Sedimentary Environments for CRP-1

Introduction

CRP-1 penetrated a succession of early Quaternary age (estimated to be in the range 1.2-1.8 Ma), extending from the sea floor down to 43.15 mbsf, and an early Miocene interval that extends from there to the base of the hole at 148 mbsf. A preliminary interpretation of the core (Cape Roberts Science Team, 1998) indicated that almost all sediments recovered were of glacimarine origin, and that sedimentation may have been interrupted by ice-grounding and erosional events. Furthermore, the initial results suggested a contrast in terms of glaciological regime, between Quaternary (polar, similar to Antarctica today) and Miocene (polythermal, similar to the High-Arctic today). A range of sedimentological investigations, made subsequent to drilling, have tested, and developed further, initial conceptual models of sedimentation. The results of these investigations are reported in the following eleven papers, and the main conclusions are highlighted here.

The core was divided into four Quaternary and three Miocene units (comprising 18 subunits) during the core recovery phase of the project (Cape Roberts Science Team, 1998). For this volume, the Miocene/Quaternary boundary has been adjusted from 43.55 to 43.15 mbsf (Fielding et al., this volume).

Preliminary sequence boundaries were established soon after core recovery, and these have been refined and placed in a sedimentary context (Fielding et al., this volume). The core reveals a cyclicity of facies associations that facilitates the development of a sequence stratigraphic framework. Eight Miocene and at least two Quaternary sequences have been identified on the basis of facies and textural associations. A typical cycle begins with diamictite/diamicton at the base, and fines upwards into sandstone and then siltstone, both commonly with limestones. The palaeoenvironmental significance of this cyclicity is discussed below.

De Santis & Barrett and Powell et al. (this volume) outline the physiographical setting for CRP-1, based on seismic and lithological data, and find that there are distinct contrasts between the Quaternary and Miocene parts of the core. Sediments of Quaternary age form a drape a few tens of metres thick. These were deposited high on the landward flank of a well-defined submarine ridge (or tectonic horst), rising several hundred metres above the bounding ice-eroded basins. The most prominent of these basins is the Mackay Sea Valley, which has a floor 900 m deep and represents a major outlet from the East Antarctic ice sheet. This ice probably combined with ice from the Ross Ice Shelf now to the south, as sediments in CRP-1 are derived from both basement and cover rocks in the Transantarctic Mountains to the west, and from the McMurdo Volcanic Group to the south. During Miocene time, strata were deposited on a planar sea floor dipping seawards (De Santis & Barrett, this volume). The depositional surface appears to have been steeper than normal continental shelves, and is therefore referred to as a “ramp” by Fielding et al. (this volume).

Detailed facies analysis, involving examination of lithology, bedding contacts, texture, fabric, sedimentary structures and colour, has been undertaken on the core. Two papers describe and interpret the facies from different standpoints:

1 - a sequence stratigraphic approach (Fielding et al., this volume), in which fining-upward cycles form the basis of defining ice advance and recession, linked to sea-level changes. Sequence boundaries are generally defined at the base of diamict units, and their significance is that they are inferred to represent a period of erosion following ice advance;

2 - a process-sedimentology approach, whereby knowledge of modern glacial depositional settings is applied to the interpretation of facies in the context of the glaciological (especially thermal) regime (Powell et al., this volume). This is undertaken with a view to assessing climate and the potential influence of the ice cover on sea level.
The dominant facies in both Quaternary and Miocene sections are diamicts (interpreted as proximal glacimarine, but rarely basal till), sand and silt (density-current deposits), mud/sand and mud or silt (fall-out from suspension), minor rhythmites (tidally influenced proximal glacimarine sediment), shell hash and calcareous diamicton (open shelf with minor ice-rafting), and gravel (included rubble-breccia of mass-movement origin or representing current/wave-winnowed lag deposits) (Fielding et al., this volume). More specific interpretations, based on comparisons with modern environments, indicate that (i) the fine-grained sediments may have accumulated in the offshore shelf zone or immediately off a grounding-line fan (ice-contact wedge of sediment built up below water-level) or delta, (ii) sands with interbedded diamicts and laminites may be ice-contact to ice-proximal with mass-flow activity associated with submarine fluvial efflux, and (iii) diamicts with interbedded sand, gravel and mud, represent rain-out deposits from floating ice and reworked as debris-flows, or, alternatively, basal till (Powell et al., this volume).

A number of studies of specific aspects of the core throw further light on the processes operating in the glacimarine environment. The finer fraction has been the subject of two studies concerned with particle-size distribution. De Santis & Barrett (this volume) used a SediGraph to compare modern sediments from the western Ross sea region with those found in the core. Their main conclusion is that the diamicts are texturally different from modern basal tills and have been modified by winnowing. This process was linked to wave and tidal currents, and suggests shallow water (<100 m) or even shoreface conditions. Woolfe et al. (this volume) used a laser diffraction instrument for particle-size determinations. In this study, the authors searched for broad trends in the core using entropy analysis. They found regular variations in the mode and median particle size every c. 5 m throughout much of the core. However, the processes responsible for these variations were not identified. These authors further identify eight broad textural zones which generally agree with sequence boundaries. Most samples show a moderate degree of sorting, suggesting that little ice-contact sediment is present and that winnowing processes occurred, consistent with the conclusion of De Santis & Barrett (this volume).

Many of the finer grained beds were initially interpreted as being gravity-flow deposits. This has been confirmed by more detailed analysis by Howe et al. (this volume) using thin-sections and laser particle-size studies, supported by entropy analysis, as in Woolfe et al. (this volume). Three main-types of gravity flow have been identified:

1 - thin beds of muddy sandstone are the most common, and are thought to have been triggered by debris rain-out from icebergs;
2 - rhythmically stacked sequences of pebbly-coarse sandstones, representing successive thin debris-flow events; and
3 - sandy-silty turbidites with rare lonestones (in the lower core only) which are distal glacimarine deposits.

Two studies focused on the coarser fractions in the core, one dealing with breccia beds, the other examining the gravel (limestone) component throughout the core. The study of breccias was made specifically by Puschier et al. (this volume) to determine the manner in which the core material had become fractured. Five breccia types were identified, and the processes involved in their formation were subglacial shearing and mass movement. Mechanisms of formation were dewatering of overpressurised sediment under a vertical load, and horizontal planar shearing, locally associated with soft-sediment deformation.

The study of the abundance of lonestones was considered important as an approximate measure of ice proximity. Brink et al. (this volume) have analysed lestone abundance throughout the core, based on core examination, analysis of digital images, and a follow-up examination of the core. They identify a periodicity of abundance in diamicts on a scale of 0.5-0.7 m, which they link to ice-margin fluctuations or to variations within individual debris flows. The results support the preliminary curve for relative distance from the ice margin already presented (Cape Roberts Science Team, 1998, Fig. 4, p. 128-129).

Two studies, focusing mainly on macrofossils, provide evidence of water depths and water temperatures for parts of the CRP-1 core. Taviani & Zahn (this volume) analysed bivalve shells for their stable oxygen isotope record, and found that there were marked contrasts between the Miocene and Quaternary parts of the core. Miocene bivalves yielded isotopic values similar to those in modern Arctic marine carbonates where mixing with abundant meltwater occurs, whereas the Quaternary bivalves gave isotopic values comparable to those of today.
Taviani & Claps (this volume) focused on the Quaternary biogenic carbonate interval, Unit 3.1, which provides a window on minimal glacial conditions during the early Quaternary Period. They identified two main assemblages: one dominated by bryozoa, mollusca and foraminifera (BRYOMOL assemblage), the other by echinoids and foraminifera (ECHINOFOR assemblage) which was associated with ice-rafted debris. Bank-type conditions, starved of terrigenous sedimentation are envisaged, with water depths in excess of 100 m. During this time the sea remained largely free of sea ice, but variable inputs of ice-rafted debris are evident.

The core was also examined for evidence of syn-sedimentary deformation and erosion by grounded ice, as lithofacies analysis alone yielded little evidence of ice grounding. Only one possible basal till was identified in the core during the drilling phase (from fabric analysis), at 63 mbsf (Cape Roberts Science Team, 1998). On the other hand sequence stratigraphic analysis indicated at least 10 sequence boundaries, some of which, underlying diamicts could be interpreted as ice-grounding events, e.g. at 44, 63 and 79 mbsf (Fielding et al. this volume). Van der Meer & Hiemstra (this volume) examined five impregnated thin sections of diamicites, describing texture, structure, plasmic fabric and diagenesis. They identified signs of subglacial deformation at 79, 123 and 124 mbsf. In addition, Passchier et al. (this volume) examined the breccias, of which those at 44 and 79 mbsf show strong signs of having been produced by subglacial shearing. Although these data are not entirely consistent, there are a number of horizons where more than one method of analysis has indicated the influence of grounded ice.

Combining the various lines of evidence in the above-mentioned papers, several conclusions can be made concerning the depositional environments:
1 - Quaternary and Miocene sediments both accumulated in mainly shallow marine environments, largely under the influence of floating ice, although movement of grounded ice across the site is evident at several levels within the core;
2 - sedimentary facies can be interpreted in terms of transgressive (local glacier retreat) and high stand (local glacier minimum) conditions, with regressive (local glacier advance) and lowstand (local glacier maximum) events being under-represented. Diamicts are inferred to follow ice-grounding events (Fielding et al. this volume). However, Powell et al. (this volume) note that the facies are not necessarily indicative of water depth;
3 - the general physiographic environment changed between Miocene and Quaternary times, from a planar slope (De Santis & Barrett, this volume) or ramp (Fielding et al., this volume), to one in which deposition took place along the flanks of major troughs that developed as a result of erosion in the intervening period;
4 - the sedimentary facies in CRP-1 provide evidence for contrasting glacier thermal regimes between the Quaternary and Miocene parts of the core (Powell et al., this volume). Quaternary facies resemble those of modern polar glaciers, such as nearby Mackay Glacier. Miocene facies resemble those from polythermal glaciers (i.e. those which have interiors at the pressure-melting point, and margins which are below). The contrast between an Arctic-like climate in the Miocene and the cold polar climate in the Quaternary Period is supported by the isotopic evidence from bivalve shells;
5 - comparison with modern glacimarine environments, where sedimentation rates are high, suggests that the 100 metres represented by the lower Miocene succession in CRP-1 probably formed largely over a few periods of perhaps tens of thousands of years or less, implying that only a small proportion of early Miocene time is represented by CRP-1 (Powell et al., this volume).

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REFERENCE