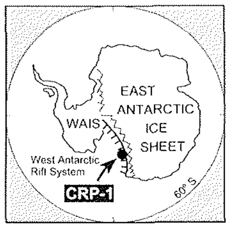
Terra Antartica
1998, **5**(3), 473-478

Recycled Pliocene Foraminifera from the CRP-1 Quaternary Succession

P.N. Webb[1] & C.P. Strong[2]

[1]Department of Geological Sciences, The Ohio State University, Columbus, OH 43210 - USA
[2]Institute of Geological and Nuclear Sciences, P.O. Box 30368, Lower Hutt - New Zealand

Received 29 July 1998; *accepted in revised form* 23 October 1998



Abstract - Mixed assemblages of Pliocene and Quaternary foraminifera occur within the Quaternary succession of the CRP-1 drillhole. Pliocene foraminifera are not present in the lowermost Unit 4.1, are rare in Unit 3.1 and 2.3, are relatively common in Units 2.2 and 2.1, and are absent in Unit 1.1. Fifteen and twelve species were documented in two of the samples from Units 2.2 and 2.1 respectively. A census count of foraminifera in a sample at 26.89 mbsf (Unit 2.2) indicated that 39% of the tests were from a Pliocene source, with the remaining 61% tests assigned to the *in situ* Quaternary assemblage. There appears to be a close correlation between the stratigraphic distribution of ice-rafted sediments and the test number and diversity of Pliocene taxa. It is concluded that Pliocene assemblages were not derived from submarine outcrops on Roberts Ridge, but are more likely to have been rafted to the site via major trunk valley drainage systems such as operated within the Mackay and Ferrar glacial valleys. The co-occurrence of marine biota (including foraminifera), fossil wood, pollen, and igneous clasts in the Quaternary succession of CRP-1, points to the marine and terrestrial facies of the Pliocene Sirius Group as a likely source. A major episode of erosion and transport of sediment into the offshore marine basins at about ~1 Ma may have been triggered by dynamism in the ice sheet-glacier system, an episode of regional uplift in the Transantarctic Mountains, sea level oscillations and associated changes in the land-to-sea drainage baselines, or some combination of these factors.

INTRODUCTION

Investigation of the Quaternary succession recovered at CRP-1 resulted in the recognition of three groups of foraminiferal assemblages, *i.e. in situ* Quaternary assemblages, recycled Quaternary assemblages, and recycled pre-Quaternary assemblages (Webb & Strong, this volume). In this investigation we document and discuss the pre-Quaternary assemblages. A suite of twenty-six samples and the lithostratigraphic scheme used in the investigation of Quaternary foraminifera is also employed here (Webb & Strong, this volume, Fig. 1).

STRATIGRAPHIC DISTRIBUTION OF PRE-QUATERNARY FORAMINIFERA

LITHOSTRATIGRAPHIC UNIT 4.1 (33.82-43.15 mbsf)

No pre-Quaternary foraminifera were recovered from the five Unit 4.1 samples. Samples positions, expressed as metres below sea floor (mbsf) and with only the uppermost meterage given, are as follows: 42.45, 40.00, 37.50, 35.80, and 33.90 mbsf.

LITHOSTRATIGRAPHIC UNIT 3.1 (31.89-33.82 mbsf)

Eleven samples were examined from Unit 3.1. Pre-Quaternary taxa documented are as follows:

33.72 mbsf - No taxa present.
33.50 mbsf - *Ammoelphidiella antarctica* and poorly preserved indeterminate foraminifera.
33.31 mbsf - *Ammoelphidiella antarctica.*
32.98 mbsf - *Trifarina earlandi*, *Ammoelphidiella antarctica* and indeterminate foraminifera. Worn and or sediment encrusted ostracods, echinoderm spines, shell, and other macrofossil debris.
32.95 mbsf - *Trifarina earlandi*, *Cibicides refulgens*, and *Ammoelphidiella antarctica.*
32.77 mbsf - No taxa present.
32.58 mbsf - No taxa present.
32.37 mbsf - No taxa present.
32.34 mbsf - No taxa present.
32.05 mbsf - No taxa present.
31.90 mbsf - *Ammoelphidiella antarctica.*

LITHOSTRATIGRAPHIC UNIT 2.3 (29.49-31.89 mbsf)

Two samples were examined from Unit 2.3. Pre-Quaternary taxa documented are as follows:

31.40 mbsf - *Trifarina earlandi*, *Globocassidulina subglobosa*, *Ammoelphidiella antarctica* and *Neogloboquadrina pachyderma*. Other foraminiferal taxa are present but preservation is poor. Sponge spicules present.
30.11 mbsf - *Globocassidulinoides porrectus*, *Cibicides refulgens*, *Ammoelphidiella antarctica.* Worn and or sediment encrusted shell fragments, echinoderm spines and bases, and ostracods present.

LITHOSTRATIGRAPHIC UNIT 2.2 (22.00-29.49 mbsf)

Four samples were examined from Unit 2.2. Sample 26.95-26.98 mbsf contains an identical recycled pre-

Quaternary assemblage to that recovered from 26.89-26.94 mbsf, and only the latter is reported here. Pre-Quaternary taxa documented are as follows:

27.40 mbsf - *Globocassidulina crassa*, *Cibicides refulgens*, *Cibicides lobatulus*, and *Ammoelphidiella antarctica*. Other pre-Quaternary fossil material includes echinoderm spines, ostracods, and fossil wood.

26.89 mbsf - This sample contains large numbers of Quaternary (32 species documented) and pre-Quaternary (15 species documented) foraminifera (Webb & Strong, this volume). Pre-Quaternary test numbers and species diversity are the largest encountered in this study. The results of a combined Quaternary and pre-Quaternary 581-test census are provided in figure 1. Although the species content is almost identical in the two assemblages, they exhibit distinctly different relative abundance's (Figs. 1 & 2, Appendix 1.1; Webb & Strong, this volume, Fig. 3, Appendix 1.12). The census count indicates that pre-Quaternary tests are less common (39%) than are Quaternary tests (61%) (Fig.1). In the pre-Quaternary assemblage, the large *Cassidulinoides porrectus* is the dominant taxon (29%), whereas in the Quaternary element the very small *Globocassidulina subglobosa* dominates (35%). The planktonic *Neogloboquadrina pachyderma* is absent from the pre-Quaternary assemblage but constitutes 4% of the Quaternary assemblage. *Ammoelphidiella antarctica*, a ubiquitous member of the recycled group throughout Units 3.1, 3.2, 2.2 and 2.1, makes up only 7.5% of the sample 26.89 mbsf (Unit 2.2) census. As noted below, distinctly different states of preservation and test sizes makes for easy separation of the two assemblage groups. Other recycled pre-Quaternary fossil material includes echinoderm spines, sponge spicules, shell fragments, ostracods, and bryozoa.

25.40 mbsf - *Globocassidulina subglobosa* and fossil wood.

LITHOSTRATIGRAPHIC UNIT 2.1 (19.13-22.00 mbsf)

Three samples were examined from Unit 2.1. Pre-Quaternary taxa documented are as follows:

21.54 mbsf - *Cibicides refulgens* and *Ammoelphidiella antarctica*. Other shell material includes sponge spicules, shell fragments and echinoderm spines.

21.04 mbsf - This sample contains a Quaternary fauna of low diversity (8 species documented). It was concluded that these are remnants of recycling processes (Webb & Strong, this volume). In contrast, the recycled pre-Quaternary group of tests are much more common and a diversity of 12 species was documented. A 125 test count of the latter showed the large *Cassidulinoides porrectus* as the dominant taxon (66%) (Fig. 3; Appendix 1.2). *Ammoelphidiella antarctica* constitutes only 2.5% of this census. Planktonic taxa were not documented. Other fossil material noted included sponge spicules, echinoderm spines, shell fragments, and fossil wood.

19.40 mbsf - No pre-Quaternary foraminifera. Sponge spicules and wood are also present.

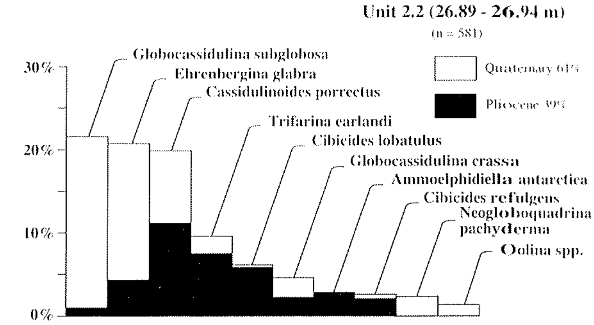


Fig. 1 - Census data for CRP-1, Unit 2.2, Sample 26.89 mbsf, based on a combined 581 test count of Pliocene and Quaternary foraminifera

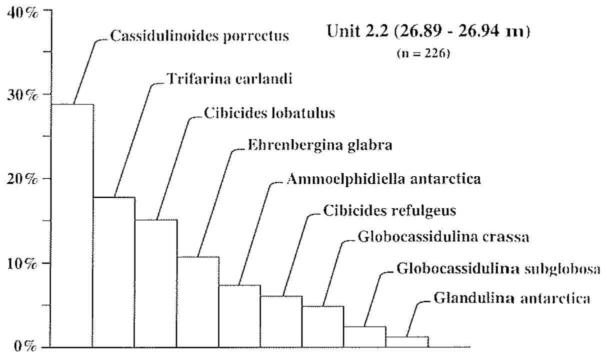


Fig. 2 - Census data for CRP-1, Unit 2.2, Sample 26.89 mbsf, based on a 226 test count of Pliocene foraminifera

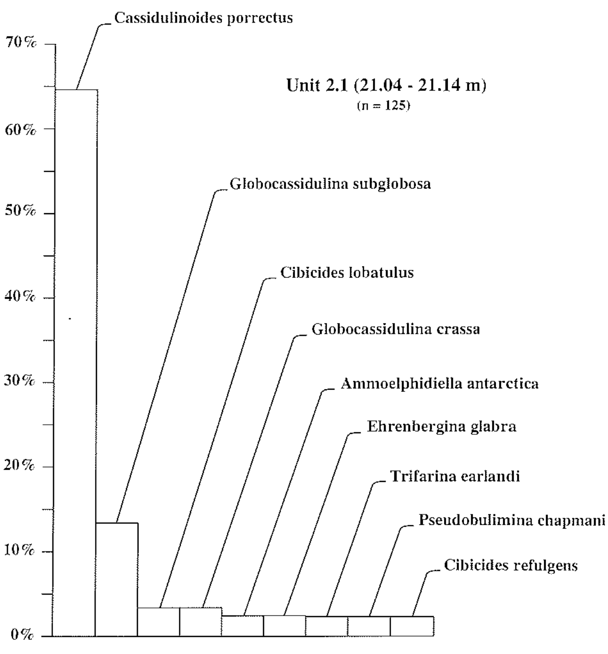


Fig. 3 - Census data for CRP-1, Unit 2.1, Sample 21.04 mbsf, based on a 125 test count of Pliocene foraminifera.

LITHOSTRATIGRAPHIC UNIT 1.1 (0.00-19.13 mbsf)

8.5 mbsf - No pre-Quaternary foraminifera. Fossil wood present.

PRESERVATION

Separation of pre-Quaternary and Quaternary tests is readily made on a basis of contrasting states of preservation. Quaternary foraminifera are usually white and include both opaque and translucent tests. Tests are normally empty, final chambers often intact, and with apertural areas free of fine matrix. Pores and fine ornament are well preserved and no matrix adheres to test exteriors. Assemblages include a wide range of test sizes, extending from diameters or lengths of >5 mm to <63 µm. Chamber walls among the various taxa range from forms with very heavily calcified to thin and fragile tests. In contrast, pre-Quaternary tests are heavily calcified, tests tend to be large, are often broken, ornament may be abraded, last chambers are often missing, test interiors are commonly filled with matrix, and matrix frequently fills apertural depressions and also adheres to the exterior of the test. In addition, they are normally stained a yellow-brown color and in some instances exhibit obvious signs of dissolution.

AGE OF RECYCLED ASSEMBLAGES

The large elphidid, *Ammoelphidiella antarctica* Conato & Segre 1974 (=*Trochoelphidiella onyxi* Webb, 1974, junior synonym) is present in low but consistent numbers in Units 3.1, 2.3, 2.2 and 2.1. The stratigraphic record for *A. antarctica* suggests that it is confined to the Pliocene. It is known from the Pecten Gravels in Wright Valley (Webb, 1974), Scallop Hill Formation on Brown Peninsula (Eggers, 1979), the DVDP 10 drillhole in eastern Taylor Valley (Ishman & Webb, 1988; Ishman & Rieck, 1992), Larsemann Hills (Quilty et al., 1990), all in East Antarctica; and the Pecten Conglomerate of Cockburn Island, West Antarctica. At two localities, the age is constrained by K/Ar ages. Webb & Andreasen (1986) reported volcanic clasts with K/Ar ages of 2.62 Ma and 2.58 Ma (Pliocene) in Scallop Hill Formation. A sample from the James Ross Island Volcanic Group immediately below the Pecten Conglomerate on Cockburn Island provided a K/Ar age of 3.65 Ma (Pliocene) (Webb & Andreasen, 1986). Ishman & Rieck (1992) employed magnetostratigraphic and biostratigraphic data to constrain the age of the *A. antarctica* Zone in the DVDP 10 drillhole to between 3.7 and 3.4 Ma (Pliocene). Hart & Webb (this volume) obtained an amino acid-based age of ~2.4 Ma from analyses of foraminiferal and molluscan calcite derived from CRP-1 (Unit 3.1).

PALEOENVIRONMENTS FOR PLIOCENE SUCCESSIONS IN EAST AND WEST ANTARCTICA

All Pliocene localities with *A. antarctica* cited above represent shallow water coastal or paleofjord environments, in which foraminiferal assemblages are accompanied by a wide variety of other fossil material, including ostracods, barnacles, bryzoans, gastropods, bivalves, etc. Webb (1988) and Gazdzicki & Webb (1996) compared Pliocene and Quaternary foraminifera, noting that shallow water and littoral Pliocene assemblages usually have species diversities of less than 20 species. Webb (1988) also noted that Pliocene species diversity is significantly lower than for Quaternary assemblages.

ASSEMBLAGE COMPOSITION AND STRUCTURE

GENERAL

Twelve of the twenty-six samples examined contain recycled Pliocene foraminifera. Of these, ten samples contain rare to abundant tests of three particularly robust species, *e.g.*, *Trifarina earlandi*, *Cibicides refulgens*, and *Ammoelphidiella antarctica*. These are clearly remnants of originally much more diverse assemblages. Particularly large collections of tests were recovered from samples 26.89 (Unit 2.2) and 21.04 mbsf (Unit 2.1), and these warrant separate discussion. Because of the relatively large number of tests present in CRP-1 samples 26.89 and 21.04 mbsf, we were able to construct relative abundance census data (Figs. 2 & 3, Appendices 1.1 & 1.2) and compare these with assemblages from the Pliocene occurrences cited above.

CRP-1 (26.89-26.94 mbsf)

This assemblage shares most of the same dominant taxa with Pliocene assemblages documented from the DVDP 10 drillhole (Taylor Valley), the Pecten Gravels (Wright Valley), and the Pecten Conglomerate (Cockburn Island), although the relative abundance ranking of these varies. Relative abundance dominance values for *Ammoelphidiella antarctica* in DVDP 10, Pecten Gravels and Pecten Conglomerate are 9%, 53% and 5-41% respectively (Webb, 1988; Gazdzicki & Webb, 1996), whereas the value is only 7.5% in CRP-1 (26.89 mbsf). This variation may be attributed to differing microenvironments and *post-mortem* restructuring at each Pliocene site, and in the case of CRP-1, to transport in glacier and shelf ice to the Roberts Ridge area. Nevertheless, it is remarkable that the CRP-1 (26.89 mbsf) assemblage appears to have retained the principal species composition and basic structure of the original population. Figures 1 and 4 highlight the fact that although the Pliocene element of 26.89 mbsf has a much lower species diversity compared with the Quaternary element (15 species versus 32 species), both parts of the fauna share the same dominant species. A low primary taxon dominance level of 29% for *Cassidulinoides porrectus* (Fig. 2) suggests that little or no relative abundance increase has occurred through size sorting in the water column during melt-out or by subsequent benthic current processes. Dominance figures for secondary (*Trifarina earlandi*) and tertiary (*Cibicides lobatulus*) taxa also appear normal, and taken together with *Cassidulinoides porrectus* make up almost 63% of the assemblage. These values would place this assemblage within the three-species (ternary) scatter field for Quaternary assemblages in CRP-1 (Unit 3.1) of Webb &

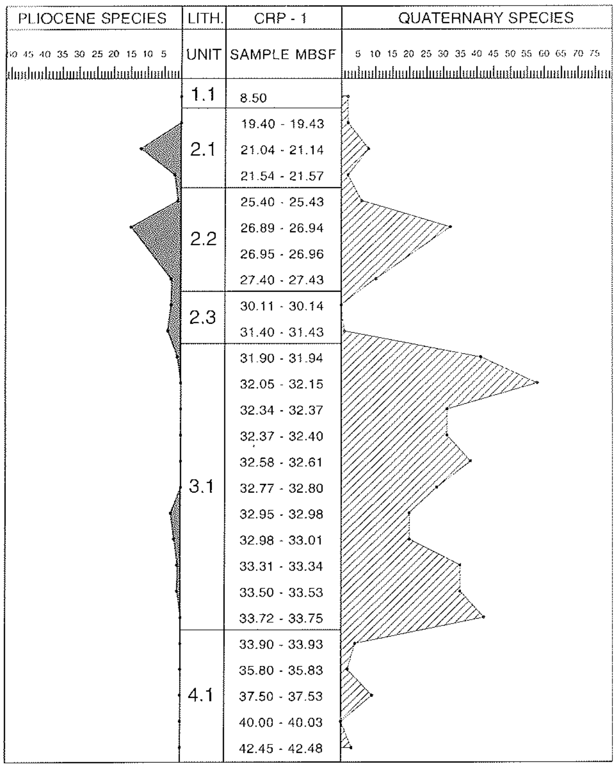


Fig. 4 - Numbers of Pliocene and Quaternary species of foraminifera per sample in twenty-six samples from CRP-1. Note increase in numbers of recycled Pliocene species in the higher levels of the CRP-1 Quaternary succession (Units 2.3, 2.2, and 2.1), low numbers in Unit 3.1, and absence from Unit 4.1. There appears to be a relationship between high test numbers, high species numbers, and the stratigraphic distribution of ice-rafted sediments.

Strong (this volume, Fig. 5). We conclude, then, that although this assemblage is recycled, it was little altered during incorporation into glacier ice and rafting to Roberts Ridge.

CRP-1 (21.04 mbsf)

This assemblage has a very similar composition to CRP-1 (26.89 mbsf).

Again, *Cassidulinoides porrectus* is the primary dominant but with a very high relative abundant value of 66%. *Ammoelphidiella antarctica* makes up only 2.5% of this assemblage. It is suggested that there has been augmentation of the primary dominant taxon value through loss of the smaller and more fragile tests during ice-rafting, melt-out, and size sorting at the sea floor.

STRATIGRAPHIC DISTRIBUTION OF RECYCLED PLIOCENE FORAMINIFERA THROUGH THE CRP-1 QUATERNARY SUCCESSION

Figure 4 depicts species totals for Quaternary and Pliocene assemblage elements in each of twenty-six samples, plotted against the stratigraphic succession and lithostratigraphic units. There is a marked increase in test numbers and species diversity towards the upper part of the Quaternary succession. Results show that no recycled Pliocene taxa occur in diamictons likely to have been deposited beneath or close to thick ice fronts (Unit 4.1). Small test numbers and low species diversity characterize muddy-sandy shell bank deposits that experienced a low incidence of ice-rafting and probably formed beneath a clast-free seasonal ice cover (Unit 3.1). Much higher recycled test numbers and higher species diversity occur in deposits that were associated with significant ice-rafting activity (Units 2.3, 2.2 and 2.1). Note, that in Unit 3.1 a peak occurrence of recycled Pliocene foraminifera occurs near the middle of the unit (Samples 32.95-32.98 and 32.98-33.01 mbsf) at a level coinciding with the occurrence of ice-rafted debris. Ice rafting in Unit 2.2 is described as minor (Cape Roberts Project Science Team, 1998). In view of our results we suggest that much of this muddy sand unit might be an ice-rafted deposit.

PROVENANCE

We conclude from assemblage composition and structure data discussed here that the recycled Pliocene assemblages were not derived from sea floor exposures on Roberts Ridge and distributed by traction currents. Rather, we propose that they were incorporated in glacier ice at some distant point of origin that was probably located within the Transantarctic drainage system, and were borne in glaciers, ice shelves, or icebergs, to Roberts Ridge, to be deposited as a component of sediment melt-out or rain-out debris.

The low species diversity and almost total absence of planktonic foraminifera suggests that the source sediment probably originated in trunk valley marine basins (paleofjords) such as existed in the Ferrar, Taylor and Wright valleys during the Pliocene, rather than an open ocean coastal site east of the Transantarctic Mountain Front. It is possible that the Mackay trunk valley drainage system and its basins were the likely source *loci* for the foraminifera documented here.

We cannot discount the possibility that Pliocene sediments were derived from a more southerly source in southwestern McMurdo Sound (*e.g.*, Ferrar Paleofjord) and transported northwards in a proto-McMurdo Ice Shelf. The presence of a significant volcanic component in the fine fraction of Quaternary sediments may lend credence to this source, but it is important to interpret whether this element of the sediment was delivered to the site via air fall or ice-rafting processes.

IMPLICATIONS FOR BASIN HISTORY

The results of this investigation suggest that a significant component of the Quaternary sediment pile at CRP-1 was derived from unconsolidated marine Pliocene sediments within the trunk valley systems of the Transantarctic Mountains. This provenance gains support from the dominance of Granite Harbor Intrusive Complex igneous rocks, and fine-grained sedimentary mineralogy characteristic of Beacon Supergroup and Ferrar Group rocks in the CRP-1 Quaternary succession. The derivation of a significant volcanic contribution to the matrix presents a problem and may indicate the existence of mixed provenances and a more complex array of glacial trajectories over time.

The widespread occurrence of recycled Pliocene microfossils (and presumably Pliocene sediments as well) in Quaternary sediments further east in the Ross Sea (Ward, 1997) suggests that there was a major regional episode that involved transfer of large volumes of sediment from the East Antarctic craton, into the Victoria Land basin, and probably into other Ross Sea rift basins. Because the Taylor, Wright and Victoria valleys do not appear to have been traversed by trunk glaciers in the late Quaternary, the Mackay (and possibly the Ferrar) trunk valley system is the drainage conduit favored for erosion of Pliocene sediments and their transport to the Ross Sea rift basins.

A major episode or series of events resulting in the deposition of the CRP-1 Quaternary succcession occurred in the last 1 million years.

The mechanism(s) that triggered this event is/are not understood at this time. Possible candidates include: (1) East Antarctic Ice Sheet build-up (climate deterioration and glaciation), (2) more dynamic glacier movements, entrapment of englacial sediment, and long distance transport during interglacials, (3) increased rates of Transantarctic Mountain uplift, and associated acceleration of glacier erosion rates in the highlands together with deeper dissection within drainage channels, and (4) high frequency oscillation of sea level, marine transgression and regression, rapid shifts of grounding lines, increased erosion and dissection due to modified land-to-sea landscape-bathymetric profiles, and active iceberg calving.

If marine sediments were involved in the sediment mass transfer event proposed here, it also seems likely that Pliocene and older terrestrial sediments should also be involved. The pollen taxon *Nothofagidites lachlaniae* occurs in both Units 2.2 and 2.1, along with recycled Pliocene foraminifera and other fossil material (Cape Roberts Project Science Team, 1998). The same pollen species is present in the Pliocene Sirius Group (Meyer Desert Formation) at Oliver Bluffs, Beardmore Glacier (Hill & Truswell, 1993; Webb & Harwood, 1991), and in the Pliocene at DSDP 274 to the north of Cape Adare, northern Victoria Land (Fleming & Barron, 1996). It seems reasonable to explain the occurrence of well preserved fossil wood debris in Units 2.1, 2.1 and 1.1 (see above) as having been derived from vascular vegetation, possibly from the southern beech genus *Nothofagus*. The implication of this interpretation is that the Pliocene Transantarctic Mountains inland of Granite Harbour were vegetated by vascular plants, and that weathering and soil development was also associated with the evolution of the landscape and terrestrial Sirius Group sedimentary environments (Webb & Harwood, 1991, 1993). Erosional remnants of formerly much more widely distributed terrestrial Sirius Group sediments crop out at the head of the Mackay trunk valley drainage system (*e.g.* Shapeless Mountain, Carapace Nunatak, Allen Hills, and Coombs Hills) and provide potential source sediments (Mayewski & Goldthwait, 1985). We conclude, then, that terrestrial Pliocene sediments of the Sirius Group were also subject to erosion and transported along with marine sediments of the Sirius Group to the Ross Sea basins.

ACKNOWLEDGEMENTS

We acknowledge the assistance of Sandra Passchier in processing of core samples for foraminifera, Matt Curren for guidance during sampling activities, and Terra Stanley and Randy Collier for preparation of illustrations. We thank Joan Bernhard, Charles Hart, Scott Ishman, Wojtek Majewski, Sandra Passchier, Michael Sperling and Barbara Ward for assistance in reviewing the manuscript. Peter Webb and Sandra Passchier participated in this study with support provided by NSF/OPP grant 9420475. Percy Strong's participation was supported by IGNS grant C-05815.

REFERENCES

Cape Roberts Science Team, 1998. Initial Report on CRP-1, Cape Roberts Project, Antarctica. *Terra Antartica*, **5**(1), 187 p.

Conato V. & Segre A.G., 1974. Depositi marini Quaternari e nuovi foraminiferi dell Antartide (Terra Vittoria, Valle Wright). *Atti della Societa Toscana di Scienze Naturali*, Ser. A **81**, 6-23.

Eggers A.J., 1979. Scallop Hill Formation, Brown Peninsula, McMurdo Sound, Antarctica. *New Zealand Journal of Geology and Geophysics*, **22**, 353-361.

Fleming R.F. & Barron J.A., 1996. Evidence of Pliocene *Nothofagus* from Pliocene marine sedimentary deposits (DSDP 274). *Marine Micropaleontology*, **27**, 227-236.

Gazdzicki A. & Webb P.N., 1996. Foraminifera from the Pecten Conglomerate (Pliocene) of Cockburn Island, Antarctic Peninsula. *Palaeontologia Polonica*, **55**, 147-174.

Hill R.S. & Truswell E.M., 1993. *Nothofagus* fossils in the Sirius Group, Transantarctic Mountains: Leaves and pollen and their climatic implications. In: Kennett J.P. & Warnke D.A. (eds.), *The Antarctic Paleoenvironment: A Perspective On Global Change, AGU Antarctic Research Series*, Washington D.C., **60**, 67-73.

Ishman S.E. & Rieck H.J., 1992. A late Neogene Antarctic glacio-eustatic record, Victoria Land Basin margin, Antarctica. In: Kennett J.P. & Warnke D.A. (eds.), *The Antarctic Paleoenvironment: A Perspective On Global Change, AGU Antarctic Research Series*, Washington D.C., **56**, 327-347.

Ishman S.E. & Webb P.N., 1988. Late Neogene benthic foraminifera from the Victoria Land Basin margin, Antarctica: application to glacio-eustatic and tectonic events. *Revue de Paleobiologie, Special Volume*, **2**(2), 523-551.

Mayewski P. & Goldthwait R.P., 1985. Glacial events in the Transantarctic Mountains: a record of the East Antarctic Ice Sheet. In: Turner M.D. & Splettstoesser J. (eds.), *Geology Of The Central Transantarctic Mountains, AGU Antarctic Research Series*, Washington D.C., **36**, 275-324.

Quilty P.G., Gillieson D., Burgess J., Gardiner G., Spate A. & Pidgeon R., 1990. *Ammoelphidiella* from the Pliocene of Larsemann Hills, East Antarctica. *Journal of Foraminiferal Research*, **20**, 1-7.

Ward C.W., 1997. *Foraminiferal biostratigraphy and paleoecology of marine sediment cores collected during NBP93-8 and NBP94-7, Ross Sea, Antarctica.* M.S. thesis, The Ohio State University.

Webb P.N., 1974. Micropaleontology, paleoecology, and correlation of the Pecten Gravels, Wright Valley, Antarctica, and description of *Trochoelphidiella onyxi* n.gen et n.sp. *Journal of Foraminiferal Research*, **4**, 184-199.

Webb P.N., 1988. Upper Oligocene-Holocene foraminifera of the Ross

Sea region. *Revue de Paleobiologie, Special Volume*, 2(2), 589-603.

Webb P.N. & Andreasen J.E., 1986. Potassium argon dating of volcanic material associated with the Pliocene Pecten Conglomerate (Cockburn Island) and Scallop Hill Formation (McMurdo Sound). *Antarctic Journal of the United States*, **21**(5), 59.

Webb P.N. & Harwood D.M., 1991. Late Cenozoic glacial history of the Ross Embayment, Antarctica. *Quaternary Science Reviews*, **10**, 215-223.

Webb P.N. & Harwood D.M., 1993. Pliocene fossil *Nothofagus* (Southern Beech) from Antarctica: Phytogeography, dispersal strategies, and survival in high latitude glacial-interglacial environments. In: Alden J.N., Mastrantonio J.L. & Odum S. (eds.), *Forest Development In Cold Climates*, NATO Advanced Science Institutes Series, Series A: Life Sciences Volume, Plenum Press, New York, **244**, 135-165.

Appendix 1 - Census count data for Lithostratigraphic Unit 2.2 and Unit 2.1. See summary graphic compilations of these data in figures 1 to 4.

Appendix 1.1 - Census data for Unit 2.2 (26.89-26.94 mbsf). Figures shown in parentheses denote percentages based on the tally for the three most dominant benthic taxa.

Genus/species	*Total Count*	*Percentage Dominance*	*Cumulative Percentage*
1. Cassidulinoides porrectus	066	29.20 (29.33)	29.20
2. Trifarina earlandi	041	18.14 (18.22)	47.34
3. Cibicides lobatulus	035	15.48 (15.55)	62.82
4. Ehrenbergina glabra	025	11.06	73.88
5. Ammoelphidiella antarctica	017	07.52	81.40
6. Cibicides refulgens	014	06.19	87.59
7. Globocassidulina crassa	012	05.30	92.89
8. Globocassidulina subglobosa	006	02.65	95.54
9. Glandulina antarctica	003	01.32	96.56
10. Cyclogyra involvens	001	00.44	97.30
11. Pyrgoella sphaera	001	00.44	97.74
12. Fissurina sp.	001	00.44	98.18
12. Planuspirinoides bucculentus	001	00.44	98.66
13. Pseudobulimina chapmani	001	00.44	99.06
14. Cribroelphidium incertum.	001	00.44	99.50
15. Neogloboquadrina. pachyderma	001	00.44	99.94
Total	226	99.94	99.94

Appendix 1.2 - Census data for Unit 2.1 (21.04-21.14 mbsf). Figures shown in parentheses denote percentages based on tally for the three most dominant benthic taxa.

Genus/Species	*Total Count*	*Percentage Dominance*	*Cumulative Percentage*
1. Cassidulinoides porrectus	082	65.60 (66.12)	65.60
2. Globocassidulina subglobosa	017	13.60 (13.70)	79.20
3. Cibicides lobatulus	004	03.20 (03.22)	82.40
4. Globocassidulina crassa	004	03.20	85.60
5. Ammoelphidiella antarctica	003	02.40	88.00
6. Ehrenbergina glabra	003	02.40	90.40
7. Trifarina earlandi	003	02.40	92.80
8. Pseudobulimina chapmani	003	02.40	95.20
9. Cibicides refulgens	003	02.40	97.60
10. Miliolidae	001	00.80	98.40
11. Lenticulina gibba	001	00.80	99.20
12. Neogloboquadrina pachyderma	001	00.80	100.00
Total	125	100.00	100.00