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Geochemical Indicators of Weathering, Cenozoic Palaeoclimates, and Provenance from Fine-Grained Sediments in CRP-2/2A, Victoria Land Basin, Antarctica

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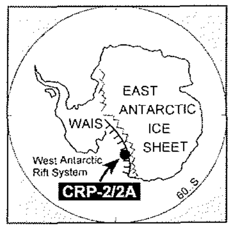
Abstract - The CRP-2/2A core, drilled in western McMurdo Sound in October and November 1998, penetrated 624 m of Quaternary, Pliocene, lower Miocene, and Oligocene glacigenic sediments. The palaeoclimatic record of CRP-2/2A is examined using major element analyses of bulk core samples of fine grained sediments (mudstones and siltstones) and the Chemical Index of Alteration (CIA) of Nesbitt & Young (1982). The CIA is calculated from the relative abundances of Al, K, Ca, and Na oxides, and its magnitude increases as the effects of chemical weathering increase. However, changes in sediment provenance can also affect the CIA, and provenance changes are recorded by shifts in the Al_2O_3/TiO_2 ratios and the Nb contents of these CRP-2/2A mudstones.



Relatively low CIA values (40-50) occur throughout the CRP-2/2A sequence, whereas the Al_2O_3/TiO_2 ratio decreases upsection. The major provenance change is an abrupt onset of McMurdo Volcanic Group detritus at ~300 mbsf and is best characterized by a rapid increase in Nb content in the sediments. This provenance shift is not evident in the CIA record, suggesting that a contribution from the Ferrar Dolerite to the older sediments was replaced by an input of McMurdo Volcanic Group material in the younger sediments. If this is true, then the relatively uniform CIA values indicate relatively consistent palaeoweathering intensities throughout the Oligocene and early Miocene in the areas that supplied sediment to CRP-2/2A.

INTRODUCTION

The Cape Roberts Project is a multinational cooperative drilling project, designed to use sediment cores as the basis for reconstructing the tectonic and climatic histories of the western side of McMurdo Sound and the adjacent portion of East Antarctica for the period from 30 Ma to approximately 100 Ma. The scientific rationale for this work, as well as the technical and logistical details of the project, have been presented by Barrett & Davey (1992), International Steering Committee (1994), Barrett (1997), and Cape Roberts Science Team (1999).

One goal of the Cape Roberts Project is to reconstruct the palaeoclimatic history of the western Ross Sea region, so biological and inorganic indicators of palaeoclimate are being examined by a number of the post-drilling studies discussed in this volume. The objective of this paper is to discuss the record provided by one such indicator, the Chemical Index of Alteration (CIA) of Nesbitt & Young (1982). The CIA is calculated from the major element geochemistry of bulk sediment samples, and was originally proposed as a means to quantify the extent to which sediments have experienced chemical weathering. Because the CIA can be affected by changes in the provenance of the sediment, independent of changes in weathering intensity, the Al_2O_3/TiO_2 ratio and the Nb content are also considered as independent records of sediment provenance. A similar approach was used by Krissek & Kyle (1998, 1999) to examine the records of palaeoweathering and sediment provenance at CRP-1 and CIROS-1.

In this paper we present an extensive set of major and trace element analyses of over 100 bulk core samples of mudstones and siltstones. The major element analyses are used to examine the stratigraphic record of CIA values in samples from CRP-2/2A. Only minor reference is made to the trace element analyses to examine the sediment provenance and detailed examination of these data will be made in subsequent publications. The CIA values suggest that chemical weathering effects were significantly and consistently low during the Oligocene and early Miocene, as would be expected in a glacially dominated environment. However, the sediment provenance during this time also affected the major element geochemistry and, therefore, the CIAs of these sediments. In particular, sediment supply from McMurdo Volcanic Group introduced material whose unweathered composition produces anomalously low CIAs. As a result, more definitive interpretations of the palaeoweathering history contained in CRP-2/2A will be available only after detailed mixing model studies have been performed to remove the effects of changing sediment provenance.

BACKGROUND OF GEOCHEMICAL INDICATORS USED

The CIA is calculated as

$$CIA = [Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)] \times 100$$

where the elemental abundances are expressed as molar proportions, and CaO* represents the CaO contained only in the silicate fraction. The CIA is generally used to provide an indication of the relative abundances of "unweathered" material and chemical weathering products; the "unweathered" materials of particular interest are the feldspars, which are common and contain relatively mobile Ca, Na, and K, whereas the chemical weathering products of particular interest are the Al-rich clays. However, the CIA of a sample can also be affected by the grain size of the sample and by the provenance of the sediment, as discussed in more detail below.

The CIA of a sediment increases as the extent of chemical weathering increases, from values of approximately 50 for "unweathered" feldspar-rich rocks to values near 100 for highly weathered, kaolinite- or gibbsite-rich sediments. CIA values for "average" shales, dominated by illite, range from 70 to 75 (Young & Nesbitt, 1998). The CIA value for a sediment also tends to increase as grain size decreases, because clay minerals are preferentially enriched in the finest grain sizes. As a result, the CIA was originally proposed for use with true shales or "lutites" (Nesbitt & Young, 1982). In a sequence where true shales are rare, such as the section cored at CRP-2/2A, care must be taken to consider the potential effect of grain size variations on stratigraphic trends in the CIA. The provenance effect is particularly important if sediment provenance changed significantly during deposition of a stratigraphic sequence, and if any of the potential sediment sources has an unusual geochemical composition. Such a provenance effect must be considered for CRP-2/2A because potential source rocks include two basic igneous units, the McMurdo Volcanic Group and the Ferrar Dolerite, whose bulk geochemistries produce CIA values lower than the CIAs of unweathered feldspar.

The Al_2O_3/TiO_2 ratio of a sediment can serve as a preliminary indicator of that sediment's source rock composition (Nesbitt, 1979; Young & Nesbitt, 1998) for two reasons: 1) the ratio varies markedly in primary igneous rocks, from approximately 10 for basalts and gabbros to approximately 47 for granites (LeMaitre, 1976), and 2) Al and Ti are both considered to be relatively immobile under most weathering regimes. Trace element abundances can also serve as valuable indicators of sediment provenance because trace elements are also relatively immobile during weathering, and because trace element abundances can vary significantly between two igneous or metamorphic bodies with relatively similar major element compositions (*e.g.*, two granites can have significantly different trace element compositions). In this study, concentrations of the trace element Nb are used to identify the relative importance of input from the McMurdo Volcanic Group, a potential source rock with elevated Nb contents.

MATERIALS AND METHODS

In this study fine grained samples were analyzed for major and trace elements by x-ray fluorescence (XRF) and instrumental neutron activation analysis (INAA) (Tab. 1). Most of the analyzed samples were bulk core collected from the finest grained lithologies (mudstones and siltstones) and taken at approximately 5-m intervals from 17 to 624 msbf. Six of the samples were a split of the <63µm size fraction remaining after foraminifera processing.

The XRF and INAA analyses were made at New Mexico Tech, using procedures similar to those described by Hallett and Kyle (1993) with some minor modifications. Major elements and S and Cl were analyzed on 104 samples using glass disks formed by fusing 1 gram of sample with 6 grams of a lithium borate flux (35.3% lithium tetraborate, 64.7% lithium metaborate) in a 95% Pt/5% Au crucible at 1100 °C. Trace elements were determined on 98 samples by XRF (V, Cr, Ni, Cu, Zn, Ga, As(X), Rb, Sr, Y, Zr, Nb, Pb, Th(X), U(X)) using pressed powder samples (Norrish & Chappell, 1977) and on 63 samples by INAA (Sc, As(I), Ba, La, Ce, Sm, Eu, Tb, Yb, Lu, Ta, Th(I), U(I)). A number of elements were measured by both XRF and INAA and showed excellent agreement. For elements As, Th and U both the XRF (X) and INAA (I) are listed (Table 1), because the INAA data are more precise. However, only 63 samples were analyzed by INAA, so the XRF data are more complete. The XRF was calibrated using a wide variety of well-analyzed rock standards. Several rock standards were used to monitor the analytical precision, and proficiency tests administered by the International Association of Geoanalysts provide data on the analytical accuracy. For the INAA analyses between 120 and 250 mg of samples was sealed in polypropylene vials and irradiated for 7 to 12 hours at the Nuclear Science Center, Texas A&M University. The activated samples were counted at New Mexico Tech using two high purity Ge detectors (25% efficient, 1.85keV resolution at 1332 keV) at various intervals following an initial 5 days of decay. National Institute of Standards and Technology (NIST) fly ash standard reference material (SRM) 1633a was used to calibrate the INAA data (Hallett and Kyle, 1993). Various rock standards were run as checks on the accuracy and precision of the INAA data (these data are available on request from P. Kyle).

The primary goal of this paper is to examine the CIA index, so no attempt is made here to examine all of the major and trace element data from CRP-2/2A. All the data are listed in Table 1 so as to be useful to other investigators. The Al_2O_3, TiO_2 and Nb analyses are used here in a preliminary effort to evaluate the effect of sediment provenance changes on the CIA record from CRP-2/2A.

As a reminder, the CIA is calculated as

$$CIA = [Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)] \times 100$$

where the elemental abundances are expressed as molar proportions, and CaO* represents the CaO contained only in the silicate fraction. For these samples, the CaO content of the silicate fraction is assumed to equal the CaO content of the bulk sample; *i.e.*, biogenic and diagenetic carbonates and biogenic apatite are assumed to contribute little or CaO to the bulk sample. The CaO contributions from biogenic and diagenetic carbonates are judged to be low because "loss-on-ignition" (LOI) values for this sample set are relatively low and fairly uniform between samples (Tab. 1). Samples analyzed by Dietrich et al. (this vol.) contain up to 3% carbonate above 300 mbsf and up to 8-13% carbonate below 300 mbsf. However, the majority of this carbonate is diagenetic and is distributed very irregularly through the core (as indicated by downhole logging results; Brink et al., this vol), so the low LOI values remain the best indicators of low CaO contributions from carbonates in this dataset. CaO contents also have been corrected for a contribution from biogenic apatite in some other studies (*e.g.*, Fedo et al., 1995) by assuming that all P_2O_5 is present as biogenic apatite. Such a correction has not been made for the CRP-2/2A samples because the P_2O_5 is uniformly low (<0.2 wt % below 300mbsf and <0.4 wt. % between 0 and 300 mbsf), and because the McMurdo Volcanic Group is a potential source rock and is usually enriched in P_2O_5. The small variations in P_2O_5 in the upper 300 meters of the core are undoubtedly due to varying amounts of McMurdo Volcanic Group detritus, which is clearly shown by elevated levels of Nb (Tab. 1) and is discussed further below.

Because a detailed age-depth model is not presently available for CRP-2/2A, the CIA, Al_2O_3/TiO_2 and Nb profiles are plotted as a function of subbottom depth (Figs. 1, 2 and 3).

DATA AND RESULTS

The complete data set, the calculated CIAs, and the calculated Al_2O_3/TiO_2 ratios for the 104 samples from CRP-2/2A are presented in table 1.

The stratigraphic profile of CIA values for CRP-2/2A is presented in figure 1. CIAs generally range between 40 and 50. The CIAs decrease slightly upsection, from an average value of 47 for the lower Oligocene/upper Eocene(?) (624-443 mbsf) to average values of 44, 45, and 44 for the Oligocene (443-307 mbsf), upper Oligocene (307-130 mbsf), and lower Miocene (130-28 mbsf), respectively. The range of CIAs also decreases upsection, most notably within the upper Oligocene section.

On first examination, the low CIA values throughout the CRP-2/2A profile suggest that this site consistently received sediment that had undergone little or no chemical weathering during the Oligocene and the early Miocene. This interpreted input of unweathered or weakly weathered material is in agreement with the importance of glacigenic lithofacies throughout CRP-2/2A. However, the fact that CIA values for CRP-2/2A are consistently less than 50, which is the value cited for unweathered feldspar by Nesbitt & Young (1982), indicates that primary phases with higher original K/Al, Ca/Al, or Na/Al ratios than those found in feldspars must be present. As a result, the possible effects of provenance changes on this profile must be considered, because the upsection decrease in CIAs at CRP-2/2A could be produced either by a decrease in the amount of weathering or by an increase in the relative importance of material whose low "apparent CIA" is independent of its weathering history.

Roser & Pyne (1989) summarized the representative geochemical compositions of six source rock types thought to have supplied sediment to CIROS-1; because CRP-2/2A and CIROS-1 are located only 70 km apart and are in similar geologic settings, similar source rock types can be expected to have supplied sediment to CRP-2/2A. As a result, the source rock compositions summarized by Roser & Pyne (1989) are used here to examine the potential effects of provenance changes on the CIA record at CRP-2/2A. The six potential source rock types are: 1) basement rocks (*e.g.*, granitoids of Ferrar Valley), 2) lower Beacon Supergroup sediments (Weller Coal Measures through the Windy Gully Sandstone), 3) Ferrar Dolerite, 4) McMurdo Volcanic Group basanites, 5) McMurdo Volcanic Group trachybasalts to trachytes, and 6) Lashly Formation sediments. Selected major element oxide abundances for these six source rock types are listed in table 2, together with the resulting CIAs and Al_2O_3/TiO_2 ratios.

The relative importance of these sediment sources to deposition at CRP-2/2A did change from the early Oligocene/late Eocene(?) to the early Miocene, as indicated by the stratigraphic profile of Al_2O_3/TiO_2 ratios (Fig. 2). The Al_2O_3/TiO_2 ratios at CRP-2/2A decrease upsection, averaging 19, 17, 17, and 14 for the lower Oligocene/upper Eocene(?) (624-443 mbsf), Oligocene (443-307 mbsf), upper Oligocene (307-130 mbsf), and lower Miocene (130-28 mbsf) sections, respectively. The Al_2O_3/TiO_2 ratio decreases just below 300 mbsf, and also becomes more variable upsection. Comparing the Al_2O_3/TiO_2 values of the potential source rock types, listed in table 2, to the CRP-2/2A profile indicates that the sediments above ~300 mbsf must contain McMurdo Volcanic Group detritus, which has a low Al_2O_3/TiO_2 ratio. Concentrations of the trace element Nb are an even better indicator of the presence of McMurdo Volcanic Group detritus in the core, and the Nb data (Fig. 3) suggest that such detritus is absent below 300 mbsf. These observations are consistent with provenance shifts that were recognized previously at 350-280 mbsf in the sand fraction, the clast population, and the bulk quartz/feldspar contents of CRP-2/2A (Cape Roberts Science Team, 1999), and that have been defined in more detail by post-drilling studies (heavy mineral assemblages (Polozek, this vol.), lonestone clast type (Talarico et al., this vol.), whole-rock geochemistry (Bellanca et al., this vol.; Armienti et al., this vol.), sand composition (Smellie, this vol.), and fine fraction mineralogy (Ehrmann, this vol.; Neumann & Ehrmann, this vol.)). Taken together, these indicators record a shift from older sediments dominated by Ferrar Dolerite and Beacon Supergroup components to younger sediments derived more from the crystalline basement and the McMurdo Volcanic Group. This upsection shift from Ferrar Dolerite and Beacon Supergroup detritus to crystalline basement input appears to record long-term uplift and erosion of the Transantarctic Mountains, whereas the influx from the McMurdo Volcanic Group was controlled by the timing of McMurdo Volcanic Group activity.

The input of McMurdo Volcanic Group detritus above

Tab. 1 - Elemental abundances, loss-on-ignition (LOI), total analyzed abundances, CIA values, and Al-oxide/Ti-oxide ratios for samples from CRP-2/2A.

Sample	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	L.O.I.	SUM	CIA	Al/Ti ratic	S	Cl	Sc	V	Cr	Ni	Cu	Zn	Ga
17.33	66.15	0.92	11.00	5.53	0.086	2.81	4.10	2.47	2.47	0.20	4.32	100.05	43.66	11.95	281	1740	13.15	94	71	28	24	68	15
20.92	65.26	0.93	10.87	5.57	0.086	2.86	3.88	2.48	2.46	0.19	4.58	99.17	44.05	11.68	417	3307	13.58	87	69	26	23	67	14
25.74	59.60	1.13	13.53	7.01	0.112	2.75	4.42	3.35	3.04	0.31	4.17	99.42	44.54	11.97	101	1689		106	79	27	91	127	21
30.22	61.35	0.89	12.88	6.25	0.106	2.53	3.79	3.69	3.34	0.23	3.38	98.44	43.72	14.41	1636	8546	11.84		51				
34.01	70.15	0.77	10.89	4.81	0.090	2.16	3.55	3.22	2.50	0.21	2.22	100.57	42.97	14.07	1236	2468		76	53	19	10	73	17
40.57	68.40	0.58	11.32	4.28	0.075	2.49	4.09	2.72	2.60	0.16	2.40	99.14	43.47	19.41	1351	4271	12.47	81	68	23	14	56	15
42.02	63.69	0.69	13.10	5.51	0.074	2.88	3.73	2.77	3.30	0.18	3.88	99.79	46.78	18.90	1157	4702	13.68	96	69	24	20	75	16
46.70	67.89	0.57	11.58	4.12	0.072	2.31	4.25	2.82	2.98	0.17	3.05	99.81	42.63	20.31	1271	3370		76	67	21	13	54	14
52.37	60.98	1.40	13.64	6.21	0.107	2.72	5.51	3.58	2.92	0.33	2.31	99.71	41.69	9.78	1108	3787	13.33	119	93	29	14	81	20
53.40	59.49	1.40	13.33	6.75	0.103	3.02	5.22	3.51	2.69	0.35	2.92	98.80	42.30	9.52	2535	4832	13.53	124	89	31	16	81	18
56.57	59.42	1.47	13.61	6.58	0.113	2.74	5.92	3.66	2.67	0.38	2.80	99.35	40.90	9.24	2542	3953		113	99	29	14	81	19
56.90	60.75	1.37	13.57	6.53	0.104	2.87	5.08	3.61	2.79	0.34	2.86	99.86	42.73	9.89	730	3196	13.42	130	78	24	16	88	20
61.64	59.93	1.09	14.08	6.47	0.093	2.94	4.69	3.62	3.06	0.32	3.32	99.62	44.17	12.92	1438	4638	12.71	97	63	23	19	88	19
62.35	58.64	1.03	13.76	6.49	0.095	2.91	4.95	3.52	3.06	0.31	3.53	98.29	43.19	13.41	1818	6046		109	65	26	21	92	20
67.67	59.96	1.00	14.03	6.49	0.094	2.96	4.71	3.40	3.19	0.28	3.54	99.67	44.34	14.05	1571	4042	13.35	109	63	25	21	91	19
71.78	59.15	0.93	13.82	6.56	0.091	3.09	4.20	3.30	3.22	0.25	3.86	98.47	45.51	14.93	2798	8258		112	69	27	23	95	19
79.38	63.37	0.73	13.19	5.37	0.083	2.77	3.94	3.28	3.42	0.18	3.22	99.56	44.77	18.08	1408	5642	12.11	93	62	23	16	79	17
85.24	69.77	0.49	11.98	3.82	0.071	2.28	4.03	3.04	2.70	0.12	1.74	100.04	44.02	24.42	838	2418	11.10	66	58	19	14	46	15
93.69	63.93	1.00	12.91	5.52	0.100	2.24	4.50	3.61	2.75	0.26	2.53	99.34	43.03	12.93	1991	4278			70				
96.64	62.21	1.10	13.54	6.05	0.097	2.62	4.64	3.51	2.71	0.29	3.01	99.78	44.11	12.26	1217	2330	10.98	113	60	22	17	88	19
104.65	66.61	0.62	12.19	4.54	0.086	2.31	4.86	3.08	2.65	0.17	2.51	99.62	42.08	19.53	1725	3054		75	55	21	16	55	15
109.17	55.65	1.83	14.17	7.85	0.128	3.06	6.03	3.52	2.32	0.44	3.50	98.51	42.37	7.76	1989	2436		144	108	31	72	115	21
113.40	56.92	1.21	14.77	6.65	0.123	2.46	4.30	4.41	3.29	0.34	4.11	98.57	44.23	12.22	2056	8205	10.56	103	50	19	12	125	24
118.84	60.74	1.46	13.36	6.98	0.101	2.95	4.87	3.33	2.51	0.34	3.11	99.75	43.93	9.15	877	2492		144	69	22	17	91	19
123.20	63.90	0.77	12.90	5.64	0.071	2.74	3.10	2.57	2.89	0.19	3.77	98.54	49.82	16.75	976	3348	13.47	106	68	24	23	84	17
130.42	65.21	0.95	12.53	5.57	0.085	2.76	4.62	2.92	2.38	0.22	2.32	99.58	44.23	13.15	1148	2639	14.21	107	62	22	48	72	16
139.40	63.84	0.91	12.96	5.87	0.082	2.74	4.07	2.97	2.65	0.23	3.37	99.70	46.10	14.19	1524	2699	13.32	105	62	22	34	84	17
141.52	57.13	0.88	12.03	5.51	0.136	2.54	8.01	2.76	2.39	0.28	6.73	98.40	35.66	13.70	1502	3107		112	62	22	31	81	16
145.21	66.91	0.61	11.77	4.93	0.069	2.36	4.83	2.63	2.35	0.14	2.72	99.32	42.94	19.37	4293	2992	12.15	75	56	27	32	55	14
149.45	61.83	0.78	12.89	5.82	0.086	3.04	5.41	2.80	2.49	0.22	3.52	98.87	42.94	16.61	1546	5046	15.84	113	69	30	34	81	17
153.62	62.41	0.77	13.01	5.78	0.083	3.04	5.53	2.73	2.63	0.18	3.73	99.89	42.80	16.99	633	2397		105	70	26	29	76	16
159.05	62.41	0.76	12.94	5.88	0.083	2.98	5.29	2.65	2.61	0.18	3.34	99.12	43.52	17.10	952	3000		110	70	29	27	76	17
163.67	62.21	0.78	13.14	6.09	0.083	3.01	5.16	2.71	2.63	0.17	3.56	99.54	44.07	16.94	1120	2831		116	74	29	28	81	18
168.95	67.12	0.76	11.92	5.11	0.081	2.37	3.71	2.84	2.45	0.18	2.90	99.43	45.88	15.74	820	2171	12.33	86	56	20	32	75	16
172.10	60.79	0.94	12.38	8.31	0.084	2.83	4.50	2.69	2.36	0.21	4.71	99.80	44.97	13.16	857	1636	15.21	129	71	45	27	92	17
177.16	62.98	1.14	12.71	6.51	0.090	2.88	4.74	3.00	2.47	0.22	3.27	100.02	43.90	11.19	916	2006	15.22	143	75	27	20	86	18
180.99	61.52	1.19	13.30	6.71	0.092	2.94	4.74	3.08	2.53	0.25	3.70	100.07	44.73	11.14	1325	2069	15.52	147	78	27	28	92	19
185.64	66.03	0.76	11.89	5.36	0.084	2.83	4.94	2.53	2.16	0.16	2.25	99.00	43.43	15.54	1358	1721			75				
193.60	71.92	0.45	9.62	4.13	0.065	2.44	4.44	2.17	1.94	0.10	1.92	99.19	41.19	21.60	3569	1329	11.59	71	59	21	19	42	11
198.94	70.39	0.55	10.84	4.39	0.076	2.49	4.48	2.44	2.19	0.12	1.95	99.91	42.73	19.80	1705	1635		70	62	22	38	55	14
207.22	68.90	0.60	10.99	4.36	0.072	2.47	4.85	2.46	2.37	0.14	2.68	99.90	41.58	18.41	1479	1749	11.52	76	56	22	33	58	15
215.20	57.78	0.70	14.18	7.42	0.089	3.96	4.36	2.53	2.75	0.16	4.73	98.66	48.50	20.24	1475	4354	17.73	133	89	38	51	98	19
221.38	60.37	0.86	12.09	5.82	0.153	2.68	6.26	2.57	2.54	0.23	5.33	98.91	39.69	13.98	1025	2265		104	66	24	55	97	18
227.62	64.99	0.69	12.55	5.57	0.082	2.79	4.06	2.68	2.62	0.16	2.87	99.06	46.18	18.27	1032	3306	14.09	96	61	23	48	74	17
232.49	68.87	0.72	11.27	4.94	0.076	2.32	3.58	2.59	2.38	0.18	2.69	99.63	45.80	15.57	809	1636	11.58	76	59	20	19	68	16
236.71	66.44	0.70	12.28	5.42	0.081	2.60	4.01	2.69	2.49	0.16	2.76	99.62	46.01	17.46	760	1985	13.59	92	59	22	31	72	18
245.60	65.72	0.76	12.18	5.34	0.076	2.57	3.66	2.69	2.68	0.17	3.42	99.26	46.59	16.03	1819	3756	12.80	91	64	24	22	81	17
251.68	68.28	0.64	11.43	4.68	0.065	2.43	3.20	2.44	2.42	0.14	3.32	99.05	47.86	17.97	1250	2808	12.98	97	69	23	30	71	15
255.39	66.54	0.62	12.27	4.82	0.055	2.17	1.94	2.44	2.92	0.16	5.56	99.50	53.44	19.65	1841	3905		117	71	22	22	92	17
260.45	67.57	0.62	11.52	4.79	0.060	2.19	2.67	2.48	2.54	0.14	4.87	99.45	49.66	18.72	1484	2804	12.11	101	68	23	22	82	15
263.32	67.61	0.59	11.63	4.78	0.054	2.19	2.15	2.26	2.65	0.13	5.38	99.44	52.54	19.62	1400	2389	12.29	106	67	23	32	82	16
269.94	65.48	0.63	11.68	5.05	0.075	2.20	3.64	2.80	2.58	0.14	3.47	97.74	45.48	18.58	2948	2937	11.52	81	53	20	27	82	18

Tab. 1 - Continued.

Sample	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	L.O.I.	SUM	CIA	Al/Ti ratic	S	Cl	Sc	V	Cr	Ni	Cu	Zn	Ga
278.80	56.37	1.07	12.72	7.10	0.116	2.59	3.98	4.46	3.05	0.20	8.29	99.95	41.57	11.85	3741	18964			79				
287.76	60.24	1.06	12.86	7.16	0.086	2.51	3.38	2.59	2.75	0.19	5.50	98.32	49.01	12.11	5289	4984			82				
296.09	65.29	0.64	11.80	5.26	0.064	2.57	4.58	2.49	2.31	0.14	3.34	98.47	44.16	18.37	5462	3709	14.78	98	66	27	25	68	15
299.32	67.09	0.65	11.69	4.49	0.073	2.43	4.92	2.30	2.31	0.14	3.27	99.37	43.41	18.06	626	2176	14.05	105	58	21	52	60	14
305.42	68.66	0.56	10.62	4.38	0.069	2.39	4.55	2.12	2.02	0.12	2.44	97.92	43.25	19.06	1416	1783		90	58	22	66	48	13
306.96	61.86	0.75	14.08	5.92	0.063	2.38	3.84	2.18	2.80	0.17	5.13	99.17	50.85	18.72	837	4915	17.24	110	63	23	45	76	17
312.04	64.33	0.73	12.88	5.14	0.058	2.39	4.17	2.18	2.59	0.16	4.03	98.65	47.95	17.58	1124	5438	16.58	113	60	19	40	61	16
316.98	65.05	0.81	11.16	5.88	0.092	2.62	6.09	2.19	1.90	0.15	4.07	100.00	40.01	13.80	3554	2504		111	55	28	26	59	14
321.68	65.73	0.82	11.21	5.64	0.081	2.71	5.51	2.25	1.95	0.14	3.57	99.61	41.44	13.65	1741	2498	16.60	133	56	27	32	67	14
325.75	65.32	0.79	10.69	5.60	0.093	2.65	6.17	2.17	1.84	0.15	3.85	99.31	38.92	13.56	1732	2817		122	53	22	25	60	13
328.08	64.65	0.79	12.65	5.11	0.069	2.68	5.03	2.14	2.42	0.16	3.89	99.59	45.27	15.98	702	1729	15.99	118	62	26	38	72	16
330.63	61.80	0.82	12.62	5.66	0.081	2.86	6.11	2.22	2.49	0.17	4.74	99.57	41.96	15.37	817	2017		113	55	29	28	75	16
335.61	61.05	0.83	12.95	5.53	0.078	2.99	5.88	2.28	2.56	0.16	4.20	98.52	42.94	15.53	883	3081	15.01	116	57	22	27	75	17
340.31	64.53	0.82	13.27	5.75	0.073	2.82	4.76	2.20	2.55	0.16	3.67	100.59	46.87	16.28	578	1721	16.05	119	59	26	29	77	16
346.44	67.31	0.78	12.10	5.19	0.063	2.43	3.50	2.13	2.36	0.13	3.47	99.47	49.34	15.51	558	2150	15.37	111	56	25	25	71	15
350.87	73.00	0.56	9.16	4.35	0.064	2.34	4.05	1.66	1.61	0.10	2.73	99.63	43.62	16.41	625	1410	14.81	96	51	22	23	42	11
357.71	68.27	0.62	11.50	4.62	0.064	2.44	4.26	1.90	2.08	0.11	3.42	99.28	46.73	18.68	505	1641		111	62	27	30	54	14
363.04	69.37	0.59	11.57	4.58	0.059	2.37	3.77	1.95	2.06	0.11	3.41	99.83	48.50	19.65	623	2019	15.66	107	58	23	30	48	14
370.16	78.19	0.40	7.62	3.65	0.056	2.02	3.25	1.39	1.34	0.07	2.15	100.14	44.10	18.99	584	1276	12.88	84	49	18	19	36	10
381.49	77.53	0.41	8.00	3.36	0.048	1.95	3.01	1.49	1.45	0.07	2.28	99.61	45.71	19.47	505	1595	13.29	83	47	20	25	37	10
390.47	74.72	0.48	9.17	4.47	0.051	2.08	3.43	1.66	1.51	0.08	2.35	100.00	46.38	19.25	2072	1370	14.50	96	51	28	21	44	11
400.67	69.11	0.63	12.18	4.56	0.051	2.25	3.60	1.90	2.13	0.12	3.11	99.64	50.44	19.45	557	1792	16.83	110	61	22	34	58	14
410.88	75.61	0.47	9.41	3.58	0.051	2.08	3.58	1.60	1.58	0.09	1.99	100.03	46.49	19.84	489	1051	13.83	89	52	21	22	40	11
418.28	76.41	0.43	8.38	3.76	0.056	2.15	3.83	1.53	1.38	0.08	2.09	100.12	43.27	19.41	504	1679		89	51	24	25	36	11
426.18	86.30	0.21	4.31	2.15	0.032	1.30	1.91	1.10	1.00	0.04	1.26	99.62	40.41	20.19	731	2946		45	34	14	15	24	5
434.76	82.57	0.31	5.21	2.99	0.049	1.84	2.75	1.18	1.09	0.05	1.09	99.14	39.05	16.65	996	2905	12.54	56	44	20	18	27	6
438.87	71.17	0.51	9.60	4.64	0.072	2.60	4.86	1.58	1.55	0.10	2.45	99.14	42.22	18.72	857	1306		94	65	26	24	44	11
443.36	61.05	0.63	11.09	6.16	0.105	2.23	7.14	1.73	1.86	0.13	6.01	98.13	38.32	17.48	1066	2595	16.93		57				
448.76	66.99	0.70	11.89	5.47	0.064	2.64	3.90	1.96	2.14	0.13	3.59	99.47	48.50	16.90	1154	1297		95	56	22	27	65	14
454.16	69.66	0.64	10.86	5.02	0.060	2.50	3.23	1.88	1.99	0.10	2.74	98.68	49.42	16.93	1109	2522		109	61	26	24	68	14
459.38	66.71	0.66	12.69	5.48	0.057	2.49	3.06	1.89	2.37	0.12	4.15	99.68	53.02	19.14	1636	2005	16.49	113	69	26	26	71	15
464.70	66.06	0.67	11.91	5.72	0.063	2.69	3.50	1.89	2.10	0.12	4.78	99.50	50.35	17.65	1484	2192	17.61	112	71	30	26	74	15
470.85	66.82	0.74	11.74	5.47	0.067	2.71	3.87	1.96	2.06	0.12	3.48	99.03	48.46	15.95	1319	3058		110	64	29	26	72	15
476.03	62.89	0.43	8.21	4.97	0.135	2.31	9.63	1.38	1.42	0.13	7.99	99.50	27.79	18.97	2248	1246	14.64	95	52	21	21	44	11
481.48	71.81	0.51	10.02	4.55	0.065	2.30	4.18	1.71	1.70	0.16	2.68	99.68	44.99	19.73	1235	1951	16.70	108	58	24	27	49	12
486.15	73.45	0.47	9.05	4.69	0.065	2.08	3.45	1.63	1.57	0.08	3.02	99.55	45.94	19.20	1161	1610		112	61	27	25	43	11
503.38	75.75	0.39	8.66	3.97	0.044	2.66	1.83	2.50	1.36	0.06	2.67	99.91	49.26	21.99	214	713	14.43	91	49	26	21	36	9
509.34	69.73	0.52	10.57	4.95	0.055	2.60	1.69	2.33	1.98	0.10	4.41	98.94	53.89	20.23	1040	1173		111	59	24	28	53	12
515.83	77.48	0.42	7.61	3.88	0.038	2.27	1.79	1.68	1.44	0.06	3.01	99.69	50.11	17.99	1040	1469	15.26	105	50	22	23	44	9
523.50	74.98	0.52	9.77	3.81	0.044	1.56	2.85	1.63	1.65	0.08	3.14	100.05	50.34	18.70	723	1218	15.18	113	55	20	27	51	11
535.83	69.76	0.39	7.25	3.54	0.107	1.86	8.23	1.15	1.19	0.17	5.90	99.53	28.57	18.82	862	637		84	43	19	21	33	9
542.43	76.58	0.49	8.81	3.44	0.051	1.93	3.48	1.48	1.40	0.08	2.05	99.79	46.16	18.09	739	1570	15.11	105	51	23	26	41	11
548.57	74.29	0.53	9.56	3.62	0.049	2.08	3.32	1.67	1.61	0.09	2.32	99.12	47.58	18.07	1172	2745		95	54	22	30	49	12
564.78	72.13	0.54	9.91	4.24	0.056	2.10	3.76	1.65	1.68	0.09	2.81	98.98	46.56	18.37	866	2306	15.75	107	57	25	23	50	12
575.45	72.28	0.49	9.81	2.93	0.042	1.68	2.58	2.63	1.65	0.08	4.67	98.85	47.61	20.22	768	1014		83	51	23	20	32	13
580.19	70.04	0.51	9.39	4.55	0.056	2.06	4.18	2.26	1.53	0.09	5.64	100.30	41.97	18.34	554	461		107	61	26	20	49	12
586.40	74.24	0.52	9.70	3.86	0.047	1.35	1.75	2.00	1.92	0.09	4.03	99.51	53.16	18.48	1301	1128		105	61	23	18	51	13
601.56	75.56	0.51	10.10	2.71	0.036	1.09	1.80	2.27	1.79	0.08	3.66	99.61	53.03	19.73	615	1059		128	63	18	27	44	14
605.77	72.67	0.52	10.21	3.92	0.049	1.64	2.40	2.35	1.80	0.08	4.22	99.86	50.07	19.68	1504	919		115	60	31	27	43	12
610.70	78.79	0.39	7.64	2.80	0.038	1.46	2.27	2.13	1.25	0.06	3.04	99.87	45.93	19.47	535	688	14.31	96	49	22	17	24	9
620.36	70.72	0.53	10.42	4.61	0.064	1.38	3.68	1.60	1.98	0.10	4.38	99.46	47.62	19.52	590	1213		115	60	25	26	42	12
623.84	72.54	0.48	9.36	4.31	0.060	1.47	4.17	1.45	1.65	0.10	4.32	99.91	44.32	19.37	2468	521	13.96	104	53	25	25	47	11

Tab. 1 - Continued.

Sample	AsX	AsI	Rb	Sr	Y	Zr	Nb	Sb	Cs	Ba	La	Ce	Sm	Eu	Tb	Yb	Lu	Hf	Ta	Pb	ThX	ThI	UX	UI
17.33	3	2.7	74	260	23	255	36	0.18	2.51	370	32.5	63.5	5.26	1.25	0.72	2.09	0.289	6.36	2.10	9	4	6.52	1	1.17
20.92	2	2.0	74	248	24	243	34	0.16	2.24	331	33.4	64.8	5.25	1.15	0.58	1.86	0.291	6.52	2.15	11	6	6.71	1	1.03
25.74	4		94	330	39	400	60			475										103	10		2	
30.22		6.4						0.19	2.55	478	52.2	101.3	8.57	1.83	1.05	3.01	0.422	8.29	3.22			9.44		1.90
34.01	5		69	304	27	266	40			416										8	4		2	
40.57	3	3.6	81	257	24	238	19	0.14	2.34	412	29.8	59.4	4.77	1.02	0.60	1.95	0.294	6.69	1.23	13	5	7.05	1	1.49
42.02	4	4.23	109	224	26	203	20	0.20	4.58	413	31.6	62.8	5.41	0.97	0.69	2.13	0.335	5.47	1.31	16	6	8.99	1	1.42
46.70	3		83	263	23	222	18			412										13	4		1	
52.37	8	7.0	73	435	33	331	49	0.13	1.24	493	42.3	80.6	7.35	1.89	0.90	2.79	0.386	8.17	2.97	12	6	6.96	2	2.09
53.40	7	7.7	74	401	33	304	47	0.20	1.55	464	44.0	85.9	7.52	1.77	0.93	2.62	0.374	7.28	2.86	12	7	7.77	2	1.97
56.57	5		70	438	33	320	53			519										10	8		1	
56.90	8	6.0	81	394	33	321	51	0.22	1.81	508	45.1	89.1	7.77	1.97	0.99	2.77	0.369	7.84	3.12	11	7	8.26	3	2.25
61.64	7	6.8	105	370	32	297	45	0.16	3.03	486	49.6	97.0	8.20	1.47	0.86	2.58	0.380	7.26	2.31	16	11	9.51	2	2.01
62.35	5		107	370	34	290	43			559										15	9		2	
67.67	6	7.0	109	340	32	275	40	0.15	2.71	505	47.4	91.5	7.14	1.34	0.81	2.56	0.346	6.67	2.25	16	9	11.49	2	1.95
71.78	7		113	279	32	258	37			500										16	9		2	
79.38	5	4.0	105	285	27	230	28	0.17	2.40	494	36.0	72.7	5.68	1.20	0.75	2.07	0.322	5.94	1.91	16	8	8.80	2	1.87
85.24	2	1.8	82	300	20	204	18	0.04	1.47	477	26.9	51.6	4.08	0.89	0.53	1.64	0.243	5.57	1.24	14	4	5.46	2	1.31
93.69										424														
96.64	7	5.2	89	335	34	326	53	0.06	2.77	440	39.4	74.4	6.23	1.38	0.74	2.31	0.293	5.68	1.98	12	8	9.16	2	3.55
104.65	4		81	287	24	231	25			444										12	5		2	
109.17	9		70	391	43	422	71			420										49	8		2	
113.40	6	4.1	98	317	51	574	113	0.20	2.44	478	78.5	147.8	10.97	2.05	1.35	4.42	0.576	12.81	6.37	15	12	12.20	3	1.79
118.84	7		83	345	35	305	47			444										13	8		3	
123.20	3	4.1	118	203	29	210	22	0.36	5.33	404	32.6	66.0	5.94	1.22	0.76	2.45	0.366	5.34	1.39	18	9	9.82	2	1.80
130.42	4	4.0	79	299	27	272	31	0.13	1.84	417	35.0	68.5	5.75	1.29	0.69	2.16	0.312	6.36	2.07	12	6	7.52	2	2.01
139.40	6	4.8	97	262	30	275	34	0.18	3.22	425	38.5	74.1	6.30	1.51	0.84	2.53	0.345	7.24	2.12	14	5	8.74	2	1.14
141.52	4		90	268	31	264	34			393										14	8		4	
145.21	5	4.0	74	282	21	184	16	0.06	1.66	423	24.4	45.1	4.35	0.94	0.53	1.63	0.262	4.95	1.07	12	4	5.53	1	1.80
149.45	5	4.4	89	262	31	226	21	0.09	2.30	439	36.6	71.6	6.29	1.11	0.82	2.47	0.380	5.83	1.42	14	8	8.95	2	2.09
153.62	5		95	279	28	210	21			467										14	6		1	
159.05	4		93	280	28	214	19			466										15	6		2	
163.67	5		99	280	26	203	20			496										15	8		1	
168.95	4	4.3	89	212	34	288	34	0.18	2.68	391	38.4	74.0	6.63	1.15	0.93	3.06	0.444	7.60	1.94	13	9	8.39	2	1.55
172.10	9	3.7	84	264	29	231	27	0.15	2.63	465	32.8	65.3	5.46	1.14	0.67	2.30	0.323	5.67	1.25	14	7	8.32	1	2.02
177.16	7	6.6	86	268	32	256	33		3.10	425	35.1	72.0	6.60	1.45	0.94	2.70	0.374	6.60	2.04	14	7	8.15	2	1.45
180.99	5	5.0	92	279	34	259	36	0.21	3.62	418	39.7	80.5	7.87	1.35	0.77	2.56	0.376	7.06	1.98	14	7	8.67	2	1.92
185.64										407														
193.60	1	1.7	63	243	20	203	15	0.09	1.50	371	23.1	45.5	3.91	0.88	0.55	1.83	0.271	5.80	1.15	12	3	8.20	1	1.63
198.94	2		71	239	26	265	25			378										11	4		1	
207.22	3	2.7	78	268	27	250	22	0.10	2.36	408	29.3	58.4	5.09	1.15	0.69	2.37	0.327	6.82	1.40	13	5	6.98	1	2.10
215.20	7	6.6	116	180	31	197	24	0.27	4.95	400	33.2	64.9	6.11	1.09	0.80	2.51	0.360	4.92	1.48	16	10	10.77	2	1.94
221.38	4		97	213	40	344	39			380										67	9		3	
227.62	4	4.5	95	209	31	256	27	0.16	3.14	391	34.9	68.2	6.07	1.20	0.80	2.85	0.397	6.76	1.81	15	7	9.10	2	1.79
232.49	4	3.7	84	207	32	287	34	0.22	2.70	356	36.3	73.4	6.38	1.18	0.83	2.80	0.396	8.07	2.37	13	7	8.56	2	1.80
236.71	4	4.0	90	217	31	264	28	0.13	2.76	389	35.6	70.6	6.15	1.28	0.83	2.89	0.382	6.42	1.79	14	7	8.89	2	2.11
245.60	4	4.7	93	192	35	291	35	0.24	3.36	370	37.0	73.5	6.71	1.26	0.97	2.96	0.446	7.67	2.26	14	7	8.58	2	2.53
251.68	6	6.4	90	182	31	277	29	0.28	4.01	370	35.5	72.0	6.34	1.13	0.86	2.81	0.405	7.70	1.86	14	8	9.45	2	2.17
255.39	7		124	155	29	176	19			387										18	10		2	
260.45	6	6.8	102	172	29	222	25	0.35	4.82	363	32.8	68.2	5.97	1.03	0.88	2.50	0.369	6.13	1.77	16	9	10.10	1	1.80
263.32	5	6.4	111	151	26	171	16	0.50	5.17	368	29.2	55.2	5.10	0.70	0.57	2.03	0.281	6.21	1.14	17	10	10.42	2	2.47
269.94	4	4.4	89	224	36	322	41	0.24	3.07	392	41.8	82.6	7.25	1.39	0.99	3.22	0.487	8.50	2.84	15	7	9.78	2	2.16

Tab. 1 - Continued.

Sample	AsX	AsI	Rb	Sr	Y	Zr	Nb	Sb	Cs	Ba	La	Ce	Sm	Eu	Tb	Yb	Lu	Hf	Ta	Pb	ThX	ThI	UX	UI
278.80										509														
287.76										405														
296.09	3	2.6	79	245	25	239	20	0.19	2.66	429	29.2	58.1	5.24	1.06	0.73	2.32	0.320	6.64	1.39	13	6	8.09	2	1.80
299.32	2	2.3	83	247	24	202	15	0.13	2.61	446	26.4	52.1	4.61	1.01	0.68	2.03	0.283	5.60	1.11	14	7	7.64	2	2.33
305.42	2		68	220	21	200	13			377										12	3		2	
306.96	4	3.2	112	203	29	181	11	0.21	5.27	437	31.3	62.0	5.69	1.14	0.82	2.73	0.381	4.93	0.92	15	8	10.64	2	1.80
312.04	3	2.79	97	206	26	189	11	0.14	4.04	428	27.9	57.3	5.25	1.10	0.76	2.38	0.32	5.61	0.80	13	8	9.22	2	1.75
316.98	5		65	225	26	217	12			372										13	5		2	
321.68	3	3.2	68	226	28	226	12	0.21	2.17	383	24.4	48.6	4.93	1.05	0.77	2.45	0.364	6.04	0.95	13	5	6.64	1	1.90
325.75	3		61	231	26	226	11			374										11	3		2	
328.08	3	3.7	93	240	27	204	13	0.21	3.87	437	27.4	56.5	5.23	1.06	0.71	2.37	0.354	5.91	0.99	15	9	8.66	2	2.22
330.63	3		94	298	27	208	13			448										16	8		2	
335.61	4	3.2	97	296	27	210	14	0.14	3.83	450	28.1	56.4	5.27	1.04	0.73	2.33	0.335	5.57	1.10	16	7	8.96	2	1.68
340.31	4	4.2	101	231	26	213	14	0.19	3.94	458	28.6	58.2	5.27	1.05	0.74	2.32	0.330	6.29	1.11	17	9	9.64	2	1.84
346.44	3	3.7	93	190	26	208	14	0.27	3.57	405	27.3	54.9	5.10	1.09	0.84	2.32	0.310	6.20	0.96	15	8	9.15	1	1.52
350.87	1	2.2	58	156	20	189	8	0.21	1.95	316	18.5	38.1	3.58	0.73	0.51	1.90	0.295	5.47	0.74	11	4	5.59	1	1.66
357.71	3		79	178	23	192	9			379										13	7		2	
363.04	3	2.8	79	170	23	182	9	0.32	3.22	365	22.5	46.9	4.26	0.85	0.63	2.10	0.313	5.27	0.75	15	6	7.15	2	0.96
370.16	1	1.4	46	126	15	149	4	0.14	1.46	264	13.9	28.1	2.59	0.54	0.35	1.47	0.221	5.13	0.33	9	4	4.20	1	1.04
381.49	1	1.2	51	129	16	159	5	0.16	1.70	294	15.2	31.3	2.87	0.64	0.47	1.51	0.223	4.50	0.50	9	3	4.87	1	1.24
390.47	2	2.4	54	141	17	189	6	0.15	1.55	309	15.9	32.6	3.00	0.72	0.41	1.62	0.233	5.34	0.48	12	4	4.97	0	1.83
400.67	2	3.0	83	168	24	188	9	0.17	3.46	382	23.6	47.9	4.43	0.96	0.66	2.17	0.313	5.38	0.64	14	7	7.71	1	1.33
410.88	1	1.8	57	150	17	184	6	0.11	1.99	302	16.8	25.3	3.30	0.67	0.50	1.63	0.231	5.21	0.57	10	4	5.20	2	1.00
418.28	1		48	145	16	142	5			278										9	5		2	
426.18	0		27	74	9	89	2			172										5	1		0	
434.76	1	0.7	30	96	12	166	3	0.08	0.64	203	10.2	21.6	1.94	0.43	0.38	1.18	0.198	5.20	0.63	6	1	3.51	1	2.05
438.87	3		57	159	20	174	7			311										11	5		2	
443.36		5.5						0.39	3.17	327	24.0	49.2	4.70	0.99	0.75	2.64	0.376	4.43	0.65			7.15		1.86
448.76	3		88	185	24	172	10			424										14	6		1	
454.16	3		82	151	22	175	10			350										14	7		2	
459.38	4	5.3	95	155	25	168	10	0.37	5.76	407	25.3	53.0	4.90	0.94	0.67	2.09	0.302	4.88	0.90	15	8	9.09	2	2.03
464.70	4	4.0	90	143	25	163	9	0.34	4.85	365	23.7	50.1	4.62	0.94	0.66	2.24	0.346	4.82	0.87	14	7	8.42	2	2.07
470.85	3		85	167	23	161	11			350										14	6		1	
476.03	3	3.7	57	166	26	128	5	0.14	2.41	268	21.6	42.5	3.97	0.74	0.65	2.41	0.359	3.84	0.48	9	6	5.41	2	1.82
481.48	2	2.7	64	142	23	175	6	0.17	2.21	325	20.7	41.7	3.92	0.75	0.62	2.19	0.301	5.11	0.66	12	6	6.12	1	0.94
486.15	1		57	155	15	163	5			291										10	3		1	
503.38	1	0.8	46	160	13	153	3	0.09	2.21	249	11.9	24.1	2.39	0.56	0.35	1.33	0.196	4.25	0.39	8	2	3.75	1	1.05
509.34	3		73	361	20	179	6			333										12	6		2	
515.83	1	1.6	49	226	13	172	4	0.10	1.66	251	11.8	24.8	2.30	0.52	0.39	1.40	0.190	6.29	0.37	8	4	4.16	0	1.67
523.50	2	2.1	62	137	19	190	6	0.15	2.29	301	16.8	36.0	3.33	0.70	0.49	1.83	0.271	5.58	0.51	9	4	6.07	1	1.32
535.83	0		44	118	25	161	4			241										7	2		2	
542.43	1	1.9	51	112	18	190	6	0.13	1.85	266	15.0	1.1	3.00	0.66	0.43	1.65	0.233	5.43	0.49	8	3	5.03	2	1.45
548.57	2		61	120	18	199	7			283										10	6		1	
564.78	2	2.7	63	131	19	192	7	0.19	2.29	311	18.1	37.5	3.46	0.77	0.53	1.98	0.267	5.67	0.63	10	6	5.78	1	0.96
575.45	2		58	156	16	185	6			281										9	2		1	
580.19	2		55	251	19	212	6			300										10	4		2	
586.40	3		74	258	20	177	7			333										10	6		3	
601.56	1		65	125	17	186	6			314										8	4		2	
605.77	2		65	160	19	199	5			314										10	6		2	
610.70	1	1.1	42	203	13	189	4	0.08	1.56	241	10.9	22.1	2.14	0.47	0.34	1.30	0.176	5.36	0.33	7	2	3.82	1	1.34
620.36	2		73	178	20	193	7			347										10	5		2	
623.84	3	2.5	62	152	19	185	6	0.11	1.93	312	16.8	34.5	3.26	0.75	0.47	2.10	0.318	5.21	0.56	10	4	5.88	1	2.15

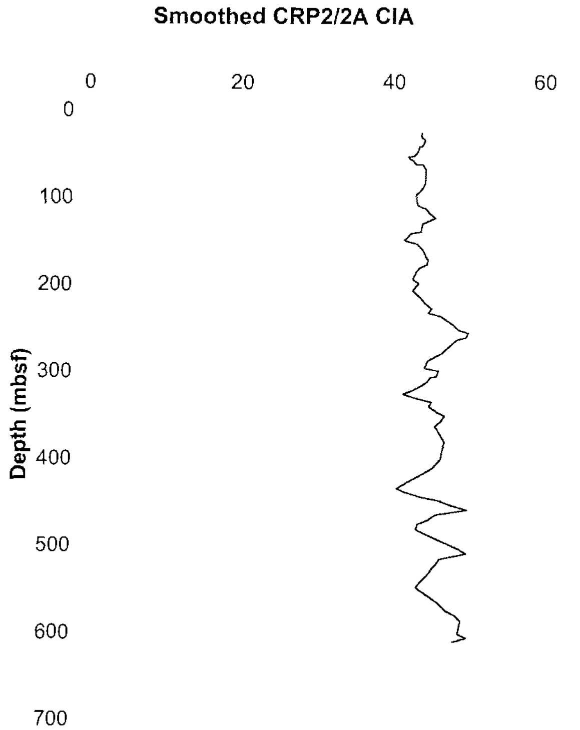


Fig. 1 - CIA profile for CRP-2/2A, smoothed with a 5-point moving average and plotted vs. subbottom depth. Note slight decrease in CIA values upsection.

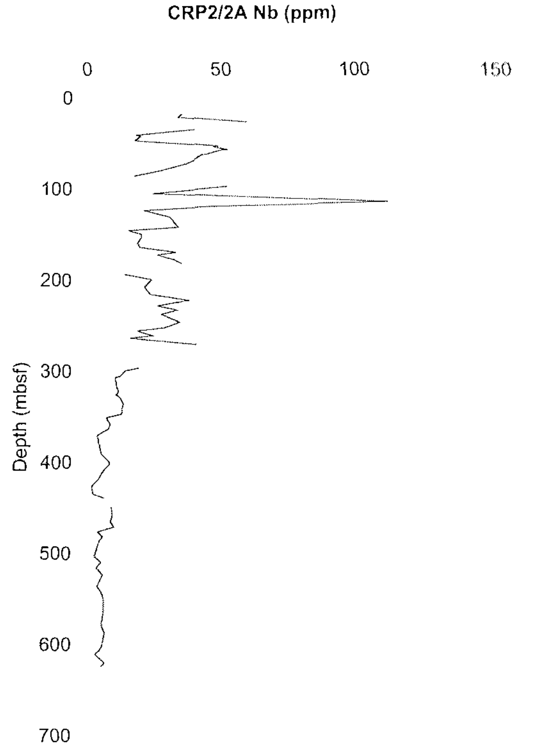


Fig. 3 - Nb concentrations with depth in CRP 2/2A cores. The sharp and rapid increase at ~300 mbsf clearly marks the incoming of McMurdo Volcanic Group detritus.

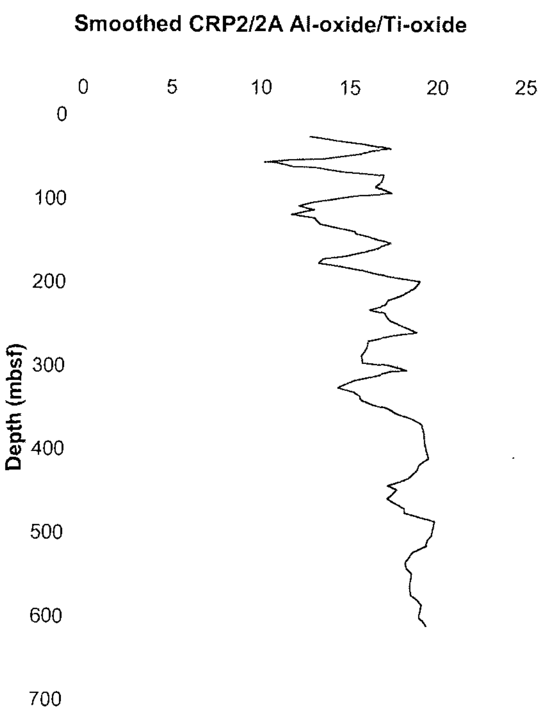


Fig. 2 - Al_2O_3/TiO_2 ratio profile for CRP-2/2A, smoothed with a 5-point moving average and plotted vs. subbottom depth.

300 mbsf might also be expected to affect the CIA profile, but CIA values do not change significantly above that level (Fig. 1). As listed in table 2, the CIA values for unweathered McMurdo Volcanic Group material are low compared to the CIA values for the basement rocks and the Beacon/Lashly sediments. However, the CIA value for unweathered intermediate McMurdo Volcanic Group material is approximately the same as the CIA for unweathered Ferrar Dolerite. As a result, the replacement of a Ferrar Dolerite component by McMurdo Volcanic Group detritus at ~300 mbsf would lower the Al_2O_3/TiO_2 ratio and increase the Nb contents without producing a significant CIA decrease. Testing this hypothesis will require more detailed compositional modeling to remove the overprint of provenance changes from the CIA record; if this hypothesis is correct, however, then the relatively uniform CIA profile indicates relatively consistent palaeoweathering intensities throughout the Oligocene and the Early Miocene in the sediment sources for CRP-2/2A. In contrast, clay mineral data (Ehrmann, this vol.; Setti et al., this vol.) have been interpreted as showing that enhanced chemical weathering influenced the sediments below approximately 490 mbsf in CRP-2/2A. Such inconsistencies in the interpreted palaeoweathering history at CRP-2/2A may result from the preliminary nature of both the geochemical and the clay mineral studies, or may reflect differences in the sensitivities of the various palaeoweathering indicators. Regardless of their cause, these inconsistencies should be examined by additional, more detailed studies.

SUMMARY AND CONCLUSIONS

The major provenance change recorded at CRP-2/2A is a rapid onset of a McMurdo Volcanic Group component above ~300 mbsf. This provenance change is not apparent in the CIA profile, however, which shows relatively uniform values throughout CRP-2/2A. The CIA profile would have been unaffected by this provenance change if

Tab. 2 - Selected geochemical data for CIROS-1 sediment source rocks (from Roser & Pyne, 1989).

Source Rock	SiO_2	Al_2O_3	TiO_2	CaO	Na_2O	K_2O	P_2O_5	CIA	Al_2O_3/TiO_2
Basement	65.25	16.14	0.72	3.88	3.63	3.69	0.17	48.7	22.4
Lower Beacon	89.73	5.7	0.24	0.68	0.2	1.44	0.02	64.6	23.8
Ferrar Dolerite	57.17	15.83	0.83	8.67	2.65	1.28	0.11	42.4	19.1
McMurdo Volcanic Group (basic)	42.69	13.83	3.82	10.78	3.53	1.49	0.86	33.9	3.6
McMurdo Volcanic Group (intermediate)	52.76	19.1	1.73	5.06	7.23	3.86	0.58	43	11
Lashly Formation	77.86	12.7	0.53	1.06	1.72	2.26	0.03	63.7	24

an older supply of Ferrar Dolerite material was replaced by a younger supply derived from intermediate McMurdo Volcanic Group rocks. If this interpretation is correct, then the relatively uniform CIA profile indicates relatively consistent palaeoweathering intensities throughout the Oligocene and early Miocene in the sediment sources for CRP-2/2A. A more detailed interpretation of the palaeoweathering and palaeoclimatic component of the CIA record, however, will only be possible after the overprint of provenance changes has been removed using mixing models and comprehensive trace element analyses.

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