

Macrofossils from CRP-2/2A, Victoria Land Basin, Antarctica

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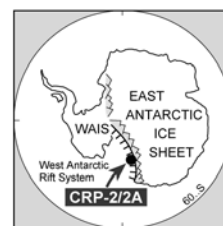
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Abstract - CRP-2/2A hole, drilled at 77.006°S and 163.719°E, about 14 km east of Cape Roberts, in the Ross Sea, reached 624 metres below sea floor and recovered a thick Miocene-Oligocene succession capped by a thin Pliocene-Quaternary cover. As many as 324 macrofossiliferous horizons have been identified in core CRP-2/2A, although the poor preservation state of most fossils prevents a full appreciation of their taxonomic identity. The macrofossils identified in core CRP-2/2A belong to Mollusca, Annelida, Cnidaria, Brachiopoda, Bryozoa, Echinodermata, Porifera and Vertebrata and represent an important source of palaeontological information on the former Antarctic biota. In particular, the CRP-2/2A drill core contains the most diverse Oligocene marine invertebrate macrofauna hitherto reported from East Antarctica. Early Miocene and Late Oligocene macrofossil assemblages are consistent with relatively cold (sub-polar) climatic conditions. One of the most significant findings in the drill core CRP-2/2A is the discovery of mussel assemblages dominated by modiolid bivalves within Early Oligocene sediments, suggestive of sea-bottom conditions characterized by high H₂S production. Modiolid bivalves are a strong indication of warmer-than-present climatic conditions. Many taxa are comparable to species recovered from coeval sediments drilled in the Ross Sea (DSDP Sites 270 and 272) and McMurdo Sound (CIROS-1).



INTRODUCTION

Cape Roberts Project drill core CRP-2/2A was collected at 77.006°S and 163.719°E, about 14 km east of Cape Roberts, in the Ross Sea down to 624 metres below the sea floor (mbsf). The cored strata (Fig. 1) consist of a thin cover of Pliocene-Quaternary sediments capping a thick Miocene-Oligocene succession (Cape Roberts Science Team, 1999). As many as 324 macrofossiliferous horizons have been detected in the core CRP-2/2A (Cape Roberts Science Team, 1999). Macrofossils are especially abundant in the Oligocene section of the core (263 horizons), providing the richest palaeontological documentation of marine macroinvertebrates for this epoch in East Antarctica. However, quantity is not matched by quality of fossils; in fact, the high palaeontological potential of core CRP-2/2A is significantly reduced by the poor preservation of most fossils, prevalently represented by minute, highly fragmented and/or highly decalcified skeletal remains which proved to be a serious challenge to an in-depth taxonomic assessment.

Macrofossiliferous horizons initially identified at the Cape Roberts Campsite Laboratory were inspected and sampled in the Crary Science & Engineering Center at McMurdo Station; macrofossil material not considered suitable for further palaeontological investigation was either sent to the Cape Roberts Project core repository facility in Bremerhaven (Germany), or sampled for other scientific purposes, *i.e.*, petrological (diagenesis) and geochemical (stable isotopes, Sr-dating) studies. The present report is

based upon a selection of the most identifiable and best-preserved body macrofossils.

TAPHONOMY

Diagenesis. Drill core 2/2A has been affected by burial processes of various intensity ranging from simple etching to complete dissolution, and, at places, to recrystallization and pyritization of most calcareous macrofossils (Cape Roberts Science Team, 1999). Highly porous sandy and mixed lithologies of the Pliocene-Quaternary succession, Lithostratigraphical Units (LSU) 2.1 and 2.2, generally contain only worn fragments of calcitic shells and tests. Early Miocene solitary corals from LSU 3.1 display a sugar-like texture and, in some cases, almost complete dissolution of the aragonitic test. Macrofossils identified in the Oligocene lithologies show quite different preservation states according to their inferred original mineralogy and host-sediment grain size. As a rule, calcitic skeletal parts belonging to worms (serpulid polychaetes), and echinoids are well preserved. Most bivalves are decalcified and represented by moulds retaining a veneer of chalky carbonate. Noticeable exceptions are a few bivalves encased in fine-grained lithologies of units LSU 8.4 and 9.4, and some mussels from LSU 13.1. Recrystallization accompanied by precipitation of sparry calcite is present in shells of gastropods, unless these are completely dissolved and represented by moulds. Concretions also occur in the Oligocene part of the drill core, especially

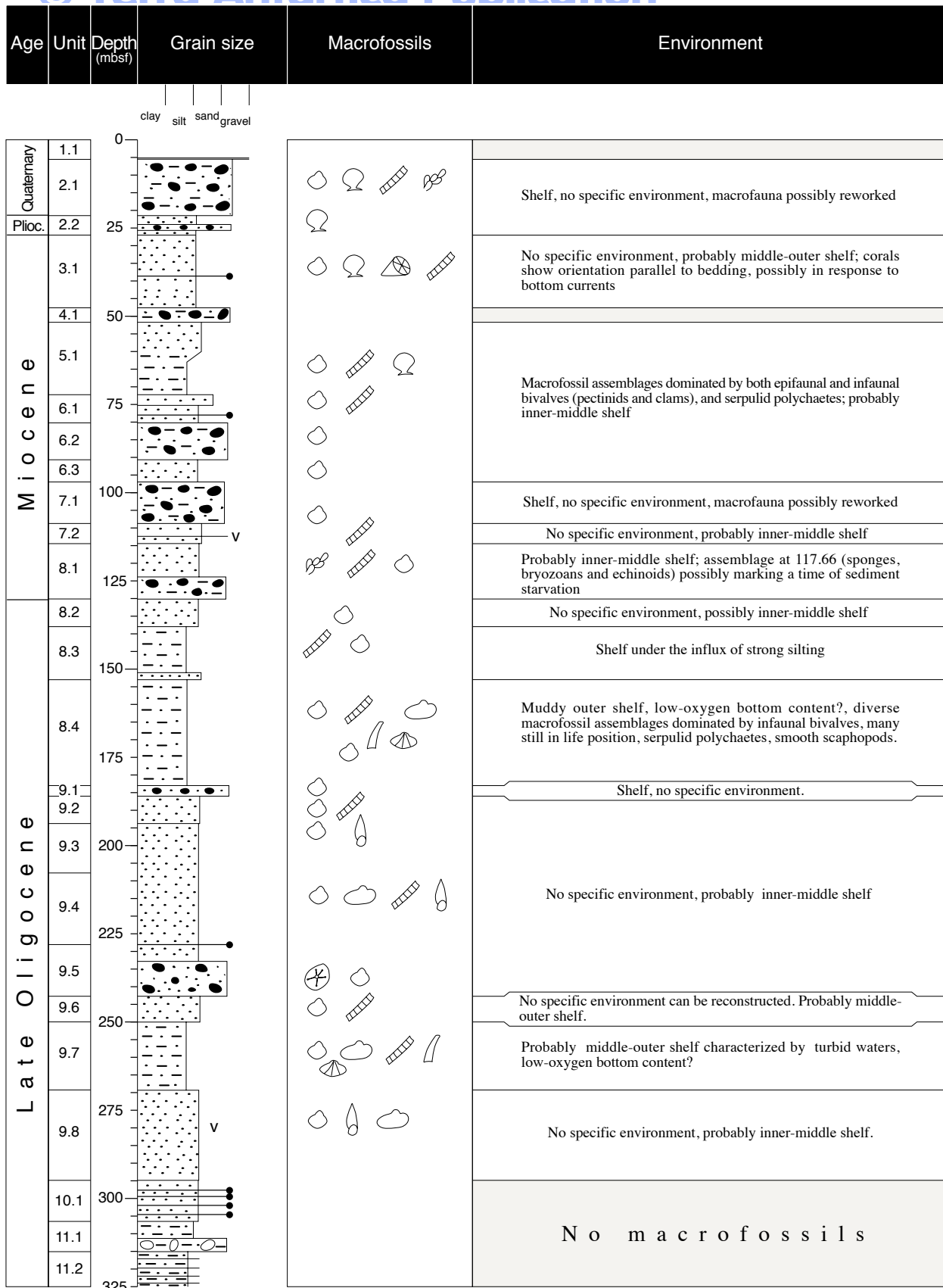


Fig. 1 - Lithostratigraphical summary of CRP-2/2A drill core showing position and composition of the major macrofossil assemblages and their palaeoenvironmental significance (slightly modified from Cape Roberts Science Team, 1999).

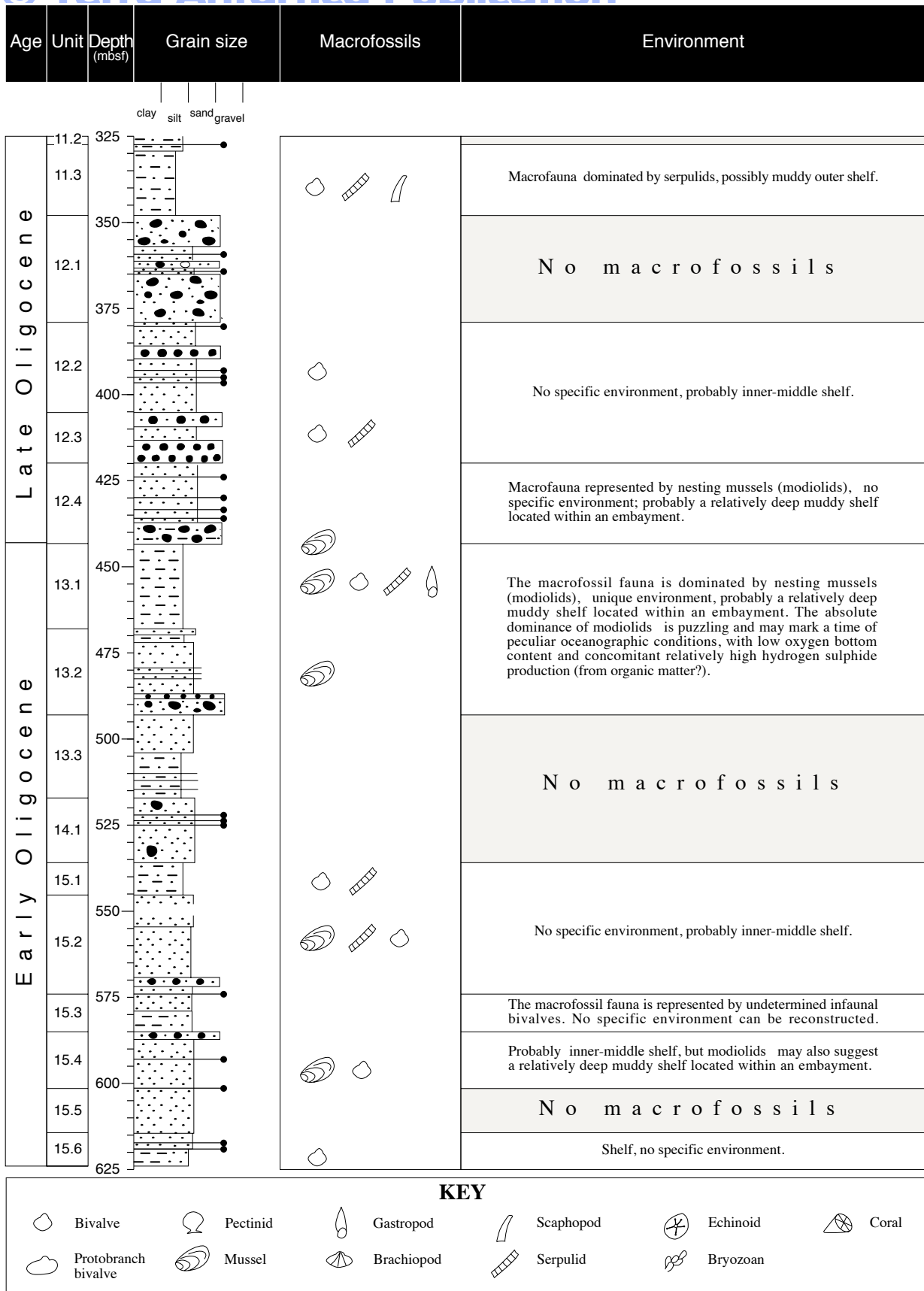


Fig. 1 - Continued.

around serpulid polychaete tubes (sometimes filled by cement, such as, for example, tubes at 141.74, 328.73, and 338.75 mbsf). At places, this process is so advanced as to form bivalve-bearing fossiliferous 'limestones'. The best examples of such rocks are the marly limestone at 249.65 mbsf (LSU 9.7), encasing an articulated *Yoldia* assemblage, and the carbonate concretions of units LSU 15.4 and 15.6, containing bivalve debris (599.21, 599.29, 599.97, 614.57 mbsf). Pyritization occurs at a few places within mudstone lithologies of the Oligocene part of the core, as patinas and/or infilling including some tubular macrofossils (interpreted as scaphopods; example at 180.08 mbsf), serpulids, brachiopods and mussels. Very likely, pyritization was a process favoured by reactions within fine-grained, organic-rich, reducing sediments (Canfield & Raiswell, 1991).

Reworking. The palaeontological content of the Pliocene-Quaternary sequence of drill core CRP-2/2A is very scant and fossils are generally abraded and fragmented. This fact suggests that some fossils are possibly reworked from older sediments, as also supported by their anomalous Sr-ages (M. Lavelle, pers. com.). This is very likely the case also for the Oligocene mussel occurrence near the base of unit LSU 12.4; in fact, this sole specimen associated with a diamictic lithology in LSU 12.4 is better interpreted as having being cannibalized from the underlying mudstone unit LSU 13.1, which contains large numbers of modiolid bivalves.

Currents. The activity of weak to relatively strong bottom currents is indicated by orientation of subhorizontal-resting solitary corals in unit LSU 3.1, aligned bryozoans in LSU 8.1 at 117.66-117.72 mbsf, and ubiquitous disarticulated bivalves lying roughly parallel to the bedding plane. However, bioturbation may be responsible for some of these post-mortem displacements.

TAXONOMIC NOTES

Seven phyla of Invertebrata have been positively identified in the CRP-2/2A drill core. They are, in order of relative abundance, Mollusca, Annelida, Cnidaria, Brachiopoda, Bryozoa, Echinodermata and Porifera. Vertebrata are documented by fish scales and teeth.

Mollusca are by far the dominant group and include, conservatively, as many as 13 species of Bivalvia, 6 of Gastropoda and 1 of Scaphopoda. The second most abundant group is Annelida, represented by 3 species of serpulid polychaete tubes.

MOLLUSCA BIVALVIA

NUCULIDAE

? *Ennucula* sp.

- 165.79 mbsf, one valve.

Remarks: The only valve is a fragment belonging to a small specimen still retaining some nacreous luster. Beu & Dell (1989) recorded *Ennucula* aff. *grayi* (d'Orbigny) from Oligocene strata in CIROS-1 (McMurdo Sound, Ross Sea).

NUCULANIDAE

?Nuculanidae, not determined:

- 194.87-194.90 mbsf, fragmentary, small articulated shell.
- 232.98-233.00 mbsf, fragmentary, small articulated shell.

Remarks: *Nuculana?* (s.l.) is recorded from Oligocene strata in CIROS-1 core by Beu & Dell (1989); the lack of figures and the poor preservation state of the material do not allow any detailed comparison between these two taxa.

MALLETIIDAE

? *Neilo* sp., (Fig. 2a: 257.60 mbsf)

- 257.60-257.63 mbsf, articulated shell with prominent commarginal sculpture:
- 214.07-214.10 mbsf, *Neilo?*, small almost complete articulated shell.
- 214.24-214.26 mbsf, one fresh fragment.
- 268.67-268.69 mbsf, small articulated shell, incomplete.
- 285.65-285.68 mbsf, incomplete articulated shell, moderately prominent commarginal ridges, posterior end shaped correctly for *Neilo*.
- 459.28-459.32 mbsf, one small, incomplete articulated shell.

SAREPTIDAE

Yoldia (Aequiyoldia) sp. (Fig 2b: 260.83 mbsf)

- 165.48-165.50 mbsf, one fragment.
- 168.17-168.20 mbsf, one large fragment
- 182.17-182.22 mbsf, incomplete articulated shell.
- 194.87-194.91 mbsf, several fragments of one valve.
- 195.44-195.48 mbsf, incomplete articulated shell.
- 195.75-195.78 mbsf, one fragment.
- 197.00-197.04 mbsf, one fragment.
- 208.58-208.60 mbsf, 2 fragmentary, small, chalky valves.
- 209.33-209.35 mbsf, one slightly incomplete valve.
- 210.10-210.14 mbsf, one large, incomplete, chalky valve (Cape Roberts Science Team, 1999, fig. 5.14a).
- 218.19-218.23 mbsf, one fresh fragment.
- 220.45-220.47 mbsf, one small fragment.
- 224.17-224.20 mbsf, good fragment of interior of articulated shell, showing hinge.
- 224.54-224.57 mbsf, several small fragments of an incomplete valve.
- 224.84-224.88 mbsf, one small fragment.
- 227.27-227.29 mbsf, fragments of large, nearly complete valve, hinge visible.
- 249.65-249.69 mbsf, several large, nearly complete articulated specimens and single valves in shelly interval (coquina).
- 254.99-255.04 mbsf, two incomplete valves with fresh, hard shell.
- 256.40-256.43 mbsf, fresh fragment of posterior end of valve.
- 260.83-260.87 mbsf, good, slightly incomplete valve

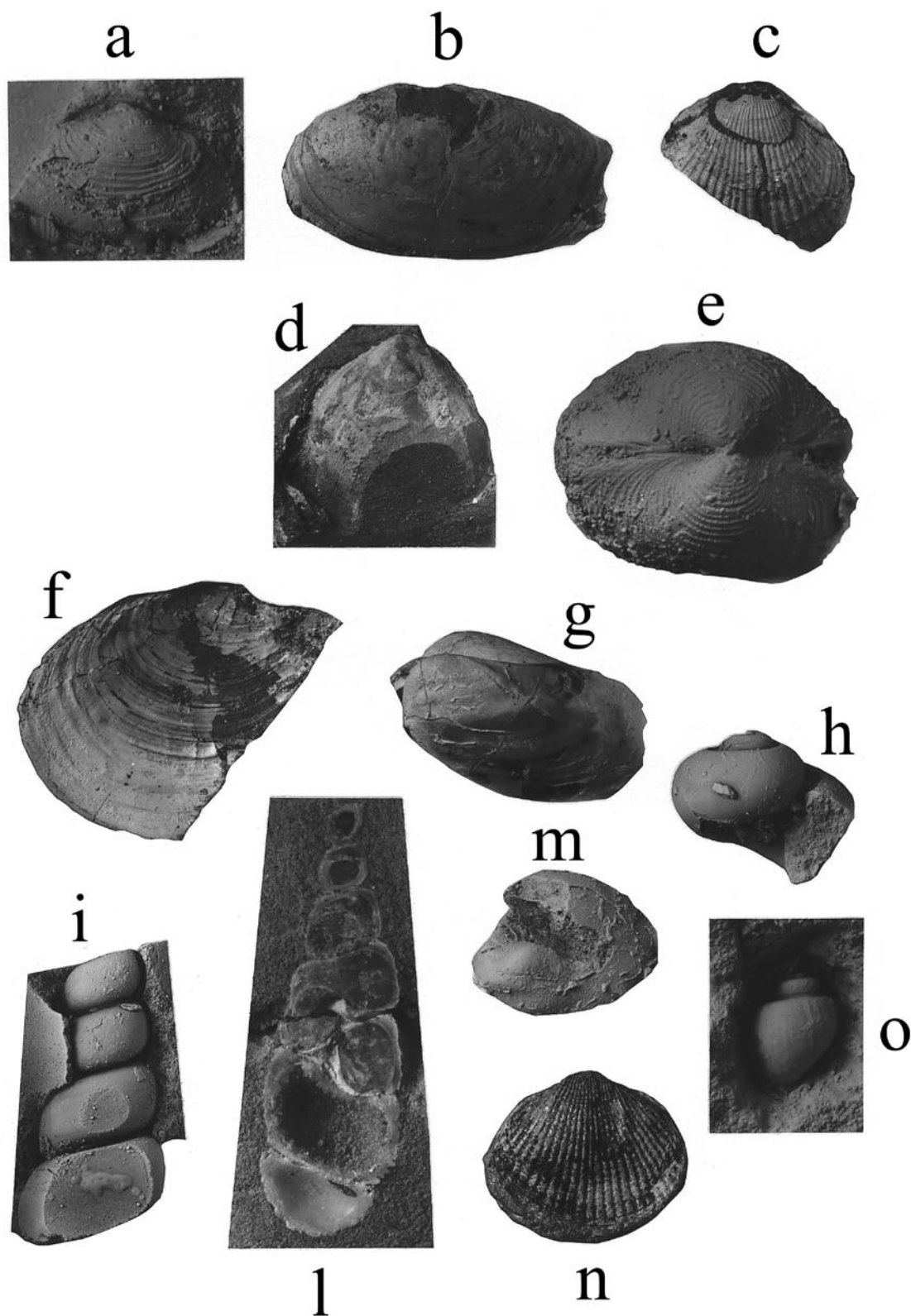


Fig. 2 - Early Miocene and Oligocene macrofossils from CRP-2/2A drill core: (a) *?Neilo* sp. (Late Oligocene, LSU 9.7, 257.60 mbsf); incomplete right valve, length 8.5 mm); (b) *Yoldia (Aequiyoldia)* sp. (Late Oligocene, LSU 9.7, 260.83 mbsf); slightly incomplete left valve, length 21 mm. (c) *Cyclocardia* sp.; (Late Oligocene, LSU 9.3, 195.36 mbsf), incomplete articulated shell, length 10.7 mm. (d) *Cardiidae?*, (Early Oligocene, LSU 13.1, 446.59 mbsf), incomplete decorticated valve, height 13.2 mm. (e) Veneroidean bivalve, (Late Oligocene, LSU 9.4, 224.41 mbsf), incomplete articulated shell, width 9.9 mm. (f) *Periploma* sp. (Early Oligocene, LSU 13.1, 443.91 mbsf), incomplete right valve, length 21 mm. (g) *Hiatella* sp. (Early Oligocene, LSU 13.1, 450.68 mbsf), slightly oblique dorso-lateral view of incomplete internal mould of articulated shell, length 16 mm. (h) Trochoidean? gastropod, (Early Oligocene, LSU 13.1, 448.58 mbsf), apertural view of internal mould, diameter 9.5 mm. (i) Turritellidae, indet., (Late Oligocene, LSU 9.8, 285.12 mbsf), incomplete internal mould, height 24 mm. (l) Turritellidae, indet., (Late Oligocene, LSU 9.4, 226.85 mbsf), formerly complete shell sectioned by drill, height 22 mm. (m) *?Crepidula* sp., (Early Oligocene, LSU 13.1, 446.59 mbsf), oblique latero-dorsal view of incomplete internal mould, length 10 mm. (n) Rhynchonellid? brachiopod, (Late Oligocene, LSU 9.7, 262.02 mbsf), dorsal view of slightly incomplete dorsal valve, width 11 mm. (o) Neogastropod, undetermined (Cancellariidae?), (Early Oligocene, LSU 13.1, 446.59 mbsf), dorsal view of internal mould, height 4.5 mm.

(umbo missing).

- 262.21-262.24 mbsf, two specimens; one large incomplete fresh valve and fragments of another.
- 263.17-263.20 mbsf, several fragments of one valve.
- 291.95-292.03 mbsf, mould of articulated shell.
- 294.07-294.13 mbsf, mould of one valve.
- 446.33-446.38 mbsf, large fragment of one valve.
- 446.59-449.63 mbsf, mould of articulated shell.
- 456.61-456.63 mbsf, large chalky fragment.
- 457.00-457.02 mbsf, mould of articulated shell, showing interior of hinge.

Remarks: No commarginal sculpture other than growth lines; most common taxon in upper 300 m of core, plus 3 occurrences in lower portion (>444 mbsf). The CRP-2/2A taxon resembles the living *Y. eightsi* (Jay, 1839) a large protobranch inhabiting sublittoral sub-Antarctic and circum-Antarctic muddy environments (Rabarts & Whybrow, 1979); our taxon appears to belong to *Aequiyoldia* but slightly differs in outline from the Recent Antarctic species, which has also been recorded from Miocene sediments at DSDP Site 270 in the Ross Sea (Dell & Fleming, 1975). Comparison between one of the best-preserved fossil specimens from CRP-2/2A (260.83 mbsf) with a modern shell of *Y. eightsi* from McMurdo Sound reveals significant analogies in the dissolution patterns of the external valve surface of both taxa (Fig. 5); etching and pitting scars on the shell of the live-collected specimen are situated in areas not protected by the leathery periostracum, presumably as a consequence of exposure to acidic waters, including pore waters. We postulate, therefore, that *Yoldia* (*Aequiyoldia*) sp. may have lived in a similar habitat to its modern analogue, *i.e.* in shallow, sheltered muddy environments rich in organic matter and relatively low in oxygen content.

PHILOBRYIDAE

?Phyllobryidae, unidentified (Fig. 4: 227.39 mbsf)

- 227.39-227.42 mbsf, one good complete, articulated specimen, inflated, with weak commarginal ridges and prominent prodissoconch, but hinge not visible.

Remarks: The very small size, the obvious but almost smooth prodissoconch (Fig. 4e), the shape and the weak commarginal sculpture of this small bivalve look most like the Cenozoic-Recent *Aupouria* Powell, 1937. The single extant species (*A. parvula* Powell, 1937) is recorded only from northern New Zealand.

MYTILIDAE

?*Modiolus* sp., (Fig. 6)

- 443.50-443.56 mbsf, one complete articulated shell (valves open).
- 444.62-444.64 mbsf, one incomplete articulated shell.
- 445.03-445.06 mbsf, one good incomplete mould.
- 445.11-445.15 mbsf, 3 good, slightly incomplete moulds of articulated shells.
- 447.43-447.48 mbsf, one complete articulated shell, valves open (Fig. 6b).
- 447.69-447.81 mbsf, one distorted mould of articulated shell.

- 449.02-449.04 mbsf, small fragment of articulated shell, umbo showing.
- 449.31-449.35 mbsf, good mould of incomplete articulated shell.
- 449.64-449.69 mbsf, 3 good incomplete moulds of articulated shells, plus a partial mould of one valve.
- 449.87-449.93 mbsf, good mould of one valve (apparently from an articulated shell).
- 452.55-452.57 mbsf, small articulated shell.
- 460.50-460.58 mbsf, 3 articulated shells.
- 460.64-460.67 mbsf, fragmentary mould of articulated shell.
- 460.76-460.78 mbsf, one decalcified valve.
- 461.53-461.57 mbsf, good incomplete chalky mould of articulated shell.
- 461.65-461.69 mbsf, incomplete mould of articulated shell.
- 461.80-461.83 mbsf, incomplete mould.
- 462.58-462.65 mbsf, 2 articulated shells.
- 463.57-457.62 mbsf, incomplete articulated shell.
- 463.98-464.00 mbsf, excellent mould of anterior half of articulated shell.
- 464.44-464.47 mbsf, incomplete mould of articulated shell.
- 464.78-464.82 mbsf, 2 incomplete moulds of articulated shells, plus fragments of 4 valves.
- 464.85-464.87 mbsf, cross-section of small articulated shell.
- 465.88-465.92 mbsf, fragment of a valve.
- 466.59-466.63 mbsf, one partial mould of articulated shell.
- 467.34-467.40 mbsf, 2 articulated shells.
- 469.87-469.93 mbsf, excellent, slightly incomplete internal mould (strongly pyritised).
- 482.91-482.93 mbsf, small fragment of articulated shell.
- 559.97-600.01 mbsf, partial mould of one valve, larger than all the others.

Remarks: Most common taxon in core below 444 mbsf. A number of articulated mussels, occasionally retaining some shell material showing weak, commarginal folds, occur below 441.59 mbsf in the mainly mudstone lithologies of LSU 12.4 (where the shell may be reworked from underlying sediments), 13.1 and 15.4. The shape and dimensions of the relatively abundant material from CRP-2A agree well with *Modiolus* s.l. Modiolid mussels occur in the Eocene of Seymour Island (Stilwell & Zinsmeister, 1992); ?*Modiolus* (s.l.) sp. has been reported from Miocene sediments in DSDP Site 270 (Dell & Fleming, 1975); *Modiolus?* sp. recorded from Oligocene sediments in CIROS-1 (Beu & Dell, 1989) may prove to be conspecific with the CRP-2A taxon. No modiolid mussels live around Antarctica at present (*e.g.*, Dell, 1990; Hain, 1990).

PECTINIDAE

?*Adamussium* n. sp., (Fig. 7: 71.42 mbsf)

- 36.29-36.30 mbsf, fragment.
- 54.28-54.29 mbsf, fragment.
- 71.42-71.47 mbsf, well preserved valve broken by core drilling.

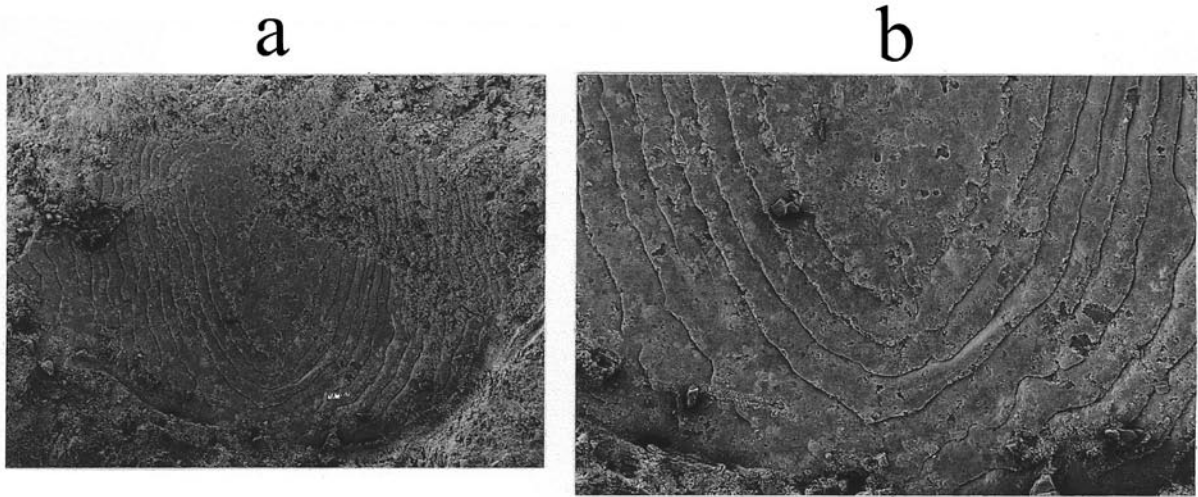


Fig. 3 - Unidentified fish scale, (Late Oligocene, LSU 8.4, 166.64 mbsf): natural mould of incomplete scale, width 4.2 mm: (a) general view, enlarged x 17; (b) detail, enlarged x 40. SEM photographs.

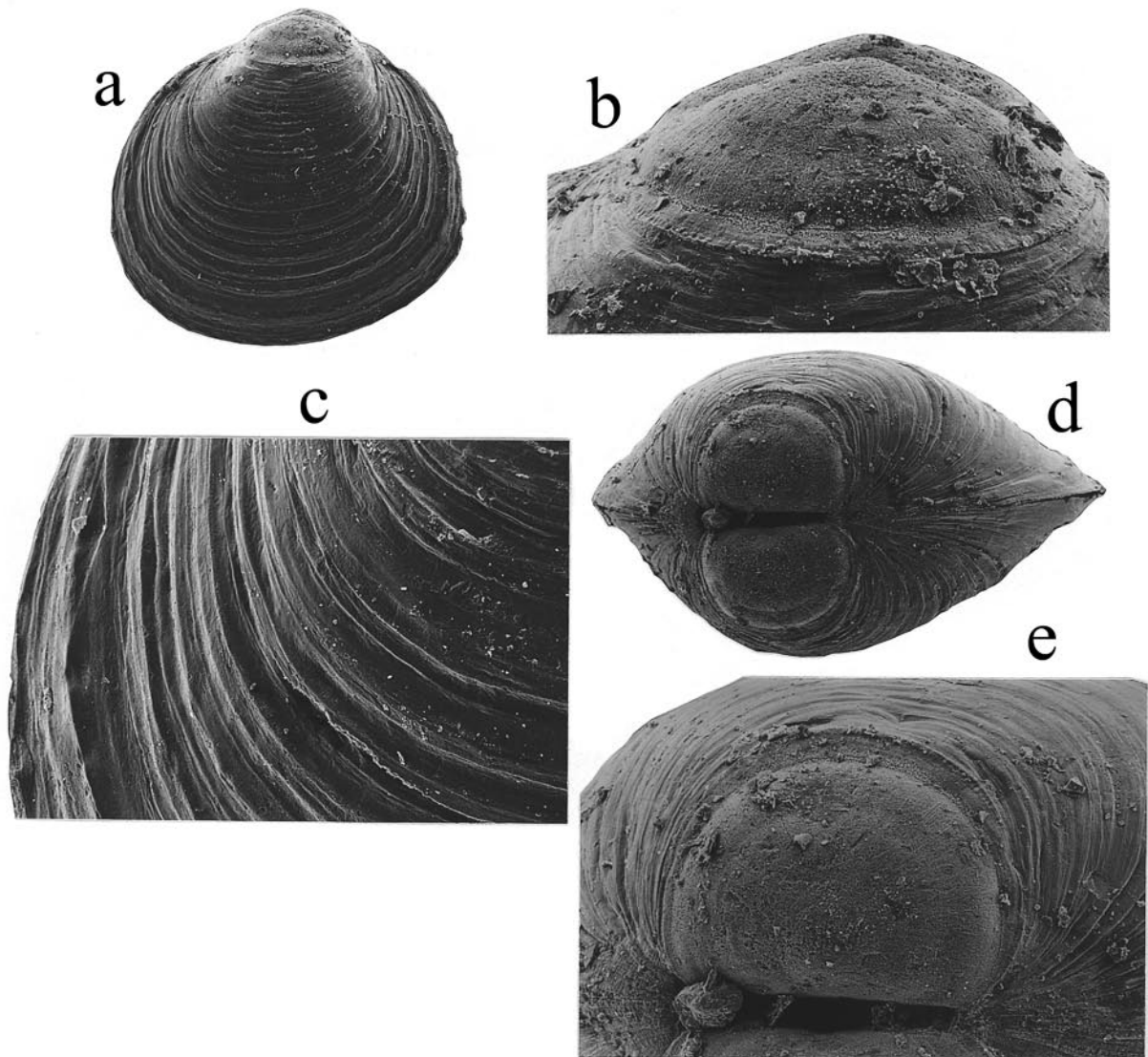


Fig. 4 - ?Phylobriidae, unidentified, (Late Oligocene, LSU 9.4, 227.39 mbsf), complete articulated specimen, width 1.4 mm: (a) right valve, enlarged x 40; (b) lateral view of prodissoconch of right valve, enlarged x 160; (c) sculpture of posterior area of right valve, enlarged x 160; (d) dorsal view of whole shell, enlarged x 60; (e) dorsal view of right valve prodissoconch, enlarged x 125. SEM photographs.

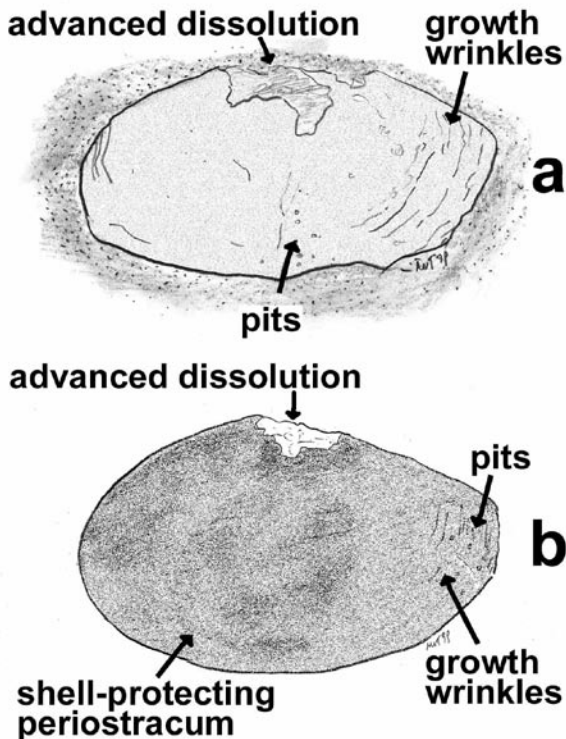


Fig. 5 - Comparison of shell features on external valve of (a) *Yoldia* (*Aequiyoldia*) sp. (Late Oligocene, LSU 9.7, 260.83 mbsf) and (b) *Yoldia* (*Aequiyoldia*) *eightisi* (Recent, McMurdo Sound, 30 metres); *camera lucida* hand drawing (M.T.) elaborated by Stefano Parisini.

- 180.17-180.22 mbsf.
- 222.35-222.38 mbsf.

Remarks: Fossils referable to this pectinid taxon recovered from the Oligocene interval of CIROS-1, and tentatively assigned to *Adamusium* Thiele by Beu & Dell (1989), were identified in Early Miocene and Late Oligocene strata in CRP-2/2A. Outside the Ross Sea this non-costate scallop, which shall be fully named elsewhere, has been recorded from King George Island (South Shetland Islands; Jonkers, 1998). The fragment from 36.29 mbsf consists of a very poorly preserved beak region of a left valve. Both auricles are incomplete, the anterior one in particular. Only 9.9 mm remains of the straight hinge. The shallow resilial pit is 2.1 mm high; below this is a wide umbonal hollow, a feature also present in the CIROS-1 taxon and in *Adamusium colbecki* (Smith, 1902). Fine sculpture of low ridgelets, comparable to those on the discs of the other CRP-2/2A specimens, is present near the bases of the exterior parts of the auricles. There is a hint of antimarginal microsculpture on the posterior auricle. The largest and best-preserved specimen, consisting of a 27.5 mm-high ventral part of the disc, was obtained from 71.42 mbsf. The missing dorsal part (umbo and hinge) is possibly present in the archive half of the core, but was unavailable for study. The convexity suggests that the incomplete shell represents a left valve. The outer surface of the fossil exhibits narrow growth increments, only 0.04-0.12 mm wide, which terminate in prominent commarginal frills (Fig. 7a). Such frills are less well

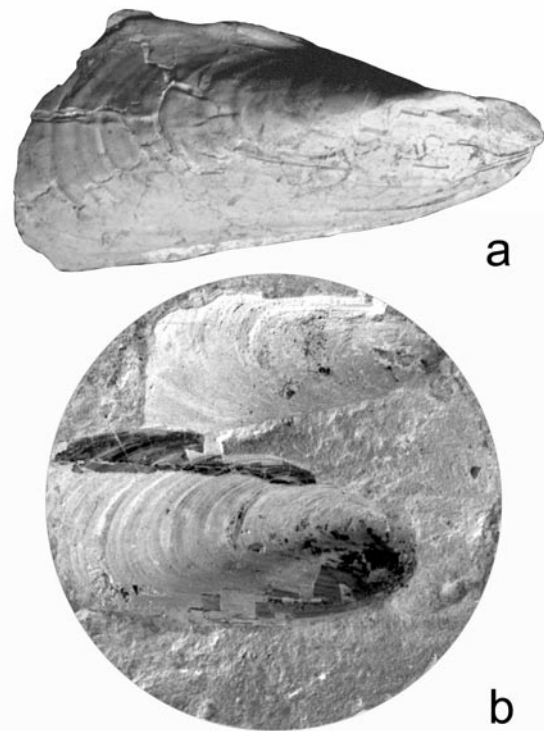
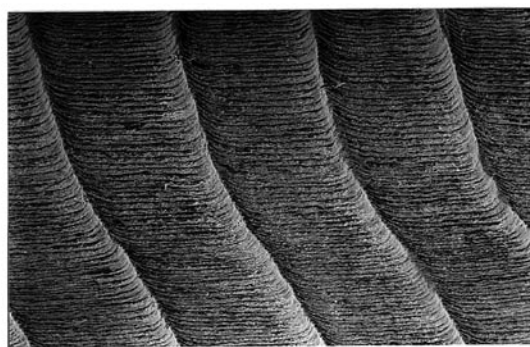
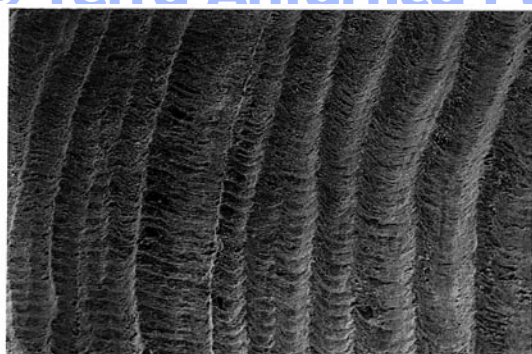


Fig. 6 - ?*Modiolus* sp. (Early Oligocene, LSU 13.1); (a) internal mould of articulated shell, 449.64 mbsf; (b) complete articulated shell with valves open (447.43 mbsf: printed as a negative to enhance visibility of ornamentation).

defined in the CIROS-1 material, but the growth bands are equally narrow. The small disc fragments from 180.17 to 222.35 mbsf show identical sculptural detail.

Microsculptural features of the Oligocene fossil compare very well with those of the sole surviving high-latitude Southern Ocean pectinid, the circum-Antarctic scallop *A. colbecki*, but commarginal frills in the modern species are much further apart (Fig. 7b): mean values in two specimens, from Stonington Island, Antarctic Peninsula, and Explorers Cove, McMurdo Sound, Ross Sea, are 0.25 mm ($n = 111$) and 0.36 mm ($n = 111$), respectively. Such frills often cease to be formed during late ontogeny and consequently growth bands are much less pronounced towards the margin of the disc. Variation in frill width of *A. colbecki* (cf. Stockton, 1984; Berkman, 1991) was interpreted to represent annual growth cycles, and individual growth bands were thought possibly to reflect fortnightly tidal cyclicity (Berkman, 1991). However, annual cyclicity has not been substantiated by stable isotope studies (Barrera et al., 1990).

The "*Chlamys*" *natans* group, known from Miocene deposits in the Ross Sea and from southern South America, displays a similar combination of commarginal frills and fine, antimarginal ridgelets (cf. Jonkers & Taviani, 1998, Figs. 3, 4), but differs significantly in a number of other morphological characters.



200 μm

Fig. 7 - ?*Adamussium* n.sp.; (a) SEM photograph showing highly oblique view of commarginal frills and antimarginal microsculpture of ?*Adamussium* n. sp. (Early Miocene, LSU 5.1, 71.42 mbsf; dorsal is to the right); (b) SEM photograph showing highly oblique view of commarginal frills and antimarginal microsculpture on a right valve of *Adamussium colbecki* from Explorers Cove, McMurdo Sound, Ross Sea (specimen courtesy of Paul Arthur Berkman); dorsal is to the right. Note that growth increments are much wider than in the Oligocene fossil.

CARDITIDAE

Cyclocardia sp., (Fig. 2c: 195.36 mbsf)

- 195.36-195.40 mbsf, incomplete articulated shell.
- 199.56-199.59 mbsf, 2 incomplete, chalky moulds, one a small articulated shell.
- 210.24-210.30 mbsf, one chalky shell.
- 228.91-228.96 mbsf, single incomplete valve.

Remarks: Shells have more prominent and clearly defined radial costae than living Antarctic taxa. This genus has a present geographic distribution encompassing polar and subpolar latitudes (Dell, 1990) and an Antarctic fossil record from the Late Eocene to the Pleistocene (Stilwell & Zinsmeister, 1992; Taviani et al., 1998).

Glyptoactis (?*Fasciculocardia*) sp.

- 232.47-232.49 mbsf, one fragment of a large valve, showing fasciculate rib profile.

Remarks: This type of carditid bivalve appears to have inhabited temperate to warm waters in New Zealand (Beu & Maxwell, 1990).

CARDIIDAE

Cardiidae?, indeterminate, (Fig. 2d: 446.59 mbsf):

- 446.59-446.63 mbsf; internal mould of incomplete single valve; symmetrical, taller than long.

Remarks: This type of elongate cardiid is typical of temperate to warm climates at present.

VENEROIDEA

Veneroidean bivalve, family not determined (Fig. 2e: 224.41 mbsf):

- 224.41-224.47 mbsf, incomplete articulated pair of valves of one small, inflated, subcircular, commarginally-ridged veneroidean without lunule or escutcheon; hinge not visible.

Remarks: This is a very distinctive, undescribed species which seems not to have obvious relatives in the Cenozoic record of Antarctica.

PERIPLMATIDAE

Periploma sp., (Fig. 2f: 443.91 mbsf):

- 247.09-247.12 mbsf, one incomplete left valve showing umbonal crack.
- 249.65-249.67 mbsf, one chalky, inflated left valve showing umbonal crack.
- 443.91-443.93 mbsf, one chalky mould of good, slightly incomplete articulated shell, no doubt of genus.

Remarks: Dell & Fleming (1975) reported *Periploma* (*Pandaloma*?) n. sp. from Miocene sediments in DSDP Site 270. The specimen from Seymour Island illustrated by Stilwell & Zinsmeister (1992, pl. 10 e, i) under the name *Periploma topei* is biconvex and seems more likely to belong to Family Thraciidae than Periplo-matidae.

HIATELLIDAE

Hiatella sp., (Fig. 2g: 450.68 mbsf):

- 80.65-80.68 mbsf, good, chalky moulds of 3 articulated shells; one specimen illustrated in Initial Report (Cape Roberts Science Team, 1999, fig. 5.14 c).
- 450.68-450.73 mbsf, good, slightly incomplete, chalky mould of articulated shell.

Remarks: Our taxon, represented by a few articulated shells in an advanced state of decalcification, resembles the living and cosmopolitan *H. arctica* (Linnaeus, 1758), also recorded from DSDP Site 270 (Dell & Fleming, 1975); *Hiatella* is also known from the late Eocene of Seymour Island (Stilwell & Zinsmeister, 1992).

Indeterminate bivalves

- 22.05-22.06 mbsf, bivalve (pectinid?) fragment.
- 22.12-22.13 mbsf, bivalve ("Chlamys"?) fragment.
- 23.90-23.91 mbsf, bivalve (pectinid?) fragment.
- 24.49-24.51 mbsf, bivalve (pectinid?) fragment.
- 36.21-36.22 mbsf, pectinid?
- 54.11-54.14 mbsf, indet. thin-shelled bivalve (pectinid?).
- 54.23-54.26 mbsf, indet. thin-shelled bivalve (pectinid?).
- 54.94-54.98 mbsf, indet. thin-shelled bivalve (pectinid?).
- 90.49-90.51 mbsf, bivalve (pectinid?) fragment.
- 91.36-91.38 mbsf, bivalve (pectinid?) fragment.

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- 96.71-96.76 mbsf, pectinid? and other bivalve fragments.
 - 126.55-126.56 mbsf, bivalve fragments (pectinid?).
 - 135.49-135.50 mbsf, 3 fragments, possibly pectinid.
 - 176.30-176.33 mbsf, large thin-shelled bivalve (pectinid?).
 - 198.52-198.53 mbsf, one incomplete valve.
 - 209.45-209.49 mbsf, chalky fragment (mytilid?).
 - 443.50-443.56 mbsf, chalky incomplete valve.

GASTROPODA

TROCHOIDEA

Trochoidean? spp., family not determinable, (Fig. 2h: 448.58 mbsf):

- 444.09-444.12 mbsf, partial mould of rounded trochoidean similar to following.
- 448.58-448.61 mbsf, good internal mould and partial external mould of low-spined, apparently smooth ?trochoidean with evenly inflated whorls (? aff. *Falsimargarita*, etc.).
- 461.53-461.54 mbsf, poor, distorted mould of specimen similar to above.

TURRITELLIDAE

Turritellidae, indet. (Fig. 2i, l: 285.12 mbsf):

- 226.85-226.89 mbsf, relatively complete shell, sectioned in core; fine spiral cords visible on whorl sides and base (Fig. 2l).
- 285.12-285.20 mbsf, good internal and external mould of one specimen, characters not visible (Fig. 2i).
- 454.45-454.49 mbsf, one small fragment of external mould.

Remarks: Spiral sculpture, most characters not visible; shape, size and spiral cords resemble those of the Southern Hemisphere turritellid genus *Zeacolpus* (e.g. Beu & Maxwell, 1990).

CALYPTRAEIDAE

?*Crepidula* sp., (Fig. 2m: 446.59 mbsf):

- 446.59-446.63 mbsf, chalky internal and external mould of a small, short calyptraeid, septum clearly visible; spire a little curved laterally.

Remarks: Our taxon shows some affinity to *Sigapatella*, an extant calyptraeid widely distributed in Cenozoic beds of New Zealand (Beu & Maxwell, 1990) and known from the Eocene of Seymour Island (Stilwell & Zinsmeister, 1992).

?STRUTHIOLARIIDAE

?*Perissodonta* sp.:

- 199.56-199.59 mbsf.

Remarks: One poor, partial internal mould of spire, with almost horizontal sutural ramp, rounded shoulder and vertical whorl side.

NATICIDAE

Naticidae, indeterminate:

- 199.56-199.59 mbsf, large, incomplete, cracked internal

mould of naticid spire.

Remarks: Dell & Fleming (1975) recorded the occurrence of naticids from Miocene strata in DSDP Site 270; naticids also occur in the Oligocene Polonez Cove Formation of King George Island (Gazdzicki & Pugaczewska, 1984).

?CANCELLARIIDAE

Neogastropod, family not determinable, shape resembles some small Cancellariidae, (Fig. 2o: 446.59 mbsf):

- 446.59-446.63 mbsf, one internal mould and incomplete external mould.

Remarks: Cancellariids are known from the Eocene of Seymour Island (Stilwell & Zinsmeister, 1992), Miocene of King George Island (Karczewski, 1987), Pleistocene in the Ross Sea (CRP-1, M. Taviani, unpublished), and still live around Antarctica (Dell, 1990).

Indeterminate gastropod

- 462.47-462.50 mbsf, one mould of columellar base and portion of whorl, severely abraded; spire sawn off in splitting core. Shape suggests a neogastropod.

SCAPHOPODA

?SIPHONODONTALIIDAE

?Siphonodentaliidae, (Cape Roberts Science Team, 1999, fig. 5.14 d):

- 165.41-165.42 mbsf, one small specimen, badly crushed
- 170.92-170.94 mbsf, one fragment in a concretion ("thecosomatous pteropod" in Cape Roberts Science Team, 1999).
- 176.74-176.75 mbsf, one small fragment ("perhaps a thecosomatous pteropod" in Cape Roberts Science Team, 1999).
- 180.08-180.10 mbsf, 2 fragments, one small and one large, badly crushed ("thecosomatous pteropod?" in Cape Roberts Science Team, 1999).
- 255.27-255.30 mbsf, one small fragment ("thecosomatous pteropod?" in Cape Roberts Science Team, 1999).
- 342.26-342.30 mbsf, one fragment.
- 344.35-344.38 mbsf, several pieces of one relatively large specimen, poorly preserved mould, shell material absent or very chalky ("thecosomatous pteropod" in Cape Roberts Science Team, 1999).
- 467.16-467.18 mbsf, two fragments (one specimen?), shell material brown but otherwise like all the above material.

Remarks: Smooth, moderately large, narrow, weakly curved scaphopod, compressed and so showing median "groove". The best-preserved tube has been figured in the Initial Report (Cape Roberts Science Team, 1999, fig. 5.14 d). Some incomplete specimens show a compressed, tubular shape with a median groove and such puzzling fossils were tentatively ascribed to holoplanktic thecosomatous pteropods in the Initial Report (Cape Roberts Science Team,

1999); later, lab preparation of a decalcified specimen from 344.35 mbsf revealed a tubular, elongated shell best interpretable as the mould of a smooth, c. 14 mm long scaphopod; accordingly we ascribe all analogous material to Scaphopoda (?Siphonodentaliidae).

ANNELIDA

POLYCHAETA

Undetermined polychaete tubes (belonging to 3 species at least; see Cape Roberts Science Team, 1999, fig. 5.14 g):

- 56.03-56.05 mbsf, poor sectioned tube.
- 56.49-56.51 mbsf, 2 small tube fragments.
- 80.65-80.68 mbsf, two good tube pieces in same small block, plus 5-6 separate segments of tubes.
- 117.66-117.70 mbsf, poor mould of small fragment of tube, plus tube fragment with sponge spicule mat.
- 117.73-117.75 mbsf, several small, well preserved tubes in same sample.
- 141.74-141.78 mbsf, bunch of tubes (recrystallized).
- 165.41-165.42 mbsf, one moderately large, well preserved tube.
- 178.89-178.93 mbsf, 2 small tube fragments.
- 182.17-182.19 mbsf, band of several poorly preserved serpulid tubes.
- 216.35-216.38 mbsf, 2 small tube fragments and traces.
- 247.67-247.71 mbsf, large coiled tubes attached to unidentified, sectioned bivalve.
- 256.04-256.05 mbsf, segment of quite well preserved, flattened tube.
- 259.16-259.20 mbsf, long, narrow, nearly straight, gently tapered tube (possibly scaphopod?); not much shell remaining; plus several tube fragments.
- 259.21-259.25 mbsf, one well preserved fragment of small tube, plus one tube fragment, black interior.
- 328.73-328.76 mbsf, one small tube fragment, brown, infilled with calcite crystals.
- 338.75 mbsf, one quite well preserved, long, curved tube, recrystallised brown carbonate.
- 341.79-341.87 mbsf, several tubes.
- 413.19-413.22 mbsf, small segment of brown tube.
- 447.24-447.26 mbsf, fragment of poorly preserved tube; possibly attached to a pebble.
- 448.17-448.19 mbsf, short fragment of pale brown tube.
- 448.48-448.50 mbsf, poor fragmentary moulds.
- 464.40-464.42 mbsf, chalky fragment of tube.
- 467.21-467.22 mbsf, short segment of well preserved but brown tube.
- 467.71-467.75 mbsf, 3 fragments of brown tubes, attached to each other.
- 559.04-559.07 mbsf, short segment of quite wide tube; brown.

Remarks: Calcitic tubes belonging to serpulid polychaetes are common and ubiquitous in the CRP-2/2A drill core. The commonest tube is represented by a slender shell with annular ornamentation and appears indistinguishable from and probably conspecific with the

Miocene worm tubes in the CRP-1 drill core figured and discussed by Jonkers & Taviani, (1998, fig. 5 & 6). The abundant tube material recovered in the CRP-2/2A allows better refinement of the habits of this taxon which appears to have been gregarious and probably living as small, branching aggregates anchored to small objects (coarse sand grains and tiny pebbles). After further removal of the mudstone matrix, the tube figured in the Initial Report (Cape Roberts Science Team, 1999, fig. 5.14 g) and considered there to be a single, arched specimen, proved to represent in fact two individuals from a branched aggregate. Two other serpulid taxa are represented by rare occurrences in the core, *i.e.* a smooth, slender tube and a single occurrence of a coiled tube still attached to a bivalve substratum at 247.67 mbsf. Furthermore, the occasional recurrence of burrow and feeding traces is possibly linked to the activity of other infaunal polychaetes (*e.g.* 153.38-153.43 and 167.85-167.86 mbsf).

CNIDARIA

SCLERACTINIA

Unidentified solitary corals:

- 36.21-36.22 mbsf, solitary coral?, sugary texture.
- 36.24-36.27 mbsf, poorly preserved solitary coral, illustrated in Cape Roberts Science Team, 1999 (fig. 5.14 h).
- 36.50-36.51 mbsf, solitary coral?, sugary texture.

Remarks: The best-preserved specimen from this unit is a "*Flabellum*"-like campanulate solitary corallum, figured in Cape Roberts Science Team, 1999 (fig. 5.14 h) but it could not be identified, even at generic level. Solitary corals are reasonably common in Cenozoic beds of Antarctica such as the Early Miocene Cape Melville and Early Oligocene Polonez Cove Formations on King George Island (Roniewicz & Morycowa, 1987; Gazdzicki & Stolarski, 1992) and Cretaceous-Paleogene beds of Seymour and Snow Hill Islands (Filkorn, 1994; Stolarski, 1996).

BRACHIOPODA

?RHYNCHONELLOIDEA

Undetermined rhynchonelloid brachiopods (Fig. 2n: 262.02 mbsf):

- 161.52-161.54 mbsf, fragment of very poor, completely decalcified mould (might be ?*Cyclocardia*).
- 262.02-262.12 mbsf, one good but abraded rhynchonelloid, fine radial sculpture, umbo abraded off (Fig. 2n).

Remarks: The sparse, poorly preserved material recovered in CRP-2/2A is unsuitable for an accurate taxonomic assessment. The better-preserved specimen shows distinct coarse ribs on the external surface; a similar ornamentation is typical of members of Rhynchonelloidea, although it is also present in species of Cancellothyroidea (*e.g.* Bitner, 1996).

Brachiopoda, indeterminate

- 285.15-285.20 mbsf, fragment of punctate brachiopod visible on broken face beside a turritellid.

Unidentified spines: reported (Cape Roberts Science Team, 1999) from

- 16.30-16.38 mbsf, "echinoid spines".
- 19.84-19.90 mbsf, "echinoid spines".

BRYOZOA

Undetermined Bryozoa are reported in Cape Roberts Science Team (1999) from:

- 16.30-16.38 mbsf, "bryozoan".
- 117.66-117.72 mbsf, "bryozoans (aligned)".

Remarks: the available material is limited to small and highly decalcified structures tentatively ascribed to bryozoan colonies.

PORIFERA

Siliceous sponge:

- 117.66-117.70 mbsf, small area of sponge spicule mat.

VERTEBRATA

Unidentified fish scale (Fig. 3:166.64 mbsf):

- 166.64-166.65 mbsf, one incomplete, well preserved fish scale.

ECHINODERMATA**ECHINOIDEA**

Unidentified echinoid:

- 230.22-230.25 mbsf, fragments of test of one? specimen.

PALAEOENVIRONMENTS

Possible marine palaeoenvironments reconstructed for core CRP-2/2A are shown in figure 1 and in cartoons (Fig.

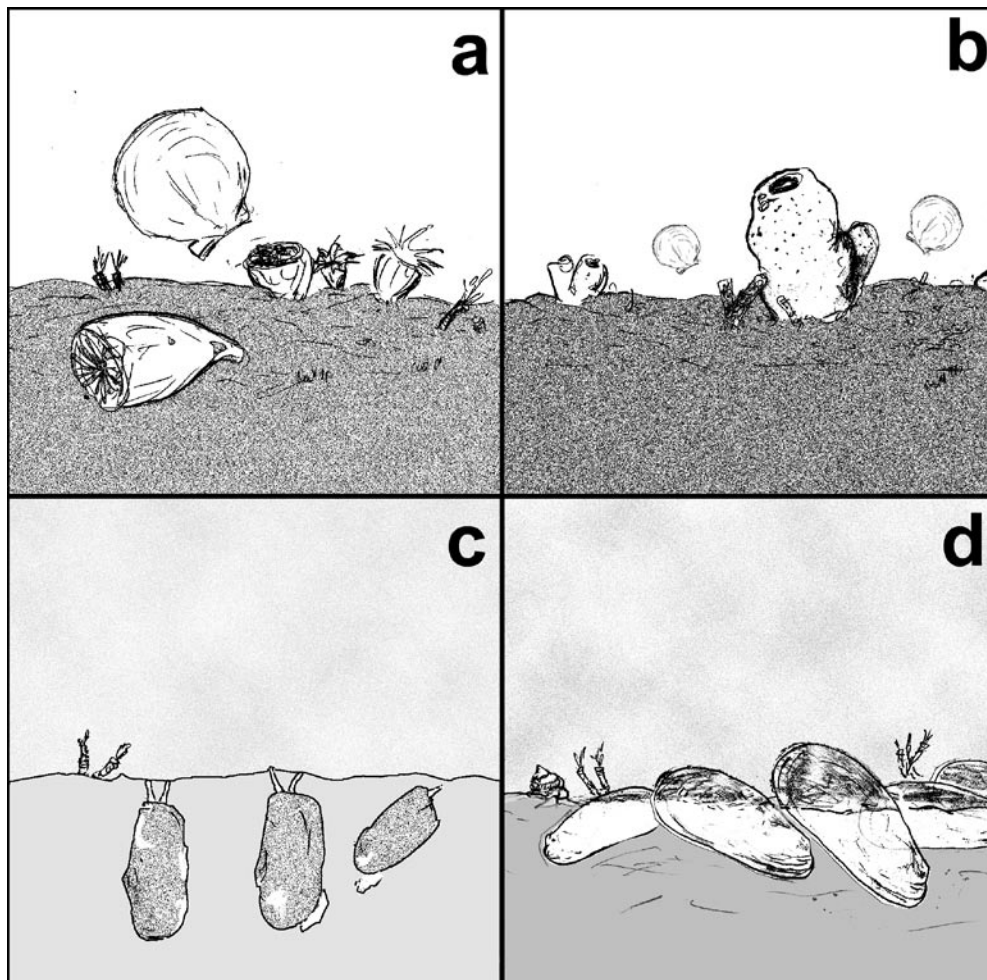


Fig. 8 - Cartoons depicting artistic reconstructions of Roberts Ridge sea-bottom at selected time-slices: (a): Early Miocene, LSU 3.1. at c. 36 mbsf: middle-outer shelf environment dominated by suspension feeders, including solitary corals, large pectinids (*Adamussium* n. sp.) and serpulid polychaetes (water depth 40-100 m?); (b), Early Miocene, LSU 8.1 at c. 117 mbsf: middle-outer shelf environment dominated by epifaunal (sponges and pectinids) and semi-infaunal suspension feeders (water depth 40-80 m?) (c) Late Oligocene, LSU 9.7 at c. 165 mbsf: fine-grained, relatively shallow (20-40 m?) shelf environment dominated by deposit (*Yoldia* and other protobranchs) and suspension (serpulid polychaetes) feeders in turbid waters; (d) Early Oligocene, LSU 13.1 at c. 464 mbsf: deep-shelf/upper-slope fine-grained, H₂S-enriched environment dominated by dense aggregates of semi-infaunal modiolid bivalves, with associated gastropods and serpulid polychaetes; (hand drawings by M.T., computer-elaborated by Stefano Parisini).

8). Reliability is often hampered by the problematic taxonomic position of most taxa so the reconstructions are necessarily tentative.

Pliocene-Quaternary. The macropalaeontological content of the c. 27 m-thick Pliocene-Quaternary succession is rather scant, of little taxonomic value and unsuitable for any significant palaeoenvironmental consideration. The macrofossils in LSU 2.1 (Quaternary) include unidentified bivalves, bryozoans and echinoids, and indicate a marine setting. The ?Pliocene LSU 2.2 contains bivalve remains that are also of little palaeoecological use, due to their extremely poor preservation and the possibility of reworking from older sediments.

Early Miocene. The macrofauna associated with LSU 3.1 includes solitary corals, as well as bivalves, serpulids and sponge mats; reconstructed sea-bottom conditions based on this assemblage are depicted in figure 8a, b.

Oligocene. The relatively good macrofossil content of the Oligocene strata, favoured by the recurrence of frequent, thick mudstone lithologies, permits the inference of past environments at a reasonable level of accuracy.

Late Oligocene LSU 8.4 and 9.7 produced some of the best fossil assemblages of CRP-2/2A and the reconstructed palaeoenvironment is depicted in figure 8c. The sea-bottom was a quiet, muddy shelf, somewhat sheltered, inhabited by dense populations of deposit and suspension feeders, represented by protobranch bivalves and veneroid clams/serpulid polychaetes respectively. The coquina layer at 249.65 mbsf, interpreted as a condensed section at a sequence boundary (Cape Roberts Science Team, 1999, figs. 3.5b and 5.13), consists of articulated *Yoldia*, mostly in life position, and *Periploma* shells. Overall, the mollusc assemblages from these strata are consistent with sub-polar but not polar conditions.

The Early Oligocene strata are typified by the presence of thick mudstone units containing mostly articulated modiolid bivalves (?*Modiolus* sp.). Modiolid bivalves are eurybathyal, recent forms having been reported from subtidal to abyssal depths (e.g., Gustafson et al., 1998). The absolute dominance of these molluscs within the mudstone lithologies from 442.99 mbsf down has important ecological implications. This dominance is not a diagenetic artefact since original mussel-shell material is preserved and demineralized moulds of aragonitic gastropods, bivalves and scaphopods co-occur. We interpret these mussel beds as fingerprints of peculiar bottom conditions at the time of their life. Dense, almost oligotypical mussel accumulations in the deep-sea are known to occur in close association with populations of bacteria fed by gas seepage (hydrogen sulphide or/and methane: Callender et al., 1990; Gustafson et al., 1998). Methane is often conducive to the precipitation of authigenic carbonates (Hovland & Judd, 1988) absent in core CRP-2/2A (Cape Roberts Science Team, 1999). On the other hand, hydrogen sulphide is a common product of reactions within reduced, organic-rich fine-grained sediments which foster a high production of bacteria (Canfield & Raiswell, 1991; Barns & Nierzwicki-Bauer, 1997), directly or indirectly exploitable by mussels (see Taviani, 2000, for a review). One possibility is that semi-stagnant, topographically driven (fiord-like?) sea-bottom conditions became established in the area, leading

to low O₂ levels and concomitant H₂S enrichment of muddy sediments, which were then settled by specialized mussel biota (Fig. 8d). Alternatively, low O₂ and high H₂S levels may have resulted from high organic production (Canfield & Raiswell, 1991). Bathymetry may have been in the range of 100-200 metres. Warmer-than-present palaeoclimatic conditions may be inferred for the strata containing these mussel beds since modiolid bivalves are unknown from modern true polar settings worldwide.

BIOGEOGRAPHICAL AND CHRONOLOGICAL IMPLICATIONS

Pliocene-Quaternary (0.00-26.75 mbsf: Cape Roberts Science Team, 1999). The late Cenozoic sediments of the core appear to lack any macrofossils of biostratigraphic value, as already discussed (Cape Roberts Science Team, 1999; p. 25). CRP-1, drilled only a short distance away from CRP-2, provided an astonishing record of shelled benthic macrofauna of Middle Pleistocene age, mostly contained within a carbonate-rich unit (Taviani et al., 1998, Taviani & Claps, 1998), which has no analogue in drill core CRP-2/2A.

Early Miocene (26.79-130.27 mbsf: Cape Roberts Science Team, 1999). Surprisingly, pectinids recovered from the Early Miocene succession of the CRP-2/2A drill core appear to refer to the non-costate *Adamussium?* n. sp., reported by Beu & Dell (1989) from Oligocene sediments in the CIROS-1 core (McMurdo Sound, Ross Sea); furthermore, the supposedly coeval sediments in CRP-1 contained a costate pectinid ("*Chlamys*" sp.1) and no *Adamussium* (Jonkers & Taviani, 1998). However, the non-costate ?*Adamussium* n. sp. is now also known from earliest Miocene deposits on King George Island, in the South Shetland Islands (Jonkers, 1998); this may either indicate that the two taxa co-existed in Antarctic waters during the Early Miocene, or that the Early Miocene pectinid-bearing sediments in CRP-2/2A are slightly older than those drilled in CRP-1.

Oligocene (130.27-624.15 mbsf: Cape Roberts Science Team, 1999). The non-costate pectinid *Adamussium* n. sp., has been recovered also in the Late Oligocene succession of CRP-2/2A, at 180.17 mbsf, allowing a possible correlation with Oligocene sediments in CIROS-1 (Beu & Dell, 1989). The modiolid bivalve from the Early Oligocene sediments of CRP-2/2A (442.99 mbsf down) is probably conspecific with *Modiolus?* sp. recovered in the Early Oligocene succession in CIROS-1 (Beu & Dell, 1989) and, possibly, with ?*Modiolus* sp. from DSDP Site 270 (Dell & Fleming, 1975). A comparative study of CRP-2/2A, CIROS-1 and DSDP Leg 28 macrofossils is in progress and, we hope, will clarify any chronostratigraphic potential.

CONCLUSIONS

The macrofossil record in core CRP-2/2A is a significant source of palaeontological information about the former Antarctic marine biota and represents the most diverse Oligocene macrofauna reported from East Antarctica.

Identified macrofossils belong to seven phyla of Invertebrata which are, in order of relative abundance, Mollusca, Annelida, Cnidaria, Brachiopoda, Bryozoa, Echinodermata and Porifera. Vertebrata are represented by fish scales and teeth. Mollusca are by far the dominant group and include, conservatively, as many as 13 species of Bivalvia, 6 of Gastropoda and 1 of Scaphopoda. The second most abundant group is Annelida, represented by 3 species of serpulid polychaete tubes.

Although the poor preservation of most fossils prevents a full appreciation of their taxonomic identity, it appears that many taxa are reasonably comparable to species recovered from coeval sediments drilled in the Ross Sea (DSDP Sites 270 and 272) and McMurdo Sound (CIROS-1).

Early Miocene and Late Oligocene macrofossil assemblages are consistent with cold-water environments and may be interpreted to indicate sub-polar conditions. Early Oligocene assemblages are definitely not truly polar and suggest significantly warmer-than-present sea water conditions and peculiar H₂S-enriched environments.

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