Terra Antartica
2000, **7**(4), 567-573

Distribution of Heavy Minerals in CRP-2/2A, Victoria Land Basin, Antarctica

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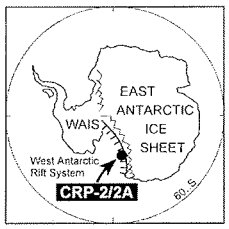
Received 3 August 1999; *accepted in revised form* 25 October 1999

Abstract - Heavy minerals from the lower Oligocene to Quaternary sediments of the CRP-2/2A drill core have been analysed in order to characterize the mineralogical composition of the sediments and to reconstruct their source areas.
In the heavy mineral spectrum, pyroxenes up to 90 % predominate. Hornblende, stable heavy minerals (zircon, garnet, epidote, titanite and apatite), opaque and altered minerals are quantitatively minor. Also titanaugite and glass occur in minor amounts.
The distribution of heavy minerals throughout the entire sediment core CRP-2/2A points to a mixed source area in the Transantarctic Mountains.
According to down-core distribution patterns of heavy minerals, the sediments of CRP-2/2A can be subdivided in two larger units. From 624 to *ca.* 270 mbsf the sediments are characterized by heavy minerals derived from source rocks in the Transantarctic Mountains, like Granite Harbour intrusive complex, Ferrar Group and Beacon Supergroup. From 270 m to top of core, an additional volcanic component, represented by titanaugite and glass, occurs in the sediments. The fluctuating influence of different source areas within the Transantarctic Mountains is shown by the existence or absence of individual minerals such as biotite and brown hornblende.



INTRODUCTION

The aim of this paper is the presentation of initial results of heavy mineral analyses carried out on sediments of CRP-2/2A core from McMurdo Sound, Antarctica, close to the Transantarctic Mountains and drilled from the seasonal sea ice of the present Ross Sea. Details of the aims, methods and further results of the Cape Roberts Project are given in this volume and Cape Roberts Science Team (1999).

In general, heavy minerals are good indicators for the reconstruction of the source area and distribution of sediments (*e.g.* Boenigk, 1983; Pettijohn et al., 1987). The dispersal of heavy minerals, and associations of different heavy minerals can in addition to other parameters, be used for reconstructing glacial history and ice sheet dynamics of Antarctica (Von der Borch & Oliver, 1968; Xianlan & Yunlong, 1990; Polozek & Ehrmann, 1998; Diekmann & Kuhn, 1999; Ehrmann & Polozek, 1999).

METHODS

The heavy minerals were separated from the very fine sand fraction (63-125 µm) of 49 samples distributed evenly throughout the CRP-2/2A core. For density separation sodium metatungstate solution was used as a heavy liquid (density = 2.83 g/cm^3). After 20 minutes of centrifuging, the test tubes containing the heavy minerals at the bottom and the light minerals at the top, were frozen in liquid nitrogen. The light and heavy mineral fractions were then thawed one after the other, decanted onto separate filters and dried. The heavy minerals were mounted with Meltmount (refraction index = 1.68), and then identified and counted under a polarization microscope.

In total, 49 samples of CRP-2/2A have been analysed so far. 23 mineral groups, including different pyroxene and amphibole varieties, were identified in the analysed sediment samples. For each sample at least 300 grains were counted along several traverses. The results are presented as grain percentages of the total heavy mineral fraction.

CHARACTERISTICS AND DISTRIBUTION

The heavy mineral dispersal in CRP 2/2A shows no significant dependence on the specific lithological facies. Consequently, sorting by different transport modes can be ruled out. Rather the heavy mineral composition is believed to reflect source area provenance.

The mineral spectrum is dominated by pyroxenes (Fig.1). Amphiboles (varieties of hornblende), stable minerals (zircon, garnet, titanite, epidote and apatite), and altered and opaque minerals occur in minor amounts. Biotite and glass are also discussed in this paper, because they are important for the reconstruction of specific local sources. Other heavy minerals are present only in trace amounts, show no significant distribution patterns and therefore are not treated in this paper.

According to the down-core distribution of heavy minerals, the sediments of CRP-2/2A can be subdivided in two larger units. From 624 to 270 mbsf (metres below sea-floor) the heavy mineral assemblage points to a source area

in the Transantarctic Mountains. From 270 mbsf to the top of the core an additional volcanic component occurs (Fig.1). It is represented by titanaugite and glass.

PYROXENES

The prismatic pyroxenes are generally pale to very pale in colour (green-brown, yellow-green, almost colourless). Some grains show exsolution lamellae. The pyroxenes are variably altered mostly to red-brown oxides (?), with the alteration apparently developing along the cleavage and extending out. Sometimes this process results in complete alteration of the original mineral. Ragged margins or cockscombs are also found, especially on grains without visible cleavage. Clinopyroxenes are most abundant, probably forming about 30-70 % of total pyroxenes. The orthopyroxenes are distinguished from clinopyroxenes only by their straight extinction, where possible, by their optical character. Therefore, pyroxenes are treated as one group in this paper (Fig.1). Titanaugite is the only pyroxene that is discussed separately. As in CRP-1 the pyroxenes can be classified according to their colour and additionally according to absence or presence of visible cleavage (Polozek & Ehrmann 1998). Thus, most pyroxenes show a distinctive cleavage, but a minor percentage have no visible cleavage. In the range from 624 to 558 mbsf, the concentration of pyroxene fluctuates strongly. The variation is caused by varying amounts of opaque, altered minerals and green hornblende. From 558 to 270 mbsf the pyroxene concentrations are relatively constant, except for a minimum at 493 mbsf. Below that level carbonate cementation is an obvious feature and most pyroxenes are transformed to calcite. In the upper part of the core (270-0 mbsf), the amounts of pyroxene vary conspicuously and are slightly lower than in the deeper part of the core. This decrease is caused by dilution with an additional occurrence of volcanic minerals (titanaugite and glass), by somewhat higher biotite amounts, as well as by a minor increase of green hornblende. Titanaugite is characterized by a typical brown-violet colour. This mineral occurs predominantly in the upper part of the core (270-0 mbsf), with its concentration increasing towards to the top of core.

STABLE MINERALS

Zircon, garnet, titanite, epidote and apatite occur only in minor concentrations of 0-5 %. Zircon grains are subrounded to rounded and range from colourless to pale yellow, red and grey-brown. Garnet grains are rounded to angular, colourless, pink and pale green. Titanite grains are subrounded and colourless to light yellow. The epidote group comprises epidote and clinozoisite. Epidote minerals occur as subrounded to rounded grains. The mainly colourless, but occasionally light grey apatite grains are subrounded to rounded. In a few samples apatite occurs in concentrations > 5 %. Because zircon, garnet, titanite, epidote and apatite very likely have the same source area

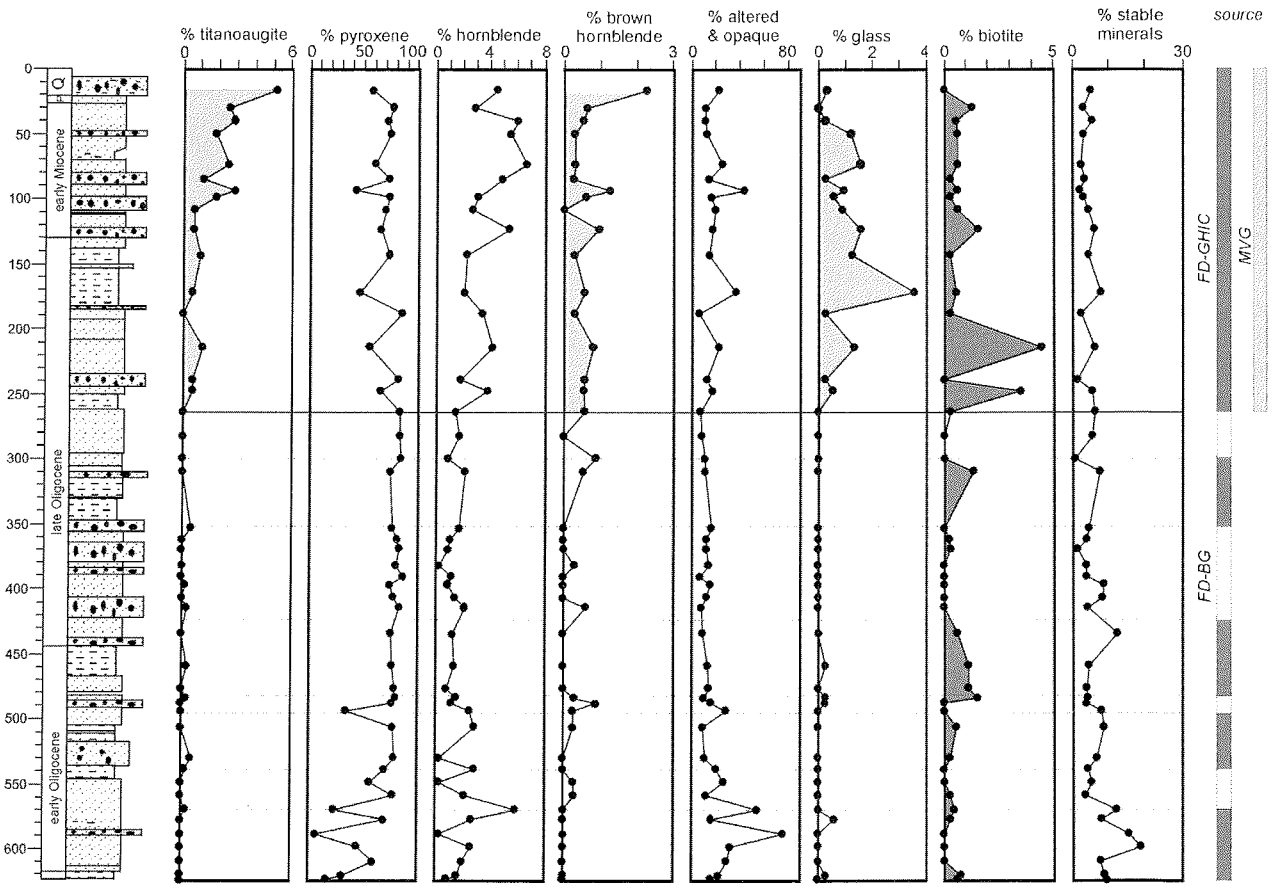


Fig. 1 - Percentage distribution of the main heavy mineral groups identified in CRP-2/2A core. The columns at right represent the dominant source. FD = Ferrar Dolerite, BG = Beacon Group, GHIC = Granite Harbour intrusive complex, MVG = McMurdo Volcanic Group.

(Ehrmann & Polozek, 1999) and because of their very low concentrations, they were combined to one group: the stable heavy minerals (Fig.1). There is no explicit correlation between the occurrence of stable minerals and that of the other mineral groups. In general, the amounts of stable minerals show a very indistinct and slight decrease between 624 and 270 mbsf. In the upper part (270-0 mbsf), the stable minerals occur in minor but constant concentrations.

AMPHIBOLES

Amphiboles were subdivided according to their colour. The petrographical characteristics suggest that they are mainly varieties of hornblende. Green hornblende shows pleochroism from green to brown, is only faintly cleaved and occurs in concentrations of 1-5 %. Colourless amphiboles (possibly tremolitic) occur only in trace amounts. Because of an assumed common source area, colourless and green amphiboles were combined into a single group (Fig.1). Down-core the green hornblende content is generally inversely correlated to the pyroxene content. From base of core to 483 mbsf, the green hornblende concentrations vary broadly, caused, in part, by higher concentrations of altered and opaque minerals and also by higher amounts of stable minerals. Above (to 270 mbsf), the concentrations are relatively constant. In the upper part, between 270 and 0 mbsf, the amounts of green hornblende, show an increasing trend.

Brown hornblende is considered separately, because it points to a different source than the other amphiboles. Brown hornblende show pleochroism from brown to red and is only faintly cleaved. Maximum concentrations are up to 5 % (Fig.1). In the lower part (624-270 mbsf) of the core, the sediments are characterized by an alternation of presence and absence of brown hornblende. An inverse correlation with biotite is obvious. Between 270 mbsf and to top of the core the amounts increase slightly, but no correlation with biotite is visible. However, there is a general correlation with volcanic minerals. Therefore, a different source is likely for the brown hornblende in this upper part.

BIOTITE

Biotite flakes are brown to dark brown with weak pleochroism. The concentrations of 0 to 5 % are low but the variations are conspicuous (Fig.1). The lower part (624-270 mbsf) of the sediment core can be subdivided in a number of individual biotite-bearing and biotite-free sections. In contrast, in the upper part of the core biotite is present in all samples, with two maxima at 214 and 247 mbsf.

VOLCANIC GLASSES

The density of volcanic glass lies at the limit of the heavy mineral fraction. The glasses discussed here, represent the brown, poor to non-vesicular varieties of the heavy mineral fraction. Therefore, the sediments likely contain more glass than observed in the heavy mineral fraction. In the heavy mineral fraction, the glasses occur in concentrations of 0-4 % above 270 mbsf. Below 270 mbsf, glass occurs only in trace amounts and only in a few samples.

ALTERED AND OPAQUE MINERALS

The heavy minerals in sediments of CRP-2/2A-core show different appearances of alteration. All brown to black minerals, which are so intensely altered that no assignment to a mineral group was possible, were grouped to altered minerals. Partially altered grains that still allowed identification of the original mineral, were included in the relevant mineral group. Because of the same down-core frequency trend, altered and opaque minerals were combined to one group. Altered minerals occur in concentrations between 5 and 40 %, opaque minerals from 1 to 6 %. In the section between 624 and 558 mbsf, the concentrations of both opaque and altered minerals increase and show strong fluctuations (Fig.1). These fluctuations correlate with the occurrence and distribution of zeolites, which developed by diagenetic processes (Neumann & Ehrmann, this volume). Up to 270 mbsf the amounts of altered and opaque minerals are quite constant, above they vary slightly.

WEATHERING OF HEAVY MINERALS

Before changes in heavy mineral spectra can be interpreted, the influence of physical and chemical weathering must be discussed. The stability and influence of weathering on heavy minerals have been discussed extensively (*e.g.* Nickel, 1973; Boenigk, 1978; Morton, 1985; Pettijohn et al., 1987). Some heavy minerals are unstable during chemical weathering but stable against physical weathering, thereby influencing the distribution of the heavy minerals. For example, garnet is less stable to chemical weathering under acidic pH conditions, but more stable to transportation. In contrast, apatite is subject to alteration in an acidic environment, but is stable under diagenetic conditions. Also, apatite grains become rounded very quickly during transportation. The pH conditions may have changed significantly and unverifiably over a long period of time. Therefore their influence on weathering of heavy minerals cannot be deduced.

Zircon is extremely stable during both chemical and physical weathering, and develops roundness only after substantial recycling. Under most conditions epidote is stable to moderately stable. Pyroxenes and amphiboles are influenced by most kinds of weathering.

In CRP-2/2 A samples, minerals mainly occur as fresh or less altered grains. Garnet and apatite are subangular to well rounded, exhibiting no evidence for chemical weathering, such as etching. Zircons and epidotes are subrounded to rounded because of transport. Pyroxenes show a variety of alteration features (see above). However, the heavy minerals show no systematic change in the intensity of alteration in their downcore distribution. Therefore, it seems that changes in the distribution patterns of heavy minerals in CRP-2/2A are not seriously biased by

weathering. The distributions probably reflect changes in sediment supply dependent on the source area. The generally low concentrations of stable minerals in the CRP 2/2A sediments must be inherited from the source rocks, which were poor in stable minerals.

SOURCE AREAS

Main sources for the heavy minerals are two different lithological areas, cropping out in the region around CRP-2/2A. The Transantarctic Mountains, west of McMurdo Sound consist of multiple rock formations. The crystalline basement consists of metamorphic rocks of amphibolite facies (*e.g.* Koettlitz Group) and the Granite Harbour intrusive complex (GHIC) composed of upper Precambrian to lower Paleozoic granitoids (Skinner & Ricker, 1968a). The overlying sedimentary rocks are mainly non-marine sandstones, quartzites and siltstones of the Devonian to Triassic Beacon Supergroup (Laird & Bradshaw, 1982; La Prade, 1982). Both basement and sedimentary rocks are intruded by sills and dykes of the Jurassic Ferrar Group. The Kirkpatrick basalts, as part of the Ferrar Group, form only a few percent of the rocks cropping out in the Transantarctic Mountains (Elliot et al., 1995). Also olivine basalts, of the McMurdo Volcanic Group (MVG), occur only in small scattered outcrops (Skinner & Ricker, 1968a). In contrast, the southern and eastern part of the McMurdo Sound, consists of outcrops of the McMurdo Volcanic Complex, which is characterized by Cenozoic alkali volcanic rocks. These rocks are exposed at Ross Island, Black Island, White Island, Brown Peninsula, Mt. Discovery and Mt. Morning (Nathan & Schulte, 1968; Cole & Ewart, 1968; Weiblein et al.,1981; Kyle, 1990).

The heavy mineral spectra of CRP-2/2A sediments are characterized by very high concentrations of pyroxenes. A source area in the Transantarctic Mountains is assumed for the pyroxenes characterized by a conspicuous cleavage. The pyroxenes possibly originate from the rocks of the Ferrar Group (Tab. 1). However, the granitoids of Granite Harbour intrusive complex are also a potential source (Smillie, 1992; Polozek & Ehrmann 1998). The other group, pyroxenes without visible cleavage, has been described from sediments in the CIROS-2 drill core, where they dominate the pyroxene assemblages. In that core their distribution pattern strongly correlates with that of heavy minerals characteristic of a volcanic provenance (Ehrmann & Polozek, 1999). Therefore a source area in the McMurdo Volcanic Group is also likely for the corresponding pyroxenes in CRP-2/2A (Tab. 1). Also, Weiblen et al. (1981) described pyroxenes from the McMurdo Volcanic Group lacking cleavage or with cleavage only poorly developed. Titanaugite is an additional indicator for sediments derived from the McMurdo Volcanic Group (Tab. 1) (Nathan & Schulte, 1968).

The green and colourless amphiboles are generally rock-forming minerals in metamorphic and intermediate magmatic rocks. A possible source for green hornblende and colourless amphiboles (tremolitic amphiboles?) could be amphibolites of the Koettlitz Group (Tab. 1). Green hornblende were also described from the GHIC (Ghent & Henderson, 1968; Skinner & Ricker, 1968a; Smillie, 1992).

Brown hornblende (oxyhornblende and kaersutite) occurs in volcanic rocks and was described from hornblende trachytes, hornblende basalts and trachyandesites of the McMurdo Volcanic Group (Cole & Ewart, 1968; Nathan & Schulte, 1968; Kyle, 1990; LeMasurier & Thomson, 1990). Another possible source is the Ferrar Group (Skinner & Ricker 1968b). Also, brown hornblende has been described from lamprophyres of GHIC (Skinner & Ricker 1968a).

For the stable minerals zircon, garnet, titanite, epidote, and apatite, a source area in the Transantarctic Mountains is assumed (Tab. 1), because these minerals are not typical for volcanic rocks. Garnet, apatite, titanite and zircon are accessory minerals in rocks of the GHIC (Ghent & Henderson, 1968; Skinner & Ricker, 1968a; Smillie, 1992). The red zircons receive their colour through long-term effects of radioactivity; so the colour will become more intense with an increase of radiation and geological age. Red zircons could be derived from Precambrian rocks (Zimmerle, 1972), as exposed in the crystalline basement of the Transantarctic Mountains. Stable minerals were also described from the metasediments and orthogneisses of the Koettlitz Group in the Transantarctic Mountains (Riddolls & Hancox, 1968; Allibone, 1987). The subrounded to rounded grains of zircon (particularly the white zircons), apatite, garnet, epidote and titanite were probably recycled from sedimentary rocks of the Beacon Supergroup (Laird & Bradshaw, 1982; La Prade, 1982) (Tab. 1).

Opaque minerals are components of all rock types. Therefore, it is difficult to focus on a predominant provenance for these minerals. However, a high concentration of opaque minerals often points to a volcanic source (Wimmenauer, 1985).

Biotite occurs in most of the intrusive and metamorphic rocks, but is rare in effusive rocks. Assumed source areas for the brown biotite are the granitoid rocks of GHIC (Tab. 1), which are partly biotite-rich (Ghent & Henderson, 1968, Skinner & Ricker 1968a; Smellie, this volume). Biotite is also known from rocks of the Beacon Supergroup, but there it is generally bleached (La Prade, 1982; Skinner & Ricker, 1968b).

Glasses are typical for volcanic rocks exposed in the south and east of McMurdo Sound, and are also described from the Jurassic Kirkpatrick basalts (Skinner & Ricker, 1968b).

DISCUSSION

The spectra of heavy minerals throughout the sediment core CRP-2/2A points to source areas in the Transantarctic Mountains. This is evident from the high percentage of pyroxenes, which occur in all samples of the CRP-2/2A core. The pyroxenes are derived mainly from the Ferrar Dolerites. Also, the proportion of clast types identified a major source in the Ferrar Dolerite (Talarico et al., this volume). From 270 mbsf to the top of core, an additional volcanic source appears in the heavy mineral fraction.

Tab. 1 - Main source rocks and provenance areas interpreted for heavy minerals in CRP-2/2A sediments.

mineral		source rocks	provenance
pyroxene	without visible cleavage	McMurdo Volcanic Group	RIS
pyroxene	with cleavage	Ferrar Group	TAM
titanoaugite		McMurdo Volcanic Group	RIS
alterites		omnipresent	RIS
opaques		omnipresent	
		McMurdo Volcanic Group	RIS
hornblende	brown	McMurdo Volcanic Group	RIS
		Ferrar Group	TAM
		lamprophyric dykes (GHIC)	TAM
hornblende	green	Koettlitz-Group	TAM
	colourless	Granite Harbour intrusive complex	TAM
biotite	brown	Granite Harbour intrusive complex	TAM
	bleached	Beacon Supergroup	TAM
glass		McMurdo Volcanic Group	RIS
		Kirkpatrick basalts (Ferrar Group)	TAM
apatite		Beacon Supergroup	TAM
		Ferrar Group	TAM
		Granite Harbour intrusive complex	TAM
zircon	colourless	Beacon Supergroup	TAM
		crystalline basement	TAM
	pink	Precambrian basement	TAM
	metamikt	?	?
titanite		Granite Harbour intrusive complex	TAM
garnet	subangular	Koettlitz Group	TAM
		Granite Harbour intrusive complex	TAM
	rounded	Beacon Supergroup	TAM
epidote	angular	Koettlitz Group	TAM
	rounded	Beacon Supergroup	TAM

TAM = Transantarctic Mountains, RIS = region of the present-day Ross Ice Shelf.

INTERVAL 624-270 MBFS

From 624 to 270 mbsf, the sediment succession can be subdivided into intervals characterized by presence or absence of biotite and brown hornblende (Fig.1). The two minerals show a roughly inverse correlation. The rocks of Granite Harbour intrusive complex are the probable source for the biotite (Ghent & Henderson 1968, Skinner & Ricker 1968a). The brown hornblende in this unit possibly derives from the Ferrar Group (Skinner & Ricker 1968b). The lamprophyric dykes of GHIC also can supply brown hornblende. However, this seems unlikely, because of the inverse correlation with biotite (Skinner & Ricker 1968 b).

The co-occurrence of stable minerals and brown hornblende in some sediments of this unit seems to imply a mixed source: the Ferrar Group and the Beacon Supergroup. According to Gunn & Warren (1962) the outcrop area of Ferrar Dolerite is about the same as that of the sedimentary rocks of the Beacon Group. Smellie (this volume) calculated for CRP-2/2A sediments a Beacon:Ferrar ratio of 80:20. This proportion cannot be confirmed by heavy mineral record, because Smellie's calculations involved mineral grains (*e.g.* quartz, feldspar) not includes in the heavy minerals of the study. The Beacon:Ferrar ratio is primary controled by quartz contents. The only direct evidence in the heavy mineral fraction for a Beacon Supergroup source are the rounded stable mineral grains. An indirect indicator is the lack of biotite (see above).

The heavy mineral concentrations of the biotite-bearing sediments points to a Ferrar Group-GHIC dominated source. This is confirm by the increased amounts of subangular to angular stable minerals.

As a result, for the entire succession of sediments, a source area in the Transantarctic Mountains can be assumed; either Ferrar-Beacon (biotite-free) or Ferrar-GHIC (biotite-bearing) dominated. This differentiation could be a faint hint for advances and retreats of glaciers. The GHIC outcrops close to the CRP drill site are situated near the coast. Rocks of the Beacon Supergroup and Ferrar Group crops out further inland. A possible scenario is that GHIC-derived heavy minerals are supplied during advances of floating or grounded ice, when the GHIC outcrop area was covered by ice. The heavy minerals derived from Ferrar-Beacon formation are supplied during the retreats of glaciers, when the GHIC outcrops are ice free and thereby are less susceptible to erosion, whereas the Ferrar-Beacon outcrops are still ice covered and intensely eroded.

The high concentration of Ferrar Dolerite derived pyroxenes in all sediments could be explain by extended Ferrar Dolerite sills and dykes indruding also the GHIC (Wilhelm & Woerner, 1996).

The trace amounts of volcanic glass in the section may originate from the Kirkpatrick Basalts of the Ferrar Group (Elliot et al. 1995; also suggested by Smellie, this volume). The volcanic glass also could be a weak indication of active McMurdo volcanism through Oligocene time, but

thus far all analysed glass grains have a tholeiitic chemistry more characteristic of the Kirkpatrick basalts (unpubl. information of P. Armienti).

INTERVAL 270-0 MBSF

From 270 mbsf to top of the core the sediments are characterized by a Ferrar Group-GHIC source and an additional volcanic source, which has to be sought in the McMurdo Volcanic Group. This volcanic source is characterized by the occurrence of titanaugite and glass. The brown hornblende in this upper part probably originates mainly from a volcanic source area, because its occurrence broadly correlates with that of titanaugite and glass (Cole & Ewart, 1968; Nathan & Schulte, 1968; Kyle, 1990). However, the brown hornblende show no significant differences, either in appearance or colour, with brown hornblende in the lower part of the core, which was derived from the Transantarctic Mountains. Also, higher concentrations of MVG-derived pyroxenes (without visible cleavage) are found only in the upper interval. The decrease of Beacon-derived minerals (rounded stable grains, biotite ?) in favour of metamorphic basement (*e.g.* the slight increase of green hornblende) and granitoid derived minerals could be an indication that less erosion of Beacon Supergroup and more erosion of the crystalline basement took place. Speculatively, this could be due to an uplift of the Transantarctic Mountains.

The volcanic components indicate that the ice masses probably have been more extensive and have reached areas of McMurdo volcanics in the southern and eastern part of McMurdo Sound, because no Oligocene and early Miocene outcrops of the MVG are known in the Transantarctic Mountains. A further likely transport mechanism is the supply of MVG detritus by marine currents.

Indications for larger explosive volcanic events, like the pumice layer at 113 mbsf, are not recorded in the heavy mineral assemblages.

The heavy mineral assemblages are very similar to those of CRP-1 (Polozek & Ehrmann 1998). Because only a few Miocene samples in CRP-2/2A were analysed so far, no correlation between the two cores is obvious.

CONCLUSIONS

The study of heavy minerals in 49 samples from CRP-2/2A has demonstrated the provenance-dependent composition of the sediments.

The heavy minerals assemblages point to a source area in the Transantarctic Mountains. Three major sources could be distinguished in the lower part of the core (624 to 270 mbsf): a Ferrar-Beacon dominated and a Ferrar-GHIC dominated source. The influence of Ferrar Dolerites, represented by pyroxenes, is constant through the entire sediment core. An indicator for a specific GHIC source is the presence of biotite, whereas the absence of biotite may indicate a dominant Beacon Supergroup source.

At 270 mbsf an additional volcanic source commences, characterized by volcanic titanaugite, glass and brown hornblende. At the same time the influence of Beacon-derived heavy minerals decreases, possibly because of incision of valleys to a depth below the Beacon Supergroup outcrops and therefore more erosion of GHIC and less erosion of Beacon Supergeroup.

The significant shift in heavy mineral distribution at 270 mbsf can be cautiously interpreted as a change in ice dynamics in late Oligocene time or a possible uplift of Transantarctic Mountains.

The present investigations has demonstrated the significance of heavy mineral assemblages for reconstructing source areas. In addition with other parametres, heavy minerals are a suitable tool for reconstruction glacial history in McMurdo Sound, Antarctica.

ACKNOWLEDGEMENTS

The project is financial supported by *Deutsche Forschungsgemeinschaft*. Sincere thanks to Helga Rhodes for her technical assistance and Ian Lerche for his helpful support.

D. Henningsen and J. Smellie is thanked for the careful reviews. Also thanks to all colleagues at Cape Roberts camp and drill site for a nice and interesting time and to the Cape Roberts Science Team for useful discussions.

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