Cretaceous Research 56 (2015) 550–562

Contents lists available at ScienceDirect

Cretaceous Research

journal homepage: www.elsevier.com/locate/CretRes

Calcareous nannofossils from the Santa Marta Formation (Upper Cretaceous), northern James Ross Island, Antarctic Peninsula

Rodrigo do Monte Guerra [a,*], Andrea Concheyro [b,c], Jackie Lees [d], Gerson Fauth [a], Marcelo de Araujo Carvalho [e], Renato Rodriguez Cabral Ramos [e]

[a] ITT Fossil, Instituto Tecnológico de Micropaleontologia, Universidade do Vale do Rio dos Sinos (UNISINOS), Av. UNISINOS, 950, B. Cristo Rei/CEP: 93.022-000, São Leopoldo, RS, Brazil
[b] Instituto Antártico Argentino (IAA), Buenos Aires, Argentina
[c] IDEAN-CONICET, Departamento de Ciências Geológicas, Universidad de Buenos Aires, Pabellón II, Ciudad Universitaria, 1428, Buenos Aires, Argentina
[d] Department of Earth Sciences, University College London, Gower Street, London, WC1E 6BT, UK
[e] Museu Nacional – Universidade Federal do Rio de Janeiro, Brazil

A R T I C L E I N F O

Article history:
Received 26 March 2015
Received in revised form
15 June 2015
Accepted in revised form 16 June 2015
Available online 11 July 2015

Keywords:
Calcareous nannofossils
James Ross Island
Antarctic Peninsula
Cretaceous
Early Campanian
Gephyrobiscutum diabolum

A B S T R A C T

This study reports on the most stratigraphically extensive nannofloras yet recovered from the Lachman Crags Member of the Santa Marta Formation, James Ross Island, Antarctic Peninsula. The productive samples are dated as early Campanian. These ages are in accord with those provided by ammonites, foraminifera, ostracods and radiolarians from the same locality. The consistent and relatively abundant presence of *Gephyrobiscutum diabolum* throughout the productive part of the section, a species that has previously only been documented from the Falkland Plateau, extends its geographic distribution to higher latitudes, at least to the Antarctic Peninsula area.

1. Introduction

The James Ross Basin constitutes one of the most significant Mesozoic to Cenozoic sedimentary basins of the southern high-latitude region, since it is located in the northern sector of the Antarctic Peninsula and, unlike other south-polar basins, has extensive, ice-free outcrops representing more than 6000 m of Cretaceous marine deposits.

These sedimentary rocks have been interpreted as having been deposited in different marine environments, from proximal to outer shelf and prodelta lobe. In general, the sections are extensive and sediments are poorly consolidated. They contain rich faunas of ammonites, bivalves, gastropods, vertebrate remains, and also plants that exhibit exceptional preservation at certain levels. The Cretaceous deposits are overlain unconformably either by the James Ross Island Volcanic Group (JRIVG) of Neogene to Pleistocene age, or by Neogene diamictites, generally intercalated between hyaloclastites of the JRIVG and Cretaceous sandstones or claystones.

Since the early 20th century, international polar expeditions have made significant progress in understanding the stratigraphy and palaeontology of the region. On James Ross Island, two thick sedimentary successions are recognised: the Gustav Group (Aptian-Coniacian) and the Marambio Group (Santonian-Danian) (Ineson et al., 1986; Olivero, 2012).

The biostratigraphy of the Marambio Group has been studied in fairly good detail using ammonites, which have good records in several sections on Vega, James Ross, Snow Hill and Seymour islands (Riccardi, 1980; Olivero, 1984, 1992, 2012; Macellari, 1986, 1988; Pirrie et al., 1991, 1997; Scasso et al., 1991; Olivero and Medina, 2000).

To improve the stratigraphy, palynomorphs, calcareous nannofossils and other microfossils have also been studied, providing

* Corresponding author.
E-mail addresses: rmguerra@unisinos.br (R.M. Guerra), andrea@gl.fcen.uba.ar (A. Concheyro), j.lees@ucl.ac.uk (J. Lees), gersonf@unisinos.br (G. Fauth), mcarvalho@mn.ufrj.br (M. de Araujo Carvalho), rramos@mn.ufrj.br (R.R. Cabral Ramos).

http://dx.doi.org/10.1016/j.cretres.2015.06.009
0195-6671/

different levels of resolution. They include studies on palynology by Dettman and Thomson (1987), Askin (1988), Harwood (1988), Pirrie and Reading (1988), Pirrie et al. (1991), Keating (1992), Barreda and Olivero (1993) and Carvalho et al. (2013), among others. However, micropalaeontological studies in the James Ross Basin are still scarce and are generally restricted to Mesozoic and Cenozoic foraminifera, ostracods, diatoms and radiolarians (MacFayden, 1966; Huber, 1988; Gázdzicki and Webb, 1996; Concheyro et al., 1997, 2007, 2010, 2014; Bertels-Psotka et al., 2001; Fauth et al., 2003; Caramés and Concheyro, 2013; Florisbal et al., 2013).

Records of calcareous nannofossils from the James Ross Basin are concentrated in the southeast, and include late Campanian and early Maastrichtian assemblages (Concheyro et al., 1991, 1995, 2004, 2010; Robles Hurtado and Concheyro, 1995), which are impoverished, compared to coeval nannofloras from Deep Sea Drilling Project (DSDP)/Ocean Drilling Program (ODP) Legs 36, 113 and 114 (respectively, Wise and Wind, 1977; Pospichal and Wise, 1990a, b; Crux, 1991), and one core drilled in the surrounding area of the northern James Ross Island (Kulhanek, 2007).

In the northern sector of James Ross Island, Brazilian and Czech scientific expeditions have recently reported Campanian calcareous nannofossils from the Lachman Crags Member of the Santa Marta Formation (Guerra et al., 2012; Švábenická et al., 2012). The latter authors have also published a pioneering study on calcareous nannofossils from the northern sector of the James Ross Basin that include specimens recovered from five different formations from the middle Coniacian to lower Campanian, and three productive samples that belong to the Santa Marta Formation.

The study presented herein covers the upper part of the Alpha Member of the Santa Marta Formation in the Lachman Crags section, where 99 micropalaeontological samples were collected for the study of foraminifera, ostracods and radiolarians (Florisbal et al., 2013). In 17 of those samples, calcareous nannofossils have been recorded. The objectives of this study are: i) to provide a more detailed record of nannofossils from the Lachman Crags section; ii) to illustrate the moderately-preserved nannofloras recovered, highlighting their significant features; and iii) to provide independent ages to compare to those established by the other fossil groups.

2. Geological setting

The James Ross Basin, a component of the larger Larsen Basin, contains a significant upper Mesozoic to lower Cenozoic sedimentary succession related to the Gondwana break-up and subsequent development in a back-arc setting (Hathway, 2000) (Fig. 1).

The James Ross Basin hosts an extensive Cretaceous sequence unique in that the outcrops are located above 65°S latitude. On James Ross Island, the Cretaceous succession can be assigned to two major stratigraphic units: the Aptian-Coniacian Gustav Group and the Santonian-Danian Marambio Group (Olivero, 2012). The former comprises the coarse-grained, submarine fan and slope deposits of the Kotick Point and Whisky Bay formations, superposed by fan-delta deposits represented by the Hidden Lake Formation (Ineson, 1989; Buatois and López-Angriman, 1992; Medina et al., 1992; Whitham et al., 2006). Outcrops of these deposits are scattered around the northern and western sectors of James Ross Island (Ineson et al., 1986; Medina et al., 1992). These grade upwards into the finer-grained sandstones, mudstones, scarce conglomerates and bioclastic mudstones indicative of the shallow-marine deposits of the Marambio Group (Rinaldi et al., 1978; Pirrie, 1989; Crame et al., 1991; Pirrie et al., 1997; Olivero and Medina, 2000; Francis et al., 2006; Olivero, 2012).

The studied samples from Lachman Crags belong to the Santa Marta Formation, the basal unit of the Marambio Group (Rinaldi, 1982). The Santa Marta Formation was subdivided into the Alpha, Beta and Gamma members (Olivero et al., 1986). The Alpha and Beta members crop out at Brandy Bay, Col Crame and Lachman Crags, and comprise facies associations that indicate a regressive sequence (Scasso et al., 1991).

The base of the Alpha Member consists of massive or laminated, muddy-tuffaceous, fine-grained sandstones, interbedded with hard, graded tuffaceous sandstones, containing dispersed, pyritised tree trunks and carbonised plant fragments, scarce invertebrates and heteromorph ammonites, as well as specimens of *Baculites* cf. *B. kirki* Matsumoto. The upper part of the Alpha Member consists of alternations of graded, tuffaceous, sandy turbidites that preserve diverse ammonite faunas, gastropods, crinoids, solitary corals, brachiopods and bivalves.

The lower part of the Beta Member consists of tuffaceous and pebbly, or coarse-grained, sandstones, incorporating resedimented ammonites, belemnites and bivalves (Olivero, 2012). In the upper part of this member, the facies associations include fine-grained, micaceous, silty sandstones, mudstones with leaves, trunks and plant fragments, and small ammonites. Beds characterised by *Pterotrigonia* sp. and *Cuccullaea* sp. are frequent, and bioclastic beds supported by belemnites, trigonids and scaphopods cut erosively-bioturbated beds that are overlain by cross-bedded and parallel-laminated clastic sandstones, which are composed of glass shards and pumice lapilli. The vertical stacking of these facies associations suggests the evolution of a progradational, deep-water delta system (Scasso et al., 1991; Olivero, 2012). The Alpha and Beta members contain six successive ammonite assemblages, characterised by *Baculites* cf. *B. kirki*, *Natalites rossensis* Olivero, *Natalites* spp. Group 1, *Grossouvrites occultus* Olivero and Medina, *Natalites* cf. *morenoi* Riccardi, *Natalites taylori* Spath, *Karapadites* cf. *centinalaensis* Blasco and *Natalites* spp. Group 2, all of which indicate early Campanian ages.

The Gamma Member of the Santa Marta Formation crops out at Santa Marta Cove and Dreadnought Point in the eastern sector of James Ross Island, and is dominated by sandstone beds with scarce *Neograhamites primus* ammonites, common gastropods, bivalves and coquinas. An ankylosaurian dinosaur, *Antarctopelta oliveroi* (Salgado and Gasparini, 2006), and a plesiosaur (Kellner et al., 2011) have also been recorded from the Gamma Member. The ammonites belong to Ammonite Assemblages 8 and 9 (late Campanian) of Olivero and Medina (2000) and Olivero (2012). Recently, the Gamma Member has been considered to be the base of the Snow Hill Island Formation, of late Campanian age (Olivero, 2012).

Pirrie (1989) defined two facies associations for the Santa Marta Formation and determined similar marine environmental conditions, in agreement with Olivero et al. (1986). Later, Crame et al. (1991) grouped the Alpha and Beta members into the Lachman Crags Member of the Santa Marta Formation.

The occurrence of tuffaceous sandstones in the studied section suggests that this is probably correlatable to the ‘tuffs’ and ‘tuffaceous sediments’, cemented by carbonate, described by Scasso et al. (1991) for the Alpha Member, the basal unit of the Santa Marta Formation (Olivero et al., 1986). In the scheme proposed by Crame et al. (1991), our section would be considered to be part of the Lachman Crags Member. Resting unconformably on top of the Cretaceous strata is a Miocene-Pleistocene basaltic volcanic field known as the James Ross Island Volcanic Group (JRIVG). This crops out in a wide area of James Ross Island. It is characterised by multiple lava-fed deltas, formed of topset basalt beds that overlie thicker, steep homoclinal hyaloclastite breccia foresets (Smellie, 2006). Also, unconformably resting on top of Cretaceous sediments and underlying the base of the JRIVG, or interbedded with

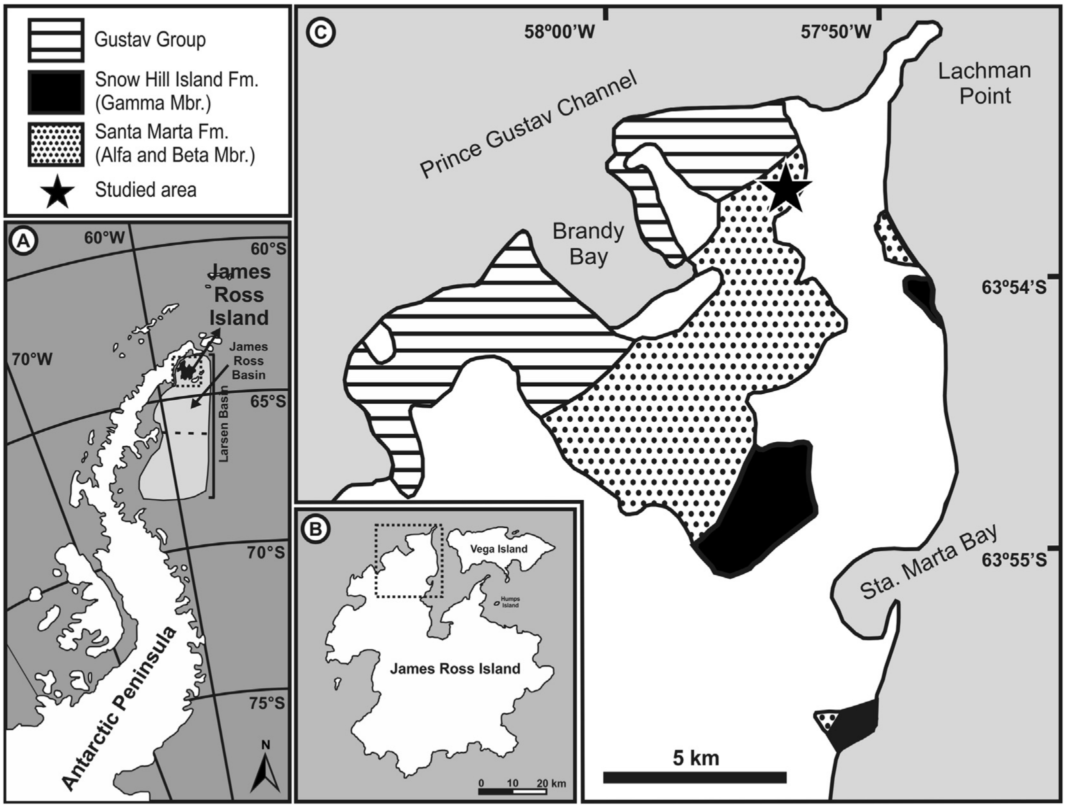

Fig. 1. Location map of the studied section, Lachman Crags, northern James Ross Island. Modified from Pirrie et al. (1991).

volcanic rocks of this group, glaciogenic sediments are exposed, and in the Lachman Crags, they belong to the Mendel Formation (Nývlt et al., 2011). These deposits have been interpreted as lodgement tills, subglacial melt-out till, glaciofluvial sands, marine sediments and glaciomarine debris-flows that contain Cenozoic marine bivalves, such as *Austrochlamys anderssoni*, and benthic foraminifera, such as *Hoeglundina asanoi* Matsunaga, *Nonionella bradii* Chapman and *Globocassidulina* sp. Strontium isotope studies developed from Lachman Crags pectinids suggest late Miocene and younger ages for the deposition of the Mendel Formation, which has an erosional contact with underlying Cretaceous deposits of the Alpha Member of the Santa Marta Formation.

3. Materials and methods

This study is based on 99 samples collected from an outcrop that comprises sedimentary rocks belonging to the Santa Marta Formation. The section was measured at Lachman Crags (63°49′44″S, 57°53′32″W), between Brandy Bay and Bibby Point, near to Col Crame, in the northern part of James Ross Island, during the project expedition *Prospecção de Fósseis do Cretáceo da Bacia de James Ross* in 2006–2007 (Fig. 1). The section comprises 126 m of very fine-to medium-grained tuffaceous sandstones, interbedded with claystones and laminated siltstones that are fossiliferous at some levels, along with rare levels of accretionary lapilli (Fig. 2). Samples were primarily selected from the siltstone and claystone beds, but some samples were also taken from the fine-grained sandstone beds (*cf.* tuffites cemented by carbonate *sensu* Scasso et al., 1991). Macrofossil content varied throughout the section, with frequent bivalves, belemnites, dispersed vegetation (stems, trunks, leaves), and rare microfossils, including Cretaceous benthic foraminifera, ostracods and radiolarians, which occur between Samples LC28 and LC95 (Florisbal et al., 2013). In general, macrofossils, where frequent at certain horizons, were contained in carbonate concretions (Fig. 2).

Samples were processed following the technique of Antunes (1997) to make the slides. We first washed each sample to remove any potential contaminants, crushed the sample and placed the powdered sediment into a test-tube previously cleaned in HCl, then rinsed. We added 40 ml of distilled water, shook the tube to mix the sediment, and waited four minutes before decantation. Some of the suspension taken with a disposable pipette from the middle of the test-tube was flooded onto a coverslip placed on a hotplate. When dry, the coverslip was affixed to a glass slide using Norland optical adhesive N° 61.

A quantitative study was performed, using a Zeiss Axio Imager A2 microscope at 1000× magnification. Because of the low abundances of calcareous nannofossils in the slides, counts were done identifying all specimens in seven longitudinal traverses, equivalent to 700 fields of view. These results are presented in the distribution chart (Table 1).

Preservation of calcareous nannofossils was evaluated using qualitative criteria to assess the degree of etching (E) and/or overgrowth (O), where E1 or O1 are relatively good - specimens exhibited little or no dissolution and/or overgrowth; E2 or O2 are moderate - specimens exhibited moderate dissolution and/or overgrowth, and were easily recognisable; and E3 or O3 are poor - specimens exhibited extreme dissolution and/or overgrowth (Roth and Thierstein, 1972; Roth, 1983).

The slides are stored in the collections of the Museu de História Geológica do Rio Grande do Sul, Universidade do Vale do Rio dos Sinos (UNISINOS), Brazil, under the curatorial numbers ULVG-11237 to ULVG-11336.

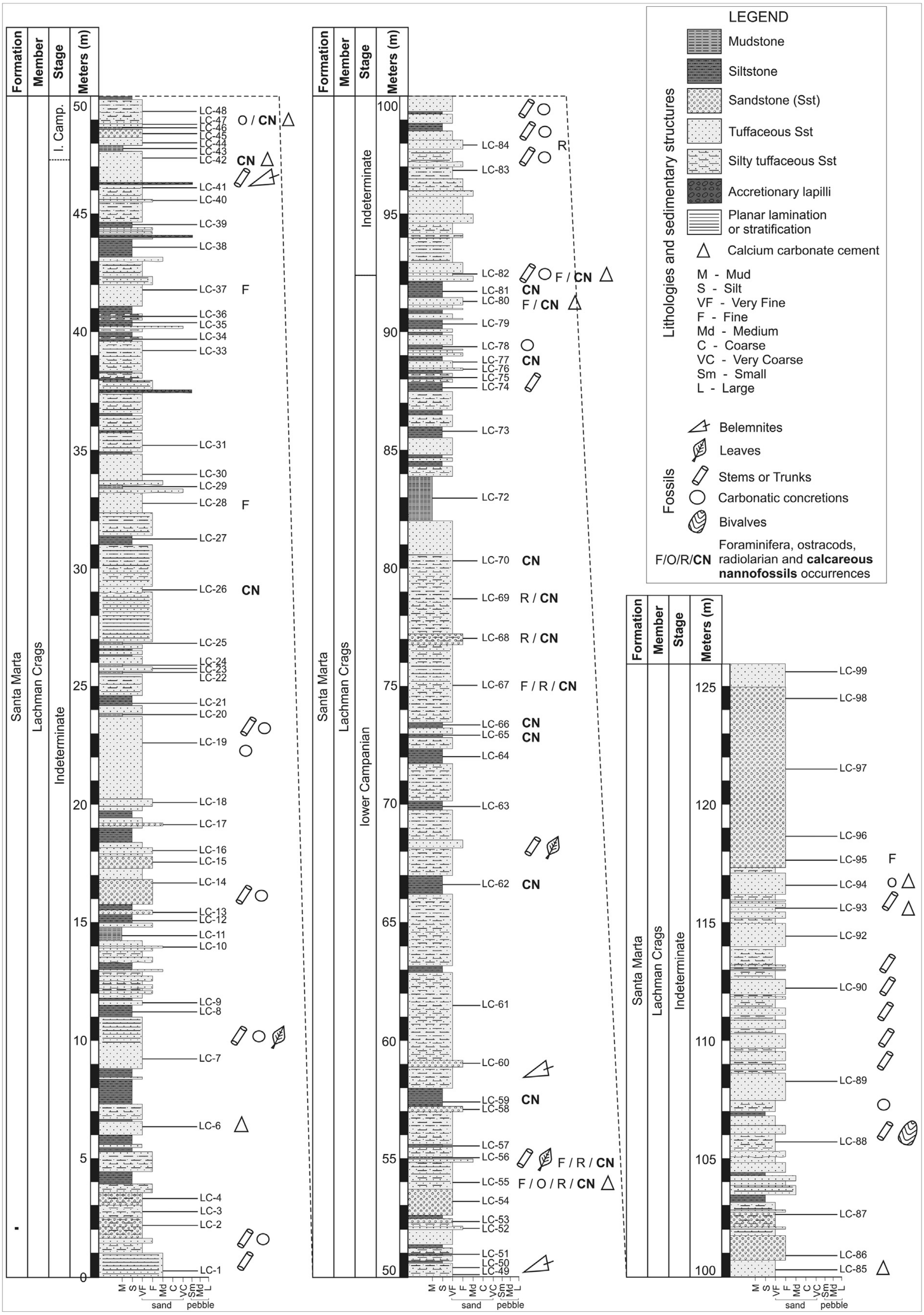

Fig. 2. Studied stratigraphic section, showing position of samples. Modified from Florisbal et al. (2013).

Table 1
Range-chart showing calcareous nannofossil data and biostratigraphic interpretation.

SAMPLE	PRESERVATION	SPECIES RICHNESS	STAGE	CALCAREOUS NANNOFOSSIL ZONE (Watkins et al., 1996)	CALCAREOUS NANNOFOSSIL ZONE (Burnett et al., 1998)	*Acuturris scotus*	*Ahmuellerella octoradiata*	***Arkhangelskiella cymbiformis***	***Biscutum constans***	*Biscutum* cf. *B. coronum*	*Biscutum dissimilis*	*Biscutum magnum*	*Braarudosphaera bigelowii*	*Broinsonia matalosa*	*Broinsonia parca expansa*	*Calculites obscurus*	*Calculites ovalis*	*Calculites* sp. (side view)	*Cervisiella saxea*	*Chiastozygus bifarius*	*Chiastozygus stylesii*	*Cyclagelosphaera reinhardtii*	*Cyclagelosphaera rotaclypeata*	*Discorhabdus ignotus*	*Eiffellithus eximius*	*Eiffellithus gorkae*	*Eiffellithus keio*	*Eiffellithus turriseiffelii*	*Gartnerago obliquum*	***Gephyrobiscutum diabolum***	*Kamptnerius magnificus*	*Lapideacassis mariae*	*Lucianorhabdus cayeuxii*	*Lucianorhabdus maleformis*	*Micula cubiformis*	*Micula staurophora*	*Octolithus multiplus*	*Percivalia? dunkleyjonesii*	*Percivalia fenestrata*	*Prediscosphaera cretacea*	*Prediscosphaera* cf. *P. grandis*	*Prediscosphaera spinosa*	*Prediscosphaera stoveri*	*Reinhardtites anthophorus*	*Repagulum parvidentatum*	*Retecapsa crenulata*	*Rhagodiscus angustus*	*Rhagodiscus reniformis*	*Rhagodiscus* cf. *R. splendens*	*Seribiscutum primitivum*	*Staurolithites elongatus*	*Staurolithites laffittei*	*Staurolithites minimus*	*Staurolithites* sp.	*Tegumentum lucidum*	*Tranolithus salillum*	*Watznaueria barnesiae*
99-83		0	**Indeterminate**																																																						
82	E1/O1	14	**lower Campanian**	***Gephyrobiscutum diabolum* to *Broinsonia dentata* Subzones**	**UC13**		7		16					13										1	6				2	37				1						4			4	6								1				10	3
81	E1/O1	23					14	1				1		58		1	3		1	2		1		1	29				1	18				1						6			1	45						1	1	1	2			13	6
80	E1/O1	35					23	1	411	1		3		124		1	1		3	1	1		1		34	1	5		2	437	6	1	2	1			2		1	12			2	66	1		5	1	2		3	15	5			49	11
79-78		0																																																						
77	E1/O1	23					5	2						7		1	3		3	1			2	1	11			1	1	16	3			2						6	1			28							3		3	1		22	4
76-72		0																																																						
70	E1/O1	1																																																		1				
69	E1/O1	23					13	9					1	11	1	1			1	1				1	17			1			4						1			6		1	2	23			2		1			1	4			55	8
68	E1/O1	1																																									1													
67	E1/O1	19					7	2	3			1		3						1				1	14					136	2									6				58			1		3	1		5	5			52	6
66	E1/O1	7														1																					1			1				2								1				10	1
65	E1/O1	1																																																						1	
64-63		0																																																						
62	E1/O1	1																																																						1
61-60		0																																																					
59	E1/O1	2																																																					1	1
58-57		0																																																					
56	E1/O1	20					2	2	114		1						1								7	1			6	642	3			2			1		1			1		3	6	1							7			8	3
55	E1/O1	30					5	6	998			1		6						6					38	1	2	1	4	1756	1		1	1				2	2	8	1		3	4	6		7	3	2			27	12		1	27	2
54-48		0																																																					
47	E1/O1	37					8	4	364		1	3		19	1	2	5			5		1			14	2	1		7	590	7		2	4	1	1	1		4	24	1		1	7	4	1	3	3	5			19	6		1	37	18
46-43		0																																																						
42	E1/O1	27				1	4	1	387					1			2	1						1	13				3	204	6			1			1		1	5		1	2	4	11		1	1	3			14		1		26	7
41-27		0																																																					
26	E2/O2	2	**Indeterminate**																						1																																2
25-1		0																																																					

4. Results

The species identified in this study are recorded in Table 1, and illustrated in Figs. 3–8. Identification of the species was aided by Perch-Nielsen (1985), Burnett et al. (1998) and Nannotax3 (Young et al.).

Despite the large number of barren samples (82), the remaining 17 allowed the recognition of 52 species. The most representative genera are *Biscutum*, *Broinsonia*, *Eiffellithus*, *Gartnerago*, *Gephyrobiscutum*, *Reinhardtites*, *Staurolithites* and *Tranolithus*.

The lower part of the section is rich in silica and predominantly barren of calcareous nannofossils, except for sample LC26, which is virtually barren. In the middle part, also relatively rich in silica, 16 samples were productive, and some of these were rich in nannofossils, with *Gephyrobiscutum diabolum* and *Biscutum constans* showing high abundances, in comparison to impoverished nannofossil assemblages recovered from other Antarctic outcrops. The presence of *G. diabolum*, previously mentioned by Švábenická et al. (2012), was confirmed by our study. This species has previously

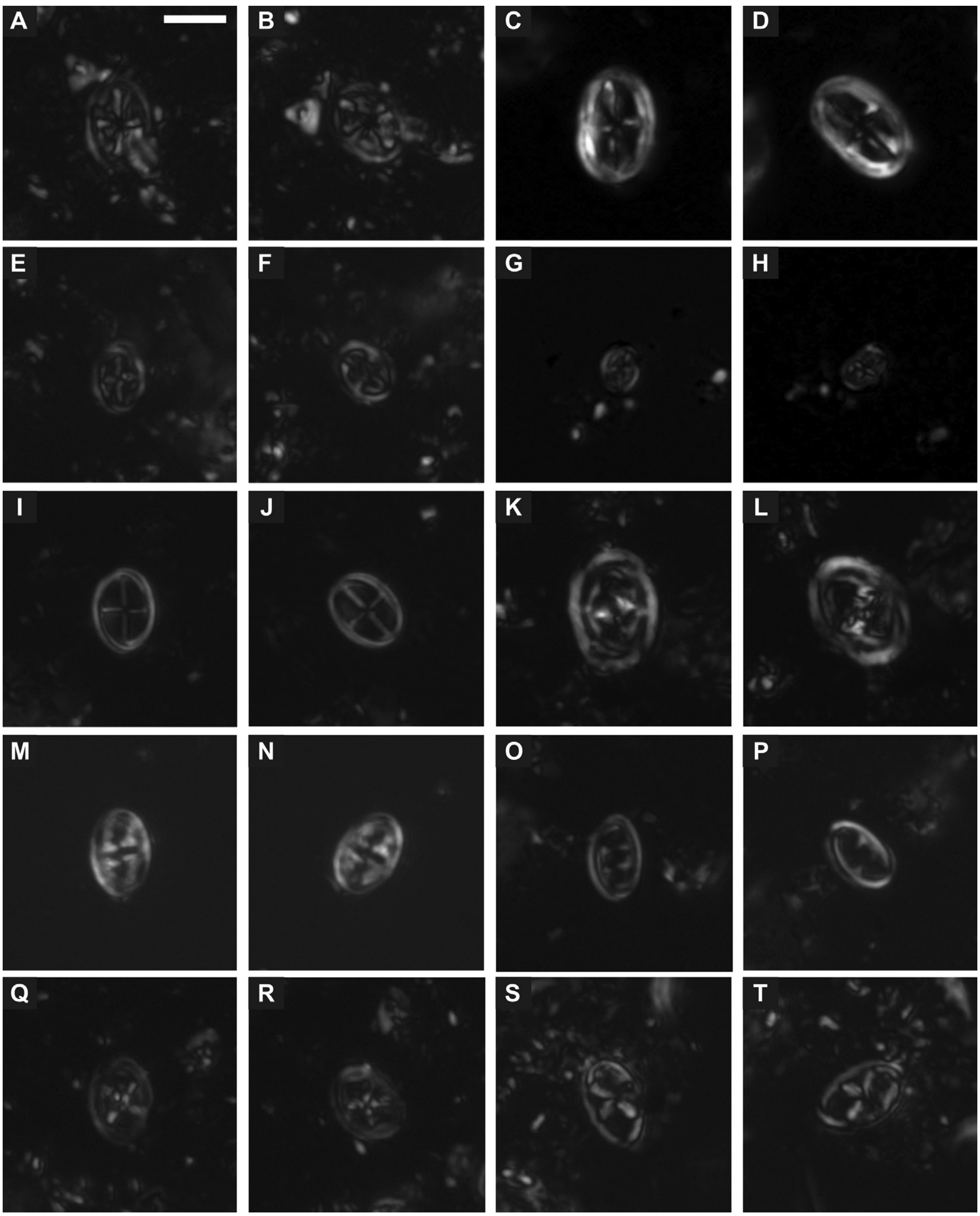

Fig. 3. A/B, *Ahmuellerella octoradiata* (ULVG-11316), sample 80, 92.30 m; C/D, *Staurolithites elongatus* (ULVG-11313), sample 77, 90.20 m; E/F, *Staurolithites laffittei* (ULVG-11291), sample 55, 55.20 m; G/H, *Staurolithites minutus* (ULVG-11291), sample 55, 55.20 m; I/J, *Staurolithites* sp. (ULVG-11278), sample 42, 48.10 m; K/L, *Reinhardtites anthophorus* (ULVG-11316), sample 80, 92.30 m; M/N, *Tranolithus salillum* (ULVG-11292), sample 56, 56.30 m; O/P, *Tranolithus salillum* (ULVG-11303), sample 67, 76.20 m; Q/R, *Chiastozygus bifarius* (ULVG-11283), sample 47, 49.50 m; S/T, *Chiastozygus stylesii* (ULVG-11316), sample 80, 92.30 m. Scale bar equal to 5 μm.

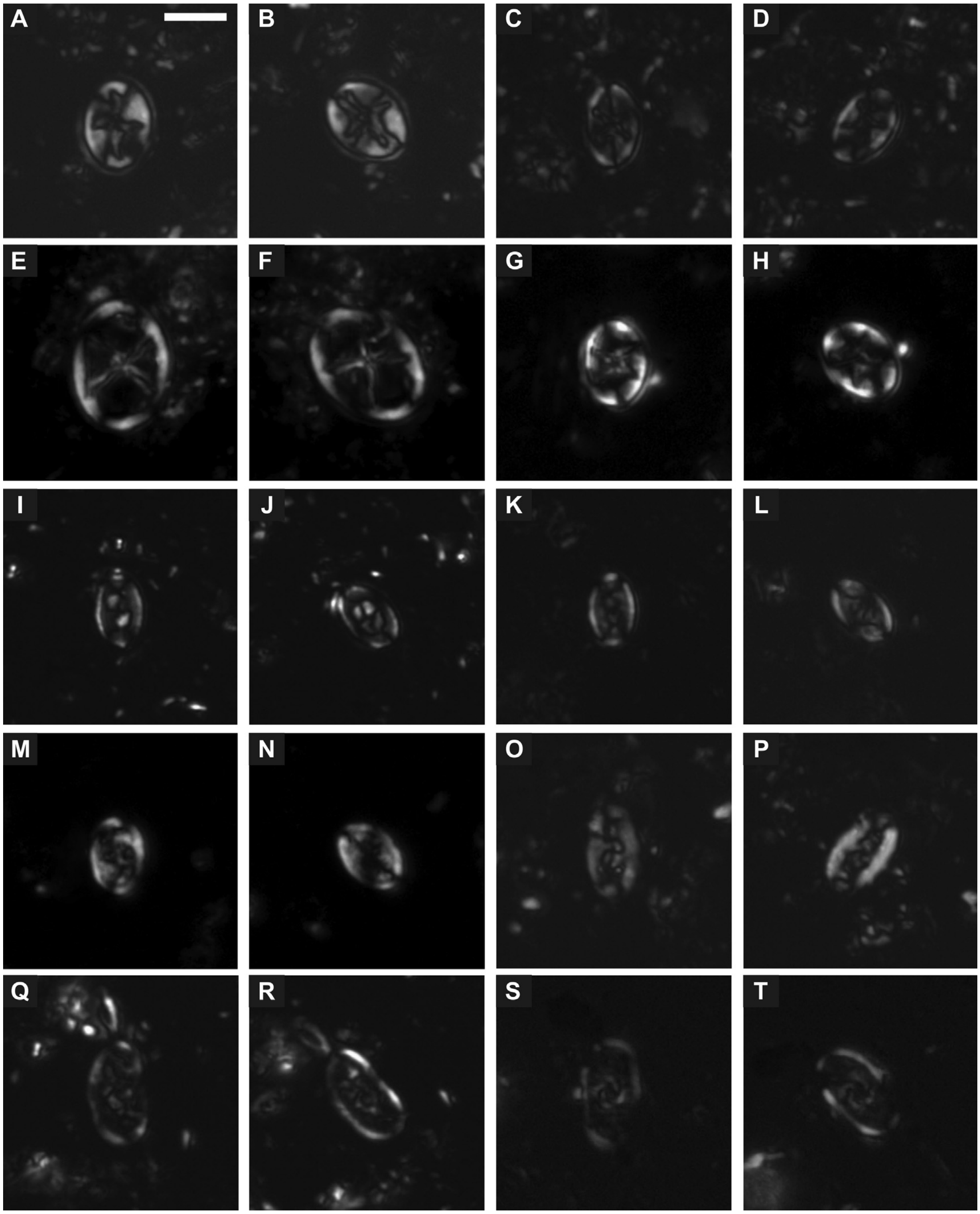

Fig. 4. A/B, *Eiffellithus eximius* (ULVG-11291), sample 55, 55.20 m; E/F; C/D, *Eiffellithus gorkae* (ULVG-11316), sample 80, 92.30 m; E/F, *Eiffellithus keio* (ULVG-11292), sample 56, 56.30 m; G/H, *Eiffellithus turriseiffelii* (ULVG-11283), sample 47, 49.50 m; I/J, *Tegumentum lucidum* (ULVG-11283), sample 47, 49.50 m; K/L, *Percivalia fenestrata* (ULVG-11278), sample 42, 48.10 m; M/N, *Percivalia*? *dunkleyjonesii* (ULVG-11283), sample 47, 49.50 m; O/P, *Rhagodiscus angustus* (ULVG-11291), sample 55, 55.20 m; Q/R, *Rhagodiscus reniformis* (ULVG-11283), sample 47, 49.50 m; S/T, *Rhagodiscus* cf. *R. splendens* (ULVG-11278), sample 42, 48.10 m. Scale bar equal to 5 µm.

only been found in the Campanian of the Falkland Plateau (Wise, 1988; Watkins et al., 1996).

4.1. Occurrences and preservation

Calcareous nannofossil assemblages are generally significantly modified through post-mortem processes acting in the water column and in the sediment, with small and delicate taxa most commonly being lost (Bown et al., 2008). The samples analysed here have clearly been deleteriously affected, as indicated by the many barren samples and by low numbers of specimens per slide and relatively very low to low species richnesses in the productive samples (see Table 1).

Barren intervals in the lower and upper parts of the section correspond to a similar pattern exhibited by foraminifera (Florisbal et al., 2013). This could reflect unsuitable facies, as part of a regressive sequence (Scasso et al., 1991; Olivero, 2012), or a dissolution effect (Florisbal et al., 2013). This part of the studied section is particularly rich in silica, devitrified glassy shards, remains of organic material, pyrite and some heavy minerals. Tree trunks and

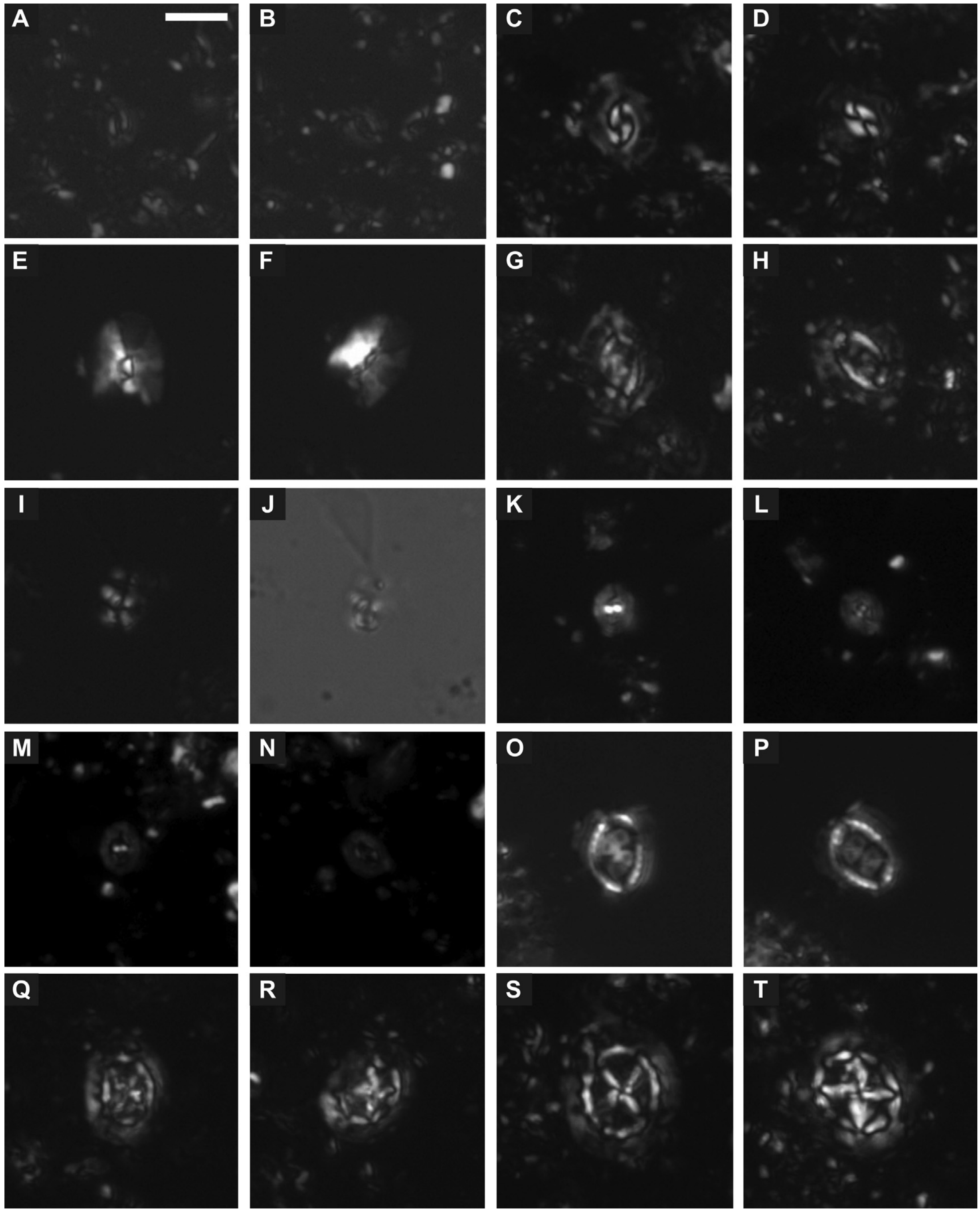

Fig. 5. A/B, *Biscutum constans* (ULVG-11283), sample 47, 49.50 m; C/D, *Biscutum* cf. *B. coronum* (ULVG-11316), sample 80, 92.30 m; E/F, *Biscutum dissimilis* (ULVG-11292), sample 56, 56.30 m; G/H, *Biscutum magnum* (ULVG-11283), sample 47, 49.50 m; I/J, *Discorhardus ignotus* (ULVG-11303), sample 67, 76.20 m; K/L, *Gephyrobiscutum diabolum* (ULVG-11283), sample 47, 49.50 m; M/N, *Gephyrobiscutum diabolum* (ULVG-11291), sample 55, 55.20 m; O/P, *Seribiscutum primitivum* (ULVG-11317), sample 81, 92.80 m; Q/R, *Prediscosphaera cretacea* (ULVG-11283), sample 47, 49.50 m; S/T, *Prediscosphaera* cf. *P. grandis* (ULVG-11316), sample 80, 92.30 m. Scale bar equal to 5 μm.

carbonate concretions are frequent at certain levels, and the presence of belemnites in Sample LC41 provided a Mesozoic age for this interval. Coarsening- and thickening-upward, friable, tuffaceous sandy turbidites, are capped by laminated, carbonised plant fragments (Olivero, 2012).

Samples richest in nannofossils (LC55, LC56 and LC80) are from a silty, tuffaceous sandstone with carbonate cement. Besides abundant nannofossils, scarce foraminifera, ostracods and radiolarians were also found in these samples. In Samples LC55 and LC80, there were some benthic foraminifera species, including *Gyroidinoides globulosus* Hagenow, which suggest deep neritic to upper bathyal palaeodepths, at least at these stratigraphic levels. Ostracod assemblages, composed of *Cytherella*, *Majungaella*, *Paracypris* and *Bythocypris* (Florisbal et al., 2013), provide a broad Cretaceous age for these samples. The presence of *Majungaella* particularly suggests deposition in a shelf environment with relatively warm waters and normal salinities (Piovesan et al., 2012).

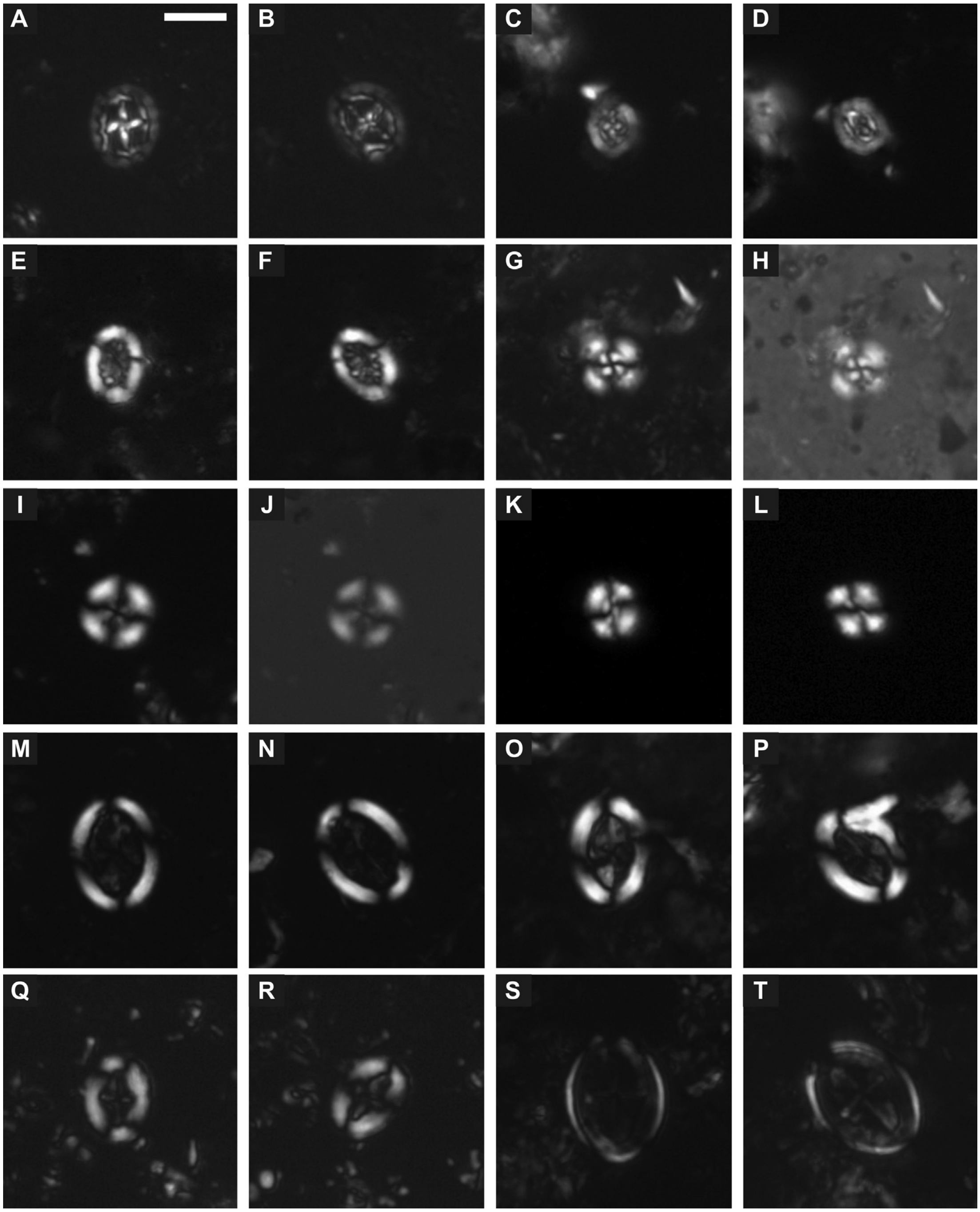

Fig. 6. A/B, *Prediscosphaera spinosa* (ULVG-11278), sample 42, 48.10 m; C/D, *Prediscosphaera stoveri* (ULVG-11283), sample 47, 49.50 m; E/F, *Retecapsa crenulata* (ULVG-11293), sample 57, 56.70 m; G/H, *Cyclagelosphaera reinhardtii* (ULVG-11317), sample 81, 92.80 m; I/J, *Cyclagelosphaera rotaclypeata* (ULVG-11316), sample 80, 92.30 m; K/L, *Watznaueria barnesiae* (ULVG-11316), sample 80, 92.30 m; M/N, *Arkhangelskiella cymbiformis* (ULVG-11313), sample 77, 90.20 m; O/P, *Broinsonia parca expansa* (ULVG-11305), sample 69, 80.50 m; Q/R, *Broinsonia signata* (ULVG-11291), sample 55, 55.20 m; S/T, *Gartnerago obliquum* (ULVG-11313), sample 77, 90.20 m. Scale bar equal to 5 µm.

4.2. Biostratigraphy

Samples from the lower part of the section (LC1 to LC41) were barren, except for LC26, which contains three specimens representing only two species. Because of the scarcity of calcareous nannofossils in this sample, this interval (LC1 to LC41) is indeterminate in age. The upper part of the section is also barren (Samples LC83 to LC99), and its age is also indeterminate.

In the middle part of the section (Samples LC42 to LC82), 16 samples were productive, to varying degrees, allowing the recognition of nannofossil (sub)zones (Table 1). This interval ranges between the *G. diabolum* and *Broinsonia dentata* Subzones (Lower Campanian) according to the austral scheme of Watkins et al. (1996), based mainly on the presence of *G. diabolum* and the absence of *Reinhardtites levis.* To provide a global stratigraphic context it was possible to assign this interval in the UC13 Zone (Lower Campanian) of Burnett et al. (1998), based on the presence of *Arkhangelskiella cymbiformis* and the absence of the overlying markers *Broinsonia parca parca* and *Broinsonia parca constricta* (species that occurs in other high-latitude site).

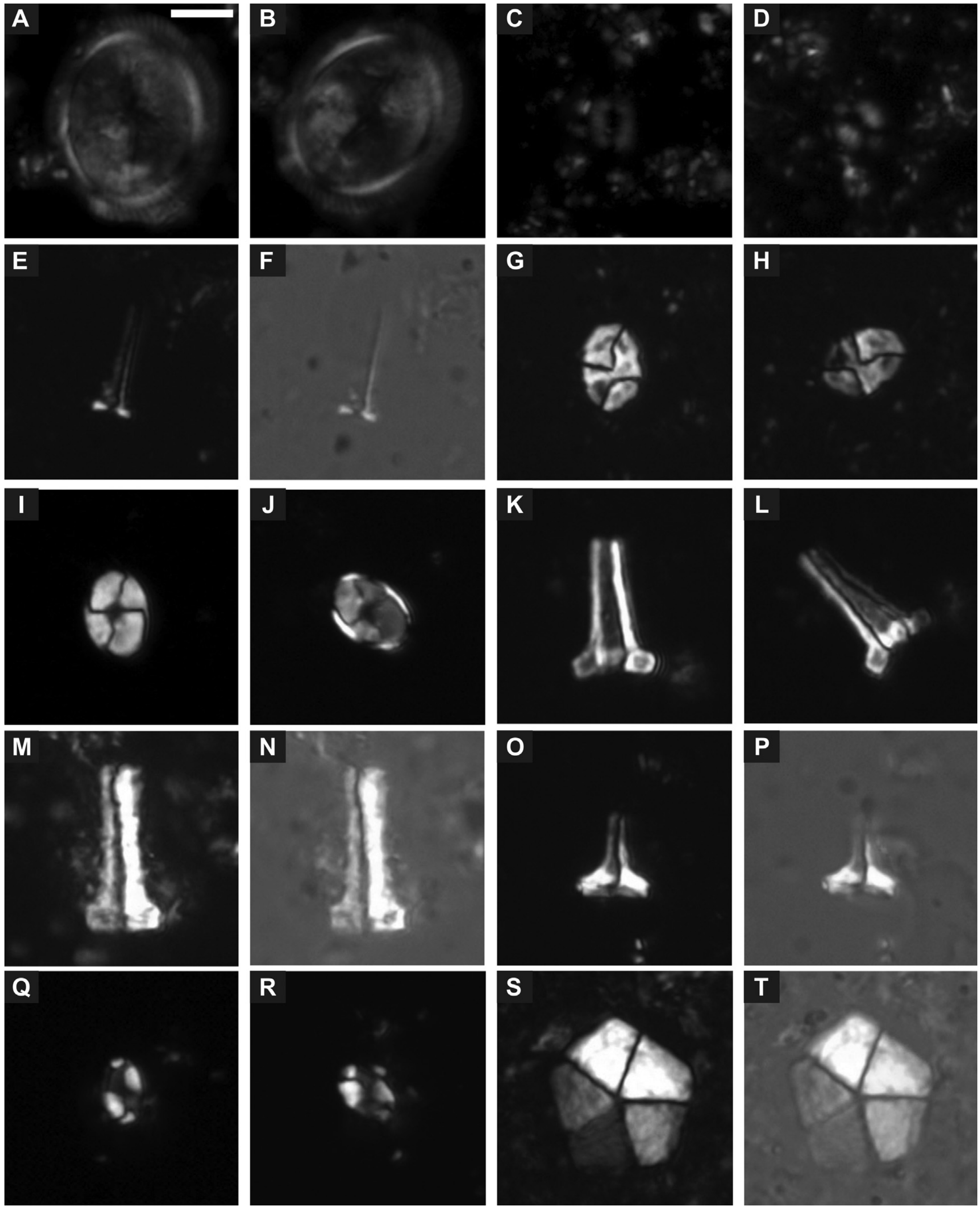

Fig. 7. A/B, *Kamptnerius magnificus* (ULVG-11291), sample 55, 55.20 m; C/D, *Repagulum parvidentatum* (ULVG-11291), sample 55, 55.20 m; E/F, *Acuturris scotus* (ULVG-11278), sample 42, 48.10 m; G/H, *Calculites obscurus* (ULVG-11283), sample 47, 49.50 m; I/J, *Calculites ovalis* (ULVG-11313), sample 77, 90.20 m; K/L, *Calculites* sp. (ULVG-11278), sample 42, 48.10 m; M/N, *Lucianorhabdus cayeuxii* (ULVG-11316), sample 80, 92.30 m; O/P, *Lucianorhabdus maleformis* (ULVG-11278), sample 42, 48.10 m; Q/R, *Octolithus multiplus* (ULVG-11316), sample 80, 92.30 m; S/T, *Braarudosphaera bigelowii* (ULVG-11305), sample 69, 80.50 m. Scale bar equal to 5 μm.

The calcareous nannofossil ages agree well with Ammonite Assemblages 2–3 of the Santa Marta Formation, which are also Campanian in age (Olivero, 2012): previous ammonite and inoceramid studies of the Alpha Member of the Santa Marta Formation suggested a Campanian age, although the base of the formation was thought to potentially reach the uppermost Santonian (Crame, 1983; Olivero, 1984, 2012; Crame et al., 1991; Carvalho, pers. comm., 2014). Ostracods, foraminifera and radiolarians from the same samples as ours provide a broader Late Cretaceous age (Florisbal et al., 2013), while palynology also suggests Campanian (Dettmann and Thomson, 1987) and early Santonian/early Campanian (Keating, 1992; Barreda and Olivero, 1993).

5. Discussion

The nannofossil distribution and preservation data compare well with previous studies in the same general area, although we encountered more units with high species richnesses. Hradecká et al. (2011) and Švábenická et al. (2012) studied a section of the Santa Marta Formation from Col Crame. There, they found 10

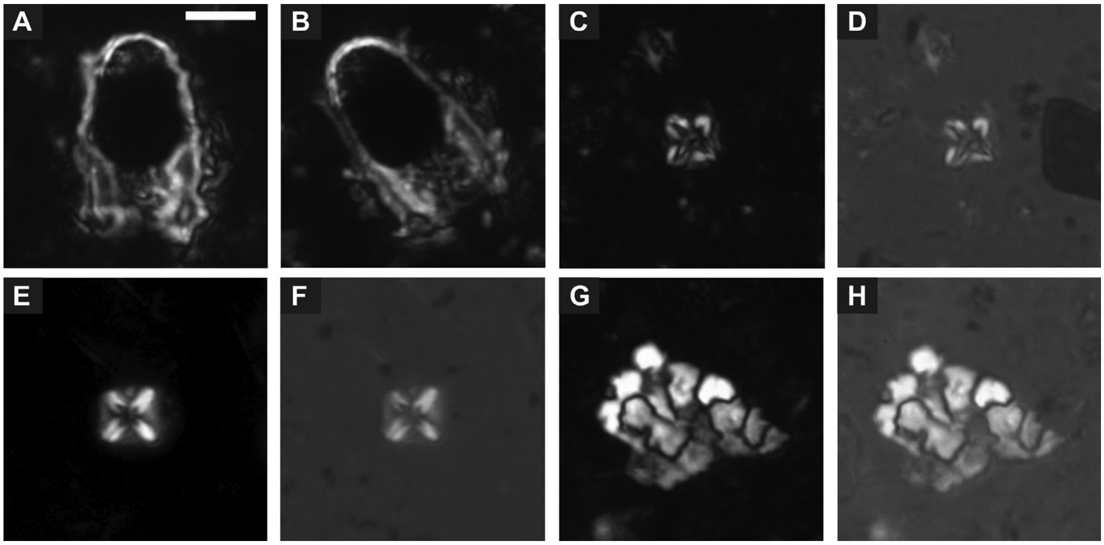

Fig. 8. A/B, *Lapideacassis mariae* (ULVG-11316), sample 80, 92.30 m; C/D, *Micula cubiformis* (ULVG-11283), sample 47, 49.50 m; E/F, *Micula staurophora* (ULVG-11293), sample 57, 56.70 m; G/H, *Cervisiella saxea* (ULVG-11305), sample 69, 80.50 m. Scale bar equal to 5 μm.

fossiliferous samples containing foraminifera, and only three samples yielded calcareous nannofossils. At their level KSM4, very near to the LC80 level of this study, they recovered the planktonic foraminifer *Archaeoglobigerina bosquensis* Pessagno, and in KSM4-5, Švábenická et al. (2012) found a moderately preserved nannoflora, reporting the occurrence of *G. diabolum*.

As mentioned, the samples richest in nannofossils (LC55, LC 56, and LC 80) are from a silty, tuffaceous sandstone. The abundance of these nanofossils may be due to the presence of volcanic ash. As summarized by Wise (1977), coccoliths in samples with higher amounts clay, zeolite, volcanic ash or siliceous microfossils are generally far better preserved than those in purer carbonate oozes as noted by Bukry (1971). Apparently, the presence of silica in solution inhibits the dissolution-diffusion-reprecipitation process that otherwise tends to convert nannofossils to chalk.

Although the nannofossil-productive assemblages described here are likely modified by diagenesis, we find that *G. diabolum* and *Biscutum constans* dominate the assemblages. *G. diabolum* has previously only been reported from the Falkland Plateau (e.g. Wise, 1988; Watkins, 1992; Watkins et al., 1996), so here we extend its geographic range into the Antarctic Peninsula, and suggest a broadly cooler-water ecology for this species, and perhaps also for *B. constans*. The rest of the taxa recorded in this study have cosmopolitan distributions, a finding similar to those found from southeast James Ross, Snow Hill and Seymour Islands (Concheyro et al., 1991, 1994; Concheyro, 2004), in upper Campanian-Maastrichtian strata.

6. Concluding remarks

Calcareous nannofossils were recovered from Upper Cretaceous deposits of the Santa Marta Formation of the Lachman Crags Member, James Ross Island. Although containing numerous barren intervals, this constitutes the most complete and well-documented sequence of nannofloras recovered from the northern area of the island to date. Application of both the austral zones of Watkins et al. (1996) and the global zones of Burnett et al. (1998) provides an early Campanian age for these samples. This age range is closely comparable to that provided by ammonites, and provides higher resolution than has been achieved with foraminifera, ostracods and radiolarians from the same locality.

The consistent presence of *G. diabolum* in the section, previously only recorded from the Falkland Plateau, extends its distribution to higher latitudes, at least in the Antarctic Peninsula area, and suggests a broadly cool-water ecology for this species.

Acknowledgements

This project was primarily funded by the Brazilian National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico [CNPq] grant n. 557347/2005-0 and 302064/2010-9 to M. Carvalho), the Research Support Foundation of Rio de Janeiro State (Fundação Carlos Chagas Filho de Amparo à Pesquisa do Rio de Janeiro [FAPERJ] grant n.E-26/103.028/2008 to M. Carvalho) and the Research Center of Petrobras (Centro de Pesquisa Miguez, Petróleo Brasileiro [CENPES-PETROBRAS] grant n. CENPES 10292 to M. Carvalho). The authors thanks the Brazilian Navy for logistical and technical support during the expedition to Antarctica and the staff of Itt Fossil, Universidade do Vale do Rio dos Sinos (UNISINOS). Sherwood W. Wise Jr. is specially thanked for the valuable suggestions, as well as Silvia Gardin, Cristianini T. Bergue and Karlos G. D. Kochhann for reviewing an early version of the manuscript. Christian Linnert and an anonymous reviewer are thanked for their comments that improved the manuscript. Andrea Concheyro thanks the Instituto Antártico Argentino for logistics provided for many years in the summer Antarctic expeditions to James Ross Island. This paper is contribution number R-127 of the Instituto de Estudios Andinos 'Don Pablo Groeber' (IDEAN-CONICET). This study was partially supported by PICTO 2010-00112, República Argentina.

References

Antunes, R.L., 1997. Introdução ao estudo dos nanofósseis calcários. Instituto de Geociências - UFRJ, Rio de Janeiro, pp. 13–16.

Askin, R.A., 1988. Campanian to paleocene palynological succession of Seymour and adjacent islands, northeastern Antarctic Peninsula. In: Feldman, R.M., Woodburne, M.O. (Eds.), Geology and Paleontology of Seymour Island, Antarctic Peninsula, Memoir, vol. 169. Geological Society of America, pp. 131–153.

Barreda, V., Olivero, E., 1993. Asociaciones esporopolínicas del Cretácico tardío de Cabo Lamb, Isla Vega, Antártida. In: Segundas Jornadas de Comunicaciones sobre Investigaciones Antárticas, Actas, pp. 153–154.

Bertels-Psotka, A., Concheyro, A., Salani, F.M., 2001. Las diamictitas de Cabo Hamilton (Mioceno Superior), Isla James Ross, Antartida, caracterización estratigráfica; sus microfósiles. In: IV Congreso de Geología y Minería de la Sociedad Cubana de Geología.

Bown, P.R., Dunkley Jones, T., Lees, J.A., Randell, R.D., Mizzi, J.A., Pearson, P.N., Coxall, H.K., Young, J.R., Nicholas, C.J., Karega, A., Singano, J., Wade, B.S., 2008. A paleogene calcareous microfossil Konservat-Lagerstätte from the Kilwa Group of coastal Tanzania. GSA Bulletin 120 (1/2), 3–12.

Buatois, L.A., López-Angriman, A.O., 1992. Trazas fósiles y sistemas deposicionales, Grupo Gustav, Cretácico de la isla James Ross. In: Rinaldi, C.A. (Ed.), Geología de la Isla James Ross, Antártida. Instituto Antártico Argentino, Buenos Aires, pp. 239–262.

Bukry, D., 1971. Cenozoic calcareous nannofossils from the Pacific Ocean. San Diego Society Natural History Transactions 16, 303–327.

Burnett, J.A., Gallagher, L.T., Hampton, M.J., 1998. Upper Cretaceous. In: Bown, P.R. (Ed.), Calcareous Nannofossil Biostratigraphy. British Micropalentological Society Series, London, pp. 132–199.

Caramés, A., Concheyro, A., 2013. Late cenozoic foraminifera from diamictites of cape lamb, Vega Island, Antarctic Peninsula. Ameghiniana 50 (1), 114–135.

Carvalho, M.A., Ramos, R.R.C., Crud, M.B., Witovisk, L., Kellner, A.W.A., Silva, H.P., Grillo, O.N., Riff, D., Romano, P.S.R., 2013. Palynofacies as indicators of paleoenvironmental changes in a cretaceous succession from the Larsen Basin, James Ross Island, Antarctica. Sedimentary Geology 295, 53–66.

Concheyro, A., 2004. Mesozoic calcareous nannofossils from Larsen Basin, southern Antarctic Peninsula. In: GeoSur International Symposium. Extended Abstracts, Buenos Aires, pp. 255–257.

Concheyro, A., Olivera, A., Santillana, S., Marenssi, S., Rinaldi, C., 1991. Nanofosiles calcáreos del Cretácico Superior de Isla Marambio, Antártida. In: Congreso Geologico Chileno. Resúmenes Expandidos, pp. 825–828.

Concheyro, A., Robles Hurtado, G.M., Olivero, E.B., 1994. Micropaleontologia del Nunatak Sanctuary Cliffs, Isla Snow Hill y de Cabo Hamilton, Isla James Ross, Antartida. In: Terceras Jornadas de Comunicaciones sobre investigaciones Antárticas, Buenos Aires, Resúmenes, pp. 17–23.

Concheyro, A., Robles Hurtado, G., Olivero, E., 1995. Sedimentology and calcareous nannofossils from the Upper Cretaceous-paleocene of James Ross Island area, Antarctica. In: VII International Symposium on Antarctic Earth Sciences. Siena, Italia. Abstracts, p. 88.

Concheyro, A., Gennari, F., Robles Hurtado, G., Morlotti, E., 1997. Microfósiles del Cretácico Superior de Punta Ekelöf, Isla James Ross, Antártida. In: IV Jornadas sobre Investigaciones Científicas Antárticas. Buenos Aires, Tomo II, pp. 305–313.

Concheyro, A., Salani, F.M., Adamonis, S., Lirio, J.M., 2007. Los depósitos diamictíticos cenozoicos de la cuenca James Ross, Antártida: una síntesis estratigráfica y nuevos hallazgos paleontológicos. Revista de la Asociación Geológica Argentina 62 (4), 568–585.

Concheyro, A., Caramés, A., Amenábar, C.R., Adamonis, S., Lirio, J.M., Ballent, S., Di Pasquo, M., Mackern, A., 2010. Cenozoic microbiotas from the eastern sector of the James Ross Island group, Antarctic Peninsula. In: SCAR XXXI & Open Science Conference.

Concheyro, A., Caramés, A., Amenábar, C.R., Lescano, M., 2014. Nannofossils, foraminifera and microforaminiferal linings in the cenozoic diamictites of cape Lamb, Vega Island, Antarctica. Polish Polar Research 35 (1), 1–26.

Crame, J.A., 1983. Cretaceous inoceramid bivalves from Antarctica. In: Oliver, R.L., James, P.R., Jago, J.B. (Eds.), Antarctic Earth Science. Australian Academy of Science, Canberra, pp. 298–302.

Crame, J.A., Pirrie, D., Riding, J.B., Thomson, M.R.A., 1991. Campanian-maastrichtian (Cretaceous) stratigraphy of the James Ross Island area, Antarctica. Journal of the Geological Society of London 148, 1125–1140.

Crux, J.A., 1991. Calcareous nannofossils recovered by LEG 114 in the Subantarctic South Atlantic Ocean. Proceedings of the Ocean Drilling Program, Scientific Results 114, 155–177.

Dettmann, M.E., Thomson, M.R.A., 1987. Cretaceous palynomorphs from the James Ross Island area, Antarctica – a pilot study. British Antarctic Survey Bulletin 77, 13–59.

Fauth, G., Seeling, J., Luther, A., 2003. Campanian (Upper Cretaceous) ostracods from southern James Ross Island, Antarctica. Micropaleontology 49, 95–107.

Florisbal, L.S., Kochhann, C.G.D., Baecker-Fauth, S., Fauth, G., Viviers, M.C., Carvalho, M.A., Ramos, R.R.C., 2013. Benthic foraminifera, ostracods and radiolarians from the lachman crags member (Santa marta formation), upper Santonian-lower campanian (Upper Cretaceous) of James Ross Island, Antarctica. Revista Brasileira de Paleontologia 16 (2), 181–196.

Francis, J.E., Crame, J.A., Pirrie, D., 2006. Cretaceous-tertiary high-latitude palaeoenvironments, James Ross Basin, Antarctica: introduction. In: Francis, J.E., Pirrie, D., Crame, J.A. (Eds.), Cretaceous-tertiary High-latitude Palaeoenvironments, James Ross Basin, Antarctica, Special Publications, vol. 258. Geological Society, London, pp. 1–5.

Gaździcki, A., Webb, P.N., 1996. Foraminifera from the pecten conglomerate (Pliocene) of cockburn island, Antarctic Peninsula. Palaeontologia Polonica 55, 147–174.

Guerra, R., Fauth, G., Concheyro, A., Carvalho, M., Rodriguez Cabral Ramos, R., 2012. Nanofósseis Calcários do Campaniano no Membro Lachman Crags (Formação Santa Marta), norte da Ilha James Ross, Península Antártica. In: 46 Congresso Geológico Brasileiro.

Harwood, D.M., 1988. Upper Cretaceous and lower paleocene diatom and silicoflagellate biostratigraphy of Seymour Island, eastern Antarctic Peninsula. In: Feldman, R.M., Woodburne, M.O. (Eds.), Geology and Paleontology of Seymour Island, Antarctic Peninsula, Memoir, vol. 169. Geological Society of America, pp. 55–130.

Hathway, B., 2000. Continental rift to back-arc basin: Jurassic-Cretaceous stratigraphical and structural evolution of the larsen Basin, Antarctic Peninsula. Journal of the Geological Society of London 157, 417–432.

Hradecká, L., Vodrázka, R., Nývlt, D., 2011. Foraminifera from the Upper Cretaceous of northern James Ross Island (Antarctica): a preliminary report. Czech Polar Reports 1 (2), 88–95.

Huber, B.T., 1988. Upper campanian-paleocene foraminifera from the James Ross Island region (Antarctic-Peninsula). In: Feldman, R.M., Woodburne, M.O. (Eds.), Geology and Paleontology of Seymour Island, Antarctic Peninsula, Memoir, vol. 169. Geological Society of America, pp. 163–252.

Ineson, J.R., 1989. Coarse-grained submarine fan and slope apron deposits in a Cretaceous back-arc basin, Antarctica. Sedimentology 36, 739–819.

Ineson, J.R., Crame, J.A., Thomson, M.R.A., 1986. Lithostratigraphy of the Cretaceous strata of west James Ross Island. Cretaceous Research 7, 141–159.

Keating, J.M., 1992. Palynology of lachman crags member, santa marta formation (Upper Cretaceous) of north-west James Ross Island. Antarctic Science 4 (3), 293–304.

Kellner, A.W.A., Simões, T.R., Riff, D., Grillo, O., Romano, P., de Paula, H., Ramos, R., Carvalho, M., Sayão, J., Oliveira, G., Rodrigues, T., 2011. The oldest plesiosaur (Reptilia, Sauropterygia) from Antarctica. Polar Research 30, 1–6.

Kulhanek, D.K., 2007. Paleocene and maastrichtian calcareous nannofossils from clasts in pleistocene glaciomarine muds from the northern James Ross Basin, western Weddell Sea, Antarctica. In: Cooper, A.K., Raymoud, C.R., et al. (Eds.), Antarctica: A Keystone in a Changing World - Online Proceedings of the 10th ISAES. USGS. Open-File Report 2007-1047, Short Research Paper 019.

Macellari, C.E., 1986. Late Campanian-Maastrichtian ammonite fauna from Seymour Island (Antarctic Peninsula). Paleontological Society, Memoir 18, 1–55.

Macellari, C.E., 1988. Stratigraphy, sedimentology and paleoecology of Upper Cretaceous/Paleocene shelf-deltaic sediments of Seymour Island (Antarctic Peninsula). In: Feldman, R.M., Woodburne, M.O. (Eds.), Geology and Paleontology of Seymour Island, Antarctic Peninsula, Memoir, vol. 169. Geological Society of America, pp. 25–53.

Mac Fayden, W.A., 1966. Foraminifera from the Upper Cretaceous James Ross Island. British Antarctic Survey Bulletin 8, 75–87.

Medina, F.A., Buatois, L., López Angriman, A., 1992. Estratigrafía del Grupo Gustav en la Isla James Ross, Antártida. In: Rinaldi, C.A. (Ed.), Geología de la Isla James Ross, Antártida. Instituto Antártico Argentino, Buenos Aires, pp. 167–192.

Nývlt, D., Kosler, J., Mlcoch, B., Mixa, P., Lisá, L., Bubík, M., Hendriks, B.W.H., 2011. The Mendel formation: evidence for late miocene climatic cyclicity at the northern tip of the Antarctic Peninsula. Palaeogeography, Palaeoclimatology, Palaeoecology 299, 363–384.

Olivero, E.B., 1984. Nuevos ammonites campanianos de la Isla James Ross, Antartida. Ameghiniana 21, 53–84.

Olivero, E.B., 1992. Asociaciones de ammonites de la Formación Santa Marta (Cretácico tardío), isla James Ross, Antártida. In: Rinaldi, C.A. (Ed.), Geología de la Isla James Ross, Antártida. Instituto Antártico Argentino, Buenos Aires, pp. 47–76.

Olivero, E.B., 2012. Sedimentary cycles, ammonite diversity and palaeoenvironmental changes in the Upper Cretaceous Marambio Group, Antarctica. Cretaceous Research 34, 348–366.

Olivero, E.B., Medina, F.A., 2000. Patterns of late Cretaceous ammonite biogeography in southern high latitudes: the family Kossmaticeratidae in Antarctica. Cretaceous Research 21, 269–279.

Olivero, E.B., Scasso, R.A., Rinaldi, C.A., 1986. Revision of the marambio group, James Ross Island, Antarctica. Contribution del Instituto Antártico Argentino 331, 1–28.

Perch-Nielsen, K., 1985. Mesozoic calcareous nannofossils. In: Bolli, H.M., Saunders, J.B., Perch-Nielsen, K. (Eds.), Plankton Stratigraphy. Cambridge University Press, Cambridge, pp. 329–426.

Piovesan, E.K., Ballent, S., Fauth, G., Viviers, M.C., 2012. Cretaceous paleogeography of southern Gondwanaland from the distribution of the marine ostracod *Majungaella* Grekoff: new data and review. Cretaceous Research 37, 127–147.

Pirrie, D., 1989. Shallow marine sedimentation within an active margin basin, James Ross Island, Antarctica. Sedimentary Geology 63, 61–82.

Pirrie, D., Riding, J.B., 1988. Sedimentology, palynology and structure of Humps Island, northern Antarctic Peninsula. British Antarctic Survey, Bulletin 80, 1–19.

Pirrie, D., Crame, J.A., Riding, J.B., 1991. Late Cretaceous stratigraphy and sedimentology of cape lamb, Vega Island, Antarctica. Cretaceous Research 12, 227–258.

Pirrie, D., Crame, J.A., Lomas, S.A., Riding, J.B., 1997. Late Cretaceous stratigraphy of the Admiralty Sound region, James Ross Basin, Antarctica. Cretaceous Research 18, 109–137.

Pospichal, J.J., Wise, S.W., 1990a. Maestrichtian calcareous nannofossil biostratigraphy of Maud Rise, ODP leg 113 sites 689 and 690, Weddell Sea. Proceedings of the Ocean Drilling Program, Scientific Results 113, 465–487.

Pospichal, J.J., Wise, S.W., 1990b. Calcareous nannofossils across the K/T boundary, ODP hole 690c, Maud Rise, Weddell Sea. Proceedings of the Ocean Drilling Program, Scientific Results 113, 515–532.

Riccardi, A.C., 1980. Nuevos amonoideos del Cretácico Superior de Antártida. Ameghiniana 17, 323–333.

Rinaldi, C.A., 1982. The Upper Cretaceous in the James Ross Island group. In: Craddock (Ed.), Antarctic Geoscience. University of Wisconsin Press, Madison.

Rinaldi, C.A., Massabie, A., Morelli, J., Rosenman, H.L., Del Valle, R.A., 1978. Geología de la isla Vicecomodoro Marambio. Instituto Antártico Argentino. Contribución 217, 1–44.

Robles Hurtado, G.M., Concheyro, A., 1995. Sedimentología y bio-cronoestratigrafía (nanofósiles calcáreos) del nunatak Sanctuary cliffs (Cretácico superior), Isla cerro Nevado, Antártida. In: VI Congreso Argentino de Paleontología y Bioestratigrafía (Trelew), Actas, pp. 231–237.
Roth, P.H., 1983. Jurassic and Lower Cretaceous calcareous nannofossils in the Western North Atlantic (Site 534): biostratigraphy, preservation, and some observations on biogeography and peleoceanography. Initial Reports of the Deep Sea Drilling Project 76, 587–621.
Roth, P.H., Thierstein, H., 1972. Calcareous nannoplankton: leg 14 of the Deep Sea Drilling Project. Initial Reports of the Deep Sea Drilling Project 14, 421–485.
Salgado, L., Gasparini, Z., 2006. Reappraisal of an ankylosaurian dinosaur from the Upper Cretaceous of James Ross Island (Antarctica). Geodiversitas 28, 119–135.
Scasso, R.A., Olivero, E.B., Buatois, L.A., 1991. Lithofacies, biofacies, and ichnoassemblages evolution of a shallow submarine volcanoclastic fan-shelf depositional system (Upper Cretaceous, James Ross Island, Antarctica). Journal of South American Earth Sciences 4, 239–260.
Smellie, J.L., 2006. The relative importance of supraglacial versus subglacial meltwater escape in basaltic subglacial tuya eruptions: an important unresolved conundrum. Earth Science Reviews 74, 241–268.
Švábenická, l., Vodrážka, R., Nývlt, D., 2012. Calcareous nannofossils from the Upper Cretaceous of northern James Ross Island, Antarctica: a pilot study. Geological Quarterly 56 (4), 765–772.
Watkins, D.K., 1992. Upper Cretaceous nannofossils from LEG 120, Kerguelen plateau, southern ocean. Proceedings of the Ocean Drilling Program, Scientific Results 120, 343–370.
Watkins, D.K., Wise, S.W., Pospichal, J.J., Crux, J., 1996. Upper Cretaceous calcareous nannofossil biostratigraphy and paleoceanography of the Southern Ocean. In: Moguilevsky, A., Whatley, R. (Eds.), Microfossils and Oceanic Environments. University of Wales (Aberystwyth Press), pp. 355–381.
Whitham, A.G., Ineson, J.R., Pirrie, D., 2006. Marine volcaniclastics of the Hidden Lake Formation (Coniacian) of James Ross Island, Antarctica: an enigmatic element in the history of a back-arc basin. In: Francis, J.E., Pirrie, D., Crame, J.A. (Eds.), Cretaceous-Tertiary High-Latitude Palaeoenvironments, James Ross Basin, Antarctica, Special Publication, vol. 258. Geological Society, London, pp. 21–47.
Wise, S.W., 1977. Chalk formation: early diagenesis. In: Anderson, N.R., Malahoff, A. (Eds.), The Fate of Fossil Fuel CO2 in the Oceans. Plenum Press, New York, pp. 717–739.
Wise, S.W., 1988. Mesozoic-Cenozoic history of calcareous nannofossils in the region of the southern ocean. Palaeogeography, Palaeoclimatology, Palaeoecology 67, 157–179.
Wise, S.W., Wind, F.H., 1977. Mesozoic and cenozoic calcareous nannofossils recovered by DSDP leg 36 drilling on the falkland plateau, Southwest Atlantic sector of the southern ocean. Initial Reports of the Deep Sea Drilling Project 36, 269–491.
Young, J.R., Bown, P.R., Lees J.A., (eds) Nannotax3 website. International nannoplankton association. URL: http://ina.tmsoc.org/Nannotaxs3.