Carbonate Diagenesis of the Cenozoic Sedimentary Succession from the CRP-3 Core, Ross Sea, Antarctica

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Abstract - The diagenetic features of the Cenozoic glaciogenic sedimentary succession recovered at the CRP-3 drillhole were first described and logged in the stratigraphic description of the CRP-3 Initial Report. Further investigations are reported herein. Sixty-seven samples from the 790 m of penetrated section were selected to study the main fabric, texture, ultratexture, mineralogy and stable isotope composition. Authigenic calcite is the most abundant precipitate throughout the CRP-3 core. Fossiliferous concretions/nodules occurring in the upper 350 m of the sedimentary succession exhibit an early marine, shallow burial cementation by fringing/sparry low-Mg calcite, related to dissolution of calcareous skeletal material. The isotopic composition of this cement ($\delta^{18}O = -7.3$ to $-10.1$‰ PDB; $\delta^{13}C = -6.2$ to $-14.3$‰ PDB) suggests that glacial meltwaters comprised 25–40% of the precipitating fluid. Carbonate cementation is prevalent below 350 mbsf in sandstone lithologies and is represented by an early stage of fringing Fe-rich calcite or siderite that is overlain by blocky crystals of calcite containing no Mg. Pressure solution patterns along the framework grains suggest that cement formation is related to compaction. $^{18}O$ depletion ($\delta^{18}O = -12.6$ to $-18.2$‰ PDB) in these cements suggest that meteoric waters make up >60% of the diagenetic fluid, which is consistent with environmental changes inferred from the interpretations of the sedimentary facies. Associated with carbonate cements are authigenic zeolite and smectite minerals, representing early precipitates. Pyrite commonly occurs either as a discrete cement phase fringing coal particles or as frambooids dispersed within the organic-rich matrix, and within biogenic tests.

INTRODUCTION

Drillholes CRP-1, -2/2A and -3 of the international Cape Roberts Project have provided a complete, cored stratigraphic transect through the Cenozoic succession of the Victoria Land Basin in McMurdo Sound, Antarctica. CRP-3, drilled in October and November 1999, completed the transect by penetrating the lowermost part of the section, of ?Late Eocene to Early Oligocene age, the basal unconformity and underlying ?Devonian sedimentary rocks.

Detailed investigations of the diagenetic features from the cores recovered in the Cape Roberts area have been previously published in the CRP-1 SR, CRP-2/2A-SR (Baker & Fielding, 1998; Claps & Aghib, 1998; Aghib et al., 2000). Few data are available from the Ross Sea area. Cenozoic sedimentary successions recovered at CIROS-1 drillhole (Bridle & Robinson, 1990), contain various diagenetic features, such as authigenic carbonates of varying fabric and authigenic silica, smectite and zeolite minerals.

The present study uses detailed sedimentological, ultratextural, and compositional data from the CRP-3 core to investigate the diagenetic history of the succession. The major objectives of the study are to (1) document and interpret authigenic phases, including low-Mg carbonate cements, Fe-rich calcite, siderite, smectite, and zeolite minerals, (2) examine the diagenetic patterns of the various carbonate main fabrics and (3) use the stable-isotope geochemistry of calcite cement phases to establish the pore-fluid composition and evolution.

MATERIALS AND METHODS

Sixty-seven samples representing different lithologies from the sedimentary sequence of the CRP-3 core were selected in order to investigate fabric, texture, ultratexture and composition. Textural and ultratextural investigations of carbonate cements and skeletal components were carried out on standard polished thin sections. Scanning electron microscopy (SEM) was conducted mainly at Dipartimento di Scienze della Terra, University of Siena, in backscattered electron imaging mode, using a Philips XL30 coupled with an EDAX DX4 microprobe. In addition, a few samples were analyzed at...
Dipartimento di Scienze della Terra, University of Milano, using a Cambridge Stereoscan 360. The mineralogy of carbonate cements and other authigenic minerals was identified by EDAX.

Eight samples representing different sedimentary types were selected for C and O isotope analysis. Powdered whole-rock samples for stable carbon and oxygen isotope analysis were reacted with anhydrous phosphoric acid at 25°C for 24 hours on an off-line extraction system (e.g., McCrea, 1950). The isotopic composition of the evolved carbon dioxide was determined on a MM602E mass spectrometer. Oxygen isotope ratios were corrected for 17O contribution (Craig, 1957) and δ18O values were calculated using an acid fractionation factor of 1.01025 for calcite at 25°C (Sharma & Clayton, 1965). Carbon and oxygen isotope ratios are reported in per mil (‰) relative to the Vienna Pee Dee belemnite (V-PDB) standard (Tab. 1). Precision is better than 0.10‰ for δ13C and δ18O values and was monitored through analysis of National Bureau of Standards (NBS) 19, NBS 20, and other powdered calcite standards.

DIAGENETIC FEATURES

The detrital sandstone petrography and clay mineralogy of the CRP-3 core have been studied by several authors and their results are discussed elsewhere (Smellie et al., 2001; Setti et al., 2001; Wise et al., 2001).

In the present paper we present data concerning the diagenesis of sandstone lithologies displaying different typologies: (1) carbonate cementation associated with skeletal fragments (mainly bivalves, gastropods, and serpulid tubes); (2) light-coloured carbonate-cemented quartzose sandstones; and (3) “nodular” carbonate-cemented sandstones.

Carbonate cementation associated with skeletal fragments

Poorly cemented, fine-grained lithologies containing siliceous biogenic tests were recorded down to 250 mbsf. Carbonate cementation in patches, concretions, and horizons, related to dissolution of biogenic tests occurs at different depths, down to 359 mbsf in all lithologies. Below 359 mbsf, the sedimentary sequence recovered at the CRP-3 drillhole is barren of calcareous micro/macrosilos (CRP-3 Initial Report). Large calcareous biogenic tests such as serpulid tubes, bivalves and gastropods show all degrees of preservation, from well preserved to partially dissolved, to fully replaced by cement.

Within fine-grained lithologies, the original shells are usually preserved although there is some localized dissolution. Biogenic tests are surrounded by diffuse patchy carbonate cementation and carbonate-cemented concretions; the macrofossils, as serpulid tubes, bivalves and gastropods are recognisable although partially dissolved. Compositional analysis revealed that carbonate cement mainly consists of low-Mg calcite showing different fabrics (Fig. 1a). Most fossiliferous concretions contain multilayered tests still preserved (Fig. 1b); the selective dissolution is present in small areas on the outer layers and the subsequent incipient cementation consists of low-Mg calcite (Fig. 1c). The inner cavities of the shells are partially occupied by fine sediments similar to the surrounding matrix and contains siliceous microfossils (Fig. 1d). The sediment infill is overgrown by two generations of low-Mg calcite, a thin fringe of fibrous cement overlain by large interlocking crystals (Fig. 1e), which fills remaining primary pore space. Pyrite frambooids and fragments of recrystallized biogenic tests are often dispersed within the matrix (Fig. 1f).

Diffuse, patchy carbonate cementation containing shell fragments was recorded at different depths (Fig. 2a). Carbonate cements envelop variably preserved bivalve fragments, some of which show the original multilayered shell (Fig. 2b). Some areas of shells are replaced by a fringing low-Mg calcite cement postdated by sparry/drusy interlocking crystals of low-Mg calcite (Fig. 2c). Scanning electron microscopy (SEM) reveals that the original multilayered shells are partially dissolved and the related incipient cementation is evident. Incipient patchy cementation by low-Mg calcite usually occurs within fine-grained, poorly–cemented matrix (Fig. 2d) containing some dispersed frambooidal pyrite crystals (Fig. 2e) and the original shell is replaced by different generations of sparry low-Mg calcite.

Carbonate-cemented sandstones - Light-coloured carbonate-cemented quartzose sandstones

The major effect of extensive carbonate cementation is visible on sandy lithologies. Light-coloured, well-sorted, clean, well-stratified quartzose sandstones were mainly recovered in two intervals: 380-530 mbsf and 605-610 mbsf. The original stratification is enhanced by the carbonate cementation, consisting of low-Mg calcite (Fig. 3a). Sand-size framework grains are subangular to well rounded and are predominantly quartz grains with subordinate partially dissolved feldspar grains (plagioclase and K-feldpars) and rock fragments (Fig. 3b). The grains are partially cemented by sparry low-Mg calcite. SEM investigations show that the boundary between the carbonate-cemented and the non-cemented (dark) areas is sharp; the framework grains are cemented by blocky crystals of low-Mg calcite (Fig. 3c). The pressure-solution patterns occurring along quartz grains are due to compaction (Fig. 3d).

“Nodular” carbonate-cemented sandstones

Carbonate cementation occurring as micro- and macro-nodules, sometimes of irregular shape (from a few mm up to 2-4 cm across) was first observed at a
Fig. 1 – (a) Working half of the core at 61.20 mbsf showing large carbonate fossiliferous concretion containing partially dissolved serpulid tubes (scale bar: 1 cm); (b) Crossed-nicols view of a well preserved serpulid tube (61.20 mbsf; scale bar: 500 µm); (c) Crossed-nicols view of a well preserved serpulid tube. Incipient dissolution is present in small areas (61.20 mbsf; scale bar: 500 µm); (d) Close-up of c). Crossed-nicols view of a well preserved serpulid tube. Two generations of leathery, equant, sparry calcite lining the inner serpulid cavity; the inner cavity of the test is partially occupied by terrigenous mud (61.20 mbsf; scale bar: 500 µm); (e) Ultratexture of a well preserved serpulid tube (61.20 mbsf; scale bar: 1 mm); (f) Fragments of recrystallized biogenic tests and frambooidal pyrite dispersed within the matrix (61.20 mbsf; scale bar: 500 µm).
depth of 234.83 mbsf. Below 280 mbsf, where carbonate cementation increases, the nodules range in size up to 4 cm, and often coalesce to form well-cemented horizons (Fig. 4a). Nodules were recovered at various depths, usually in muddy greenish sandstones that range from well- to poorly-sorted and from fine- to coarse-grained. Between 540.00 and 789.77 mbsf, the sandstones show a "greenish" colour due to the alteration of clay minerals (see Setti et al., 2001). Below 576.00 mbsf, the nodule-bearing sandstones are relatively quartzose, with feldspar (plagioclase and K-feldspar), volcanic lithic grains, and other rock fragments as minor components. Below this depth, both alteration of clay minerals and dissolution and replacement of framework grains are also common. All feldspar and volcanic lithic grains show evidence of dissolution before or during calcite cementation. Framework grains have been replaced by calcite, pyrite, and probably zeolite minerals.

SEM investigation reveals that the porous and poorly carbonate-cemented areas surrounding the nodules are mostly composed of quartz grains. The elongated carbonate-cemented micro-nodules in fine sandstones show a sharp boundary between carbonate-cemented and uncemented medium-grained sand (Fig. 4b). Calcitic cementation often occurs within framework grains (feldspar and volcanics) which are partially replaced by low-Mg calcite. The main fabric of the carbonate-cemented micronodules is composed of 2-5µm rim of siderite (Fig. 4c: white rim) overlain by equant, blocky, and euhedral crystals of low-Mg calcite cement (Fig. 4c). Zeolite minerals 5-10µm in size were observed in a few samples. Siderite and zeolites are interpreted as authigenic minerals formed during an early stage of diagenesis, whereas low-Mg calcite represents a late stage of pervasive cementation. The effects of compaction are well represented by pressure solution patterns, such as grain contacts and deformation of quartz grains (Fig. 4d).
Authigenic Zeolites

Authigenic zeolite minerals occur both as pore-fillings in carbonate-cemented sandstones and as grain coating of detrital quartz grains, with the latter prevalent below a depth of 766.00 mbsf. Both forms represent an early stage of diagenesis before a late extensive low-Mg calcite cementation.
Fig. 4 – (a) Working half of the core at 608.10 mbsf showing the massive carbonate cemented sandstone as result of micro-nodule coalescence (scale bar 1 cm); (b) Crossed-nicols view of the carbonate-cemented sandstones, showing the sharp boundary between cement and terrigenous mud (in black). Grains are commonly quartz and feldspar partially replaced by no-Mg calcite (608.10 mbsf, scale bar: 500 µm); (c) Ultratexture of the millimetric carbonate-cemented nodules: rim of siderite followed by blocky ultratexture of the equant crystals of no-Mg calcite (608.10 mbsf, scale bar 200 µm); (d) Close-up of c), showing pressure solution patterns along quartz grains (608.10 mbsf, scale bar 100 µm); (e) Ultratexture of authigenic smectites, consisting of a thin fringe around framework grains. The pore space has been definitively filled by calcite precipitation (389.32 mbsf; scale bar 100 µm).
Authigenic Smectites

Authigenic smectites have been recorded at different depths, below 368 mbsf. The geochemistry and mineralogy of the smectite minerals are discussed in papers by several authors (Setti et al., 2001; Wise et al., 2001). The main fabric of the authigenic smectites consists of a thin layer (5-10 µm), which completely rims the framework grains. Textural and ultratextural observations suggest that smectites were precipitated as an early phase, prior to compaction and extensive carbonate cementation (Fig. 4e). According to some authors (Ehrmann, 1998; Setti et al., 2001), Fe content and smectite mineralogy may provide insight into a detrital versus authigenic origin. According to Setti (pers. comm.), the smectites from the upper ~ 500 m of the CRP-3 sedimentary sequence may have a detrital nature; below this depth the Fe enrichment would reflect an authigenic origin.

No mineralization has been found in the upper ~ 750 m of the sedimentary sequence to support the hypothesis that diagenesis could have been affected by hydrothermal seepage related to the intrusion at ~ 820 mbsf. However, slightly elevated temperatures could affect the formation of authigenic minerals in the lower part of the core (Setti et al., 2001; Pompilio et al., 2001).

STABLE ISOTOPE ANALYSES

Whole-rock samples examined in the present study exhibit a wide range of carbon and oxygen isotope compositions (Tab. 1). Oxygen isotope compositions vary by nearly 11‰ and tend to decrease with increasing depth in core (Fig. 5). Carbon isotope compositions fall into two distinct groups, one is characterised by δ13C values ranging from approximately −5 to −6‰ and the other is characterised by distinctly lower δ13C values that range from approximately −15 to −20‰ (Tab. 1). Carbon isotope compositions do not exhibit any clear relationships with burial depth or rock type.

Oxygen Isotope Compositions

Given the cold temperature regime and the largely siliciclastic nature of the sediments, water-rock exchange reactions would have been slow enough that pore waters probably experienced little isotopic modification prior to cement precipitation (Morse and Mackenzie, 1990). As such, the isotopic composition of the carbonate phases can be assumed to reflect roughly the isotopic character of ambient waters. Assuming that the bulk of carbonate analysed isotopically is early diagenetic calcite cement, low δ18O values suggest a significant meteoric influence. A significant presence of meteoric water in sedimentary pore fluids is supported by sedimentological interpretations, which suggest that the CRP-3 drillsite was affected by seasonal melting of nearby glaciers through much of the late Eocene-earliest Oligocene (Cape Roberts Science Team, 2000).

Tab. 1 – Results of stable isotope analyses for selected samples.

<table>
<thead>
<tr>
<th>Depth in Core (mbsf)</th>
<th>Description of Sample</th>
<th>δ18O (% PDB)</th>
<th>δ13C (% PDB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>39.29</td>
<td>Slightly calcareous siltstone containing serpulid tubes</td>
<td>−7.3</td>
<td>−6.2</td>
</tr>
<tr>
<td>141.20</td>
<td>Calcareous sandy siltstone containing bivalve shell fragments</td>
<td>−10.1</td>
<td>−14.7</td>
</tr>
<tr>
<td>368.06</td>
<td>Carbonate-cemented quartzose sandstone</td>
<td>−14.7</td>
<td>−15.2</td>
</tr>
<tr>
<td>456.18</td>
<td>Quartzose sandstone containing coal debris, nodular carbonate cement</td>
<td>−12.6</td>
<td>−5.9</td>
</tr>
<tr>
<td>567.48</td>
<td>Quartzose sandstone, nodular carbonate cement</td>
<td>−16.1</td>
<td>−6.3</td>
</tr>
<tr>
<td>587.00</td>
<td>Greenish sandstone, nodular carbonate cement</td>
<td>−14.1</td>
<td>−6.2</td>
</tr>
<tr>
<td>593.53</td>
<td>Dark sandstone, nodular and millimetric carbonate cement</td>
<td>−13.6</td>
<td>−5.2</td>
</tr>
<tr>
<td>787.84</td>
<td>Carbonate-cemented pebbly sandstone</td>
<td>−18.2</td>
<td>−19.8</td>
</tr>
</tbody>
</table>
Influence of Glacial Meltwaters

Using the constraints outlined above, the $\delta^{18}O$ value of the fluid from which the carbonate cements in CRP-3 precipitated can be assessed (Fig. 6). These calculations indicate that the $\delta^{18}O$ value of the pore fluid responsible for precipitating early cement phases in the sample taken from 32.39 mbsf fell within the range of $-7\%e$ to $-10\%e$ SMOW. It is evident that pore water $\delta^{18}O$ values were lower in older parts of the section, with the lowest values ($c. -18\%e$ to $-21\%e$ SMOW) calculated for the sample taken from 787.84 mbsf.

The oxygen isotope composition of snowfall depends largely on temperature, such that $\delta^{18}O$ values of snow (and snowmelt) increase with increasing temperature. Investigations of an ice core recovered from Byrd Station in Antarctica reveal that $\delta^{18}O$ values fluctuate with depth and, over an interval spanning approximately 120 ky, range from approximately $-34\%e$ to $-41\%e$ SMOW, with the higher $\delta^{18}O$ values being associated with warmer climate intervals (Johnsen et al., 1972). A similar record derived by the same authors from an ice core from Camp Century in Greenland yielded more positive $\delta^{18}O$ values. Given that climate conditions during deposition of the section recovered at CRP-3 are postulated to have been warmer than at present, the $\delta^{18}O$ value of snow (and associated meltwater) was likely on the order of $-25\%e$ to $-30\%e$ SMOW. Although changes in the $\delta^{18}O$ value of sea water due to variable storage of water in ice caps may have occurred during late Eocene-earliest Oligocene time, for purposes of the present exercise the $\delta^{18}O$ value of sea water is assumed to have remained constant at 0$\%e$ SMOW.

In combination with cement $\delta^{18}C$ values, the above estimates of the oxygen isotope compositions of marine and meteoric end members allow assessment of the contribution of meteoric water to sedimentary pore fluids (Fig. 7). Calculations suggest that over the temperature range examined (5–15$^\circ$C), the contribution of meteoric water ranges from 25%–40% for the sample taken from 32.39 mbsf ($\delta^{18}O = -7.3\%e$) to $>60\%$ for the sample with the most negative $\delta^{18}O$ value ($-18.2\%e$), which was taken from a depth of 787.84 mbsf. Because the oxygen isotope compositions of samples tend to become more depleted in $^{18}O$ with increasing core depth (Fig. 5), these calculations suggest that the influence of meteoric waters at the CRP-3 drill site gradually decreased through time. This is consistent with the interpreted environmental change inferred from facies characteristics in CRP-3 (Cape Roberts Science Team, 2000).

Carbon Isotope Compositions

Low $\delta^{13}C$ values of whole-rock samples (Tab. 1) are interpreted to reflect the dominance of carbon derived from organic matter to sedimentary pore waters (as opposed to carbon derived from dissolved CO$_2$ in marine waters, which is relatively enriched in $^{13}C$). It is possible that late-stage diagenetic carbonates exceedingly depleted in $^{13}C$ may have contributed to the lowest $\delta^{13}C$ values observed in whole-rock samples ($-14.7\%e$, $-15.2\%e$, and $-19.8\%e$ for samples taken from 141.20, 368.06, and 787.84 mbsf, respectively). Regardless, the range of carbon isotope compositions observed is consistent with a significant meltwater component in pore waters, in which dissolved CO$_2$ was derived largely from the oxidation of organic matter, potentially within poorly developed soils in nearby regions.

DISCUSSION

Petrographic observations suggest that much of the carbonate in the whole-rock samples analysed are carbonate cements that were precipitated at shallow burial depths and prior to any significant physical compaction. Early precipitation is suggested by the fact that grain-grain contacts have mainly point to floating relationships. Very few contacts encompass
entire grain boundaries and no suture contacts were observed. Given these petrographic constraints on the timing of precipitation, it is likely that cements formed at temperatures similar to ambient surface temperatures. Sedimentological investigations of CRP-3 suggest that the upper part of the section (down to a depth of ~787 mbsf) records a shallow marine depositional environment that was subject to significant freshwater influxes from glacial meltwaters (Cape Roberts Science Team, 2000). Below ~787 mbsf, depositional conditions are interpreted as predominantly non-marine. Inferred climate conditions are cold-temperate with likely mean annual surface temperatures in the range of 5–15 °C (Cape Roberts Science Team, 2000).

Four major cement phases which occlude the primary pore spaces were distinguished by conventional petrography and under SEM. These are (from the earliest stage to the last): fringing low-Mg calcite; drusy/sparry low-Mg calcite; fringing Fe-rich calcite or siderite; blocky no-Mg calcite. Fringing and drusy/sparry low-Mg calcites occlude most of the pore space of the concretions containing biogenic tests and is present in intraskeletal voids. Fringing Fe-rich calcite or siderite is present as an early precipitate rimming the framework grains in barren sandstone lithologies. The remaining pore space is completely filled by a late stage of blocky no-Mg calcite. The fringing Fe-rich calcite or siderite is not always developed or is partially obliterated by pressure solution patterns occurring along framework grains.

**Fringing low-Mg calcite; drusy/sparry low-Mg calcite**

Fringing calcite is the earliest cement phase associated with skeletal fragments in the upper 350 m of the CRP-3 core, forming layers of euhedral crystals as replacement of the original multilayered shells. Drusy/sparry calcite occurs mainly within the intraskeletal pores. The mineralogy of these fabrics consists of low-Mg calcite.

Stable isotope analyses of fringing calcites and drusy/sparry calcites have been determined from two samples (Tab. 1). They show values ranging from ($\delta^{18}O = -7.3$ to $-10.1 \%e$ PDB; $\delta^{13}C = -6.2$ to $-14.3 \%e$ PDB).

**Fringing Fe-rich calcite and siderite**

Fringing Fe-rich calcite and siderite seem to be the first cement precipitate below the depth of 350 mbsf in barren sandy lithologies. They develop as thin layers (5-10 µm) rimming the framework grains. During compaction the rims are partially obliterated. Unfortunately, these crystals are too small to be sampled by conventional methods for stable-isotope analyses.

**Blocky no-Mg calcite**

The fabric is a mosaic of clear, equant, blocky no-Mg calcite crystals filling the remaining void space. This is interpreted as a late stage of cementation, where compactional effects as grain contacts and pressure solution patterns are evident.

Six stable isotopes analyses of the blocky no-Mg calcite display values ranging from ($\delta^{18}O = -12.6$ to $-18.2 \%e$ PDB and $\delta^{13}C = -5.9$ to $-19.8 \%e$ PDB).

**INTERPRETATION**

During diagenesis, sediments are commonly cemented by authigenic minerals. Carbonates are the most common precipitate within the sedimentary successions recovered in the Ross Sea area, as previously described by Bridle & Robinson (1990) for the CIROS-1 core, by Baker & Fielding (1998); Claps & Aghib (1998) for the CRP-1 core, and by Aghib et al. (2000) for the CRP2/2A core. Several authors (Rao, 1981; Eyles et al., 1985; Fairchild et al., 1988; Fairchild & Spiro, 1990) emphasised the geochemical aspects of the carbonate cementation in glacigenic sequences. On the basis of textural, ultratextural, compositional investigations and stable isotope measurements, we propose the following interpretation for the carbonates recovered from the CRP-3 core.
Very shallow-burial origin of the cements associated with biogenic tests (fringing/drusy/sparry low-Mg calcite)

Since the initial descriptions in the Ross Sea area by Rao (1981), Taviani & Claps (1998), Claps & Aghib (1998); Aghib et al (2000), the crystal habit of fringing and drusy/sparry low-Mg calcites might be considered primary. Because carbon and oxygen isotopic compositions, and Mg contents were consistent with the marine composition under some influence of melting waters, low-Mg calcites of the carbonate cements can be interpreted as cements, directly precipitated from circulating seawater during very shallow burial conditions. It has been suggested that the transformation of the original shells is a process of incongruent dissolution whereby MgCO$_3$ is lost into dissolution without any destruction of the calcite fabrics (Towe & Hemleben, 1976). The precipitation of low-Mg calcites is thus dependent on circulating porewaters, which are possible under marine and very shallow-burial conditions. Isotopic data from whole rocks, fossils and pore-filling cements allowed estimates of the relative contributions of marine and glacial melt waters to diagenetic fluids. The calcitic cements associated with biogenic tests must be therefore related to dissolution of the original shell during an early stage of diagenesis at very shallow-burial conditions.

Shallow-burial origin of Fe-rich calcite and siderite

Fringing Fe-rich calcite and siderite are documented only from few diagenetic studies in the Ross Sea area. Petrographic studies by Bridle & Robinson (1990) on carbonates from the CIROS-1 core indicate the occurrence of siderite and ankerite. Siderite has been previously recorded in the CRP-1 core (Baker & Fielding, 1998) and in the CRP2/2A core (Aghib et al., 2000). Fringing iron-rich calcite, siderite and ankerite have been interpreted as related to low-salinity porewaters (glacial melt waters?) at shallow burial depths (Mortimer et al, 1997). Moreover, Droomgole & Walter (1990) interpreted the Fe-content as an indicator of low-salinity pore fluids. In the CRP-3 core, these cements are interpreted to be precipitated during an early stage of diagenesis and to reflect the sediment composition combined with the effects of low-salinity fluid flows from glacial melting waters and/or along major fault system at shallow burial depths.

Late-burial origin of blocky No-Mg calcite

This cement marks the change from an incipient diagenesis (fringing cements) to widespread cementation of calcite with a mosaic or equant crystal habit. The mean stable isotope composition of this cement shows a depletion in $^{18}$O and rather constant values in $^{81}$C.

As suggested by Given & Wilkinson (1985) crystal morphology, composition and carbonate mineralogy of abiotic sedimentary carbonates are essentially controlled by the kinetics of surface nucleation and the concentration of carbonate ions. Their composition and significant change in crystal habit indicate precipitation under conditions with higher availability of CO$_3^{2-}$. The source of ions (Ca$^{2+}$, CO$_3^{2-}$) needed to maintain supersaturation for deep-burial calcite cement precipitation is still an unsolved problem. Input of melting waters and/or fluid flows along the main fault system is likely in the CRP sedimentary succession. Pressure solution might be an autotchonous ion source for deep-burial cements for the warm-water carbonates (Rao, 1988), whereas the source and the precipitation mechanism for most glacial extensive carbonate cementation are as yet unclear (Fairchild & Spiro, 1990). In a glaciogenic section from the CIROS-1 core, the carbonates are rather depleted in $^{18}$O (Wada & Okada, 1990). The stable isotope composition combined with the evidence for excess burial of 400-1100 m would suggest a burial origin for most of the carbonates. In a recent study by Baker & Fielding (1998) on the glacimarine sediments from the CRP-1 core, the isotopic signature of the carbonates is consistent with their formation at very shallow burial depths under the influence of meteoric pore waters.

CONCLUSIONS

The diagenetic history of CRP-3 sedimentary succession is characterized by progressive burial conditions, with marine diagenesis prevalent in the upper 350 m of the core and the influence of glacial meltwaters becoming greater below this depth.

The diagenesis of the carbonates recovered at CRP can be summarized as follows:

- Cementation by sparry/drusy calcites resulted in partial replacement of biogenic shells (bivalves, gastropodes, serpulides tubes) by low-Mg cement. Isotopic data suggest that diagenetic fluids consisted of mixtures of sea water (60-75%) and glacial melt water (25-40%).
- Early phase of cementation by Fe-rich calcite or siderite cements rimming the framework grains, under the influence of low-salinity porewaters.
- Early stage of cementation by authigenic smectites.
- Extensive cementation by blocky calcite, under a stronger influence of glacial melting porewaters (60%) with visible increase in pore occlusions (cementation), and indicating the transition to relative deeper burial conditions.

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