Terra Antartica
2001, 8(4), 523-532

Mineralogy of Sediments from CRP-3, Victoria Land Basin, Antarctica, as Revealed by X-Ray Diffraction

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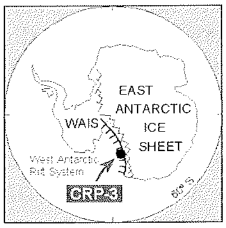
Received 11 December 2000; *accepted in revised form* 7 June 2001



Abstract - The mineralogy of the lower Oligocene (to possibly upper Eocene) sediments of core CRP-3 drilled on the continental shelf of McMurdo Sound in the Ross Sea, Antarctica, has been examined by the X-ray diffraction method. Quartz, plagioclase, K-feldspar and pyroxene are the most important non-clay minerals. Amphibole occurs in minor amounts. The composition of the sediments points exclusively to an origin in the Transantarctic Mountains for 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 Supergroup could serve as possible source lithologies. The distribution of the detrital minerals reflects a long-term history of successive erosion and beginning valley incision. During the deposition of the lowest part of the Cenozoic sediments of CRP-3, the majority of detrital minerals was probably derived from the sediments of the upper Beacon Supergroup (Victoria Group) and the Ferrar Supergroup, as indicated by the high quartz and pyroxene concentrations. Only a very minor proportion probably was contributed by basement rocks. From *c*. 620 to *c*. 420 mbsf the sandstone-dominated Taylor Group of the Beacon Supergroup probably acted as the main source rock and was responsible for maximum quartz concentrations and the strongly lowered feldspar and pyroxene amounts in the CRP-3 core. Above *c*. 420 mbsf the erosion in the valleys cutting through the Transantarctic mountains reached the level of the basement rocks and therefore the amount of basement-derived minerals like K-feldspar and amphibole in the CRP-3 sediments became more important.

INTRODUCTION

Major objectives of the international Cape Roberts Project (CRP) are to reconstruct the Cenozoic Antarctic climate, to study the dynamics of the Antarctic ice masses, and to enlighten the uplift history of the Transantarctic Mountains (Cape Roberts Science Team, 1998, 1999, 2000). These goals are approached by studying Quaternary to lower Oligocene or possibly upper Eocene sediments from drill cores recovered on the Antarctic continental shelf in Ross Sea. The sediments are investigated with a large variety of different sedimentological, geochemical, petrological, palaeontological and geophysical methods (Hambrey & Wise, 1998; Barrett & Ricci, 2000a, b). Our paper contributes to the project by presenting initial results on the mineralogical composition of the Cenozoic sediments recovered in the upper 790 mbsf (metres below sea floor) of the CRP-3 drill core. The bulk mineralogy was analysed by X-ray diffraction (XRD). This technique has been successfully used already for drill cores CRP-1 and CRP-2/2A in order to identify source rocks of the sediments and to document temporal changes in the source area (Ehrmann, 1998a; Neumann & Ehrmann, 2000).

CRP-3 was drilled as the last core of the Cape Roberts Project from October to December 1999. The drillsite was situated in the Victoria Land Basin on the continental Antarctic shelf of McMurdo Sound in the Ross Sea (Fig. 1). After the previous drilling campaigns of CRP-1 and CRP-2/2A in 1997 and 1998 (Cape Roberts Science Team, 1998, 1999), it was intended to recover sediments older than early

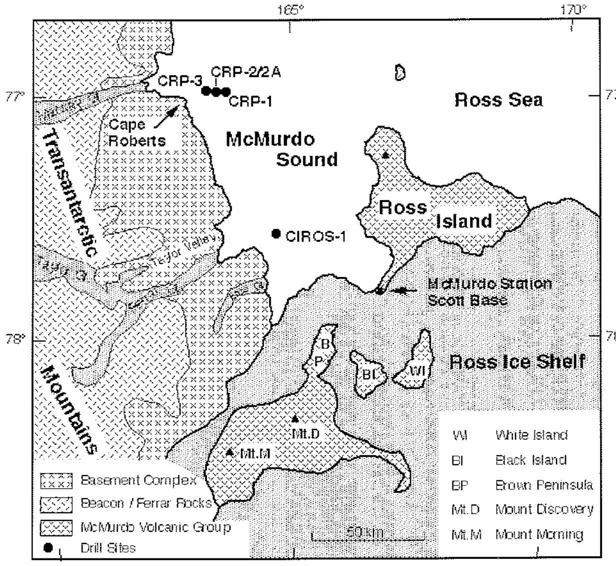


Fig. 1 - Location of the drillsites CRP-1, CRP-2/2A and CRP-3 on the continental shelf of McMurdo Sound in Ross Sea, Antarctica, and generalised geology of the hinterland (after Warren, 1969).

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Oligocene. It was expected that these sediments should document the change from a warm climate in Eocene to a cooler climate and an ice-covered Antarctica in Oligocene time. The expectations were only partly met (Cape Roberts Science Team, 2000). CRP-3 reached a depth of 939.40 mbsf and is the deepest bedrock drillhole of the Antarctic continent.

Nearly all of the cored sediments above 823 mbsf are of early Oligocene age. Only the lowermost sediments of this interval may possibly be assumed as Eocene. The sediments comprise mainly conglomerates, diamictites, sandstones and rarely siltstones and mudstones (Fig. 2). All these sediments were deposited in a glacially influenced environment. The facies range from distal to proximal glacimarine including iceberg influence and ice marginal sediments. Fluvial and deltaic sediments are also common. Evidence for glacial processes was found throughout the Cenozoic interval of CRP-3 (Cape Roberts Science Team, 2000).

The underlying sediments of CRP-3, from 823 mbsf to the final depth, have a preliminarily specified age of mid-Devonian and were assigned to the Beacon Supergroup. Mid-Devonian sandstones of the Beacon Supergroup crop out westward of the drillsite in the Transantarctic Mountains in an altitude of about 2 km. The recovery of Beacon Sandstones in such a deep level on the McMurdo shelf is an impressive evidence for the tectonic activity during the generation and opening of the West Antarctic Rift System. Thus, also the CRP-3 core did not penetrate sediments of a preglacial Cenozoic climate that is expected to have existed in Palaeocene and most of Eocene time.

The deepest sample investigated for this paper comes from about 790 mbsf. The conglomerates between 790 and 823 mbsf and the Beacon sandstone are not treated. We concentrate on presenting and discussing the downhole distribution of the main sediment components only. Details on the composition and distribution of the clay mineral assemblages and of the heavy mineral fraction are presented in separate papers (Ehrmann, this volume; Neumann, this volume; Setti et al., this volume). The composition of the sand and gravel fractions is highlighted by Smellie (this volume) and Sandroni & Talarico (this volume).

METHODS

Ninety six sediment samples taken in almost constant intervals of about 7 to 10 m from the CRP-3 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, and the gravel fraction (>2 mm) was removed by sieving. One aliquot of each sample was used further for studying heavy minerals (Neumann, 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 (α-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 1 second 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 using the "MacDiff" software (Petschick, freeware). 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 and were set in relation to those of the corundum standard. In this way, we obtained relative abundances of the individual minerals.

The abundance of quartz is presented as the ratio between 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/muscovite.

The abundance of total feldspar is expressed as the ratio between 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.

Pyroxenes 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 triple peak in some samples was disturbed by other minerals, mainly calcite; these peak areas had to be corrected manually or graphically by the software.

The abundance of amphiboles is presented as the ratio of the peak area at 8.4 – 8.5 Å and that of corundum. Hornblendes, tremolites, actinolites and riebeckites have basal reflections at about this d-value. A distinction of individual amphiboles, however, was not possible.

Zeolites of the heulandite-clinoptilolite group were identified by their d-spacings between 8.95 and 9.06 Å. Heulandite and clinoptilolite can be distinguished by their d-spacings. Whereas a peak at 8.97 Å is significant for heulandite, a 8.95 Å peak is characteristic for clinoptilolite.

Opal-CT is characterized by peaks at 4.05 and 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 as a shoulder of the d(100) quartz peak at 4.26 Å. Because plagioclase is present in high amounts, the 4.05 Å peak of opal-CT is superimposed by plagioclase. 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.

The presented data on the sand content of the sediments were a by-product gained by sieving aliquots of our samples for clay and heavy mineral analyses (Ehrmann, this volume; Neumann, this volume). 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 at www.pangaea.de.

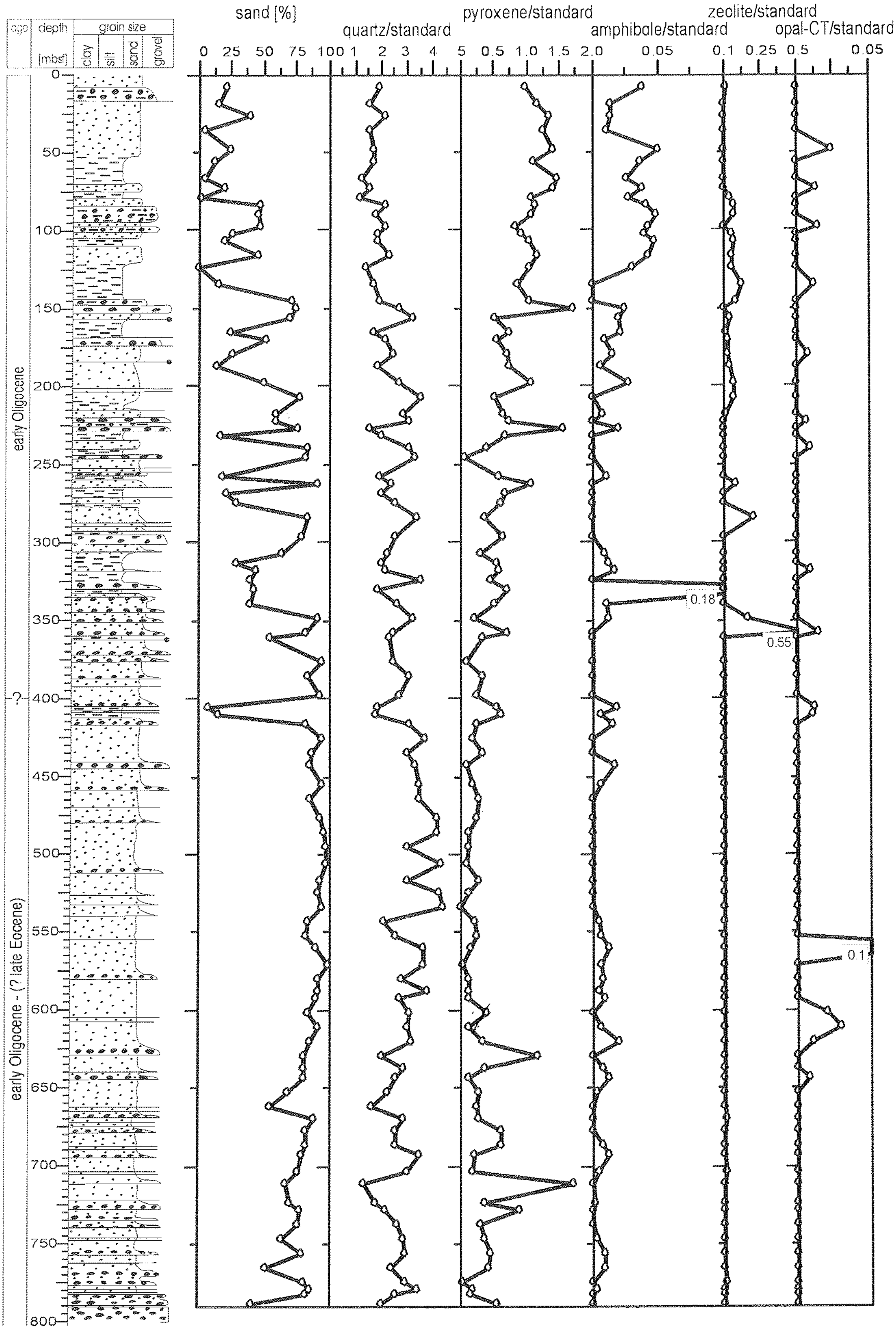

Fig. 2 - Sand content (63 µm - 2 mm), abundance of quartz, pyroxene, amphibole, zeolite and opal-CT in the Cenozoic CRP-3 sediments. Lithology simplified after Cape Roberts Science Team (2000).

RESULTS

The XRD measurements allow the identification of four main minerals or mineral groups in the CRP-3 samples (Figs. 2, 3, 4). Quartz, plagioclase, K-feldspar and pyroxenes are the most important non-clay minerals and occur in various amounts throughout the core. Amphiboles are present in minor amounts, but not in all samples. Zeolites and opal-CT are recorded as traces in isolated samples of CRP-3.

Carbonate

Carbonate, mainly calcite, was detected in variable amounts in many of the investigated CRP-3 samples.

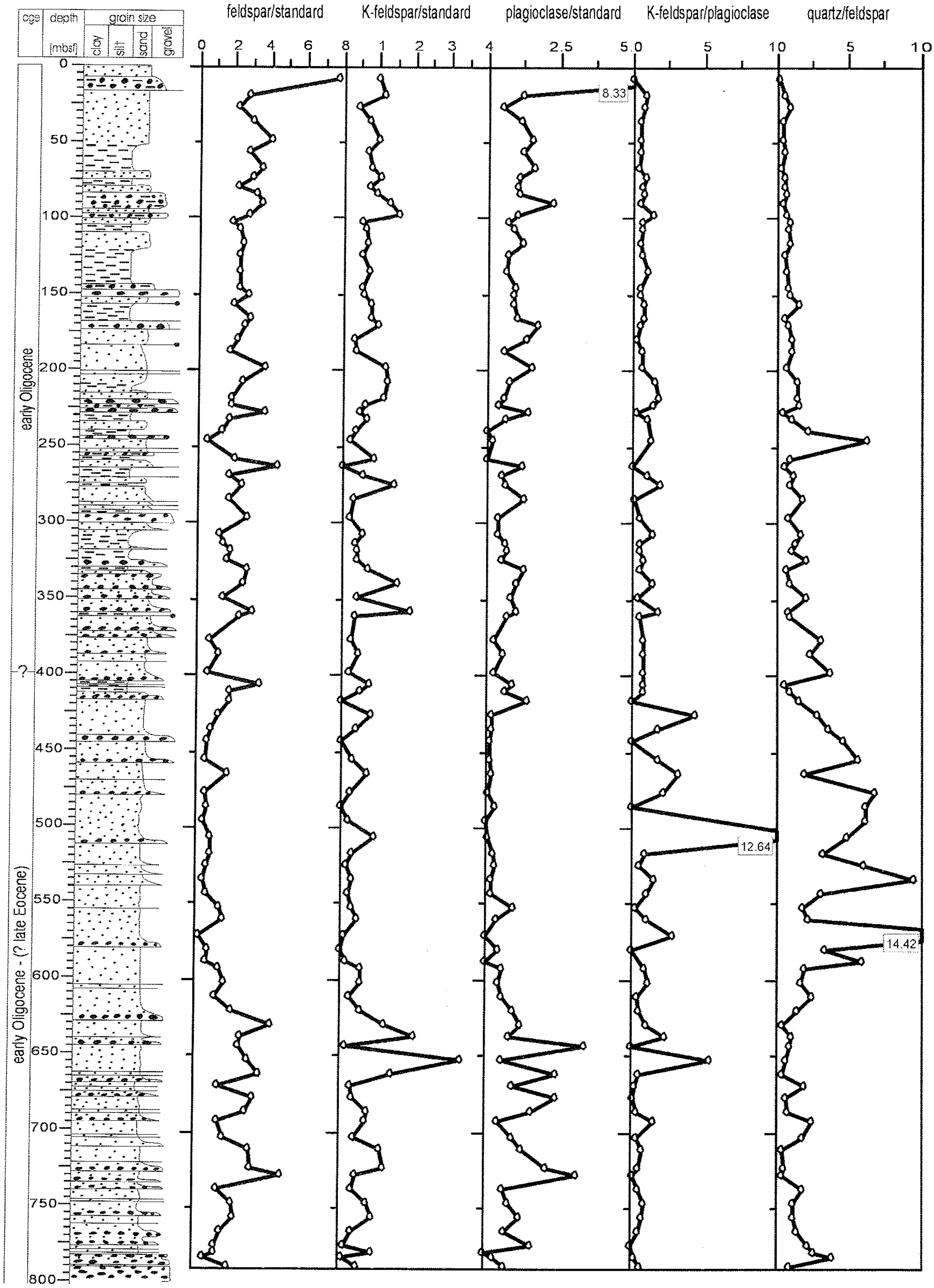

Fig. 3 - Abundance of total feldspar, K-feldspar and plagioclase, K-feldspar/plagioclase ratio and quartz/feldspar ratio in the Cenozoic CRP-3 sediments. Lithology simplified after Cape Roberts Science Team (2000).

However, they were not quantified and are not discussed in this paper, because the results of chemical carbonate analyses from our sample set are reported by Dietrich et al. (this volume).

Clay minerals

No quantitative data on the distribution of clay minerals were produced for this study, because details on the composition of the clay fraction are published in special papers (Ehrmann, this volume; Setti et al., this volume). However, clay minerals are major components of the CRP-3 sediments and, therefore, some general trends obvious from this study deserve mentioning. The main clay minerals present in CRP-3 sediments are illite, chlorite and smectite. Illite and chlorite govern the clay mineral spectrum of the upper *c.* 90 m. In this interval smectite occurs in small amounts only. Between 90 and 150 mbsf illite and smectite are the main clay minerals, whereas chlorite plays a minor role. Below 150 mbsf, in contrast, smectite is the dominant clay mineral, and all other clay minerals are totally absent or present in trace amounts only.

Quartz

Quartz occurs in high amounts in the Cenozoic sediments of CRP-3. The quartz content increases from the sea floor to 420 mbsf as indicated by quartz/standard ratios increasing from *c.* 1 to 3.5 (Figs. 2, 4). Between 420 and 620 mbsf the quartz content reaches its maximum with quartz/standard at around 4. Below the maximum, the quartz/standard ratios slowly decrease to *c.* 2.5 at the bottom of the investigated core interval. Except for the depth interval 0-140 mbsf the ratio trend is strongly fluctuating.

Feldspars

The concentration pattern of total feldspar in the core above 790 mbsf can be divided into three sections (Figs. 3, 4). There is a trend of feldspar/standard ratios decreasing from *c.* 4 to 1 between 0 and 420 mbsf. From 420 to 620 mbsf the feldspar/standard ratios are quite low and range constantly around 1. Finally, between 620 and 790 mbsf the feldspars reach a high concentration level with feldspar/standard ratios around 3 and with an

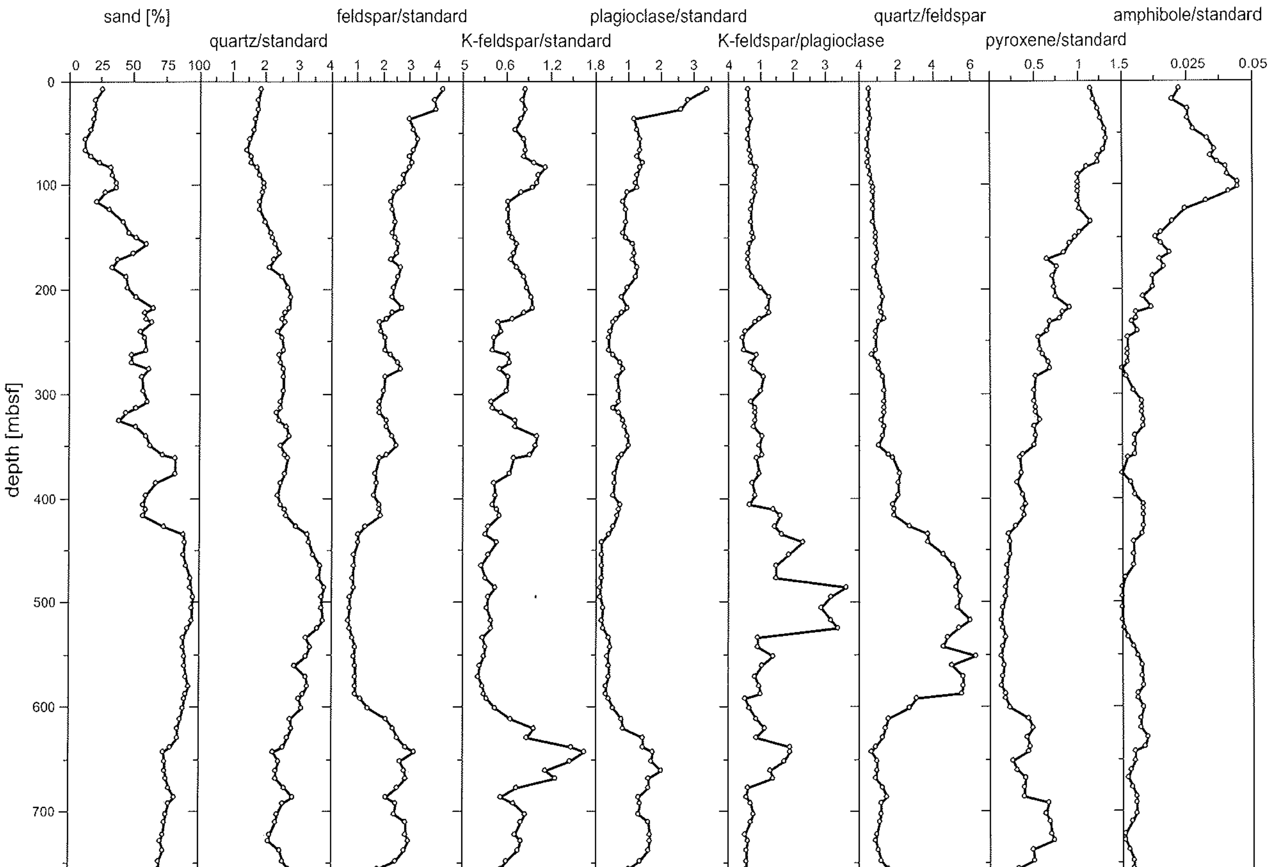

Fig. 4 - Smoothed (5-point-average) abundance of bulk mineralogy in the Cenozoic CRP-3 sediments (The outliers in quartz/feldspar at 246.03 mbsf and in amphibole/standard at 330.97 mbsf had been removed prior to the calculations).

increase at the beginning and a decrease at the end of the interval.

The described pattern of total feldspar content is mainly caused by the plagioclase abundance. However, the K-feldspar abundance curve shows a similar trend to the plagioclase curve (Figs. 3, 4). The ratio of K-feldspar/plagioclase is quite constant and fluctuates only between 0.5 and 1 above 420 mbsf and below 660 mbsf (Figs. 3, 4). K-feldspar is often more substantial than plagioclase in the interval from 420-660 mbsf, as expressed by K-feldspar/plagioclase ratios >1 (Figs. 3, 4).

The quartz/feldspar ratio curve combines and accentuates the trends of the quartz and feldspar curves (Figs. 3, 4). Because of increasing quartz and decreasing feldspar the quartz/feldspar ratio increases slightly from 0-420 mbsf. Due to the feldspar minimum and the quartz maximum at 420-620 mbsf the quartz/feldspar ratio reaches maximum values from 4 up to 14 in that interval. From 620 to 790 mbsf the ratio is quite low, constantly between 1 and 2, with a slightly increasing trend below 720 mbsf (Fig. 4).

Pyroxenes

Similar to the curves of feldspar, the distribution pattern of pyroxene can be subdivided into three main sections (Figs. 2, 4). From 0 to 420 mbsf the pyroxene/standard ratios decrease from >1 to 0.3. Between 420 and 620 mbsf the ratios are relatively constant around 0.2. The lower interval from 620 to 790 mbsf is characterized by generally enhanced pyroxene contents, but with pyroxene/standard ratios fluctuating between 0 and >1.6. The paper by Neumann (this volume) discusses the pyroxene record in the heavy mineral fraction.

Amphiboles

Amphiboles do not occur in all samples of the CRP-3 core in detectable amounts (Figs. 2, 4). In the uppermost part of CRP-3, between 0 and 130 mbsf, the amphibole/standard ratios reach up to 0.05. Apart from one strong maximum of a single sample at 330 mbsf, below 130 mbsf the amphiboles show only an incomplete occurrence and decrease generally to *c.* 0.01 – 0.02. Larger gaps in the amphibole record can be observed at 540-460 mbsf, 400-350 mbsf and 300-260 mbsf. Amphiboles in the heavy mineral fraction are treated in a paper presented by Neumann (this volume).

Zeolites

Minerals of the heulandite-clinoptilolite group were detected in low concentrations in some of the investigated samples (Fig. 2). Except for one maximum at 357.80 mbsf with a zeolite/standard ratio of about 0.55, the samples have ratios <0.2. Noteworthy, significant concentrations of zeolites occur only in the upper part of CRP-3, between 75 and 360 mbsf. In 19 of the 29 zeolite-containing samples the zeolite consists of heulandite. Only 10 isolated samples contain traces of clinoptilolite.

Opal-CT

Opal-CT is confined mainly to some isolated samples (Fig. 2) in the intervals 50-250 mbsf, 310-420 mbsf and 550-650 mbsf. Opal-CT/standard ratios in these samples average around 0.02. A maximum value of 0.1 is reached in a solitary sample at 560 mbsf.

DISCUSSION

The Cenozoic clastic sediments of the CRP-3 core were deposited in glacimarine and fluvial settings (Cape Roberts Science Team, 2000). Thus, the mineralogical composition is mainly controlled by composition of the source rocks in the hinterland. Analysing the bulk mineralogy of the sediments by XRD should therefore help in identifying source areas, weathering conditions and transport paths. Downcore changes in the distribution of individual clastic minerals are of special interest, because they could indicate reorganizations of the climate and the sediment delivery, and could help in reconstructing the uplift history of the Transantarctic Mountains. In general, the composition of the CRP-3 sediments is quite similar to those recovered at CRP-1 and CRP-2/2A (Ehrmann, 1998a; Neumann & Ehrmann, 2000).

Former investigations of drill cores CRP-1 and CRP-2/2A identified source areas in the Transantarctic Mountains to the west and in the region of the Ross Ice Shelf in the south (*e.g.* Ehrmann, 1998a; Smellie, 1998, 2000; Talarico & Sandroni, 1998; Neumann & Ehrmann, 2000; Polozek, 2000). The geology of the Transantarctic Mountains (Fig. 1; *e.g.* Warren, 1969) is characterized by a crystalline basement consisting of late Precambrian to early Palaeozoic 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 Jurassic Ferrar Dolerite. In contrast, the region of the present-day Ross Ice Shelf is characterized by large outcrops of volcanic rocks of the Cenozoic McMurdo Volcanic Group. Also for the CRP-3 sediments a multi-component source in the Transantarctic Mountains could be identified, already by preliminary analyses of the gravel and sand composition (Cape Roberts Science Team, 2000). In contrast to CRP-1 and CRP-2/2A, however, the volcanic rocks of the McMurdo Volcanic Group did not act as a source. Changes in the mineralogy of the CRP-3 sediments as revealed by the XRD analyses can be interpreted as the result of changing successive erosion and incision of valleys in the Transantarctic Mountains.

The quartz distribution in the CRP-3 core shows a rough correlation to the sand content. In general, a high amount of sand in the sediments correlates to a high quartz content (Fig. 2). Although both parameters show the same main trend, they notably differ in detail. The amplitudes in the fluctuations of the sand are very different from those of the quartz content throughout the core (Fig. 2). This implies that besides transport processes there is an additional control for the distribution pattern of quartz, probably the source area.

Quartz is a constituent of most rocks of the Transantarctic Mountains and the main component of the sandstones of the Beacon Supergroup. Because of the high quartz amounts from 620 to 420 mbsf we can assume the main sediment source for this interval in the Beacon Sandstones. This is supported by a distinctly enhanced proportion of rounded quartz grains (Smellie, this volume). The influence of the Beacon Sandstone source is obviously less pronounced below 620 mbsf and above 420 mbsf. The lower quartz content below 620 mbsf may be a result of the erosion of a mixed source consisting of the quartz-rich Beacon Supergroup sediments and the quartz-poor but pyroxene-rich Ferrar Supergroup rocks. Decreasing quartz abundances above 420 mbsf can be interpreted as a result of the progressing erosion cutting through the Beacon Supergroup sediments into the basement rocks. The quartz content further decreases in the upper Oligocene and lower Miocene sediments of core CRP-2/2A and thus indicates an ongoing incision of the valleys (Neumann & Ehrmann, 2000).

In general, the total feldspar content, which comprises the records of K-feldspar and plagioclase, shows a rough inverse correlation to both quartz content and sand concentration in the CRP-3 core (Fig. 4). Feldspars are less stable than quartz against weathering, transport and diagenesis, because of their softness, cleavage and chemical composition. Therefore they prevail commonly in finer grained sediments, predominantly in coarse siltstones (*e.g.* Blatt, 1992). However, like in CRP-2/2A, maximum feldspar amounts in CRP-3 are not confined to siltstones, but occur also in fine to medium grained sandstones and conglomerates (*e.g.* 722.92, 407.09, 330.97, 262.70 and 227.90 mbsf). This means that in addition to weathering and transport, the composition of the source area influences the feldspar content of the sediments.

K-feldspar comes mainly from crystalline basement rocks (Barrett et al., 1986; George, 1989; Hambrey & Wise, 1998; Smellie, 2000). The presence of K-feldspar in the lowermost part of the core documents that the basement was exposed and active as sediment source since early Oligocene or even late Eocene. The occurrence of small granitoid and metamorphic clasts (Cape Roberts Science Team, 2000) points into the same direction. The K-feldspar source seems to be almost exhausted between *c.* 620 and 400 mbsf. Above *c.* 400 mbsf a slight increase of K-feldspar amount (Fig. 4) indicates that the basement source became more important, even if the Beacon Supergroup still contributed large amounts of detritus of the CRP-3 sediments. This becomes also evident from the sandstone detrital modes (Smellie, this volume).

Plagioclase feldspars of CRP-3 can be mainly derived from sources such as the basement rocks, the Ferrar Supergroup, the sandstones of the Beacon Supergroup and the volcanic rocks of the McMurdo Volcanic Group (Barrett et al., 1986; George, 1989; Hambrey & Wise, 1998; Smellie, 2000). However, no volcanic rocks of the McMurdo Volcanic Group were detected in the sand and gravel fractions of the CRP-3 sediments (Cape Roberts Science Team, 2000; Smellie, this volume). Another possible source for the plagioclase could be seen in the 48 Ma old alkaline volcanism of northern Victoria Land, which is recorded by volcanic glass shards occurring in the Cenozoic interval of the CRP-3 core (Cape Roberts Science Team, 2000).

The most striking feature in the distribution of plagioclase is its very low concentration between 620 and 420 mbsf coinciding with a higher and stronger fluctuating K-feldspar/plagioclase ratio (Figs. 3, 4). The strongly reduced plagioclase input in this interval may be explained by a sediment source in the Beacon Sandstones as documented by maximum sand and quartz contents. The steady increasing feldspar abundance above 420 mbsf may be explained by an enhanced erosion of the either basement rocks or dolerites of the Ferrar Supergroup.

High abundances of pyroxenes generally indicate a volcanic source. In CRP-3, the Ferrar Supergroup is a very likely source (Polozek, 2000; Smellie, this volume). The McMurdo Volcanic Group can be excluded as a source (see above). Granite Harbour Intrusive Complex and Koettlitz Group could contribute only minor amounts of pyroxene. Unfortunately, individual pyroxene group minerals are not distinguishable by XRD. Therefore the pyroxenes could not be attributed to a specific source. In general, pyroxenes are unstable against weathering and alteration. Thus, the distribution pattern of the pyroxene group minerals may be a combined result of changing sources and varying climate and transport conditions.

The slightly enhanced pyroxene content at 750-620 mbsf may indicate the erosion of pyroxene-bearing rocks. A possible source for the pyroxene in this part of the core is the upper part of the stratigraphic sequence in the Transantarctic Mountains, including the Victoria-Group of the Beacon Supergroup and the Ferrar Supergroup with Ferrar Dolerite and Kirkpatrick Basalt. Thus, abundant clasts of Ferrar Dolerite are reported from this part of the core (Cape Roberts Science Team, 2000).

The conspicuously low pyroxene abundances at 620-420 mbsf coincide with high quartz content and low feldspar content. Such a mineral assemblage may be explained by the erosion of the older part of the Beacon Supergroup, the Taylor Group, which is almost void of Ferrar Dolerites and hence pyroxene-free. This interpretation is in accordance with the findings by Smellie (this volume) based on investigations of sandstone detrital modes. Only very low occurrences of dolerite clasts were reported from this part of the core (Cape Roberts Science Team, 2000).

The increasing pyroxene content in the upper 420 mbsf coincides with increasing feldspar and decreasing quartz abundances, which we explained as a result of erosion in the valleys of the Transantarctic Mountains reaching the basement level. However, basement rocks that represented <20% of the provenance area as postulated by Smellie (this volume) cannot explain the high pyroxene concentrations. An additional source is required and could be seen in the sills and dykes of the Ferrar Supergroup. This idea finds support in the occurrence of abundant dolerite clasts throughout this part of the core (Cape Roberts Science Team, 2000). The trend of increasing pyroxene/standard ratios continues throughout most of the sedimentary sequence of CRP-2/2A (Neumann & Ehrmann, 2000).

In the absence of detritus delivered from the McMurdo Volcanic Group, the main source for amphiboles is the pre-Devonian basement. The sporadic occurrence of amphiboles in the lower part of CRP-3 may indicate that small areas of basement were exposed to erosion. The distinct increase of amphibole amounts above *c.* 250 mbsf (Fig. 4) marks the beginning of an intensified erosion of basement rocks in incised valleys in the Transantarctic Mountains. In CRP-1 and CRP-2/2A amphibole/standard ratios were recorded which are similar or slightly higher than those in the upper part of core CRP-3 (Ehrmann, 1998a; Neumann & Ehrmann, 2000). Further investigations of the amphiboles as part of the heavy mineral fraction in CRP-3 sediments are presented by Neumann (this volume).

Although the diagenesis of the CRP-3 sediments is not a major topic of this paper, some information was gained from the XRD analyses. Opal-CT can be used as an indicator of the diagenetic alteration of the sediments. Opal-CT originates from opal-A of siliceous microfossils or from volcanic glass. It is metastable and it is transformed to microcrystalline quartz under progressing diagenesis. The transformation is mainly influenced by host rock lithology and interstitial water chemistry, time and temperature (Riech & von Rad, 1979). Siliceous microfossils as an opal source are present above 200 mbsf (Cape Roberts Science Team, 2000). Volcanic glass as the other probable source was described throughout the CRP-3 core (Cape Roberts Science Team, 2000). In CRP-3 opal-CT occurs only in trace amounts and only in isolated samples (Fig. 2). The extremely low concentrations of opal-CT may indicate that the physicochemical conditions for an opal-CT precipitation were not realised in the sediments. Another explanation for the low concentrations may be that most of the opal-CT already has transformed to microcrystalline quartz. In CRP-2/2A relatively high opal-CT/standard ratios of up to 0.1 were restricted to the upper 320 m of the core comprising lower Miocene and upper Oligocene sediments. Within this interval a clear trend to downcore decreasing concentrations could be observed. The interval 320 to 620 mbsf of CRP-3 was virtually void of opal-CT (Neumann & Ehrmann, 2000). Therefore, the poor record of opal-CT in the lower Oligocene and possibly upper Eocene sediments of CRP-3 can be regarded as the progression of the diagenetic path in the sediments off Cape Roberts.

Diagenetic minerals of the heulandite group are restricted to the interval between 360 and 70 mbsf (Fig. 2). Heulandites are potassium-rich marine zeolites, but are also known from hydrothermal formation in drusy effusive rocks or from volcanic ashes (Rößler, 1984). In marine environments heulandite precipitates from silica-rich interstitial water in the presence of sufficient aluminium, alkalines and earth alkalines (Kastner & Stonecipher, 1978), which probably come from the dissolution of volcanic feldspar components. The silica may be derived from volcanic glass or from microfossils.

Very low amounts of clinoptilolite are restricted to 10 isolated scattered samples. Clinoptilolite precipitates only under low Si/Al-ratios in the interstitial water (Kastner & Stonecipher, 1978). The far-reaching absence of clinoptilolite leads to the assumption that the Si/Al-ratios in the interstitial water were raised. The absence of remarkable amounts of clinoptilolite is an important difference to most of the Oligocene and older sediments in the Antarctic Ocean. For example, clinoptilolite was found in several Oligocene and Eocene cores recovered by the Ocean Drilling Program (Bohrmann & Ehrmann, 1991; Ehrmann & Mackensen, 1992). Also the upper Eocene sediments of the nearby CIROS-1 core contained clinoptilolite (Ehrmann, 1998b).

In CRP-2/2A, minerals of the heulandite group are mainly restricted to the lower Oligocene sediments below *c.* 480 mbsf. Maximum zeolite/standard ratios reached values of 0.1 to 0.18 (Neumann & Ehrmann, 2000). In CRP-3 the uppermost sample with notable zeolite content comes from a depth of 70 mbsf. Zeolite/standard ratios are similar as in CRP-2/2A.

CONCLUSIONS

The presented data on the bulk mineralogy of the CRP-3 sediments between the seafloor and a depth of 790 mbsf are semiquantitative abundances of individual minerals. Quartz, plagioclase, K-feldspar and pyroxene are the most common constituents of the CRP-3 sediments above 790 mbsf. These main minerals are present in all samples throughout the core, but in fluctuating amounts. Amphibole, zeolite and opal-CT contribute insignificantly to the bulk mineralogy. Relative changes of the abundance of individual minerals or mineral groups or between minerals or mineral groups give information on the sediment source as well as on the uplift and erosional history of the adjacent Transantarctic Mountains.

All of the detected, non-diagenetic minerals point to a sediment source in the Transantarctic Mountains west of the Cape Roberts region. The plutonic and metamorphic rocks of the basement, the sedimentary rocks of the Beacon Supergroup and the volcanic rocks of the Ferrar Supergroup all contribute to the detrital components of the CRP-3 sediments. Although the abundances of individual sediment components are fluctuating, they do not indicate a major change in the location of the source during the time documented by the CRP-3 core. However, the CRP-3 sediments document a gradual change in the lithology of the rocks eroded in the Transantarctic Mountains. The oldest recovered Cenozoic interval from 790 to *c.* 620 mbsf contains predominantly quartz, feldspar and pyroxene. We assume that the youngest stratigraphic units of the hinterland served as a source. These units are the upper Beacon Supergroup (Victoria Group) and the Ferrar Supergroup including the Kirkpatrick Formation. However, the occurrence of K-feldspar and of trace amounts of amphiboles indicate that probably small areas of the basement were exposed already at that time.

The sandstone-dominated Taylor Group of the Beacon Supergroup probably is the main source rock for sediments of the interval from *c.* 620 to *c.* 420 mbsf characterized by very high quartz concentrations. The lower proportion of Ferrar Dolerite sills in the Taylor Group results in the decreased pyroxene concentration of this interval. Above *c.* 420 mbsf the erosion in the Transantarctic Mountains reached the level of the basement rocks and, therefore, the amount of the basement-derived minerals amphibole and K-feldspar became more important in the CRP-3 sediments, whereas the quartz concentrations decreased steadily. The rising concentrations of plagioclase and pyroxene require an additional source, probably the sills and dykes of the Ferrar Supergroup.

Our XRD data confirm and extend the results from analyses of the composition of the gravel and sand fractions (Cape Roberts Science Team, 2000; Smellie, this volume). These studies document also a progressive shift in the source rock lithologies from sediments of the Beacon Supergroup to basement rocks caused by a progressive uplift during deposition of the sediments below 500 mbsf, and by a stable, reduced uplift during deposition of the sediments above 500 mbsf.

Some diagenetic alteration of the sediments is indicated by the occurrence of trace amounts of opal-CT in several intervals of CRP-3 and by some zeolite mainly confined to depths between 360 to 80 mbsf.

ACKNOWLEDGEMENTS - Thanks to the Cape Roberts Camp Team and the Crary Lab Team at McMurdo for discussions, sampling and a fine drilling season. All laboratory work for this study was carried out at the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany. H. Rhodes is appreciated for technical assistance. Reviews by L. Marinoni, I. Memmi and U. Schüssler helped to improve the manuscript. Financial support was provided by the *Deutsche Forschungsgemeinschaft*.

REFERENCES

Barrett P.J. & Ricci C.A. (eds.), 2000a. Studies from the Cape Roberts Project, Ross Sea, Antarctica. Scientific Results of CRP-2/2A. Part I. *Terra Antartica*, **7**, 211-412.

Barrett P.J. & Ricci C.A. (eds.), 2000b. Studies from the Cape Roberts Project, Ross Sea, Antarctica. Scientific Results of CRP-2/2A. Part II. *Terra Antartica*, **7**, 413-654.

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, 1998a. Initial Report on CRP-1, Cape Roberts Project, Antarctica. *Terra Antartica*, **5**, 1-187.

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

Cape Roberts Science Team, 2000. Studies from the Cape Roberts Project, Ross Sea, Antarctica. Initial Report on CRP-3. *Terra Antartica*, **7**, 1-209 (+ supplement 305 pp.).

Dietrich H.-G., Klosa D. & Wittich C., 2001. Carbonate content in CRP-3 drillcore, Victoria Land Basin, Antarctica. This volume.

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

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

Ehrmann W., 2001. Variations in smectite content and crystallinity in sediments from CRP-3, Victoria Land Basin, Antarctica. This volume.

Ehrmann W.U. & Mackensen A., 1992. Sedimentological evidence for the 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.

Hambrey M. & Wise S. (eds.), 1998. Studies from the Cape Roberts Project, Ross Sea, Antarctica. Scientific Report of CRP-1. *Terra Antartica*, **5**, 255-713.

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.
Neumann M., 2001. Preliminary investigations of the heavy mineral record from CRP-3 drillcore, Victoria Land Basin, Antarctica. This volume.
Neumann M. & Ehrmann W., 2000. Mineralogy of sediments from CRP-2/2A, Victoria Land Basin, Antarctica as revealed by X-ray diffraction. *Terra Antartica*, **7**, 561-566.
Polozek K., 2000. Distribution of of heavy minerals in CRP-2/2A, Victoria Land Basin, Antarctica. *Terra Antartica*, **7**, 567-573.
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 Palaeoenvironment*. AGU, Maurice Ewing Ser., **3**, 315-340.
Rößler H.J., 1984. Lehrbuch der Mineralogie. Deutscher Verlag für Grundstoffindustrie, Leipzig, 834 p.
Sandroni S. & Talarico F., 2001. Petrography and provenance of basement clasts and clast variability in CRP-3 drillcore (Victoria Land Basin, Antarctica). This volume.
Setti M., Marinoni L. & Lopez-Galindo A., 2001. Crystal-chemistry of smectites in sediments of CRP-3 drillcore (Victoria Land Basin, Antarctica): preliminary results. This volume.
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**, 579-587.
Smellie J., 2000. Erosional history of the Transantarctic Mountains deduced from sand grain detrital modes in CRP-2/2A, Victoria Land Basin, Antarctica. *Terra Antartica*, **7**, 545-552.
Smellie J., 2001. History of Oligocene erosion, uplift and unroofing of the Transantarctic Mountains deduced from sandstone detrital modes in CRP-3 drillcore, Victoria Land Basin, Antarctica. This volume.
Talarico F. & Sandroni S., 1998. Petrography, mineral chemistry and provenance of basement clasts in the CRP-1 drillcore (Victoria Land Basin, Antarctica). *Terra Antartica*, **5**, 601-610.
Warren G., 1969. Geology of Terra Nova Bay - McMurdo Sound Area. - *Antarctic Map Folio Series 12*. Am. Geogr. Soc., New York, Geology, Sheet 14.