

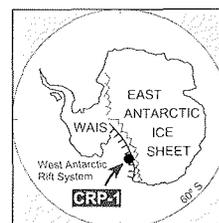
Provenance of CRP-1 Drillhole Fine-Grained Sediments, McMurdo Sound, Antarctica: Evidence from Geochemical Signals

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Abstract - Geochemical data are presented for samples from strata, mainly of Miocene age, in the Cape Roberts-1 core (western McMurdo Sound, Antarctica) to assess the sediment provenance. Bulk (major and trace element) chemistry together with bulk mineralogy of fine-grained sandstones, siltstones, mudstones, and diamictites indicate that chemical alteration of source materials, fractionation due to sedimentary sorting, and diagenetic effects were not significant in the Cape Roberts sediment history. Relevant geochemical parameters are consistent with the Cape Roberts sediments being derived mainly from the crystalline basement and the Beacon Supergroup. On the basis of element distributions, an additional contribution from the Ferrar Dolerite and, mainly above about 60 m, influxes of detritus derived from basaltic to intermediate members of the McMurdo Volcanic Group are recognised.



INTRODUCTION

This paper presents the results of major and trace element analyses performed on samples of mainly Miocene age from the CRP-1 drillhole (Cape Roberts Science Team, 1998). The chemical data are interpreted in terms of detritus fluxes and provenance reconstruction. To avoid misleading conclusions due to element fractionation resulting from sedimentary processes or from mobilisation during alteration processes, we carefully examined the data in combination with investigations of the bulk mineralogy.

SAMPLES AND PROCESSING

Analyses were performed on 24 samples distributed throughout the drillhole from 26.18 to 146.07 m and representing different lithologies (fine-grained sandstone, siltstone, mudstone, and fine matrix of diamictite). Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P and Cr, Ba, La, Ce, V, Zr, Y, Sr, Rb, Ni were determined by X-ray fluorescence spectrometry (XRF) on pressed, boric-acid backed pellets of bulk rock. Data reduction was achieved using the method described by Franzini et al. (1975). Certified reference materials were used as monitors of data quality. Analytical errors were below 1% for Si, Al, Na; below 3% for Ti, K, Fe, Ca; and below 10% for Mg, Mn, P and trace elements. All samples were washed repeatedly in deionized water to avoid contamination resulting from drilling mud and seawater. Mineralogical analyses were performed by X-ray diffractometry (CuK α radiation filtered by Ni, scanning speed 2 $^\circ$ 2 θ /min).

RESULTS

BULK MINERALOGY

Based on XRD analyses, the bulk mineralogy of CRP-1 sediments is dominated by quartz and feldspars (both K-feldspar and plagioclase). Biotite, pyroxene and amphibole (probably hornblende) occur in minor amounts, while kaolinite and, more rarely, chlorite are also present. The XRD-diagram of one sample (at 49.66 m) exhibits peaks identified as chabazite, but the lack of a hand specimen prevented us from confirming the identification. Authigenic zeolites are common to abundant in the CIROS-1 drillhole (Bridle & Robinson, 1989; Bellanca et al., 1997), but the analysed CRP-1 samples do not contain these minerals. This is consistent with the general freshness of the volcanic material present throughout the CRP-1 drillhole (Cape Roberts Science Team, 1998).

BULK CHEMISTRY

Major and minor element analyses of CRP-1 samples are given in tables 1 and 2 and in figures 2 to 7. The data plotted in the figures are recalculated to 100%, volatile-free.

Concentrations of SiO₂ vary from ~58 to ~78 wt%, although most samples cluster in the range 60-65 wt%. The strong negative correlations between SiO₂ and most elements (r varying from -0.62 for Na₂O to -0.98 for Fe₂O₃) reflect significant dilution of the sediments by quartz. Al₂O₃ correlates positively with many elements but best with Fe, K, Rb, and Ba ($r = 0.82, 0.87, 0.83, 0.77$, respectively), due to the presence of feldspars (hosting Ba and Rb), biotite and hornblende (hosting Rb). Good to

Tab. 1 - Major element concentrations (wt %) of CRP-1 samples.

Sample	Lithology	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	L.O.I.
26.18	sandstone	62.24	1.18	12.09	6.26	0.09	4.13	3.80	2.09	2.91	0.17	5.04
49.66	silty sandstone	57.22	1.73	13.86	7.83	0.09	3.49	5.27	2.69	3.14	0.30	4.37
54.68	mudstone	62.90	0.91	13.46	6.09	0.08	3.20	4.39	2.49	2.98	0.12	3.37
58.19	silty sandstone	61.44	1.39	13.50	6.57	0.08	3.04	4.07	3.15	3.03	0.21	3.51
66.83	mudstone	72.43	0.51	11.18	3.78	0.07	2.66	3.74	2.12	2.25	0.03	1.23
69.87	silty sandstone	66.90	0.84	12.65	5.09	0.07	2.98	2.90	2.02	2.99	0.07	3.48
76.49	mudstone	63.64	0.87	13.77	5.70	0.08	2.94	4.31	2.62	2.88	0.10	3.08
78.31	mudstone	60.98	0.77	14.52	6.31	0.08	3.52	4.62	2.69	2.95	0.08	3.47
83.37	siltstone	62.88	1.20	13.67	5.82	0.09	2.78	4.15	2.99	3.27	0.23	2.93
85.59	siltstone	62.87	1.09	13.95	5.64	0.09	2.87	4.07	3.20	3.31	0.16	2.76
86.06	siltstone	64.54	1.11	12.26	6.08	0.10	2.50	4.05	3.13	2.83	0.28	3.13
92.45	siltstone	62.91	1.02	13.66	5.95	0.10	2.75	3.95	3.08	3.26	0.18	3.13
94.17	siltstone	64.22	0.84	12.82	5.88	0.12	2.49	4.24	3.17	3.02	0.22	2.99
97.58	siltstone	61.76	1.12	13.03	6.65	0.11	2.33	3.69	3.52	3.36	0.26	4.18
104.49	siltstone	69.64	0.66	11.74	4.33	0.10	2.16	3.90	2.73	2.65	0.20	1.89
106.03	siltstone	68.34	0.67	12.01	4.48	0.09	2.30	3.91	2.85	2.56	0.20	2.58
108.43	siltstone	67.31	0.70	12.20	4.72	0.10	2.34	4.07	3.00	2.64	0.20	2.73
109.36	fine sandstone	72.67	0.41	10.98	3.60	0.09	2.13	3.76	2.48	2.23	0.13	1.52
113.25	fine sandstone	59.21	1.49	12.74	7.31	0.14	2.68	4.69	3.38	2.81	0.47	5.10
117.20	fine sandstone	77.63	0.26	9.22	2.76	0.07	2.06	3.14	2.30	1.81	0.00	0.76
129.32	diamictite	62.52	0.96	13.05	5.75	0.11	2.99	5.02	3.09	2.82	0.28	3.40
141.35	diamictite	63.67	0.72	13.25	5.42	0.11	3.14	4.61	2.69	2.74	0.20	3.45
141.82	diamictite	60.26	1.13	13.42	6.56	0.11	3.40	4.78	2.89	2.96	0.29	4.21
146.07	sandstone	60.70	1.02	13.53	6.26	0.10	3.21	4.42	2.90	3.14	0.27	4.46

strong correlations of V with Mg ($r = 0.71$) and Fe ($r = 0.93$) suggest the association of V with ferromagnesian minerals.

The Chemical Index of Alteration [$CIA = Al_2O_3 / (Al_2O_3 + Na_2O + K_2O + CaO^*) \times 100$ (Nesbitt & Young, 1982)] and Chemical Index of Weathering [$CIW = Al_2O_3 / (Al_2O_3 + Na_2O + CaO^*) \times 100$ (Harnois, 1988)] are moderate to low (CIA from 54 to 61; CIW from 61 to 72).

DISCUSSION

REASONABLE SEDIMENT SOURCE

The CIA and CIW data indicate only moderate chemical alteration of the source materials for the CRP-1 sediments and limited fractionation of these materials during sedimentary recycling.

The lack of CIW-Na₂O, CIW-K₂O, CIW-CaO, and CIW-TiO₂ correlations (Fig. 1) may be interpreted as

being due to the contribution to these sediments of moderately weathered materials from a multicomponent source. The scatter of TiO₂ and K₂O in the plots also suggests significant variations in the component proportions.

Discrimination of CRP-1 sediments from potential source rocks can be effected by spider diagrams (Fig. 2) in which element/aluminium ratios are normalised against the rocks that are inferred to represent, on the basis of local geology (Barrett et al., 1989; Woolfe & Barrett, 1995), potential sources. Previous CIROS-1 studies have suggested that the local rock units were the main contributors for the detritus. These units include: granites and metamorphic rocks of the Late Precambrian and Early Palaeozoic crystalline basement, quartzose or quartzo-feldspathic strata of the Palaeozoic and Mesozoic Beacon Supergroup, tholeiitic dikes and sills of the Ferrar Group, and basanites and trachybasalts to trachytes of the McMurdo Volcanic Group. Element mean values for the source terrains are those reported in Roser & Pyne (1989, Tab. 3).

Tab. 2 - Trace element concentrations (ppm) of CRP-1 samples.

Sample	Lithology	Cr	Ba	La	Ce	V	Zr	Y	Sr	Rb	Ni
26.18	sandstone	50	350	44	85	118	306	20	277	99	19
49.66	silty sandstone	50	475	63	136	163	498	32	500	106	16
54.68	mudstone	53	512	32	101	137	381	29	337	120	15
58.19	silty sandstone	42	470	42	78	148	313	20	296	94	16
66.83	mudstone	58	391	23	53	86	167	10	274	80	18
69.87	silty sandstone	57	419	48	81	129	153	13	166	95	18
76.49	mudstone	53	487	36	99	134	233	16	240	103	12
78.31	mudstone	56	481	37	75	144	299	27	283	135	21
83.37	siltstone	38	540	58	71	133	431	28	383	122	13
85.59	siltstone	41	528	58	81	116	303	14	290	110	14
86.06	siltstone	59	489	60	72	121	278	20	312	92	17
92.45	siltstone	38	505	61	150	133	296	17	274	110	9
94.17	siltstone	64	517	45	104	105	249	21	256	95	28
97.58	siltstone	60	503	63	115	119	433	31	322	115	19
104.49	siltstone	68	430	32	37	90	197	17	271	93	15
106.03	siltstone	69	429	47	66	101	217	18	281	96	18
108.43	siltstone	65	482	46	86	108	198	15	274	92	19
109.36	fine sandstone	69	454	15	40	86	157	9	272	81	24
113.25	fine sandstone	74	439	76	141	166	355	28	356	93	22
117.20	fine sandstone	52	346	8	22	60	174	10	261	64	15
129.32	diamictite	78	508	47	68	133	184	17	277	89	22
141.35	diamictite	82	475	34	77	122	178	15	241	96	28
141.82	diamictite	95	499	46	112	143	186	14	282	92	33
146.07	sandstone	79	538	60	110	124	252	25	309	118	26

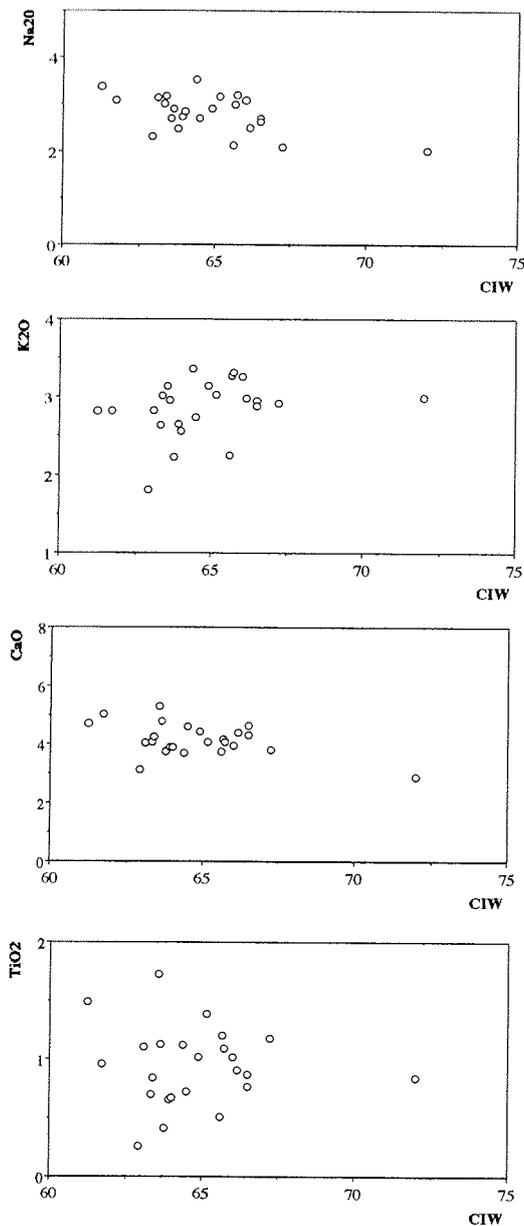


Fig. 1 - Diagrams showing CIW values vs Na_2O , K_2O , CaO and TiO_2 for CRP-1 samples.

The spider diagrams show that, if CRP-1 samples are normalised against basement rocks, most of the values (including Rb/Sr ratios) plot around unity, which is indicative of a significant basement component for the CRP-1 sediments. However, additional detrital influxes may be inferred from some features of the patterns in figure 2a, such as systematic relative enrichments, particularly in Cr and Ni, but also in Mg and V, and scattering of Ti, Zr and La. These features are a clear record of detrital inputs from sources different from the Palaeozoic basement.

Figure 3 illustrates that on the plots total alkalis, K_2O , and Rb vs SiO_2 , CRP-1 data fall within an area delimited by straight lines joining points representing mean basement, Beacon and Ferrar compositions. Although many points cluster close to the basement values, the data appear to define a linear trend from basement towards Beacon, indicating that the chemistry of CRP-1 samples is

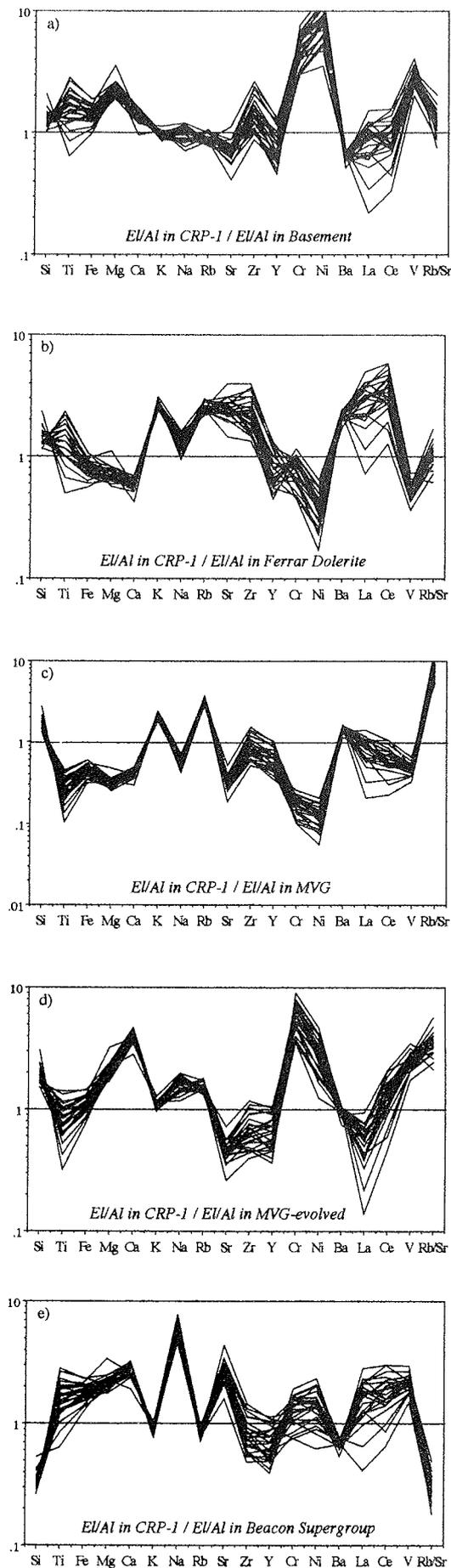


Fig. 2 - Patterns of element/aluminium and Rb/Sr ratios for CRP-1 samples normalised to potential source rocks. Mean values for source terrains from Roser & Pyne (1989).

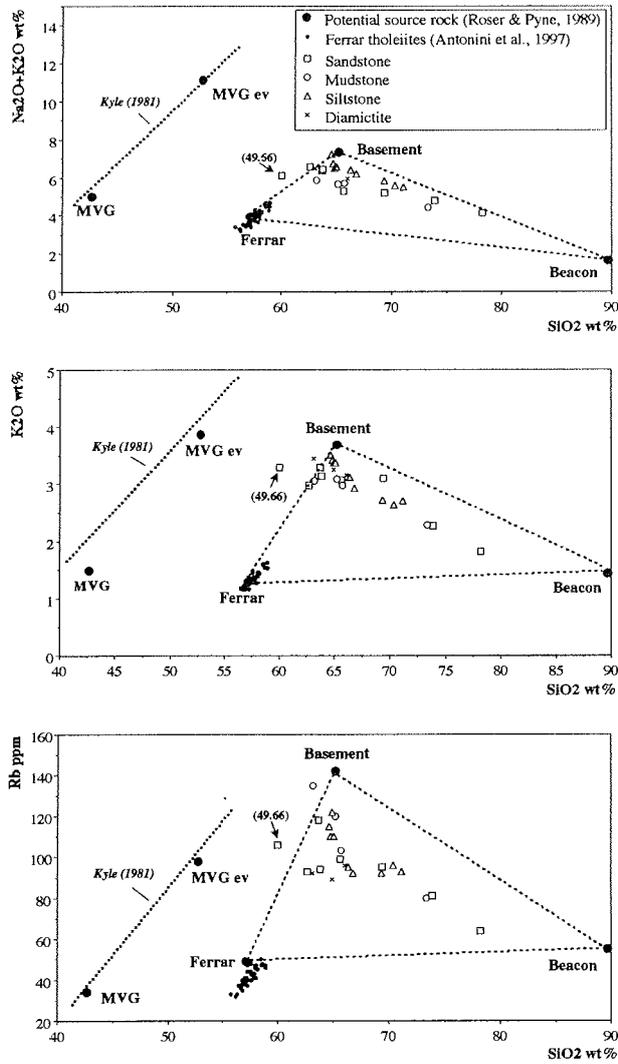


Fig. 3 - Total alkalis vs SiO₂, K₂O vs SiO₂, and Rb vs SiO₂ for CRP-1 samples. See text for explanation. MVG = McMurdo Volcanic Group; ev = evolved.

influenced by a mixing of the two sources. The mineralogy of the Beacon detritus is largely dominated by quartz, which accounts for the strong negative correlations between SiO₂ and other elements reported above. On the other hand, a clear shift of this trend to the Ferrar field is also evident in figure 3, suggesting an additional contribution

of Ferrar detritus. With the exception of one sample (at 49.66 m), the CRP-1 data plot far from McMurdo Volcanic compositions represented by full circles corresponding to the geochemical averages reported by Roser & Pyne (1989) and by a dotted line representing the trend defined by element abundances for volcanic samples from the Dry Valley Drilling Project on Ross Island (Kyle, 1981). As the majority of the analysed samples come from the Miocene section of CRP-1, these results are consistent with previous reports (for example, Cape Roberts Science Team, 1998) that indicate a reduction of volcanic detritus below 62 m.

Except for a spike at 113.25 m, the depth profiles for Fe/Al, Ti/Al, and V/Al (Fig. 4) exhibit a clear decrease in the ratios below ~60 m, which may be explained by the presence in the uppermost samples of spinel (titano-magnetite) or titaniferous pyroxene derived from the McMurdo Volcanic Group (MVG). Nevertheless, many data falling outside the triangles in the plots V vs Fe₂O₃ and Ti/Cr vs Ni (Figs. 5 & 6) may indicate persistence of the McMurdo Volcanic Group detritus, or of volcanics of similar chemistry throughout the CRP-1 drillhole. However, it must be considered that outcrops of these volcanic rocks in the McMurdo Sound region only extend in age back to 18-20 Ma (Kyle & Muncy, 1989), although debris of similar composition was found in Oligocene strata of the CIROS-1 drillhole (George, 1989; Roser & Pyne, 1989).

Ni/Al and Cr/Al ratios (Fig. 4) define downward increasing trends, suggesting two interpretations:

- 1) samples of the upper part of the hole (above about 60 m) show Ni and Cr values (Tab. 2) well below those reported by Kyle (1981) for McMurdo basanites (typically 20 and 50 ppm as opposed to 250 and 500 ppm, respectively), and more similar to those of intermediate McMurdo Volcanic rocks. These low values could also reflect a sediment lacking in olivine, as also suggested by sand-grain observations (Cape Roberts Science Team, 1998);
- 2) the higher ratios in samples from the lower part of the hole are quite similar to the average ratios of Ferrar dolerites (Ni/Al = 7.3 and Cr/Al = 11.5; Roser & Pyne, 1989) and may reflect a strong influence of the Ferrar detritus.

We plotted our results in a Cr vs Zr diagram, commonly

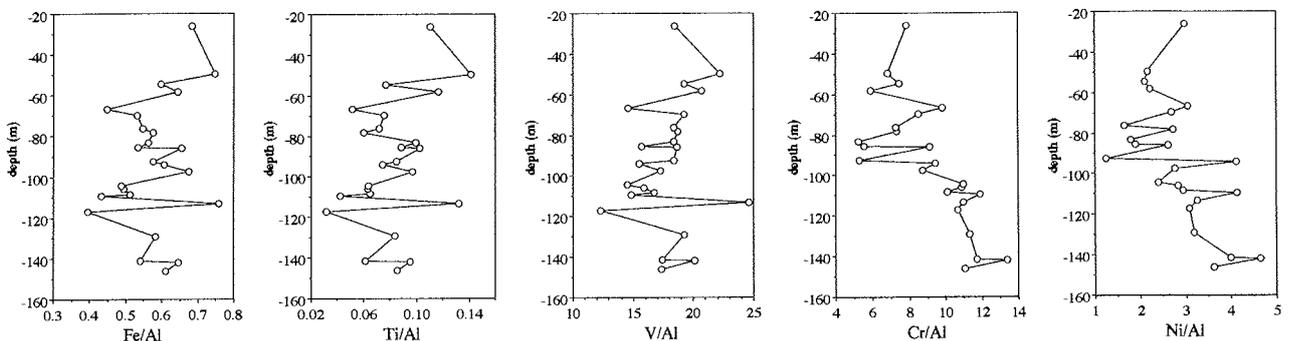


Fig. 4 - Element/Al depth profiles for CRP-1 samples.

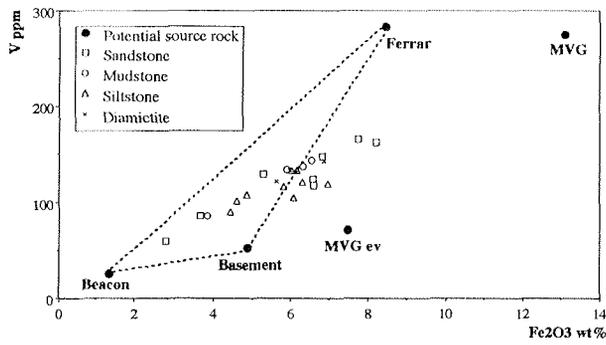


Fig. 5 - V vs Fe_2O_3 diagram for CRP-1 samples.

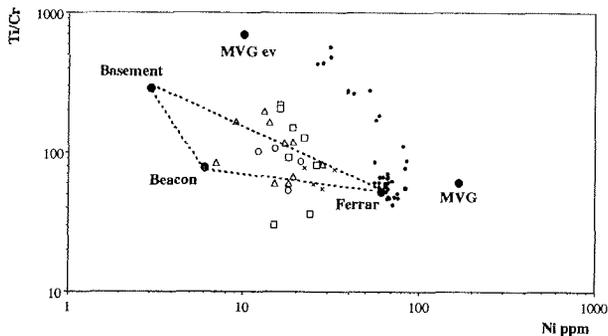


Fig. 6 - Ti/Cr vs Ni diagram for CRP-1 samples. Symbols and abbreviations as in figure 3.

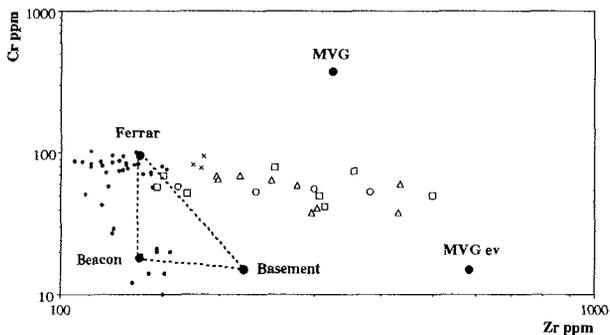


Fig. 7 - Cr vs Zr diagram for CRP-1 samples. Symbols and abbreviations as in figure 3.

used in interpreting rock chemistry in terms of compatible-incompatible element relationships. As shown in figure 7, many samples are enriched in Zr. This enrichment might be interpreted as evidence for an influence of Zr-rich McMurdo Volcanic Group materials, but we cannot exclude sedimentary sorting effects on the Zr distribution through the Cape Roberts drillhole. However, the lack of any apparent correlation between chemistry and grain size in the Cr vs Zr graph, as well as in previous graphs, may indicate that sorting did not significantly affect the element distribution.

CONCLUSIONS

1) Bulk mineralogy and chemistry of analysed CRP-1 samples show no evidence of significant diagenesis.

- 2) The weathering indices apparently indicate a detrital contribution of low to moderately weathered materials from a multicomponent source for these sediments.
- 3) The most relevant chemical parameters indicate a more important contribution of detritus from crystalline basement and from the Beacon Supergroup. Concentrations of some elements, in particular heavy metals, provide evidence for an additional contribution from the Ferrar Dolerite.
- 4) Significant influxes of volcanic detritus are recorded mainly above about 60 m. Based on major and trace element contents, this detritus was probably derived from sources compositionally similar to basanitic to intermediate members of the McMurdo Volcanic Group.

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REFERENCES

- Antonini P., De Marchi G., Piccirillo E.M. & Orsi G., 1997. Distinct Magma Pulses in the Ferrar Tholeiites of Thern Promontory (Victoria Land, Antarctica). *Terra Antarctica*, **4**, 33-39.
- Barrett P.J., Hambrey M.J., Harwood D.M., Pyne A.R. & Webb P.N., 1989. In: P.J. Barrett (ed.), *Antarctic Cenozoic History from the CIROS-1 Drillhole, McMurdo Sound*, *DSIR Bull.*, **245**, 241-251.
- Bellanca A., Neri R. & Palumbo B., 1997. Geochemical Features of Cenozoic Sediments from CIROS-1 Drillhole, McMurdo Sound, Antarctica: Implications for Provenance and Diagenesis. *Terra Antarctica*, **4**, 127-132.
- Bridle I.M. & Robinson P.H., 1989. Diagenesis. In: P.J. Barrett (ed.), *Antarctic Cenozoic History from the CIROS-1 Drillhole, McMurdo Sound*, *DSIR Bull.*, **245**, 201-207.
- Cape Roberts Science Team, 1998. Summary of Results from CRP-1, Cape Roberts Project, Antarctica. *Terra Antarctica*, **5**(1), 125-137.
- Franzini M., Leoni L. & Saitta M., 1975. Revisione di una metodologia analitica per fluorescenza X basata sulla correzione completa degli effetti di matrice. *Rend. Soc. Ital. Miner. Petrol.*, **21**, 99-108.
- George A., 1989. Sand provenance. In: P.J. Barrett (ed.), *Antarctic Cenozoic History from the CIROS-1 Drillhole, McMurdo Sound*, *DSIR Bull.*, **245**, 159-167.
- Harnois, L., 1988. The CIW index: a new chemical index of weathering. *Sediment. Geol.*, **55**, 319-322.
- Kyle P.R., 1981. Mineralogy and geochemistry of a basanite to phonolite sequence at Hut Point Peninsula, Antarctica, based on core from Dry Valley Drilling Project Drillholes 1, 2 and 3. *J. Petrol.*, **22**, 451-500.
- Kyle P.R. & Muncy H., 1989. Geology and geochronology of McMurdo volcanic group rock in the vicinity of Lake Morning, McMurdo Sound, Antarctica. *Antarctic Science*, **1**, 345-350.
- Nesbitt H.W. & Young G.M., 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. *Nature*, **299**, 715-717.
- Roser B.P. & Pyne A.R., 1989. Wholerock geochemistry. In: P.J. Barrett (ed.), *Antarctic Cenozoic History from the CIROS-1 Drillhole, McMurdo Sound*, *DSIR Bull.*, **245**, 175-184.
- Woolfe K.J. & Barret P.J., 1995. Constraining the Devonian to Triassic Tectonic Evolution of the Ross Sea Sector. *Terra Antarctica*, **2**(1), 7-21.