

Palaeogene Macrofossils from CRP-3 Drillhole, Victoria Land Basin, Antarctica

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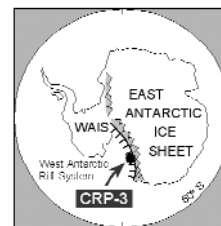
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Abstract - CRP-3 cored Palaeogene strata to 823 metres below the sea floor (mbsf), before passing through Devonian bedrock (Beacon Supergroup) to a depth of 939 mbsf. Palaeogene body fossils have been identified at 239 horizons in the core. The best preserved macrofossils from the core help elucidate the taxonomy, chronology and biogeography of Cenozoic ecosystems of Antarctica, although poor preservation prevents identification to species level in most cases. The lithostratigraphic unit (LSU) of the core top (LSU 1.1) contains an almost monospecific modiolid assemblage, similar to mussel beds recovered in the bottom part of the CRP-2/2A core. These semi-infaunal mussels appear to be conspecific,

apparently indicating the same age (Early Oligocene) and environment, *i.e.*, a deep muddy shelf characterized by high turbidity and dysoxic/anoxic bottom conditions (high H₂S sediment content). LSU 1.2 contains reasonably diverse assemblages representing inner/middle shelf environments dominated by epifaunal suspension feeders. LSU 2.1 contains low-diversity assemblages of suspension feeders (bivalves, brachiopods and bryzoans), probably indicating inner/middle shelf environments. LSU 3.1 contains assemblages including infaunal and epifaunal suspension feeders (bivalves, including a scallop, *?Adamussium* n.sp., and solitary corals) and infaunal deposit-feeders, possibly indicating deposition on a deep muddy shelf. Both the coral and the scallop previously have been recorded from Oligocene to Miocene rocks in Antarctica. Inner to middle shelf environments are suggested by macrofossils in LSU 5.1, mostly infaunal and epifaunal suspension-feeding bivalves. A similar environment is suggested for LSU 6.1, which contains epifaunal scallops and gastropods and infaunal bivalves. LSU 8.1 contains a relatively diverse macrofauna of infaunal suspension feeding bivalves and semi-infaunal/epifaunal gastropods, probably indicating middle shelf environments. *?Adamussium* n.sp. occurs lowest in LSU 8.1, establishing an Oligocene age for CRP-3 down to 320.43 mbsf. One poorly preserved gastropod at 359.07 mbsf indicates marine deposition for LSU 9.1. The only macrofossil below this is one modiolid mussel in LSU 13.2. The species apparently is different from that observed in the top of CRP-3. An Eocene age for this mussel is possible but uncertain. The presence of relatively warm-water taxa in the diamicton-dominated part of the CRP-3 core indicates that these taxa did not become extinct abruptly with the onset of Antarctic glaciation, but progressively decreased in diversity as sea-temperatures gradually decreased.



INTRODUCTION

CRP-3 hole, drilled at 77.011°S and 163.640°E, about 12 km east of Cape Roberts, in the Ross Sea, reached 939 metres below sea floor (mbsf). It recovered a thick Palaeogene (Oligocene-?Eocene) succession capping Palaeozoic (Devonian) rocks of the Beacon Supergroup (Cape Roberts Science Team, 2000).

239 macrofossiliferous horizons have been identified in core from CRP-3. Horizons initially identified at the Cape Roberts Laboratory were inspected in the Crary Science & Engineering Center at McMurdo Station. Macrofossil material not suitable for further palaeontological investigation was either sampled for geochemical (oxygen and carbon stable isotope composition, Sr-chronology) and diagenetic studies or stored to be shipped to the Cape Roberts

Project core repository facility in Bremerhaven (Germany). Macrofossils suitable for more detailed palaeontological study were cleaned at the Crary Science & Engineering Center at McMurdo Station using dental tools and delicate specimens hardened using a solution of water and dilute PVA glue.

This report is based on a selection of the best preserved and most identifiable body macrofossils. Even so, most fossils are minute, highly fragmented and/or highly decalcified, and their poor preservation state made their identification challenging. As in previous reports on CRP macropalaeontology, many taxa from CRP-3 have not been identified to specific or even generic level. The collection is temporarily retained as a discrete entity in the Institute of Geological and Nuclear Sciences, Lower Hutt.

Macrofossils are common in the Oligocene section of the core, providing further palaeontological

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documentation of marine macroinvertebrates for this epoch in Antarctica. The CRP-3 drill core adds new data to the growing palaeobiological information for the Oligocene epoch in Antarctica, which combines results from previous drilling operations in the Ross Sea region: DSDP Leg 28 (Dell & Fleming, 1975), CIROS-1 (Beu & Dell, 1989), and CRP-2/2A (Taviani et al., 2000) and from erratics at McMurdo Sound (Harwood & Levy, 2000; Stilwell & Feldmann, 2000). A few CRP-3 macrofossils, however, originated from sedimentary units of uncertain age and

depositional environment low in the core (LSU 9.1 and 13.2). These may prove to be of diagnostic value, considering the overall scarcity of palaeontological information in the lower part of the core.

TAPHONOMY

Diagenesis. Most carbonate is in an advanced stage of dissolution (Cape Roberts Science Team, 2000). In general, only calcitic fossils of pectinid

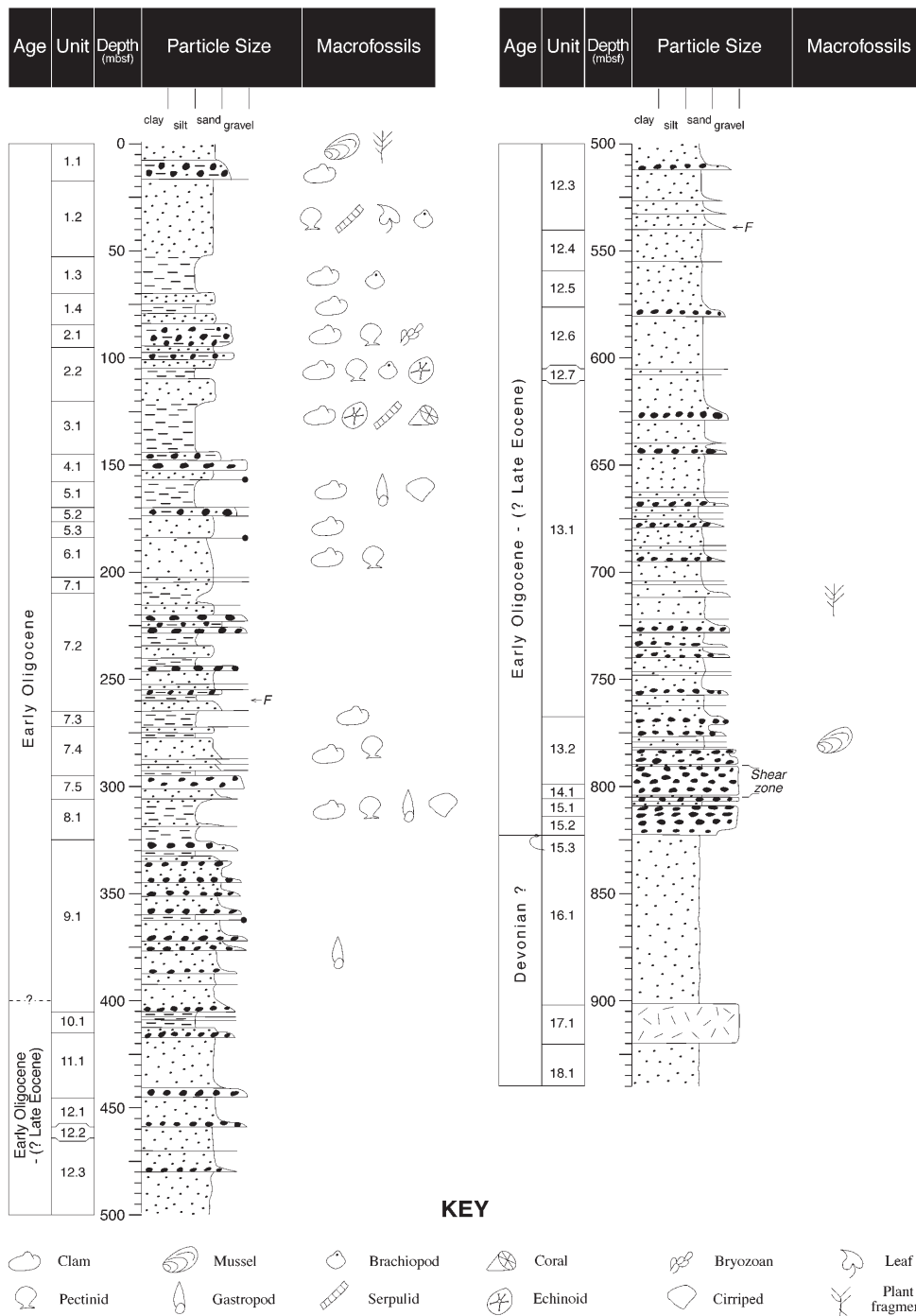


Fig. 1 - Lithostratigraphical summary of the CRP-3 drill core showing position and composition of the major macrofossil assemblages (slightly modified from Cape Roberts Science Team, 2000).

bivalves (*i.e.*, ?*Adamussium* n.sp.), worms (serpulid polychaetes) and echinoids are well preserved. Most aragonitic bivalves and gastropods show advanced decalcification and are represented by moulds, some of which retain a veneer of chalky carbonate. Shell breakage and fragmentation is common in the CRP-3 core but we are unsure whether it is mostly linked to skeletal dissolution (as we suspect) or to reworking. CaCO₃ concretioning has been observed around bivalves and gastropods at 141.20 and 359.07 mbsf and in the sediment matrix infilling serpulid polychaete tubes (*e.g.*, at 38.53 mbsf). Pyritized moulds of bivalves occur in LSU 1.3 at 64.42 mbsf.

TAXONOMY

Eight phyla of marine Invertebrata have been identified positively in the CRP-3 drill core. They are, in order of relative abundance, Mollusca, Annelida, Cnidaria, Brachiopoda, Crustacea, Bryozoa, Echinodermata and Porifera (Fig. 1). Re-examination of the inferred Vertebrata (fish remains) recorded in the Initial Report at 406.36 and 406.38 mbsf (Cape Roberts Science Team, 2000) reveals that such macrofossils are very likely plant fragments. Macroplant remains were also identified in CRP-3, as leaves (*Nothofagus* sp.) and stems (Cape Roberts Science Team, 2000, fig. 5.9d, m) and are discussed in detail by Cantrill (this volume). The organic nature of putative macrofossils from LSU 12.3 (465.77, 509.16 and 533.47 mbsf: Cape Roberts Science Team, 2000) could not be confirmed.

Macrofossils from CRP-3 have been treated in some detail in the Initial Report (Cape Roberts Science Team, 2000) and the best preserved specimens are figured there. The present article offers an updated perspective of the macrofossil assemblages with special reference to Mollusca, and their ecological and biogeographical significance. Annelida are also discussed here.

Mollusca are by far the dominant group and include, conservatively, at least 15 species of Bivalvia, 6 of Gastropoda and 1 of Scaphopoda. Cnidaria (scleractinian corals) are discussed by Stolarski & Taviani (this volume).

Brachiopoda, Echinodermata, and Bryozoa are under consideration for a detailed systematic study in the near future and only limited information is given here. Brachiopoda are represented by a smooth punctate species, presumably a terebratulid, reaching at least 20 mm in height (*e.g.* 62.61, 121.19 mbsf). Echinodermata are represented by echinoid debris (including a crushed shell) at 44.12, 114.23 and 121.41 mbsf. An undetermined encrusting bryozoan partially envelops a lonestone at 88.19 mbsf. Crustacea (a group not recorded in the Initial Report) is added to the list of taxa on the basis of barnacle plates previously recorded from LSU 5.1 and LSU

8.1 as unidentified bivalves (Cape Roberts Science Team, 2000). Barnacles (Cirripedia) have only rarely been reported from the Cenozoic of Antarctica (Zullo *et al.*, 1988; Buckeridge, 2000) and the Subantarctic (Carriol *et al.*, 1992; Giret *et al.*, 1994). The CRP-3 material consists of a very small fragment of the margin of a strongly ribbed shell at 168.39 mbsf (presumably a fragment of a barnacle plate, recorded in the Initial Report as “small crenulate shell fragment”), and one small, incomplete but well-preserved balanoid barnacle plate, plus several fragments of other plates, at 308.68 mbsf (recorded in the Initial Report as “many small fragments of unidentified bivalves”).

MOLLUSCA

BIVALVIA

?NUCULIDAE

?*Nucula* sp.

- 122.22-122.24 mbsf: One very small, articulated, chalky bivalve, hinge not visible.

Remarks: Small Nuculidae occur in the Cretaceous-Palaeogene of Antarctica, including the Ross Sea region (Beu & Dell, 1989; Stilwell, 2000; Taviani *et al.*, 2000).

SAREPTIDAE

?*Yoldiella* sp.

- 120.34-120.37 mbsf: Incomplete left valve of small, elongate, smooth protobranch bivalve, taxodont hinge visible, aff. *Yoldiella*.
- 122.22-122.24 mbsf: One small left valve of a smooth protobranch(?) bivalve, shaped as in *Tindaria*, *Jupiteria*, *etc.*, hinge not visible; outline most nearly resembles those of *Yoldiella antarctica* (Thiele) and *Y. profundora* (Melville & Standen) (Dell, 1990, figs. 17, 21).
- 124.93-124.96 mbsf: Several small bivalves, at least 3 valves, smooth, chalky, no hinges visible, but presumably the same taxon as above; another smaller, moderately elongate, weakly rostrate, rather thick-shelled protobranch bivalve, also a ?*Yoldiella* sp., ventral margin strongly abraded before fossilisation, indeterminate.
- 124.96-125.01 mbsf: 6-7 small bivalves, rather poor and chalky, no hinges visible but apparently all smooth, rostrate protobranchs, the same two species as above (a smaller and a larger ?*Yoldiella* species).
- 125.18-125.20 mbsf: 5-6 more small fragments of apparently the same, larger ?*Yoldiella* sp. as in the above three samples.
- 126.40-126.42 mbsf: Two bivalve fragments; (a) from the shape, one is probably ?*Yoldiella* sp., as above; (b) the other is very small, indeterminate.
- 127.34-127.36 mbsf: One poor, chalky valve of ?*Yoldiella* sp., as above, plus two small, unidentifiable bivalve fragments.

Remarks: Members of this family inhabit cold, deep waters world-wide, including modern Antarctica (Dell, 1990); *Yoldiella* has been recorded recently from Eocene erratics at Mt Discovery, McMurdo Sound, by Stilwell (2000).

?LIMOPSISIDAE

?*Limopsis* sp.

- 200.12-200.14 mbsf: Two fragments of one valve of a relatively thick-shelled, symmetrical, subcircular bivalve with weak commarginal sculpture; small area of symmetrical, serrated hinge visible in profile; probably *Limopsis* sp.

Remarks: The small species *Limopsis antarctominuta* has been described from Eocene erratics in the McMurdo Sound (Stilwell, 2000); the extant, large circum-Antarctic taxon *L. marionensis* occurs in the Pleistocene deposits of Cape Barne, Ross Island (personal observations).

MYTILIDAE

?*Modiolus* sp. 1 (Cape Roberts Science Team, 2000, fig. 5.9a)

- 6.80-6.88 mbsf: One decalcified shell.
- 10.80-10.85 mbsf: One articulated mould.
- 10.88-10.89 mbsf: Two articulated, decalcified shells.

Remarks: This species is the same as that recovered in the Early Oligocene sediments of the CRP-2/2A drill core (Taviani et al., 2000, fig. 6). The muddy lithologies of LSU 1.1 of core CRP-3 contain some articulated mussels, mostly decalcified.

?*Modiolus* sp. 2 (Cape Roberts Science Team, 2000, fig. 5.9n)

- 781.34-781.36 mbsf: One articulated, highly decalcified shell.

Remarks: The single specimen (Fig. 2a) represents the lowermost occurrence of marine macrofossils in CRP-3. The poorly preserved shell belongs to a species of Mytilidae tentatively ascribed to *Modiolus* s.l. Because of advanced decalcification, no important shell characters are visible. Some growth lines are evident near the edge of the right valve. The shell consists of articulated valves lying parallel to bedding (in a polymictic, coarse sandstone) but it is difficult to ascertain whether the shell is in life position or has suffered some minor displacement. Comparison with other mussels in Antarctica suggests that ?*Modiolus* sp. 2 is different from any other Mytilidae described so far from the Cenozoic rocks of Antarctica (Zinsmeister, 1984; Stilwell & Zinsmeister, 1992; Stilwell, 2000).

PECTINIDAE

?*Adamussium* n. sp.

- 29.94-29.96 mbsf: Fresh broken valve (Cape Roberts Science Team, 2000: fig. 5.9b) with auricles.
- 38.81-38.82 mbsf: Broken fragment, fresh.
- 41.61-41.63 mbsf: Two fresh, broken valves.
- 47.55-47.57 mbsf: One fragment.
- 83.95-83.97 mbsf: Fragments of a smooth pectinid (?); no umbo or auricles; apparently ?*Adamussium* n. sp. as in CRP-1 and CRP-2/2A.

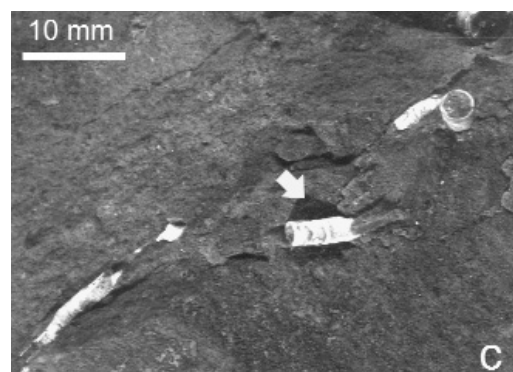
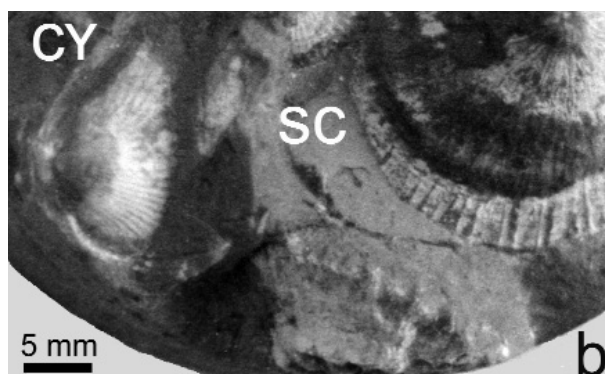
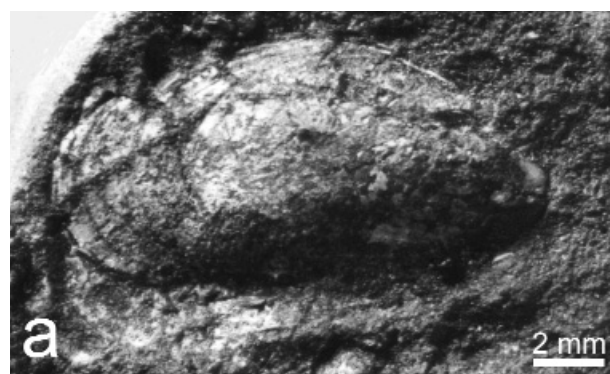


Fig. 2 - Macrofossils from CRP-3 drill core: (a) Modiolid mussel (?*Modiolus* sp. 2) from 781.34 mbsf; note that the highly decalcified specimen is an articulated shell, slightly gaped (age uncertain: Early Oligocene-Late Eocene); (b) bivalve-scleractinian assemblage at 140.69 mbsf: CY = articulated carditid bivalve (*Cyclocardia* sp.), SC = solitary scleractinian coral (*Flabellum variseptatum*), both probably in life position (Age: Early Oligocene); (c) well preserved serpulid polychaete tube aggregates (?*Serpula* sp.) from 38.53 mbsf; this taxon shows distinct growth wrinkles and rings (arrow).

- 114.19-114.22 mbsf: Fragments.
- 190.29-190.31 mbsf: Fragments.
- 308.20-308.25 mbsf: One articulated shell and fragments (Cape Roberts Science Team, 2000: fig. 5.9i).
- 309.29-309.33 mbsf: Two broken, well preserved valves (Cape Roberts Science Team, 2000: fig. 5.9l).
- 320.40-320.43 mbsf: Fragment, probably ?*Adamussium* n. sp.

Remarks: This taxon evidently is the same ?*Adamussium* n. sp. as in CRP-1 and CRP-2/2A and discussed in detail by Jonkers & Taviani (1998) and Taviani et al. (2000). The stratigraphic significance of pectinids in the Cenozoic of Antarctica has been discussed by Jonkers (1998).

Pectinidae sp.

- 38.81-38.83 mbsf: A small fragment (severely damaged during core preparation, less than a quarter of the disc; but 20 mm in longest dimension) of an external mould of the exterior of the disc of a strongly radially costate pectinid, shell material chalky; many very fine radial costellae on surface of radial costae. A latex cast confirms that this is from a pectinid with wide, convex-crested costae and narrow costal interspaces.

Remarks: This pectinid has not been reported from Antarctica before (Dell & Fleming, 1975; Dell, 1990; Stilwell & Zinsmeister, 1992; Jonkers, 1998; Jonkers & Taviani, 1998; Stilwell, 2000) and probably is unnamed, but the material is too poor for further comment. The auricle was abraded off before fossilisation, an indication that the fossil underwent transport or reworking.

?LIMIDAE

?*Lima* sp.

- 163.65-163.68 mbsf: Part of an incomplete, articulated specimen of a bivalve, perhaps ?*Lima* sp.; superficially similar to the narrowly ribbed *Cyclocardia* sp. that is common above this level, but differs in being (a) apparently originally calcitic, rather than aragonitic; (b) larger; and (c) with costae that diverge at a much lower angle, *i.e.*, this specimen originally was significantly taller and narrower than *Cyclocardia*.

Remarks: If confirmed, this is the first record of Limidae in the Oligocene of Antarctica, although this family is known from Late Cretaceous (Zinsmeister & Macellari, 1988) and Eocene beds of Seymour Island (Zinsmeister & Stilwell, 1992; Stilwell & Gazdicki, 1998), as well as from Pleistocene deposits of McMurdo Sound (Cape Barne: Speden, 1962; and personal observations) and the Ross Sea (Taviani et al., 1998). Limidae are also among the most conspicuous elements of the Recent Antarctic shelf fauna (*e.g.*, Bullivant, 1967; Dell, 1990).

LUCINIDAE

Lucinidae spp.

- 196.99-197.02 mbsf: One small piece of an incomplete valve (umbonal area lost during core preparation) of a fairly thick-shelled, weakly inflated bivalve with an almost circular shell and prominent, narrow, widely spaced commarginal lamellae; possibly the lucinid *Lucinoma*.
 - 127.84-127.87 mbsf: One very poor, chalky, weakly inflated, superficially smooth, subcircular, articulated bivalve, Lucinidae?, not determinable.
- Remarks:* Lucinids (*Saxolucina*, *Miltha*) previously have been recorded from Eocene rocks of the Antarctic Peninsula and McMurdo Sound (Zinsmeister, 1984; Stilwell & Zinsmeister, 1992; Stilwell, 2000).

CARDITIDAE

Cyclocardia spp.

- 6.48-6.51 mbsf: One chalky fragment from a radially ribbed, subtriangular bivalve, probably *Cyclocardia* sp.
- 120.34-120.37 mbsf: *Cyclocardia* sp., with narrow, well defined radial costae, as in CRP-2/2A (Taviani et al., 2000), one small valve.
- 120.43-120.47 mbsf: One fragment of a fairly thick shell with prominent radial sculpture and weaker commarginal sculpture; presumably *Cyclocardia* sp.
- 120.58-120.60 mbsf: Two fragments (part and counterpart of one fragment?) of *Cyclocardia* sp., as above.
- 120.60-120.62 mbsf: One slightly incomplete valve of *Cyclocardia* sp., as at 120.34-120.37 m, and probably the same as at 120.58-120.60 mbsf.
- 121.19-121.22 mbsf: One small fragment of a coarsely radially sculptured bivalve, probably *Cyclocardia*.
- 121.23-121.27 mbsf: *Cyclocardia* sp., as above, and as at 120.34, 120.58 and 120.60 mbsf, one fairly complete (but very chalky) valve, one incomplete articulated pair (chalky), and a few fragments.
- 121.29 mbsf: *Cyclocardia* sp., as above, one articulated but opened pair (part and counterpart on broken faces of core) and one good fragment with relatively undisturbed sculpture.
- 121.49-121.51 mbsf: *Cyclocardia* sp. (as above), one articulated pair, sawn through in preparing core; shell chalky.
- 126.48-126.51 mbsf: Fragments of one valve of a narrowly ribbed *Cyclocardia* sp., as above.
- 126.66-126.69 mbsf: Fragments of two valves of a narrowly ribbed *Cyclocardia* sp., as above.
- 127.84-127.87 mbsf: One fairly good but very chalky, articulated specimen of *Cyclocardia* sp., as above.
- 128.58-128.60 mbsf: One small fragment of a narrowly ribbed *Cyclocardia*.
- 136.35-136.38 mbsf: One very chalky, poor, incomplete, articulated specimen of a narrowly ribbed *Cyclocardia* sp.

- 137.33-137.35 mbsf: One small, chalky fragment of a narrowly ribbed *Cyclocardia* sp., as above.
- 140.02-140.04 mbsf: Fragments of the umbonal area of a chalky, articulated specimen of a narrowly ribbed *Cyclocardia* sp., as above.
- 140.11-140.14 mbsf: One poor, chalky fragment of a narrowly ribbed *Cyclocardia* sp., as above.
- 140.69-140.74 mbsf: Fragments and shells (including articulated ones) of 7-8 specimens of the narrowly ribbed *Cyclocardia* sp. (Fig. 2b), as above.
- 140.79-140.81 mbsf: One chalky, poor valve (and fragments from the same specimen) of the narrowly ribbed *Cyclocardia* sp., as above.
- 141.92-141.95 mbsf: Part of one very poorly preserved, chalky valve of the narrowly ribbed *Cyclocardia* sp., as above.
- 165.66-165.68 mbsf: Narrowly ribbed *Cyclocardia* sp., as above; one incomplete, chalky, articulated specimen, cut in preparing core.
- 319.97-319.99 mbsf: Poor, chalky fragments of an articulated specimen of a narrowly ribbed bivalve, presumably the same *Cyclocardia* sp. as is so common above.

Remarks: Two different species seems to be present of the cosmopolitan genus *Cyclocardia* Conrad, 1867, which is well represented in the Cenozoic and Recent of the palaeoaustral region, including Antarctica (Hendy et al., 1969; Beu & Maxwell, 1990; Dell, 1990; Stilwell & Zinsmeister, 1992; Taviani et al., 1998; Stilwell, 2000; Taviani et al., 2000). One species, characterized by a subcircular outline, seems conspecific with *Cyclocardia* sp. identified in the Late Oligocene of CRP-2/2A (Taviani et al., 2000; fig. 2c); the second species has a more elongate shell (Fig. 2; and Cape Roberts Science Team, 2000, fig. 5.9f).

VENEROIDEA

- 127.94-127.97 mbsf: One very poor, incomplete, chalky bivalve, severely compressed diagenetically, apparent posterior-umbonal ridge probably produced entirely by compression; weak commarginal sculpture; shape resembles a venerid, but identity not determinable.
- 139.46-139.47 mbsf: One indeterminate, chalky bivalve fragment; shape resembles a venerid, but no useful characters visible.
- 197.85-197.86 mbsf: Small fragment of the posterior area of a small bivalve; presence of a weak radial posterior-umbonal angulation and of low commarginal sculpture suggests that this is a veneroidean, but family not identifiable; appears to be the same taxon as above.

Remarks: Absent from the Antarctic Recent fauna, veneroid bivalves were in contrast, common in the warmer Palaeogene waters around this continent (Zinsmeister, 1984; Stilwell & Zinsmeister, 1992;

Stilwell, 2000). An undescribed species also has been reported from Late Oligocene sediments in the CRP-2/2A drill core (Taviani et al., 2000).

?PERIPLOMATIDAE

aff. *Periploma* sp.

- 62.61-62.69 mbsf: Fragments of moulds (with some chalky shell material remaining) of ca. 20 mm-long, very thin-shelled, weakly biconvex bivalve with two valves articulated, and with weak, rounded commarginal folds, aff. *Periploma* or similar? but no umbonal area or outline visible, indeterminate.
- 120.34-120.37 mbsf: Fragment of a small, thin-shelled bivalve with one valve almost flat, the other more convex, cf. *Periploma*?, but smaller and more inflated than usual for *Periploma*.

Remarks: Taviani et al. (2000) discussed previous records of *Periploma* from the Cenozoic rocks of Antarctica, to which must be added the recent report from McMurdo Sound erratics by Stilwell (2000).

?LATERNULIDAE

aff. *Laternula* sp.

- 140.69-140.74 mbsf: One large fragment (ca. 24 mm long) of a very thin-shelled, fragile (now severely distorted) bivalve with weak commarginal growth ridges (aff. *Laternula*?).

Remarks: The extant species *Laternula elliptica* (King & Broderip, 1831) is one the most common shallow-water circum-Antarctic bivalves. It also is recorded from a number of Pleistocene outcrops (Berkmann et al., 1998), but the pre-Pleistocene history of this family is obscure.

?THRACIIDAE

?*Thracia* sp.

- 75.54 mbsf: Partial, chalky, crushed, elongate, articulated bivalve with weak commarginal sculpture, damaged in core preparation, no hinge visible. Indeterminate but possibly *Thracia* sp.?
- 76.03-76.04 mbsf: At least three articulated (but all slightly to severely incomplete and chalky) specimens of a small (ca. 10-12 mm long), elongate, moderately inflated (but right valve less strongly inflated than left), weakly commarginally sculptured bivalve, with rounded anterior end and weakly rostrate, truncated posterior end, possibly *Thracia* sp.?

Remarks: The Cenozoic record of Thraciidae in Antarctica previously has been limited to Pleistocene records of the extant taxon *T. meridionalis* Smith, 1885 (e.g., Speden, 1962, listing earlier records; Berckmann et al., 1998).

Indeterminate bivalves:

Indeterminable fragments (mostly chalky moulds)

of bivalves were recognised at the following depths: 10.88-10.99 mbsf (*cf. Macoma, Laternula*); 50.46-50.48 mbsf; 51.20-51.23 mbsf; 64.42-64.43 mbsf; 89.02-89.03 mbsf; 96.27-96.29 mbsf; 94.37-94.38 mbsf; 98.31-98.33 mbsf (? aff. *Limopsis*, but shell thin); 99.59-99.61 mbsf (?Veneridae); 115.43-115.45 mbsf (?Pectinidae); 119.08-119.10 mbsf (aff. *Thracia?* or *Yoldia?*); 119.45-119.47 mbsf (aff. *Thracia?* or *Yoldia?*); 120.75-120.79 mbsf (*ca.* 8 small (8-10 mm) bivalves, *Yoldiella?*); 121.29 mbsf; 122.22 mbsf; 126.32-126.35 mbsf; 126.45-126.47 mbsf; 127.34-127.36 mbsf; 127.84-127.87 mbsf; 128.58-128.60 mbsf (Lucinidae or Veneridae?); 128.64-128.66 mbsf; 157.71-157.75 mbsf; 274.27-274.31 mbsf (?Pectinidae, but with widely spaced commarginal grooves); 308.68-308.71 mbsf; 315.66-315.69 mbsf (taxodont); 320.40-320.43 mbsf.

SCAPHOPODA

DENTALIIDAE

aff. *Dentalium* sp.

- 38.44-38.45 mbsf : Chalky fragments of a straight, approximately cylindrical calcareous tube, now compressed. One fragment of exterior shows both irregular commarginal rings (growth ridges?) and longitudinal costae; evidently a scaphopod

Remarks: Scaphopods identified in the Oligocene successions at Cape Roberts (CRP-2/2A: Taviani et al., 2000; CRP-3: this paper) are all poorly preserved but belong to at least two different taxa, one with a smooth shell (CRP-2/2A), the other costate, like the specimen collected at 157.83 mbsf (see below). Scaphopods, including *Dentalium*, have been recorded previously from Cenozoic beds of Antarctica and Subantarctica (Pugaczewska, 1984; Stilwell & Zinsmeister, 1992; Stilwell, 2000).

Scaphopod, not determinable

- 157.83-157.86 mbsf: Short length of a gently tapering, cylindrical tube, cut during core preparation; not compressed; very chalky, not determinable, but certainly a scaphopod.

GASTROPODA

TROCHOIDEA

Trochoidea, family not determinable:

- 198.88-198.89 mbsf: Small fragment of the outer lip and base of a nacreous indeterminate gastropod (?Trochidae) with sculpture of numerous low, narrow, close spiral ridges.

Remarks: The poorly preserved moulds and fragments of trochoidean shells recorded so far in the Cenozoic successions at Cape Roberts (CRP-2/2A: Taviani et al., 2000; CRP-3: this paper) are

difficult to classify even at family level, although the nacreous internal layer confirms the superfamily position. Trochoidea are among the most conspicuous elements of the Recent Antarctic macrofauna (Smith, 1902; Dell, 1990; Hain, 1990) and have a continuous record in Antarctica since at least Eocene time (Stilwell & Zinsmeister, 1992; Stilwell, 2000).

TURRITELLIDAE

Turritella (sensu lato) sp. (Cape Roberts Science Team, 2000, fig. 5.9h)

- 311.25-311.27 mbsf: Fragment, at least 20 mm high, and formerly >35 mm high and *ca.* 8-10 mm in diameter, of the interior of a calcitic replacement of a very high-spined, almost flat-sided turritellid(?) gastropod. The large number (6-7) of primary spiral ridges and several orders of secondary and tertiary ridgelets suggest that it might be a previously unknown genus of Turritellidae.

Remarks: Members of Family Turritellidae occur quite commonly in Cenozoic outcrops of Antarctica and Subantarctica. *Colposigma euthenia* Stilwell & Zinsmeister, 1992, is common in the Late Eocene macrofauna of La Meseta Formation, Seymour Island (Stilwell & Zinsmeister 1992). Karczewski (1987) mentioned three species from the Miocene Cape Melville Formation of King George Island (South Shetlands), including the European Neogene *Archimediella cf. subangulata* (Brocchi, 1814), a misinterpretation. A turritellid is also recorded from the Miocene of Kerguelen (Giret et al., 1994). More recently, two species of Turritellidae have been identified by Stilwell (2000) in McMurdo Sound erratics: *C. euthenia* (erratics from Mt. Discovery, Middle to Late Eocene; see Harwood & Levy, 2000) and *Zeacolpus?* sp. (erratics from Mt. Discovery, age not specified; see Harwood & Levy, 2000) but both appear to be different from the CRP-3 taxon.

?CALYPTRAEIDAE

?*Sigapatella* sp.

- 66.64-166.66 mbsf: Good internal mould of a calyptraeid gastropod, similar to *Sigapatella*.

Remarks: The single CRP-3 specimen has a taller spire than any *Sigapatella* species we know of, with the possible exception of *S. colossa* recently described by Stilwell (2000) from ?Eocene (age not reported) erratics in McMurdo Sound.

NATICIDAE

Naticidae, indeterminate

- 198.50-198.53 mbsf: Poor, chalky specimen of a naticid gastropod (Cape Roberts Science Team, 2000; fig. 5.9g); not identifiable, but the moderately thick shell and moderately exert spire suggest aff. *Polinices* or *Amauropsis (etc.)* rather than *Bulbus (cf. Dell, 1990)*.

- 317.88-317.92 mbsf: Indeterminable naticid



Fig. 3 - Undetermined gastropod from LSU 9.1 at 359.07 mbsf; the original macrofossil is a highly decalcified shell sliced by core splitting and embedded in a coarse sandy matrix; *camera lucida* hand drawing (M.T.) elaborated by Alessandro Remia.

gastropod; comments as for specimen above, but this one is even more poorly preserved.

- 326.72-326.78 mbsf: Incomplete internal and external mould of a large, indeterminable naticid(?) gastropod, *ca.* >40 mm in diameter, cut through by the drill.

Remarks: Members of family Naticidae have been recorded frequently from the Cenozoic of Antarctica and Subantarctica (Dell & Fleming, 1975; Gazdzicki & Pugaczewska, 1984; Giret et al., 1994; Stilwell & Zinsmeister, 1992; Stilwell, 2000; Taviani et al., 2000).

?PYRAMIDELLIDAE

?Pyramidellidae sp.

- 157-76-157.83 mbsf: Internal mould of a gastropod protoconch, apparently heterostrophic, possibly ?Pyramidellidae, genus indeterminable.

Remarks: Our determination is uncertain; this family of ectoparasitic opisthobranch gastropods has an extremely poor fossil record in Antarctica (Pleistocene of Cape Barne, Ross Island: Hedley, 1916) and very few modern representatives (Dell, 1990).

Indeterminable gastropods:

- 197.29-197.32 mbsf: Internal view of the spire of a low-spined gastropod, poor, very chalky; indeterminable.
 - 359.07-359.11 mbsf: Internal view of high-spined gastropod, very poorly preserved, longitudinally sliced by core splitting (Fig. 3).
- Remarks:* Not much can be said about this gastropod (from 359.07-359.11 mbsf) because of its

extremely poor preservation. This finding is, however, of some relevance since it represents one of the few fossils recorded in this part of the CRP-3 core. It is important to note that the specimen resembles a turrillid or similar tall-spined marine group of gastropods. It therefore probably indicates a marine depositional setting for LSU 9.1.

Mollusca *incertae sedis*

166.64-166.66 mbsf: Part of one valve of a strange bivalve(?) with a calcitic outer layer (particularly shown on the counterpart) and a chalky (presumably aragonitic) inner layer, and with sculpture of low commarginal folds, surface otherwise smooth; the alternative hypothesis of belonging to a thecosomatous pteropod (such as *Cavolinia* or *Diacria*?) should be also taken into account.

319.09-319.10 mbsf: Another fragment with the same shell structure as above; apparently the same taxon.

ANNELIDA

Polychaeta

Calcareous polychaete tubes are scattered within the upper part of the CRP-3 drill core. Reasonably well preserved tubes occur in LSU 1.2 and 3.1, associated with predominantly sandy and muddy lithologies respectively. Possible polychaete bioturbation is also indicated by burrow-fillings of *ca.* 3-5 mm diameter (*e.g.*, 50.46 and 62.62 mbsf).

?*Serpula* sp.

- 38.44-38.45 mbsf: Fragments.
- 38.53-38.66 mbsf: Various tubes, well preserved, aggregated (Cape Roberts Science Team, 2000, fig. 5.14 g and Fig. 2c).
- 50.42-50.43 mbsf: One short length of a relatively large, almost smooth, now severely compressed, thin-shelled, cylindrical calcareous tube; with very fine commarginal growth ridges, but the thinness and finely fibrous shell structure suggest it is a polychaete tube rather than a scaphopod. Preservation better than at 38.53-38.66 mbsf, shell material pale brown; sulfides in matrix perhaps suggest a different diagenetic history at this level from that above and below.
- 94.37-94.38 mbsf: Two fragments from a mould of a small tube, *ca.* 2 mm diameter, presumably formerly calcareous (polychaete?).
- 120.60-120.62 mbsf: One moderately large (*ca.* 7 mm diameter) calcareous tube, smooth apart from growth ridges, relatively thin, slightly compressed; evidently a polychaete tube.
- 121.06-121.07 mbsf: One badly crushed, cylindrical, smooth calcareous tube, presumably a polychaete.

Remarks: The best preserved material consists of an

aggregation of various specimens (>3) at 38.53 mbsf (Fig. 2c). Based on tube features, including raised collars and growth rings, similar to those of the extant Antarctic species *Serpula narconensis* Baird, 1865 (*cf.* Hartmann, 1966; Knox & Cameron, 1998), we tentatively attribute this material to *Serpula*. Serpulid polychaetes, very similar to the CRP-3 tubes, have been identified in Early Oligocene to Early Miocene sediments previously cored at Cape Roberts (Jonkers & Taviani, 1998; Taviani et al., 2000).

Serpulidae, indeterminate

- 39.00-39.01 mbsf: Two large, slightly chalky, now slightly compressed fragments of one calcareous, cylindrical tube, sawn through in preparing the core; this specimen (unlike that at 38.44- 38.45 m) is smooth externally, and has a prominent, regrown break halfway along; apparently a polychaete tube.
- 41.84-41.85 mbsf: Two more fragments of a smooth, compressed, presumed polychaete tube, as above.
- 43.70-43.72 mbsf: One fragment of a smooth, compressed, presumed polychaete tube, as above.

Incertae sedis

- 124.93-124.96 mbs: One small, circular, calcitic(?) bivalve, or possibly a non-punctate brachiopod brachial valve, apparently lacking a normal bivalve hinge after careful excavation.
- 165.50-165.53 mbsf: Small fragment of a very small tube, < 1 mm diameter; structure is radially fibrous; non-biological? Perhaps a foraminiferan?
- 324.35-324.39 mbsf: Unidentifiable shell fragment.
- 533.47-533.48 mbsf: Small fragment of a solid, probably cylindrical, calcareous object with concentric structure. This shows superficial similarities to an echinoid spine, and confirmation would be important because of the depth in the core (within the unfossiliferous interval). However, removal from the matrix demonstrated that it is definitely a clast.

PALAEOENVIRONMENTS

The lithostratigraphic unit of the core top (LSU 1.1) contains almost monospecific modiolid assemblages, correlatable with mussel beds recovered in the bottom part of the CRP-2/2A core (Taviani et al., 2000). These undescribed semi-infaunal mussels appear to be conspecific, indicating the same age (Early Oligocene) and environment postulated for CRP-2/2A (*i.e.*, a deep muddy shelf characterized by high turbidity and, very likely, peculiar bottom conditions such as a high H₂S sediment content). Unit LSU 1.2 contains reasonably diverse assemblages that indicate inner/middle shelf environments dominated by epifaunal suspension feeders, including gregarious serpulid polychaetes (*Serpula*), scallops (?*Adamussium*

n.sp.), scaphopods (?*Dentalium*), terebratulid brachiopod, and aragonitic bivalves. Unit 2.1 contains assemblages of low diversity, consisting of epifaunal (?*Adamussium* n.sp., terebratulid brachiopods, encrusting bryozoans) and infaunal (bivalves) suspension feeders, probably indicating inner/middle shelf environments. Unit LSU 3.1 contains macrofossil assemblages possibly indicating deposition on a deep muddy shelf, characterized by moderate water activity and turbidity and enrichment in organic matter. The macrobenthic assemblages include infaunal and epifaunal suspension feeders, such as bivalves (*Cyclocardia*, lucinid) and solitary corals (*Flabellum rariseptatum*), as well as infaunal deposit-feeders, such as protobranch bivalves (*Yoldiella*). Inner to middle shelf environments are suggested by macrofossils in LSU 5.1, most of which are infaunal (*Cyclocardia*) and epifaunal (?*Lima*) suspension-feeding bivalves. A similar environment is also suggested for LSU 6.1, based on the occurrence of epifaunal scallops (?*Adamussium* n.sp.) and gastropods (trochid, naticid) and infaunal bivalves (lucinid). Unit LSU 8.1 contains a relatively diverse macrofauna consisting of infaunal suspension feeders (*Cyclocardia*) and semi-infaunal/epifaunal gastropods (naticid, turritellid), probably indicating deposition in middle shelf environments. LSU 8.1 also includes the lowest occurrence of ?*Adamussium* n.sp. in CRP-3, indicating a relatively low sedimentation rate.

The likely climatic conditions reconstructed for the Early Oligocene of East Antarctica have been presented in our previous study on CRP-2/2A macrofossil assemblages (Taviani et al., 2000) and are not repeated here. It is sufficient to say that the presence of such macrofossils as turritellids, modiolid mussels and veneroidean bivalves suggests that the climate was warmer than at present, comparable to that of the present-day Subantarctic.

Marine macrofossils appear again in LSU 9.1 (359.07 mbsf: undetermined gastropod), and finally in LSU 13.2 at 781.34 mbsf with the single occurrence of an undescribed modiolid mussel. The palaeoclimatic significance of modiolid mussels in Antarctica has been discussed in detail by Taviani et al. (2000).

It is possible that this mussel inhabited deep marine (slope? basin?), organic-rich sediments, sporadically influenced by gravity mass flows. This reconstruction differs from the depositional environment interpreted from physical-sedimentological arguments, which imply instead a near-shore, deltaic setting, possibly above wave base (Cape Roberts Science Team, 2000: Fig. 7.4). At present, we consider that neither interpretation can be taken as definitive. For now, we point out some arguments that support our alternative hypothesis of a deep setting rather than a shallow one, at least for the part of the core containing the mussel.

Environment: Modiolid mussel assemblages are often associated with “turbiditic” environments where hydrogen sulfide and/or methane seepage from

decomposing organic matter may take place, providing sustenance for the bivalves, and of course they are well-known members of the deep-sea hydrothermal vent community (briefly reviewed by Cosel & Olu, 1998, p. 660; and others references therein).

Community: It is true that today such peculiar mussel-supporting environments occur in a wide spectrum of water depths, from brackish-lagoonal to abyssal. However, in the case of shallow communities, mussels are but one of many components of such assemblages, while in the CRP-3 core (as in many deep-sea mussel communities) there is no sign of accompanying macrofossils. Furthermore, nearshore environments are normally marked by a substantial signature of adjacent terrestrial biota (such as phytoliths), but this is not the situation in the CRP-3 drill core. This seems to indicate that deposition took place at a significant distance from reservoirs of terrestrial biota.

Historical record: Our knowledge of the biodiversity of macroinvertebrates inhabiting shallow Antarctic waters during the Palaeogene is now relatively advanced. None of the mussel taxa so far described appears to be conspecific (or even congeneric) with the CRP-3 mussel, a possible indication of CRP-3 environmental settings decidedly different from the shallow-water ones reported elsewhere in Antarctica.

Our interpretation of the lithostratigraphic unit containing this mussel as possibly deposited in a deep-sea dysoxic/anoxic environment has some important implications for determining the age of this critical part of the CRP-3 core.

BIOGEOGRAPHICAL AND CHRONOLOGICAL IMPLICATIONS

The lithostratigraphic unit of the core top (LSU 1.1) contains almost monospecific modiolid assemblages, correlatable with mussel beds recovered in the bottom part of the CRP-2/2A core (Taviani et al., 2000), consistent with this part of the core being the same age (Early Oligocene) as that postulated for CRP-2/2A.

Units LSU 1.2 and 2.1 contain the pectinid *?Adamussium* n.sp., whose known stratigraphic range extends from the Oligocene to the Miocene of Antarctica (Taviani et al., 2000). Unit LSU 3.1 contains the solitary coral *Flabellum rariseptatum* and *?Adamussium* n.sp., with a known stratigraphic range extending from the Oligocene to the Early Miocene of Antarctica. LSU 8.1 represents the lowermost occurrence of *?Adamussium* n.sp., establishing an Oligocene age for the CRP-3 core down to 320.43 mbsf.

Macrofossils reappear in LSU 13.2 with the single mussel, a species different from the modiolid observed in the top of the CRP-3 drill core and from

other mussels recorded from the Palaeogene of Antarctica (Zinsmeister, 1984; Stilwell & Zinsmeister, 1992; Stilwell, 2000). This macrofossil may prove of critical importance not only for the environmental interpretation outlined above, but also for its biochronological potential. Its *apparent* absence from sediments of established Oligocene age in the Ross Sea region possibly indicates an older age, leaving open the possibility that it is Eocene. However, this particular mussel is not recorded from any Eocene outcrops in Antarctica, neither on the Antarctic Peninsula (Stilwell & Zinsmeister, 1992) nor in the McMurdo Sound erratics (Stilwell, 2000). If our environmental interpretation is correct, however, its absence from other Eocene rocks could reflect the lack of comparable depositional settings; other Antarctic Palaeogene rocks apparently all were deposited in shallow water. CRP-3 may represent the first record of "deep-sea" Eocene sediments examined so far in Antarctica. A possible Eocene age for CRP-3 at ca. 780 mbsf is not in conflict with the other available palaeontological evidence.

An interesting aspect of the CRP-3 macrofauna for the history of the Antarctic fauna is its preservation in diamicton-dominated rocks. Relatively warm-water taxa (such as turritellid gastropods, modiolid mussels and veneroidean bivalves), not now living around Antarctica, apparently still lived there after the onset of Antarctic glaciation. A still more diverse molluscan fauna inhabited Antarctica during Eocene time (Stilwell & Zinsmeister, 1992; Stilwell, 2000), including diverse mussels, mastrid bivalves, diverse Veneridae, shallow-water Trochidae, and large, shallow-water turrid and volutid gastropods. It seems that, rather than undergoing an abrupt extinction with the onset of major Antarctic glaciation, these taxa that are not present around Antarctica today progressively were lost from the Southern Ocean as sea temperatures continued gradually to decrease. Rather than being expelled suddenly with the onset of glaciation (a "mass extinction"), the Antarctic biota may have waned gradually to its present impoverished diversity.

CONCLUSIONS

Identified marine macrofossils in core CRP-3 belong to eight phyla of marine Invertebrata which are, in order of relative abundance, Mollusca, Annelida, Bryozoa, Cnidaria, Crustacea, Brachiopoda, Echinodermata and Porifera. Mollusca are by far the dominant group and include, conservatively, 15 species of Bivalvia, 6 of Gastropoda and 1 of Scaphopoda. Unfortunately, the poor preservation of the available material means that most taxa must remain unidentified at the generic and specific level.

Mussel-dominated beds from the core top unit (LSU 1.1) are correlatable with mussel assemblages

from CRP-2/2A bottom units, suggesting similar environmental conditions (deep sea muddy shelf/slope, warmer-than-present sea water conditions and peculiar H₂S-enriched sediments) and age (Early Oligocene).

Macrofossiliferous horizons are common in CRP-3 down to *ca.* 325 mbsf (LSU 1.2 to 8.1) and contain fossils whose stratigraphic range does not extend earlier than Early Oligocene (the pectinid *?Adamussium* n.sp. and the scleractinian coral *Flabellum rariseptatum*). These assemblages are interpreted as deposited in shelf settings, most typically muddy, organic-rich middle-outer shelf environments, as testified by the dominance of infaunal deposit- and suspension-feeding bivalves (largely, carditids and protobranchs).

Below 325 mbsf the macrofossil content is limited to single occurrences of marine molluscs: an undetermined gastropod at 359.07 mbsf (LSU 9.1) and an articulated modiolid mussel at 781.34 mbsf (LSU 13.2). The latter is significant, as it is one of the few fossils found within a *ca.* 350 m-thick sedimentary succession at the base of the core, almost barren of fossils, of uncertain age and problematic depositional setting (LSU 9.1 to 13.2). It is possible that this mussel lived on a relatively deep slope influenced by gravity flows, and it is compatible with a (?Late) Eocene age.

Taxa of relatively warm-water affinities that do not now live around Antarctica are present in the diamicton-dominated rocks of CRP-3, and evidently continued to live around Antarctica after the onset of major glaciation. The Antarctic biota apparently did not undergo a “mass extinction” with the onset of glaciation, but progressively waned to its present impoverished diversity as sea temperatures gradually continued to fall.

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