, chlorophycean and prasinophycean algae

Cyclopsiella spp.
Micrhystridium spp.
Palambages Form A Manum & Cookson 1964
Palambages Form C Manum & Cookson 1964
Schizosporis cf. *reticulatus* Cookson & Dettmann 1959
Cymatiosphaera spp.
Tasmanites spp.

Appendix II. Taxonomic notes

Six previously undescribed dinoflagellate cyst morphotypes of potential stratigraphical value were recorded.

[1]*Canningia* sp. I
Fig. 5 c–e

Remarks: *Canningia* sp. I is distinguished from *C. pistica* Helby 1987 by its smaller size (54 μm w; 46 μm l), lack of paratabulation and a generally coarser ornament. *Canningia reticulata* Cookson & Eisenack 1960 is larger and has a finer reticulum supporting the ectophragm.

[2]*Canninginopsis* sp.I
Fig. 5 g & h

Remarks: *Canninginopsis* sp. I is distinguished from other species of *Canninginopsis* by its relatively small size (58 μm w ; 43 μm l), minor variations in paratabulation and relative lack of dorso-ventral compression. In addition, the paratabulation of *C. denticulata* Cookson & Eisenack 1962 is defined by a denticulate ornament rather than the parasutural ridges evident in this species. *Cannninginopsis intermedia* Morgan 1980 displays paratabulation only on the dorsal surface of the hypocyst; *C.* sp. I is fully paratabulate. *Canninginopsis bretonica* Marshall 1990 is also larger and more variable in shape.

[3]*Maduradinium* sp. I
Fig. 5 i & j

Remarks: *Maduradinium* sp. I differs from *M. pentagonum* in lacking an apical horn and in having a generally more robust form. The angular peridinacean ambitus with the common indentation of the apex distinguish it from *M. pentagonum* subsp. *ovale* (Cookson & Eisenack 1982) Lentin & Williams 1985. All three morphologies commonly display variable ornament, but it would appear, from comparison within the Antarctic material and with published records of the described taxa, that the ornament of *M.* sp. I is generally coarser and more widespread. *Maduradinium* sp. I superficially resembles the form described as *Maduradinium ?* sp. A by Davey (1978) from the Turonian–Maastrichtian of the Cape Basin, off south-western Africa, and subsequently reported from the Early Cretaceous of Denmark by Davey (1982). The latter, however, has an apical excystment aperture; the present form has a variable archaeopyle involving the mid-dorsal intercalary (2a) and precingular (4″) paraplates.

[4]*Nelsoniella* sp. I
Fig. 4 d

Remarks: *Nelsoniella* sp. I is distinguished from previously described species of *Nelsoniella* by its small size (55 μm w; 55 μm l), fine ornament and relatively thin cyst walls.

[5]*Odontochitina* sp. I
Fig. 5 f

Remarks: *Odontochitina* sp. I differs from other species of *Odontochitina* in the development of very short, broad antapical and postcingular horns. In other respects this form resembles *O. operculata.* It is possible that *O.* sp. I may represent an ecotype of the latter (cf. Harding 1990, who described short horned variants of *Pseudoceratium pelliferum* Gocht 1957).
Note: this taxon has a consistent periphragm-endophragm relationship and does not appear to be damaged.

[6]*Odontochitina* sp. II
Fig. 5 b

Remarks: This species is probably identical with the cyst figured as "*Odontochitina* sp." by Cookson & Eisenack (1968, fig. 2D). *Odontochitina* sp. II differs from *O. operculata* in having a sub-triangular cyst body and thick walled horns arising at a relatively large angle (in the latter both the antapical and postcingular horn point in a direction approximately parallel to the apical-antapical mid line). In broken or poorly preserved specimens the thick-walled, distally perforate horns are diagnostic. Similarly the thick periphragm, sub-triangular body and lack of distal spade-like development of the horns distinguishes *O.* sp. II from *O. cribropoda.*

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