Preliminary Investigations of the Heavy Mineral Record from CRP-3 Drillcore, Victoria Land Basin, Antarctica

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Abstract - Cenozoic and Devonian sediments obtained in CRP-3 drillcore recovered on the continental shelf of McMurdo Sound in Ross Sea, Antarctica, have been investigated for their heavy mineral content. The heavy mineral spectrum of the CRP-3 sediments is dominated by pyroxenes, amphiboles, stable minerals, alterites and opaque grains. Within the group of stable heavy minerals, zircon, garnet, titanite, apatite and tourmaline are quantitatively most important. Several sections of the CRP-3 core contain considerable amounts of carbonate minerals or topaz. The core section above c. 150 mbsf contains on average twice as many heavy minerals as the section below 150 mbsf including the Devonian Beacon sandstone. The Cenozoic sediments can be distinguished from the Devonian sediments by the presence of pyroxenes and garnet in the Cenozoic sediments, which are absent in the Devonian Beacon sediments. This paper is confined to the presentation of the results of heavy mineral analyses. Only short discussions or references to other investigations and results of the CRP-3 core are made. More detailed interpretations require a higher resolution of analysis, which is scheduled to be carried out.
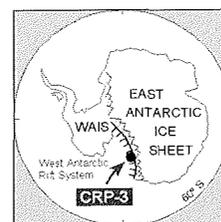
INTRODUCTION

The CRP-3 core was recovered from the last drill hole of the international Cape Roberts Project in the Victoria Land Basin on the continental Antarctic shelf of McMurdo Sound in the Ross Sea. The history, objectives and results of the Cape Roberts Project and CRP-3 are given in detail in Cape Roberts Science Team (1998, 1999) Hambrey & Wise (1998), Barrett & Ricci (2000a, b) and in Neumann & Ehrmann (this volume).

Major objectives of the Cape Roberts Project are to study changes in the Cenozoic Antarctic climate and in the dynamics of the Antarctic ice masses. These goals are approached with different sedimentological, geochemical, petrological, palaeontological and geophysical methods. Within that scope, the results of the initial investigations on the heavy mineral record of CRP-3 are presented here. We use heavy mineral analysis as a method for reconstructing relationships between sediments and their source areas. It has to be considered, however, that not only the source rocks control the heavy mineral distribution in sediments. The heavy mineral content of sediments will be affected by climate and the kind of erosion in the source area, the chemical and physical conditions during transport processes, sorting and hydraulic effects and mineral solution and recrystallisation during diagenesis (Boenigk, 1983; Mange & Maurer, 1991; Morton & Hallsworth, 1999).

METHODS

Ninety six samples were available for heavy mineral separation, taken at almost constant intervals from the Cenozoic section of the CRP-3 core. Fifty four of the 96 samples were selected for heavy mineral optical analysis. The average distance between the selected samples was about 16 m. Additionally, 7 samples of the Devonian Beacon Sandstone section from 939.40 to 823.11 mbsf (metres below seafloor) of CRP-3 were used for heavy mineral identification.

The preparation of the samples was done in the same way as for the heavy mineral investigation of CRP-1 and CRP-2/2A (Polozek & Ehrmann, 1998; Polozek, 2000). The very fine sand fraction (63-125 μm) of each sample was gained by sieving. The samples were not treated with any chemicals or subjected to any other type of separation (e.g. magnetic separation) before or after the density separation. A sodium metatungstate solution with a density of 2.85 $g \cdot cm^{-3}$ was used for the separation of the light and heavy minerals. After 20 minutes centrifuging at 3000 rpm (rotations per minute), the heavy minerals at the bottom of the test-tubes were fixed by freezing with liquid nitrogen. Then the light mineral fraction was washed with distilled water into a filter and after defreezing the heavy mineral fraction was washed into another filter. The dried heavy mineral fraction of each sample was weighed and mounted in Meltmount (refractive index=1.68) onto

glass slides under maximum temperatures of 120°C. Identification and counting of the heavy mineral grains was exclusively performed with a polarising microscope. A minimum of 300 grains in each sample were counted and identified along different traverses. The results of the heavy mineral distribution are presented as grain percentages (Fig.1) based on the number of counted heavy mineral grains in each sample.

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

RESULTS

The heavy mineral concentrations range from <1 wt% up to 30 wt% (Fig. 1). The section above 150 mbsf contains an average heavy mineral content of 5 to 20 wt%. Below 150 mbsf, the sediments contain only 0-5 wt% of heavy minerals, with some isolated peak values reaching up to 25 wt%.

Twenty four minerals and mineral groups were identified during optical analysis. The heavy mineral content of the CRP-3 core is dominated by pyroxenes, stable minerals, alterites, opaque grains and amphiboles. A strikingly high content of carbonates (up to 85 %) was recorded between c. 550 and 450 mbsf.

CENOZOIC SECTION (0 – 823.11 mbsf)

Pyroxenes

The pyroxenes in sediments from CRP-3 are mainly clinopyroxenes. The average clinopyroxene/orthopyroxene ratio is 11.3 and there are no significant differences between the distribution pattern of clinopyroxenes and orthopyroxenes throughout the Cenozoic interval of the core. A more detailed distinction of single pyroxene minerals is not possible by optical means. All varieties of pyroxenes are combined in a single "pyroxenes" group. The following main intervals can be distinguished in the pyroxene distribution. From 780 to 630 mbsf the pyroxene content ranges between 20% and 80%, from 823 to 780 mbsf and from 630 to 200 mbsf between 0% and 10% with four isolated, unusual higher abundances up to 90% at 542.73, 361.92, 297.31 and 227.90 mbsf. The highest pyroxene concentration was recorded above 200 mbsf with 60% to 90% (Fig. 1).

Almost all clinopyroxenes and orthopyroxenes show cleavage. Grains without a visible cleavage are very rare. The mineral grains often show solution marks, hence the subrounded to rounded grains appear angular or broken. Besides the pale green to pale brownish-green pyroxenes without pleochroism, more intensively coloured grains show weak pleochroism. Titanaugite, often found in the other CRP holes, was not found in any of the analysed samples.

Stable minerals/garnet

Several minerals, which are relatively stable against weathering, mechanical abrasion and diagenesis, form the group of the "stable minerals". The group comprises minerals of the epidote group (epidote, clinozoisite), zircon, titanite, rutile, apatite and tourmaline. Above 200 mbsf the stable minerals occur in minor amounts < 5%. Below 200 mbsf all of the stable minerals become more abundant. Proportions of individual stable minerals reach up to 70 % (e.g. garnet at 505 mbsf and 570 mbsf). The content of stable minerals (stable minerals + garnet) between 823.11 and 200 mbsf fluctuates from 5% to 90%. Because of the differing distribution pattern of garnet (no garnet in the Devonian section below 823.11 mbsf), this stable mineral is shown separately in figure 1. The occurrence curve of garnet in the Cenozoic section resembles essentially the curve of the stable minerals. Some more important divergences of the distribution of garnet compared with other stable minerals are recorded at 406.09 mbsf, 443.05 mbsf, 571.10 mbsf and at 774.84 mbsf. In general the amounts of garnet (0-70%) fluctuate more strongly than the content of other stable minerals (0-30%).

In order to circumvent problems of dilution caused by abundant pyroxene grains above 200 mbsf, the pyroxenes were excluded by statistic calculations. The results of the additional statistics show that the contents of stable minerals and garnet are not greatly diminished in the section above 200 mbsf compared with lower levels in the core.

Alterites & opaque grains

All the minerals lacking definite optical characteristics were counted as alterites. They are always dark coloured and, as a result of progressive alteration, at most translucent. The nontransparent mineral grains were counted as opaque grains.

The content of alterites and opaque grains in the Cenozoic CRP-3 section ranges up to 10% above 200 mbsf and fluctuates from 5% to 45% below 200 mbsf (Fig. 1). Opaque minerals are significantly more abundant than the alterites in the intervals below c. 520 mbsf and from c. 410 to 200 mbsf. The combined alterites and opaque grains reach a relatively constant concentration of about 25% between 450 and 200 mbsf and below 750 mbsf. The lowered values between 750 and 430 mbsf and above 200 mbsf are a result of the diluting effect of high carbonate or pyroxene content at the same depth interval.

A few grains of the opaque minerals in different samples are magnetic.

Preliminary Investigations of the Heavy Mineral Record from CRP-3 Drillcore 519
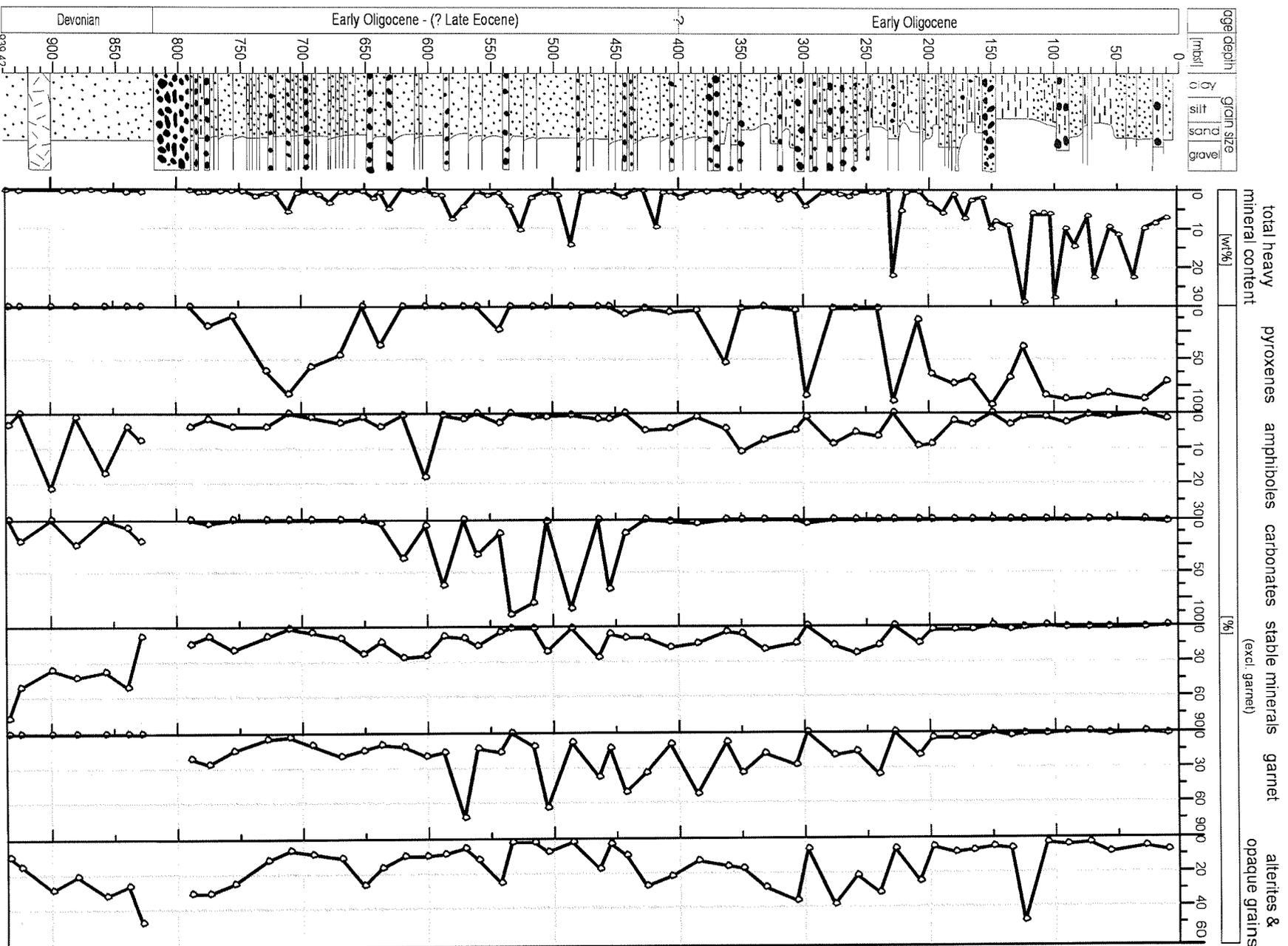
Fig. 1 - Abundance of selected heavy minerals or mineral groups in the CRP-3 sediments. Lithology simplified after Cape Roberts Science Team (2000).

Amphiboles

The amphiboles are green, brown, red or blue coloured, colourless, with or without pleochroism and show cleavage or no cleavage. The amphiboles total includes all varieties of amphiboles. Amphiboles occur in nearly all samples of the Cenozoic CRP-3 core (Fig. 1). Above 200 mbsf and below 400 mbsf the amphibole content is quite low (<5%). From 400 to 200 mbsf the amphibole proportion ranges from around 5% up to 10%. At 601.75 mbsf a sample containing 18.1% amphiboles was recorded. The most abundant amphiboles are greenish-brown or greenish-blue hornblendes with maximum contents of c. 5%. Although occurring only in small amounts < 2.5%, some amphiboles differ in their distribution patterns. Thus, blue amphiboles (glaucophane or riebeckite) are restricted to a depth interval from 770 to 200 mbsf and colourless amphiboles (tremolite ?) occur almost exclusively above 410 mbsf. Identification of the blue amphiboles is only by optical methods, not by chemical or microprobe analyses, and all are provisionally classified as blue, Na-bearing or alkaline amphiboles (cf. Mange & Maurer, 1991). Blue alkaline amphiboles can be used as a specific source-related mineral like titanaugite. After Ghent & Henderson (1968), these amphiboles are present in the Precambrian and lower Palaeozoic rocks of the basement and as arfvedsonite in the McMurdo Volcanic Group. Skinner & Ricker (1968a, 1968b) described blue amphiboles from the Beacon Supergroup and from the granitoids of the Granite Harbour Intrusive Complex. No significant distribution of cleaved and uncleaved amphiboles was observed. Because of their provenance-specific nature, further investigations shall include a more detailed classification of amphiboles.

Carbonates

A striking feature of the heavy mineral assemblage in the CRP-3 record is the erratic but generally high abundance of carbonate minerals in the interval from c. 650 to 450 mbsf (up to 84% of the heavy mineral fraction). The mainly colourless, sometimes reddish-brown-coated carbonates have an angular to subrounded shape and are partly contaminated with dirty coatings. The carbonate grains often have an internal nucleus consisting of pyroxene. This could indicate that the carbonate is authigenic. A reaction between the pyroxenes and the sodium metatungstate solution during the separation of heavy and light minerals can be excluded. Such a reaction might produce scheelite. Since scheelite was not observed in the samples, it is not probable that the minerals were influenced by the density separation. Taking all optical characteristics of the carbonate grains into account, it is likely that the samples in the interval 650 to 450 mbsf contain minerals of the dolomite-ankerite series.

Others

Other minerals occur in very low amounts or with patchy distribution. Micas, represented mainly by biotite and chlorite, were detected above 200 mbsf only in amounts < 5%. Below that depth, micas become more abundant in few samples with concentrations up to 19%. Although not a heavy mineral, rare grains of glass with a general abundance < 1% were recorded at 756 mbsf, 450 mbsf and from 330 to 150 mbsf.

BEACON SANDSTONES (823.11 to 939.42 mbsf)

The heavy mineral distribution of the Beacon Sandstones of the CRP-3 core is based on 7 samples (Fig. 1). The heavy mineral content of the sandstones is dominated by alterite and opaque minerals, stable minerals and amphiboles (Fig. 1). Pyroxenes are very rare and garnet is absent. Alterite and opaque minerals range from 10 to 50% with a decreasing downcore trend. The stable minerals alternate with the alterite and opaque minerals and show an increasing downcore trend from 10% up to 80%. Amphiboles are more abundant in the Beacon Sandstones than in the Cenozoic section. The amphibole content reaches up to 22% with no obvious trend.

The alterites/opaque grains ratio in the sandstones is rather irregular. Whereas alterites dominate in the upper samples, very well rounded opaque grains clearly preponderate in the lowermost sample at 935.32 mbsf. The appearance of the alterite minerals changes throughout the section. In particular, the sample at 828.08 mbsf, close to the lowermost Cenozoic conglomerates, contains reddish-brown angular alterites with very angular rims, which resemble the carbonate minerals in the Cenozoic section from c. 650 to 450 mbsf. These alterites can be distinguished from the carbonates, which are also present in that sample. The other alterites are usually dark grey to brownish black and subrounded to angular.

Zircon, tourmaline, titanite and apatite are the most abundant stable minerals. The ratios of the single stable minerals vary throughout the Devonian section. Zircon dominates the sample at 858.12 mbsf, tourmaline the sample at 840.27 mbsf - each mineral forming 27% of the total heavy mineral fraction. Apatite reaches 35% in sample 935.12 mbsf. In that sample strongly weathered apatites with solution marks also occur uniquely, together with well rounded and fresh apatites and nearly isotropic apatites with a hexagonal shape. Zircon occurs as colourless, clear and sub- to well rounded grains and as idiomorphic to subrounded turbid grains with many concentric growth lines. The subrounded titanites are commonly strongly weathered and show a dark and scarred surface.

The amphibole group mainly consists of brownish green and reddish brown hornblendes. Amphiboles without cleavage are slightly more abundant than grains with cleavage. A small number of blue sodic amphiboles (glaucophane or riebeckite) were recorded in five of the seven Beacon sandstone samples.

Other minerals occurring in the Beacon section of CRP-3 are topaz, micas (mainly biotite) and rare clinozoisites. Topaz contents range up to 11%. Carbonate, between 20% and 25% is contained in the samples at 828.08, 880.46 and 925.97 mbsf. The other samples have low (<10%) or no carbonate.

DISCUSSION

The preliminary results of the heavy mineral distribution of the CRP-3 sediments show some significant characteristics. The Cenozoic sediments are distinguished from the Devonian Beacon Sandstone by the absence of garnet and the near-absence of pyroxenes in the Beacon Sandstones in the analysed samples. Amphiboles seem to be more abundant in the Beacon Sandstones than in the Cenozoic sediments. The differences in the heavy mineral assemblages of Cenozoic and Devonian sediments will be investigated further in the future. In particular, more samples from the Beacon Sandstones will be investigated for their heavy mineral content in order to determine specific characteristics and to compare them with samples of Beacon Sandstones from the Transantarctic Mountains.

The Cenozoic interval of the CRP-3 core shows two sections with differing heavy mineral distribution patterns. Above 200 mbsf, the heavy mineral fraction consists mainly of pyroxenes and minor alterites and opaque minerals. Below 200 mbsf, the heavy mineral assemblage mainly comprises stable minerals, alterites, opaque minerals and small amounts of amphiboles. Minerals of the pyroxene group and carbonate minerals are dominant in various intervals between 200 mbsf and at the base of the Cenozoic section of the CRP-3 core.

The upper heavy mineral assemblage (200-0 mbsf) of CRP-3 is similar to lower part of CRP-2/2A with a comparable high pyroxene content. The pyroxene group of CRP-2/2A contains minor but distinct amounts of titanaugite and pyroxenes without a visible cleavage (Polozek & Ehrmann, 1998; Polozek, 2000). Titanaugite and pyroxenes without a visible cleavage are closely related to the McMurdo Volcanic Group, which is their source rock (Nathan & Schulte, 1968, Weiblein et al.,1981). In CRP-3, titanaugite and pyroxenes without a visible cleavage are totally absent. The lack of titanaugite and uncleaved pyroxenes in CRP-3 indicates that the McMurdo Volcanics did not contribute to the sediments of CRP-3. This is in accordance with the preliminary clast and sand grain analyses, which detected no input from the McMurdo Volcanic Group to the CRP-3 sediments (Sandroni & Talarico, this volume; Smellie, this volume). Thus, the rocks of the western adjacent Transantarctic Mountains are the likeliest source area. In general, all of the recorded heavy minerals of the Cenozoic CRP-3 section can originate from rocks of the Transantarctic Mountains. Polozek & Ehrmann (1998) and Polozek (2000) indicate different sources for the heavy minerals found in the CRP-1 and the CRP-2/2A core.

Previous investigations (Neumann & Ehrmann, this volume; Neumann & Ehrmann, 2000; Smellie, 2000; Smellie, this volume) document a gradual change in the lithology of the rocks eroded in the Transantarctic Mountains. In an early phase, mainly sediments of the Beacon Supergroup acted as source rocks. This was followed by a phase with a dominance of basement-derived sediments in CRP-2/2A. The heavy mineral distribution of the CRP-3 core does not clearly reflect the postulated uplift history of the Transantarctic Mountains. For example, if we assume a stronger influence of the basement rocks relative to the younger Cenozoic sediments of the CRP-3 core, the content of stable minerals should show an increasing or at least a constant trend throughout the upper 200 mbsf. The origin of the abundant garnet below 200 mbsf also generates questions. Although the investigated Beacon Sandstones samples from the bottom of CRP-3 and samples from the Transantarctic Mountains (unpublished data of the author) represent a minor section of the Beacon Supergroup, which is believed to be a main source rock for the Cenozoic sediments of CRP-3 between 790 and 420 mbsf (Neumann & Ehrmann, this volume), they contain no or at most very rare garnet. Smellie (this volume) pointed out that the basement rocks as the other source for garnet (Skinner & Ricker, 1968a, 1968b) represent <20% of the provenance area for the lower Cenozoic part of the CRP-3 sediments. Such a restricted provenance area represent a contrast to the recorded garnet concentrations up to 70%. It will be a main goal of the further investigations to balance inconsistent trends and to solve these contradictions. It is expected that erosion, transport, weathering and sorting have affected the heavy mineral distribution of the CRP-3 sediments.

The clearly subdivided absolute heavy mineral content of the samples (Fig. 1) could be a hint to the character of the main source rocks. The younger sediments above 150 mbsf with an higher total heavy mineral content are probably immature first-cycle sediments and a result of mainly non sedimentary source rocks (i.e. likely basement). Lower heavy mineral contents in the Cenozoic section below 150 mbsf are caused by multiple recycled sedimentary source rocks. Thus, the significantly decreased content of weathering - and transport-resistant pyroxenes between 650 and 200 mbsf can be interpreted as a result of repeated recycling of former recycled rocks.

Enriched concentrations of the stable minerals can be also explained by multiple recycling. The contents of stable minerals and garnet are increased in the section below 200 mbsf, which is contemporaneously characterized by lower total heavy mineral amounts. Interpreting these three distribution patterns of the section 650-200 mbsf (lower total heavy mineral concentrations, decreased pyroxenes, increased stable minerals and garnet contents) as a result of repeated recycling, suggests that sedimentary rocks acted as the main source rock. Therefore the sandstones of the Beacon Supergroup are the likeliest source rock for that section of CRP-3. Lower pyroxene concentrations may be caused by source rocks, which contain primarily no or reduced pyroxene. The sandstones of the Taylor Group as part of the Beacon Supergroup are the most important rocks containing nearly no pyroxene, respectively the lowest amount of Ferrar Dolerite sills as main source for pyroxenes. Continuing this idea the Taylor Group is the most probably source for the sediments of CRP-3 between 650 mbsf and 200 mbsf, troodly similar to interpretations of CRP-3 sand grain modes by Smellie (this volume).

The carbonate-rich samples at 650 mbsf to 450 mbsf are relatively close to the fault zone at 539 mbsf. Probably the carbonates are authigenic and were precipitated from circulating water provided by the tectonic structures. The authigenic nature of the carbonates is supported by the fact that, in samples below 180 mbsf, pyroxenes are invariably replaced by smectite or rare carbonate (Cape Roberts Science Team, 2000). On the other hand the Beacon Sandstones contain considerable amounts of carbonate in their heavy mineral fraction and are a alternative potential source rock for the Cenozoic section.

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