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Biogenic Quaternary Carbonates in the CRP-1 Drillhole, Victoria Land Basin, Antarctica

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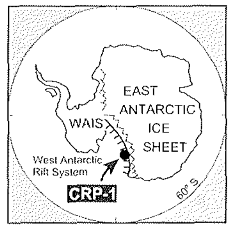

Abstract - A carbonate-rich sedimentary unit was encountered between 33.82 and 31.89 metres below sea floor (mbsf) in CRP-1 core, Cape Roberts, Victoria Land Basin. The unit is dominated by shells of benthic organisms including bryozoa, mollusca and foraminifera, which represent a typical high-latitude *bryomol* assemblage. An *echinofor* assemblage occurs in association with a coarse ice-rafted debris layer. The carbonate-rich unit is inferred to represent bank-type sedimentation occurring under summer open-marine conditions at depths >100 m. Muddy beds are interpreted as fair-weather deposits, whereas shell-hash packstones are interpreted as storm lags. Carbonate deposition was occasionally interrupted by brief episodes of detrital deposition, presumably by ice-rafting. The carbonate unit represents a terrigenous sediment starvation under open marine conditions in the McMurdo embayment during the middle Pleistocene.

INTRODUCTION

A 2m-thick carbonate-rich unit of middle Pleistocene age was unexpectedly recovered in CRP-1, Cape Roberts, Victoria Land Basin (Unit 3.1: Cape Roberts Science Team, 1998c; Fig. 1). The interval contains up to 80% of carbonate. Carbonate grains within the unit are entirely skeletal, consisting of whole and fragmented shells, branches and tests, admixed with varying proportions of diatoms and sponge spicules, and minor terrigenous sediment (Fig. 2).

This sedimentary unit is significant in the context of growing interest in cold water carbonates (*e.g.*, Henrich et al., 1992; James et al., 1992; Boreen & James, 1993; Taviani et al., 1993; Rao & Jayawardane, 1994; Rao et al., 1995; Henrich et al., 1995; Schäfer et al., 1996; James & Clarke, 1997; Freiwald, 1998). Moreover, carbonate sediments are scarce in the Neogene record of Antarctica in general, and high-latitude biogenic carbonates have a strong potential to yield palaeoclimatic information (*e.g.*, Ramm, 1989; Freiwald et al., 1991; Taviani et al., 1993; Taviani & Anderson, 1995; Domack et al., 1995). Therefore, the carbonate unit in the CRP-1 drillhole represents a unique archive of Antarctic nearshore conditions during a time-slice (middle Pleistocene) for which no other data are available. Similar biogenic sediments are known only from younger deposits exposed onshore (*e.g.*, Hendy et al., 1969; Ward & Webb, 1986) or cored offshore (*e.g.*, Domack, 1988; Taviani et al., 1993; Taviani & Anderson, 1995).

The carbonate-rich unit occurs between 33.82 and 31.89 metres below sea floor (mbsf) and is bounded by sharp contacts with predominantly glacimarine sediments of terrigenous derivation (Cape Roberts Science Team, 1998b).

METHODS

Ten undisturbed bulk samples were inspected under a binocular microscope and their microfacies, fabric and major biogenic components described. Samples were then wet-sieved at 63 µm, 500 µm and 1 mm, and the resulting fractions were similarly described (see Tab. 3 in Cape Roberts Science Team, 1998b). Six samples were pre-impregnated using a mixture of acetone and metal resin. These were then vacuum-impregnated with a two-component epoxy. Standard thin sections were then prepared.

CARBONATE COMPONENTS

The carbonate-rich sediments range from skeletal hashes to sandy muds. Bryozoan skeletal debris predominates over other bioclastic components and includes mollusca, foraminifera, polychaetes, echinoids, octocorals and ostracods. Carbonate sediment producers mainly belong to benthic biota (Taviani et al., this volume; Webb & Strong, this volume), while calcareous planktic components are strongly subordinate. The muddy fraction is mostly terrigenous but contains minor amount of skeletal-derived mud amongst which are some remarkable calcareous thoracosphaerid nannofossils (Villa & Wise, this volume).

Bryozoa are important skeletal sediment producers and commonly give rise to the *bryomol* (BRYOzoa and MOLlusca) assemblage which is characteristic of cool-water shelves (Nelson et al., 1988; Hayton et al., 1995; Schäfer et al., 1996). Modern examples include temperate-cool shelves of southern Australia (James et al., 1992; Boreen & James, 1993; Bone & James, 1993), Tasmania

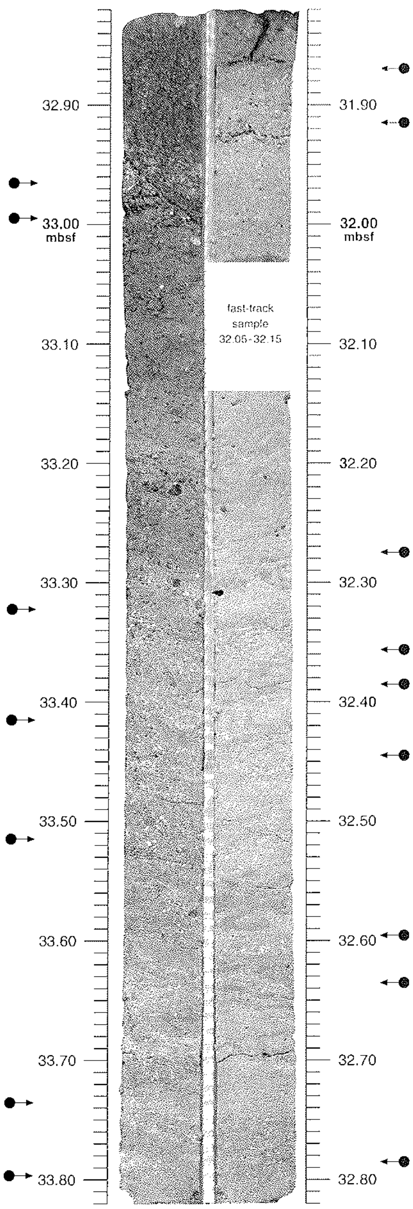

Fig. 1 - Photographic log of the carbonate-rich unit, from 31.89 to 33.82 mbsf. Arrows point to the position of the samples investigated.

(Rao & Jayarwardane, 1994), New Zealand (Nelson et al., 1988), Antarctica (Taviani et al., 1993; Rao et al., 1995), Rockall Bank in the northeastern Atlantic (Wilson, 1979) and the central Greenland Sea (Henrich et al., 1992). Zoarial forms are dominated by robust cellariniforms and cellariforms. Encrusting forms are subordinate, reflecting the paucity of suitable substrata (large shells, pebbles and hard bottoms). The analysis of the carbonate-rich unit has distinguished four main intervals (Fig. 3).

The basal unit between 33.82-33.30 mbsf is a greenish grey mixed siliciclastic-carbonate sediment with 10-40% biogenic content. The terrigenous fraction includes silt and fine-to-very fine polymictic sand; some granules and small pebbles are present throughout this interval, and their frequency increases upwards. The biogenic sandy-fraction includes bioclasts/biosomes derived from bryozoa, foraminifera, octocorals, gastropods, bivalves, sponge (spicules), scalpellid barnacles and echinoids. The contact with the underlying diamicton is sharp.

The base of the interval is a thin-bedded alternation of coarse bioclast-rich and fine bioclast-poor layers (Fig. 4). This vertical arrangement becomes less evident in the upper part, where layering is poorly defined. Elongated fragments of bryozoa and octocorals commonly show imbrication and preferred orientation within the coarse layers.

The interval between 33.30-32.82 mbsf records a decrease in carbonate content (to 10-15%). The colour darkens rapidly to become olive black at the very top. This interval shows an increase in outsized clasts which are interpreted as ice-rafted debris (IRD) culminating at 32.90 mbsf in the deposition of a predominantly polymictic, poorly sorted layer with cobbles up to 20 cm in diameter (Fig. 5). A pocket of coarse-grained, mixed terrigenous-carbonate sediment is evident at the base of a large dolerite cobble at 32.95 mbsf. The bioclastic component mostly comprises echinoid spines (*Sterechinus*) and coarse platy bivalve fragments (*Adamussium* sp.). This skeletal assemblage differs from that above and below, and represents an *echinofor* (ECHINOids and FORaminifera) assemblage, *sensu* Hayton et al. (1995). The coarse bioclastic fraction is concentrated directly below the dolerite clast; the interval appears to be massive and shows no evidence of layering.

Above the ice-rafted layer, in the interval between 32.82-31.95 mbsf, carbonate concentrations increase to 70% or more. The main biogenic components in this interval are bryozoa, foraminifera, bivalves, gastropods, octocorals, echinoids, sponge spicules, ostracods and polychaete tubes. Some bryozoa appear to be preserved in growth position (*e.g.* at 32.50 mbsf, Fig. 6). The terrigenous matrix is represented by silt and fine-to-very-fine sand with minor dolerite and volcanic granules.

This interval displays a well-developed centimetre-scale bedding of bioclast-rich beds separated by thin (millimetre) bioclast-poor lamellae. The coarse bioclastic layers show preferred orientation of elongated bioclasts (generally bryozoa and octocorals) and an imbricated fabric, and in places contain small clay chips. The contact between coarse and fine-grained layers is commonly sharp, but no evidence of erosive or scoured surfaces is recognizable.

The interval between 31.95-31.89 mbsf shows a decrease in the carbonate fraction and a greater admixture of ice-rafted detritus. The biogenic component is represented by foraminifera, bryozoa, echinoids, octocorals, gastropods and bivalves. The terrigenous component is dominantly poorly sorted silt and fine sand with small dolerite pebbles and granules.

FACIES ANALYSIS

Two main sedimentary facies are distinguishable on the basis of overall composition, the relative proportions of terrigenous and biogenic components, sedimentary structures and fabric.

Facies A is represented by alternations of mm-to-cm-thick, medium- to coarse-grained bioclastic layers (packstones) and mm-to-cm-thick muddy layers. Bioclastic

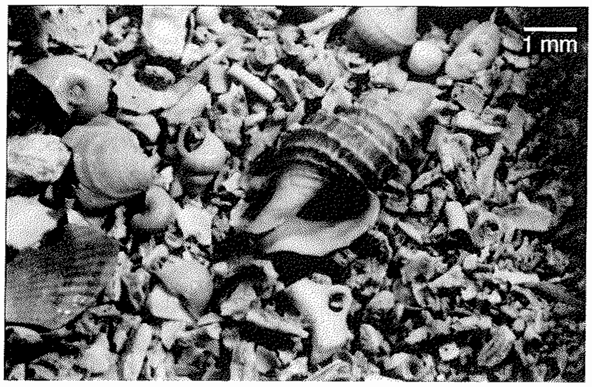

Fig. 2 - Examples of *bryomol* skeletal assemblages from the carbonate-rich unit. *a)* Carbonate sand from 32.34 mbsf; the skeletal assemblage is mainly fragmented bryozoa, echinoid spines (*Sterechinus*) and sponge spicules. *b)* Carbonate sand from 32.77 mbsf; the skeletal assemblage is mainly fragmented bryozoa and mollusca, benthic foraminifera, echinoid spines (*Sterechinus*) and sponge spicules. *c)* Bryozoan-dominated sand fraction from 32.58 mbsf characterised by the abundance of the robust erect bryozoan *Hornera*. *d)* Bryozoan hash from 32.37 mbsf showing the dominance of laminar erect plates of *Lageneschara lyrulata*. *e)* Bryozoan-dominated sand fraction from 32.31 mbsf characterised by the abundance of the robust erect bryozoan *Hornera* associated with bivalve (*Lissarca*) and Eatoniellid gastropod (*Onoba*) molluscs. *f)* Echinoid-rich gravelly-sand from the base of a large dolerite cobble at 32.95 mbsf (*echinofor* skeletal assemblage). *g)* Bryozoan-mollusc sandy hash from 32.58 mbsf; large gastropod is *Prosipho*.

layers commonly display an imbricate fabric, or a preferred orientation of its skeletal components (mostly bryozoa). The bioclastic-rich layers contain little or no matrix. Muddy layers contain delicate aragonitic biosomes. Certain intervals display a clear alternation of coarse- and fine-grained layers, forming distinct couplets (Figs. 4 & 6). Admixture with terrigenous components varies considerably. The relative proportions of terrigenous and bioclastic components and the thickness of the couplets are used to subdivide Facies A into two subfacies.

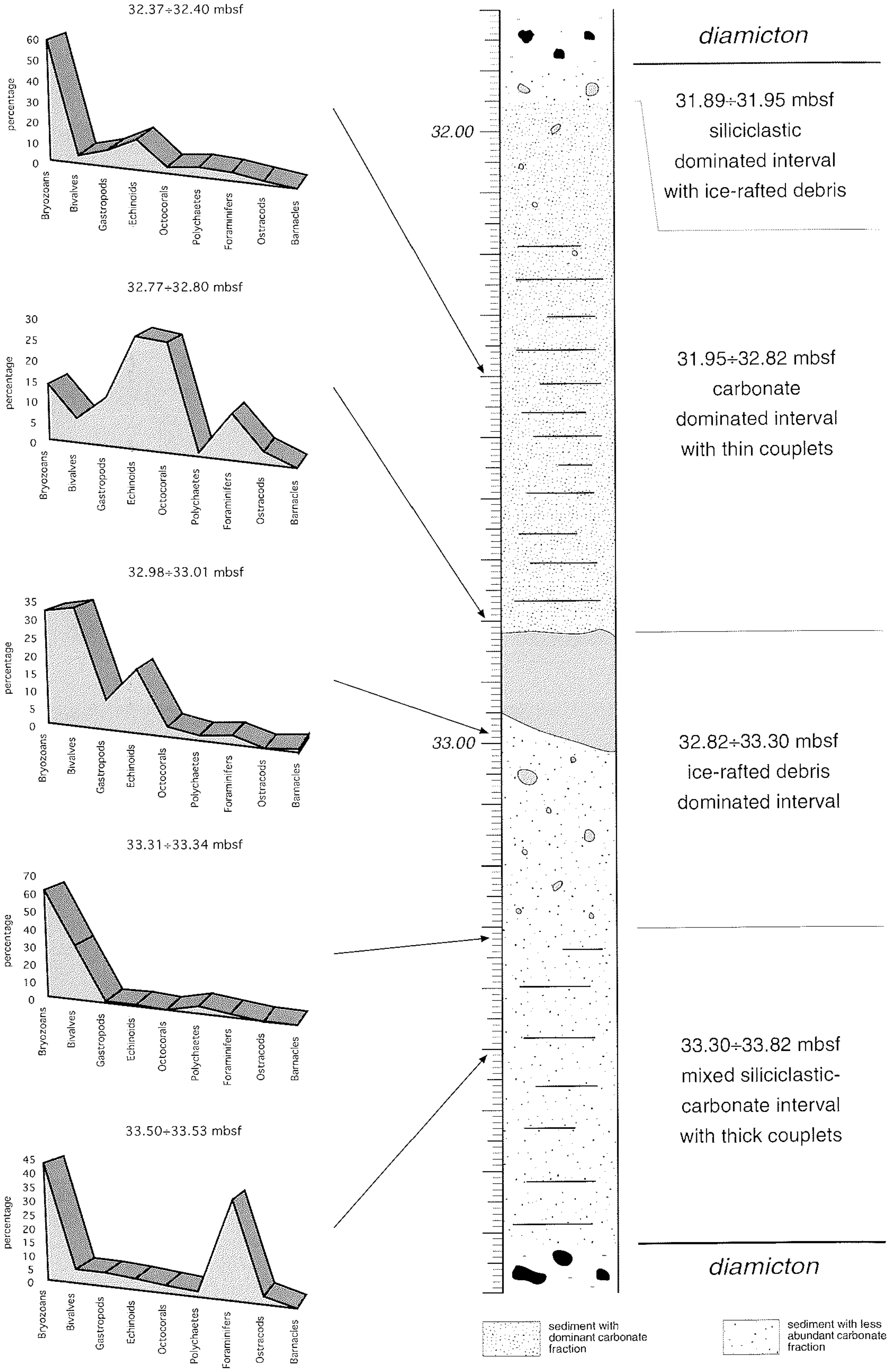

Fig. 3 - Schematic lithostratigraphic log showing the principal intervals recognised in the carbonate-rich unit and the principal carbonate biogenic fraction groups for representative samples.

Subfacies A1 is predominantly terrigenous, carbonate components account for 20-40% of the sediment. Among the terrigenous component are sparse quartz grains and rock fragments (dolerite and basalt) with abundant clay. The biogenic skeletal component consists of bryozoa, foraminifera and octocorals. Subfacies A1 typifies the lower part of the carbonate-rich unit, between 33.82 and 33.30 mbsf, where couplets are well developed (Fig. 4).

Subfacies A2 is a packstone containing 70-80% carbonate. Where preserved (Fig. 6), couplets are thinner

Fig. 4 - Detail of mud-rich and carbonate-rich couplets in the Subfacies A1 (33.80-33.66 mbsf; scale bar 1 cm).

Fig. 5 - Detail of the upper part of the Facies B, dominated by ice-rafted debris. Note relative coarsening of sediment at the base of the large dolerite cobble, possibly eddy-generated (32.85-33.09 mbsf; scale bar 1 cm).

Fig. 6 - Detail of the lower part of Subfacies A2, from 32.44-32.67 mbsf, showing high concentration of bioclastic sediments. The couplets are the typical sedimentary feature of this interval, but appear thinner than in Facies A1. In the lower part bryozoa are preserved in growth position; in the upper part fragments of bryozoa and octocorals display imbricated fabric (scale bar 1 cm).

than those in Subfacies A1, with muddy layers developed at mm-scale. A distinct series of couplets predominates in the interval between 32.82 and 32.25 mbsf, grading upward into more homogeneous, coarser-grained, bioclastic sand. The contacts between carbonate-rich and carbonate-poor beds are commonly sharp (Fig. 7). The increase in biogenic

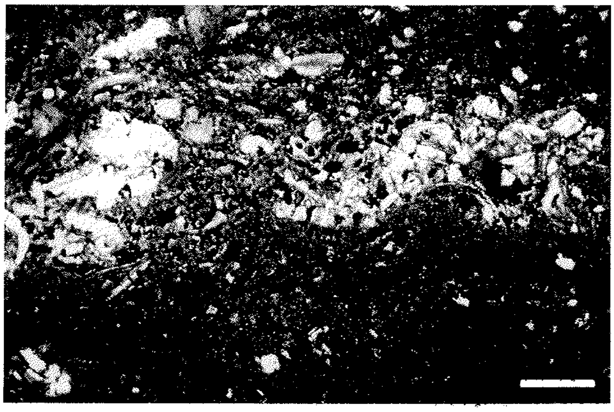

Fig. 7 - Sharp contact between the carbonate-rich microlayer (top) and the mud-rich microlayer (bottom) at 32.58-32.66 mbsf (scale bar 250 μm).

skeletal components occurs gradually within the muddy layer. In the biogenic fraction, bryozoan fragments are dominant (Fig. 8), but also relatively abundant are echinoid spines and plates; foraminifera and mollusca are also common; polychaete worm tubes are rare. Biogenic particles are commonly oriented parallel to the bedding (Fig. 9).

Very fine-grained terrigenous particles dominate the muddy beds, but skeletal microdebris is also present, along with rare basic igneous microclasts. Sponge spicules are the dominant biogenic component in the muddy layers, but are relatively less abundant in the carbonate-rich layers. In a few cases, the layering becomes disorganized and traces of bioturbation are discernible. Subfacies A2 characterises the interval between 32.82 and 31.95 mbsf, lying immediately above an ice-rafted debris-rich layer.

Facies B is a predominantly terrigenous sediment with minor bioclastic components. It incorporates almost bioclastic-free, pebbly-gravelly sand inferred to represent ice-rafted debris (32.98 mbsf: Fig. 5). The contact with the underlying Facies A is often gradational; in the upper part of the unit, at 31.95 mbsf, it appears sharp but with no erosive surface. The decrease of biogenic skeletal components is abrupt and only few scattered biogenic components are present in the overlying diamicton.

No sedimentary structures were observed. This may reflect a high degree of bioturbation. Lenses of terrigenous mud enclosed in the carbonate-rich fraction are interpreted as burrows. The coarse-grained biogenic fraction contains large fragments, and locally whole specimens of bryozoa, octocorals, echinoids, gastropods and foraminifera. These skeletal fragments (Fig. 10) are enclosed in a matrix of skeletal microdebris mixed with silt-sized and very fine-grained terrigenous material (mainly quartz and clay). The terrigenous fraction consists of subrounded to angular quartz, plagioclase, pyroxene and amphibole, clay minerals, lithoclasts, dolerite clasts, and rare volcanic glass.

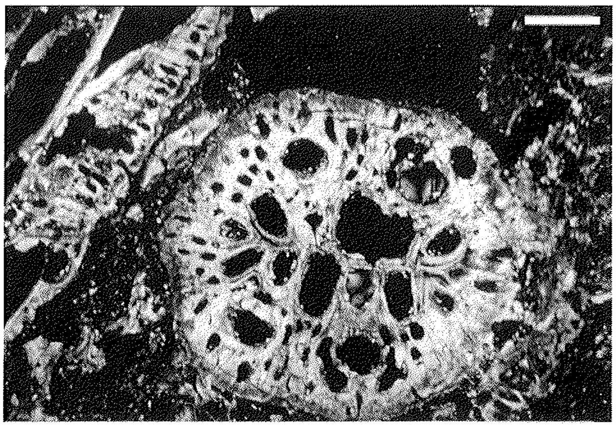

Fig. 8 - Bryozoan fragments in the carbonate dominated interval at 32.24-32.30 mbsf (scale bar 250 μm).

Fig. 9 - Microlayer rich in sponge spicules in the muddy semicouplet, showing a clear orientation of the fragments. Sample at 32.24-32.30 mbsf (scale bar 250 μm).

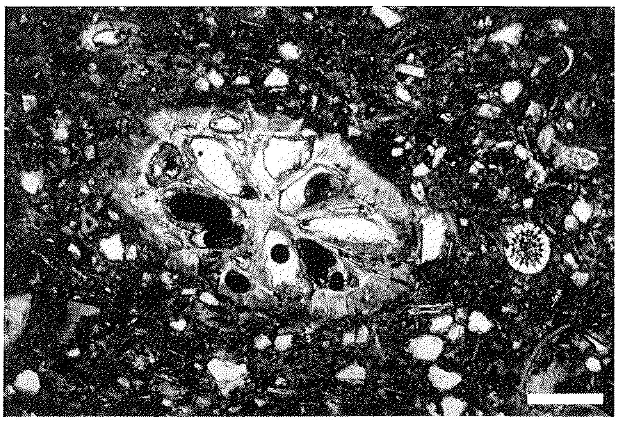

Fig. 10 - Large skeletal bioclast and echinoid spine floating within a terrigenous-dominated matrix. Sample at 31.85-31.91 mbsf (scale bar 250 μm).

DISCUSSION

The main depositional theme is of shell lags alternating with muddy layers, suggestive of sedimentation occurring under episodic bottom current conditions. Times of diminished current activity are marked by the deposition of fine-grained sediment, but these thin layers are seldom preserved intact. At times, currents had enough energy to rework whole bioclastic grains, causing total or partial winnowing of the fine matrix. This is consistent with the observed imbrication of clasts and preferred orientation of elongated particles. Considering the estimated water palaeodepth in excess of 100 m (possibly in the range of 100-150 m or more: Taviani et al., this volume), it is hypothesized that bottom currents may have been generated during particularly strong storms. However, given the inferred water depth, it is unlikely that this currents were the direct action of waves, but possibly generated by return or shelf-wide flows. The bottom shear-stress was only moderate as evidenced by the: (1) preservation of delicate skeletal biosomes within packstones (including thin-walled aragonitic shells), (2) lack of substantial abrasion in many bioclasts, (3) preservation of previously-deposited thin layers, and (4) the complete absence of biota typically thriving under strong bottom currents. It is likely that most bioclasts were sourced only a short distance away from their depositional setting, as suggested by substantially *in situ* branched bryozoa in close association with bryozoan-rich packstones.

Similar deposits form today in open marine conditions, where there is absence of an ice-shelf, relatively shallow water depths, and little dilution by terrigenous sediment as is the case of Antarctic banks and deep-shelves of the Ross Sea (*e.g.*, Taviani et al., 1993). Thus, we infer that the Cape Roberts Ridge (Cape Roberts Science Team, 1998a) on which the CRP-1 has been drilled, temporarily acted as a sediment-starved bank under open marine conditions, where lush carbonate biota could thrive at favourable times during the Pleistocene Epoch.

This depositional theme shows temporary interruptions by fluxes of poorly sorted terrigenous sediment intepreted to be ice-rafted debris (Cape Roberts Science Team, 1998b). The most conspicuous of these events is marked by the cobble-bearing layer at *c.* 32.98 mbsf. This layer represented a suitably hard substrate for some sponge-eating organisms, such as specialized limpets (*i.e., Iothia coppingeri*: Taviani et al., this volume). Some of the associated macrofauna show evidence of corrosion by cold, undersaturated waters and fungal bioerosion. However, there is no sign of attached epifauna on the external surface of the dolerite cobble, an indication of short-lived (probably a few years) sea-bottom exposure of this cobble before its final burial by finer sediments. The sandy fraction of this ice-rafted debris layer shows evidence of reworking by bottom currents.

PALAEOENVIRONMENTAL IMPLICATIONS

The carbonate-rich unit is interpreted as forming from bank-type sedimentation occurring under summer open-marine conditions. Palaeontological (Taviani et al., this volume; Webb & Strong, this volume) and geochemical (oxygen stable isotopes: Taviani & Zahn, this volume) data document a true polar setting for the entire unit, with bottom temperatures between *c.* -2 and 0°C. The presence or absence of seasonal sea ice cannot be established based on the carbonate sedimentary record alone. However, biota similar to that recorded in CRP-1 are living today in Antarctica under seasonal sea ice conditions (*e.g.*, Bullivant, 1967). Fair-weather conditions are marked by the deposition of muddy layers. Storm-triggered currents may be over represented in the unit because thin, fair-weather layers were more easily winnowed away or reworked. The supply of terrigenous sediment to the carbonate bank was initially high and diminished with time. The time of prolific carbonate production over the bank marks a period of glacial retreat and optimal climatic conditions. The complete shut-off of the carbonate factory seems to have been quite abrupt and probably linked to a glacial readvance.

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