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The Weddell Sea Formation: post-Late Pliocene terrestrial glacial deposits on Seymour Island, Antarctic Peninsula

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ABSTRACT: A sequence of glacial deposits up to 4 m thick unconformably overlies the Eocene La Meseta Formation on the Seymour Island plateau (meseta) and forms a lithostratigraphically distinct unit in the succession of the James Ross Basin, which is formally named here as the Weddell Sea Formation. The formation is thus far known only from Seymour Island. This is a terrestrial melt-out till which contains abundant erratics and also reworked Cretaceous–Tertiary micro- and macrofossils within a silty clay matrix. The terrestrial origin of this till is shown by glacial striations at the base of the unit. The largest erratics (up to 3 m in diameter) are composed of plutonic (granitoids) and metamorphic (gneiss and crystalline schist) rocks of the Antarctic Peninsula provenance. Smaller in size and much more numerous are erratics of volcanic rocks, represented by andesite, basalt and corresponding pyroclastics of the James Ross Island Volcanic Group. Less common are erratics of sedimentary rocks, sometimes bearing fossils derived from the underlying Tertiary and Cretaceous strata. A few erratics from the top of the studied sequence are conglomerates of the Cockburn Island Formation with a foraminifer fauna. These are the youngest clasts within the Weddell Sea Formation. The presence of the Pliocene index fossil *Ammoelphidiella antarctica* Conato *et* Segre, 1974 indicates a lower age limit of latest Pliocene or earliest Pleistocene age. The upper age limit of the formation has not been established. An encrusting, unilamellar, colony of the bryozoan *Escharella* Gray, 1848 has been found on the one of erratics from the Weddell Sea Formation. This is the first fossil record of this genus in Antarctica.

Key words: Antarctica, Seymour (Marambio) Island, post-Late Pliocene glacial strata (Weddell Sea Formation), Bryozoa.

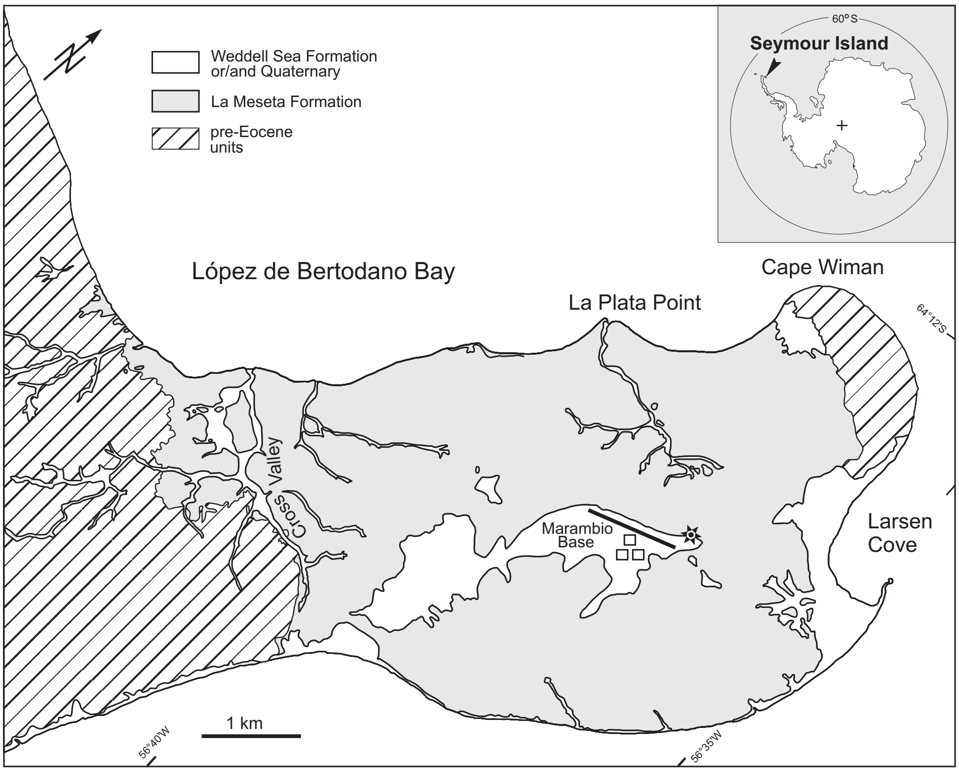

Fig. 1. Index map of Seymour (Marambio) Island. An asterisk indicates locality of the type section of the Weddell Sea Formation, situated just north of the airstrip on the meseta (see Fig. 3).

Introduction

The main aim of this paper is to present data useful in formalizing the lithostratigraphic position of the Weddell Sea Formation in the sedimentary succession of Seymour Island (Antarctic Peninsula).

An evenly thin veneer of glacial deposits covering sedimentary rocks of the La Meseta Formation (Eocene) on the plateau of the permanently ice free Seymour (Marambio) Island (Figs 1, 3, 8), has been informally referred to as the "Weddell Formation" (Zinsmeister and de Vries 1983). According to Malagnino *et al.* (1981), this is the glacio-marine diamictite of Quaternary age. The age was suggested on the basis of foraminiferan assemblages found in matrix of the diamictite. However, new evidence of pre-Quaternary glaciations found on the South Shetland Islands archipelago (Birkenmajer 1991), during deep-sea drilling of the ocean sediments around Antarctic continent (Hambrey and Barrett 1993), and in geophysical high-resolution seismic profiles on the Antarctic shelf (Anderson 1999), as well as the suggested deterioration of Antarctic climate at the end of the Eocene (Zinsmeister and Camacho 1982; Webb 1990, 1991; Gaździcki *et al.* 1992) fol-

Fig. 2. Northwestward view of the exposures of the Eocene La Meseta Formation on Seymour Island. Lenses of rocks of the La Meseta Formation (*in situ*) with glacial striae on the surface (arrowed) indicate the NW-SE direction of glacier movement (see Fig. 6 for close-up). James Ross and Cockburn Islands are seen in the background. Hammer for scale is 30 cm long.

Fig. 3. View of the north-west edge of the meseta. Arrow indicates the contact between the La Meseta and the Weddell Sea Formations.

lowing global climatic changes (Frakes *et al.* 1992; Zachos *et al.* 2001), lead to a suspicion that the Weddell Sea Formation could be much older.

The field work was carried out in the 1992 and 1994 austral summers during the Argentine Antarctic Expeditions to Seymour Island with participation of the Polish scientists A. Gaździcki and A. Tatur.

Geological setting

Glacial drift covers the plateau (meseta) built of Late Eocene sands of the La Meseta Formation that dip gently to SE (Figs 1, 3). A thin, discontinuous veneer (ca. 4 m thick) of glacial drift adheres to the lower part by permafrost. Solifluction and surface gravity flows during summer melting cause erosion that lead to exposure of sandy bedrock at isolated places on the plateau. Outcrops along the NW edge of the meseta are relatively well preserved and are not totally covered by muddy flows (Figs 3, 4, 8). The top surface of the meseta, containing the glacial drift and the uppermost part of the La Meseta Formation is cut in several places by a network of thin (usually < 3 cm) fissures through the permafrost. The fissures filled initially by ice after its melting, were later refilled by greenish-brown clay washed down from the matrix of the overlying glacial drift. Several fissures are oriented horizontally within

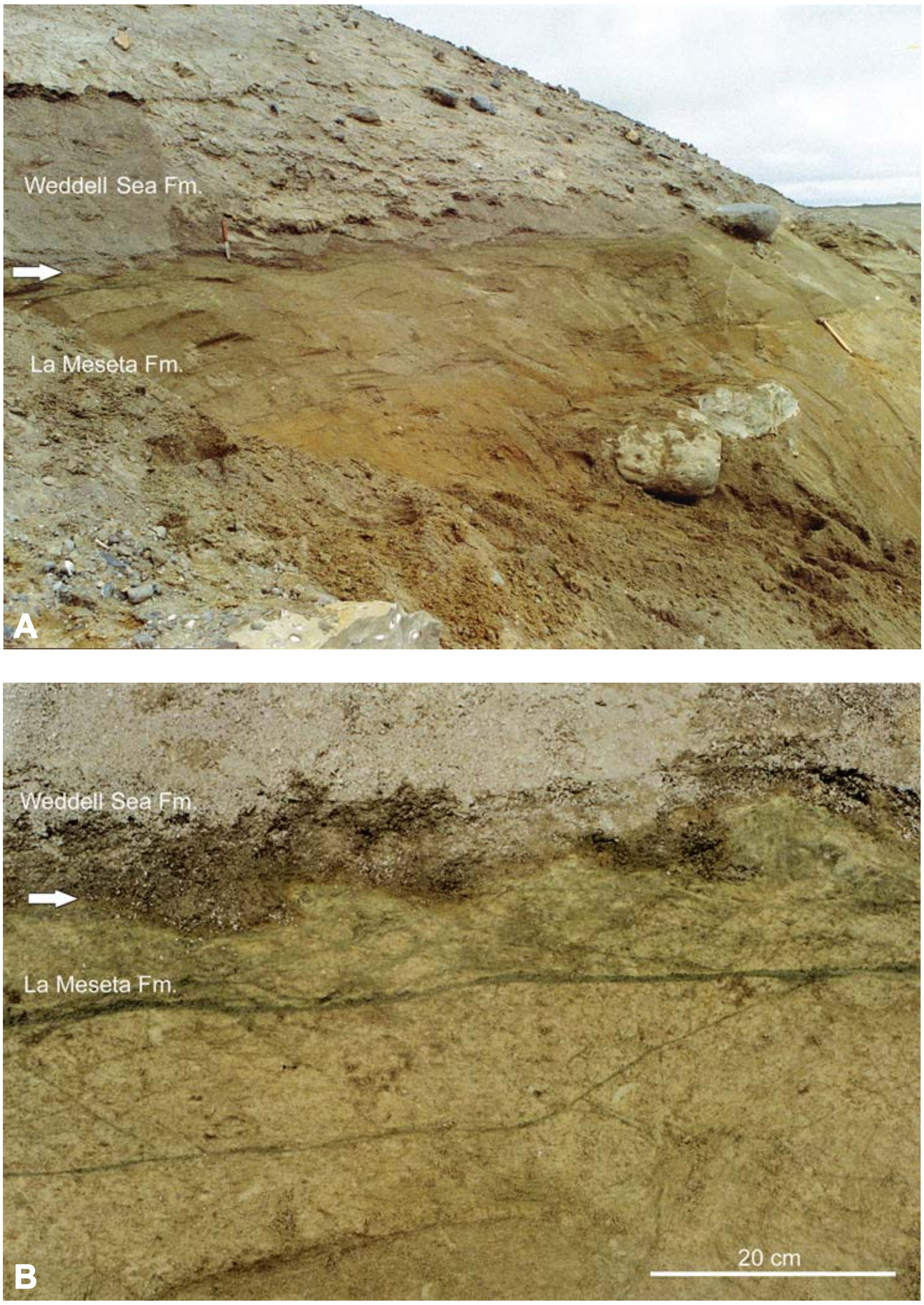

Fig. 4. **A**. Close-up of the contact between the La Meseta Formation and the glacial deposits of the Weddell Sea Formation (arrowed). Hammer for scale is 30 cm long. **B**. Cryogenic perturbation and deformations at the boundary between the La Meseta and Weddell Sea Formations.

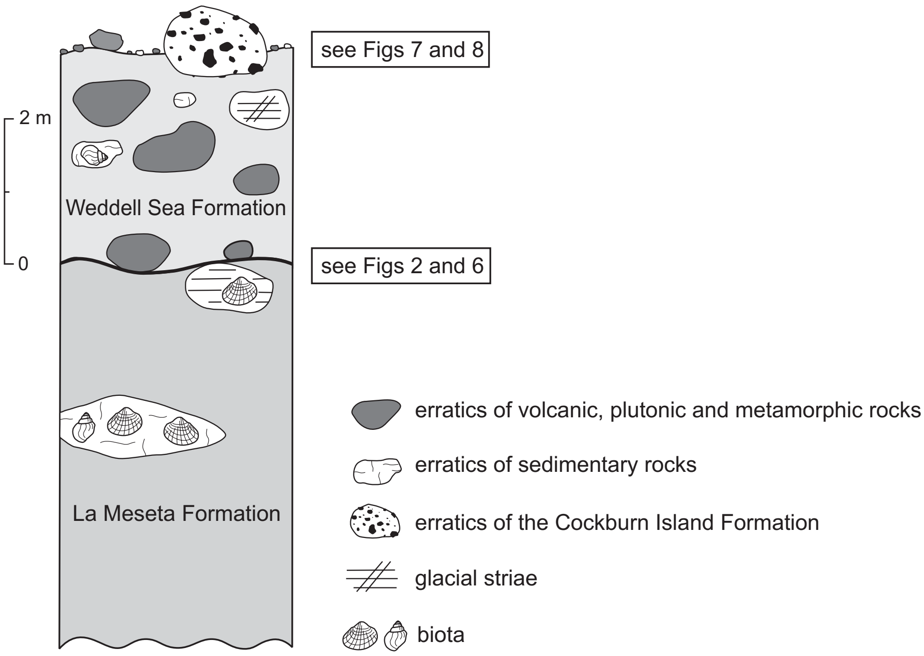

Fig. 5. The uppermost La Meseta–Weddell Sea Formations section.

the La Meseta Formation (up to 3 m beneath the lower boundary of the Weddell Sea Formation), and may extend continuously for dozens of meters. Despite cryogenic perturbations, the boundary between the La Meseta and the glacial drift is very well exposed, providing evidence of dynamic processes proceeding during advance of the glacier (Fig. 4A, B). Structures indicative of the eastward transport of sands by the base of the moving glacier occur at several places. They may develop from anundulating boundary sediment layer to form ripples, seams, flat lenses and even continuous horizons composed of the La Meseta Formation sands within the Weddell Sea Formation. Cryogenic perturbation and deformation along the boundary also produced structures that appear as interfingerings of the two formations (Fig. 4A, B). A summary of field observations is presented in Figs 3–5.

A moving glacier once slipped on the hard surface of shell-bearing calcareous concretions that occurs at the top of the La Meseta sands (Fig. 4A). Glacial striae have been observed in some places on the upper surface of shell conglomerates located *in situ* at the NW edge of the plateau (Figs 2, 6). The orientation of striae suggests eastward glacier movement from the ice cap of James Ross Island (Fig. 2). Numerous striae found on surfaces of local calcareous erratics (concretions and lithified boulders of marlstone) occurring within the glacial drift are usually oriented in various directions.

The unconsolidated matrix of glacial drift is composed of dark-brown silty clay to yellow sand with scattered macro- and microfossils. The sediment contains

Fig. 6. Close-up of the parallel glacial striae on the *Cucullaea* shell bed of the uppermost part of the La Meseta Formation (Telm7). Hammer for scale is 30 cm long.

erratics up to boulder size (Fig. 8). Most of the large erratics are of local origin. The largest blocks (up to 3 m in diameter) are mainly granitoids and metamorphic schists, dominated by dark grey gneiss showing porphyroblastic structure. Smaller erratics are represented mainly by black to brown, often porous andesites and basalts, as well as by related pyroclastic rocks. More than 90 per cent of the erratics have direct affinities with igneous, metamorphic and volcanic rocks known from the Antarctic Peninsula (Nelson 1975).

Erratics of sedimentary rocks form only a few per cent of the clasts. Among these the most frequent are fossiliferous calcareous concretions containing bivalves of the genera *Cucullaea* and *Eurhomalea.* They were clearly derived from the upper units of the Eocene La Meseta Formation. However, other fossiliferous rocks derived from Paleocene and Mesozoic sedimentary and volcanogenic sequences also occur dispersed in the matrix. These include: (1) iron-rich calcareous concretions displaying glacial striae, derived probably from the Telm2 of the Eocene La Meseta Formation; (2) concretions from the Upper Cretaceous López de Bertodano Formation with well preserved ammonites and serpulids (*Rotularia*); (3) pebbles of bituminous shale resembling the Middle to Late Jurassic Mount Flora Formation; (4) pale tuffites of the Jurassic–Lower Cretaceous Antarctic Peninsula Volcanic Group; and green-grey greywackes of the Upper Perm-

Fig. 7. Erratic boulder of the Pliocene Cockburn Island Formation on the meseta. Hammer for scale is 30 cm long.

ian–Triassic Trinity Peninsula Group. One of the erratics collected is a pale pink quartz sandstone of unknown origin.

A few erratics of conglomerate (Fig. 7) composed of black basaltic clasts cemented by yellow clay matrix were identified as derived from the Pliocene Cockburn Island Formation (= *Pecten* Conglomerate of Andersson, 1906). This formation is known from the adjacent Cockburn Island, a small island situated between James Ross and Seymour Islands (see Gaździcki and Webb 1996; Jonkers 1998, 2003). The matrix of the conglomerate (Fig. 7) contains characteristic calcareous benthic foraminifera of the species *Ammoelphidiella antarctica* Conato *et* Segre, 1974, along with representatives of the family Cassidulinidae d'Orbigny, 1839. The foraminifer *A. antarctica*, apparently a good Pliocene index fossil, has not been hitherto reported from pre- or post-Pliocene strata of Antarctica (Conato and Segre 1974; Webb 1988; Quilty *et al.* 1991; Ishman and Rieck 1992; Gaździcki and Webb 1996; Jonkers *et al.* 2002; Jonkers 2003).

One black erratic (metamorphic schist) of pebble size (12 cm across) is encrusted by a well preserved colony of the bryozoan *Escharella* sp. (Fig. 9). This is the first paleontological record of the genus in Antarctica.

Formal lithostratigraphy

The Weddell Sea Formation, exposed today only at the top of the Seymour Island meseta (Figs 3, 8), most probably represents a small relic of a much larger glacial drift deposit that once covered most of the area. It was, and still is, highly affected by erosion and modified by cryogenic processes.

Distribution: Shown on Figs 1, 3, 4.

Status of unit: Formal.

Synonyms and references: *Depósitos glaciarios de la meseta* (Malagnino *et al*. 1981); described as glacial marine deposits by Zinsmeister and de Vries (1983), informally referred to as the Weddell Formation.

Origin of name: After location close to the Weddell Sea.

Type section: NW tip of Seymour Island, close to the lighthouse (Figs 1, 3–5).

Overlying unit: None.

Underlying unit: Upper Eocene clastic sediments (Telm7) of the La Meseta Formation (Fig. 2).

Thickness: Ca. 4 meters, reduced by on-going erosional processes.

Main lithologies: The clastic components were derived mainly from the James Ross Basin. Most of the clastics (90%) come from rocks known from the Antarctic Peninsula sector. Igneous and metamorphic rocks form boulders, whereas pebbles are mainly represented by basalts and andesites. Less common (<10%) are blocks of rock eroded directly from the substratum (calcareous concretions bearing Tertiary and also Cretaceous fossils). A few fragments of typical but uncommon rocks occurring in the Antarctic Peninsula were also recognized. The matrix of the glacial drift was derived mainly from the underlying fossiliferous Tertiary and Cretaceous sedimentary rocks.

Lower boundary definition: The lower boundary of the Weddell Sea Formation is defined by a distinct erosional surface that cuts the uppermost unit (= Unit III of Elliot and Trautman 1982; Telm7 of Sadler 1988; Submeseta Allomember of Marenssi 1995, Marenssi *et al.* 1988) of the La Meseta Formation (Figs 2, 4A).

Subdivision: None.

Fig. 8. The Weddell Sea Formation exposed at the top of the meseta in the north end of Seymour Island.

Age: Post-Late Pliocene.

Dating method: Foraminifera in the youngest erratics (Cockburn Island Formation) of the Weddell Sea Formation till.

Upper age limit: Marine terraces, as well as marine abrasion platforms undisturbed by glacial drift, occur up to an elevation of 270–250 meters on Cockburn Island and 200 meters on Seymour Island (Zinsmeister 1980; Malagnino *et al.* 1981). They clearly post-date the Weddell glacial drift. Therefore, an Early Quaternary or even the latest Pliocene age may be suggested for the Weddell Sea Formation diamictite, because sea level was much lower than the 200 m altitude during the Middle–Late Pleistocene glaciations (Ishman and Rieck 1992, fig. 7, see also Abreau and Anderson 1998). The Weddell Sea Formation was most probably deposited during the first glaciation that affected the area after the Pliocene transgression 2–3 Ma ago (see Hodell and Warnke 1991; Gaździcki and Webb 1996).

Lower age limit: The lower age limit is well determined by the occurrence of boulders of the Pliocene Cockburn Island Formation (= *Pecten* Conglomerate) within the Weddell Sea Formation (Fig. 7). This can be established by comparison of the lithology and foraminifer assemblages in boulders with those ones occurring in the *Pecten* Conglomerate on Cockburn Island (see Gaździcki and Webb 1996). Boulders of the Pliocene Cockburn Island Formation represent the youngest rocks within the Weddell Sea Formation recognized so far.

Genesis: A glacio-marine origin for the diamictite, here named the Weddell Sea Formation, was suggested by Malagnino *et al.* (1981). The assemblages of agglutinated benthic foraminifera reported by Malagnino *et al.* (1981) and palynomorphs are most probably reworked from the Cretaceous and Tertiary strata of the James Ross Basin (see also Zinsmeister and de Vries 1983). No any other undoubtedly autochthonous foraminifera that might prove a marine origin for the diamictite are known from the Weddell Sea Formation. However, the occurrence of glacial drift on the plateau elevated up to 200 m a.s.l. precludes its marine origin, at least for the Early–Late Quaternary time. Moreover, striae on the concretions scattered on the substratum surface (Figs 2, 6), structures at the contact line with underlying sediments (Fig. 4A, B) and the occurrence of rocks eroded from the lower part of the La Meseta Formation, all suggest a terrestrial origin for the Weddell Sea Formation and its morphology suggests inner-morainic deposition (see Menzies 2002).

Bryozoan colony from the Weddell Sea Formation

On one metamorphic erratic from the Weddell Sea Formation was found a single well-preserved encrusting bryozoan colony belonging to *Escharella* Gray, 1848 (Fig. 9A, B).

The cheilostome bryozoan family Romancheinidae encomposses a relatively large number of genera among which *Escharella* is particularly speciose. Since the Neogene escharellids have been a common element of Southern Hemisphere bryofaunas. They are represented in the western part of the South Pacific and South Indian Ocean beyond the Antarctic Convergence.

Of about fifty-seven species of *Escharella* which have been described, only two seem to be restricted to Antarctic waters and may be regarded as endemic Antarctic species.

Hayward (1995) described *Escharella watersi* Hayward and Thorpe, 1989 which is distributed from South Georgia, through the Palmer Archipelago, to the Ross Sea, and probably occurs throughout Antarctica. The second species, *Escharella mamillata* Hayward and Thorpe, 1989 is presently known from Shag Rocks, the South Shetland Islands, the South Sandwich Islands, and from the Ross Sea. Specimens of *Escharella fistula* Brown, 1952 range in age from Middle Oligocene to Pliocene and have been reported from New Zealand. Another New Zealand species, *Escharella spinosissima* (Hincks, 1881) is known from the Recent as well as from Pliocene of Hawkes Bay (New Zealand) and Bass Strait (southern Australia).

Escharella sp. from the post-Late Pliocene Weddell Sea Formation described below represents the earliest stratigraphical occurrence of *Escharella* in Antarctica. The earliest Southern Hemisphere escharellid is recorded from the Cretaceous of Madagascar where the *Escharella cretacea* was described by Canu (1922). According to Crame (1999) both palaeontological and phylogenetic evidence suggest that a number of key benthic groups in southern high-latitudes at the present day have a Late Cretaceous origin. However, representatives of the Romancheinidae are extremely rare among the evolutionarily important La Meseta bryofauna with a single exception of *Escharoides* (see Hara 2001). Escharellids are a significant component of benthic bryozoan assemblages and vicariant species occur in cold and cold temperate waters of both hemispheres. They colonize a wide range of hard substrata (Hayward 1995).

Systematic paleontology

Suborder Ascophora Levinsen, 1909
Infraorder Umbonulomorpha Gordon, 1989
Superfamily Lepralielloidea Vigneaux, 1949
Family Romancheinidae Jullien, 1888
Genus *Escharella* Gray, 1848
Type species: *Lepralia immersa* Fleming, 1828
Escharella sp.
(Fig. 9 A–F)

Material. — ZPAL Br.9/1, one, small, unilaminar, fan-shaped colony, attached to a rocky substratum. Colony well-preserved, slightly worn in the proximal part. Small, round holes and fractures are observed on the convex frontal wall of some autozooecia.

Dimensions. — Colony 13 × 15 mm in size; autozooecial length 0.96–1.12 mm, autozooecial width 0.40–0.72 mm; orifice width 0.23–0.32 mm, orifice lenght 0.14–0.20 mm; lyrula length 0.15–0.18 mm; length of ovicell 0.5 mm, width of ovicell 0.42–0.48 mm.

Description. — Colony encrusting, unilaminar, fan-shaped (Fig. 9A, B). Autozooecia with umbonuloid frontal shield, elongate, or sub-hexagonal in shape, arranged in longitudinal rows, alternately, in somewhat radiating pattern, distinctly separated by marginal furrows on either side of which are areoral pores (Fig. 9C, D). Primary orifice rectangular, immersed; lyrula well-developed, anvil-shaped, broad, low with a straight distal edge, occupying almost the whole proximal border of orifice (Fig. 9E). Peristomial rim developed as a stout, median proximal mucro (Fig. 9D, F). Distal peristomial rim in some autozooecia possesses cervicorn processess resembling teeth. There are usually four oral spines in the distal part of the peristome but only the bases of spines are preserved. The spines are not present in ovicellate zooecia. Frontal wall ventricose (convex), finely granular, bordered by a single row of marginal areolae (Fig. 9C, D). Avicularia wanting. Ovicell large, globular, imperforate, with a length of 0.5 mm and median width of 0.45 mm, slightly recumbent on succeeding zooecium, placed in the distal part of zooecium; opening is hidden (Fig. 9D, F).

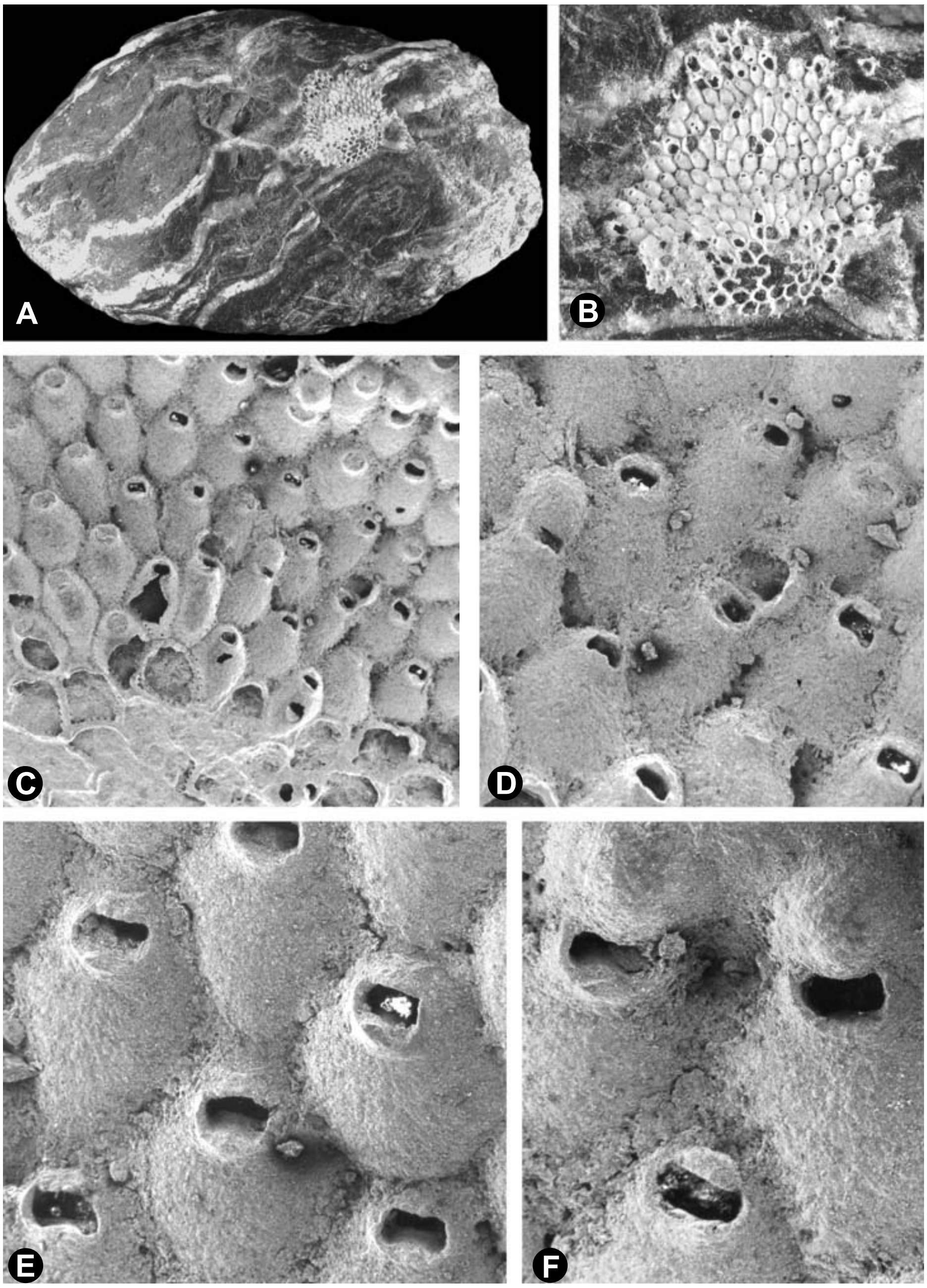

Fig. 9. *Escharella* sp. **A**. Metamorphic boulder encrusted by the bryozoan colony, × 1. **B**. Encrusting, unilamellar, oval to fan-shaped bryozoan colony with a worn proximal part, × 3. **C**. Pattern of arrangement of elongate to sub-hexagonal autozooecia, × 12. **D**. Group of autozooecia with some ovicellate ones, × 28. **E**. Group of autozooecia showing the proximal border of the primary orifice almost entirely occupied by the broad, low lyrula, × 45. **F**. Autozooecia with large, globular, imperforate ovicells, slightly recumbent on succeeding autozooecium; the primary orifice aperture is hidden in the peristome, × 55. Seymour Island, Weddell Sea Formation (post-Late Pliocene).

Remarks. — The figured specimen (Fig. 9A–F) shows all the characters of the genus *Escharella* Gray, *i.e*. umbonuloid frontal wall with marginal areolae, orifice with a well-developed lyrula and prominent, globular imperforate ovicell. The single Weddell Sea Formation bryozoan colony is generally well-preserved, although small holes or fractures in some frontal walls were observed (see Fig. 9 D–F). Only in three autozooecia, the shape of these fractures may match the shape of avicularia, which are usually directed midlaterally, however, the avicularia are usually wanting but can be adventitiously present in *Exochella.* In the studied specimen only the bases of spines are preserved, however, they are barely seen (Fig. 9E). In some features the specimen studied resembles the Recent cold temperate species *Escharella watersi* (Hayward and Thorpe, 1989) from the South Indian Ocean which, however, differs in having smaller sized autozooecia and a narrower lyrula. Another species, *Escharella ventricosa* (Hassall, 1842), shows similarities in the general shape of the zooecia and the pattern of their arrangement. However, in respect to morphometry, *Escharella* sp. differs from *E. ventricosa* in the larger size of the autozooecia and in possessing a narrower lyrula.

In view of the sparse bryozoan material available from the Weddell Sea Formation specific determination is deferred.

Gordon (1989) included the genus *Escharella* in the *Exochellidae* Bassler, 1935 but later (Gordon 1997, 2001) showed that the autozooecial frontal wall in the type species is of the umbonuloid type, and reassigned *Escharella* to the family Romancheinidae Jullien, 1888. According to Hayward (1995) it is probable that all species of *Escharella* apparently a remarkably homogenous genus, will be found to display umbonuloid frontal wall ontogeny, but the majority of described species have yet to be examined by SEM.

Occurrence. — Seymour Island (Antarctic Peninsula), Weddell Sea Formation, (post-Late Pliocene).

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