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Mineralogy of Sediments from CRP-1 as Revealed by X-Ray Diffraction

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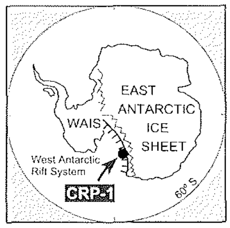


Abstract - The mineralogy of the lower Miocene and Quaternary sediments of the drillcore CRP-1 (McMurdo Sound, Ross Sea, Antarctica) has been analysed using the X-ray diffraction method. Quartz, plagioclase feldspars, K-feldspars are the most important non-clay minerals. Amphiboles occur throughout the core in minor amounts. The composition of the sediments points to an origin in the Transantarctic Mountains for the majority of the detrital components. There, the plutonic and metamorphic rocks of the basement, the sediments of the Beacon Supergroup and the volcanic rocks of the Ferrar Dolerite could serve as possible source lithologies. The quartz abundance is strongly linked to the grain size of the sediments with maxima correlating with coarse grain sizes. The downcore distribution of the other detrital minerals is relatively invariable, and does not indicate a major change in the source area during the time represented by the CRP-1 sediments. Some diagenetic alteration of the sediments is indicated by the occurrence of minor amounts of opal-CT and by some clinoptilolite below 110 m depth.

INTRODUCTION

Although several drilling activities were undertaken on the shelf of McMurdo Sound in the Ross Sea during the last some 25 years (Fig. 1; *e.g.* Barrett & Scientific Staff, 1985; Barrett, 1986, 1989), during the Cape Roberts Project largely undisturbed cores of early Miocene and Quaternary sediments were recovered from the Victoria Land Basin for the first time. The Miocene sediments are about 104 m thick and have an age of *c.* 22-17.5 Ma. The Quaternary sediments are about 43 m thick. The two sequences are separated by a major hiatus. The CRP-1 drillcore consists entirely of proximal and distal glacimarine sediments, which document several ice advances and retreats (Cape Roberts Science Team, 1998).

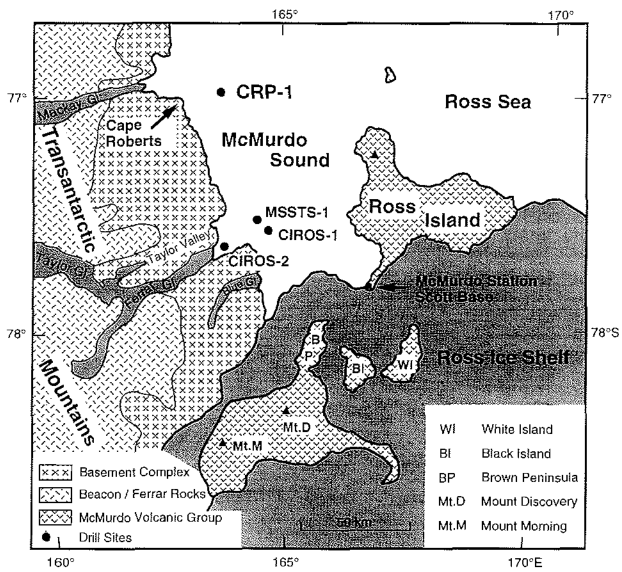


Fig. 1 - Location of the drillsite CRP-1 on the continental shelf of McMurdo Sound in Ross Sea, Pacific sector of the Antarctic Ocean. The positions of the earlier drill sites CIROS-1, CIROS-2 and MSSTS-1 are also indicated. Bedrock geology is from Warren (1969).

One of the major objectives of the Cape Roberts Project is to study changes in the Antarctic climate and the dynamics of the Antarctic ice masses. This goal is approached using a large variety of sedimentological, geochemical, petrological, palaeontological and geophysical methods. This paper contributes to the problem by presenting initial results on the mineralogical composition of the sediments recovered in the CRP-1 drillcore. It focuses on the downcore distribution of non-clay minerals as revealed by X-ray diffraction (XRD), especially the abundance of quartz and feldspars. The composition and distribution of the clay minerals, as well as the distribution of heavy minerals, are treated in separate papers (Ehrmann, this volume; Polozek & Ehrmann, this volume; Setti et al., this volume).

METHODS

Mineralogical data of samples from the CRP-1 core were obtained by XRD. After freeze-drying the chemically and mechanically untreated samples, the gravel fraction (>2 mm) was removed from the bulk samples by sieving.

The <2 mm fraction was mechanically ground and the samples were mixed with an internal standard consisting of corundum (α-Al_2O_3, BDH Chemicals Ltd., Poole, England) at a sample/standard ratio of 5:1. Further grinding in an agate vial under acetone enhanced homogenisation.

Random powder mounts were X-rayed from 3 to 100 °2Θ with a step size of 0.02 °2Θ and a measuring time of 2 seconds per step. The equipment consisted of a Philips generator PW 1830, a goniometer PW 3020 with an automatic divergence slit, an electronic control PW 3710, and an automatic sample changer PW 1775. CoKα radiation (40 mV, 40 mA) was used. The diffractograms were evaluated on an Apple Macintosh Personal Computer using the "MacDiff" software (Petschick, unpublished freeware). The analysed pattern was calibrated against the position of the d(012) peak of the corundum standard at 3.479 Å. The peak heights and the peak areas of the individual minerals were measured after subtraction of background counts.

In order to estimate the content of individual minerals, their peak height or peak area was set in relation to the same parameters of the corundum standard. For estimating the individual minerals and mineral groups, the main XRD reflections of quartz, plagioclase feldspar, K-feldspar, calcite, pyroxene, amphibole, opal-CT and of the heulandite-clinoptilolite group were used. All raw data are available *via* the internet from the data bank of the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany (www.pangaea.de).

RESULTS

Based on the XRD records, several minerals and mineral groups were identified in the CRP-1 samples (Figs. 2, 3 & 4). The clay minerals illite and chlorite were found in all samples. Smectite was detected in some samples above *c.* 65 mbsf (metres below sea floor). Quantitative data and details on the clay mineral distribution and composition are published by Ehrmann (this volume) and Setti et al. (this volume).

The mineral/standard ratios presented in this paper cannot be used for determining the absolute concentration of the individual minerals in the CRP-1 sediments. However, they allow detection of temporal relative abundance changes of each mineral.

Quartz, plagioclase feldspars and K-feldspars are the most important non-clay minerals. They were found in high amounts in all samples. Also pyroxenes and amphiboles occur throughout the core, whereas zeolites and opal-CT are present only in minor amounts and not in all samples. Carbonates are present only sporadically.

CARBONATE

Carbonates occur in detectable amounts only in two samples at 32.23 and 32.54 mbsf. They consist of calcite. The samples come from a carbonate-rich interval within the Quaternary part of the core, which is characterised by a muddy packstone with numerous calcareous micro- and macrofossils (Cape Roberts Science Team, 1998; Taviani & Claps, this volume). More detailed analyses of the carbonate content and carbonate composition were performed by Dietrich & Klosa (this volume).

QUARTZ

The abundance of quartz is presented as the ratio of the d(101) quartz peak height at 3.343 Å and the d(012) corundum peak height at 3.479 Å (Fig. 2). The heights of the quartz peak at 3.343 Å correlate well with the heights of the peak at 4.26 Å (correlation coefficient > 0.90). The almost constant ratio of the two peaks indicates that the 3.343 Å peak is not disturbed by illite and therefore can be used for estimating quartz content.

Quartz occurs in medium concentrations below 70 mbsf, with quartz/standard ratios fluctuating between 5 and 8. Maxima are found around 70-60 mbsf and in the upper *c.* 42 m of the core. At the maxima, quartz content is about twice that of the lower part of the core. Minima occur at 60-42 and at 32 mbsf. The latter minimum correlates with the enhanced carbonate concentrations within the Quaternary packstone interval. The minimum at 60-42 mbsf has quartz/standard ratios of around 5 and therefore contains less quartz than the sediments in the lower part of the core.

FELDSPARS

The abundance of total feldspar is presented as the ratio of the combined peak areas of the feldspar peaks at 3.24 Å, 3.21 Å and 3.18 Å and the corundum peak area at 3.479 Å. The feldspar abundance seems quite constant throughout the core with most feldspar/standard ratios ranging from 4 to 6 (Fig. 2).

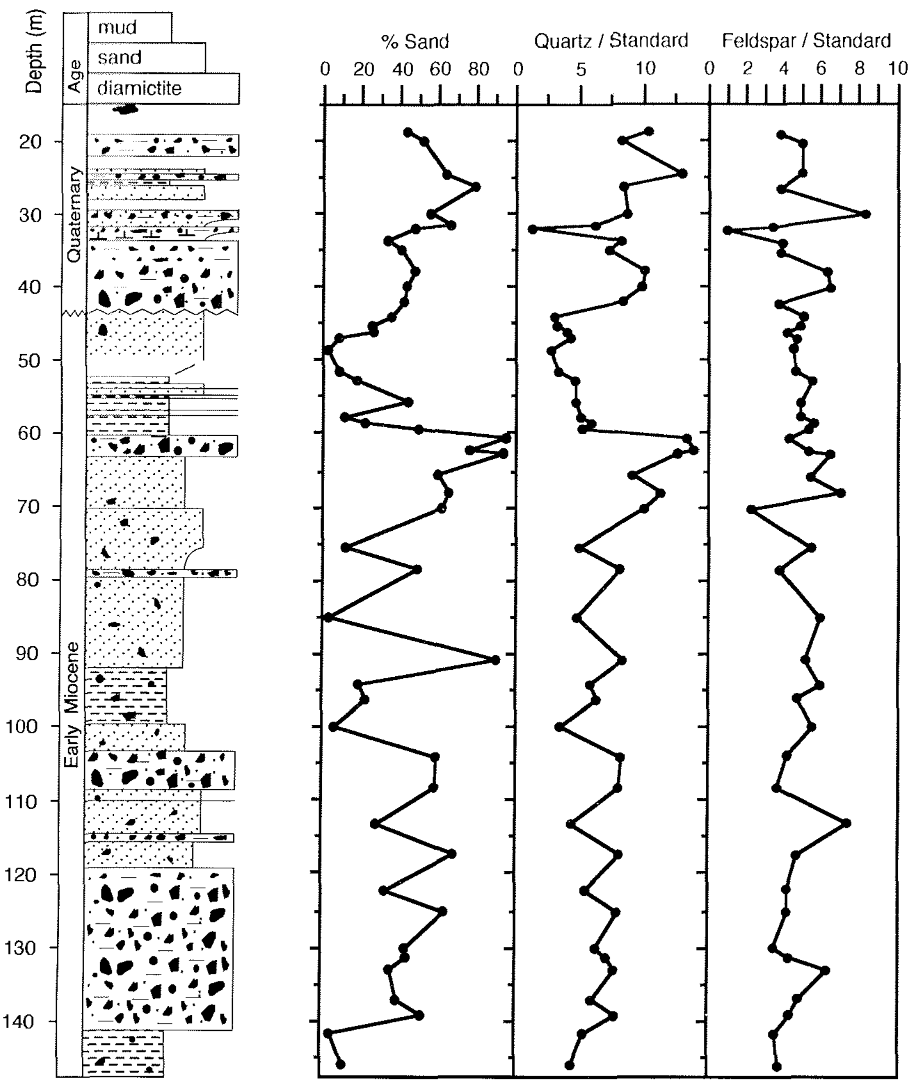
K-feldspar/standard ratios are based on the 3.24 Å K-feldspar peak height (Fig. 3). They range mainly from 1 to 2.5. Plagioclase/standard ratios are based on the 3.18 Å plagioclase peak height. Neither the K-feldspar curve nor the plagioclase curve exhibit clear or systematic changes in the downcore distribution of the individual feldspars. Also the K-feldspar/plagioclase and the quartz/feldspar ratios are relatively invariable. They range from 0.2 to 1.2 and 0.5 to 2, respectively, and show no major downcore compositional variations (Fig. 3).

CLINOPYROXENES

Clinopyroxenes were identified by their main reflections forming a typical peak triplet at 3.0, 2.95 and 2.90 Å. Distinction of individual clinopyroxenes was not possible. Clinopyroxenes occur throughout the core in almost constant concentrations, with pyroxene/standard ratios fluctuating between 1 and 2 (Fig. 4). Data on the distribution of pyroxenes in the heavy mineral fraction are presented in a paper by Polozek & Ehrmann (this volume).

AMPHIBOLES

The abundance of amphiboles is presented as the ratio of the peak area at around 8.42 Å and that of corundum. Hornblendes, tremolites, actinolites and riebeckites have basal reflections at about this d-value, at 8.4-8.5 Å. Distinction of the individual amphiboles, however, was not possible. Amphiboles occur throughout the CRP-1 core in minor amounts, with amphibole/standard ratios fluctuating between 0 and 0.15 (Fig. 4). Data on the distribution of amphiboles in the heavy mineral fraction are presented in a paper by Polozek & Ehrmann (this volume).



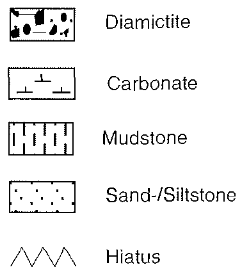


Fig. 2 - Sand content (63 µm - 2 mm) and abundance of quartz and feldspars in the CRP-1 sediments. Quartz abundance is presented as the ratio of the 3.343 Å quartz peak area to the 3.479 Å peak area of the internal standard corundum. Feldspar abundance comprises the areas of the feldspar peaks at 3.24 Å, 3.21 Å and 3.18 Å in relation to the area of the standard peak. Lithology is simplified after Cape Roberts Science Team (1998).

ZEOLITES

In general, minerals of the heulandite-clinoptilolite group (d-spacings between 8.97 and 9.06 Å) were identified in trace amounts only. However, below 110 mbsf, three of the eleven samples investigated had somewhat enhanced concentrations (Fig 4).

OPAL-CT

Opal-CT, a diagenetic mineral, is characterized by opal-CT peaks at 4.05-4.11 Å and by the d(101) lattice of tridymite at 4.32 Å. Because quartz is present in high amounts in all samples, the tridymite peak can be seen, if at all, only on the shoulder of the d(100) quartz peak at 4.26 Å. Because plagioclase feldspars are present in high amounts, the 4.05 Å peak is also an unreliable indicator of opal-CT. Therefore, only the 4.11 Å peak could be used for identifying opal-CT. Thus, the data on the occurrence of opal-CT are somewhat weak. Opal-CT seems to be present in minor amounts in most of the investigated samples. Maximum concentrations occur between 115 and 85 mbsf and between 60 and 45 mbsf (Fig. 4).

DISCUSSION

The purpose of this study was to characterise the mineralogical composition of the sediments of the CRP-1 core and to reconstruct their source area. Analyses of the gravel composition during the initial core description have suggested a lithologically diverse source area (Cape Roberts Science Team, 1998). Also the more detailed post-drilling petrographic investigations document a large variety of different source rocks (Armienti et al., this volume; Polozek & Ehrmann, this volume; Smellie, this volume; Talarico & Sandroni, this volume). Clay minerals in the CRP-1 core also indicate a complex history of sediment transport to the drillsite, with different source areas being active at different times (Ehrmann, this volume). Thus, the sediments in the lower part of the core, below *c.* 65 mbsf, indicate a main source area in the Transantarctic Mountains. The geology of the Transantarctic Mountains is characterised by a crystalline basement consisting of late Precambrian to early Paleozoic granites and mainly amphibolite-grade metamorphic rocks. The basement is overlain by sedimentary rocks, mainly sandstones, of the Devonian to Triassic Beacon Supergroup. Both basement rocks and sedimentary rocks are intruded by sills and dykes of the

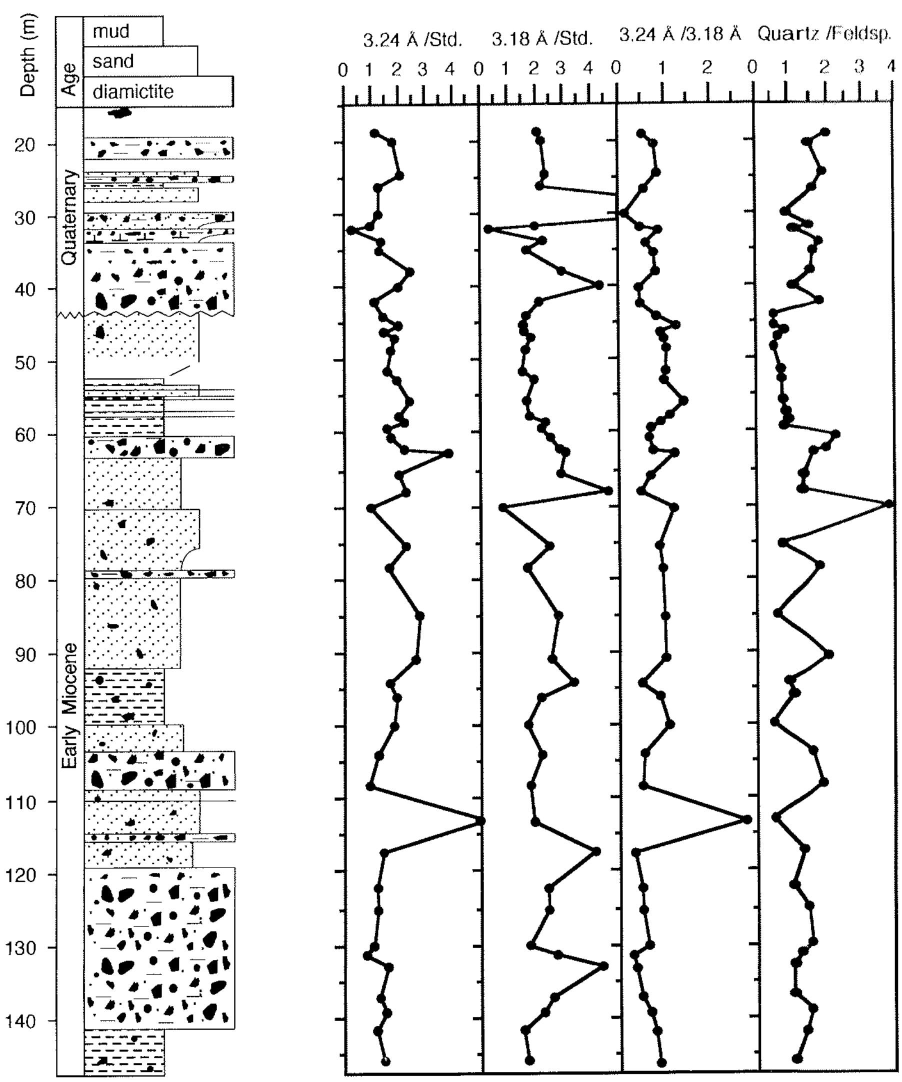


Fig. 3 - Abundance of K-feldspar (3.24 Å / standard) and of plagioclase feldspar (3.18 Å/standard), K-feldspar/plagioclase feldspar ratio (3.24 Å / 3.18 Å) and quartz / feldspar ratio in the CRP-1 sediments. Lithology is simplified after Cape Roberts Science Team (1998), for legend see figure 2.

Jurassic Ferrar Dolerite (Fig. 1). In the upper part of the core, three intervals have been identified that point to a main source area in the region of the present-day Ross Ice Shelf (Ehrmann, this volume). This region is characterised by large outcrops of volcanic rocks of the McMurdo Volcanic Group (Fig. 1).

The quartz content of the CRP-1 sediments, as quantified by the XRD analyses, depends strongly on the grain-size distribution. The coarser the sediments are, the higher is their quartz content (Fig. 2; *cf.* Smellie, this volume). In fact, the quartz curve correlates peak by peak with the sand concentration curve.

The quartz contents do not document the change from a quartz-rich source in the Transantarctic Mountains to a quartz-poor source in the McMurdo Volcanic Group to the south, as is suggested by the composition of the clay and sand fractions of the sediments that occur at *c.* 65 mbsf (Ehrmann, this volume; Smellie, this volume). The quartz concentrations rather indicate that the Transantarctic Mountains acted as a source throughout.

Feldspar grains are less stable than quartz, because they are softer, have a good cleavage, are usually twinned, and because of their chemical composition. They may be attacked or even lost during weathering, transport and diagenesis. Due to their relative instability, detrital feldspars are normally finer grained than the associated quartz grains. In general, the highest feldspar concentrations are therefore found in coarse siltstones, and decrease with an increase in the grain size of the sediments (*e.g.* Blatt, 1992).

In the CRP-1 sediments, the feldspar distribution pattern shows no correlation with the sediment facies. In contrast to quartz, feldspar concentrations are relatively constant throughout the sequence and seem to be largely independent of the grain sizes of the sediments (Fig. 2). Thus, the intensity of chemical weathering on the Antarctic continent, and the mechanical abrasion that took place during transport, were not strong enough to affect the sizes of the feldspar grains. Also, the values of the chemical index of alteration (CIA) are uniformly low throughout the CRP-1 core. They indicate glacial dominance and only limited chemical weathering (Krissek & Kyle, this volume).

K-feldspars are indicative of a source in the crystalline basement (Barrett et al., 1986; George, 1989; Cape Roberts Science Team, 1998; Smellie, this volume). In the CRP-1 core, they show a relatively constant concentration throughout (Fig. 3). This implies that the basement source in the Transantarctic Mountains has contributed to

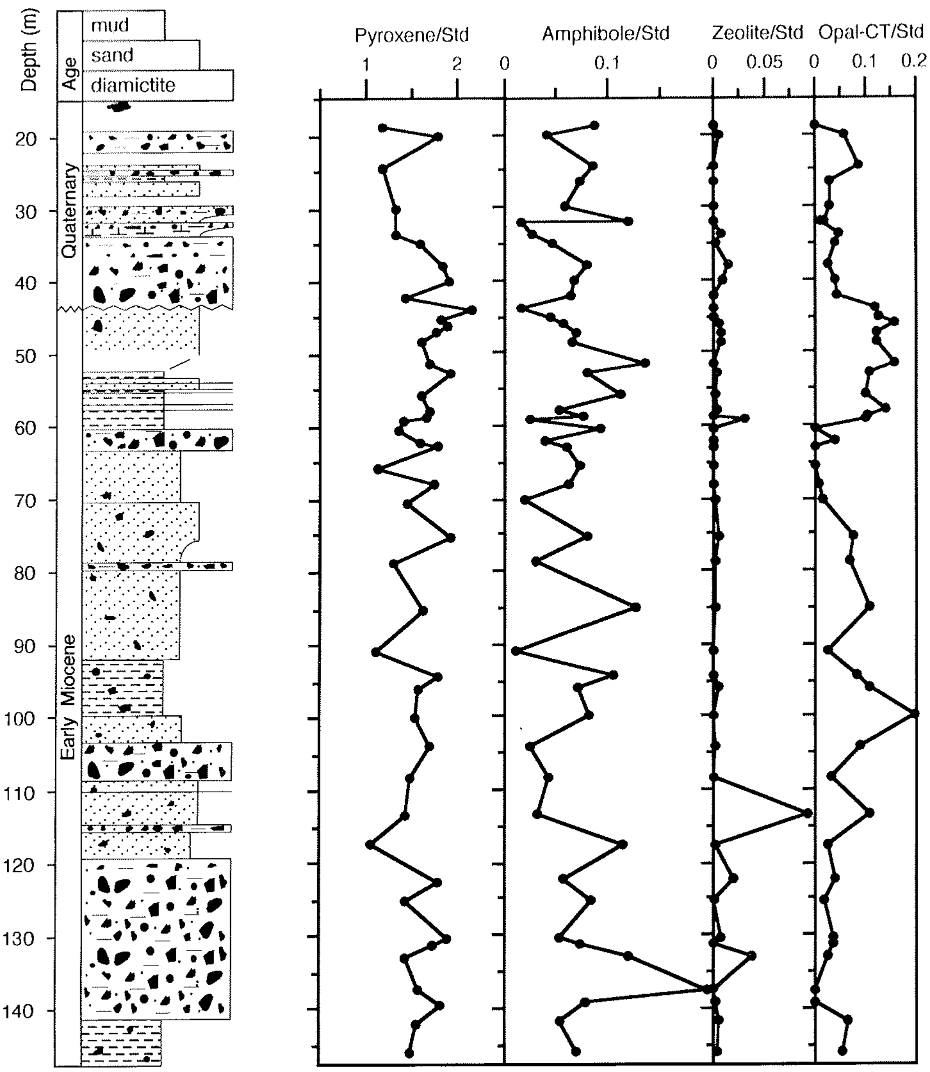


Fig. 4 - Abundance of pyroxenes, amphiboles, zeolites (clinoptilolite) and opal-CT in the CRP-1 sediments presented as ratios of mineral to corundum standard. Lithology is simplified after Cape Roberts Science Team (1998), for legend see figure 2.

sedimentation at the CRP-1 drillsite throughout the time represented by the core.

Plagioclase feldspars may be derived from various sources, such as the basement rocks, the Ferrar Dolerite, the sediments of the Beacon Supergroup, and the volcanic rocks of the McMurdo Volcanic Group (Barrett et al., 1986; George, 1989; Cape Roberts Science Team, 1998; Smellie, this volume). Also, the plagioclase minerals occur in relatively constant concentrations and do not indicate a major change in the source area (Fig. 3). Because both K-feldspars and plagioclase feldspars have relatively uniform downcore distributions, the plagioclase/K-feldspar ratio also shows no major or systematic fluctuations (Fig. 3).

Thus, the bulk mineralogy points to the main source of the sediments being the Transantarctic Mountains. The plutonic and metamorphic rocks of the basement, the sediments of the Beacon Supergroup and the volcanic rocks of the Ferrar Dolerite all contribute to the detrital components of the CRP-1 sediments. The XRD analyses of the bulk mineralogy do not indicate a major change in the source area during the time represented by the core. Therefore, they reproduce the results from the analyses of the composition of the gravel fraction, which is dominated by basement rocks (Cape Roberts Science Team, 1998; Talarico & Sandroni, this volume).

By contrast, changing source areas resulting in a sediment input from the south during deposition of the upper part of the core, are indicated by the composition of the clay mineral assemblages (Ehrmann, this volume). A possible explanation for this discrepancy could be that the fine sediment components have been transported in suspension by currents, whereas the bulk of the sediment, and especially the coarser components, have been transported by ice. Furthermore, it cannot be ruled out by the XRD analyses that the volcanic rocks of the McMurdo Volcanic Group in the south also contributed to the CRP-1 sediments, because the most diagnostic minerals of this source, such as brown hornblendes, cannot be distinguished by this method from minerals derived from the Transantarctic Mountains. Other minerals, like plagioclase feldspars, are common to both possible sources.

Although no special investigation of the diagenesis of the sediments has been carried out on these samples, some information may be gained from the XRD analyses of the sediments. A typical mineral indicating diagenetic alteration is opal-CT. This mineral occurs in relatively low amounts (Fig. 4). Opal-CT is well established as an intermediate silica phase within the maturation sequence from opal to quartz. Opal may be derived from siliceous microfossils or from volcanic glass. Because the opal-CT occurs in proximal and distal glacimarine sediments, microfossils are an unlikely source for the silica. A volcanic origin is much more probable. A persistent volcanic sediment input from the McMurdo Volcanic Group is indicated by the presence of glass and volcanic rock fragments in the sand fraction (Cape Roberts Science team, 1998; Smellie, this volume). Beside host rock lithology and interstitial water chemistry, time and temperature are the most important factors controlling the transformation of silica phases. Opal-CT occurs at lower temperatures in older sediments, whereas less time for its formation is required at higher temperatures and deeper burial (Riech & von Rad, 1979).

The diagenetic mineral clinoptilolite occurring in some samples below 110 mbsf (Fig. 4) is a potassium-rich marine zeolite of the heulandite family. It precipitates from pore water in the presence of alkalines and earth alkalines if sufficient aluminium is combined with a high level of dissolved silica (Kastner & Stonecipher, 1978). The silica may be derived either from microfossils or from volcanic glass. In the case of the Miocene sediments of CRP-1, a derivation from volcanic glass is most likely. Clinoptilolite precipitates mainly in Oligocene and older sediments, and also has been found in the Southern Ocean (Bohrmann & Ehrmann, 1991; Ehrmann & Mackensen, 1992). In the CIROS-1 drillcore, clinoptilolite occurs in upper Eocene sediments below 500 mbsf (Ehrmann, 1998).

CONCLUSIONS

Although the data presented in this paper cannot be used to determine the absolute abundances of the individual minerals in the CRP-1 core, the mineral/standard ratios make it possible to detect relative temporal abundance changes of each mineral. Most of the minerals occur in relatively constant abundances throughout the core. This indicates that the main source of the detrital sediment components did not change during the time represented by the CRP-1 core. Quartz shows the strongest fluctuations of all major detected minerals. These changes, however, do not indicate changes in the source area, but are the result of fluctuating grain-size distributions in the sediments, with maximum quartz abundances occurring in the coarser grained parts of the sediment core. Besides quartz, K-feldspars and plagioclase feldspars are abundant in all samples, whereas pyroxenes and amphiboles are less common. The bulk mineralogy strongly suggests that the principal source is the Transantarctic Mountains. The plutonic and metamorphic rocks of the basement, the sediments of the Beacon Supergroup and the volcanic rocks of the Ferrar Dolerite are possible source lithologies for the CRP-1 sediments. However, volcanic rocks of the McMurdo Volcanic Group in the south also contributed to the CRP-1 sediments. Some diagenetic alteration of the sediments is indicated by the occurrence of minor amounts of opal-CT and by some clinoptilolite below 110 mbsf.

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