



Nannofossils, foraminifera and microforaminiferal linings in the Cenozoic diamictites of Cape Lamb, Vega Island, Antarctica

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Abstract: Micropaleontological and palynological samples from three Cenozoic diamictites at Cape Lamb, Vega Island, James Ross Basin were analysed. Fossiliferous samples yielded reworked and autochthonous assemblages of Mesozoic calcareous nannofossils, impoverished Cretaceous foraminifera together with Neogene species, as well as Late Cretaceous dinoflagellate cysts, pollen, spores and abundant Cenozoic microforaminiferal linings. The recovered nannoflora indicates Early Cretaceous (Hauterivian–Albian) and Late Cretaceous (Santonian–Early Campanian) ages, suggesting an intensive reworking of marine sediments. The presence of the Early Cretaceous species *Nannoconus circularis* Deres *et* Acheriteguy in the diamictite represents its first record for the James Ross Basin. The scarce foraminiferal fauna includes *Pullenia jarvisi* Cushman, which indicates reworking from lower Maastrichtian–lower Paleocene sediments, and also the Neogene autochthonous *Trochammina* sp. aff. *T. intermedia*. The inner-organic layer observed inside this specimen appears to be identical to microforaminiferal linings recovered from the same sample. Palynomorphs found in the studied samples suggest erosion from the underlying Snow Hill Island and the López de Bertodano Formation beds (upper Campanian–upper Maastrichtian). These recovered assemblages indicate either different periods of deposition or reworking from diverse sources during Cenozoic glaciation, originating in James Ross Island and the Antarctic Peninsula with the influence of local sediment sources.

Key words: Antarctica, James Ross Basin, Cenozoic diamictites, calcareous nannofossils, Foraminifera, microforaminiferal linings.

Introduction

The study of diamictites in high latitudes has increased in recent years due to growing interest in the history of the southern glaciation during the Cenozoic in order to make inferences about the evolution of the Antarctic Ice Sheet during the Quaternary. Some of these studies allow analysis of the response of biota to these climate changes.

Diamictites have been studied previously in different Antarctic basins, in both eastern and western regions of the continent. Reviews of those results mainly focus on the sedimentology, stratigraphy and paleontology of these deposits (*e.g.*, Andersson 1906; Gaździcki and Webb 1996; Marenssi *et al.* 2001; Lirio *et al.* 2003; Concheyro *et al.* 2007; Hambrey *et al.* 2008; Smellie *et al.* 2008; Nelson *et al.* 2009; Marenssi *et al.* 2010; Nývlt *et al.* 2011; Salzmann *et al.* 2011).

In the James Ross Basin, there are several well-exposed diamictite deposits that indicate the onset of glaciation in this basin began around the Miocene or later, with local variation (Concheyro *et al.* 2007; Lirio *et al.* 2007; Nelson *et al.* 2009).

In Cape Lamb, Vega Island, glacial deposits are concentrated in three localities: Sandwich Bluff, Leal Bluff and Cape Lamb (Caramés and Concheyro 2013). At Leal Bluff in particular, a megafauna of bivalves (pectinids and mussels) was found in the lower levels of the diamictites that underlie the lowermost pyroclastic deposits of the James Ross Island Volcanic Group (Marenssi *et al.* 2001).

Few contributions about autochthonous and reworked Mesozoic and Cenozoic microbiota from these diamictites have been published (Caramés *et al.* 2008; Concheyro *et al.* 2010; Caramés and Concheyro 2013). For this reason, the objective of this study is to introduce and illustrate new records of calcareous nannofossils and the associated foraminifera recovered from diamictite deposits at Sandwich Bluff and Leal Bluff, Cape Lamb, Vega Island, Antarctica. Additionally, membrane-like molds of foraminifera, so-called microforaminiferal linings, obtained from palynological residues are also presented.

Geological setting

The Cenozoic diamictite deposits studied here occur on Cape Lamb, southern Vega Island on the eastern tip of the Antarctic Peninsula, and include Sandwich Bluff and Leal Bluff localities (Fig. 1). There, the diamictites overlie Cretaceous sedimentary rocks belonging to the Santa Marta Formation and underlie the basaltic lavas of the Cenozoic James Ross Island Volcanic Group (JRIVG).

The Sandwich Bluff diamictite is 60 cm thick and includes blocks of metamorphic rocks with subparallel striations and E-W orientation. It is considered a subglacial till produced by glaciers coming from the Antarctic Peninsula to the James Ross Basin (Marenssi *et al.* 2001). The absence of local volcanic clasts in

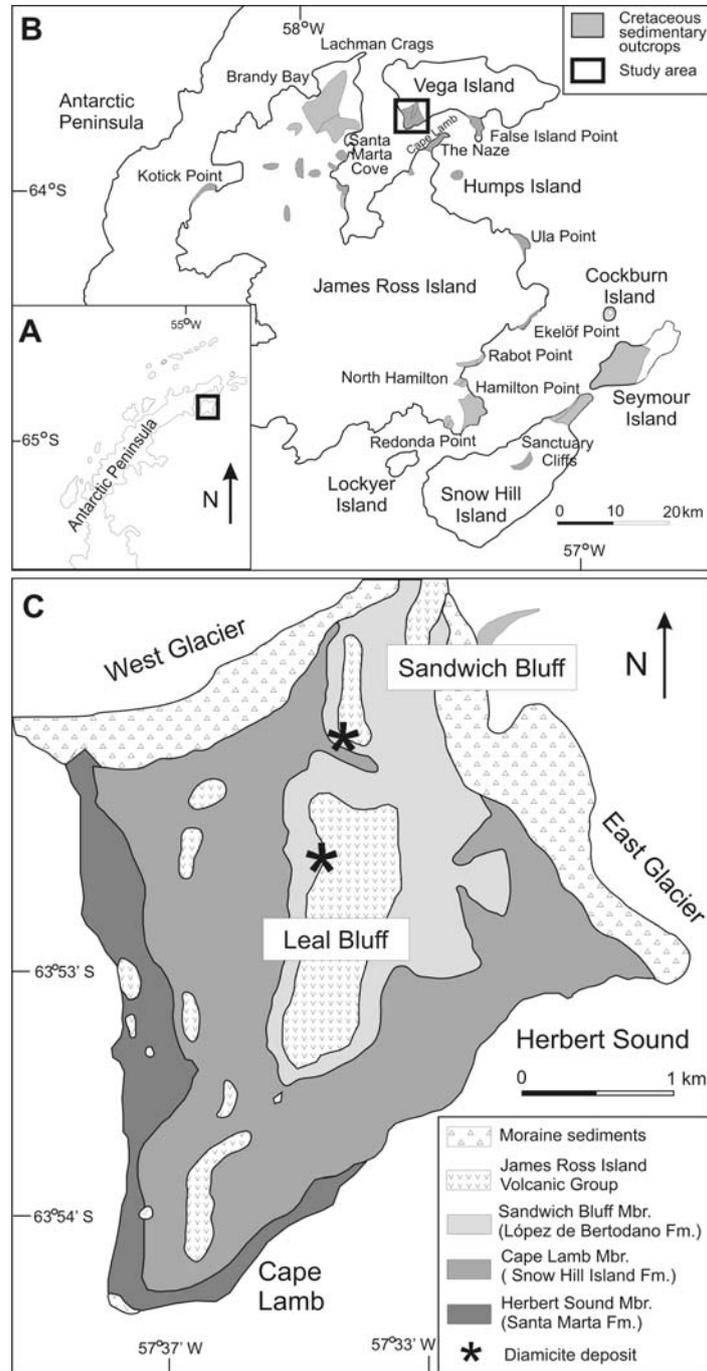


Fig. 1. **A.** Location map of Vega Island relative to the Antarctic Peninsula. **B.** Location of Sandwich and Leal Bluff diamicrites on Cape Lamb, Vega Island. **C.** Geological map of Cape Lamb, Vega Island. (Modified from Marensi *et al.* 2001).

the Sandwich Bluff diamictite would suggest an older age for this deposit than the JRIVG at Cape Lamb.

The Leal Bluff diamictite is a matrix-supported conglomerate 22 m thick that is composed of an unsorted clastic fraction, mainly volcanic in origin, and metamorphic rocks in minor proportions. The presence of abundant local volcanic clasts in this deposit would suggest a younger age than the Sandwich Bluff diamictites. Marensi *et al.* (2001) proposed a glacial origin for this deposit.

The age of the Cape Lamb diamictites has been dated using $^{40}\text{Ar}/^{39}\text{Ar}$ on the basis of their stratigraphical relationship with volcanic lava from the JRIVG (Smellie *et al.* 2008). Thus, the Sandwich Bluff diamictite is older than the basal delta lavas at Sandwich Bluff (5.42 ± 0.08 Ma), and the Leal Bluff diamictite is older than the overlying subaerial lava caprock of Cape Lamb delta (2.09 ± 0.11 Ma).

Micropaleontological background

Records of calcareous nannofossil associations from the Antarctic Peninsula region are still scarce. The first reports were by Huber *et al.* (1983) for the Upper Cretaceous of the James Ross Basin. Later, complementary studies of the nannoflora have concentrated on the upper Campanian–upper Maastrichtian beds of Seymour Island (Concheyro *et al.* 1991; 1995) and the Campanian–Maastrichtian sediments of Snow Hill Island (Concheyro *et al.* 1995; Robles Hurtado and Concheyro 1995). Furthermore, a reworked Upper Cretaceous nannoflora in Cenozoic sediments of Cockburn Island has been documented (Gaździcka and Gaździcki 1994). Samples from the Antarctic Peninsula and the western sector of James Ross Island provided a Tithonian calcareous nannofossil assemblage (Concheyro and Scasso 1999; Concheyro 2004). Recently, Kulhanek (2007, 2009) found a reworked Campanian and Maastrichtian nannoflora at the Site NBP0602A-9, Weddell Sea. Guerra *et al.* (2012) and Svabenicka *et al.* (2012) identified a Santonian and lower Campanian nannoflora of the Santa Marta Formation at the Lachman Crag, James Ross Island.

Diverse foraminiferal assemblages from the Antarctic Peninsula have been documented from the Upper Cretaceous (MacFadyen 1966; Huber 1988; Gennari 1995; Concheyro *et al.* 1997; Hradecká *et al.* 2011; Florisbal *et al.* 2013), Paleocene (Huber 1988) and Eocene outcrops (Gaździcki and Majewski 2009, 2012). Less diverse foraminiferal assemblages have been recorded from Oligocene (Gaździcki 1989), Miocene (Birkenmajer and Łuczowska 1987; Bertels-Psotka *et al.* 2001; Jonkers *et al.* 2002; Lirio *et al.* 2003; Concheyro *et al.* 2007; Majewski *et al.* 2012; Nývlt *et al.* 2011), Miocene–Pliocene (Adamonis *et al.* 2010) and Pliocene to early Pleistocene exposures (Holland 1910; Gaździcki and Webb 1996; Jonkers *et al.* 2002; Lirio *et al.* 2003; Caramés and Concheyro 2013).

The Antarctic records of microforaminiferal linings include rare illustrated specimens of the early Maastrichtian of the James Ross Island (di Pasquo and Martin

2013) and during mention of the Cretaceous–Paleogene boundary of Seymour Island (Rodríguez Brizuela *et al.* 2007). Furthermore, a Turonian–?Santonian assemblage of Prydz Bay, East Antarctica contains microforaminiferal linings in very low proportions and a single specimen has been illustrated (Macphail and Truswell 2004a). Cenozoic records are slightly more abundant than in the Upper Cretaceous. They include the upper Miocene–Pliocene of Leal Bluff diamictite, Vega Island (Concheyro *et al.* 2010), northern Antarctic Peninsula. However, most microforaminiferal lining records are known from cores drilled in eastern Antarctica. They are from the Paleogene and Neogene of Prydz Bay (Quilty 2003; Macphail and Truswell 2004b), and early Miocene (Hannah *et al.* 1998), and Plio-Pleistocene from Ross Sea (Quilty *et al.* 2000; Warny *et al.* 2006; Scherer *et al.* 2007; Mearns 2010). Although in papers on Cenozoic, mainly the Plio-Pleistocene, palynology, only one or two microforaminiferal linings are illustrated, they are present in relatively high abundance (*e.g.*, nearly 62 specimens per gram of sediment per sample, in Mearns 2010) in the assemblages. These linings are considered part of the autochthonous material (coeval with deposition of the Cenozoic diamictite), separating them from the reworked palynomorphs (those from rocks of one age that have been eroded, transported, and redeposited in sediments of a younger age); the latter were thought to be very abundant in Cenozoic Antarctic deposits (*cf.* Salzman *et al.* 2011). However, other authors (Warny *et al.* 2007; Warny 2009) consider that the microforaminiferal linings obtained from the late Pleistocene glaciomarine cores in the Weddell Sea are reworked from Maastrichtian to Oligocene and possibly Miocene rocks.

Materials and methods

Seven samples were collected from Cenozoic diamictites of Cape Lamb, Vega Island, but only four were fossiliferous (Fig. 1). They were examined to identify calcareous nannofossils, foraminifera and associated microforaminiferal linings. Sandwich Bluff yielded two samples (SB1 and SB2) and Leal Bluff another two productive samples (DO2 and NLB). Only one sample contained a nannoflora (SB2). Very rare foraminifera were recovered from three samples (SB1, SB2 and DO2). Palynomorphs were present in all samples (SB1, SB2, DO2 and NLB) in variable amounts, and microforaminiferal linings came only from Leal Bluff (sample DO2).

Calcareous nannofossils were analysed using simple smear slides (Bown and Young 1998) and standard light-microscope techniques. Samples were studied qualitatively along two long transverses of the slide.

For foraminiferal studies, approximately 100 grams of sediment were disaggregated in Hydrogen Peroxide, Solution (5% 200 vols.), and washed over 74 µm and 297 µm sieves. The washed samples were dried and the foraminifera picked. Palynomorphs (including the microforaminiferal linings) were extracted from Ce-

nozoic rocks using palynological procedures that consisted of removing organic matter by digesting the carbonates and silicates with HCl and HF, respectively. The residue was sieved with 25 µm and 10 µm meshes and finally mounted on microscope slides with glycerine gel.

Paleontology

Calcareous nannofossils recognised in this study are presented in alphabetical order. Some remarks are included when necessary. Foraminiferal species are described herein. Description of the microforaminiferal linings morphotypes follows the informal classification of Stancliffe (1989). Some calcareous nannofossils, foraminifera and microforaminiferal linings are illustrated in Figs 2–4.

All fossils are housed at the Departamento de Ciencias Geológicas, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Argentina. Calcareous nannofossil slides are under the catalogue numbers BAFC-NP 3815-3817, foraminiferal species under LM-FCEN 3183-3187 and microforaminiferal linings under BAFC-PI 2028.

Calcareous nannofossils

Heterococcoliths

Biscutum constans (Górka) Black in Black and Barnes, 1959

Material. — Sample SB2, Sandwich Bluff diamictite, Cape Lamb, Vega Island.

Remarks. — This species is common in the Austral Basin, Argentina, and the Southern Ocean (Wise and Wind 1977; Perez Panera 2010). Due to their small size it is difficult to recognise different species of this genus. Perez Panera (2010) differentiated *Biscutum constans* and *B. ellipticum* in the Falkland Plateau. Wise and Wind (1977) used the increase in the abundance of *B. constans* as a biostratigraphic event to define a subzone in the late middle Albian.

Distribution. — Albian at Falkland Plateau (Wise and Wind 1977; Wise 1983); Campanian–Maastrichtian of Snow Hill and Seymour Islands, James Ross Basin, Antarctica (Concheyro 1995; Robles Hurtado and Concheyro 1995).

Cyclagelosphaera margerelii Noël, 1965

Material. — Sample SB2, Sandwich Bluff diamictite, Cape Lamb, Vega Island.

Remarks. — Under crossed nicols, this species has a wide distal shield, and a highly birefringent narrow proximal shield. Closed central area or with a small perforation, extremely birefringent.

The genus *Ellipsagelosphaera* Noël and *Cyclagelosphaera* Noël are similar, but they differ in their external shape, circular in *Cyclagelosphaera* and elliptical in *Ellipsagelosphaera*.

Distribution. — Early Aptian–early Albian of the Atlantic Ocean (Roth and Thierstein 1972). Albian of the Falkland Plateau (Wise and Wind 1977; Wise 1983).

Eiffellithus gorkae Reinhardt, 1965

(Fig. 2N)

Material. — Sample SB2, Sandwich Bluff diamictite, Cape Lamb, Vega Island.

Remarks. — This small species is easily recognizable, and differs from *E. turriseiffeli* (Deflandre) Reinhardt in its reduced central “X” cross, and in having the central area completely covered by calcite plates.

Distribution. — Campanian of the Santa Marta Formation, James Ross Island, Antarctica (Guerra *et al.* submitted).

Eiffellithus turriseiffelii (Deflandre) Reinhardt, 1965

(Fig. 2M, O–P)

Material. — Sample SB2, Sandwich Bluff diamictite, Cape Lamb, Vega Island.

Remarks. — This species is abundant in Late Cretaceous calcareous nannofossil associations and is easily recognizable by its high birefringence and typical central area. All specimens seen are fragmented and partially etched.

Distribution. — Campanian–Maastrichtian of Snow Hill and Seymour Islands, James Ross Basin, Antarctica (Concheyro *et al.* 1991; Concheyro 1995; Robles Hurtado and Concheyro 1995). Albian–Maastrichtian of the Austral Basin, Argentina (Mostajo 1991; Ronchi and Angelozzi 1994; Concheyro 1995; Concheyro and Angelozzi 2002; Pérez Panera 2009).

Prediscosphaera cretacea (Arkhangelsky) Gartner, 1968

(Fig. 2Q–S)

Material. — Sample SB2, Sandwich Bluff diamictite, Cape Lamb, Vega Island.

Remarks. — This is one of the most common calcareous nannofossil in worldwide Upper Cretaceous sedimentary rocks. Although the central cross bar is often found broken and the coccoliths reduced to an open rim, transmitted light images of the ring structure, with 16 elements are so distinct that proper taxonomic assignment can be made with little uncertainty.

Distribution. — Cretaceous of Austral Basin, Argentina (Concheyro 1995). Campanian–Maastrichtian of the Snow Hill and Seymour Islands, James Ross Basin, Antarctica (Concheyro 1995; Robles Hurtado and Concheyro 1995).

Tranolithus orionatus (Reinhardt) Perch-Nielsen, 1968

(Fig. 2T)

Material. — Sample SB2, Sandwich Bluff diamictite, Cape Lamb, Vega Island.

Remarks. — The large blocky elements of the central area appear bright when the longitudinal axis of the muralith is oriented parallel to the plane of either nicol.

Distribution. — Cenomanian Leg 14, DSDP South Atlantic Ocean (Roth and Thierstein 1972). Late Cretaceous, Austral Basin, Argentina (Concheyro 1995). Santa Marta Formation, Lachman Crags, James Ross Island (Guerra *et al.* submitted). Albian of the Falkland Plateau (Wise and Wind 1977; Wise 1983). Cam-

panian–Maastrichtian of the Snow Hill and Seymour Islands, James Ross Basin, Antarctica (Concheyro 1995; Robles Hurtado and Concheyro 1995).

Watznaueria barnesiae (Black in Black and Barnes) Perch-Nielsen, 1968

(Fig. 2I–K)

Material. — Sample SB2, Sandwich Bluff diamictite, Cape Lamb, Vega Island.

Remarks. — This is the more conspicuous calcareous nannofossil recovered in Cretaceous sediments and particularly in Cape Lamb diamictites. Under a light microscope, the distal shield is integrated by two counterclockwise overlapping calcite cycles; the proximal shield remains elevated in comparison with the distal. The central area has a small aperture, partially covered by irregular plates. Under crossed nicols, the extinction pattern aligns with the major and minor ellipse axes, and when moving the plate, the calcite elements form two sigmoidal bars that converge in the central area, forming a cross in the central area. *W. barnesiae* (Black) Perch-Nielsen differs from *Ellipsagelosphaera* Noël in the absence of a birefringent central tube. This species is named *W. barnesiae* (Black) Perch-Nielsen to replace the former *W. barnesae* (Black) Perch-Nielsen, considering the ICBN Code, and following Lees (2005).

Distribution. — Cretaceous of the Falkland Plateau (Wise and Wind 1977; Wise 1983). Cretaceous of Antarctica (Concheyro 2002). Cretaceous of Austral Basin, Argentina (Ronchi and Angelozzi 1994; Concheyro 1995; Concheyro and Angelozzi 2002; Pérez Panera 2009) and Cretaceous of Tierra del Fuego, Austral Basin, Argentina (Mostajo 1991).

Watznaueria britannica (Stradner) Reinhardt, 1964

(Fig. 2H)

Material. — Sample SB2, Sandwich Bluff diamictite, Cape Lamb, Vega Island.

Remarks. — Under the light microscope the cyclic distal shield is composed of more than 30 oblique elements, with horizontal inner plates, overlapping one another in the same direction, coincident with the external plates; simple proximal shield with a large central area. Central tube composed of vertical elements that define a central area crossed by a straight bridge of calcite microcrystals whose orientation coincides with the minor axis of the ellipse. Under crossed nicols, oval and wider central area with a bright middle bridge is observed.

Distribution. — Bathonian–Hauterivian of Falkland Plateau (Wise 1983). Valanginian–Cenomanian of Austral Basin, Argentina (Concheyro 1995; Concheyro and Angelozzi 2002) and Cretaceous of Tierra del Fuego, Austral Basin, Argentina (Mostajo 1991).

Watznaueria fossacincta (Black) Bown in Bown and Cooper, 1989

(Fig. 2E–G)

Material. — Sample SB2, Sandwich Bluff diamictite, Cape Lamb, Vega Island.

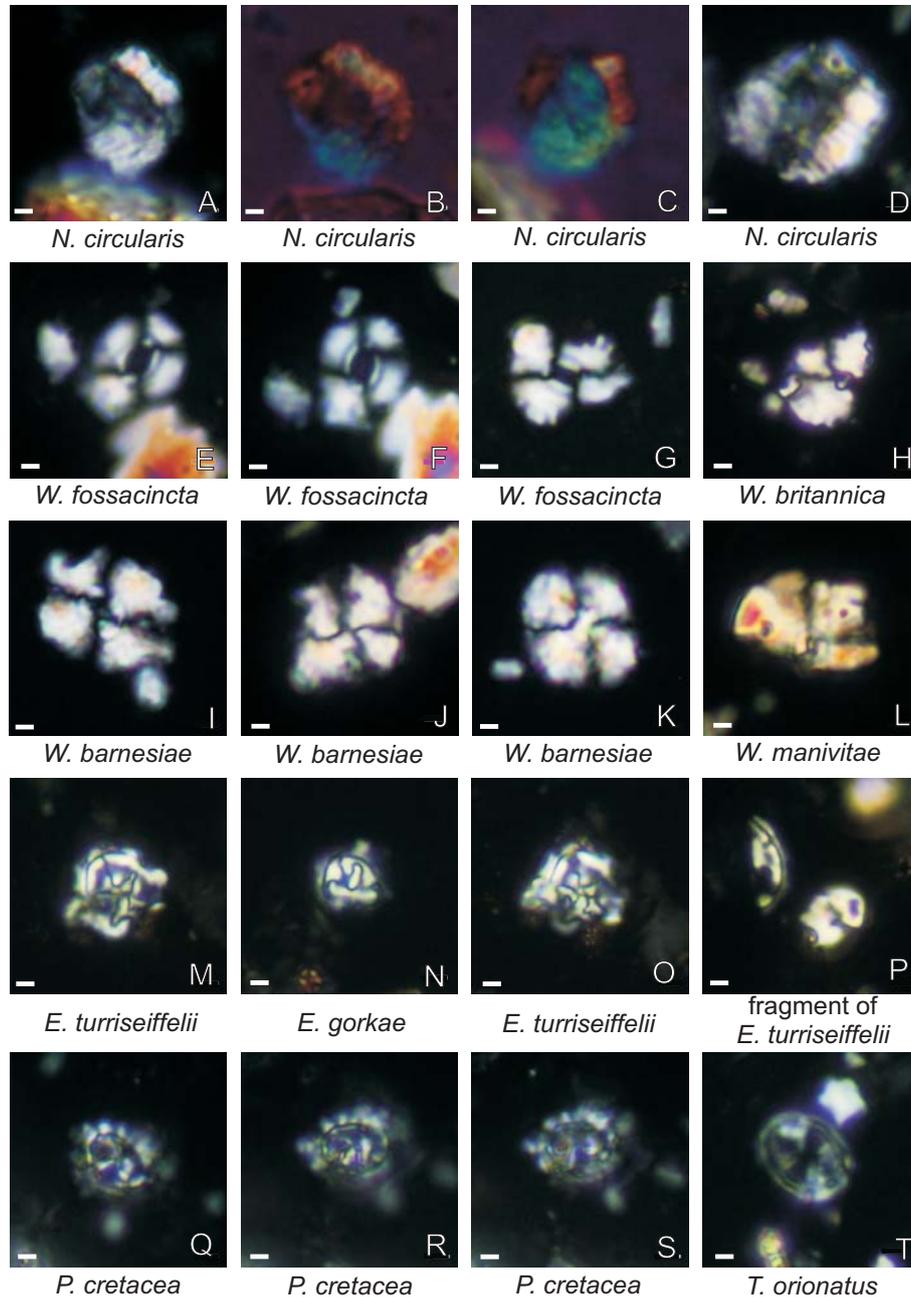


Fig. 2. Reworked Mesozoic calcareous nannofossils recovered from sample SB2 (BAFC-NP 3815), Sandwich Bluff diamictite, Cape Lamb, Vega Island, Antarctica. A–D. *Nannoconus circularis*. E–G. *Watznaueria fossacincta*. H. *Watznaueria britannica*. I–K. *Watznaueria barnesiae*. L. *Watznaueria manivitae*. M, O. *Eiffellithus turriseiffelii*. N. *Eiffellithus gorkae*. P. Fragment of *Eiffellithus turriseiffelii*. Q–S. *Prediscosphaera cretacea*. T. *Tranolithus orionatus*. All photographs are taken with crossed nicols, being their BAFC-NP 3815. Scale bars 1 μm .

Remarks. — *W. fossacincta* differs from *Watznaueria barnesiae* in having a completely open central area and from *Watznaueria britannica* in the central bridge that coincides with the minor axis of the ellipse, in the central area.

Distribution. — Valanginian–Hauterivian of Austral Basin, Argentina (Concheyro and Angelozzi 2002).

Watznaueria manivitae Bukry, 1973

(Fig. 2L)

Material. — Sample SB2, Sandwich Bluff diamictite, Cape Lamb, Vega Island.

Remarks. — This species differs from others of the same genus in its large size, rounded shape and elliptical and narrow central area. *Watznaueria manivitae* differs from *Cyclagelosphaera deflandrei* (Manivit) Roth in its elliptical shape.

Distribution. — Campanian–Maastrichtian of Colorado Basin, Argentina (Pérez Panera and Angelozzi 2006).

Nannoliths

Nannoconus circularis Deres *et* Achéritéguy, 1980

(Fig. 2A–D)

Material. — Sample SB2, Sandwich Bluff diamictite, Cape Lamb, Vega Island.

Remarks. — *N. circularis* Deres and Achéritéguy is easily distinguished from other nannoconids in cross section because it has a circular section that defines a very wide channel (four to nine times the width of the wall). The channel is usually filled with pyrite crystals or micrite. In side view, the central canal is also very wide. This species, together with *Nannoconus bucheri*, has been used as a late Valangianian marker in the Tethyan, correlating with the *Teschenites callidiscus* Zone (Gardin *et al.* 2000). Furthermore, the first occurrence of *N. circularis* is a reliable marker for the Lower Cretaceous of the Neuquén Basin (Argentina), a secondary bioevent that defines the CC4-A Subzone (Lescano and Concheyro 2009).

Distribution. — Cretaceous of the Austral Basin, Argentina (Mostajo 1991; Ronchi and Angelozzi 1994; Concheyro 1995; Concheyro and Angelozzi 2002).

Foraminifera

Cibicides sp.

(Fig. 3J–L)

Material. — Sample SB1, Sandwich Bluff diamictite, Cape Lamb, Vega Island, 1 specimen.

Description. — Test small, trochospiral, biconvex; periphery subacute and noncarinate; apertural face triangular; spiral side flat, evolute, proloculus and one and a half whorls visible, 11 chambers in final whorl, sutures flush, limbate and curved, spiral suture flush; umbilical side convex, umbilicus small and slightly depressed, sutures radial and gently curved near the periphery; aperture interior-

marginal equatorial, extending a short distance on the spiral suture; wall calcareous, perforate.

Dorothia sp.

(Fig. 3G–I)

Material. — Sample DO2, Leal Bluff diamictite, Cape Lamb, Vega Island, 1 specimen.

Description. — Test elongate, tapering, initial end acute, greatest breadth one third of length from apertural end, subrectangular in transverse section; early stage trochospiral and conical, later biserial with two pairs of low and quadrangular chambers. Chambers slightly inflated. Sutures slightly depressed. Aperture a low arch at the base of the final chamber. Wall agglutinated, highly variable grain size, surface roughly finished.

Gavelinella sp.

(Fig. 3O–Q)

Material. — Sample SB1, Sandwich Bluff diamictite, Cape Lamb, Vega Island, 1 specimen.

Description. — Test small, low trochospiral, plano-convex; axial periphery subrounded and noncarinate; dorsal side convex, evolute, earlier whorls visible behind translucent central boss, 10 chambers in the final whorl, sutures flush, curved; ventral side flat, show the last whorl only, sutures limbate, gently elevated becoming flush near the periphery and elevated in the umbilical area; umbilicus partially closed by calcareous projections of the chambers; aperture interiomarginal equatorial extending a short distance on the ventral side; wall calcareous, perforate.

Remarks. — The species is similar to *Gavelinella mariae* (Jones) illustrated by Frenzel (2000) from the Maastrichtian of Germany. However, our specimen is smaller, with elevated ventral sutures and more rounded periphery. *G. mariae* was originally described as *Rosalina mariae* Jones from the Paleocene of England (Jones in Morris, 1852). Frenzel's synonymy includes *Cibicides ekblomi* Brotzen, a species described from the lower Paleocene of Sweden (Brotzen 1948).

Pullenia jarvisi Cushman, 1936

(Fig. 3M–N, R–S)

Material. — Sample SB2, Sandwich Bluff diamictite, Cape Lamb, Vega Island, 1 specimen.

Description. — Test large, robust, planispiral, involute, axial periphery rounded. Five chambers in final whorl, the last one damaged; chambers inflated increasing gradually in size; sutures nearly radial, slightly depressed; umbilicus small and depressed. Wall calcareous perforate. Aperture not visible due to the poor preservation of the specimen.

Remarks. — Despite its poor preservation, the specimen conforms well to the original description of *Pullenia jarvisi*. The rough surface could be evidence of severe dissolution. Figure 3S shows the test after a treatment with hydrochloric acid

for some seconds. This procedure was used to eliminate the possibility of the presence of punciuli (prolongation of the shell substance across the suture) or canals in the septa, to exclude the possibility that the specimen belongs to *Cribrononion* or *Cribroelphidium*. *Pullenia jarvisi* was described from the Upper Cretaceous of Trinidad, Gulf region, and reported from the Campanian of Site 511, DSDP Leg 71, Falkland Plateau (Basov and Krasheninnikov 1983), Maastrichtian and lower Paleocene of the López de Bertodano Formation, Seymour Island (Huber 1988) and the lower Maastrichtian of ODP Sites 689 and 690, Maud Rise, Weddell Sea (Thomas 1990).

Trochammina sp. aff. *T. intermedia* Rhumbler, 1938

(Fig. 3A–F)

Material. — Sample DO2, Leal Bluff diamictite, Cape Lamb, Vega Island, 1 specimen.

Description. — Test small, trochoid, concavo-convex, with low trochoid spire, periphery subacute, poorly preserved, last chamber broken; dorsal side, convex, evolute, clearly showing proloculus followed by about three whorls of 31 rapidly enlarging chambers; earlier whorls have 9–10 chambers, the final whorl only 6; ventral side concave, umbilical area open, only six triangular chambers of the final whorl visible on umbilical side; last chambers are poorly preserved and seem collapsed; umbilicus depressed; sutures distinct, curved strongly backwards and depressed on spiral side; curved, elevated and sigmoid on umbilical side; wall thin, arenaceous with variable size grains, smooth. The earliest two and a half whorls consist of a globular proloculus and 23 chambers, which under stereo microscope are clearly visible due to the brown inner organic linings that show through the siliceous wall. The last whorl has a whitish wall. The organic linings of each individual chamber are in the form of a trapezium with upper and lower sides almost parallel, the anterior lateral side almost right-angled or slightly convex and the posterior lateral side concave and more curved than the anterior. The aperture is poorly visible and seems to be interiomarginal.

Remarks. — Fortunately, the specimen shows the organic linings of the first chambers, and because these linings are well preserved the depressed umbilical side of the test is considered to be a specific feature rather than the result of *post-mortem* deformation. The siliceous wall composition was confirmed by the low birefringence observed under crossed-polarized light microscopy.

The specimen is similar to *Trochammina intermedia* (Rhumbler) recorded along the Bellingshausen Sea coast of the northern Antarctic Peninsula by Ishman and Domack (1994) and originally described as *Trochammina squamata* Jones and Parker forma *intermedia* Rhumbler from the Recent of Germany. It has been classified as *Trochammina* sp. aff. *T. intermedia* due to its moderate preservation. It resembles *Paratrochammina* (*Lepidoparatrochammina*) *bartrami* (Hedley, Hurdle and Burdett) recorded from the Antarctic Peninsula in the

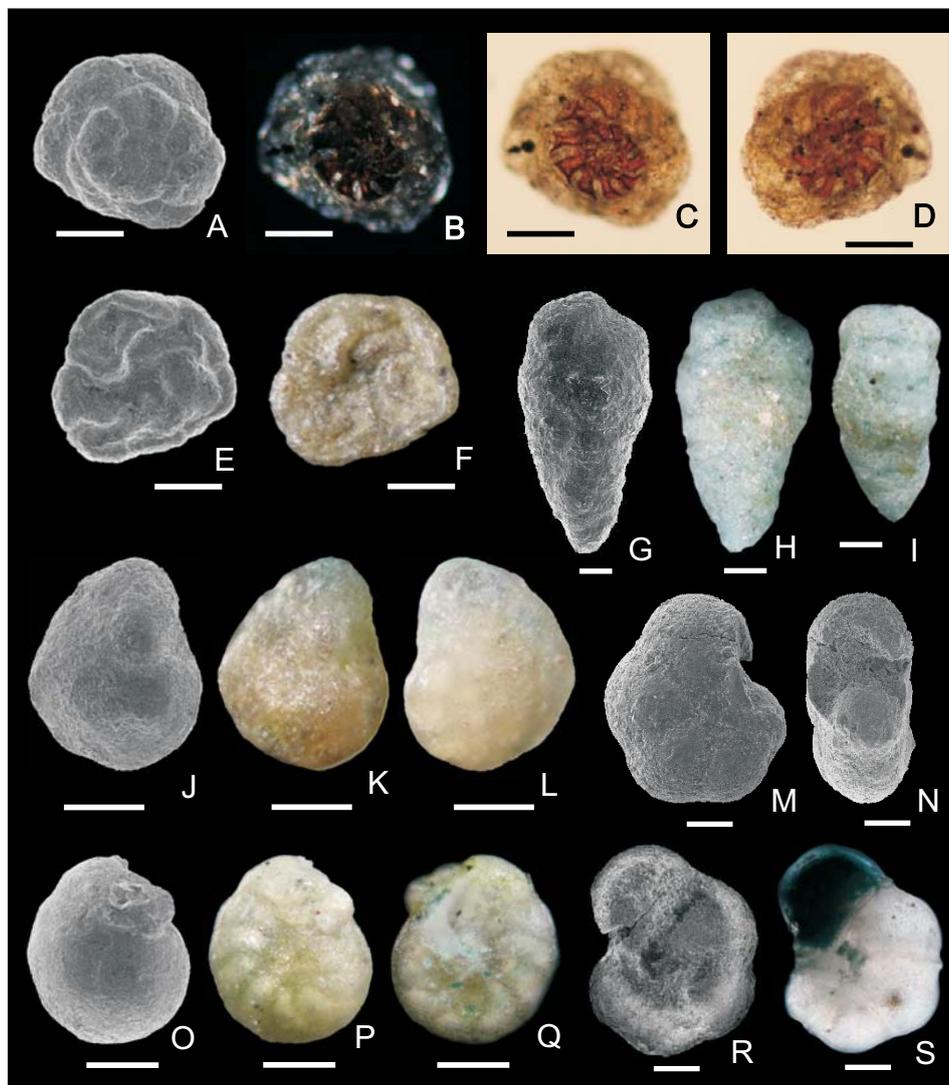


Fig. 3. Foraminifera recovered from the Leal Bluff and Sandwich Bluff diamictites, Cape Lamb, Vega Island, Antarctica. A, E, G, J, M, N, O, R, micrographs under scanning electron microscope (SEM); B, micrograph with crossed nicols in a petrographic microscope; C and D, micrographs with parallel light in a petrographic microscope; F, H–I, K–L, P–Q, S, micrographs under a magnifying glass. Scale bar: 100 μm . A–F. *Trochammina* sp. aff. *T. intermedia*, sample DO2 (LM-FCEN 3185), Leal Bluff diamictite, in spiral (A–C) and umbilical (D–F) views. G–I. *Dorothisia* sp., sample DO2 (LM-FCEN 3184), Leal Bluff diamictite; in lateral (G, H) and oblique apertural (I) views. J–L. *Cibicides* sp., sample SB1 (LM-FCEN 3186), Sandwich Bluff diamictite; in umbilical (J, K) and spiral (L) views. M, N, R, S. *Pullenia jarvisi*, sample SB2 (LM-FCEN 3183), Sandwich Bluff diamictite; in lateral (M, R, S) and peripheral (N) views, S – specimen under a treat with hydrochloric acid for some seconds. O–Q. *Gavelinella* sp., sample SB1 (LM-FCEN 3187), Sandwich Bluff diamictite, in dorsal (O, P) and ventral (Q) views.

Recent of King George Island (Gaździcki and Majewski 2003; Majewski 2005), the Holocene of the Firth of Tay located between Joinville and Dundee Islands (Majewski and Anderson 2009), and also from East Antarctica in the late Quaternary of Lützow-Holm Bay (Igarashi *et al.* 2001), but differs from it in having a less compressed lateral view and more inflated chambers. It is striking, however, that while the original description of *Trochammina bartrami* Hedley, Hurdle and Burdett (1967) mentions a slightly darker colour of the initial whorls, showing at least two layers, this species was later reassigned to *Paratrochammina*, a genus which has a single layer.

Trochammina sp. aff. *T. intermedia* also slightly resembles *T. ribstonensis* Wickenden, a species described from the Upper Cretaceous of Canada (Wickenden 1932) and recorded in low abundance in the Upper Campanian–Danian of the López de Bertodano Formation of James Ross and Seymour Islands (Huber 1988), but differs in its more excavated umbilical side and strongly curved umbilical sutures.

Microforaminiferal linings

The microforaminiferal lining is the inner organic layer that lies between the cytoplasm and the internal surface of the test of several foraminifera. Linings are produced mainly by benthic foraminifera, both calcareous and agglutinated (de Vernal 2009). However, it can also be produced by some planktonic foraminifera (Arai and Koutsoukos 1998) or can even represent early planktonic stage of benthic foraminifera (Davey 1978). Microforaminiferal linings are composed of chitin derivatives, proteins and polysaccharides in variable quantities, and some of them may even have lignin compounds (Ní Fhlaithearta *et al.* 2013). Since linings are acid-resistant, they are usually recovered in palynological preparations.

Microforaminiferal linings studied herein come from the Leal Bluff diamictite (sample DO2). They are part of the autochthonous palynomorph assemblage together with rare acritarchs, prasinophytes and a single scolecodont. The linings account for 22.7% of palynomorphs. The assemblage also contains Late Cretaceous (Campanian–Maastrichtian) reworked dinoflagellate cysts, pollen and spores, algae and scolecodonts, which represent 72.7% of the palynomorphs. The reworked forms consist of age-diagnostic dinoflagellate cysts similar to those found in units outcropping on Cape Lamb, Vega Island. Both autochthonous and reworked species are summarized in Table 1. Microforaminiferal linings are described below.

Trochospiral, type I, Stancliffe, 1989

(Fig. 4A, C–G)

Stancliffe (1989) defined this morphotype for those microforaminiferal linings that can be distinguished only when a second whorl is developed.

Material. — Sample DO2, Leal Bluff diamictite, Cape Lamb, Vega Island, 35 complete specimens and 14 fragmented.

Table 1
 Palynomorph and miscellaneous recovered from the analysed samples, listed in major categories. Abbreviations correspond to the studied diamictites: DO2: Leal Bluff diamictite, NLB: North Leal Bluff, SB1 and SB2: Sandwich Bluff.

Palynomorph and miscellanea	Diamictites samples			
	SB1	SB2	NLB	DO2
Spores				
<i>Ceratosporites equalis</i> Cookson <i>et</i> Dettmann, 1958			×	
<i>Cyathidites minor</i> Couper, 1953			×	×
<i>Leptolepidites verrucatus</i> Couper, 1953				×
<i>Matoniesporites</i> sp.				×
<i>Retitriteles austroclavatidites</i> (Cookson, 1953) Doring <i>et al.</i> in Krutzsch, 1963				×
Pollen				
<i>Callialasporites</i> sp.			×	
<i>Microcachryidites antarcticus</i> Cookson, 1947				×
<i>Nothofagidites dorotensis</i> Romero, 1973	×	×		×
<i>Peninsulapollis gillii</i> (Cookson, 1957) Dettmann <i>et</i> Jarzen, 1988				×
<i>Phyllocladidites mawsonii</i> Cookson, 1947 <i>ex</i> Couper, 1953				×
<i>Podocarpidites</i> sp.				×
<i>Batiacasphaera</i> sp.				×
Dinoflagellate cysts				
<i>Criboperidinium</i> sp.	×			
<i>Impletosphaeridium clavus</i> (Wrenn <i>et</i> Hart, 1988) <i>emend.</i> Bowman <i>et al.</i> , 2013				×
<i>Isabelidinium cretaceum</i> (Cookson, 1956) Lentin <i>et</i> Williams, 1977	×	×		×
<i>Isabelidinium pellucidum</i> (Deflandre <i>et</i> Cookson, 1955) Lentin <i>et</i> Williams, 1977				×
<i>Isabelidinium</i> sp.			×	
<i>Manumiella seymourensis</i> Askin, 1999			×	
<i>Manumiella</i> sp.				×
<i>Nelsoniella semireticulata</i> Cookson <i>et</i> Eisenack, 1960				×
<i>Trichonodinium castanea</i> Deflandre, 1935				×
Algae				
<i>Palambages</i> sp.			×	
<i>Pterospermella</i> sp.	×		×	
Acritarch				
<i>Palaeostomocystis</i> sp.				×
Miscellaneous				
Microforaminiferal linings				×
Scolecodonts				×
Fungal mycelium			×	
Cuticles of (?) arthropods				×
Carbonized diatom fragments				×

Description. — Trochospiral form in which the chambers generally overlap and the larger chambers commonly have proximal connections with the succeeding and preceding chambers (after Stancliffe, 1989).

Dimensions (20 specimens). — Number of chambers: 10–22. First chamber (corresponds to the proloculus): breadth: 10–25 × length 15–25 μm. Second chamber: breadth: 15–25 × length 15–28 μm. Last chamber: breadth: 12–120 × length 15–150 μm. Overall size: 80–250 μm.

Remarks. — In these trochospiral forms more than two whorls and some chambers of a third whorl are observable in a spiral view. The specimens are low trochospiral in equatorial view (Fig. 4C, D). The proloculus, when present, has a well-defined circular morphology (Fig. 4A–E, G). It has a thicker wall in comparison with the following chambers, which are typically more deformed due to their thinner walls. Each individual chamber has a trapezoidal shape that has the upper and lower sides almost parallel, the anterior lateral side almost right-angled or slightly convex and the posterior lateral side concave and more curved than the anterior side. The surface ornamentation of the chambers varies from smooth to granular. Chambers are connected by a neck located in the inner side of the chamber. Some chambers have a conspicuous protuberance, strongly triangular in outline, on the inferior side pointing inwards the coil (Fig. 4E–G). The chambers of the second whorl are typically dark brown in colour, although their outer chambers are often more thin-walled and translucent. This feature is best seen in the complete specimen (Fig. 4A).

Discussion

The recovered calcareous nannofossils were very scarce and consist of 11 Cretaceous species. All specimens came from Sandwich Bluff, the Leall Bluff samples being barren of nannofossils. Due to the bias in the preservation of the nannoflora, two associations were recognised in the same sample, and represent different ages, Early and Late Cretaceous.

The older association is composed of placoliths, including the long-ranging taxa such as *Watznaueria* and *Cyclagelosphaera*. All are partially etched, with some dissolved distal or proximal shield; however, it is possible to identify the general morphology, and some crucial taxonomic features. The presence of *Nannoconus circularis* is confirmed and constitutes the first record for the James Ross Basin, Antarctica, of a useful marker for the Early Cretaceous. Its provenance is likely to be Kotick Point Formation strata (Aptian–Upper Albian), located in the western sector of the James Ross Island, or to other older stratigraphic units of the Antarctic Peninsula. This species ranges from the Hauterivian to Albian (Deres and Achérítéguy 1980) and its age would correlate with some Gustav Group beds (Ineson *et al.* 1986; Medina *et al.* 1992).

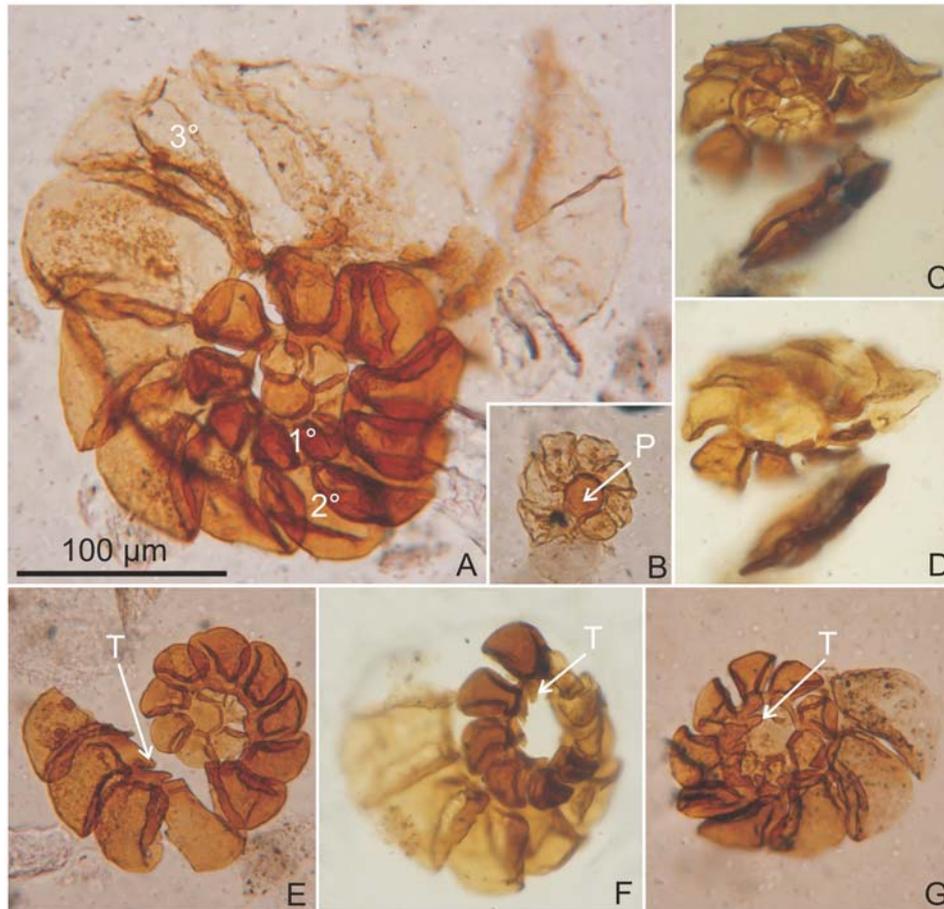


Fig. 4. Microforaminiferal linings recovered from the sample DO2 (BAFC-PI 2028), Leal Bluff diamictite, Cape Lamb, Vega Island, Antarctica. Scale bar: 100 µm. P: proloculus. T: triangular protuberance in their posterior inferior side. **A.** Trochospiral specimen, note a complete specimen with the proloculus and more than two whorls (1°, 2° and some chambers of the 3° whorl) with the latest greatest chambers, BAFC-PI 2028 (2): P26. **B.** Fragment of microforaminiferal linings, note the proloculus and the following chambers, BAFC-PI 2028 (2): V33. **C, D.** Trochospiral specimens in different focus, the upper specimen shows a spiral view and the lower specimen shows an equatorial view. Note how extremely low the trochoid spire of this specimen is, BAFC-PI 2028 (1): A31. **E.** Trochospiral specimen, BAFC-PI 2028 (1): G36-3. **F.** Trochospiral specimen, the proloculus and the first chambers are missing, BAFC-PI 2028 (3): P22/3. **G.** Trochospiral specimen, BAFC-PI 2028 (1): F47/1.

The younger nannofossil association contains fragmented or poorly preserved specimens of *Tranolithus orionatus*, *Eiffellithus gorkae* and *Prediscosphaera cretacea*. These species have been previously identified *in situ* in sediments of the Santa Marta Formation, Santonian to lower Campanian in age, at Lachman Crags (Guerra *et al.* 2012; Švábenická *et al.* 2012).

So far, Cenozoic calcareous nannofossils have not been identified in these diamictites; the presence of the Cretaceous species suggests intense reworking

from the Cretaceous marine units, and incorporation into the Cenozoic diamictites. The presence of *Nannoconus circularis* together with other Late Cretaceous nannofossils indicates severe erosion from Cretaceous sediments, with a general provenance from the Antarctic Peninsula, or the western sector of the James Ross Island, with the additional influx of nannofossils from a proximal local area, situated at Lachman Crags, James Ross Island.

Foraminifers from Sandwich Bluff and Leal Bluff were very rare, and poorly preserved. With the exception of *Pullenia jarvisi* Cushman from the Sandwich Bluff diamictite and *Trochammina* sp. aff. *T. intermedia* from the Leal Bluff diamictite, taxa could not be determined specifically and remain in open nomenclature. Among the taxa recovered from Sandwich Bluff, *Pullenia jarvisi* is a well-known Late Cretaceous species. *Gavelinella* sp. and *Cibicides* sp., have not been reported previously from the Cretaceous of Antarctica. Since the cosmopolitan genus *Gavelinella* occurs commonly in the Cretaceous and decreases dramatically in the Cenozoic worldwide, it is probable that the specimen studied herein comes from the underlying Cretaceous (Snow Hill Island and López de Bertodano Formation). However, the lack of records of this taxon in the Antarctic Cretaceous deposits might be due to the limited number of studies undertaken in the area.

Only two species, *Trochammina* sp. aff. *T. intermedia* and *Dorothia* sp., both represented by single specimens, have been recovered from the Leal Bluff diamictite (sample DO2). Taxonomic comparisons were especially made with other taxa reported from Cretaceous–Cenozoic Antarctic deposits. Initially, we considered that our *Trochammina* could be a distorted specimen of the Cretaceous species *Trochammina ribstonensis* but the well-preserved organic linings inside the foraminifera (see Paleontology) allow us to consider its depressed umbilical side a specific feature characteristic of the Recent *Trochammina intermedia* Rhumber, and thus reject our initial assumption. Furthermore, *Trochammina* sp. aff. *T. intermedia* and *Trochammina intermedia* might be related, being *Trochammina* sp. aff. *T. intermedia* an ancestor of *Trochammina intermedia*.

The microforaminiferal linings were recovered only from the Leal Bluff diamictite (sample DO2). They are all trochospiral type I, except for the fragments that are probably part of the same morphotype. Although some specimens are broken, most of them have a well preserved delicate structure suggesting that these linings are autochthonous and are not reworked. Another reason to consider them coeval with the deposition of the Cenozoic diamictite is that they are present in the Leal Bluff diamictite in significant amounts (22.7% of total assemblage). In contrast, in Late Cretaceous palynological assemblages inner organic tests are scarce (Macphail and Truswell 2004a; di Pasquo and Martin 2013). Moreover, Late Cretaceous microforaminiferal linings recovered from localities of the Antarctic Peninsula region and East Antarctica (Macphail and Truswell 2004a, pl. P7.4; di Pasquo and Martin 2013, fig. 8, Z. AA) have a different morphology from those found in Leal Bluff diamictite. Cretaceous specimens have more rounded cham-

bers and have neither chambers with a trapezoidal shape nor the triangular protuberance developed in the inner side of the chambers as have those specimens studied herein and considered Cenozoic.

The microforaminiferal linings are common as autochthonous elements in Plio-Pleistocene assemblages of East and West Antarctica. Our trochospiral type I specimens match the one illustrated by Scherer *et al.* (2007, fig. 4.5) from the Pliocene of Ross Sea, as they both have the characteristic triangular protuberance. Other published specimens apparently lack this protuberance. Nevertheless, our specimens resemble them in terms of morphology and arrangement of the chambers, for example it is similar to the specimen illustrated by Quilty *et al.* (2000, fig. 6.G) from late Pliocene of Vestfold Hills.

Finally, taking into account the close similarity of the overall shape, size and arrangement of the inner organic layer in the first chambers of *Trochammina* sp. aff. *T. intermedia* (Fig. 3B–D) recovered from the Leal Bluff diamictite, and those trochospiral type I linings in the palynological sample of the same locality (Fig. 4), we propose that they are closely related.

The abundance of microforaminiferal linings is only partially related to that of foraminifera. In Leal Bluff diamictites, organic-inner linings are well represented in the assemblage though foraminifera are scarce. Oboh (1992) reported that sediments that are rich in microforaminiferal linings might be barren of recognisable agglutinating or calcareous foraminifera when they are processed under standard micropaleontological techniques. However, although the linings in palynological slides are normally considered to reflect dissolution of calcareous tests during sample preparation, large numbers of free linings may also be produced by natural dissolution in the depositional environment. Some foraminifera may yield linings that are thin, insubstantial and unlike those usually observed in palynological preparations (Tyson 1995). In the case of the Leal Bluff diamictite the reason there are a larger number of microforaminiferal linings than foraminifera is not clear. The dissolution factor can be ruled out because it could affect calcareous foraminifera but not agglutinated foraminifer with organic cement, *Trochammina*. Hence, there is not sufficient information to explain the taphonomic bias between the inorganic and the organic material in the deposits. A patchy distribution of both foraminifera and microforaminiferal linings in diamictite samples is a plausible explanation for this bias, considering as very poor sorting is a typical feature of glacial deposits.

Concluding remarks

Cenozoic diamictites cropping out at Cape Lamb, Vega Island, yielded both reworked and autochthonous microfossils, despite the small number of specimens recovered. Reworked nanofloras are evidence that Lower Cretaceous (Hauteri-

vian–Albian) and Upper Cretaceous (Santonian–Lower Campanian) marine sediments have been incorporated in these diamictites. *Nannoconus circularis* constitutes the first record of nannoconids in the James Ross Basin, Antarctica.

Scarce reworked palynomorphs and foraminifera indicate an erosion of Upper Cretaceous (upper Campanian–lower Maastrichtian) units, and the foraminifer *Pullenia jarvisi* indicates reworking from lower Maastrichtian–lower Paleocene sediments.

The Cenozoic diamictites have locally-sourced material (foraminifera and palynomorphs) from both the underlying Snow Hill Island and López de Bertodano Formation beds (upper Campanian–upper Maastrichtian).

Reworked calcareous nannofossils are derived from the Santa Marta Formation (Santonian–lower Campanian), northern James Ross Island. Furthermore, if we take into account other nannofossil records, the furthest provenance would be the Gustav Group (Hauterivian–Albian), northwestern James Ross Island, or even Upper Jurassic (Tithonian) units of the Antarctic Peninsula.

The data constitutes the first record of reworked nannofossils in Cenozoic diamictites of Vega Island, and allow us to increase knowledge of the Early Cretaceous assemblages of Antarctica.

Until now, *Gavelinella* sp. and *Cibicides* sp. have not resembled other Antarctic foraminiferal taxa, but *Gavelinella* sp. could suggest a Cretaceous source.

The autochthonous material includes the foraminifer *Trochammina* sp. aff. *T. intermedia*, whose inner-organic layer is identical to those microforaminiferal linings (trochospiral type I morphotype) recovered from the same sample.

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