Geochemical dispersion patterns associated with submarine geothermal activity in the Bay of Plenty, New Zealand

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Abstract–Trace element analyses of marine sediments from the Bay of Plenty indicate that submarine geothermal activity does not contribute significantly to the trace element geochemistry of sediments in this locality. The terrigenous sediments are similar in composition to North Island greywackes and are probably derived principally from the erosion of Mesozoic greywackes on the western flanks of the Huiarau Ranges rather than from the Quaternary acid volcanics of the Taupo region. There is no evidence for the diagenetic remobilisation of manganese or other trace elements in the sediments of this locality.

INTRODUCTION

Recent evidence has indicated the influence of submarine geothermal activity on the trace element characteristics of marine sediments (NIINO, 1959; HARDER, 1960; ZELENOV, 1964; SKORNYAKOVA, 1965; BONATTI and JOENSUU 1966; MILLER *et al.*, 1966; DEGENS and ROSS, 1969; BOSTRÖM, 1970a; TOOMS, 1970), particularly in the region of the East Pacific Rise (BOSTRÖM and VALDES, 1969; FISHER and BOSTRÖM, 1969; BENDER *et al.*, 1970; BOSTRÖM, 1970b,c; HOROWITZ, 1970; VEEH and BOSTRÖM, 1971; ANDERSON and HULUNEN, 1974; MCMURTY and BURNETT, 1975). Since submarine volcanism has been widely considered to be a major factor in controlling the deposition of authigenic marine minerals (ARRHENIUS *et al.*, 1964; ARRHENIUS and BONATTI, 1965; BONATTI and NAYUDU, 1965; BOSTRÖM, 1967), a more detailed study of the trace element characteristics of marine sediments from a region of known submarine geothermal activity has been undertaken. The area selected for study lies to the south of Whale Island in the Bay of Plenty, New Zealand. Submarine geothermal activity within this area has previously been reported by DUNCAN and PANTIN (1969), GLASBY (1971) and LYON *et al.* (in press) and evidence of volcanic activity within the surrounding region has been extensively described in the literature (*see* KOHN and GLASBY, in press, for references).

SAMPLE LOCATION AND DESCRIPTION

During previous cruises of the MV *Taranui* and MV *Ikatere* to the Bay of Plenty in June and July 1970, detailed echo sounding observations indicated the occurrence of a well-defined bubble zone to the south of Whale Island (GLASBY, 1971). Although no influence of the emanations on the hydrological characteristics of the bottom waters could be detected, subsequent studies of the chemical and isotopic composition of the gas bubbles from this region confirmed this as a zone of geothermal activity (LYON *et al.*, in press). In this paper, the trace element geochemistry of piston cores taken in the region of the geothermal activity during the MV *Taranui* Bay of Plenty cruises of June 1970 and January 1971 is described and the implications of the data to theories of authigenic

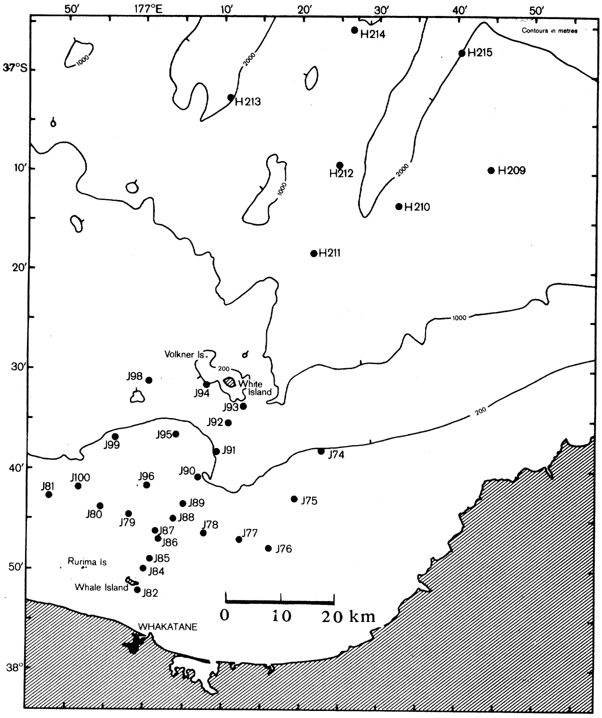

Fig. 1. Schematic diagram showing station positions in the Bay of Plenty. Contours in metres.

mineral formation are discussed. Station locations are illustrated in Fig. 1. The cores consist of grey-green terrigenous mud interbedded with well-defined tephra layers. A more detailed account of the sediment distribution in the area, together with precise locations of station position, is published elsewhere (KOHN and GLASBY, in press).

METHODS

Sediment cores were sectioned longitudinally into halves and one half of the core was retained for reference purposes. Five centimetre sections of the core were then taken at approximately 30cm intervals, dried at 80°C overnight and sieved to pass 240mesh. Subsamples were analysed for a series of elements by atomic absorption spectrophotometry with standard corrections being applied for blank samples. In order to minimise sampling errors only green muds were analysed except where otherwise stated (Appendix) and sampling procedures were adopted to optimise analytical reproductibility (ONDRICK and SUHR, 1969). Analytical precision for individual elements is shown in Table 1.

RESULTS AND DISCUSSION

The influence of submarine geothermal activity The most characteristic feature of the data (Table 1, Appendix) is the extreme uniformity in composition within each sediment core and the lack of any marked variation in composition between sediment cores. Analytical data within individual cores generally lie within the precision limits of the analytical method and t test analysis indicates that, with the exception of cores J92–95 which were sampled immediately to the south of White Island, differences in composition between cores are not generally significant at the 99% confidence level.

The most interesting feature of the data is the lack of any significant enrichment of ferrides in core J82 which was taken directly over the zone of geothermal activity compared with cores from the surrounding region. This suggests that submarine geothermal activity is not a significant contributor to the trace element distribution in sediment cores from the Bay of Plenty. This lack of enrichment of ferrides in the sediments from a region of well-defined submarine geothermal activity may reflect either the small quantity of geothermal waters discharged into the overlying bottom waters in this region (GLASBY, 1971)

Table 1. Summary of mean analyses of sediments from each core station (see Appendix for complete data). Analyses in mg/kg, except where otherwise stated. Percentage analytical precision at the 95% confidence level (2σ) is given at the base of the table. Analyses by atomic absorption spectrophotometry.

	V	Cr	Mn	Fe, %	Co	Ni	Cu	Zn
J 74	79	41	308	2.59	42	58	22	69
J 75	68	30	294	1.97	38	36	12	58
J 76	74	26	299	2.33	41	38	12	64
J 77	64	21	320	2.10	41	33	10	57
J 78	47	22	312	1.77	39	27	7	53
J 79	73	28	298	2.43	34	32	11	68
J 80	63	20	363	2.15	37	31	11	60
J 81	45	11	388	1.78	31	28	9	51
J 82	80	21	268	2.19	38	26	15	67
J 84	78	37	313	2.09	54	33	11	42
J 85	71	24	308	2.37	31	21	13	80
J 86	81	25	289	2.27	33	29	11	67
J 87	81	27	283	2.16	54	40	12	66
J 88	74	23	307	2.21	48	36	12	65
J 89	70	26	359	1.95	51	36	13	84
J 90	89	33	269	2.30	51	38	15	67
J 91	68	38	354	2.04	53	43	13	53
J 92	110	51	284	2.71	53	50	22	68
J 93	185	112	539	3.41	69	75	32	71
J 94	169	140	650	3.48	72	104	45	73
J 95	88	37	354	2.33	69	38	62	69
J 96	68	19	362	2.26	53	47	18	64
J 98	117	53	355	2.61	46	45	22	57
J 99	82	25	306	2.41	50	26	19	56
J100	53	10	452	1.84	68	24	25	45
% Precision (2σ)	±19	±32	± 7.1	±6.7	±32	±30	±32	±32

or the low trace element abundance in the thermal waters (Table 2). Other factors such as the high bottom current velocity in the area and the low salinity of the thermal waters compared with normal seawater may contribute to the rapid dispersion of ferrides in the Bay of Plenty and the high rate of terrigenous sedimentation may mask the contribution of geothermally derived trace elements to the sediments. Because of the high pH and ionic strength of seawater (Boström, 1967; Atkinson and Stefánsson, 1969), however, the ferrides would not be retained in solution on mixing of the geothermal waters with seawater and would therefore be incorporated in the sediment column.

Re-examination of the rock samples from five adjacent seamounts in the Bay of Plenty (Duncan 1970) indicates a complete absence of manganiferous coatings on outcrops within the area and iron staining occurs as a thin veneer in samples from only one station (E637). This suggests that submarine geothermal activity has no direct influence on the deposition of manganiferous and ferriferous coatings on rock fragments within this locality (Arrhenius *et al.*, 1964; Arrhenius and Bonatti, 1965; Bonatti and Nayudu, 1965). Similar conclusions hold for rock samples taken from regions of active submarine volcanism on the flanks of the Kermadec Ridge to the north (Brothers, 1967).

Since submarine geothermal activity appears to have no role to play in controlling either the trace element distribution in sediment cores or the deposition of authigenic marine minerals in a region of known submarine geothermal activity in the Bay of Plenty, the argument of previous authors (*see earlier*) that submarine geothermal activity is a major contributor to trace element abundance patterns in regions of supposed geothermal activity requires more detailed examination. This is particularly apparent in the case of the East Pacific Rise where the only evidence indicating the occurrence of geothermal

Table 2. Trace element analysis of Whale Island and White Island thermal waters. Whale Island sample collected in January 1971 and analysed by J. BINNS, Chemistry Division, D.S.I.R.; White Island sample collected and analysed by W. F. GIGGENBACH, Chemistry Division, D.S.I.R., represents the acid stream which forms the main drainage of the White Island crater floor. Major element analyses published elsewhere (GLASBY, 1971). See KOGA (1967a, b) and WILSON and MOORE (1970) for comparison. Analyses in mg/kg.

	Whale Island	White Island*
Fe	46	2040
Mn	0.38	54
Cu	<0.01	0.2
Ni	ND	0.5
Zn	0.06	0.6
Co	ND	0.3

ND = Not detected

* *Other characteristics of White Island sample:*
T 27°C; flow rate 15.6 l sec^{-1}; pH 1.78; Cl 17,050 p.p.m.; Na 3,310 p.p.m.; K 510 p.p.m.; Mg 1,850 p.p.m.; Ca 1,650 p.p.m.; Al 870 p.p.m.; B 80 p.p.m.; SiO_2 380 p.p.m.; Pb 0.9 p.p.m.

activity is the high heat flow associated with the crest of an active mid-ocean ridge system with no direct evidence of submarine geothermal activity or volcanism such as observed on the flanks of the Kermadec Ridge (KIBBLEWHITE, 1966, 1967). Although direct comparison of the two regions may be of limited value in view of possible differences in sedimentation characteristics and geothermal activity between the two areas, the data indicate the need for caution in interpreting trace element enrichment patterns in sediments in terms of submarine geothermal activity (GLASBY, 1973).

Provenance of sediments Comparison of the data with previously obtained analyses of geological samples from the North Island of New Zealand (Tables 1 and 3) indicates a marked similarity in composition between the marine sediments analysed in this study and the greywacke facies, the trace element abundance of the rhyolites being significantly lower than that of the marine sediments, particularly in the concentrations of V, Cr, Co and Ni. Although comparisons of data in this way may not be strictly valid because of inter-laboratory bias, the data suggest that the parent material for the terrigenous green muds in the eastern sector of the Bay of Plenty is derived principally from the erosion of the Mesozoic greywackes of the axial ranges with only minor contributions from the Quaternary acid volcanics of the Taupo region. This conclusion is supported by the much lower porosity of the acid volcanics compared with the greywacke facies and the fact that the acid volcanics lie in a downfaulted region whereas the greywackes lie in a tectonically rising area; both factors favouring the erosion of the greywackes. This enhanced erosion of the greywackes is best illustrated by the incised nature of the valleys and gorges of the principal rivers draining the greywacke ranges (the Whakatane, Waimana, Waiotahi, Waioeka and Motu) compared with the rivers draining the acid volcanics (Kaituna, Tarawera and Rangitaiki) which display extensive flood plains and show evidence of coastal progradation (PULLAR and SELBY, 1971). In the central sector of the Bay of Plenty, however, volcanic material from the Tarawera and Rangitaiki rivers may play a more important role in marine sedimentation processes. Tephrachronological evidence also supports this conclusion and indicates severe erosion of the greywacke ranges between the Rotoma and Waiohau eruptions (*ca.* 8,000 ~ 11,000y B.P.) and between the Waiohau and Rerewhakaaitu eruptions (11,000 ~ 15,000y B.P.) (PULLAR, pers. comm). Similarly, the area to the east of the Rangitaiki River and comprising largely Cretaceous and Tertiary greywackes is mostly devoid of ashes older than the Rerewhakaaitu (*ca.* 15,000y B.P.). The area to the west comprising ignimbrite sheets and domes has old ashes (Hamilton and

Table 3. Mean analysis of rock types from the North Island, New Zealand. All analyses in mg/kg, except where otherwise stated

	V	Cr	Mn	Fe, %	Co	Ni	Cu	Zn
Argillaceous greywacke	74	26	318	1.70	76	24	10	30
Arenaceous greywacke	116	46	450	3.14	76	48	30	54
Rhyolitic pumice (EWART *et al.*, 1968)	2.2	0.8	–	1.72	ND	ND	24	–
Rhyolitic lavas (EWART *et al.*, 1968)	4.6	ND	–	1.04	ND	ND	3.2	–
Rhyolitic ignimbrites (EWART *et al.*, 1968)	12	1.6	–	1.23	ND	ND	3.0	–
Dacite (EWART *et al.*, 1968)	26	0.9	–	3.38	4.6	2.8	5.9	–
Andesite (EWART *et al.*, 1968)	145	35	–	4.38	20	18	39	–
Basalt (EWART *et al.*, 1968)	255	140	–	7.80	37	32	35	–
"Andesitic" greywackes and argillites (EWART *et al.*, 1968)	97	27	–	3.93	13	15	39	–
Mt. Edgecumbe andesites and dacites (DUNCAN, 1970)	142	28	930	4.31	13	7.6	17	–

ND = Not detected

older) (*ca*. 100,000y). The implication is that the tephra (air-fall) material to the east of the Rangitaiki River must have been buried by later greywacke material eroded and transported during the last ice age and continuing to 8,000y (PULLAR, pers. comm.).

Although sediment discharge data for the rivers draining the Bay of Plenty are sparse, the data presented in Table 4 indicate that, for those rivers gauged, the total mean annual run-off into the Bay of Plenty is of the order of 11,789 cusecs and the total mean annual sediment discharge, calculated by the mean flow method, is of the order of 2184 tons/day. Assuming that primary terrigenous sedimentation in the Bay of Plenty is significant over a shelf area of some 60 nautical miles by 100 nautical miles and that the sediments of the Bay of Plenty have a mean density of 1.6g/cc, it can be calculated that the mean sedimentation rate within the shelf area of the Bay of Plenty is of the order of 2.5 cm/10^3y. Although this figure is considerably lower than previously determined rates of continental shelf sedimentation around New Zealand of 69 ~ 230 cm/10^3y in Hawke Bay (PANTIN, 1966), 0 ~ 360 cm/10^3y in the region Napier to Castlepoint (LEWIS and KOHN, 1973) and 15 ~ 28 cm/10^3y in the Bay of Plenty (KOHN and GLASBY, in press), the actual

Table 4. Summary of sediment discharge into the Bay of Plenty using mean flow method. Data supplied by Ministry of Works, Hamilton

River	$\log_{10}$ Gs* = a $\log_{10}$ Q + b	Gs (tons/day)
Kaituna	2.9331 $\log_{10}$ 1451 – 7.2851	97.5
Tarawera	2.0947 $\log_{10}$ 1261 – 4.2992	157.8
Rangitaiki	3.1106 $\log_{10}$ 2530 – 8.2433	222.2
Whakatane	2.4743 $\log_{10}$ 2100 – 5.5363	481.9
Waioeka	2.25 $\log_{10}$ 913 – 4.1495	325.1
Motu	2.7529 $\log_{10}$ 3534 – 6.8138	899.5

* *Gs is the sediment discharge in tons/day, Q is discharge in cusecs and a and b are constants. Total sediment discharge into the Bay of Plenty is therefore 2184 tons/day.*

rate of sedimentation may be significantly higher than the calculated value, since –

1. The mean flow method of calculating sediment discharge rates employed in this study generally give rise to low sediment discharge values compared with the flow-duration method.
2. Not all rivers draining into the Bay of Plenty were considered in this calculation because of the lack of sediment discharge data.
3. The shelf area in which terrigenous sedimentation was considered may have been overestimated.
4. Erosion of the greywacke ranges may have been more rapid during the Quaternary glaciations (McLEAN, 1969). Other errors present in this calculation have been discussed by MEADE (1969).
5. Sediment discharge may be significantly higher during periods of flood. According to W. A. PULLAR (pers. comm.), the 1964 Whakatane River flood (85,000 cusecs) was very dirty with much greywacke in suspension.
6. Mass movement on slopes may be an important mode of sediment transport (SELBY, 1967; PAIN, 1969).

It is therefore concluded that sediment deposition within the Bay of Plenty is derived principally from river run-off. The data also indicate that sediment discharge from the rivers draining the greywacke belt (Whakatane, Waioeka and Motu) is much higher (1706 tons/day) than that of the rivers draining the acid volcanic zone (Kaituna, Tarawera and Rangitaiki) (478 tons/day) confirming the conclusion that terrigenous sedimentation in the eastern sector of the Bay of Plenty is derived principally from the erosion of greywacke beds. The observation of abundant volcanic glass shards in the sand size fraction of the sediments, however, indicates that erosion of the acid volcanics must play some role in defining the sedimentation characteristics of the region.

Although the trace element compositions of sediments from the Bay of Plenty lie within relatively narrow limits, certain deviations from the mean concentration of terrigenous sediments are observed. Sediments from cores J92–95 taken immediately to the south of White Island, for example, show a significant enrichment in all elements analysed, particularly V, Cr, Ni and Cu, compared with the sediments from other localities. Although the precise origin of this element enrichment is not known, it may be related either to the outpouring of acid waters enriched in ferride elements from the crater of White Island (Table 2) or to the contribution of andesitic material from White Island (DUNCAN and VUCETICH, 1970; KOHN and GLASBY, in press), in either case leading to ferride element enrichment in the sediment. Since inter-element ratios of the "excess" abundance of elements in the sediments taken to the south of White Island do not correspond closely to those in either the White Island thermal waters (Table 2) or andesite (Table 3), it is possible that a combination of the two processes is being observed. It should be emphasised, however, that a substantial amount of iron is being discharged into the sea from the White Island crater each year (of the order of 1,000 tons/y) and that this could scavenge substantial quantities of trace elements from seawater as colloidal ferric hydroxide.

In the case of the one discrete ash layer analysed from the onshore volcanic zone (J77, 122 ~ 127 cm), the tephra show a marked depletion in the contents of V, Cr, Ni and Cu compared with the surrounding green muds and are more similar in composition to the central North Island rhyolitic pumices reported by EWART *et al.* (1968) (Table 3).

Influence of diagenesis Finally, there appears to be no evidence of enrichment of manganese and other ferrides in the upper layers of the sediment cores from this region. This suggests that diagenetic processes such as suggested by LYNN and BONATTI (1965) are not important in controlling element migration in this sedimentary environment. Enrichment of ferrides in the upper layers of the sediment column is observed, however, in sediments taken in the north of the study area in a deep water environment (Tables 5 and 6) (KOHN and GLASBY, in press). This suggests the occurrence of a distinct geographical boundary at a depth of approximately 1,500m at which diagenetic remobilisation of ferrides becomes important.

Table 5. Trace element analyses of sediment samples collected from the Bay of Plenty during the MV Taranui cruise of January 1971. All analyses in mg/kg, except where otherwise stated.

Depth (cm)	Ti	V	Cr	Mn	Fe, %	Co	Ni	Cu	Zn
Station H209									
0–2	3232	88	32	1294	2.39	32	39	27	57
91–97	3426	108	52	328	2.63	32	38	26	61
Station H210									
0–2	3168	78	41	363	2.31	34	34	24	49
61–66	3841	96	45	373	2.81	41	37	26	56
Station H211									
0–4	3252	100	48	647	2.50	38	38	24	51
305–310	4305	113	41	311	2.77	40	34	25	58
Station H212									
0–2	3410	66	45	688	2.39	37	36	33	58
91–97	3802	90	58	393	2.77	40	36	37	68
Station H213									
0–5	2369	44	18	5320	1.81	28	45	34	49
122–127	2879	67	38	392	2.13	36	37	36	55
Station H214									
0–2	2369	48	22	6095	1.81	30	69	34	58
91–97	2669	33	48	512	1.81	26	33	30	49
Station H215									
0–5	3178	63	30	717	2.30	32	33	31	49
91–97	3314	67	28	360	2.42	30	41	35	49

Table 6. Semiquantitative analyses of sediments by optical emission spectrography. Analyst H. J. Todd, Chemistry Division, D.S.I.R. All analyses im p.p.m.

Depth (cm)	B	Cr	Mn	Cu	Ni	Ba	V	Sr	Be	Zr	P	Zn	Pb	Sn	Ga
Station H213															
0–3	150	25	>1000	500	25	500	50	25	5	50	100	25	25	5	10
122–127	150	50	1000	300	50	500	100	25	5	100	100	25	25	1	10

Not detected: Mo, Co, Hg, As, Sb, Tl, Au, Ge, W, La and Ag. Copper values possibly contaminated from Cu arcing rods.

Summary

The present evidence indicates that no detectable ferride element enrichment is observed in the associated sediments in a zone of known submarine geothermal activity in the Bay of Plenty, New Zealand. This conclusion is not unexpected in view of the low ferride element contents of geothermal discharges (Goguel and Ritchie, 1975). However, this does not preclude the possibility that submarine volcanism may contribute to the metal content of seawater and therefore indirectly to the formation of metalliferous sediments and manganese nodules in other parts of the world's oceans.

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APPENDIX

Trace element analyses of sediment samples collected from the Bay of Plenty during the MV *Taranui* cruise of June 1970. All analyses in mg/kg except where otherwise stated. All samples are green muds except where indicated to the contrary.

Depth (cm)	V	Cr	Mn	Fe, %	Co	Ni	Cu	Zn	Remarks
Station J74									
0–8	71	35	345	2.34	34	39	16	62	
30–36	73	69	349	2.34	31	67	35	61	
61–66	NA	49	348	2.48	60	124	20	55	
91–97	81	34	304	2.49	42	42	18	68	
122–127	79	37	282	2.49	39	50	21	72	
152–157	75	32	286	2.72	42	49	23	74	
183–188	75	35	284	2.75	42	49	21	75	
213–218	89	35	285	2.79	42	49	25	76	
244–249	89	41	287	2.72	42	52	22	75	
Mean	79	41	308	2.59	42	58	22	69	
Std dev.	6.9	11.7	30.4	0.18	8.0	26.0	5.4	7.6	
Station J75									
0–5	56	27	309	2.13	41	36	10	65	
61–66	74	30	305	1.90	41	34	13	58	
122–127	67	36	279	1.95	41	46	10	55	
183–188	75	27	272	1.91	30	29	14	56	
Mean	68	30	294	1.97	38	36	12	58	
Std dev.	8.8	4.2	15.4	0.11	5.5	7.1	2.1	4.5	
Station J76									
0–5	79	25	282	2.29	39	32	13	65	
30–36	88	26	326	2.41	36	38	12	69	
61–66	77	28	287	2.51	40	37	14	66	
91–97	68	28	273	2.53	37	37	13	66	
122–127	78	37	278	2.60	38	50	13	67	
152–157	72	24	302	2.40	61	44	12	60	
213–218	74	31	286	2.51	39	43	15	67	
244–249	64	23	302	2.41	33	31	12	64	
274–279	64	22	316	1.76	62	44	9	62	
305–310	83	27	306	2.27	37	33	12	63	
335–340	63	20	329	1.93	33	25	9	60	
Mean	74	26	299	2.33	41	38	12	64	
Std dev.	8.3	4.7	19.2	0.26	10.2	7.2	1.8	2.9	
Station J77									
0–5	75	26	299	2.32	34	34	12	67	
30–36	74	25	299	2.51	36	34	14	63	
61–66	61	28	308	2.34	35	26	10	63	
91–97	51	21	326	2.18	33	25	9	61	
122–127*	9	1	419	1.03	28	8	5	46	White ash
152–157	56	19	323	2.09	58	38	11	53	Green mud with black layers
183–188	87	24	326	2.25	42	30	9	53	Green mud with black layers
213–218	47	15	379	1.72	37	24	5	47	Green mud with minor quantities of white ash
244–249	59	15	295	1.85	40	45	9	57	Green mud with black pebbles
274–279	64	18	328	1.63	54	38	10	52	Green mud with black pebbles
Mean	64	21	320	2.10	41	33	10	57	
Std dev.	12.8	4.8	25.7	0.30	9.0	7.0	1.2	6.6	

* *Not included in calculation of mean* *NA = Not analyzed*

(Cont'd)

Depth (cm)	V	Cr	Mn	Fe, %	Co	Ni	Cu	Zn	Remarks
Station J78									
0–5	48	19	313	1.79	40	33	8	54	
61–66	46	25	312	1.76	38	21	7	53	
Mean	47	22	312	1.77	39	27	7	53	
Station J79									
0–5	78	27	294	2.20	38	28	15	64	
61–66	73	28	281	2.29	40	33	10	68	
122–127	84	31	291	2.57	33	35	9	71	
185–190	66	24	393	2.33	34	36	8	69	Green mud containing limited quantity of white volcanic ash particles
244–249	59	32	279	2.61	34	33	11	71	
305–310	72	27	271	2.37	26	30	10	65	
366–371	78	27	279	2.61	32	26	12	68	
Mean	73	28	298	2.43	34	32	11	68	
Std dev.	8.3	2.7	42.5	0.17	4.5	3.7	2.3	2.7	
Station J80									
0–5	72	22	346	2.27	38	28	12	62	
61–66	54	18	380	2.03	36	35	11	59	
Mean	63	20	363	2.15	37	31	11	60	
Station J81									
23–28	54	12	284	1.81	32	24	8	54	
122–127	25	13	311	1.21	30	18	8	42	
244–249	57	7	568	2.33	30	26	10	56	
Mean	45	11	388	1.78	31	23	9	51	
Station J82									
0–5	103	20	308	2.40	29	30	16	65	
18–20	90	18	311	2.11	34	19	12	59	
30–36	71	22	301	2.13	37	22	14	66	
61–66	80	20	271	2.07	34	23	13	60	
91–97	75	19	281	2.16	46	30	16	66	
122–127	73	19	269	2.16	48	39	13	61	
152–157	76	22	277	2.13	43	31	13	64	
183–188	77	26	283	2.16	42	25	15	67	
213–218	76	22	300	2.13	35	31	17	68	
244–249	81	22	218	2.33	37	26	15	71	
274–279	80	25	274	2.30	38	19	18	72	
305–310	85	20	165	2.22	39	22	15	70	
335–340	72	21	131	2.14	38	25	15	76	
Mean	80	21	268	2.19	38	26	15	67	
Std dev.	8.7	2.3	56.2	0.10	5.2	5.7	1.7	4.9	
Station J84									
0–5	92	42	356	2.22	58	26	11	37	Slight black mottling
61–66	72	44	300	1.98	58	32	11	37	
122–127	67	21	301	2.08	66	44	10	58	
183–188	68	42	318	1.80	54	31	9	37	
244–249	88	44	308	2.28	38	34	11	43	
305–310	82	32	298	2.18	48	34	14	43	
Mean	78	37	313	2.09	54	33	11	42	
Std dev.	10.7	9.2	22.1	0.18	9.7	5.9	1.7	8.1	

(Cont'd)

Depth (cm)	V	Cr	Mn	Fe, %	Co	Ni	Cu	Zn	Remarks
Station J85									
0–5	70	23	325	2.36	33	25	12	92	Green mud containing small quantity of white ash particles
30–36	70	26	315	2.35	31	23	14	75	
122–127	73	24	284	2.41	30	16	14	74	
Mean	71	24	308	2.37	31	21	13	80	
Station J86									
0–5	77	23	312	2.11	28	7	12	62	Black mottling
61–66	74	24	292	2.14	30	32	10	64	
122–127	95	30	269	2.34	29	34	10	69	
183–188	86	28	268	2.48	24	31	12	70	
244–249	74	28	268	2.29	63	44	12	64	
305–310	78	18	324	2.26	27	27	13	73	
Mean	81	25	289	2.27	33	29	11	67	
Std dev.	8.3	4.4	24.7	0.14	14.6	12.2	1.2	4.3	
Station J87									
0–5	77	26	282	2.23	50	35	13	69	
61–66	84	30	297	2.23	50	41	11	70	
122–127	84	28	279	2.26	50	44	13	68	
183–188	83	26	278	2.00	56	35	11	64	
244–149	65	24	290	1.95	65	40	11	55	
305–310	91	31	274	2.30	53	46	13	68	
Mean	81	27	283	2.16	54	40	12	66	
Std dev.	8.9	2.7	8.6	0.15	5.9	4.5	1.1	5.6	
Station J88									
0–5	74	18	337	2.23	27	29	9	61	
61–66	80	28	293	2.41	58	38	13	67	
122–127	73	22	293	2.31	54	37	12	68	
183–188	72	24	300	2.18	51	39	13	67	
244–249	69	23	314	1.98	49	36	12	63	
305–310	79	22	307	2.15	51	36	12	64	
Mean	74	23	307	2.21	48	36	12	65	
Std dev.	4.2	3.2	16.7	0.15	10.9	3.5	1.5	2.8	
Station J89									
0–5	80	29	323	2.15	48	37	13	100	
46–51	43	19	439	2.13	52	28	9	79	
91–96	72	29	382	1.53	47	37	16	101	
152–157	75	26	332	2.03	55	39	14	73	
213–218	79	26	318	1.90	53	37	12	66	
Mean	70	26	359	1.95	51	36	13	84	
Std dev.	15.3	4.1	51.6	0.25	3.4	4.3	2.6	15.9	
Station J90									
0–5	101	35	261	2.13	53	40	11	71	
61–66	90	36	245	2.30	46	37	12	73	
122–127	93	34	262	2.37	50	40	10	69	
183–188	75	28	322	2.26	49	33	11	68	
244–249	86	32	266	2.35	50	41	13	71	
305–310	92	34	257	2.40	56	38	32	49	
Mean	89	33	269	2.30	51	38	15	67	
Std dev.	8.6	2.9	27.0	0.10	3.4	2.9	8.5	8.9	

(Cont'd)

Depth (cm)	V	Cr	Mn	Fe, %	Co	Ni	Cu	Zn	Remarks
Station J91									
30–36	79	53	412	2.28	58	57	20	57	
91–97	58	23	297	1.80	49	29	7	50	
Mean	68	38	354	2.04	53	43	13	53	
Station J92									
0–5	87	40	268	2.59	53	45	18	77	
61–66	89	47	298	2.43	60	51	17	68	
122–127	147	76	281	3.04	54	68	37	64	Slight black mottling
183–188	115	48	284	2.73	51	45	21	63	
244–249	110	44	288	2.74	49	43	18	66	
Mean	110	51	284	2.71	53	50	22	68	
Std dev.	24.3	14.3	10.9	0.23	4.2	10.3	8.4	5.6	
Station J93									
0–5	138	62	330	2.70	58	47	31	74	
156–163	226	170	698	4.14	78	96	54	66	
244–249	192	104	588	3.38	72	82	40	72	
Mean	185	112	539	3.41	69	75	42	71	
Station J94									
38–43	186	92	688	3.62	72	86	62	72	
122–127	168	166	628	3.44	72	116	38	76	
274–279	154	162	634	3.38	72	110	34	72	
Mean	169	140	650	3.48	72	104	45	73	
Station J95									
0–5	92	26	286	2.40	66	34	39	75	
122–127	84	48	422	2.26	72	42	86	64	
Mean	88	37	354	2.33	69	38	62	69	
Station J96									
0–5	68	19	362	2.26	53	47	18	64	
Station J98									
30–36	137	49	351	2.62	52	54	25	59	
122–127	128	53	354	2.62	44	52	25	59	
244–249	109	65	366	2.60	37	41	21	59	
366–371	109	71	397	2.79	42	50	21	57	
488–493	102	29	307	2.41	56	26	17	53	
Mean	117	53	355	2.61	46	45	22	57	
Std dev.	14.8	16.3	32.4	0.13	7.7	11.5	3.3	2.6	
Station J99									
0–5	48	20	328	2.21	41	21	15	64	
61–66	89	27	300	2.49	52	17	18	58	
122–127	96	27	295	2.57	46	32	21	61	
183–188	96	26	300	2.38	60	34	22	40	
Mean	82	25	306	2.41	50	26	19	56	
Std dev.	23.1	3.4	15.0	0.16	8.2	8.3	3.2	10.8	
Station J100									
0–5	51	11	404	1.96	39	25	20	57	
10–15	61	12	423	2.26	69	27	30	53	
122–127	46	8	358	1.22	96	23	NA	40	
244–249	56	NA	622	1.92	68	22	NA	29	

(Cont'd)

Depth (cm)	V	Cr	Mn	Fe, %	Co	Ni	Cu	Zn	Remarks
Mean	53	10	452	1.84	68	24	25	45	
Std dev.	6.4	—	117	0.44	23.3	2.2	—	12.8	
Arenaceous greywacke									
	74	26	318	1.70	76	24	10	30	
Argillaceous greywacke									
	116	46	450	3.14	76	48	30	54	