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Mineralogy of Sediments from CRP-2/2A, Victoria Land Basin, Antarctica as Revealed by X-ray Diffraction

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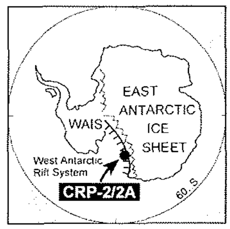

Abstract - The mineralogy of the lower Oligocene to Quaternary sediments of core CRP-2/2A drilled on the continental shelf of McMurdo Sound in Ross Sea, Antarctica, was examined by the X-ray diffraction method. Quartz, plagioclase feldspar and K-feldspar are the most important non-clay minerals. Pyroxene and amphibole occur in minor amounts throughout the core. 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 Group could serve as possible source lithologies. The distribution of the detrital minerals reflects a long-term history of successive erosion and valley incision. During the deposition of the lower part of the core, the detrital minerals were probably mainly derived from the sediments of the Beacon Supergroup, as indicated by the high quartz but relatively low feldspar abundances. In the upper *c.* 350 m of the core, the influence of a source in the basement became stronger and results in lower quartz contents but increasing abundance of feldspar. Some diagenetic alteration of the sediments is indicated by the occurrence of zeolites below *c.* 320 mbsf and of opal-CT above *c.* 320 mbsf.

INTRODUCTION

CRP-2/2A was drilled from October to December 1998 on the continental shelf of McMurdo Sound in Ross Sea, Pacific sector of the Southern Ocean, during the second campaign of the international Cape Roberts Project (Cape Roberts Science Team, 1999). Lower Miocene to Quaternary sediments had been drilled in the Victoria Land Basin during the the first campaign in 1997 (Cape Roberts Science Team, 1998). A major goal of CRP-2/2A was to recover sediments older than early Miocene. The drilling campaign was successful in this respect, and CRP-2/2A reached a depth of 624.15 mbsf (metres below sea floor). The CRP-2/2A core sampled lowermost Oligocene to Quaternary sediments (Cape Roberts Science Team, 1999).

The CRP-2/2A core consists almost entirely of proximal to distal glacimarine sediments. The lithologies comprise mainly conglomerates, diamictites, sandstones, siltstones and mudstones. The lithological sequence has been subdivided into numerous cycles, each representing a glacial sequence starting with an ice advance and followed by an ice retreat. However, no indication was found that the ice for certain time intervals totally retreated from the coast or even disappeared from the Antarctic continent (Cape Roberts Science Team, 1999).

A major objective of the Cape Roberts Project is to study changes in the Antarctic climate and dynamic of ice masses. This goal is approached with a large variety of different sedimentological, geochemical, petrological, palaeontological and geophysical methods. This paper contributes to the solution of the problem by presenting initial results on the mineralogical composition of the sediments recovered with the CRP-2/2A drill core. It focusses on the downcore distribution of non-clay minerals as revealed by X-ray diffraction (XRD). The composition and distribution of the clay minerals, of the heavy mineral fraction and of the sand fraction are treated in separate papers (Ehrmann, this volume; Polozek, this volume; Setti et al., this volume; Smellie, this volume).

METHODS

Seventy four sediment samples from the CRP-2/2A core were analysed for this study in order to investigate the mineralogical composition of the sediments by the X-Ray diffraction method. About 10 cm^3 of bulk sediment were freeze-dried. The gravel fraction (>2 mm) was removed by sieving. One aliquot of each sample was used for studying heavy minerals (Polozek, this volume) and clay minerals (Ehrmann, this volume). The other aliquot was mechanically ground. For the XRD measurement and analysis, it was mixed with an internal standard of corundum (a-Al_2O_3) at a sample/standard ratio of 5:1.

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, freeware available via the internet). The diffraction patterns were calibrated against the position of the d(012) peak of the corundum standard at 3.479 Å before being analysed.

The peak heights and the peak areas of the individual minerals were measured after subtraction of background counts. Peak heights or peak areas of the individual minerals were set in relation to those of the corundum standard. In this way, relative abundances of the individual minerals were obtained.

The abundance of quartz is presented as the ratio of the d(100) quartz peak height at 4.26 Å and the d(012) corundum peak height at 3.479 Å. We refrained from using the higher d(101) quartz peak at 3.343 Å, because this peak may be influenced by other mineral peaks, mainly by illite.

The abundance of total feldspar is expressed as the ratio of the combined 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. K-feldspar/standard ratios are based on the 3.24 Å K-feldspar peak height. Plagioclase/standard ratios are based on the 3.18 Å plagioclase peak height.

Clinopyroxenes were identified by their main reflections forming a typical peak triplet at 3.0, 2.95 and 2.90 Å. A distinction of individual pyroxenes was not possible. The characteristic peak triplet in some samples was disturbed by the occurrence of other minerals, mainly calcite. In these cases, the peak areas had to be corrected by graphically removing the calcite peaks.

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 8.4-8.5 Å. A distinction of individual amphiboles, however, was not possible.

Minerals of the heulandite-clinoptilolite group were identified by their d-spacings between 8.97 and 9.06 Å. Opal-CT 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 analysed 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 not a reliable indicator for 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 have tentative character.

All raw data are stored in the data bank of the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany, and are available via the internet (www.pangaea.de).

RESULTS

Several minerals and mineral groups could be identified in the CRP-2/2A samples (Figs. 1, 2 and 3). Quartz, plagioclase and K-feldspar are the most important non-clay minerals and occur in high amounts throughout the core. Pyroxenes and amphiboles are also common. Zeolites and opal-CT are present in minor amounts, but not in all samples.

CLAY MINERALS

No quantitative data on the distribution of clay minerals were produced for this study. Details on the composition of the clay fraction are included in special papers (Ehrmann, this volume; Setti et al., this volume). However, some general trends are also obvious from this study. The dominant clay minerals in CRP-2/2A sediments are illite and chlorite. Smectite occurs only in trace amounts. Two intervals with enhanced smectite contents, however, were found in the lower part of the core at 624-605 mbsf and 530-485 mbsf.

CARBONATE

Carbonate was detected in most of the CRP-2/2A samples. Quantification confined to a groupig into three classes: traces, common, abundant. In general, highest carbonate contents occur below *c.* 300 mbsf, with maxima at 624-545, 493, 460-424 and 338-329 mbsf. Above *c.* 300 mbsf carbonate occurs in trace amounts only. The XRD data on the carbonate content show a relatively good correlation with the chemical data from the same sample set (Dietrich et al., this volume).

QUARTZ

Quartz occurs in relatively high amounts in the lower part of the core (Fig. 1). Thus, the quartz/standard ratios range from 2 to 3 below *c.* 350 mbsf. Within this interval, a distinct minimum with quartz/standard ratios <2 is found at 485-445 mbsf. Quartz contents are lower above *c.* 350 mbsf, with quartz/standard ratios fluctuating mainly between 1 and 2 and with an upcore decreasing trend. Short but distinct maxima occur at *c.* 280, 180 and 150 mbsf.

FELDSPARS

Although the content of total feldspar fluctuates strongly, it shows a generally increasing trend between 624 and *c.* 90 mbsf, and a generally decreasing trend in the upper some 90 m of the core (Fig. 1). The same trend is visible, although less distinct, in the distribution curves of K-feldspar and plagioclase feldspar (Fig. 2). Because of the similar distribution patterns of K-feldspar and plagioclase, the K-feldspar/plagioclase ratio is relatively constant throughout the core (Fig. 2). The quartz/feldspar curve combines the features already known from the quartz and feldspar curves. On the one hand, there is an upwards decreasing trend in the quartz/feldspar ratios. On the other hand, the ratios show a steplike decrease at about 350 mbsf (Fig. 2).

PYROXENES

The distribution pattern of pyroxene shows strongly varying values from the bottom of the core to *c.* 490 mbsf. From 490 to 350 mbsf the pyroxene/standard ratios are relatively constant at about 1.2. At *c.* 350 mbsf they increase slightly to about 1.5. A second interval with strongly fluctuating values occurs in the upper part of the core at 180-120 mbsf. Above 120 mbsf the pyroxene/standard ratios range around 1.8 (Fig. 3). The record of pyroxenes in the heavy mineral fraction is subject of a paper by Polozek (this volume).

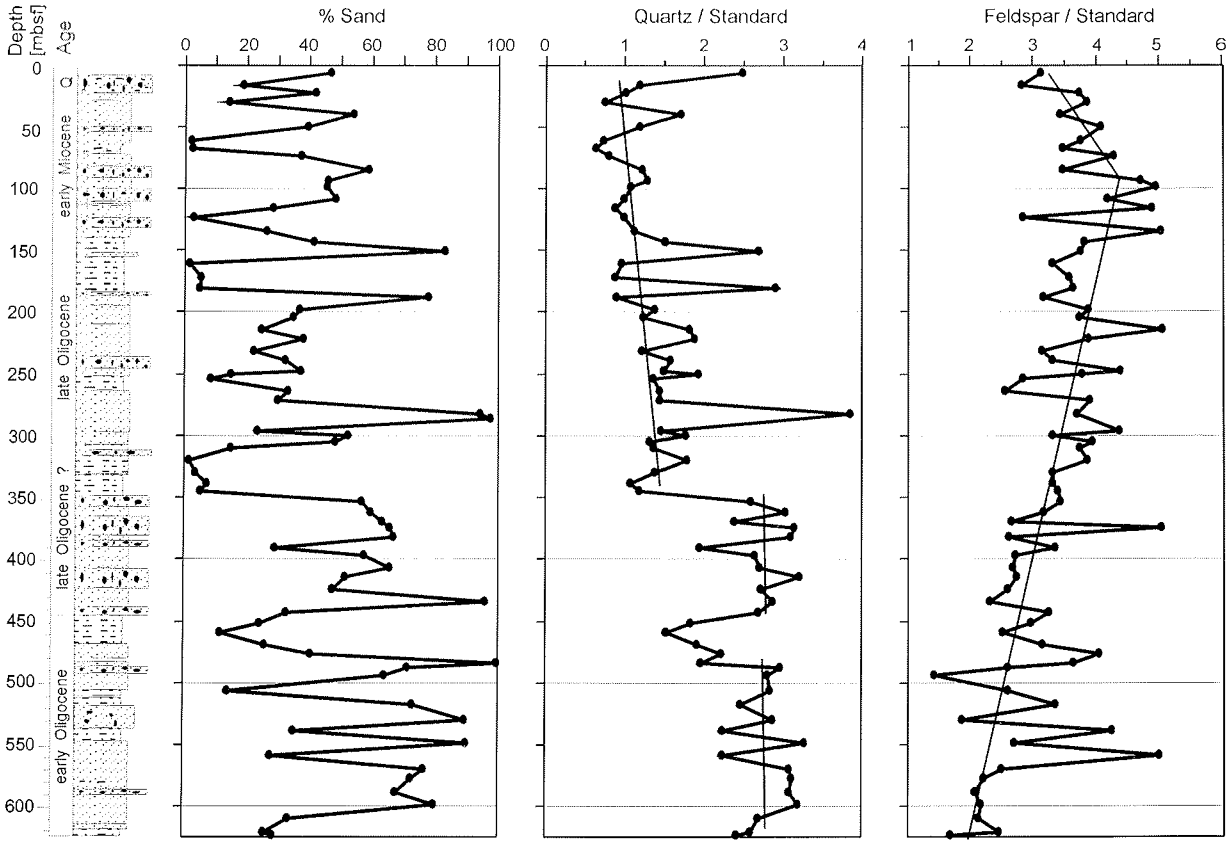

Fig. 1 - Sand content (63 µm - 2 mm) and abundance of quartz and feldspars in the CRP-2/2A sediments. Trend lines were fitted by eye. Lithology simplified after Cape Roberts Science Team (1999).

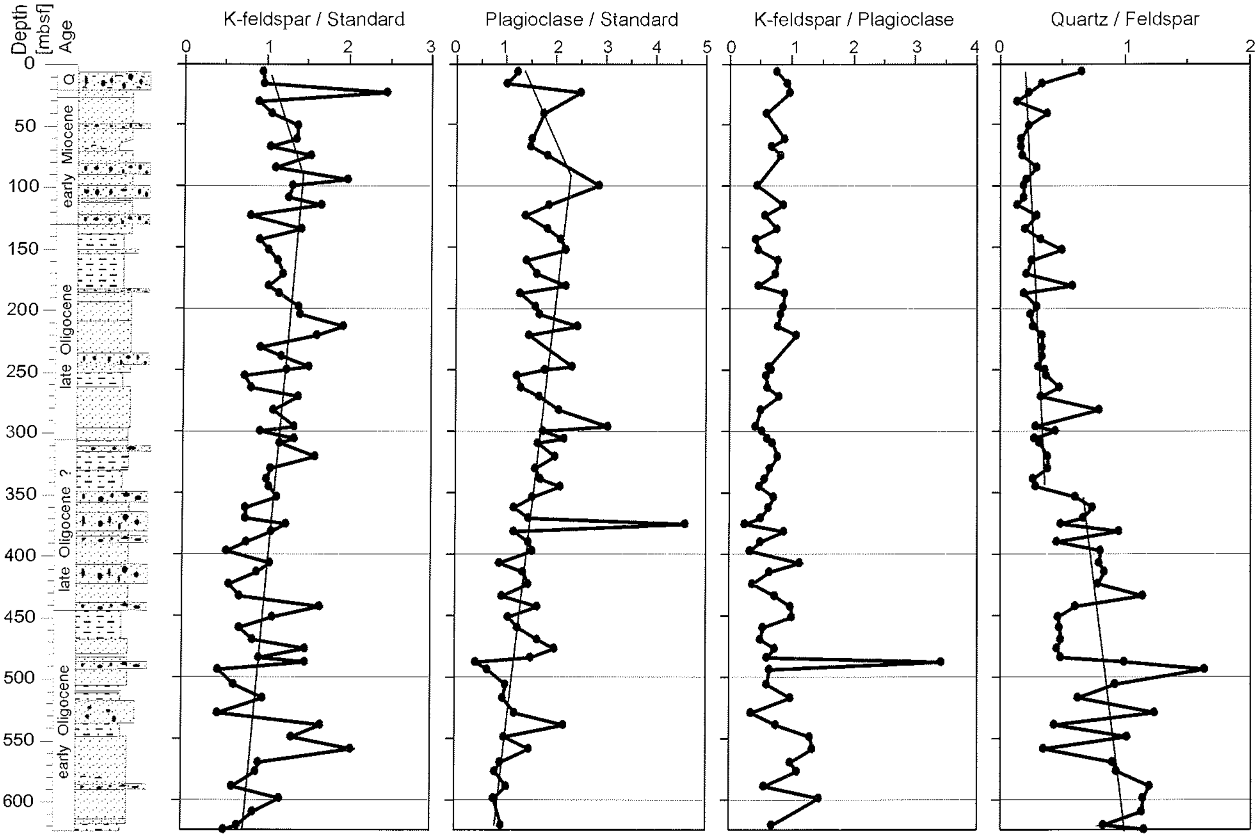

Fig. 2 - Abundance of K-feldspar and of plagioclase feldspar, K-feldspar/plagioclase feldspar ratio and quartz/feldspar ratio in the CRP-2/2A sediments. Trend lines were fitted by eye. Lithology simplified after Cape Roberts Science Team (1999).

AMPHIBOLES

Amphiboles occur throughout the CRP-2/2A core in minor amounts, with amphibole/standard ratios fluctuating between 0 and 0.1. Only 2 samples reach ratios >0.1 (Fig. 3). No distinct trend is obvious in the distribution curve. Data on the distribution of amphiboles in the heavy mineral fraction are presented in a paper by Polozek (this volume).

ZEOLITES

Minerals of the heulandite-clinoptilolite group occur in varying amounts in about half of the samples between 624 and 320 mbsf. Above, minor concentrations of zeolites were found only in a few isolated samples (Fig. 3).

OPAL-CT

The occurrence of opal-CT in the CRP-2/2A sediments is inverse to the occurrence of zeolites, i.e. detectable amounts of this mineral are confined to the upper 320 m of the core, with a trend to upcore increasing opal-CT/standard ratios (Fig. 3).

DISCUSSION

The purpose of this study was to characterize the mineralogical composition of the sediments of the CRP-2/2A core and to reconstruct their source area. A possible source area lies to the west of CRP-2/2A, in the Transantarctic Mountains. The geology of the Transantarctic Mountains (*e.g.* Warren, 1969) is characterized by a crystalline basement consisting of late Precambrian to early Paleozoic granitoids 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 dolerite sills and dykes of the Jurassic Ferrar Group. In contrast, the region of the present-day Ross Ice Shelf south of CRP-2/2A is characterized by large outcrops of volcanic rocks of the Cenozoic McMurdo Volcanic Group.

Analyses of the gravel and sand composition during initial core description (Cape Roberts Science Team, 1999) suggested a lithologically diverse source area. The sediments below a major unconformity at *c.* 307 mbsf are dominated by Ferrar Dolerite and by rounded quartz derived from the Beacon Supergroup. In contrast, the sediments above *c.* 307 mbsf comprise mainly basement-derived granitoids and minor Ferrar Dolerite. The gravel and sand fractions therefore indicate a source in the Transantarctic Mountains. The compositional change was interpreted as the result of successive erosion and valley incision in the Transantarctic Mountains, through the sediments into the basement. Above 307 mbsf there is an additional minor influx of fresh volcanic clasts sourced in the McMurdo Volcanic Group (Cape Roberts Science Team, 1999; Smellie, this volume).

Further information on the source areas comes from

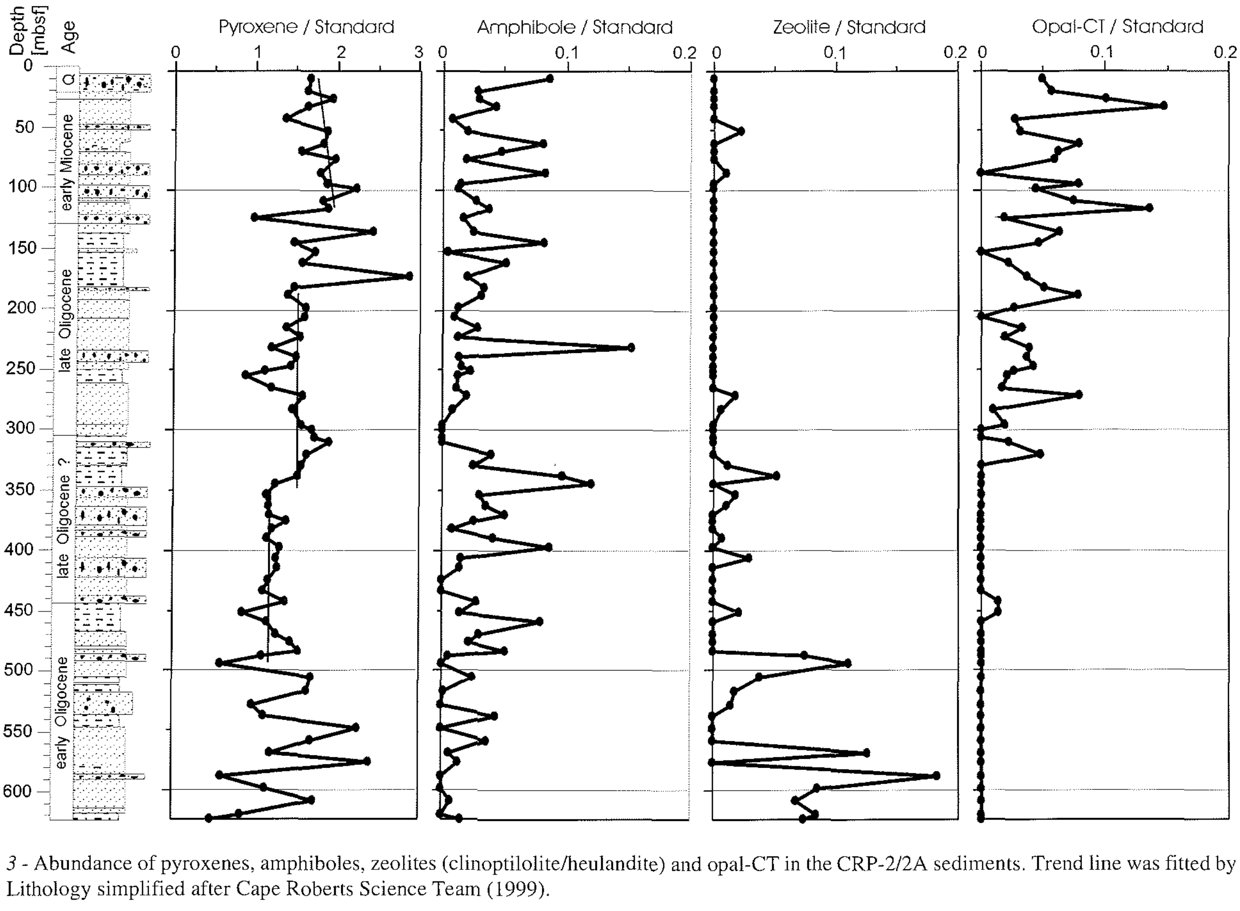

Fig. 3 - Abundance of pyroxenes, amphiboles, zeolites (clinoptilolite/heulandite) and opal-CT in the CRP-2/2A sediments. Trend line was fitted by eye. Lithology simplified after Cape Roberts Science Team (1999).

the XRD analyses. The quartz content of the CRP-2/2A sediments correlates roughly with the grain size distribution. The higher the sand concentration in the sediments, the higher is their quartz content (Fig. 1). The high quartz abundances below 350 mbsf could reflect the erosion of a quartz-rich source like the sandstones of the Beacon Supergroup. During deposition of the upper 350 m of the core, lower amounts of quartz accumulated, possibly because of the erosion of a mixed source including basement rocks, which are less rich in quartz. A shift of the source is also documented by the roundness of quartz grains. In the lower part of the core, rounded quartz grains dominate and indicate a source in the Beacon Supergroup. In the upper part of the core, angular quartz grains suggest a basement source (Smellie, this volume). This change in the composition of the source is also visible in the quartz/feldspar ratios (Fig. 2). The slightly decreasing quartz amounts in the upper 350 mbsf could indicate a further progressive shift in the source area, from Beacon Supergroup to basement rocks.

Feldspar grains are less stable than quartz. They are more susceptible to abrasion, because of a good cleavage, usual twinning, and because of their complex chemical composition. They moreover may be attacked or even dissolved during chemical weathering and diagenesis. Due to their relative instability, detrital feldspars are normally finer grained than the associated quartz grains. In general, 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-2/2A sediments, the feldspar distribution pattern shows no correlation with the sediment facies. In contrast to quartz, feldspar concentrations above *c.* 480 mbsf seem to be largely independent from the grain sizes of the sediments (Fig. 1). Thus, the intensity of chemical weathering on the Antarctic continent and the mechanical abrasion during transport was not strong enough to affect the sizes of the feldspar grains. In contrast, below *c.* 480 mbsf, feldspar contents slightly correlate inversely with the sand content. This could imply that during deposition of the lowermost part of the core some chemical weathering was active on the Antarctic continent (*cf.* Ehrmann, this volume).

K-feldspars indicate a source in the crystalline basement (Barrett et al., 1986; George, 1989; Cape Roberts Science Team, 1998; Smellie, 1998). In the CRP-2/2A core, they show increasing concentrations between 624 and *c.* 90 mbsf (Fig. 2). This implies that the basement source in the Transantarctic Mountains has been active since the early Oligocene and that it became more and more important during the Oligocene and earliest Miocene. In the upper *c.* 90 m the slight decreasing trend indicates a less strong influence from this source.

Plagioclase feldspars can 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 feldspars show slightly increasing concentrations between 624 and *c.* 90 mbsf (Fig. 2). Because they show the same trend as K-feldspars, they should be derived from the same source. The correlation of K-feldspars and plagioclase feldspars results in a relatively uniform K-feldspar/plagioclase ratio throughout the core.

Pyroxenes indicate a volcanic source like the Ferrar Group (dolerite, basalt) in the Transantarctic Mountains or the McMurdo Volcanic Group (basalt, trachyte, phonolite) in the south of McMurdo Sound. Because a distinction of individual pyroxenes was not possible, they could not be attributed to a specific source. However, the pyroxene abundance indicates a permanent and distinct, but variable influx of volcanic detritus (Fig. 3). Investigations of clasts and sand grains document an occurrence of Ferrar Dolerite throughout the core and an additional influx of detritus from the McMurdo Volcanic Group in the upper some 300 mbsf (Cape Roberts Science Team, 1999; Smellie, this volume; Talarico et al., this volume).

Within the group of amphiboles, brown hornblendes (oxyhornblende, kaersutite) indicate a source in the McMurdo Volcanic Group, whereas green and colourless hornblendes indicate a basement source (Polozek, this volume). Because a distinction of individual amphiboles was not possible, the distribution curve (Fig. 3) cannot be interpreted in respect of provenance.

Although no special investigation of the diagenesis of the sediments has been carried out, some information can 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 in the upper 320 m of core CRP-2/2A (Fig. 3). 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 glaciomarine sediments, microfossils are an unlikely source for the silica. A volcanic origin is 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 above *c.* 307 mbsf (Cape Roberts Science Team, 1999; 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). Opal-CT was found in relatively high amounts also in the upper 70 mbsf of CIROS-1 (Ehrmann, 1998a) and throughout the CRP-1 core (Ehrmann, 1998b).

The diagenetic mineral clinoptilolite occurring in some samples below 320 mbsf (Fig. 3) is a potassium-rich marine zeolite of the heulandite family. It precipitates from silica-rich interstitial water in the presence of sufficient aluminium, alkalines and earth alkalines (Kastner & Stonecipher, 1978). The silica may be derived from microfossils or from volcanic glass. The alteration of pyroxene minerals is another possible source, as indicated by the negative correlation between the pyroxene and zeolite abundances below 480 mbsf (Fig. 3; *cf.* Polozek, this volume). The abundance of aluminium, earth alkalines and alkalines in the interstitial water could be due to the dissolution of volcanic components.

Clinoptilolite precipitates mainly in Oligocene and older sediments and also was found in the Antarctic Ocean (Bohrmann & Ehrmann, 1991; Ehrmann & Mackensen, 1992). In the CIROS-1 drill core, clinoptilolite occurs in upper Eocene sediments below 500 mbsf (Ehrmann, 1998a). It is striking that in CRP-2/2A there is no overlap in the occurrences of opal-CT and clinoptilolite (Fig. 3). Obviously the physiochemical conditions for an opal-CT precipitation were not reached in the sedimentary level of clinoptilolite formation, probably because of a lower silica and higher aluminium content. The formation of large amounts of diagenetic carbonate is also restricted to the core interval below 320 mbsf (Dietrich et al., this volume).

CONCLUSIONS

Although the data presented in this paper cannot be used for determining the absolute abundances of the individual minerals in the CRP-2/2A core, the mineral/standard ratios allow to detect relative temporal abundance changes of each mineral.

Besides quartz, K-feldspars and plagioclase feldspars are abundant in all samples, whereas pyroxenes and amphiboles are less common. The bulk mineralogy points to a main source for the sediments in the Transantarctic Mountains. The plutonic and metamorphic rocks of the basement, the sediments of the Beacon Supergroup and the volcanic rocks of the Ferrar Group all contribute to the detrital components of the CRP-2/2A sediments.

The XRD analyses of the bulk mineralogy do not indicate a major change in the location of the source during the time represented by the core. However, they document a gradual change in the lithology of the rocks eroded in the Transantarctic Mountains. The lower part of the core, below 350 mbsf, represents an early phase of erosion and valley incision in the Transantarctic Mountains. During this phase, mainly sediments of the Beacon Supergroup were eroded. Therefore, the CRP-2/2A sediments are characterized mainly by quartz. As erosion progressed and the valleys were deeply incised, basement rocks were prone to erosion. This is mainly indicated by a decrease of the quartz contents and a successive increase of the K-feldspar abundance.

The XRD data confirm the results from analyses of the composition of the gravel and sand fractions. Those studies also document a progressive shift in the source rock lithologies from sediments of the Beacon Supergroup to basement rocks (Cape Roberts Science Team, 1999; Smellie, this volume; Talarico et al., this volume).

Some diagenetic alteration of the sediments is indicated by the occurrence of minor amounts of opal-CT in the upper 320 m of CRP-2/2A and by some clinoptilolite below 320 mbsf.

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REFERENCES

Barrett P.J., McKelvey B.C. & Walker B.C., 1986. Sand provenance. In: Barrett P.J (ed.), Antarctic Cenozoic History from the MSSTS-1 Drillhole, McMurdo Sound. *DSIR Bull.*, **237**: 137-144.

Blatt H., 1992. *Sedimentary Petrology*. 2nd ed., Freeman & Company, New York, 515 p.

Bohrmann G. & Ehrmann W.U., 1991. Analysis of sedimentary facies using bulk mineralogical characteristics of Cretaceous to Quaternary sediments from the Kerguelen Plateau: sites 737, 738, and 744. In: Barron J., Larsen B. et al., *Proc. ODP, Sci. Res.*, **119**, 211-223.

Cape Roberts Science Team, 1998. Initial Report on CRP-1, Cape Roberts Project, Antarctica. *Terra Antartica*, **5**(1), 187 p.

Cape Roberts Science Team, 1999. Studies from the Cape Roberts Project, Ross Sea, Antarctica. Initial Report on CRP-2/2A. *Terra Antartica*, **6**(1/2), 173 + 228 pp.

Ehrmann W., 1998a. Implications of late Eocene to early Miocene clay mineral assemblages in McMurdo Sound (Ross Sea, Antarctica) on paleoclimate and ice dynamics. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, **139**, 213-231.

Ehrmann W., 1998b. Mineralogy of sediments from CRP-1 as revealed by X-ray diffraction. *Terra Antartica*, **5** (3), 627-632.

Ehrmann W.U. & Mackensen A., 1992. Sedimentological evidence for tbe formation of an East Antarctic ice sheet in Eocene/Oligocene time. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, **93**, 85-112.

George A., 1989. Sand provenance. In: Barrett P.J. (ed.), Antarctic Cenozoic History from the MSSTS-1 Drillhole, McMurdo Sound. *DSIR Bull.*, **237**, 159-167.

Kastner M. & Stonecipher S.A., 1978. Zeolites in pelagic sediments of the Atlantic, Pacific, and Indian oceans. In: Sand L.B. & Mumpton F.A. (eds.), *Natural Zeolites, Occurrence, Properties, Use*. New York, Pergamon Press, 199-218.

Riech V. & von Rad U., 1979. Silica diagenesis in the Atlantic Ocean: diagenetic potential and transformations. In: Talwani M., Hay W. & Ryan W.B.F. (eds.), *Deep Drilling Results in the Atlantic Ocean: Continental Margins and Paleoenvironment*. AGU, Maurice Ewing Ser., **3**, 315-340.

Smellie J., 1998. Sand grain detrital modes in CRP-1: provenance variations and influence of Miocene eruptions on the marine record in the McMurdo Sound region. *Terra Antartica*, **5**(3), 579-587.

Warren G., 1969. Geology of Terra Nova Bay - McMurdo Sound Area. - *Antarctic Map Folio Series 12*. Am. Geogr. Soc., New York, Geology, Sheet 14.