Occurrence, Stratigraphic Distribution and Palaeoecology of Quaternary Foraminifera from CRP-1

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Abstract - Foraminifera are examined in twenty-six samples from a 44 metre succession of Quaternary glacial sediments recovered from the CRP-1 drillhole on Roberts Ridge, southwestern Ross Sea, Antarctica. *In situ* marine assemblages were documented in at least three of the six lithostratigraphic units, and it is likely that the remaining three interbedded diamicton units are also marine in origin. Peak foraminiferal diversities are documented in Unit 3.1 (73 species) and Unit 2.2 (32 species). Calcareous benthics dominate the assemblages, but may be accompanied by abundant occurrences of the planktonic *Neogloboquadrina pachyderma*. Low diversity agglutinated faunas appear in the uppermost strata of Units 4.1 and 2.2. A close relationship between lithofacies and foraminiferal biofacies points to marine environments that alternated between proximity to and distance from active glaciers and ice-shelf fronts, with associated variations in salinity, sea-surface ice cover and the levels of rainout from debris-laden ice.
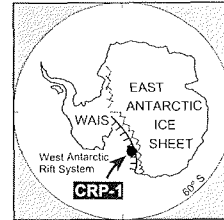
INTRODUCTION

Cape Roberts Project drillhole CPR-1 was drilled to a depth of 148 metres below the sea floor (mbsf) on Roberts Ridge. The site lies in 150 m of water at 77.008°S and 163.755°E, 16 km offshore from Cape Roberts. The sequence comprises a Quaternary glacial interval down to 43.15 mbsf and this succession is underlain by Lower Miocene sediments that are also glacial in origin (Cape Roberts Science Team, 1998) (Fig. 1). There is no record of *in situ* Pliocene sediments in this succession.

The twenty-six samples used in the present foraminiferal study span the stratigraphic interval 8.50 to 42.48 mbsf (158.50 to 192.48 m below present sea level) and are assigned to lithostratigraphic units defined for the drillhole (Cape Roberts Science Team, 1998).

We emphasize the following aspects of the foraminifera recovered from the Quaternary interval of the CRP-1 drillhole: generic and specific identifications, the occurrence of foraminifera in the six defined litho-stratigraphic units, assemblage characterization (species diversity, relative abundance of species, etc.), assemblage trends within lithofacies and across unit boundaries, comparison of foraminiferal data with datasets developed for other palaeontological groups, and the application of the foraminiferal data to interpretation of Quaternary glacial environments and events.

SIGNIFICANT ISSUES

The Quaternary marine and terrestrial stratigraphy, biostratigraphy, chronostratigraphy, and palaeoclimate of Antarctica is still quite poorly documented. The succession recovered in the CRP-1 drillhole is a particularly valuable addition to the Quaternary data base for the Ross Sea sector of Antarctica. As a preamble to this report on the Foraminifera, we consider briefly the following issues and questions, and develop each later in the text.

Glacial history. CRP-1 is located at the western margin of the Victoria Land Basin close to the East Antarctic cratonic margin. The multi-unit lithostratigraphic succession provides an opportunity to monitor climate variations in nearby terrestrial environments, to correlate the marine record with the land-based rock and ice sheet ice core records, to examine erosion and sediment transport patterns from terrestrial to marine settings, and by using recycled fossils to reconstruct on-land stratigraphy and palaeoenvironments for which a record either no longer exists or is covered by an ice sheet.

Chronostratigraphy. It is crucial that the temporal span of the multi-unit stratigraphy recognised at CRP-1 be determined. Does the succession represent a relatively short time, characterized by dynamic shifts of near-shore glacial environments and associated depositional processes, and with inter-unit boundaries involving little or no loss of time; or is the succession one involving a series of short-lived sedimentary events bounded by multiple disconformities representing significant non-deposition and or erosion, thereby providing an intermittent record that spans, *in toto,* much of the Quaternary.

Sequence and Seismic Stratigraphy. High resolution regional seismic coverage and identification of seismic units in near-seafloor sedimentary successions will eventually become available for large areas and for selected high priority regions of the Ross Sea. The detailed stratigraphy, biostratigraphy and chronostratigraphy
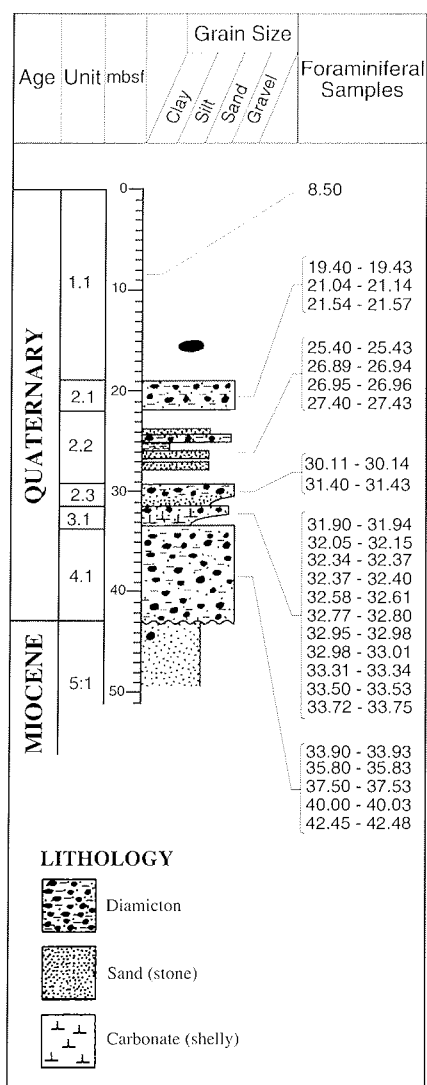
Fig. 1 - Quaternary succession and lithostratigraphic units for CRP-1 drillhole (mbsf = metres below sea floor). The stratigraphic distribution of the twenty-six samples used in the present investigation are indicated.

developed at CRP-1 should aid the calibration and correlation of seismic stratigraphy.

Interpretation of Glacial Environments. Crucial topics and processes which must be considered and addressed in the process of characterizing the record at CRP-1 include; bathymetry and bathymetric oscillations (glacial and/or tectonically induced eustatism), characterization of past ice environments in the region of the drillsite on Roberts Ridge (glacier ice, shelf ice, ice bergs, sea-ice), water column chemistry (hyposalinity resulting from high levels of meltwater injection; and hypersalinity caused by sea-ice formation and brine rejection), position of the calcium carbonate compensation depth (CCD), and seafloor processes and phenomena (bottom currents, sedimentation rates and processes, bottom current activity).

Micropalaeontology (Foraminifera). Many of the above issues can be elucidated by examining foraminiferal records and trends within each stratigraphic unit and population responses close to boundaries between the units. Because glacial processes are notorious for the transport of individual specimens and even whole communities along complex recycling pathways and into

totally alien final phase sites of deposition, it is important to prove beyond all doubt, that the foraminifera and sediments from which they are recovered are coeval. Are foraminifera recovered from CRP-1 members of final depositional phase biocoenoses, or might all or some have been introduced by ice-berg and ice-shelf meltout and rainout, and by bottom current transport. Whereas a single assemblage might be transported and redeposited in an almost original state, it is unlikely that natural population trends between stratigraphically contiguous assemblages would be preserved in the course of water-related recycling or glacial allogeny. In this study we approach the problem by characterizing the salient features of a suite of assemblages arranged in stratigraphic order. This allows the recognition of probable *in situ* unmodified death assemblages, slightly to severely modified death assemblages, and detection of biotic allogenes, and allogenic (allochthonous or *remanie*) assemblages.

Pliocene allogenes are very common in the CRP-1 Quaternary and have been treated separately (Webb & Strong, this volume). Pre-Quaternary allogenes are detected by the recognition of biostratigraphic ranges, states of preservation (damage, color, dissolution, recrystallization, etc.), presence of matrix-filled and encrusted tests, size sorting, and lack of a coherent assemblage structure.

STRATIGRAPHY

Our study employs the lithostratigraphic subdivisions developed for Quaternary sediments in the CRP-1 Initial Report (Cape Roberts Science Team, 1998). This scheme recognizes six units and subunits (Fig. 1).

PALAEONTOLOGICAL LABORATORY PROCEDURES

Twenty-six samples were examined. The sample taken at 8.5 mbsf was a full-round core extracted from the tricone bit; and that from 32.05-32.15 mbsf a half core. All other samples were 3 cm one-quarter core segments. Samples were soaked in warm water, agitated gently until fully in suspension, and sluiced through a stack of seives. All material >63 µm was retained and dried in a low temperature oven. Floatation procedures were not employed.

Faunal lists for each sample are based on exhaustive picking of whole residues (Tab. 1). Census counts and relative abundance data reported herein are based on splits of whole residues (>63 µm), using a Sepor Microsplitter. Wherever possible, specimen counts have a lower limit of 300 tests (Appendix 1).

IDENTIFICATION OF FORAMINIFERA

Foraminiferal identifications are based on the following literature: Barker (1960), Brady (1884), Earland (1934), Heron-Allen & Earland (1922, 1932), Loeblich & Tappan (1964, 1988), Parr (1950), Ward (1985), and Ward & Webb (1986).

Tab. 1 - Occurrence of foraminifera in Unit 3.1 (eleven samples between 31.90 and 33.75 mbsf) and Unit 2.2 (26.89 mbsf).

FORAMINIFERA	33.72 33.75	33.50 33.53	33.31 33.34	32.98 33.01	32.95 32.98	32.58 32.61	32.77 32.80	32.37 32.40	32.34 32.37	32.05 32.15	31.90 31.93	26.89 26.94
Glomospira sp.			*			*			*	*		
Cyclogyra involvens (Reuss)	*	*				*	*	*	*	*	*	*
Spiroloculina sp.						*						
Cornuspiroides foliaceus (Philippi)										*		
Planispirinoides bucculentus (Brady)	*	*	*			*		*	*	*	*	
Quinqueloculina sp.										*		
Cruciloculina triangularis d'Orbigny						*	*	*				
Triloculina lamellidens Parr						*			*		*	
?Triloculina subvalvularis Parr											*	
Triloculina trigonula Lamarck	*		*			*	*	*	*	*	*	*
Pyrgo depressa (d'Orbigny)				*		*	*	*	*	*	*	
Pyrgo elongata d'Orbigny	*		*			*				*		
Pyrgo murrhyina (Reuss)						*			*	*		
Pyrgo patagonica (d'Orbigny)	*	*	*			*	*	*	*	*	*	
Pyrgoella sphaera (d'Orbigny)	*	*	*	*			*	*	*	*	*	
Sigmoilina umbonata Heron-Allen & Earland	*	*	*		*	*	*	*	*	*	*	
Dentalina communis d'Orbigny				*						*		
Lagena costata (Williamson)	*		*			*				*		*
Lagena digitale Heron-Allen & Earland										*		
Lagena distoma Parker & Jones										*		*
Lenticulina gibba (d'Orbigny)	*	*	*		*	*	*	*	*	*	*	
Lagena gracilis Williamson										*		*
Lagena laevis (Montagu)										*		
Astacolus crepidulus (Fitchell & Moll)	*					*				*		
Entolingulina biloculi (Wright) Ward						*						
Fissurina alveolata (Brady)	*											
Fissurina fimbriata (Brady)	*	*	*							*		
Fissurina kerguelensis Parr										*	*	
Fissurina nelsoni (Heron-Allen & Earland)	*					*	*	*		*	*	
Fissurina radiata Sequenza	*									*		
Fissurina seguenza (Fornasini) Barker	*	*	*		*					*		
Fissurina semimarginata Reuss	*	*	*			*	*	*	*	*	*	*
Fissurina subcircularis Parr	*	*		*		*	*	*	*	*	*	*
Fissurina sulcata (Walker & Jacob)												
Fissurina wrightiana (Brady) Barker									*			
Glandulina antarctica Parr	*	*	*	*	*	*	*	*	*	*	*	*
Siphoglobulina siphonifera Parr								*		*		
Oolina apioplewa (Loeblich & Tappan)		*	*		*	*				*		*
Oolina apiculata Reuss	*	*								*	*	
Oolina botelliformis (Brady)					*							
Oolina desmophora (Rhymer Jones)	*											
Oolina felsinea (Fornasini) Barker						*	*				*	
Oolina globosa Reuss	*	*					*		*	*	*	
Oolina hexagona (Williamson)	*					*				*	*	
Oolina lineata Williamson	*	*	*							*	*	*
Oolina melo d'Orbigny						*				*	*	*
Oolina squamosulcata (Heron-Allen & Earland)	*		*			*			*	*	*	*
Oolina sp. (bag-shaped)		*								*	*	*
Bolivina earlandi Parr Barker						*						
Buliminella turbinata (Terquem)			*									
Parafissurina ovata (Wiesner) Parr	*	*								*		
Cassidulinoides parkerianus (Brady)	*	*	*	*	*	*	*	*		*		*
Cassidulinoides porrectus (Heron-Allen & Earland)	*	*	*	*	*	*	*	*	*	*	*	*
Trifarina earlandi Parr	*	*	*	*			*	*	*	*	*	*
Epistominella exigua (Brady)	*	*	*	*	*	*	*	*	*	*	*	*
Rosalina globularis d'Orbigny	*	*	*	*	*	*	*	*	*	*	*	*
Schackoinella antarctica Ward						*			*			
Heronallenia kempi (Heron-Allen & Earland)	*	*	*			*		*		*	*	*
Patellina corrugata Williamson	*	*	*	*	*	*	*	*	*	*	*	*
Patellinoides concava Heron-Allen & Earland										*		
Spirillina tuberculata Brady			*				*			*	*	
Cribroelphidium incertum (Williamson)	*		*			*				*	*	*
Neogloboquadrina pachyderma (Ehrenberg)	*	*	*	*	*	*	*	*	*	*	*	*
Cibicides lobatulus (Walker & Jacob)	*	*	*	*	*	*	*	*	*	*	*	*
Cibicides refulgens Montfort	*	*	*	*						*	*	*
Fursenkoina earlandi (Parr)	*	*				*			*	*	*	*
Ehrenbergina glabra Heron-Allen & Earland	*	*	*	*	*	*	*	*	*	*	*	*
Globocassidulina crassa (d'Orbigny)		*	*	*	*		*	*		*	*	*
Globocassidulina subglobosa (Brady)	*	*	*	*	*	*	*	*	*	*	*	*
Astrononion antarcticum (Parr)	*	*	*	*	*	*	*	*	*	*		*
Nonionella iridea Heron-Allen & Earland	*	*	*	*	*	*	*	*	*	*	*	*
Pullenia subcarinata (d'Orbigny)	*	*	*	*	*		*			*	*	*
Pseudobulimina chapmani (Heron-Allen & Earland)	*	*	*		*	*	*	*	*	*	*	

STRATIGRAPHIC DISTRIBUTION OF FORAMINIFERA

SAMPLES

The distribution of samples through the six lithologic units is shown in figure 1. Twenty-five of the twenty-six samples are from a 23.08 m interval between 19.40 and 42.48 mbsf, for an average sample separation of slightly less than a metre. Actual spacing varies unit to unit and in the case of Unit 3.1 (thickness 1.93 m) the eleven samples have an average spacing of about 16 cm. A sample at 8.5 mbsf is the only collection examined from the upper 19 m of the CRP-1 drillhole.

LITHOSTRATIGRAPHIC UNIT 4.1 (33.82-43.15 mbsf)

Lithology. Olive-grey to olive-black, compact uncemented, structureless, very poorly sorted, clast-poor to clast-rich muddy to sandy diamicton (Fig. 1).

Foraminifera. Five samples were examined from this 9.73-m unit. Calcareous benthic taxa are well preserved but rare, with some possibly recycled. Agglutinated tests are relatively common, reasonably well preserved and interpreted as part of an *in situ* marine assemblage. At least seven species are present. The lowermost assemblage occurs just above the base of Unit 4.1 (*i.e.* 42.45 mbsf). The largest number of agglutinated tests occur at 33.90 mbsf, immediately below the sharp contact with overlying Unit 3.1.

42.45 mbsf - *Reophax* sp., *Trochammina* sp. (most
    common), *Verneuilina* sp.
40.00 mbsf - no foraminifera.
37.50 mbsf - *Hyperammina* sp., *Thurammina* sp., *Textularia*
    sp., *Spiroplectammina* sp., *Trochammina* spp. (most
    common), *Astacolus* sp., *Oolina* sp., *Ehrenbergina*
    glabra, *Nonionella* sp., and echinoderm spines.
35.8 mbsf - *Trochammina* spp., *Verneuilina* sp.
33.90 mbsf - *Reophax* sp., *Textularia* sp., *Trochammina*
    spp (most common), *Cassidulinoides porrectus,* shell
    fragments and sponge spicules.

LITHOSTRATIGRAPHIC UNIT 3.1 (31.89-33.82 mbsf)

Lithology. Green-grey to olive-grey, compact,
uncemented, weakly stratified, highly fossiliferous, poorly
sorted, muddy gravelly sand (Fig. 1).

Foraminifera. Eleven samples from this 1.93 m thick
unit were examined and all contain abundant Quaternary
foraminifera. Recycled Pliocene foraminifera are also
common throughout Unit 3.1 and are discussed separately
(Webb & Strong, this volume). Forty-two genera and 73
species of foraminifera have been identified in Unit 3.1
(Tab. 1). This includes a single planktonic species,
Neogloboquadrina pachyderma. The most common taxa
include the benthics *Cassidulinoides porrectus, Trifarina
earlandi, Epistominella exigua, Rosalina globularis,
Patellina corrugata, Neogloboquadrina pachyderma,
Ehrenbergina glabra* and *Globocassidulina subglobosa*
(Appendix 1). Miliolidae are represented by several species,
most of which are very large (up to 5 mm) and have heavily
calcified tests. This group includes *Planispirinoides
bucculentus, Cruciloculina triangularis, Pyrgo depressa,
Pyrgo elongata, Pyrgo patagonica,* and *Pyrgoella sphaera*.
The miliolids from Unit 3.1 provided adequate biogenic
carbonate for amino acid racemization dating (Hart &
Webb, this volume).

    Characterization of individual foraminiferal assemblages
from Unit 3.1, together with analysis of stratigraphic trends
in population structure, and application of these data to
environmental interpretations are discussed below.

LITHOSTRATIGRAPHIC UNIT 2.3 (29.49-31.89 mbsf)

Lithology. Olive-black, compact, uncemented, massive,
poorly to very poorly sorted, clast-poor to clast-rich,
muddy to sandy diamicton (Fig. 1).

Foraminifera. Two samples (31.40 and 30.11 mbsf)
from this 2.40 m-thick unit were examined. Foraminifera
are common, well to poorly preserved, and heavily
calcified, with many tests matrix-filled and matrix-
encrusted. The presence of *Ammoelphidiella antarctica* in
both samples suggests that most if not all foraminifera are
recycled from Pliocene deposits (Webb & Strong, this
volume). No definite Quaternary foraminifera were
recovered and it is difficult to ascertain whether Unit 2.3
was deposited in a subglacial marine environment. Other
fossil material noted in the residues include possible
radiolaria, sponge spicules (very common), shell debris,
and echinoderm spines and plates.

LITHOSTRATIGRAPHIC UNIT 2.2 (22.00-29.49 mbsf)

Lithology. Olive-black, compact, uncemented,
structureless, locally fossiliferous, moderately to poorly
sorted, muddy medium-grained sand (Fig. 1).

Foraminifera. Four samples (27.40, 26.95, 26.89, and
25.40 mbsf) were examined from this 7.49 m-thick unit.
The lower three samples contain an abundant mixture of
well preserved Quaternary and Pliocene foraminifera.
Pliocene foraminifera are treated separately by Webb &
Strong (this volume). All Quaternary taxa, with the
exception of agglutinated taxa in 25.40-25.43 mbsf, are
also present in underlying Unit 3.1.
27.40-27.43 mbsf - *Triloculina* sp., *Cassidulinoides
    porrectus* (24% of the assemblage) *Trifarina
    earlandi, Rosalina globularis, Neogloboquadrina
    pachyderma, Fursenkoina earlandi, Ehrenbergina
    glabra* (8%), *Globocassidulina crassa* (56%),
    Globocassidulina subglobosa (6%). This
    assemblage totals only ten species and is probably
    strongly modifed from the original. The occurrence
    of *G. crassa* as a dominant taxon in this assemblage
    is noteworthy. In the assemblages of underlying
    Unit 3.1, *G. crassa,* is always among the subordinate
    taxa (Appendix 1).
26.95-26.96 mbsf: Fauna identical to the immediately
    suprajacent sample at 26.89-26.94 mbsf.
26.89-26.94 mbsf - Mixed Quaternary and Pliocene (Webb
    & Strong, this volume) assemblages. Dominant taxa
    among the 23 genera and 32 species recovered from
    the Quaternary element of the fauna (Tab. 1) include
    *Globocassidulina subglobosa, Ehrenbergina glabra,
    Cassidulinoides porrectus, Globocassidulina crassa,
    Trifarina earlandi,* and *Neogloboquadrina
    pachyderma*. The assemblages from 26.95, 26.89, and
    27.40 mbsf are essentially identical to those occurring
    in Unit 3.1.
25.40-25.43 mbsf - Dominantly agglutinated with rare
    recycled Pliocene foraminifera. Quaternary taxa present
    include probably *in situ Trochammina* sp., *Miliammina
    arenacea* and undetermined members of the
    Verneuilinidae.

LITHOSTRATIGRAPHIC UNIT 2.1 (19.13 to 22.00 mbsf)

Lithology. Olive black, compact, uncemented, massive,
very poorly sorted, clast-rich to clast-poor, muddy
diamicton (Fig. 1).
21.54 mbsf - Assemblage consists only of recycled Pliocene
    foraminifera (Webb & Strong, this volume).
21.04 mbsf - Assemblage dominated by recycled Pliocene
    foraminifera (Webb & Strong, this volume). A low
    number of probably recycled Quaternary foraminifera
    including *Planispirinoides bucculentus, Lenticulina
    gibba, Oolina hexagona, O. squamosulcata, Oolina*
    sp., and *Parafissurina ovata*.
19.40 mbsf - *Miliammina arenacea, ?Trochamina* sp.,
    as well as light coloured well preserved mineralized
    wood and sponge spicules that are probably
    recycled.

LITHOSTRATIGRAPHIC UNIT 1.1 (19.13 – 0.00 mbsf)

Lithology. Diamicton (Fig. 2)

Foraminifera. 8.5 mbsf - A single specimen of *Notorotalia profunda* Vella, and debris including sponge spicules, bryozoa, and diatoms

FORAMINIFERAL BIOSTRATIGRAPHY AND CHRONOSTRATIGRAPHY

No meaningful foraminiferal biostratigraphy or chronostratigraphy can be deduced from this thin succession. Microfaunal assemblages and individual taxa characterize the lithofacies in which they occur, with faunal entries and exits demarcated by lithostratigraphic unit boundaries. Diamictons (Units 4.1, 2,3, 2.1) are either unfossiliferous, contain low numbers of recycled calcareous tests, or provide low diversity and presumably *in situ* agglutinated assemblages. In contrast, muddy gravely sands (Units 3.1 and 2.2) contain very large assemblages of *in situ* foraminifera. The latter assemblages are identical to modern, Holocene and late Quaternary Ross Sea assemblages (Bernhard, 1987; Ward, 1985; Ward & Webb, 1986; Ward et al., 1987).

Diatom biostratigraphy was used to establish an age of 1.25-1.8 Ma for Units 3.1 and 2.3 (Cape Roberts Science Team, 1998). This age has been subsequently revised to 0.7-1.35 Ma (Bohaty et al., this volume).

An ⁴⁰Ar/ ³⁹Ar date of 1.2 Ma was obtained from a volcanic clast in Unit 3.1, indicating a maximum age for Units 3.1 and overlying units (McIntosh, this volume). Strontium isotope ages of ~1 Ma were obtained from *in situ* macrofossils and miliolids (foraminifera) from Unit 3.1 (Lavelle, this volume). Amino acid racemization analyses of bivalves and miliolid foraminifera from Unit 3.1 provided an age in the range of 210- to 430 k.y. (Hart & Webb, this volume).

Microfaunas discussed here are regarded as Quaternary in age. The total temporal span of the multi-unit CRP-1 Quaternary succession is yet to be accurately resolved but it appears to be less than 1 Ma. Palaeoecological analyses discussed below suggest gradational shifts between the foraminiferal biofacies up through the series of lithofacies packages. Our preliminary interpretation is that the CRP-1 succession may be a semi-continuous record representing a limited amount of late Quaternary time.

CHARACTERIZATION OF ASSEMBLAGES

GENERAL COMMENTS

Specific benthic and planktonic taxa and complete foraminiferal assemblages from glacial facies are potentially powerful tools in unravelling glacial history records, particularly at sites close to coastlines where they offer the possibility of relating a variety of terrestrial and marine glacial and deglacial episodes and events. Here, we specifically refer to the advance and retreat of glacier systems and ice shelves, ice-berg events, oscillations of open water and sea ice cover, and the sedimentary processes and physical oceanographic phenomena that characterize each of these specific environments.

Because of the ability for ice to transport near complete biocoenoses considerable distances and with little apparent modification, special care must be taken in using foraminiferal assemblages in glacial history analysis. The abundant and species-rich assemblages of Units 3.1 and 2.2 are potentially very useful for purposes of glacial history analysis. However, it must be shown that they represent *in situ* biocoenoses that are coeval with the sedimentary unit in which they occur.

To address this question we examined a series of eleven closely spaced samples from the 1.93 m-thick Unit 3.1. If this almost contiguous suite of *in situ* assemblages are
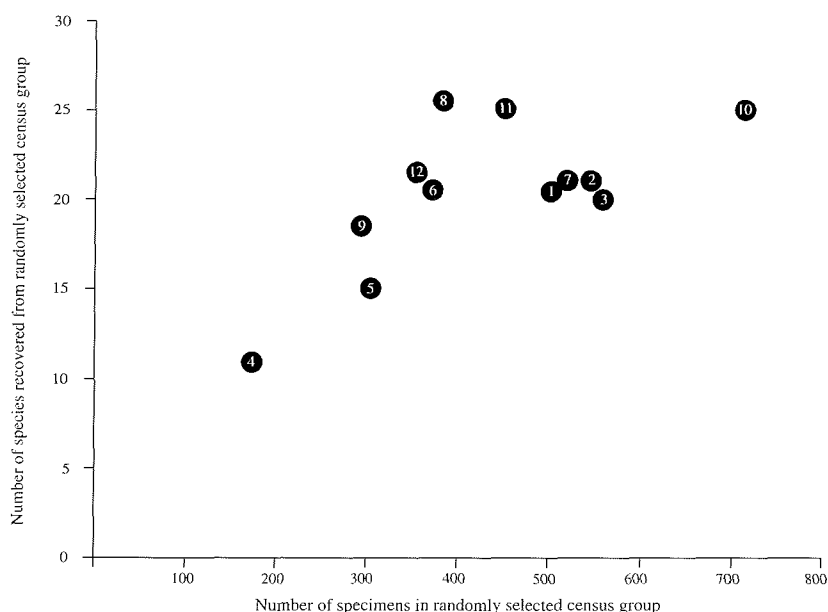

Fig. 2 - Number of species documented in census counts from Unit 3.1 (eleven assemblages) and Unit 2.2 (one assemblage). Tests were randomly selected from residue material >63 μm. A 300-test count captures between 20 and 25 species and there is little gain from larger counts. Numbers denote individual assemblages and increase stratigraphically upwards in succession. Stratigraphic position as follows, with only the upper meterage indicated for each sample (mbsf): 1 = 33.72, 2 = 33.50, 3 = 33.31, 4 = 32.98, 5 = 32.95, 6 = 32.77, 7 = 32.58, 8 = 32.37, 9 = 32.34, 10 = 32.05, 11 = 31.90, and 12 = 26.89 mbsf. See appendix 6.1 through 6.12 for details of each census count.

biocoenoses, they should exhibit a relatively similar assemblage content and meaningful inter-species relationships. Subtle changes in relationships and trends might be expected at the microstratigraphic level, and these might be useful in palaeoecological interpretation. We note then, the total generic and specific content for each assemblage, subject each assemblage to relative abundance census counts, identify the most abundant species, track abundance trends of dominant taxa stratigraphically, and relate assemblage variations to sedimentary features. Benthic and planktonic data are treated both separately and jointly, in an attempt to characterize contemporary sea-floor and sea-surface environments as well as water-column linkages between the two.

Assemblage diversity has been used as a palaeo-environmental indicator in low- and middle-latitude basin margin and continental shelf settings, usually in depths no greater than 200 m. By contrast in Antarctica, bathymetry close to coastlines, especially where trunk glacier valleys emerge at the coastline, often reach depths of 800 m or more and species richness is controlled by other factors. These include the fluctuations in the carbonate compensation depth, occurrence of hyper-hyposaline water masses resulting from marine ice formation and salt rejection and dilution effects resulting from melting of sea and glacier ice and seasonal productivity fluxes. In this study we employ species diversity, test abundance, state of preservation, replication of relative species abundance, and other factors, to determine the existence of a marine biocoenoses that are suitable for detailed assemblage analysis.

UNIT 4.1 (33.82-43.15 mbsf)

Foraminifera are not present in numbers sufficient for quantitative analysis.

UNIT 3.1 (31.89-33.82 mbsf)

Test abundance and species diversity. Eleven samples from Unit 3.1 yielded 42 genera represented by 73 species. The total species richness for individual samples is mostly a reflection of time spent in picking. For example, very exhaustive picking (several thousands of tests) of sample 32.05-32.15 mbsf produced a total of 58 species (Tab. 1, Fig. 2). Much of this high total is made up of single or a few-test occurrences by species such as *Lagena, Fissurina, Parafissurina* and *Oolina*. Much less exhaustive picking of other samples from Unit 3.1 provided assemblages of 30 to 40 species. This exercise suggested that all samples contain large and diverse assemblages and are useful for more detailed analysis.

Number of species-number of tests relationship in census counts. In the present study a minimum 300 random test count[*] has been adhered to wherever possible (Appendix 1). Figure 2 shows the number of species identified in census counts, plotted against differing numbers of tests from eleven samples in Unit 3.1 and one from Unit 2.2 (26.89 mbsf). A maximum number of 15 to 25 species is attained in 300 to 700 test counts, with no obvious advantage in instances where counts extend to 700 or more randomly selected tests. It is important to note

that counts include any randomly selected test larger than 63 µm. As will be shown below, the dominant three to five species in each assemblage are considered most useful in assemblage characterization and comparisons.

Relative abundance. The results of census counts are shown in tabular form (Appendix 1) and in graphic form as histograms (Fig. 3). Only tests with abundances greater than 1% are shown in the histograms. The planktonic *Neogloboquadrina pachyderma* is a major component of many assemblages and the abundance rank of this species is highlighted in a series of histograms (Fig. 3). For analysis of sea floor environments and history the benthic component is also calculated without the planktonic component and the relative abundance percentage contribution for the three most dominant benthic taxa shown in parentheses (Appendix 1).

Dominance. Census counts indicate a strong separation of the three to five most dominant species from the remainder of the census pool (Fig. 3, Appendix 1). The dominant taxon in each combined benthic and planktonic assemblage is always a calcareous benthic species, with dominance levels ranging between 25 and 41%. In instances where the planktonic *Neogloboquadrina pachyderma* is abundant and its tally extracted from the count, the dominance figure of the primary benthic taxon is further augmented to as much as 50 and 56% (*e.g.*, in 32.34-32.37 and 32.58-32.61 mbsf). Dominance percentages for the primary taxon in the Unit 3.1 suite are generally higher than is documented for similar modern live assemblages in the same geographic area (Ward, 1985; Ward et al., 1987). This difference between living and Quaternary assemblages might be real, or may result from post-depositonal loss of a significant number of agglutinated taxa. This issue is discussed below.

Combined benthic and planktonic census values in the eleven samples from Unit 3.1 indicate that between 5 and 11 species make up 90% of the eleven assemblages we studied, and that the "tail" species contribute at very low levels (Fig. 3, Appendix 1). The dominant species throughout the suite of assemblages tend to be the same small group of species.

Because we are interested in determining the degree to which benthic assemblages represent *in situ* biocoenoses, it is suggested that the relative abundance relationship between the more dominant taxa might be used to express the level of coherence within and between Unit 3.1 assemblages. In figure 4 the percentage values for the two most dominant species are displayed in a bivariate plot. Primary and secondary dominants make up between 50 and 80% of the assemblages, with the primary species distinctly dominant over the secondary species. There is a reasonable degree of scatter, a crude separation into two broad groups, and a slight tendency for grouping by stratigraphic sequence.

The same procedure is repeated in figure 5, but here we use a trivariate plot for the first three most dominant species. In this case, clustering is concentrated within the primary-secondary field, and well removed from the field of the third most dominant taxon. The total contribution for first-three dominant species in the eleven assemblages ranges between 58 and 84%.
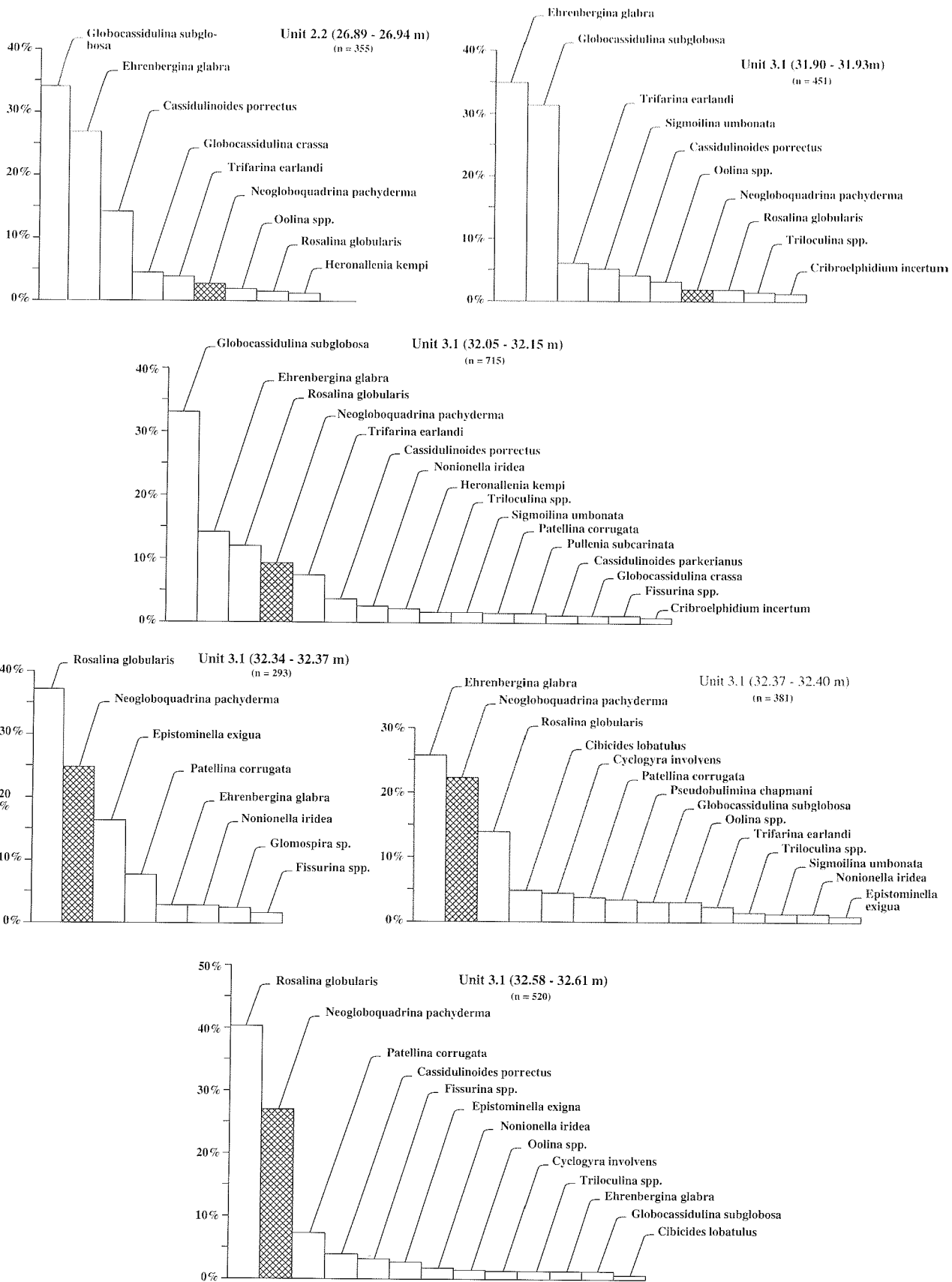
Fig. 3 - Histograms showing relative abundances for benthic and planktonic (*Neogloboquadrina pachyderma*) taxa contributing one percent or more to each assemblage. The complete census count for each assemblage is provided in appendix 1.1 through 1.12.

Close clustering of these dominant species might also result from bottom current sorting and selective preservation. In refuting this possibility we note that assemblages include a wide range of tests sizes, *e.g.*, *Rosalina globularis* (63-125 μm) to *Planispirinoides*, *Pyrgoella, and Pyrgo* (up to 5 mm diameter), and that
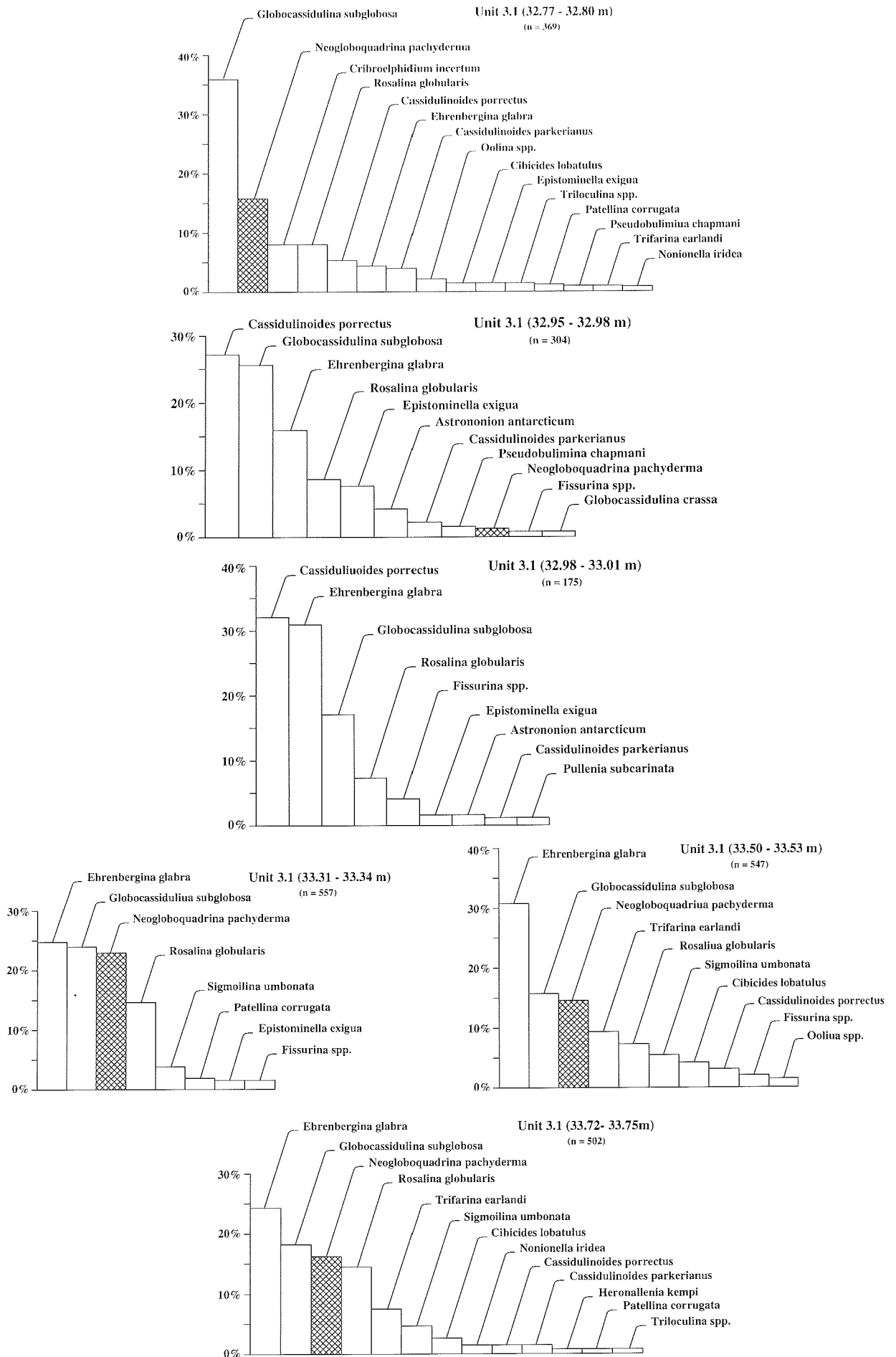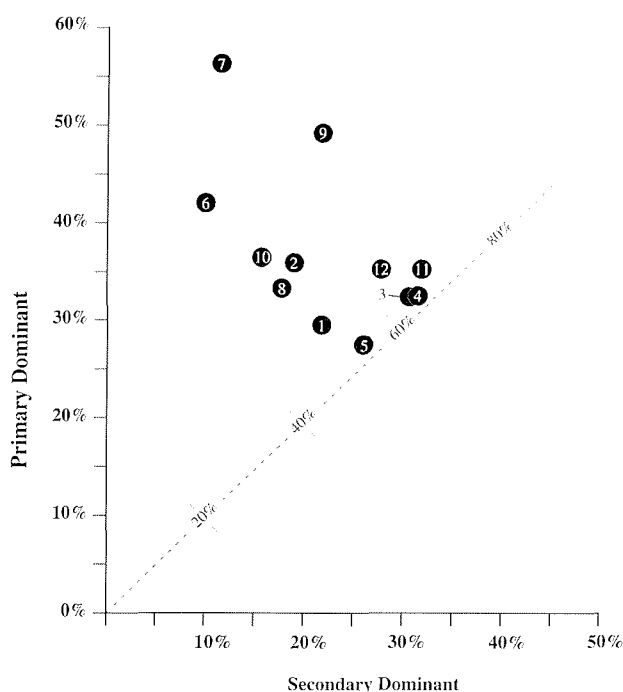
Fig. 3 - Continued.

Fig. 4 - Primary dominant benthic taxa plotted against secondary dominant benthic taxa for Unit 3.1 (eleven assemblages) and Unit 2.2 (one assemblage). Numbers denote individual assemblages and increase stratigraphically upwards in succession. Stratigraphic position as follows, with only the upper meterage indicated for each sample (mbsf): 1 = 33.72, 2 = 33.50, 3 = 33.31, 4 = 32.98, 5 = 32.95, 6 = 32.77, 7 = 32.58, 8 = 32.37, 9 = 32.34, 10 = 32.05, 11 = 31.90, and 12 = 26.89 mbsf. The complete census count is provided in appendix 1.1 through 1.12 and is summarised in figure 3.

Fig. 5 - Ternary plot for three most dominant benthic taxa from Unit 3.1 (eleven assemblages) and Unit 2.2 (one assemblage). Numbers denote individual assemblages and increase stratigraphically upwards in succession. Stratigraphic position as follows, with only the uppermost meterage indicated (mbsf): 1 = 33.72, 2 = 33.50, 3 = 33.31, 4 = 32.98, 5 = 32.95, 6 = 32.77, 7 = 32.58, 8 = 32.37, 9 = 32.34, 10 = 32.05, 11 = 31.90, and 12 = 26.89 mbsf. The complete census count is provided in appendix 1.1 through 1.12 and is summarised in figure 3.
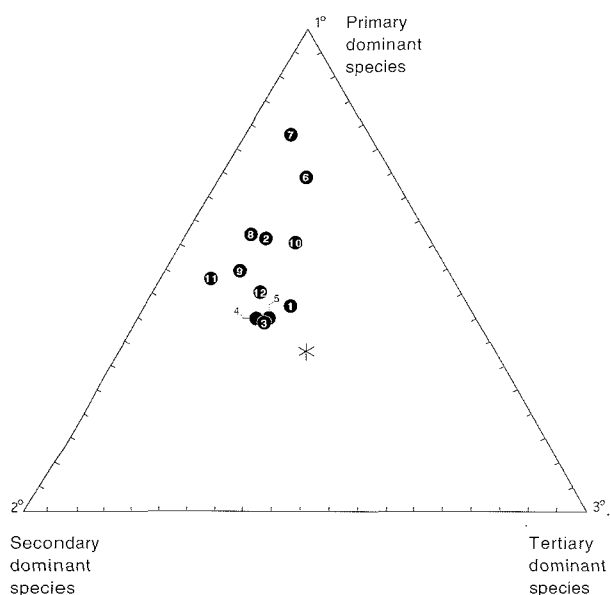
complete ontogenetic growth series are represented in some of the dominants, *e.g. Ehrenbergina glabra* and *Cassidulinoides porrectus*. We conclude from these infra-assemblage dominance relationships that the Unit 3.1 assemblages are *in situ*, almost unmodified by *post-mortem* sea-floor processes, and can be used for palaeo-environmental analysis.

Dominant taxa. Census studies indicate that the following constitute the dominant benthic group of species: *Cassidulinoides porrectus*, *Trifarina earlandi*, *Epistominella exigua*, *Rosalina globularis*, *Patellina corrugata*, and *Ehrenbergina glabra* (Fig. 3, Appendix 1). *Neogloboquadrina pachyderma* is the single planktonic representative among the dominant species. Most dominant species are present in each assemblage but in varying proportions. *Ehrenbergina glabra* is the primary dominant in five of the eleven assemblages, with dominance scores ranging between 29.45 and 36.99%. *Globocassidulina subglobosa* is the primary dominant in two assemblages (36.99 and 43.54%), *Rosalina globularis* is dominant in two assemblages (50.00 and 56.38%), and *Globocassidulina crassa* is also dominant in two assemblages (28.00 and 32.57%).

UNIT 2.3 (29.49-31.89 mbsf)

Quaternary foraminifera not documented.

UNIT 2.2 (22.00-29.49 mbsf)

Test abundance and species diversity. The four samples taken from near the middle of this 7.49 m-thick sand span a stratigraphic interval of 2 m. The lowermost (27.40 mbsf) and uppermost (25.40 mbsf) samples contain a low number of Quaternary tests and are not suitable for assemblage studies. Two contiguous samples (26.89-26.94 and 26.95-96 mbsf) contain large test numbers but only the former has been subjected to assemblage characterization. This sample contains 21 genera and 32 species (Tab. 1, Appendix 1).

Number of species-number of specimens relationship in census counts. A 355 test census count produced an assemblage of 23 species and placed it within the cluster field for assemblages from Unit 3.1 (Fig. 2).

Dominance. Eight species make up 90% of the combined benthic and planktonic assemblage (Appendix 1, Fig. 3). The primary and secondary dominant benthic taxa constitute 63.84% of the assemblage and when the third most dominant is added the figure rises to 78.7%. Bivariate and trivariate plots for the most dominant taxa again place this assemblage within the cluster field for Unit 3.1 (Figs. 4 & 5). The assemblage is interpreted as *in situ* and probably represents an almost intact biocoenosis.

Dominant taxa. The assemblage is dominated by *Globocassidulina subglobosa*, *Ehrenbergina glabra* and *Cassidulinoides porrectus*. *Neogloboquadrina pachyderma* contributes only 3.38% to the total assemblage. All taxa also occur in Unit 3.1, and the assemblage shares similarities in internal structure to that present in 31.90-31.94 mbsf at the top of Unit 3.1.

PALAEOECOLOGICAL INTERPRETATIONS

UNIT 4.1 (33.82-43.15 mbsf)

Large assemblages are not available for study. The small agglutinated assemblage encountered at several levels of Unit 4.1 and extending to the top of the unit (33.90 mbsf) suggests a low salinity environment close to or beneath thick glacier ice.

UNIT 3.1 (31.89 to 33.82 mbsf)

Diversity-stratigraphic trends in census data. In figure 6 we portray variations by the principal assemblage components according to stratigraphic sequence. Census-based assemblage diversity ranges are relatively stable and vary within a range of 15 to 26 species.

Planktonic trends. High planktonic dominance occurs at two stratigraphic levels within Unit 3.1 (Fig. 6). *N. pachyderma* contributes 23% to the 33.31-33.34 mbsf assemblage near the top of the the lower carbonate unit; and 27.69% to the 32.58-32.61 mbsf assemblage near the middle of the upper carbonate unit. *N. pachyderma* is also a significant contributor (16%) to the assembage (33.72-33.75 mbsf) close to the base of Unit 3.1. The species is absent or poorly represented in both ice-rafted debris intervals, near the middle (32.82-33.30 mbsf) and at the top (31.89-32.05 mbsf) of Unit 3.1 (Fig. 6). The abrupt appearance of *N. pachyderma* immediately above the Unit 4.1-3.1 contact might be associated with an abrupt shift from low-salinity marine waters, proximity to ice, and diamicton deposition that resulted in the *in situ* agglutinated foraminiferal assemblage (Unit 4.1), to normal marine conditions, seasonal sea-ice cover, and high levels of organic productivity in basal Unit 3.1. *N. pachyderma* declines in the upper part of Unit 3.1 as the boundary with diamicton Unit 2.3 is approached, suggesting perhaps a close relationship between the two units, a return to hyposaline waters and/or closer proximity to an ice front. Two variants of *N. pachyderma* are represented in Unit 3.1, relatively rare large kuemmerform tests and much more abundant tiny four to four and one half chambered forms. The latter variant has been reported alive in annual sea ice (Lipps & Krebs, 1974; Dieckmann et al., 1991; Spindler et al., 1990). It is suggested, then, that annual sea ice conditions probably prevailed during the deposition of the two carbonate facies.

Benthic trends. The dominance values for four benthic species are plotted in figure 6. *Cassidulinoides porrectus* appears to favor siliciclastic sediments under the influence of ice rafting sedimentation (Subunits 3 and 1 in Fig. 6). *Rosalina globularis* appears to favor the carbonate-rich sediments of Subunit 4 and particularly those of Subunit 2 (Fig. 6). *Ehrenbergina glabra* declines steadily up section where its lowest value coincides with the peak value for *Neogloboquadrina pachyderma* (32.58-32.61 mbsf) and then increases towards the top of Unit 3.1 (although at 32.34-32.37 mbsf a low value again coincides with a high value for *N. pachyderma*. The dominance peaks and minima for the benthic *Rosalina globularis* and planktonic *Neogloboquadrina pachyderma* appear in phase. Dominance trends for *N. pachyderma* and *Cassidulinoides*

porrectus appear to be opposed. There is a weakly developed anti-sympathetic relationship between *Ehrenbergina glabra* and *Globocassidulina subglobosa*. Sympathetic and anti-sympathetic trends in dominance values among benthic species and between benthic and planktonic species might reflect the type of ice cover above the water column, absence of ice cover, slight changes in sea floor substrate, turbidity, subtle oscillation in bottom-water characteristics, and reproduction dynamics. The impact of burrowing and predation at and below the seafloor mudline may also be a significant factor but cannot be assessed.

UNIT 2.3 (29.49-31.89 mbsf)

Quaternary foraminifera not documented.

UNIT 2.2 (22.00-29.49 mbsf)

The assemblage from 26.89 - 26.94 mbsf indicates an association of ice rafting, near sea-surface turbidity and a resultant poor development of planktonic foraminiferal numbers. *N. pachyderma* contributes only 3.38% to the census count (Appendix 1, Fig. 3). The dominant benthic combination of *G. subglobosa, E. glabra,* and *C. porrectus* (79% of the benthic census count) resembles assemblages from the siliciclastic-dominated interval with ice-rafted debris in uppermost part of Unit 3.1

COMPARISON OF THE FORAMINIFERAL AND CRP-1 DIATOM DATASETS

The principal observations on foraminiferal stratigraphic distribution and palaeoecology should be mirrored in other palaeontological datasets. Diatoms occur with foraminifera through much of the Quaternary succession and provide a support for many of our interpretations of lithofacies/biofacies associations, modes of sedimentation, sea surface environments, and proximity to glacier and shelf ice. In the present discussion, diatom data are derived from the CRP Initial Report (Cape Roberts Science Team, 1998, p. 50-53).

UNIT 4.1

Diatoms occur throughout the unit, are fragmented, and thought to be recycled.

It was concluded that diatom productivity was prevented by an ice mass cover above the diamicton. Planktonic diatoms and calcareous benthic foraminifera are documented at 38.40 and 37.50 mbsf respectively, but are thought to be recycled from pre-existing Quaternary strata. The assemblage of agglutinated foraminifera at 33.90 mbsf supports the view that the diamicton was deposited in marine hyposaline waters, possibly beneath or close to glacier or shelf ice.

UNIT 3.1

Diversity and abundance peaks for diatoms, foraminifera, silicoflagellates and thoracosphaerids (calcareous nannoplankton) occur within the lower and upper carbonate units. A three-fold diatom-based
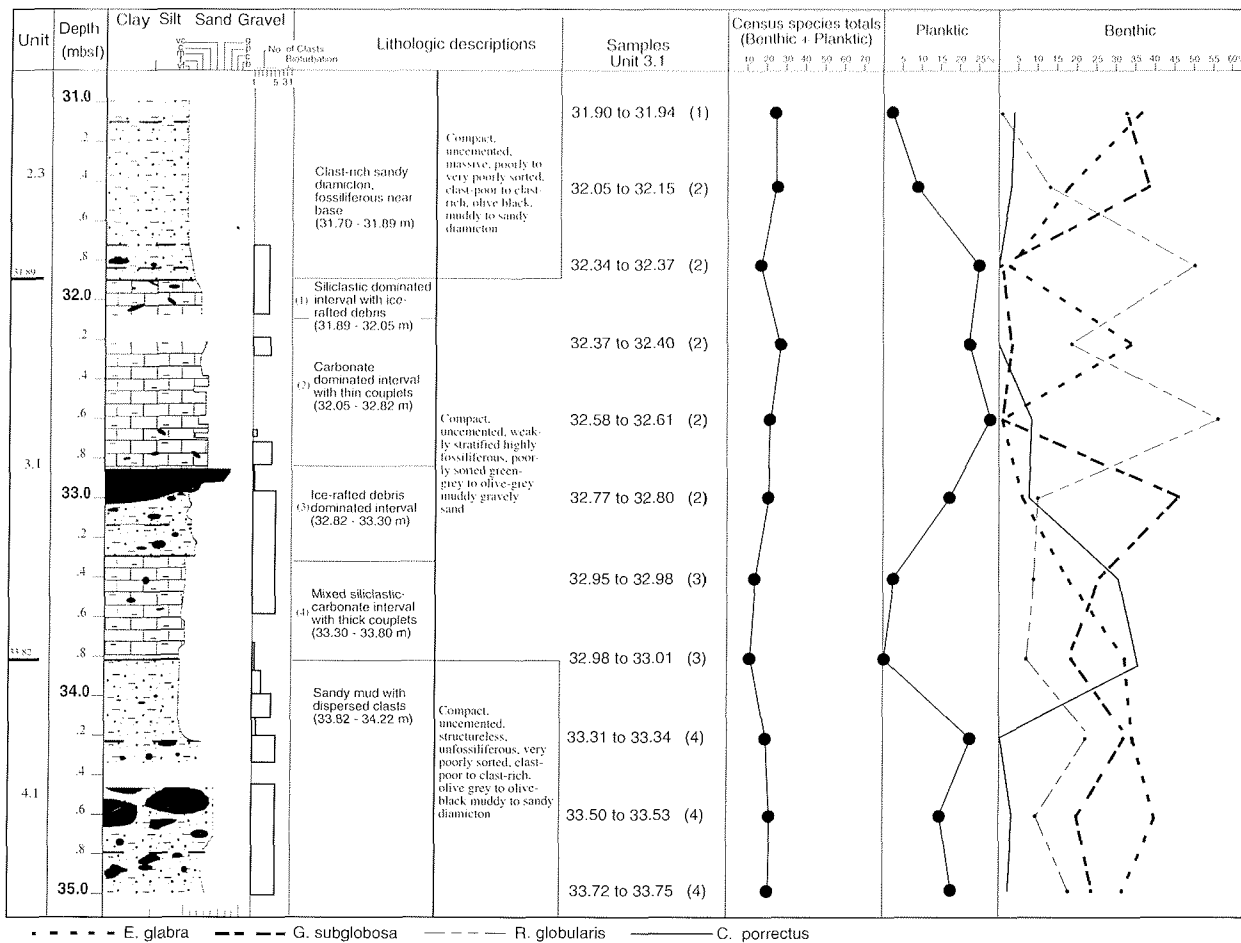
. - - - - E. glabra   — - — - G. subglobosa   — — — — R. globularis   —————— C. porrectus

Fig. 6 - Summary compilation of census data (175-700 random test counts) for eleven assemblages from Unit 3.1. Combined benthic and planktonic census data for nine assemblages (Unit 3.1, Subunits 1, 2 and 4) range between 20 and 26 species, indicating assemblage stability through much of Unit 3.1. Two assemblages from ice-rafted sediments (Unit 3.1, Subunit 3) near the centre of the unit (32.95 and 32.98 mbsf) are test –poor, provide lower census totals of 15 and 12 species respectively, and have suffered apparent *post-mortem* modificication. Planktonic tests (*Neogloboquadrina pachyderma*) constitute between 0 and 28% of assemblages. Note that *N. pachyderma* makes up 16% of the assemblage close to the Unit 4.1-Unit 3.1 contact (33.72 mbsf). This species is absent or rare in the ice-rafted interval between 32.82 - 33.30 mbsf. *N. pachyderma* peaks of 23 and 28% occur in the lower and upper carbonate units respectively; with the figure dropping to 2% (31.90 mbsf) close to the Unit 3.1 - Unit 2.3 contact. Relative abundance trends among benthic taxa and relationships to *N. pachyderma* trends are discussed in the text. Data derived from appendix 1.1 through 1.12.

subdivision of Unit 3.1 parallels the lithostratigraphy of the unit and closely resembles subdivisions derived from benthic and planktonic foraminifera.

The lowermost diatom-based subunit (33.15-33.82 mbsf) contains both planktonic and benthic diatoms and sea-ice diatoms are said to be extremely rare. Peak occurrences of *Neogloboquadrina pachyderma* confirm the existence of periods of normal salinity ice-free surface water, but large numbers of small ?juvenile tests suggest the possible presence of sea ice. It was suggested that on the basis of diatom content, that the lower part (carbonate-rich) of Unit 3.1 represents "warmer conditions" than during the deposition of the upper part (carbonate-rich) of Unit 3.1. Our foraminiferal data cannot be used to support a refute this interpretation.

A diatom-poor interval (32.82-33.15 mbsf) that coincides with clastic and ice-rafted sediments near the middle of Unit 3.1 also coincides with foraminiferal assemblages that are lower in total benthic diversity and contain few or no planktonic tests. Diluted surface salinities during ice melting, sediment rainout and decreased upper water mass salinity, and reduced nutrient productivity are

the likely cause. Depletion of the benthic foraminiferal community in the same sediments may also result from an increase in bottom current flow.

The uppermost of the three diatom-based assemblages ranges from 31.89-32.82 mbsf, includes both benthic and planktonic diatoms, and coincides with high diversity for planktonic and benthic foraminifera. The absence of sea ice and ice-edge diatom taxa is used to argue for "warmer" conditions at this stratigraphic level. Foraminiferal data from the upper part of Unit 3.1 (31.90 to 32.15 mbsf) point to a depletion of the planktonic component, coincident with the appearance of ice-rafted debris. This development is apparently not documented in diatom data.

UNIT 2.3

Recycled diatoms and foraminifera (Pliocene) characterize this unit and no convincing *in situ* Quaternary foraminifera are present. Freshwater diatoms in basal Unit 2.3 sediments (31.70 mbsf) support the argument based on benthic foraminifera that there was a shift from normal salinity to hyposalinity across the Unit 3.1-Unit 2.3

boundary. The lack of Quaternary benthic foraminifera in Unit 2.3 also lends supports to diatom-based arguments for ice proximal or sub-ice environments during the deposition of much of Unit 2.3. While the relatively sharp lithological boundary at about 31.89 mbsf represents a sudden lithofacies and biofacies shift, there is probably no significant hiatus at this level.

UNIT 2.2

Diatom data indicate a two-fold subdivision of Unit 2.2, into a lower marine assemblage between 29.49 and 25.53 mbsf, and an upper freshwater and brackish-water assemblage from 25.53 and 22.00 mbsf. This subdivision is also reflected in the foraminifera. *In situ* foraminiferal assemblages at 27.40-27.43, 26.95-26.96, and 26.89-26.94 mbsf are diverse species-wise and include taxa common to underlying Unit 3.1. Numbers of *Neogloboquadrina pachyderma* are low and reach a peak of only 4% in 26.89-26.94 mbsf. A high incidence of sea-ice diatoms between 26.95 and 28.10 mbsf, along with the low numbers of *N. pachyderma* provides support for the presence of sea-ice. The occurrence of abundant and little modified Pliocene foraminifera along with Oligocene and middle-upper Miocene diatoms indicates active ice rafting from a source beyond the immediate area during the deposition of Unit 2.2 (Webb & Strong, this volume).

Agglutinated foraminiferal assemblages at 25.40-25.43 mbsf occur with rich assemblages of freshwater and brackish-water diatoms. Low salinity marine environments close to melting ice fronts are preferred to diatom-based arguments for derivation of sediments containing non-marine diatoms from terrestrial sites.

UNIT 2.1

Low numbers of Quaternary and large numbers of recycled Pliocene foraminifera are present in three samples between 21.54-21.57 and 19.40-19.43 mbsf. Rare freshwater diatoms at 19.27 mbsf and a few agglutinated foraminifera at 19.40 mbsf may be remnants of the ice-proximal marine community of the Unit 2.1 diamicton.

UNIT 1.1

No *in situ* diatoms have been identified from this diamicton unit and it is uncertain whether the lone *Notorotalia profunda* is in place.

SUMMARY

Independent palaeoecological interpretations based on diatoms and foraminifera appear to be in agreement in almost all instances. This is significant in that the two microfossil groups have distinctly different size limits and might be expected to react quite differently to bottom current and water column processes. Both groups are critical in providing interpretations of sea-surface conditions and to estimations of proximity/distance to/from glacier and/or sea ice. While the record of both appears closely related to lithostratigraphy and lithofacies shifts, neither appears useful in separating perturbations of glacier and ice shelf positions resulting from possible eustatic effects through the Quaternary interval represented at CRP-1.

COMPARISON OF CRP-1 QUATERNARY ASSEMBLAGES WITH MODERN ASSEMBLAGES FROM WESTERN McMURDO SOUND

In an attempt to better comprehend the generic and specific composition, internal population dynamics, and palaeoecological usefulness of the CRP-1 Quaternary assemblages of foraminifera, we now review information provided by ecological studies in the same geographic region and in similar lithotopes (lithofacies) and water depths. We concentrate on two studies which document the biocoenosis (life assemblage) and thanatocoenosis (death assemblage) in the same sample. This exercise lends support to some of our palaeoecological interpretations, but also raises several intriguing questions. There are numerous studies of Quaternary and Holocene foraminifera from the Ross Sea region, but only Ward (1985; Ward et al., 1987) and Bernhard (1987) provide comprehensive data on live and dead populations/assemblages.

WESTERN SHELF

Ward (1985) studied surface samples from the western, southern and eastern coastlines of the McMurdo Sound region, in water depths ranging between 79 and 856 m. Over 39 000 tests were examined in the course of the study. On the average, only 6% of each assemblage were found to be living tests. Ward recognized three major assemblages, *i.e.*, the *Shallow Water Assemblage* (110-650 m), the *Harbor Assemblage* (79-796 m), and the *Deep Water Assemblage* (620-856 m). The Calcium Compensation Depth (CCD) in this region of the Ross Sea occurs at about 620 m. The CRP-1 Quaternary succession is situated between 150 and 193 m below present day sea level. The microfaunal content, geographic location, and bathymetry during high and low stands of sea level suggest Quaternary CRP-1 foraminifera are likely to have most in common with Ward's *Shallow Water Assemblage*. Comparisons were made between the census dataset developed from the eleven samples taken from Unit 3.1. and two of Ward's stations in southwestern McMurdo Sound, offshore and northeast of Blue Glacier (81-9, depth 213 m, pebbly sand substrate, and 81-10, depth 110 m, pebbly sand sponge mat substrate).

A census count of 753 (110 live and 643 dead) benthic tests from Ward's sample 81-9 provided a total of 26 live species (11 agglutinated and 15 calcareous; Ward, 1985). Percentage representation (based on relative abundance) for live agglutinated and calcareous species was 61.5% and 38.5% respectively. Dominance for leading live species was as follows (with dead test percentages in parentheses): *Trifarina earlandi* 18% (21%),

Portatrochammina antarctica 14% (16%), *Ehrenbergina glabra* 12% (12%), *Cassidulinoides porrectus* 8% (4%), *Cribrostomoides jeffreysii* 7% (9%), and *Globocassidulina crassa* 7% (7%).

A census count of 1927 (59 live and 1868 dead) benthic tests from Ward's 81-10 provided a total of 18 live species (11 agglutinated and 7 calcareous; Ward, 1985). Percentage representation (based on relative abundance) for live agglutinated and calcareous species was 35.8% and 64.2% respectively. Dominance for the principal live species was as follows (with dead test percentages in parentheses): *Ehrenbergina glabra* 22% (46%), *Reophax subdentaliniformis* 17% (0%), *Trifarina earlandi* 10% (6%), *Trochammina glabra* 7% (2%), *Fissurina marginata* 7% (0.3%), *Cribrostomoides jeffreysii* 5% (4%), *Fissurina tingellifera* 5% (1%) and *Pullenia subcarinata* 5% (0.4%).

Important distinctions are apparent between the modern McMurdo Sound and CRP-1 foraminiferal datasets. In CRP-1, assemblages with agglutinated taxa are only encountered in environments interpreted to be close to or below glacier or shelf ice (*e.g.* Units 4.1 and 2.2) and in these the number of species is very small. Agglutinated taxa are absent from Unit 3.1. One explanation might be that in Unit 3.1 all agglutinated taxa in all samples have been destroyed by physical and/or chemical processes. Based on Ward's data for 81-9 and 81-10, this could mean that the number of tests in the original Unit 3.1 assemblages have been depleted by ~38% to ~62%. It is curious, however, why at least a few agglutinated tests have not survived, if indeed present in the original life assemblage. Other potential explanations are that:

1) the Roberts Ridge shell bank environments were covered by carbonate-saturated, slightly hypersaline waters that strongly favoured calcareous benthic taxa,
2) that there was insufficient detrital sand and silt to sustain agglutinated foraminifera,
3) that they could not tolerate a shelly substratum,
4) that they were excluded by competition with calcareous foraminifera,
5) that they were destroyed by mudline burrowing, or
6) that they did not survive laboratory processing procedures.

Note, however, that even with the total removal of a sizeable agglutinated component the ratio among the calcareous benthic taxa remains the same, although the percentage dominance value is significantly increased.

A further interesting point to emerge from consideration of Ward's data is the percentage dominance shifts for live and dead tests of the same species and in the same sample. For the more dominant species this entails a depletion or enhancement of one to five percent. However, note that in Ward's sample 81-10, the live to dead count for *Ehrenbergina glabra* is elevated twenty four percent, from 22% to 46%. The percentage representation for the primary and even secondary dominant species in the CRP-1 assemblage suite from Unit 3.1 are generally in the region of 20 to 35% and in a few instances are significantly higher.

Perhaps most striking, is the contrast in species diversity between the living and dead components of each sample. Ward's sample 81-9 contains 26 and 44 living and dead species respectively; and 81-10 contains 18 and 70 living and dead species respectively. This marked contrast emphasizes the difference between a living population that represents a moment in time *versus* an assemblage from a short interval of core that might represent decades, centuries or even millenia.

Natural population variability over time, perhaps influenced by subtle micro-habitat and environmental changes, and coupled with the *post-mortem* physical and chemical phenomena, probably determined some of the differences noted here between the modern and fossil datasets. We must pose the question, however, as to whether, despite the gross systematic similarity between our dataset and that presented in Ward's study, there might be an as yet unexplained and fundamental differences between present day and Quaternary biotopes.

RELATIONSHIPS BETWEEN
ASSEMBLAGE COMPOSITION AND
STRUCTURE TO DIVERSE SUBSTRATES

The generic and specific composition and internal structure of benthic foraminiferal populations are known to be strongly influenced by the nature of the seafloor substrate upon which and within which they live. The sediment composition and texture present in the CRP-1 Quaternary succession includes muddy-sandy diamicton, sand, sand-granule-cobble-shell, shell, and shell-sponge lithologies.

A study of live foraminiferal biotopes in water depths of 2 to 27 m at New Harbor, southwestern McMurdo Sound, is pertinent to the present study (Bernhard, 1987). Although concentrating on the ecological impact of substrates, Bernhard also considers other significant factors, such as depth, distance from shore, sea floor gradients, sediment grain size, associated fauna, influx of terrestrial meltwater, and the oxygen content of bottom waters, etc. Even though water depths are much shallower at New Harbor than is interpreted to have existed at CRP-1 during the Quaternary, many of the calcareous benthic species are common to both settings. Bernhard's study examined seven micro-environments, *i.e.*, sponge mat, sediments below sponge mats, sediments adjacent to glacial erratic boulders, sediments with anchor ice, shallow water sediments lacking anchor ice, and seasonally anoxic basin sediments. Biotope characteristics were assembled for each micro-environment. Tests for geographic patchiness within surface biotopes established that except for *Cassididulinoides porrectus* and *Portatrochammina antarctica*, all species appeared to be distributed homogeneously.

The percentage of live foram tests in the six sediment categories ranged up to 40%, and up to 60% in the case of anchor ice communities. This is significantly higher figure than presented by Ward (1985) for deeper waters in western McMurdo Sound. As in Ward's study, Bernhard found agglutinated test numbers to be a very significant part of most populations, *e.g.*, erratic boulder fields (20%),

open deep water (54%), sponge mats (45%), sediments below sponge mats (70%), shallow water (54%) and anchor ice (70%). More than sixty species of agglutinated and calcareous benthic foraminifera were recovered from all biotopes combined.

Bernhard noted that some species are restricted to specific biotopes. For example,

Ehrenbergina glabra, Fursenkoina earlandi, Pseudobulimna chapmani, Astrononion echolsi and other species also encountered in CRP-1 (Unit 3.1) occur only in the deeper water biotope at New Harbor. *Planispirinoides bucculentus*, a relatively common and very large species in the carbonate facies of CRP-1 (Unit 3.1), occurs only in sponge mats and in sediments beneath them. *Cassidulinoides porrectus* and *Miliammina arenacea*, occur most commonly in deeper offshore water on finer grained clastic bottoms.

Total test abundances (live + dead) also varied by microhabitat, being greatest in the boulder and sub-sponge mat biotopes. Bernhard noted that environmental stability varied in the different biotopes and microenvironments, reflecting the effects of a variety of physical, chemical, and biological disturbances. The sub-sponge mat biotope has the highest live+dead abundances, probably because of the protection afforded by the overlying sponge mat. The sponge mat biotope is the only one of the seven microenvironments predominantly composed of calcareous species. The range of surface lithotopes (lithofacies) and the associated variation of assemblage composition and internal relative abundance structure documented in the New Harbor study helps explain some of the assemblage variability recognized in the quite similar lithofacies at CRP-1.

The range of lithotopes (lithofacies) and the associated variation of assemblage composition and internal relative abundance documented in the New Harbor study helps explain some of the assemblage variability recognized in the quite similar lithofacies at CRP-1. Sponge mat lenses or beds are not present at CRP-1 although sponge spicules are quite common at some levels of Units 3.1 and 2.2. It is possible that abundant shell and shell-hash beds in Unit 3.1 afforded a similarly protective microhabitat to that of a sponge mat. We note that the CRP-1 shell beds also contain very large assemblages of foraminifera and include common and very large tests of *Pyrgo, Planispirinoides, Triloculina, Cruciloculina, Pyrgoella*, and *Sigmoilina*.

SYNTHESIS AND CONCLUSIONS

1) From an examination of foraminifera, it is suggested that Units 4.1, 3.1, and 2.2 are marine. Units 2.3 and 2.1, and 1.1 are also likely to have been deposited below sea level.

2) There exists a close relationship between lithofacies and the *in situ* foraminiferal biotopes. This is useful in the recognition of discreet glacial environments and gradations between these environments. Although we favor dynamic glacier and/or ice shelf advances and recession (and associated grounding and ungrounding)

in a coastal and basin margin setting as the prime controlling mechanism, we cannot exclude the potential for eustatic oscillations to produce some of the vertical (or stratigraphic) biofacies shifts observed.

3) Assemblage trends in the uppermost levels of Units 4.1, 3.1 and 2.2, such as decrease in abundance of planktonic specimens and replacement of calcareous benthic by agglutinated assemblages, are interpreted as evidence for gradual ice advance, creation of a hyposaline water column, possible elevation of the calcium carbonate compensation depth, and increased water column turbidity due to ice rafting.

4) The sudden appearance of large calcareous assemblages, including the planktonic *Neogloboquadrina pachyderma,* immediately above base of Units 3.1 and 2.2 is taken to indicate relatively rapid retreat and possible ungrounding of glacier or shelf ice and an equally rapid return to a normal marine water column.

5) Detailed characterization of the dominant taxa in eleven assemblages distributed through the 1.93 m-thick Unit 3.1 demonstrates a meaningful relationship between the relative abundance of certain benthic taxa, variations in the sedimentary character of the substratum, and the incidence of ice-rafted debris. We also observe a relationship between the relative abundance of planktonic *N. pachyderma* and certain benthic taxa. This is interpreted as indicating high frequency changes of sea surface states, such as the presence or absence of sea ice and subtle variations in the volume of biotic and non-biotic particles transported through a ~150 m-thick water column to the sea floor.

6) All observed assemblage shifts noted for the foraminifera can be explained without invoking major changes of ocean water temperature over Roberts Ridge. A relatively simple and perhaps local glacial-deglacial model seems more appropriate to a more extreme glaciation-interglaciation model, that requires small but significant elevation of ocean water temperature over wide areas of the Ross Sea and Southern Ocean. With the exception of an anomalous and possibly recycled occurrence of the New Zealand late Neogene age *Notorotalia profunda* at 8.5 mbsf in Unit 1.1, we see no evidence in the Quaternary of CRP-1 for the penetration of "warm" water immigrants from the north.

7) Both benthic and planktonic foraminifera and planktonic diatoms exhibit basically similar patterns of presence, absence, peak abundance, and assemblage relationships to specific lithofacies. There is also a general concurrence in the palaeoenvironmental analyses proposed for these two groups.

8) At this time the Quaternary foraminifera of CRP-1 cannot be used biostratigraphically to advance subdivision of the Quaternary as they closely resemble modern living assemblages. Large tests of miliolids (Family Miliolidae) from Unit 3.1 (32.05-32.15 mbsf) were used as a carbonate source for amino acid racemization-based geochronology and provided an age in the range of 210 to 430 k.y. (Hart & Webb, this

volume). A similar narrow range of D/L ratios and deduced ages were obtained from bivalve carbonate from several levels within Unit 3.1. These indicate that macro-and microfossils are the same age, and also that the benthic biota is almost certainly the same age as the deposition of Unit 3.1.

9) Patterns of change in foraminiferal assemblages both within and between the lower five lithogical units suggest a close temporal relationship. Boundaries between units may, therefore, represent little loss of record through prolonged ice grounding, or non-deposition. This entire multi-unit sedimentary succession may, therefore, have been deposited in a relatively short period of time.

10) Recycled Pliocene foraminifera are particularly common in Units 3.1 and 2.2 and are associated with ice-rafted sediments (Webb & Strong, this volume). We suggest that this microfaunal element was not derived from exposures on Roberts Ridge, but was transported from coastal or Transantarctic Mountain trunk valley palaeofjord sites.

ACKNOWLEDGEMENTS

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Appendix 1 - Census count data for Lithostratigraphic Unit 3.1 and Unit 2.2. See summary graphic compilations of these data in figures 2 through 6.

Appendix 1.1 - Cenus data for Unit 3.1 (33.72 to 33.75 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. Ehrenbergina glabra	124	24.70 (29.45)	24.70
2. Globocassidulina subglobosa	092	18.32 (21.85)	43.02
3. Neogloboquadrina pachyderma	081	16.13	59.15
4. Rosalina globularis	075	14.94 (17.81)	74.09
5. Trifarina earlandi	039	07.76	81.85
6. Sigmoilina umbonata	024	04.78	86.63
7. Cibicides lobatulus	014	02.78	89.41
8. Nonionella iridea	007	01.39	90.80
9. Cassidulinoides porrectus	007	01.39	92.19
10. Cassidulinoides parkerianus	006	01.19	93.38
11. Heronallenia kempi	005	00.99	94.37
12. Patellina corrugata	005	00.99	95.36
13. Triloculina spp.	005	00.99	96.35
14. Epistominella exigua	004	00.79	97.05
15. Cribroelphidium incertum	003	00.59	97.64
16. Pseudobulimina chapmani	003	00.59	98.23
17. Fissurina spp.	003	00.59	98.82
18. Pullenia subcarinata	002	00.39	99.21
19. Cornuspira involvens	001	00.19	99.40
20. Fursenkoina earlandi	001	00.19	99.59
21. Cibicides refulgens	001	00.19	99.78
Total	502	99.78	99.78

Appendix 1.3 - Census data for Unit 3.1 (33.31 to 33.34 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. Ehrenbergina glabra	139	24.95 (32.55)	24.95
2. Globocassidulina subglobosa	135	24.23 (31.61)	49.18
3. Neogloboquadrina pachyderma	130	23.33	72.51
4. Rosalina globularis	083	14.90 (19.43)	87.41
5. Sigmoilina umbonata	021	03.77	91.18
6. Patellina corrugata	010	01.79	92.97
7. Epistominella exigua	006	01.07	94.04
8. Fissurina spp.	006	01.07	95.11
9. Cribroelphidium incertum	004	00.71	95.82
10. Trifarina earlandi	004	00.71	96.53
11. Cassidulinoides parkerianus	003	00.53	97.06
12. Triloculina spp.	002	00.35	97.41
13. Cibicides refulgens	002	00.35	97.76
14. Cibicides lobatulus	002	00.35	98.11
15. Nonionella iridea	002	00.35	98.46
16. Heronallenia kempi	002	00.35	98.81
17. Pseudobulimina chapmani	002	00.35	99.16
18. Pullenia subcarinata	002	00.35	99.51
19. Planispirinoides bucculentus	001	00.17	99.68
20. Oolina sp.	001	00.17	99.85
Total	557	99.85	99.85

Appendix 1.2 - Census data for Unit 3.1 (33.50 – 33.53 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. Ehrenbergina glabra	172	31.44 (36.90)	31.44
2. Globocassidulina subglobosa	088	16.08 (18.88)	47.52
3. Neogloboquadrina pachyderma	081	14.80	62.32
4. Trifarina earlandi	045	08.22 (9.65)	70.54
5. Rosalina globularis	041	07.49	78.03
6. Sigmoilina umbonata	031	05.66	83.69
7. Cibicides lobatulus	024	04.38	88.07
8. Cassidulinoides porrectus	017	03.10	91.17
9. Fissurina spp.	011	02.01	93.18
10. Oolina spp.	008	01.46	94.64
11. Patellina corrugata	004	00.73	95.37
12. Nonionella iridea	004	00.73	96.10
13. Pullenia subcarinata	004	00.73	96.83
14. Cassidulinoides parkerianus	003	00.54	97.37
15. Cibicides refulgens	003	00.54	97.91
16. Astrononion antarcticum	003	00.54	98.45
17. Heronallenia kempi	002	00.36	98.81
18. Pseudobulimina chapmani	002	00.36	99.17
19. Planispirinoides bucculentus	001	00.18	99.35
20. Pyrgoella sphaera	001	00.18	99.53
21. Glandulina antarctica	001	00.18	99.71
22. Fursenkoina earlandi	001	00.18	99.89
Total	547	99.89	99.89

Appendix 1.4 - Census data for Unit 3.1 (32.98 – 33.01 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	057	32.57	32.57
2. Ehrenbergina glabra	055	31.42	67.99
3. Globocassidulina subglobosa	030	17.14	81.13
4. Rosalina globularis	013	07.42	88.55
5. Fissurina spp.	007	04.00	92.55
6. Epistominella exigua	003	01.71	94.26
7. Astrononion antarcticum	003	01.71	95.97
8. Cassidulinoides parkerianus	002	01.14	97.11
9. Pullenia subcarinata	002	01.14	98.25
10. Oolina sp.	001	00.57	98.82
11. Patellina corrugata	001	00.57	99.39
12. Nonionella iridea	001	00.57	99.96
Total	175	99.96	99.96

Appendix 1.5 - Census data for Unit 3.1 (32.95-32.98 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	084	27.63 (28.00)	27.63
2. Globocassidulina subglobosa	079	25.98 (26.33)	53.61
3. Ehrenbergina glabra	049	16.11 (16.33)	69.72
4. Rosalina globularis	027	08.88	78.60
5. Epistominella exigua	024	07.89	86.49
6. Astrononion antarcticum	013	04.27	90.76
7. Cassidulinoides parkerianus	007	02.30	93.06
8. Pseudobulimina chapmani	005	01.64	94.70
9. Neogloboquadrina pachyderma	004	01.31	96.01
10. Fissurina spp.	003	00.98	96.99
11. Globocassidulina crassa	003	00.98	97.97
12. Patellina corrugata	002	00.65	98.62
13. Pullenia subcarinata	002	00.65	99.27
14. Pyrgo depressa	001	00.32	99.59
15. Nonionella iridea	001	00.32	99.91
Total	304	99.91	99.91

Appendix 1.7 - Census data for Unit 3.1 (32.58-32.61 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. Rosalina globularis	212	40.76 (56.38)	40.76
2. Neogloboquadrina pachyderma	144	27.69	68.45
3. Patellina corrugata	039	07.50 (10.37)	75.95
4. Cassidulinoides porrectus	021	04.03 (05.58)	79.98
5. Fissurina spp.	017	03.26	83.24
6. Epistominella exigua	015	02.88	86.12
7. Nonionella iridea	010	01.92	88.04
8. Oolina spp.	009	01.73	89.77
9. Cyclogyra involvens	008	01.53	91.30
10. Triloculina spp.	008	01.53	92.83
11. Ehrenbergina glabra	008	01.53	94.36
12. Globocassidulina subglobosa	007	01.34	95.70
13. Cibicides lobatulus	005	00.96	96.66
14. Glomospira	004	00.76	97.42
15. Pseudobulimina chapmani	003	00.57	97.99
16. Schackoinella antarctica	002	00.38	98.37
17. Bolivina earlandi	002	00.38	98.75
18. Cassidulinoides parkerianus	002	00.38	99.13
19. Spiroloculina sp.	001	00.19	99.32
20. Entolingulina biloculi	001	00.19	99.51
21. Heronallenia earlandi	001	00.19	99.70
22. Astrononion antarcticum	001	00.19	99.89
Total	520	99.89	99.89

Appendix 1.6 - Census data for Unit 3.1 (32.77-32.80 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. Globocassulina subglobosa	135	36.58 (43.54)	36.58
2. Neogloboquadrina pachyderma	059	15.98	52.56
3. Cribroelphidium incertum	030	08.13 (9.67)	60.69
4. Rosalina globularis	030	08.13 (9.67)	68.82
5. Cassidulinoides porrectus	020	05.42	74.24
6. Ehrenbergina glabra	018	04.87	79.11
7. Cassidulinoides parkerianus	016	04.33	83.44
8. Oolina spp.	008	02.16	85.60
9. Cibicides lobatulus	007	01.89	87.49
10. Epistominella exigua	007	01.89	89.38
11. Triloculina spp.	007	01.89	91.27
12. Patellina corrugata	006	01.62	92.89
13. Pseudobulimina chapmani	005	01.35	94.24
14. Trifarina earlandi	005	01.35	95.59
15. Nonionella iridea	004	01.08	96.67
16. Cyclogyra involvens	003	00.81	97.48
17. Sigmoilina umbonata	002	00.54	98.02
18. Pyrgoella sphaera	002	00.54	98.56
19. Fissurina spp.	002	00.54	99.10
20. Eponides sp.	002	0.54	99.64
21. Pyrgo patagonica	001	0.27	99.91
Total	369	99.91	99.91

Appendix 1.8 - Census data for Unit 3.1 (32.37 to 32.40 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. Ehrenbergina glabra	100	26.24 (34.01)	26.24
2. Neogloboquadrina pachyderma	087	22.83	49.07
3. Rosalina globularis	054	14.17 (18.36)	63.24
4. Cibicides lobatulus	019	04.98 (06.46)	68.22
5. Cyclogyra involvens	017	04.46	72.68
6. Patellina corrugata	015	03.93	76.61
7. Pseudobulimina chapmani	014	03.67	80.28
8. Globocassidulina subglobosa	013	03.41	83.69
9. Oolina spp.	013	03.41	87.10
10. Trifarina earlandi	010	02.62	89.92
11. Triloculina spp	007	01.83	91.55
12. Sigmoilina umbonata	005	01.31	92.86
13. Nonionella iridea	005	01.31	94.17
14. Epistominella exigua	004	01.04	95.21
15. Planispirinoides bucculentus	003	00.78	95.99
16. "Anomalina" sp.	003	00.78	96.77
17. Fissurina spp.	002	00.52	97.29
18. Astrononion ?echolsi	002	00.52	97.81
19. Pyrgo depressa	001	00.26	98.07
20. Pyrgo patagonica	001	00.26	98.33
21. Pyrgoella sphaera	001	00.26	98.59
22. Lenticulina gibba	001	00.26	98.85
23. Glandulina antarctica	001	00.26	99.11
24. Heronallenia kempi	001	00.26	99.37
25. Globocassidulina crassa	001	00.26	99.63
26. Cassidulinoides parkerianus	001	00.26	99.89
Total	381	99.89	99.89

Appendix 1.9 - Census data for Unit 3.1 (32.34-32.37 mbsf). Figures shown on parentheses denote percentages based on the tally for the three most dominant benthic taxa.

	Genus/species	Total Count	Percentage Dominance	Cumulative Percentage
1.	Rosalina globularis	110	37.54 (50.00)	37.54
2.	Neogloboquadrina pachyderma	073	24.91	62.45
3.	Epistominella exigua	048	16.38 (21.81)	78.83
4.	Patellina corrugata	023	07.84 (10.54)	86.67
5.	Ehrenbergina glabra	008	02.73	89.40
6.	Nonionella iridea	008	02.73	92.13
7.	Glomospira sp.	007	02.38	94.51
8.	Fissurina spp	005	01.70	96.21
9.	Cyclogyra involvens	002	00.68	96.89
10.	Trifarina earlandi	002	00.68	97.57
11.	Triloculina sp.	001	00.34	97.91
12.	Oolina sp	001	00.34	98.25
13.	Cassidulinoides porrectus	001	00.34	98.59
14.	Cibicides lobatulus	001	00.34	98.93
15.	Fursenkoina earlandi	001	00.34	99.27
16.	Globocassidulina subglobosa	001	00.34	99.61
17.	Astrononion antarcticum	001	00.34	99.95
	Total	293	99.95	99.95

Appendix 1.11 - Census data for Unit 3.1 (31.90-31.93 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.	Ehrenbergina glabra	160	35.47 (36.19)	35.47
2.	Globocassidulina subglobosa	144	31.92 (32.57)	67.39
3.	Trifarina earlandi	028	06.20 (06.33)	73.59
4.	Sigmoilina umbonata	023	05.09	78.68
5.	Cassidulinoides porrectus	019	04.21	82.89
6.	Oolina spp.	014	03.10	85.99
7.	Neogloboquadrina pachyderma	009	01.99	87.98
8.	Rosalina globularis	009	01.99	89.97
9.	Triloculina sp.	007	01.55	91.52
10.	Cribroelphidium incertum	005	01.10	92.62
11.	Pseudobulimina chapmani	004	00.88	93.50
12.	Cibicides lobatulus	004	00.88	94.38
13.	Pullenia subcarinata	004	00.88	95.26
14.	Patellina corrugata	004	00.88	96.14
15.	Cyclogyra involvens	003	00.66	96.80
16.	Pyrgo depressa	003	00.66	97.46
17.	Globocassidulina crassa	003	00.66	98.12
18.	Cibicides refulgens	002	00.44	98.56
19.	Nonionella iridea	001	00.22	98.78
20.	Cassidulinoides parkerianus	001	00.22	99.00
21.	Lenticulina gibba	001	00.22	99.22
22.	Heronallenia kempi	001	00.22	99.44
23.	Epistominella exigua	001	00.22	99.66
24.	Spirillina tuberculata	001	00.22	99.88
	Total	451	99.88	99.88

Appendix 1.10 - Census data for Unit 3.1 (32.05 to 32.15 mbsf). Figures shown in parentheses denote percentages based on the tally for the three most dominant benthic taxa.

	Genus/Species	Total Count	Percentage Dominance	Cumulativep Percentage
1.	Globocassidilina subglobosa	239	33.42 (36.99)	33.42
2.	Ehrenbergina glabra	103	14.40 (15.94)	47.82
3.	Rosalina globularis	087	12.16 (13.46)	59.98
4.	Neogloboquadrina pachyderma	069	09.54	69.63
5.	Trifarina earlandi	053	07.41	77.04
6.	Cassidulinoides porrectus	026	03.63	80.67
7.	Nonionella iridea	019	02.65	83.32
8.	Heronallenia kempi	015	02.09	85.41
9.	Triloculina spp.	011	01.53	86.94
10.	Sigmoilina umbonata	011	01.53	88.47
11.	Patellina corrugata	010	01.39	89.86
12.	Pullenia subcarinata	009	01.25	91.11
13	Cassidulinoides parkerianus	008	01.11	92.22
14.	Globocassidulina crassa	008	01.11	93.33
15.	Fissurina spp.	008	01.11	94.44
16.	Cribroelphidium incertum	007	00.97	95.41
17.	Fursenkoinina earlandi	006	00.83	96.24
18.	Pseudobulimina chapmani	006	00.83	97.07
19.	Epistominella exigua	005	00.69	97.76
20.	Cibicides lobatulus	005	00.69	98.45
21.	Pyrgo depressa	003	00.41	98.86
22.	Pyrgo patagonica	002	00.27	99.13
23.	Cyclogyra involvens	002	00.27	99.40
24.	Oolina spp.	002	00.27	99.67
25.	Astrononion antarcticum	001	00.13	99.80
	Total	715	99.80	99.80

Appendix 1.12 - Census data for Unit 2.2 (26.89 to 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.	Globocassidulina subglobosa	123	34.64 (35.86)	34.64
2.	Ehrenbergina glabra	096	27.04 (27.98)	61.68
3.	Cassidulinoides porrectus	051	14.26 (14.86)	76.04
4.	Globocassidulina crassa	015	04.22	80.26
5.	Trifarina earlandi	013	03.66	83.92
6.	Neogloboquadrina pachyderma	012	03.38	87.30
7.	Oolina spp.	006	01.69	88.99
8.	Rosalina globularis	005	01.40	90.39
9.	Heronallenia kempi	004	01.12	91.55
10.	Triloculina spp.	003	00.84	92.35
11.	Lagena spp	003	00.84	93.19
12.	Cyclogyra involvens	003	00.94	94.03
13.	Epistominella exigua	003	00.84	94.87
14.	Nonionella iridea	003	00.84	95.71
15.	Pullenia subcarinata	003	00.84	96.55
16.	Cassidulinoides parkerianus	003	00.84	97.39
17.	Fissurina spp.	002	00.56	97.95
18.	Cibicides refulgens	002	00.56	98.51
19.	Glandulina antarctica	001	00.28	98.79
20.	Patellina corrugata	001	00.28	99.07
21.	Cibicides lobatulus	001	00.28	99.35
22.	Astrononion antarcticum	001	00.28	99.63
23.	Cribroelphidium incertum	001	00.28	99.91
	Total	355	99.91	99.91