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TRACE METAL GEOCHEMISTRY OF SEDIMENTS, NORTHEAST PACIFIC OCEAN

B.D. BORNHOLD
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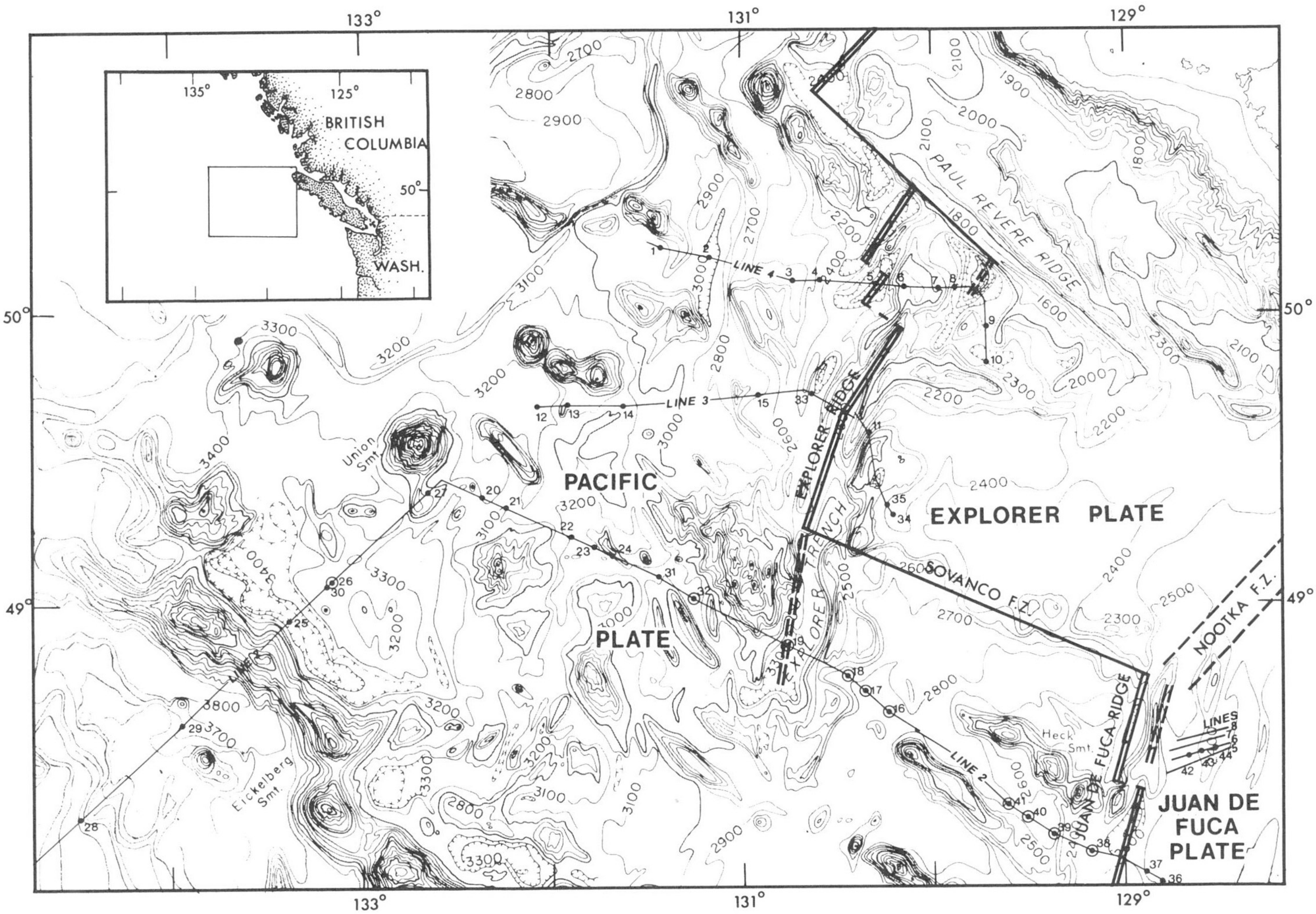

Figure 1. Location map showing the major tectonic elements, subbottom profiles and core sites. Circled cores are those in which subsamples of Unit 2 were significantly enriched in trace elements.

TRACE METAL GEOCHEMISTRY OF SEDIMENTS, NORTHEAST PACIFIC OCEAN

Abstract

Forty-two cores from the vicinity of the Juan de Fuca and Explorer ridges in the northeast Pacific were analyzed for Zn, Cu, Pb, Ni, Co, Mo, Mn, Fe and Ca. In all but one core, the trace element concentrations tend to be less than those of average Pacific pelagic clay. The exception is a core located northwest of Explorer Ridge which penetrated dark brown sediments at the base of the sedimentary section. These sediments have trace element abundances comparable to those found in metalliferous sediments from the East Pacific Rise and elsewhere in the eastern equatorial Pacific. In view of the very high rates of pelagic and hemipelagic sedimentation, metal-rich sediments overlying basaltic crust are expected to be thin in the northeast Pacific or to be localized along fault scarps or near basement outcrops where hydrothermal fluids emanate.

Résumé

Quarante-deux carottes provenant des environs des crêtes de Juan de Fuca et d'Explorer ont été soumises au dosage du Cu, Zn, Pb, Ni, Co, Mo, Mn, Fe et Ca. Dans toutes sauf une, les concentrations en éléments-traces tendaient à être moindres que dans les argiles pélagiques courantes du Pacifique. L'exception est une carotte provenant du nord-ouest de la crête d'Explorer, forée dans des sédiments brun foncé à la base de la coupe sédimentaire. Les concentrations en éléments-traces de ces sédiments se comparent à celles mesurées dans les sédiments métallifères de la dorsale est Pacifique, et d'ailleurs dans l'est du Pacifique équatorial. En raison des vitesses très élevées de sédimentation pélagique et hémipélagique, on s'attend à ce que les sédiments métallifères qui recouvrent la croûte basaltique soient minces dans le nord-est du Pacifique, ou concentrés le long des escarpements de failles ou à proximité des affleurements du socle, d'où émanent des solutions hydrothermales.

INTRODUCTION

The discovery in recent years of the association between metal-enriched sediments, first described by Murray and Renard (1891), and active oceanic spreading centres has significance for our understanding not only of geochemical systems in the ocean but of ancient base metal deposits as well (Fryer and Hutchinson, 1976). To date attention has been focused primarily on areas of relatively low sedimentation in the southeastern and equatorial Pacific, such as the East Pacific Rise (e.g. Bostrom and Peterson, 1969; Piper, 1973; Sayles and Bischoff, 1973; Dymond and Veeh, 1975; Heath and Dymond, 1977), the Bauer Deep (e.g. Dymond and Veeh, 1975; Heath and Dymond, 1977; Dymond et al., 1973), basal sediments in Deep Sea Drilling Project holes in the eastern Pacific (e.g. Dymond et al., 1973; Cronan, 1976), and sediments associated with major nodule fields (DOMES site) (Bischoff and Rosenbauer, 1977).

It was the purpose of this study to undertake a reconnaissance examination of sediments in the vicinity of the northern Juan de Fuca and Explorer ridges, active spreading ridges in the northeast Pacific, (Fig. 1) in order to determine the nature and extent of any metalliferous sediments in this area of relatively high pelagic and hemipelagic sedimentation. Iron- and manganese-rich crusts have been recovered in the northeast Pacific in dredge hauls (Barr, 1972; Piper et al., 1975) suggesting that such sediments might occur throughout the region at or near the base of the sedimentary section immediately overlying the basaltic crust. Forty-two cores were recently obtained in this area (Tiffin et al., 1978; Table 1; Appendix A) and analyzed for nine elements (Appendix B).

Regional setting

Three major lithospheric plates meet off western Canada – the American, Pacific and Juan de Fuca plates. The smallest of these, the Juan de Fuca plate, lies between the two larger plates in the study area. It is being generated at the Juan de Fuca and Explorer spreading centres at an average rate of about 2-3 cm/a[1] (Riddihough, 1977) and consumed by subduction under the American plate. The Juan de Fuca plate, due to its small size and position between much larger plates, has been broken into smaller pieces or subplates which, in their most recent history, move almost independently. Thus the Juan de Fuca subplate is separated from the Explorer subplate to the north by the Nootka Fault Zone and moves with left-lateral relative motion at 2 cm/a (Hyndman et al., 1979). The Juan de Fuca and Explorer ridges, and the Sovanco Fracture Zone, also separate the Juan de Fuca and Pacific plates. Relative movement across the spreading centres is 4-6 cm/a on average.

The northern section of Juan de Fuca Ridge is characterized by three linear valleys of which the most westerly is now active as a spreading centre (Riddihough et al., 1980). South of the Heck Seamount Chain, the ridge lacks a pronounced axial valley, a feature which is typical of slow spreading centres.

The Explorer spreading centre is a poorly defined irregular central ridge with a series of pronounced troughs ranging in depth from 2800 m in the northeast to more than 3300 m in the large Explorer Trench to the southwest. At its northern end where it terminates against Paul Revere Ridge, the Explorer Ridge is marked by two short, parallel trough segments separated by a high ridge. Although some evidence suggests that spreading has "jumped" to the more northern segment during the past million years (Riddihough et al., 1980), recent dredging of very fresh-looking basalts from the southern segment indicates that spreading may still be active there (R.L. Chase, personal communication, 1979).

[1] a is the SI abbreviation for years

Table 1. Core numbers, locations, water depths, total core lengths, and lengths of each lithologic unit

Core No.	Water Depth metres	Core Length centimetres	Latitude	Longitude	1.	Thickness of Core Units (cm) 2.	3.	4.	3+4	5.
1	3015	17	50° 12.01'	131° 26.14'	NR	1	NR	16		
2	3030	42	50° 10.56'	131° 10.58'	4	4.5			33.5	
3	2650	60.5	50° 05.64'	130° 44.96'	2	9	9	43.5		
4	2540	151	50° 05.65'	130° 36.74'	9	7	69	66		
5	2690	59	50° 05.25'	130° 19.07'	NR	3	56	NR		
6	1805	155	50° 04.24'	130° 09.31'	8	6	54	87		
7	2070	283	50° 03.99'	129° 59.20'	22	5.5			255.5	
8	2550	190	50° 04.67'	129° 54.22'	6	12			172	
9	2350	133	49° 57.16'	129° 43.74'	NR	6			127	
10	2465	152	49° 49.50'	129° 43.86'	NR	5			147	
12	3240	167	49° 38.97'	132° 04.04'	12	24	NR	131		
13	3260	169	49° 40.45'	131° 56.24'	NR	2	NR	164		3
14	3170	193	49° 40.11'	131° 38.20'	3	8	9	173		
15	2760	121	49° 42.40'	130° 56.03'	NR	2	6	113		
16	2855	85	48° 37.51'	130° 14.81'	NR	4	5	76		
17	2845	146	48° 41.04'	130° 21.77'	4.5	8.5			133	
18	2830	130	48° 44.34'	130° 27.21'	NR	12.5			117.5	
19	3405	218	48° 52.03'	130° 45.07'	3	10	16	189		
20	3225	182	49° 21.55'	132° 21.90'	6	29	NR	147		
21B	3215	165	49° 19.26'	132° 14.21'	12	7	14.5		131.5	
22	3260	300	49° 13.59'	131° 54.19'	27	22	NR	251		
23	3235	300	49° 11.30'	131° 48.47'	9	17	NR	274		
24	3245	300	49° 09.70'	131° 42.04'	NR	17	NR	283		
25	3480	287	48° 55.83'	133° 23.12'	9	19	14	245		
26	3280	209	49° 04.29'	133° 09.27'	NR	46	26	137		
27	3165	240	49° 22.48'	132° 39.13'	3	18	9	210		
28	3725	238	48° 15.60'	134° 30.27'	3	6	5	224		
29	3695	589.5	48° 34.24'	133° 56.69'	NR	2	NR	587.5		
31	3230	107	49° 04.75'	131° 27.14'	NR	3	13	91		
32	3290	115	49° 00.07'	131° 15.92'	NR	10	2	103		
33	2775	169	49° 43.43'	130° 38.87'	14	3	2	150		
34	2445	115	49° 18.14'	130° 12.76'	1.4	2.5	8	103		
35	2500	62	49° 20.25'	130° 14.14'	NR	15	NR		47	
36	2605	91	48° 00.54'	128° 48.50'	8	6	8	69		
37	2540	188	48° 03.15'	128° 10.47'	16	6	1	165		
38	2565	225	48° 07.34'	129° 10.47'	2.5	6.5			216	
39	2700	115	48° 11.14'	129° 23.50'	NR	19	7	89		
40	2680	102	48° 14.54'	129° 30.98'	NR	13	8	81		
41	2820	281	48° 17.16'	129° 36.49'	47	11	3	220		
42	2475	53	48° 27.15'	128° 39.41'	NR	3	NR	50		
43	2440	101	48° 27.77'	128° 36.83'	NR	0.5	11	89.5		
44	2425	140	48° 28.42'	128° 32.56'	NR	5	NR	135		

1 = Upper grey unit
2 = Dark brown unit
3 = Transitional unit
4 = Medium and dark grey unit
5 = Very dark brown basal unit
NR = Not represented

The Explorer Ridge is offset from the Juan de Fuca Ridge by the Sovanco Fracture zone, which meets the Explorer ridge segment near the north end of Explorer Median Valley. This has led to speculation that the southwest end of Explorer Ridge, over 50 km long, is cut off by the Fracture Zone and is no longer active (Keen and Hyndman, 1979).

The Sovanco Fracture zone forms the southwest edge of a broad plateau at approximately 2450 m depth. Immediately southwest of the fault, water depths exceed 2800 m.

Seamounts and seamount chains cover much of the area of Juan de Fuca and Explorer ridges. They are mainly confined to the Pacific plate; the number of seamounts on the Juan de Fuca and Explorer subplates is small. Although greater thicknesses of sediment are present on the latter plates, the basement topography defined by seismic profiles does not indicate the presence of a proportionate number of buried seamounts.

Pelagic and hemipelagic sedimentation on the spreading ridges west of British Columbia is greater than on most oceanic spreading ridges. The proximity of the North American landmass, and the effects of Pleistocene glaciation on the continent, have provided large quantities of sediment to the continental shelf and slope, and eventually to the ocean floor. Pelagic sedimentation rates on the Juan de Fuca ridge 100 km south of the study area are in excess of 1.0 cm/10^3a (Opdyke and Foster, 1970) and on the Gorda Rise to the southeast, are between 6 and 7 cm/10^3a (Heath et al., 1976). Since turbidites are encountered in many of the cores analyzed, these rates are considered to be minimum for much of the area. For example, rates of 170 cm/10^3a at the northern end of Middle Valley in Juan de Fuca Ridge and up to 60 cm/10^3a on the north flank of Juan de Fuca Ridge in the vicinity of Heck Seamount have been suggested (Barr, 1972; Fig. 1). Much higher rates have been found in JOIDES drillholes east of the ridge (von Huene and Kulm, 1973).

Sedimentary accumulations are found over most parts of the region investigated. Thick fan deposits and turbidites rest between the Juan de Fuca and Explorer ridges and the base of the continental slope to the east (Ewing et al., 1968). Near the crests basement depressions contain more than 2000 m of sediments (Barr, 1972). West of the crest, while sediments may be thinner (Lister, 1970), major accumulations exist in basins between seamounts. Our 3.5 kHz profiles obtained along the ship's tracks shown in Figure 1 indicate that sediment exists over many parts of the west side of the ridge, not only in the basins, but on elevated areas as well. The ubiquitous folding and faulting of these sediments (Fig. 2) attests to the degree of tectonic activity throughout the area. Perhaps much of the sediment found on the higher elevations has been moved there after deposition at lower elevations (McManus et al., 1972).

The present bathymetric map (Mammerickx and Taylor, 1971; see also Fig. 1) while showing the main features of the region, does not adequately express the rugged nature of the seafloor. Many of the silled basins are floored by sediments broken by outcrops of dykes and probable volcanic peaks projecting well above the basin floor. Small bumps and "v"-shaped depressions in these areas were targets for coring (Fig. 3). Cores were also selected on some higher elevations and near faults. Cores 42, 43 and 44 were taken in an area of tilted fault blocks (Fig. 4) with a coincident heat flow high.

Methods

An ORE 3.5 kHz high resolution subbottom profiling system with twelve hull-mounted transducers was used to obtain shallow subbottom profiles across the ridge segments.

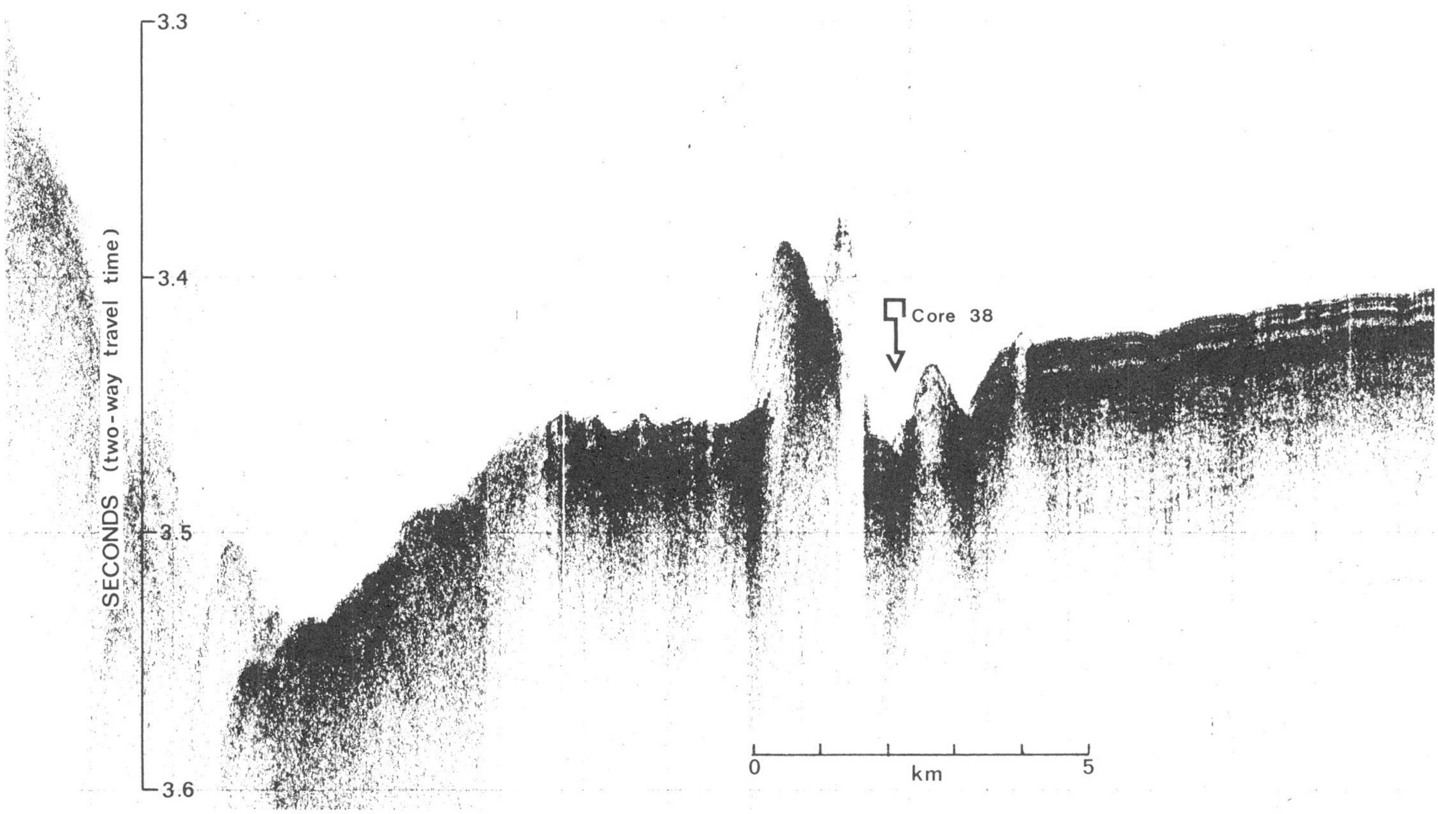

Figure 2. 3.5 kHz profile near the axis of the Juan de Fuca Ridge (Line 2).

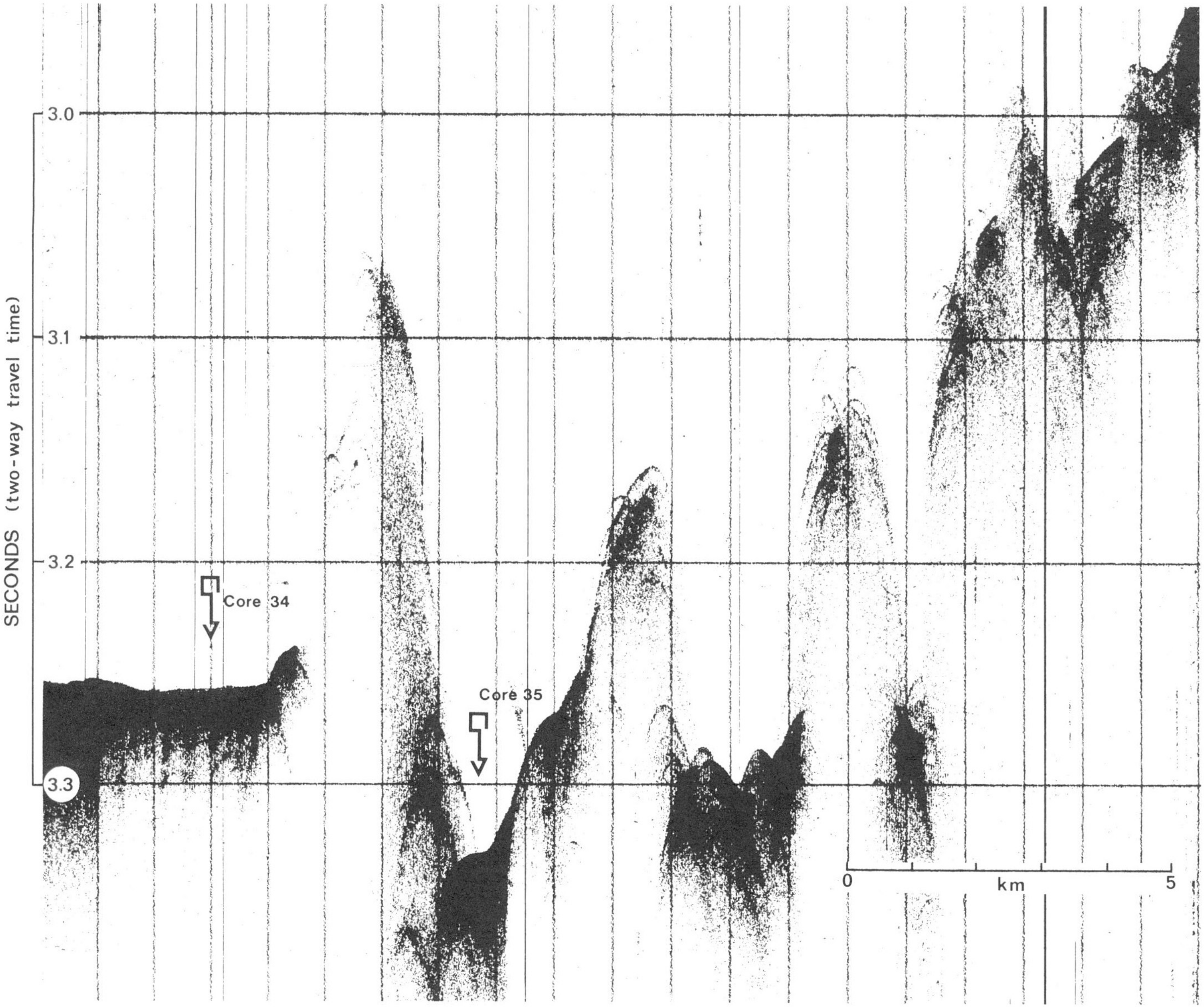

Figure 3. 3.5 kHz profile on the southeast flank of the Explorer Ridge (Line 3).

Specific core sites were selected from the subbottom records, the most favourable general locations having been previously chosen on the basis of tectonics, bathymetry and previously obtained continuous seismic profiles.

Navigation was by LORAN-C which, with an estimated relative accuracy of 30 m, permitted very accurate reoccupation of core sites chosen from echosounding and subbottom profiling records.

Sediment cores up to 5.5 m long were collected using a 550 kg gravity corer, piston corers, and Boomerang corers. Upon recovery each core was immediately split, subsampled for geochemical analysis, described, with the aid of a binocular microscope, and photographed. Subsamples were frozen and the remainder of the cores stored at 4°C.

Geochemical analyses on 348 samples were carried out with a Techtron AA-6 spectrophotometer using the following procedures: (1) samples were dried at 50°C and ground to minus 200 mesh; (2) 1.00 g of sediment was mixed with 1 mL nitric, 3 mL perchloric, and 10 mL hydrofluoric acid and taken to dryness at 200°C; (3) the residue was taken up in 25 mL of 10% perchloric acid; (4) Cu, Zn, Mn, Fe, Ni, Pb and Co were aspirated in an air-acetylene flame and Mo and Ca, in a nitrous oxide-acetylene flame. Ni, Pb and Co were simultaneously background corrected. Precision, based on standard soil samples, duplicate pairs, and internal laboratory standards, was found to be ± 5 to 16 per cent except for Mo whose measured values were only slightly above the 1 ppm detection limit. Results in this study are reported in ppm for all elements except Fe and Ca which are reported in per cent.

Total $CaCO_3$ was determined on duplicate pairs from 50 subsamples in four arbitrarily chosen cores. The method used involved leaching in 2N hydrochloric acid and washing the supernatant and residue several times through preweighed Millipore filters (0.45 μm nominal pore diameter). The sample and filter paper were dried at 105°C, reweighed, and per cent $CaCO_3$ determined by weight loss. Precision of this

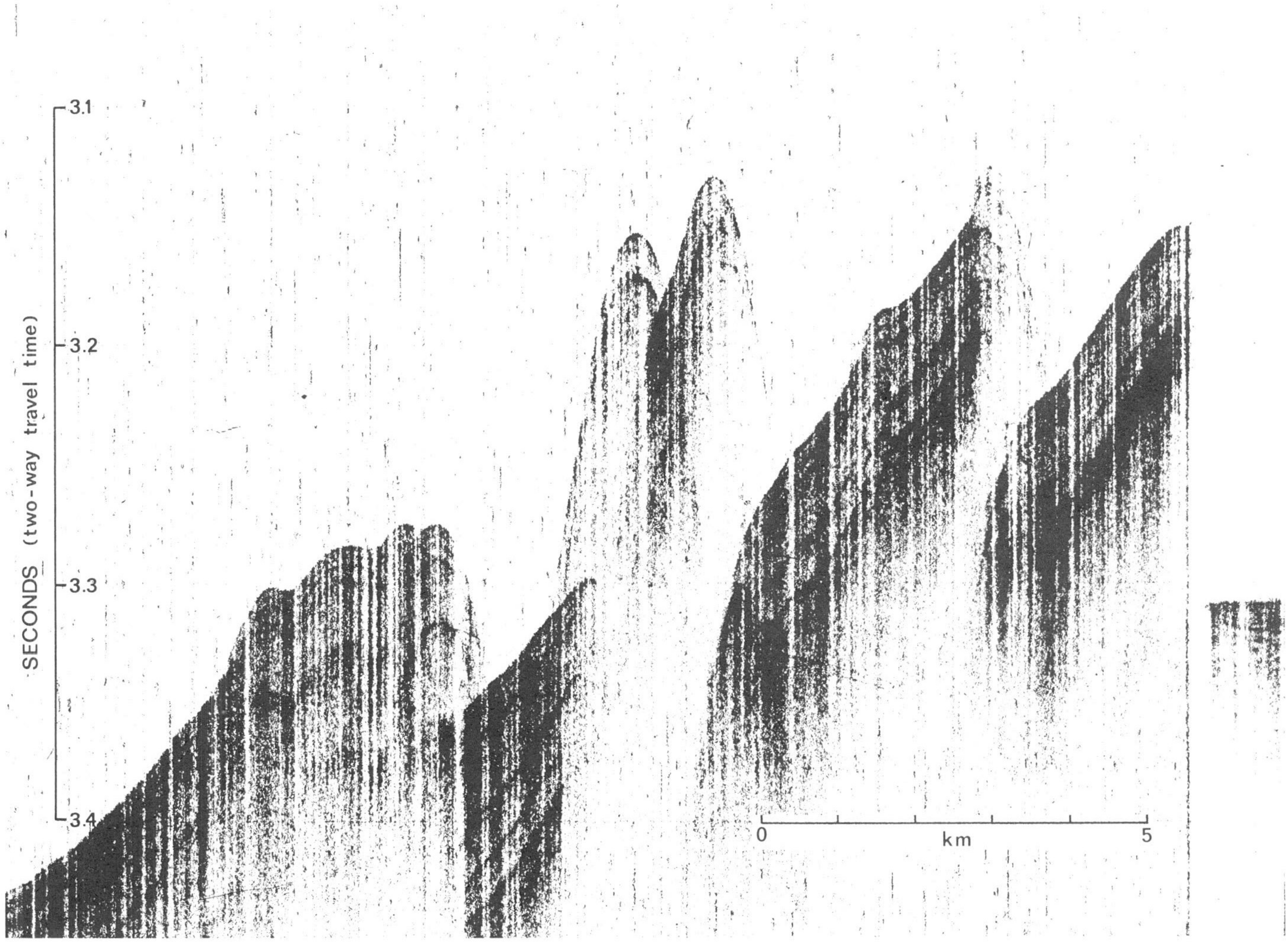

Figure 4. 3.5 kHz profile (Line 5) across several tilted fault blocks on the northeastern flank of the Juan de Fuca Ridge.

method is 10 to 15% and tends to slightly overestimate actual $CaCO_3$ concentrations by removing other easily leachable minerals, such as Fe and Mn oxides.

Many workers (e.g. Boström and Peterson, 1969; Sayles and Bischoff, 1973; Dymond et al., 1973) reported analytical results on a carbonate-free basis. We have chosen not to do this since, with the exception of cores 26 to 29 (those farthest from the ridges) virtually all of the samples analyzed contained less than 10 per cent $CaCO_3$. Although the major effect of carbonate on trace element concentrations is dilutive, as shown by significant negative correlations between Ca and most other elements (Table 3), the trace element content in most samples is sufficiently low that the biogenic contribution of some elements may be quite significant (Chester and Aston, 1976). If, for example, a sample contains 10 per cent $CaCO_3$ contributed by foraminifera, the carbonate could conceivably yield more than half of the Pb measured in these sediments.

RESULTS

Sediment lithology

The sediments throughout the study area are strikingly similar lithologically. The same general succession of lithologic units can be identified in almost all of the cores (Fig. 5). The uppermost unit (Unit 1) consists of a soft, medium grey to olive-grey silty lutite varying in thickness from 0.5 to 27 cm; this unit occurs in 23 of the 42 cores (Table 1).

Underlying Unit 1, usually with sharp contact, is a dark, red-brown soft lutite (Unit 2), ranging from 0.5 to 46 cm in thickness. This succession was previously noted by Bramlette (1961) and identified by Horn et al. (1970) as being characteristic of cores from their Central North Pacific Province. They attribute much of the darker colour in Unit 2 to an increase in disseminated Mn.

A "transitional" unit (Unit 3) underlies the dark brown lutite commonly with sharp, though occasionally gradational, contact. This unit was present in approximately one half of the cores and ranges from 1 to 69 cm in thickness and consists of banded olive grey-green and olive-brown firm, silty lutites.

The lowest unit (Unit 4) penetrated by most cores underlies Unit 3 with a gradational contact and consists of banded medium to dark grey, firm silty lutites. Disseminated foraminifera are present throughout and commonly occur concentrated in thin layers. Thin (1 to 5 cm) layers of fine terrigenous sand are present in this unit in some of the cores. In ten cores Units 3 and 4 could not be differentiated visually and are grouped as Unit 3-4 (undiff.) in Table 1.

The basal few centimetres in core 13 (166-169 cm) (Fig. 6), defined as Unit 5, consist of a dark brown, very stiff lutite containing fragments of nodular manganese-iron oxide and olivine basalt. This was the only core to have penetrated the entire sedimentary sequence to oceanic basement.

Table 2. Weighted average elemental concentrations (μg/g) in core subsamples from the northeast Pacific (this study) and mean values from elsewhere in the Pacific

Area	Zn	Cu	Pb	Ni	Co	Mn	Mo	Fe	Ca	n	Reference
All Samples – Mean Range	136 42-801	68 14-1400	14 6-340	75 10-540	23 10-490	2100 460-38000	4.0 1-48	5.3 2.1-12-2	4.9 1.2-28.0	348 348	This study
Unit 1	152	68	14	85	21	2730	6.0	5.3	3.2	46	
Unit 2	193	103	18	143	31	10900	8.6	5.1	3.8	63	
Unit 3	172	74	15	85	21	1200	3.5	5.3	4.9	23	
Unit 4	119	65	13	66	24	1500	3.8	5.2	5.4	166	
Unit 3 & 4 (Undiff.)	135	57	13	66	20	1200	3.5	5.5	3.6	49	
Unit 5	320	1400	340	450	490	29500	2.0	12.2	1.6	1	
Unit 2 – Cores 16-19, 26, 32, 38-41	253	128	20	190	35	21800	14	5.0	4.1	18	
Pacific Pelagic Clay	160	320	68	210	100	4780	-	5.06	0.66	-	Cronan, 1976
	-	570	-	293	116	12500	18	6.5	-	-	Chester and Aston, 1976
North Pacific Pelagic Clay	-	531	-	212	80	5465	-	5.23	-	-	Bonatti, 1975
East Pacific Rise crest	380	730	-	430	105	60000	30	18	-	9	Bostrom & Peterson, 1969
flank	290	960	-	675	230	30000	113	10.5	-	12	Bostrom & Peterson, 1969
basal sediments	470	790	100	460	82	60600	-	20.07	1.47	13	Cronan, 1976
Bauer Deep	330	910	-	820	67	46000	-	14.1	-	7	Dymond et al., 1973
Crustal Abuncance	70	55	12	75	25	950	1	5.63	4.15	-	Cronan, 1976

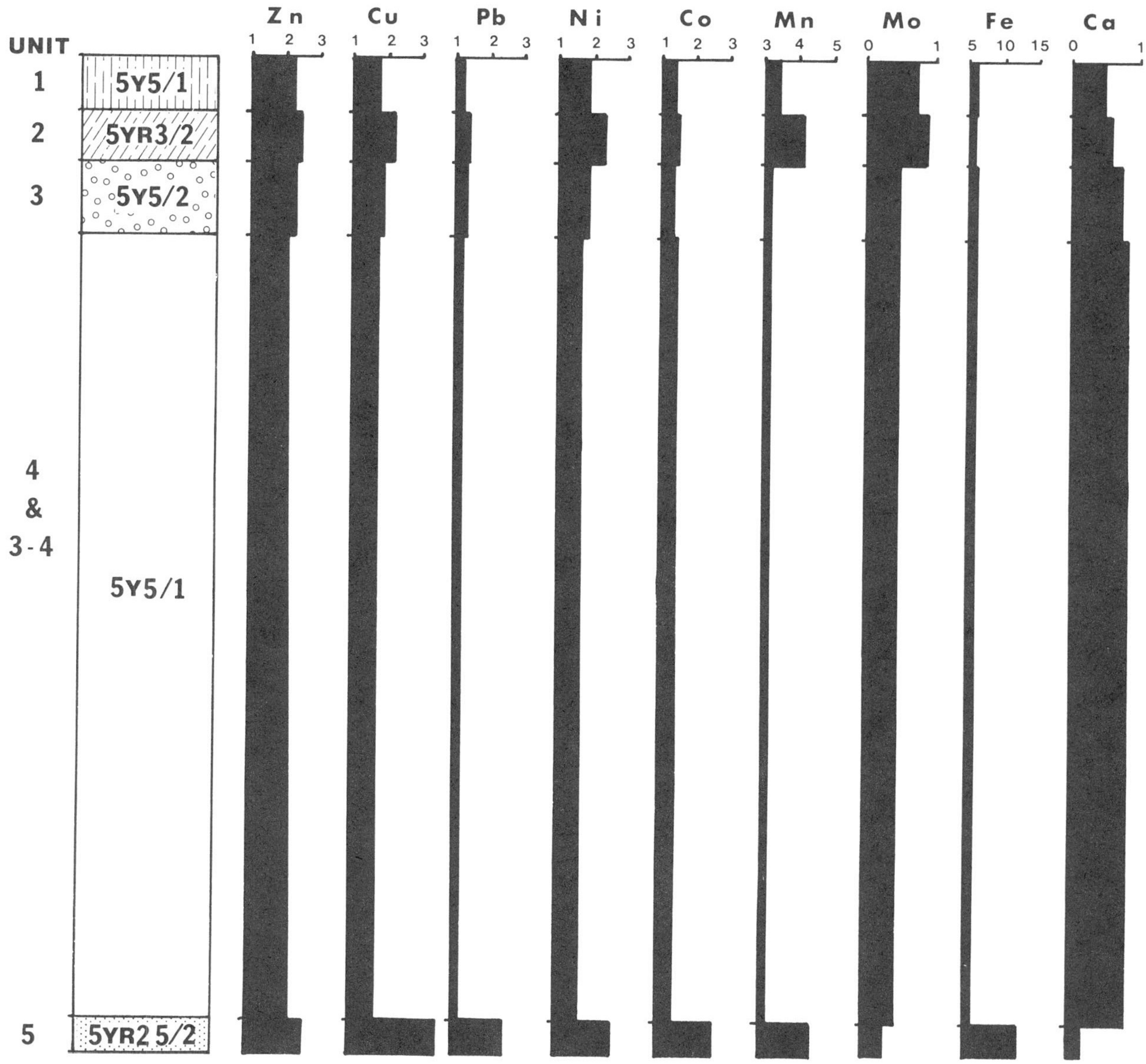

Figure 5. *Diagrammatic representation of the major lithologic units and their average trace element contents. Elemental concentrations are* log_{10} *ppm except for Fe which is reported as per cent.*

Chemical composition

A summary of the average concentrations of the nine elements in each of the five major units is presented in Table 2 with the overall means, and ranges for all the samples.

Histograms for both the total sample and subsets chosen by lithologic unit, revealed the expected log-normal distributions for all elements except Fe which appears to be normally distributed (Cronan, 1976; Krumbein and Graybill, 1965). Thus, in the statistical treatments of data presented in this paper, a logarithmic transformation has been applied for all elements except Fe. The means and standard deviations presented in Table 2 are weighted on the basis of core or unit length and have not been log-transformed in order to permit comparison with results of other studies.

Figure 7 is a graph of Ca, determined by spectrophotometry, against $CaCO_3$, determined by weight loss after acidification. Since most of the Ca values lie at or below the theoretical line for Ca in $CaCO_3$, we feel confident that most of the Ca in the samples is contained in the carbonate fraction and that our measured values of Ca are at least representative of the $CaCO_3$ content of the samples.

Several general comments can be made regarding the trace elements in each of the major lithologic units.

Unit 1

This surficial unit is characterized by trace element concentrations of all elements, except Zn and Fe, that are 20 to 60 per cent of those reported for average Pacific pelagic clays (Cronan, 1976; Chester and Aston, 1976; Table 2); values for Zn and Fe are comparable to reported values. The average concentrations in Unit 1 are similar to those in Units 3, 4 and 3-4 (undiff.).

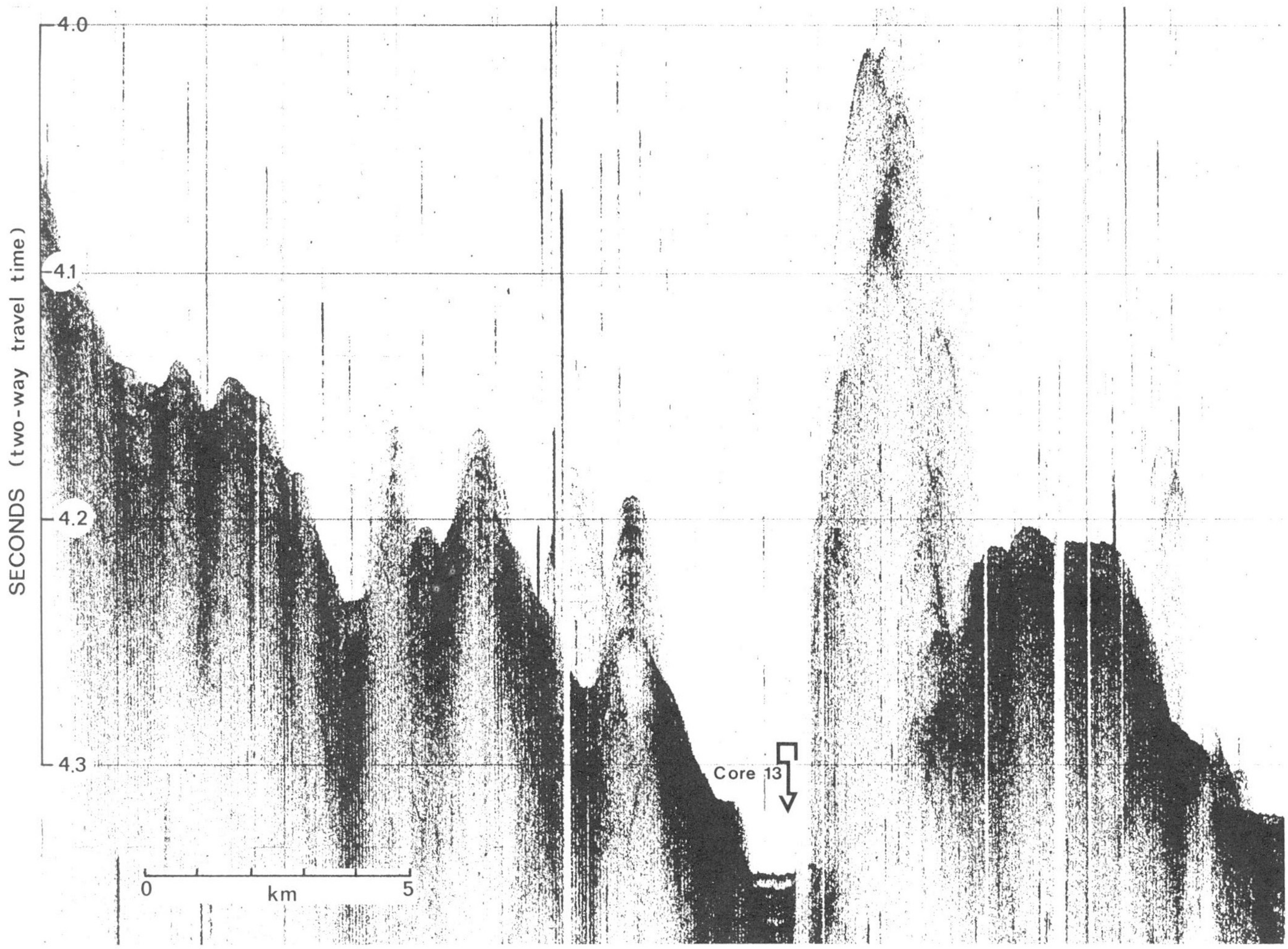

Figure 6. 3.5 kHz profile over core site 13 in which metal-rich sediments were recovered from the basal few centimetres.

Unit 2

Of all the lithologic units except Unit 5, the highest concentrations of all elements except Fe and Ca were found in Unit 2. Even those values, however, tend to be well below those for average Pacific pelagic clays: Cu, Pb, Co, Mo and Ca concentrations are 25 to 50 per cent of those in average Pacific clays. Zn, Mn and Fe have comparable concentrations to average deep-sea clays.

In an effort to discover any regional differences in trace element abundances in Unit 2, those cores which contained samples with three or more elements whose concentrations were more than two standard deviations above the mean were identified. The ten cores fitting these criteria (Fig. 1) fall along the southernmost line of cores including all cores from the north flank of the Juan de Fuca Ridge, across southwestern Explorer Median Valley. The single additional core is located in a broad plain between Union and Eickelberg seamounts. In these cores, Zn values are particularly high (200-340 ppm) and are comparable to those in metalliferous sediments from the East Pacific Rise (Table 2). Mn levels in Unit 2 from these cores are approximately five times higher than in average Pacific pelagic clays, but other trace elements are comparable to or lower than average Pacific pelagic clay concentrations.

Unit 3

This unit appears to be "transitional" not only visually between Units 2 and 4 but geochemically as well. Trace element values fall between those of the over- and underlying units for Zn, Cu, Pb and Ni.

Unit 4 and 3-4 (undiff.)

The lowest concentrations of all elements except Fe and Ca were found in the lowermost units. Values are commonly less than 20 per cent of those reported for average Pacific clay.

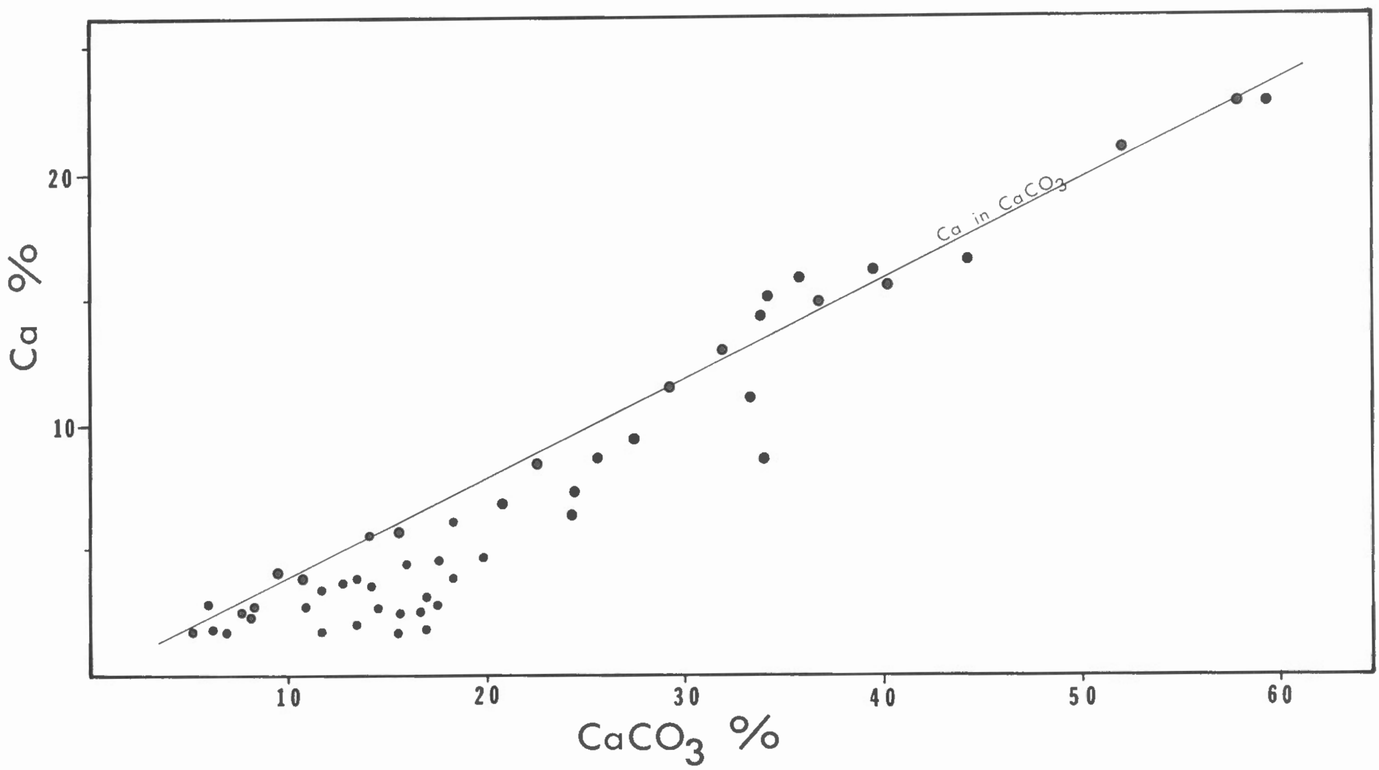

Figure 7. Graph of Ca determined by atomic absorption spectrophotometry against $CaCO_3$ determined by weight loss after acidification.

Unit 5 (basal sediments – core 13)

The dark brown, stiff lutite found at the base of core 13 contained the highest concentrations of Cu, Pb, Ni, Co and Fe measured in this study, and are equal to or greater than those found in metalliferous sediments associated with the East Pacific Rise (Table 2; Fig. 8). In particular, Cu, Pb and Co are high compared to other ferromanganoan sediments. Although the Mn and Zn concentrations are not the highest measured in this study they are in the same range as values in metalliferous sediments from the equatorial and southeastern Pacific. The Mo and Ca content of Unit 5 is also notable as it is very near the low end of the range of values observed.

Discussion

The depositional model presented by Boström and Peterson (1969) for the formation of metalliferous sediments at active oceanic ridges appears to be supported by this study. They suggested that the first sediments overlying newly formed seafloor would be rich in Mn and Fe and associated trace elements. With increasing distance from the ridges this zone of enrichment would then be covered by normal pelagic sediments. The basal metalliferous sediments are produced principally through the local addition of metals from the discharge of hydrothermal fluids onto the seafloor and secondly, as hydrogenous minerals deposited by slow chemical precipitation from seawater.

Heat flow studies in the vicinity of the Explorer and Juan de Fuca ridges suggest that hydrothermal circulation is both extensive and efficient in ventilating heat from the crust (Lister, 1970). Heat flow in the vicinity of the Explorer and Juan de Fuca ridges displays tremendous variability ranging from 50 to more than 1300 mWm^{-2} (Hyndman et al., 1978; Davis et al., 1980). Davis et al. (1980) conclude that absolute levels of heat flow are regionally low compared to values expected from oceanic crust of similar age because heat is dissipated rapidly and efficiently by hydrothermal circulation to fault scarps or other basement outcrops. Significantly higher heat flows were found near many of the numerous normal faults in the region.

Recent studies concerning the origin of basal metalliferous sediments (Heath and Dymond, 1977; Rona, 1978; Hékinian et al., 1978; Bonatti, 1975; Hoffert et al., 1978) have attempted to distinguish between hydrogenous and hydrothermal deposits on the basis of elemental concentrations and ratios. In a single bulk sediment sample, however, it is usually difficult to ascribe a unique mode of formation: "metalliferous sediments of hydrothermal origin may mix with and/or exhibit transitional characteristics with metalliferous sediments of hydrogenous origin." (Rona, 1978) The sample from the base of core 13 (Unit 5) has an Fe/Mn ratio of approximately 4, consistent with either a hydrogenous or hydrothermal origin, and a Ni + Co + Cu content of 2430 ppm, a value somewhat high for purely hydrothermally derived sediments. On the ternary diagram (Fig. 9) Fe-Mn-(Ni + Co + Cu), the sample falls in the uppermost part of the metalliferous sediment field suggesting perhaps a predominance of hydrogenous processes.

Cronan (1976) concluded that most of the Fe in the basal D.S.D.P. core samples he studied is hydrothermal and that Mn and other transition elements are derived from seawater. Heath and Dymond (1977) partitioned Fe, Mn and other trace elements among hydrothermal, hydrogenous, biogenic and detrital sources for the East Pacific Rise, Bauer Deep, and Central Basin of the Nazca plate. They concluded that: (1) most Fe, Mn, Ni, Cu and Zn are hydrothermally derived on the ridge crest; (2) Ni is mainly hydrogenous in the basins; (3) 30-50 per cent of the Cu and Zn is hydrogenous in the basins; (4) on the ridge crest, biogenic contribution of Zn and Cu is important; and (5) detrital Fe and Zn are important

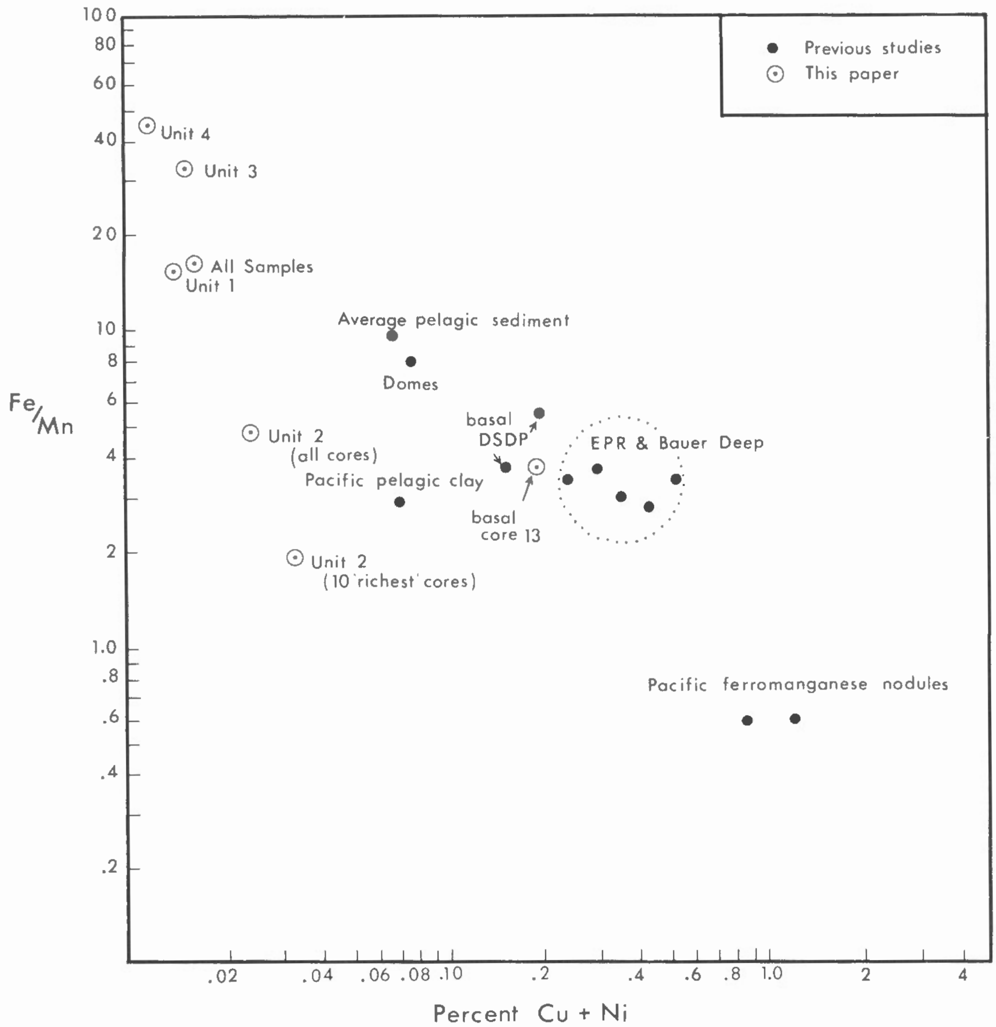

Figure 8

Fe/Mn against (Cu + Ni) showing the relationship between sediments analysed in the present study and metalliferous sediments and nodules from elsewhere in the Pacific (modified from Bischoff and Rosenbauer, 1977). EPR = East Pacific Rise.

in the Central Basin. The scenario they propose involves: leaching of Fe, Mn and transition metals from newly formed basalt by hydrothermal fluids; as hydrothermal fluids enter oxygenated seawater, Fe forms amorphous hydroxide flocs which adsorb other elements, including transition metals, from seawater and the hydrothermal solutions; a small fraction of the Fe reacts with available silica to form Fe-rich smectites; Mn and most transition metals are rejected by smectite and persist as hydroxides to become further enriched in Ni and, to a lesser extent, Cu, Zn, and Mn added directly from seawater; additional trace elements, particularly Zn and Cu, are released through oxidation of organic matter and dissolution of carbonate and opaline silica, and are taken up by the hydroxide components; and, in basinal areas up to one-sixth of the Zn is contributed from detrital sources. Their model thus involves a complex interaction of several sources in the production of the ultimate metalliferous sediment.

The basal section of core 13 has within it fragments of both basalt and ferromanganese oxides and is comparable in both trace element concentration and elemental ratios to the basal sediments described by Cronan (1976) from D.S.D.P. holes in the eastern Pacific and to East Pacific Rise and Bauer Deep sediments. On the basis of low-frequency echosounding profiles over the site and the occurrence of basaltic fragments in the sample, we feel that the ferromanganoan sediments at the core 13 site are probably very thin. Despite the fact that many other cores were obtained in areas of very thin sedimentary cover, none appears to have penetrated a basal metal-rich unit, which suggests that, if present throughout the area, such a layer is probably very thin.

Since the thickness and "grade" of metalliferous sediments in the vicinity of active spreading centres is a function of the area of supply of mineralizing solutions from the newly formed crust, their dissipation by seafloor currents, and the rate of pelagic sedimentation (Boström and Peterson, 1969; Chester and Aston, 1976; Bender et al., 1971) we suggest that the apparent absence of extensive, thick, metalliferous sediments in this area is a result of the close proximity of the western Canadian continental margin and the consequent high rates of pelagic and hemipelagic sedimentation. These rates are many times more rapid than those encountered on the East Pacific Rise and in the Bauer Deep: Dymond and Veeh (1975) reported rates of 0.14 cm/10^3a for a core in Bauer Deep with a $CaCO_3$ content of 1.2 per cent to 0.43 and 0.93 cm/10^3a, in cores on the flank and crest of the East Pacific Rise, respectively, with $CaCO_3$ contents of about 90%. It is, therefore, perhaps not surprising that mineralized precipitates from hydrothermal sources along the Juan de Fuca and Explorer ridges are drastically "diluted" by sedimentation within a very short distance of their origin.

The concentration of Mn and many other trace elements in Unit 2, relative to other lithologic units, is not apparently related to the processes which have emplaced the basal metal-rich sediments. Rather, this zone reflects the commonly observed remobilization of these elements through interstitial waters from lower more reducing parts of the sedimentary sections and their reprecipitation in the upper oxidized layers. Bonatti et al. (1971) discussed the post-depositional mobility of several elements in an East Pacific core and conclude that in terms of mobility Mn >> Ni, Co > Fe, Cu. The cores analyzed in this study tend to support these conclusions. Mn values in Unit 2 are from 6 to 8 times greater than those in Units 4 and 3-4 (undiff.) whereas Fe undergoes no significant changes in the cores whatsoever and appears unrelated to almost all other elements analyzed as shown by the very low correlation coefficients (Table 3; Fig. 10). This lack of any correlation between Mn and Fe is in marked contrast to the very high correlation coefficients found between the two elements for the basal Mn-Fe-enriched sediments in the eastern Pacific (Cronan, 1976).

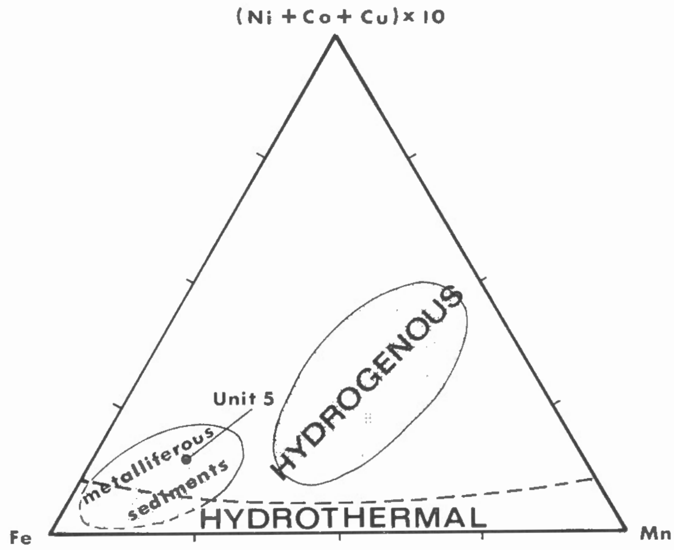

Figure 9*. Ternary diagram Fe-Mn-(Ni+Co+Cu) showing the geochemical distinction between hydrogenous and hydrothermal sources for metal-rich deposits (after Rona, 1978).*

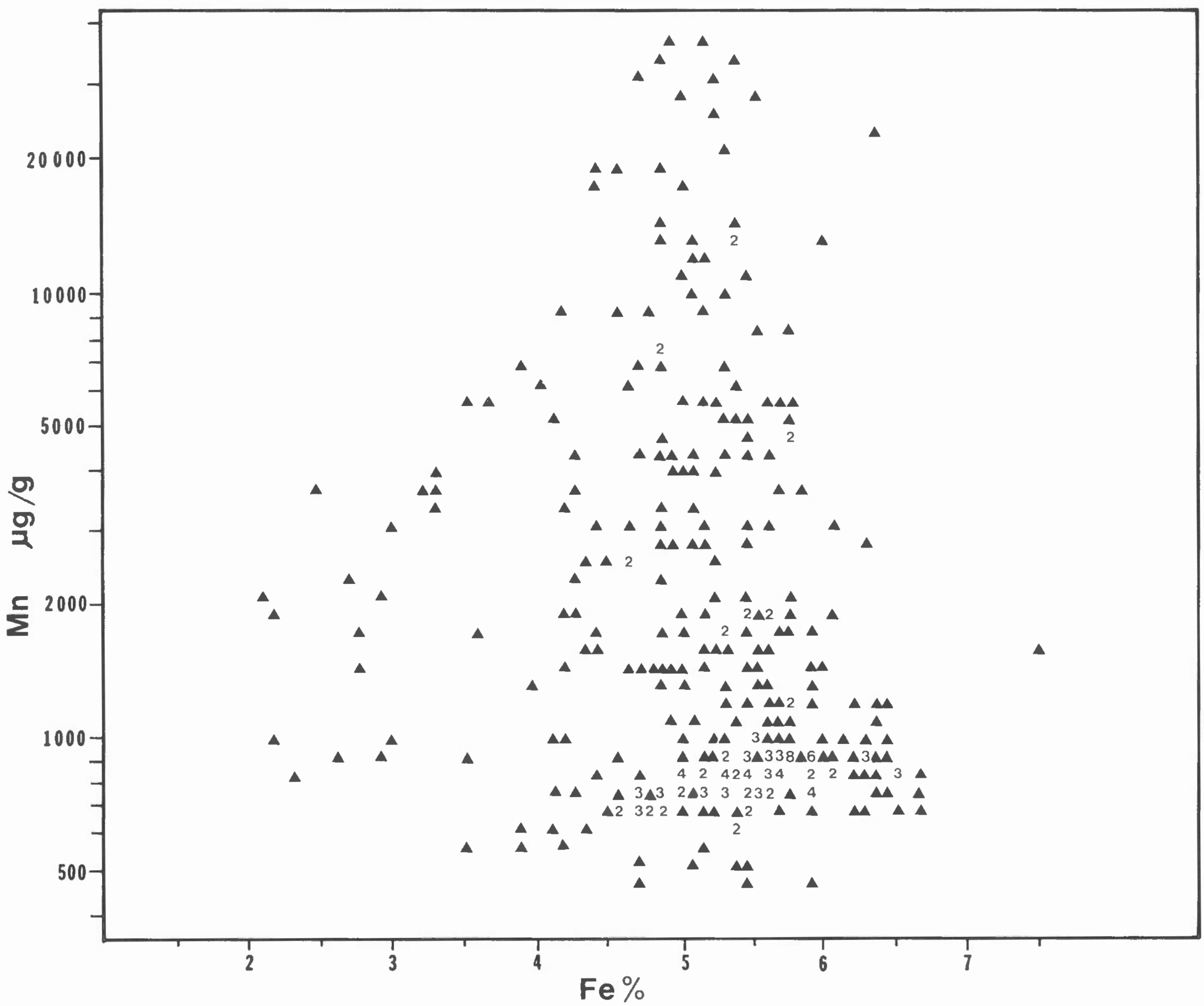

Figure 10*. Mn versus Fe for all samples in this study showing the apparent lack of significant correlation between the two elements.*

Table 3. Correlation coefficients between elements in each of the five major lithologic units using log-transformed data

	Zn	Cu	Pb	Ni	Co	Mn	Mo	Fe	Ca
Zn	1.0								
Cu	0.68**	1.0							
Pb	0.64**	0.64**	1.0						
Ni	0.71**	0.94**	0.66**	1.0		UNIT 1			
Co	0.15	0.73**	0.33 *	0.65**	1.0				
Mn	0.61**	0.85**	0.58**	0.84**	0.59**	1.0			
Mo	0.17	0.36**	0.18	0.27 *	0.24	0.56**	1.0		
Fe	-0.04	-0.16	-1.10	0.01	-0.11	-0.26 *	-0.26 *	1.0	
Ca	-0.55**	-0.15	-0.26 *	-0.30 *	0.32 *	-0.19	-0.07	-0.42**	1.0
Zn	1.0								
Cu	0.58**	1.0							
Pb	0.46**	0.45**	1.0						
Ni	0.64**	0.74**	0.41**	1.0		UNIT 2			
Co	0.18	0.74**	0.24**	0.61**	1.0				
Mn	0.73**	0.76**	0.50**	0.79**	0.52**	1.0			
Mo	0.54**	0.43**	0.42**	0.66**	0.24**	0.76**	1.0		
Fe	0.04	-0.09	0.04	0.04	-0.15	-0.11	-0.09	1.0	
Ca	-0.43**	0.16	-0.22 *	-0.11	0.57**	-0.17	-0.33**	-0.39**	1.0
Zn	1.0								
Cu	0.74**	1.0							
Pb	0.85**	0.75**	1.0						
Ni	0.88**	0.86**	0.83**	1.0		UNIT 3			
Co	-0.27	0.30	-0.07	0.14	1.0				
Mn	0.27	0.61**	0.35 *	0.56**	0.64**	1.0			
Mo	-0.19	0.09	-0.01	-0.01	0.37 *	0.28	1.0		
Fe	0.36 *	-0.14	0.27	0.17	-0.34 *	-0.18	-0.49**	1.0	
Ca	-0.81**	-0.39 *	-0.65**	-0.53**	0.65**	0.11	0.21	-0.41 *	1.0
Zn	1.0								
Cu	0.58**	1.0							
Pb	0.53**	0.76**	1.0						
Ni	0.62**	0.82**	0.70**	1.0		UNIT 4			
Co	0.39**	0.82**	0.66**	0.71**	1.0				
Mn	0.25**	0.60**	0.42**	0.52**	0.75**	1.0			
Mo	0.07	0.22**	0.19**	0.16 *	0.27**	0.21**	1.0		
Fe	0.53**	0.07	0.01	0.18 *	0.01	-0.12	0.01	1.0	
Ca	0.38**	0.08	0.02	-0.06	0.11	0.23**	0.02	-0.79**	1.0
Zn	1.0								
Cu	0.94**	1.0							
Pb	0.82**	0.84**	1.0						
Ni	0.90**	0.94**	0.82**	1.0		UNIT 3&4 (UNDIFF.)			
Co	0.58**	0.72**	0.61**	0.64**	1.0				
Mn	0.63**	0.69**	0.64**	0.61**	0.63**	1.0			
Mo	0.04	0.06	0.06	0.06	0.06	0.24 *	1.0		
Fe	0.34**	0.23	0.19	0.25 *	0.26 *	0.10	0.10	1.0	
Ca	-0.27 *	-0.04	-0.18	-0.22	0.23	-0.06	-0.10	-0.34	1.0

* Significant at 95 per cent level

** Significant at 99 per cent level

Table 4. Comparison of correlation coefficients between Mn and other rare elements in Units 2 and 4

Lithologic Unit	Correlation Coefficients (r) Zn	Cu	Pb	Ni	Co	Mo	Number of samples
2	0.73	0.76	0.50	0.79	0.52	0.76	63
4	0.25	0.60	0.42	0.52	0.75	0.21	166
Significance of difference between r's	9%	95%	n.s.	99%	99%	99%	

Ni, Mo, Cu and Zn appear to be depleted in Unit 4 and enriched in Unit 2. Their association with Mn is shown in Table 4 where correlation coefficients are presented for Units 2 and 4. A statistical comparison of the coefficients for the two units shows that significantly higher (95% level) correlations between Mn and Zn, Ni, Mo and Cu occur in Unit 2 than in Unit 4, suggesting a coprecipitation of these elements with Mn in the more oxidizing upper parts of the cores.

Two principal differences exist between our results and those of Bonatti et al. (1971). First, Co does not appear to be enriched significantly in the oxidized zone and, in fact, shows a significantly greater association with Mn in Unit 4 than in Unit 2. At present, we have no good explanation for this observation, but it is interesting to note that Co routinely displays high positive correlations with Ca in these samples (Table 3) an association not previously noted by other investigators. Secondly, Cu appears to be more mobile and to undergo a greater enrichment in Unit 2 than would be predicted from the results of Bonatti et al. (1971).

The reasons for the occurrence of the grey Unit 1, rather than the dark brown Unit 2, at the surface of many cores is somewhat problematical. Unit 1 sediments are depleted in all trace elements relative to the underlying Unit 2. Mn and related trace elements migrate upwards in the sediments until redox and pH conditions permit their precipitation. With high rates of sedimentation, the necessary conditions of oxidation may be met several centimetres below the seawater-sediment interface (J.A.J. Thompson, personal communication, 1979). Consequently Mn and other trace elements accumulate in a zone overlain by "normal" pelagic sediments. Because of the high rates of terrigenous dilution, there is also little opportunity for manganese oxides and other hydrogenous sediments to be precipitated or adsorbed from seawater at the seafloor as occurs in areas of low sedimentation. Mn is 2 to 3 times higher in Unit 1 than in Units 3 or 4 suggesting a possible slight addition directly from seawater or, possibly, from the underlying Unit 2, but levels are still considerably below those of even average Pacific deep-sea clays; elements other than Mn do not even show this trend. In cores which do not have a surficial grey unit, either the sediment was "missed" in coring or sedimentation is sufficiently slow at these sites to permit the Mn accumulating from depth in the core, to merge with the zone of Mn concentration at the sediment surface derived directly from seawater.

CONCLUSIONS

Very thin iron- and manganese-rich sediments with significant concentrations of trace elements were found in one core north of the Explorer Ridge at the base of the sedimentary section. Because of the dilutive effect of high sedimentation rates, which are an order of magnitude higher than those in the vicinity of the East Pacific Rise in equatorial areas, we conclude that metalliferous sediments comparable in thickness and extent to those found in the equatorial and southeast Pacific do not occur in the northeastern Pacific Ocean. This conclusion does not preclude their localized accumulation in areas of low sedimentation, such as on fault scarps or other bedrock outcrops, where hydrothermal fluids are likely emanating from fractured basaltic crust.

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Appendix A

Description of cores obtained in the vicinity of Explorer and Juan de Fuca Ridges in 1977.

Core END 77-1

Water depth	3015 m	Latitude	50° 12.01'N
Core length	16 cm	Longitude	131° 26.14'W

0 - 1 cm LUTITE, 10 YR 3/3 (dark brown), soft, slightly silty

1 - 16 cm LUTITE, 5Y5/1 (gray), moderately stiff, slightly fine sandy, with a few thin laminae (3-4 mm) of 10YR3/3 (dark brown) silty clay.

Core END 77-2

Water depth	3030 m	Latitude	50° 10.56'N
Core length	42 cm	Longitude	131° 10.58'W

0 - 4 cm SILTY LUTITE, 5Y5/1-6/1 (light gray to gray), very soft, scattered rounded, frosted, fine quartz sand, sharp lower contact.

4 - 8.5 cm LUTITE, mixed 5Y3/2 (dark reddish brown) and 5Y6/2 (light olive gray), very soft, slightly silty and sandy, gradational lower contact.

8.5 - 42 cm SILTY LUTITE, 5Y5/1-5/2 (gray to olive gray), firm, widely scattered, fine, well-rounded quartz sand grains, slightly mottled, vague suggestion of horizontal stratification.

Diatoms are abundant throughout the core.

Core END 77-3

Water depth	2650 m	Latitude	50° 05.64'N
Core length	60.5 cm	Longitude	130° 44.96'W

0 - 2 cm SILTY LUTITE, 2.5Y6/2 (light brownish gray), soft, 'wisps' of underlying brown unit within this zone, highly diatomaceous, forams common, sharp lower contact.

2 - 11 cm SILTY LUTITE, 10YR3/4 (dark yellowish brown), soft, diatoms common but less abundant than above, minor forams, sharp lower contact.

11 - 17 cm LUTITE, 5Y5/2 (olve gray), firm, slightly silty, homogeneous, diatoms rare, gradational lower contact.

17 - 60.5 cm LUTITE, 5Y5/1-5/2 (gray to olive gray), very firm, slightly silty, becoming more firm with depth, homogeneous, slightly mottled, abundant diatoms.

Core END 77-4

Water depth	2540 m	Latitude	50° 05.65'N
Core length	152 cm	Longitude	130° 36.74'W

0 - 7.5 cm LUTITE, 10YR5/1 (gray), very soft, disseminated forams, diatoms.

7.5 - 15 cm SILTY LUTITE, 10YR3/3-3/4 (dark brown to dark yellowish brown), very soft, disturbed, minor fine sand, lower contact sharp.

15 - 86 cm LUTITE, 5Y5/3 (olive), firm, slightly mottled, prominent horizontal laminae (1 cm) of alternating olive gray (5Y5/2) and olive (5Y5/3) between 69 and 86 cm, sharp lower contact.

86 - 131 cm LUTITE, 2.5Y5/0 (gray), very firm, homogeneous, sharp lower contact.

131 - 152 cm LUTITE, alternating zones (2-4 cm) of 5Y5/1 (gray) and 5Y5/2 (olive gray), three fine sand layers (0.5 cm) at 142, 147 and 149.5 cm, diatoms and forams sparse.

Core END 77-5

Water depth	2690 m	Latitude	50° 05.25'N
Core length	59 cm	Longitude	130° 19.07'W

0 - 3 cm SILTY LUTITE, 10YR3/3 (dark brown), fluid, disseminated obsidian sand grains, sharp lower contact.

3 - 59 cm LUTITE, 2.5Y5/2 (grayish brown) firm, homogeneous, disseminated obsidian grains.

Cutter and retainer - coarse obsidian sand and large angular obsidian and basaltic fragments; large fragment (6-8 cm diam.) of olivine-zeolite-obsidian.

Core END 77-6

Water depth	1805 m	Latitude	50° 04.24'N
Core lengyh	155 cm	Longitude	130° 09.31'W

0 - 16 cm SILTY LUTITE, 5Y6/2 (light olive gray), soft, minor fine sand, more sandy zone of coarse black grains and subrounded frosted quartz at 11-14 cm, gradational lower contact.

16 - 68 cm LUTITE, 5Y6/1 (gray), firm, slightly sandy, mottled, vague suggestion of horizontal stratification, sharp lower contact.

68 - 155 cm SILTY LUTITE, 5Y5/1 (gray), stiff, minor sand, zones (4-5 cm thick) of more silty and sandy lutite, sand is rounded to subrounded quartz, mottled, homogeneous.

Core END 77-7

Water depth	2070 m	Latitude	50° 03.99'N
Core length	283 cm	Longitude	129° 59.20'W

Section 1

0 - 22 cm LUTITE, 10YR5/1 (gray), soft, slightly fine sandy, sharp lower contact.

22 - 27.5 cm SILTY LUTITE, 2.5Y6/4 (light yellowish brown), soft, slightly fine sandy (obsidian), gradational lower contact.

27.5 - 145 cm SILTY LUTITE, 5Y5/2-5/3 (olive gray - olive), firm, slightly mottled, alternating laminae (2 mm to 1 cm thick) of silty and less silty lutite, disseminated basaltic and subrounded, frosted quartz grains increasing in size and concentration with depth.

Section 2

145 - 283 cm continuation of above 253-257 cm fine sand layer composed of subangular to subrounded, clear and frosted quartz, angular basaltic grains, and planktonic forams, sharp upper and lower contacts.

Core END 77-8

Water depth	2550 m	Latitude	50° 04.67'N
Core length	190 cm	Longitude	129° 54.22'W

Section 1

0 - 6 cm LUTITE, 5Y6/1 (gray), soft, slightly fine sandy, sharp lower contact.

6 - 9 cm SILTY LUTITE, 10YR4/4 (dark yellowish brown), softy, common disseminated fine sand composed of clear and frosted quartz sand and Mn micronodules, gradational lower contact.

9 - 73 cm LUTITE, 5Y5/2 (olive gray), firm, slightly mottled, silty laminae (1 cm) at 19 cm and 23 cm, structureless except for vague impression of horizontal stratification between 17 and 37 cm.

73 - 95 cm LUTITE, 5Y4/2 (olive gray), firm, slightly mottled, structureless except for 1-cm layers of gray lutite at 82.5 and 90.5 cm, forams common.

Section 2

95 - 190 cm Continuation of above with more apparent horizontal stratification (1 cm bands) from 95 to 160 cm; 160 - 190 cm core becomes slightly more gray, mottles filled with darker more silty and sandy sediment, sandy laminae (1-1.5 cm) at 127 and 146 cm.

Core END 77-9

Water depth	2350 m	Latitude	49° 57.16'N
Core length	133 cm	Longitude	129° 43.74'W

0 - 6 cm LUTITE, 5Y4/2 (dark grayish brown), very soft, slightly sandy with sand content increasing with depth, gradational lower contact.

6 - 133 cm LUTITE, 5Y5/2 (olive gray), firm, slightly mottled, slight suggestion of horizontal stratification with occasional laminae (0.5 cm) of slightly more silty and fine sandy lutite.

Core END 77-10

Water depth	2465 m	Latitude	49° 49.50'N
Core length	152 cm	Longitude	129° 43.86'W

0 - 5 cm LUTITE, 5YR3/3 (dark reddish brown), very soft, sharp lower contact.

5 - 152 cm LUTITE, 5Y4/2 (olive gray), soft becoming firm to stiff with depth, slightly mottled, suggestion of horizontal stratification, becoming more apparent 110 - 152 cm, zones of somewhat more silty lutite common throughout.

Core END 77-12

Water depth	3240 m	Latitude	49° 38.97'N
Core length	167 cm	Longitude	132° 04.04'W

0 - 12 cm LUTITE, 5Y5/1 (gray), very soft, homogeneous, sharp lower contact

12 - 36 cm SILTY LUTITE, 5YR3/3 (dark reddish brown) becoming gradually more gray with depth to 5Y5/2 (grayish brown) at base of unit, disseminated fine sand, gradational lower contact.

36 - 167 cm LUTITE, 2.5Y5/0 (gray), homogeneous, no mottling, markedly higher increase in sand-size basaltic grains in lower 20 cm.

Core END 77-13

Water depth 3260 m — Latitude 49° 40.45'N
Core length 166 cm — Longitude 131° 56.24'W

0 - 2 cm LUTITE, 10YR4/3 (brown - dark brown), very soft, sharp lower contact.

2 - 11 cm LUTITE, 5Y6/1 (gray), soft, homogeneous, sharp lower contact.

11 - 94 cm SILTY LUTITE, 2.5Y6/2-6/4 (light brownish gray - light yellowish brown) becoming slightly more gray with depth, firm to stiff, overall slight mottling with intensely mottled dark gray (5Y6/1) zone from 61-63 cm, very gradational lower contact.

94 - 156 cm SILTY LUTITE, 5Y5/3-5/2 (olive to olive gray), stiff becoming very stiff with depth, occasional slightly more silty zones (e.g. at 109-111 cm), small pebble (1 cm) at 128 cm, sharp lower contact.

156 - 166 cm SILTY LUTITE, 5Y5/1 (gray), very stiff, manganese oxide fragments abundant.

Cutter and retainer - Fe-Mn oxide fragments and angular basaltic fragments in a very stiff silty lutite.

Core END 77-14

Water depth 3170 m — Latitude 49° 40.11'N
Core length 193 cm — Longitude 131° 38.20'W

Section 1

0 - 3 cm LUTITE, 5Y6/1 (gray), softy, disseminated fine sand, forams, radiolaria, diatoms, sharp lower contact.

3 - 11 cm SILTY LUTITE, 10YR3/3 (dark brown), soft, becoming stiffer and more silty with depth, gradational lower contact.

11 - 20 cm SILTY LUTITE, alternating 10YR3/3 (dark brown), 5Y5/3 (olive) and 5Y6/1 (gray), firm, gradational lower contact.

20 - 101 cm LUTITE, 5Y6/1 (gray), soft-firm, a few zones (5 cm thick) of more olive (5Y5/3) sediment (e.g. 43-48 cm), disseminated fine-medium quartz sand, in upper 45 cm of unit intervals (1-2 cm thick) of more sandy and silty sediment, overall homogeneous with only slight suggestion of horizontal stratification, unit becomes darker gray with depth.

Section 2

101 - 105 cm Continuation of above unit, sharp lower contact.

105 - 193 cm LUTITE, 5Y6/1-5/1 (gray), lighter than above unit, soft-firm, layer of fine sand (mainly clear angular quartz) from 168-169.5 cm underlain by a sand-filled burrow from 171-176 cm.

Core END 77-15

Water depth 2760 m — Latitude 49° 42.40'N
Core length 121 cm — Longitude 130° 56.03'W

0 - 2 cm LUTITE, 10YR3/4 (dark yellowish brown), very soft, disseminated forams, sharp lower contact.

2 - 8 cm LUTITE, 5Y5/3 (olive), soft, transitional between over- and underlying units.

8 - 121 cm LUTITE, 5Y5/1 (gray) overall with local zones of olive 5Y5/3), firm, locally more silty intervals (e.g. 63-68 cm, 40-43 cm), slightly mottled with occasional burrows (1 cm diam.) containing very dark gray soft lutite (e.g. at 93 cm).

Core END 77-16

Water depth 2855 m — Latitude 48° 37.51'N
Core length 85 cm — Longitude 130° 14.81'W

0 - 4 cm SILTY LUTITE, 5Y3/2 (dark reddish brown), soft, homogeneous, sharp lower contact.

4 - 83.5 cm LUTITE, 5Y5/1 (gray), firm, vague suggestion of horizontal stratification, sharp lower contact.

83.5 - 85 cm SILTY LUTITE, 5Y6/1 (gray), firm, homogeneous.

Core END 77-17

Water depth 2845 m — Latitude 48° 41.04'N
Core length 146 cm — Longitude 130° 21.77'W

0 - 4.5 cm LUTITE, 5Y5/1 (gray), very soft, sharp lower contact.

4.5 - 13 cm LUTITE, 5YR3/3 (dark reddish brown), soft, gradational lower contact.

13 - 146 cm LUTITE, 5Y5/2 (olive gray) becoming more gray near the base, intervals (4-5 cm thick) of more silty sediment at 39, 53 and 122 cm, thin, fine sandy and silty graded laminae at 95-96 cm and 143-144.5 cm, sandy layers are 5Y4/1 (dark gray), moderately mottled, suggestion of horizontal stratification of gray and olive gray.

Core END 77-18

Water depth 2830 m — Latitude 48° 44.34'N
Core length 130 cm — Longitude 130° 27.21'W

0 - 12.5 cm SILTY LUTITE, 5Y3/2 (dark reddish brown), soft, sharp lower contact.

12.5 - 130 cm LUTITE, 5Y5/2 (olive gray), firm, more silty and more gray 22-61 cm, prominent laminae (1 cm thick) of silty lutite at 75, 78, 81, 84, 86, 89, 93, 97, 104, 117 cm, burrows are common and are filled with softer, more gray sediment (e.g. 65, 79, 87-94, 110 and 117 cm.

Core END 77-19

Water depth 3405 m — Latitude 48° 52.03'N
Core length 218 cm — Longitude 130° 45.07'W

Section 1

0 - 3 cm LUTITE, 5Y5/1 (gray), very soft, sharp lower contact.

3 - 13 cm SILTY LUTITE, 5Y3/2 (dark reddish brown), very soft (3-6 cm) becoming soft at base of unit, scattered forams, sharp undulating lower contact.

13 - 29 cm LUTITE, 5Y5/3 (olive) at top to 5Y5/1 (gray) at base, slightly silty, soft becoming firm with depth, structureless, sharp lower contact.

29 - 52 cm SILTY LUTITE, 5Y5/1 (gray), stiff, mottled, suggestion of horizontal stratification, Mn micronodules common, forams abundant, sharp lower contact.

52 - 107 cm SILTY LUTITE, 5Y4/2 (olive gray), softer and less silty than overlying unit, gray silty laminae (1 cm) at 63, 66, 69, 74, 80, 84, 95, 100, 103 cm, pyritized burrows (1-2 mm) common in silty laminae, unit intensely burrowed at top.

Section 2

107 - 218 cm Continuation of above
Prominent gray silty intervals at 123-128, 165-170, and 216-217 cm.

Core END 77-20

Water depth 3225 m — Latitude 49° 21.55'N
Core length 182 cm — Longitude 132° 21.90'W

Section 1

0 - 6 cm LUTITE, 10YR6/1 (gray) very soft, sharp lower contact.

6 - 35 cm LUTITE, 5YR3/3 (dark reddish brown) near top grading to 5Y5/3 (olive) at base, soft near top to firm near base, more silty near base, sharp lower contact.

35 - 89 cm LUTITE, 10YR6/1 (gray), soft-firm, with more silty and fine sandy laminae (1 cm thick) at 52, 55, 60, 71, and 83 cm, moderate degree of mottling, clear, angular quartz sand in lenses at 71 and 83 cm, gradational lower contact.

89 - 96 cm SILTY, FINE SAND, 5Y5/1 (dark gray).

Section 2

96 - 109 cm Continuation of above unit.
100 to 102 cm - softer and more silty than over- and underlying sediment, 10YR6/1 (light gray); 102-109 cm - dark, fine sand with prominent horizontal laminae throughout; sand becomes coarser towards base of unit; sand is clear, angular quartz and opaques, sharp lower contact.

109 - 182 cm LUTITE, 10YR6/1 (gray), firm, similar to 35-89 cm interval, silt laminae at 124, 150-154, and 164 cm; prominent burrow at 152 cm, sand layer (1 cm thick) at 163 cm; some colour variations throughout with units from 3 to 10 cm thick.

Core END 77-21B

Water depth 3215 m — Latitude 49° 19.26'N
Core length 165 cm — Longitude 132° 14.21'W

0 - 12 cm LUTITE, 5Y5/1 (gray), very soft, sharp lower contact.

12 - 19 cm LUTITE, 5YR3/2 (dark reddish brown) grading downwards to 7.5YR4/4 (brown), soft, slightly mottled, gradational lower contact.

19 - 33.5 cm LUTITE, 5Y5/3 (olive), soft at top becoming firm near base, slightly more silty than above, sharp lower contact.

33.5 - 165 cm LUTITE, 5Y5/1 (gray) overall, soft to firm, intensely mottled, many large burrows filled with very soft, dark gray sandy lutite (e.g. at 56, 62, 70-80, 103 cm), prominent silty laminae (1 cm thick) from 80 to 165 cm.

Core END 77-22

Water depth	3260 m	Latitude 49° 13.59'N
Core length	298 cm	Longitude 131° 54.19'W

Section 1

0 - 27 cm LUTITE, 5Y5/1 (gray), soft, homogeneous, sharp lower contact.

27 - 49 cm LUTITE, 5YR3/2 (dark reddish brown) at top grading through 7.5YR4/4 (brown) to 5Y5/3 (olive) at base, rare disseminated Mn micronodules, sharp lower contact.

49 - 148 cm LUTITE, 5Y5/1 (gray), alternating soft and stiff (silty) intervals, sand lense at 142 cm of fine, angular quartz and abundant opaques.

Section 2

148 - 298 cm continuation of above.
195-280 cm homogeneous, becoming darker gray with depth.

Core END 77-23

Water depth	3235 m	Latitude 49° 11.30'N
Core length	300 cm	Longitude 131° 48.47'W

Section 1

0 - 9 cm LUTITE, 5Y5/1 (gray), slightly silty with trace very fine sand, scattered forams, sharp lower contact.

9 - 26 cm LUTITE, 5YR3/2 (dark reddish brown) in upper 3 cm grading to 5Y5/2 (olive gray), soft near top becoming firm near base, slightly more silty near base, sharp lower contact.

26 - 147 cm LUTITE, 5Y5/1 (gray) overall with local very fine sand and silty laminae of darker gray, soft to firm; sandy, silty layers (< 1 cm) at 38, 53, 95, 109, 121, 133 cm.

Section 2

147 - 300 cm continuation of above.
Sandy, silty laminae (< 1 cm) at 156, 175, 188, 206, 215, 237 and 258 cm, thicker silty, sandy intervals at 285-288 cm and 295-300 cm.

Core END 77-24

Water depth	3245 m	Latitude 49° 09.70'N
Core length	298 cm	Longitude 131° 42.04'W

0 - 17 cm LUTITE, 5YR3/2 (dark reddish brown) at surface (0-4 cm) becoming 5Y5/2 (olive gray) near base, soft to firm, lower part of unit moderately mottled, scattered Mn micronodules, gradational lower contact.

17 - 298 cm LUTITE, 5Y5/1 (gray), soft to very firm, occasional silty intervals and laminae of fine sand and silt, slightly darker gray, slightly mottled.

Core END 77-25

Water depth	3480 m	Latitude 48° 55.83'N
Core length	287 cm	Longitude 133° 23.12'W

Section 1

0 - 9 cm LUTITE, 5Y5/1 (gray), very soft, sharp lower contact.

9 - 28 cm LUTITE, 10YR3/4 (dark yellowish brown) in upper 5 cm becoming 5Y5/4 (light olive brown) near base of unit, soft becoming very firm near base, mottled in lower part, gradational lower contact.

28 - 42 cm SILTY LUTITE, 5Y5/4 (light olive brown) at top to 5Y5/2 (olive gray) at base, stiff, sharp lower contact.

42 - 152 cm LUTITE, 5Y5/1 (gray) and 5Y4/1 (dark gray), soft to firm, occasional silty laminae at 60, 76, 82, and 140 cm.

Section 2

152 - 287 cm continuation of above.
Silt layer at 250 cm; prominent dark fine sandy-silty layer at 285-287 cm, large sand-filled burrow at 280-285 cm.

Core END 77-26

Water depth	3280 m	Latitude 49° 04.29'N
Core length	209 cm	Longitude 133° 09.27'W

Section 1

0 - 3 cm LUTITE, 5YR3/2 (dark reddish brown), soft, forams abundant, sharp lower contact.

3 - 11.5 cm LUTITE, 7.5YR4/2-5/2 (brown), very soft, sharp lower contact.

11.5 - 52 cm LUTITE, 5YR3/2 (dark reddish brown) at top becoming 10YR5/2 (grayish brown) at base, soft becoming firm with depth, base mottled with gray sediment from underlying unit, forams abundant 47-52 cm, fairly sharp lower contact.

52 - 72 cm SILTY LUTITE, 5Y6/2 (light olive gray), stiff, abundant forams, slightly mottled, sharp lower contact.

72 - 103 cm LUTITE, 5Y5/1-5/2 (gray to olive gray), firm; less silty, fewer forams than above, slightly mottled; 5Y4/1 (dark gray) lutite 100-103 cm, sharp lower contact.

103 - 149 cm SILTY LUTITE, 2.5Y6/2 (light brownish gray), overall with intervals and laminae of 2.5Y5/2 (grayish brown) at 113, 124, 132-139, 141 and 148 cm, firm, forams common, gradational lower contact.

149 - 152 cm LUTITE, 5Y5/1 (gray), soft, slightly silty, slightly mottled.

Section 2

152 - 188 cm continuation of above unit.
161-188 cm, 5Y4/1 (dark gray), sharp lower contact.

188 - 209 cm FORAM LUTITE, 5Y6/2 (light olive gray) firm, slightly mottled.

Core END 77-27

Water depth	3165 m	Latitude 49° 22.48'N
Core length	240 cm	Longitude 132° 39.13'W

Section 1

0 - 3 cm LUTITE, 5Y5/1 (gray), soft, scattered forams, sharp lower contact.

3 - 30 cm LUTITE, 7.5YR4/4 (brown) at top grading to 5Y6/2 (light olive gray), soft to firm, slightly silty, mottled, forams and radiolaria common, sharp lower contact.

30 - 137 cm LUTITE, 5Y5/1 (gray), firm but locally stiff and silty, mottled, 130-137 cm layer of dark gray, dense, silty lutite, sharp lower contact.

137 - 148 cm LUTITE, 5Y6/1 (light gray), firm, mottled, forams common.

Section 2

148 - 160 cm continuation of above.
157-160 cm 5Y4/1 (dark gray) interval.

160 - 186 cm LUTITE, 5Y6/1 (light gray) to 5Y5/1 (gray), firm, forams common, ash layer at 178 cm.

186 - 240 cm LUTITE, 5Y6/1 (light gray) and 5Y5/1 (gray), firm, intervals (several cm) of stiff silty lutite, mottled.

Core END 77-28

Water depth	3725 m	Latitude 48° 15.60'N
Core length	238 cm	Longitude 134° 30.27'W

Section 1

0 - 3 cm FORAM OOZE, 2.5Y6/2 (light brownish gray), soft, sharp lower contact.

3 - 9 cm LUTITE, 10YR3/2 (dark grayish brown), soft, sharp lower contact.

9 - 14 cm LUTITE, mixed 10YR3/2 (dark grayish brown) and 2.5Y6/2 (light brownish gray), soft, mottled, transition between over- and underlying units.

14 - 55 cm FORAM OOZE, 2.5Y6/4-6/2 (light yellowish brown), soft, more mottled and darker 50-55 cm, gradational lower contact.

55 - 78 cm LUTITE, 2.5Y5/2 (grayish brown), firm, mottled, forams abundant throught except for 70-75 cm, sharp lower contact

78 - 133 cm FORAM OOZE, 2.5Y6/4-6/2 (light yellowish brown), structureless 78-115 cm, mottled with horizontal stratification 115-133 cm, gradational lower contact.

Core END 77-28 (continued)

133 - 148 cm LUTITE, 2.5Y5/2 (grayish brown), firm silty less foram-rich than above.

Section 2

148 - 162 cm continuation of above. Gradational lower contact.

162 - 170 cm FORAM OOZE, 2.5Y6/4-6/2 (light yellowish brown), firm, 164-166 cm and 167-170 cm darker lutite intervals, pebble (1 cm diam.), rounded, dark at 166 cm, sharp lower contact.

170 - 201 cm SILTY LUTITE, 2.5Y5/2 (grayish brown), firm, suggestion of horizontal stratification, slightly darker from 198-201 cm, sharp lower contact.

201 - 209 cm FORAM LUTITE, 2.5Y6/2 (light brownish gray), firm, mottled, slightly silty, sharp lower contact.

209 - 230 cm SILTY LUTITE, 2.5Y5/2 (grayish brown), firm, with small lenses of lighter foram ooze at 221 and 234 cm, sharp lower contact.

230 - 238 cm FORAM OOZE, 2.5Y6/4-6/2 (light yellowish brown), firm, slightly mottled.

Core END 77-29

Water depth	3695 m	Latitude	48° 34.24'N
Core length	589.5 m	Longitude	133° 56.69'W

0 - 2 cm SILTY LUTITE, 10YR3/4 (dark yellowish brown), soft, forams common, sharp lower contact.

2 - 27 cm FORAM-DIATOM OOZE, 2.5Y7/2 (light gray), soft, mottled, gradational lower contact.

27 - 71 cm LUTITE, 5Y4/2 (olive gray), soft to firm, forams common, mottled, gradational lower contact.

71 - 82.5 cm LUTITE, 10YR4/1 (gray), soft to firm, forams rare to absent, fairly sharp lower contact.

82.5 - 128.5 cm LUTITE, uppermost 23 cm 5Y5/2 (olive gray), middle 15 cm 5Y6/2 (light olive gray), lowermost 8 cm 2.5Y4/2 (dark grayish brown), firm, mottled, inclusions from overlying unit in upper 7 cm, forams common, silt content variable but highest in middle 15 cm interval, sharp lower contact.

128.5 - 203.5 FORAM LUTITE, 2.5Y7/2 (light gray) grading to 2.5Y5/2 (grayish brown), firm, 5 distinct dark silty laminae (1 cm) at 137, 140, 145 and 152 cm, moderately mottled in lowermost 40 cm, gradational lower contact.

203.5 - 534.5 cm LUTITE, 5Y5/2 (olive gray), firm, mottled, forams rare to locally common, large burrows filled with soft diatomaceous and foram lutite at 408 and 523.5 cm, sharp lower contact.

534.5 - 589.5 cm FORAM OOZE, 2.5Y6/2 (light brownish gray), firm, mottled, lowermost 5 cm very light brown and highly foraminiferal.

Core END 77-31

Water depth	3230 m	Latitude	49° 04.75'N
Core length	103 cm	Longitude	131° 27.14'W

0 - 16 cm LUTITE, dark brown in upper 3 cm grading to medium brown in lowermost 13 cm, soft to firm, mottled, gradational lower contact.

16 - 103 cm LUTITE, medium to dark gray, firm, forams rare to common, 1.5 cm lamina at 67 cm of greenish gray silty lutite, silt content diminishes with depth.

Core END 77-32

Water depth	3290 m	Latitude	49° 00.07'N
Core length	115 cm	Longitude	131° 15.92'W

0 - 10 cm SILTY LUTITE, dark brown, soft, sharp basal contact.

10 - 12 cm SILTY LUTITE, olive gray to brown, firm, transitional to underlying unit, gradational lower contact.

12 - 115 cm LUTITE, dark gray, firm, laminae of soft silty and fine sandy lutite (0.5 cm) at 16 cm and 49 cm and interval of similar sediment 32-34 cm.

Core END 77-33

Water depth	2775 m	Latitude	49° 43.43'N
Core length	169 cm	Longitude	130° 38.87'W

0 - 14 cm LUTITE, 5Y5/1 (gray), soft, brown sediment from underlying unit occurs within lowermost 2-3 cm of unit, sharp, irregular lower contact.

14 - 17 cm LUTITE, 7YR3/2 (dark brown), soft-firm, gradational lower contact.

17 - 19 cm SILTY LUTITE, 5Y6/2 (light olive gray), firm, transition zone, gradational lower contact.

19 - 169 cm SILTY LUTITE, 5Y4/1 (dark gray) overall with 5Y4/2 (olive gray) from 116-153 cm, firm, 94-113 cm several thin laminae of coarse silt, dark olive gray.

Core END 77-34

Water depth	2445 m	Latitude	49° 18.14'N
Core length	115 cm	Longitude	130° 12.76'W

0 - 1.5 cm LUTITE, 5Y5/1 (gray) soft, scattered forams, sharp lower contact.

1.5 - 4 cm LUTITE, 7.5Y3/4 (dark yellowish brown), soft, sharp lower contact.

4 - 12 cm LUTITE, 5Y5/3 (olive), firm, transition zone, silty, gradational lower contact.

12 - 115 cm SILTY LUTITE, 5Y5/1 (gray) with intervals of 5Y4/1 (dark gray) at 29-31, 45, 71 and 83 cm; these intervals are more silty and contain very fine sand.

Core END 77-36

Water depth	2605 m	Latitude	48° 00.54'N
Core length	91 cm	Longitude	128° 48.50'W

0 - 8 cm LUTITE, 5Y5/1 (gray), soft, sharp lower contact.

8 - 14 cm SILTY LUTITE, 5Y2.5/2 (dark reddish brown), soft, sharp lower contact.

14 - 22 cm LUTITE, 5Y5/2 (olive gray) at top grading to 5Y5/2 (olive gray) at base, firm, scattered forams, very gradational lower contact.

22 - 91 cm LUTITE - SILTY LUTITE, 5Y54/2 (olive gray) in silty lutites and 2.5Y4/0 in lutites, firm, scattered forams, lower 41 cm has distinct silt layers at 68, 74, 76, 79, and 85 cm.

Core END 77-37

Water depth	2540 m	Latitude	48° 03.15'N
Core length	188 cm	Longitude	128° 53.56'W

0 - 16 cm LUTITE, 5Y5/1 (gray), soft, scattered forams, sharp, steeply inclined (45°) lower contact.

16 - 22 cm SILTY LUTITE, 5Y3/2 (dark reddish brown), soft, scattered forams, inclined (35°) lower contact.

22 - 23 cm SILTY LUTITE, 5Y5/3 (olive), soft, forams common, lower contact gradational.

23 - 188 cm LUTITE, alternating 5Y5/1 (gray) and 5Y4/2-4/3 (olive gray - olive) intervals, firm, silt and fine sand lenses at 88, 90, and 104 cm, very fine sand lamina at 98 cm, 131-132 cm foram sand layer, 142-146, 171, 174, 175 cm fine quartz sand with abundant opaques.

Core END 77-38

Water depth	2565 m	Latitude	48° 07.34'N
Core length	225 cm	Longitude	129° 10.47'W

0 - 2.5 cm SILTY LUTITE, 5Y5/1 (gray), soft, sharp lower contact.

2.5 - 9 cm LUTITE, 5YR3/2 (dark reddish brown) changing to 5Y5/3-5/2 (olive to olive gray) in basal 5 cm, soft, scattered forams, finely disseminated opaques, sharp lower contact.

9 - 74 cm LUTITE, 5Y54/2 (olive gray), firm, scattered forams, locally abundant, gradational lower contact.

74 - 83 cm LUTITE, 5Y5/3 (olive), firm, gradational lower contact.

83 - 225 cm LUTITE, alternating 5Y4/2 (olive gray) and 5Y4/1 (dark gray), firm, several black silty-sandy laminae, layer of fine, black sand at 199-205 cm.

Core END 77-39

Water depth	2700 m	Latitude	48° 11.14'N
Core length	115 cm	Longitude	129° 23.50'W

0 - 19 cm LUTITE, 10YR2/2 (very dark brown), soft to firm, sharp, inclined (45°) lower contact.

19 - 26 cm SILTY LUTITE, 5Y5/2-5/3 (olive gray to olive), scattered forams, gradational lower contact.

26 - 115 cm SILTY LUTITE, 5Y4/2-3/2 (olive gray to dark olive gray), firm to stiff, scattered forams.

Core END 77-40

Water depth	2680 m	Latitude	48° 14.54'N
Core length	102 cm	Longitude	129° 30.98'W

0 - 13 cm SILTY LUTITE, 5Y5/2.5/2 (dark reddish brown), soft to firm, scattered forams, gradational lower contact.

13 - 21 cm SILTY LUTITE, 5Y5/2-5/3 (olive gray to olive), firm, gradational lower contact.

21 - 102 cm SILTY LUTITE, 5Y4/2 (olive gray), firm to stiff, very silty laminae at 78 and 95 cm.

Core END 77-41

Water depth	2820 m	Latitude	48° 17.16'N
Core length	281 cm	Longitude	129° 36.49'W

0 - 47 cm SILTY LUTITE, 5Y4/1 (gray), soft, sharp lower contact.

47 - 58 cm LUTITE, 5YR2.5/2 (dark reddish brown), soft, sharp lower contact.

58 - 61 cm SILTY LUTITE, 5Y4/2-4/3 (olive - olive gray) firm, gradational lower contact.

61 - 281 cm SILTY LUTITE, 5Y4/1-4/2 (dark gray - olive gray), firm, 223-230 cm interval with fine black sand, 170-281 cm several intervals of olive gray more silty lutites.

Core END 77-42

Water depth	2475 m	Latitude	48° 27.15'N
Core length	53 cm	Longitude	128° 39.41'W

0 - 3 cm SILTY LUTITE, brown, firm, scattered forams, sharp lower contact.

3 - 53 cm SILTY LUTITE, gray, firm.

Core END 77-43

Water depth	2440 m	Latitude	48° 27.77'N
Core length	101 cm	Longitude	128° 36.83'W

0 - 0.5 cm SILTY LUTITE, dark brown, firm, gradational lower contact.

0.5 - 11.5 cm SILTY LUTITE, olive gray, firm, abundant forams especially near base, sharp lower contact.

11.5 - 101 cm SILTY LUTITE, alternating dark gray and olive gray, firm to stiff, scattered forams.

Core END 77-44

Water depth	2425 m	Latitude	48° 28.42'N
Core length	140 cm	Longitude	128° 32.56'W

0 - 6 cm SILTY LUTITE, mixed gray and dark brown, soft, scattered forams, sharp lower contact.

6 - 140 cm SILTY LUTITE, dark gray, firm, fine, dark sand layers common (< 0.5 cm), vague horizontal stratification, small pockets of foram ooze.

Appendix B

Elemental analyses of core subsamples used in this study. Values are expressed as µ/g except for Fe and Ca (percent).

CORE	DEPTH CM	ZN	CU	PB	NI	CO	MN	MO	FE %	CA %
1	0	290	84	10	118	24	3500	3	4.30	2.60
1	1	265	96	16	132	26	3150	3	4.65	2.65
1	10	96	28	10	36	12	960	3	4.25	4.10
2	0	240	78	12	112	20	4350	7	4.75	2.10
2	8	260	96	11	119	24	5700	4	5.20	2.40
2	42	255	96	19	146	22	1140	3	5.75	2.70
3	0	210	68	22	104	18	3000	5	4.40	2.95
3	1	210	74	18	106	18	1480	4	5.00	3.10
3	5	230	76	18	144	22	11000	17	5.00	1.75
3	14	240	80	22	95	14	940	3	5.75	1.75
3	56	174	62	13	10	22	910	3	5.90	4.10
4	0	178	66	18	92	18	1590	4	5.25	2.80
4	4	192	72	15	102	20	880	3	5.80	3.45
4	12	220	76	20	112	20	5300	7	5.50	1.85
4	18	245	80	20	108	16	740	3	5.90	2.25
4	46	240	78	18	112	20	700	3	5.90	2.00
4	81	130	56	15	72	25	840	4	6.50	5.45
4	92	108	32	9	41	16	880	3	6.00	3.00
4	145	80	28	11	34	14	750	3	4.75	3.60
5	0	142	70	18	78	16	650	3	5.45	1.95
5	30	174	72	14	78	16	680	4	4.70	1.90
5	59	178	76	15	80	18	700	5	4.80	1.90
6	0	96	38	16	38	15	850	10	4.45	3.60
6	5	100	38	12	38	16	820	3	5.30	3.90
6	12	86	34	9	34	15	700	3	4.90	4.20
6	25	94	42	10	39	17	780	3	5.20	6.00
6	73	80	32	8	30	15	710	2	4.70	2.85
6	155	108	44	13	50	18	790	4	5.80	2.35
7	0	100	38	9	37	16	760	13	5.00	3.40
7	8	96	38	10	38	16	740	3	4.85	4.15
7	25	116	46	13	54	15	560	3	5.15	3.80
7	50	94	32	8	34	18	820	2	5.50	3.70
7	75	106	38	12	36	18	780	3	5.30	3.10
7	100	102	38	10	37	18	800	3	5.40	3.55
7	125	110	40	9	38	20	880	4	5.80	3.45
7	145	108	42	12	40	18	760	4	5.50	3.50
7	175	106	44	13	44	18	740	3	5.30	4.95
7	200	106	38	8	34	18	900	3	5.80	3.10
7	225	112	36	12	38	18	900	5	5.65	3.10
7	250	86	34	11	32	16	800	3	5.00	3.90
7	254	60	24	7	23	12	630	3	3.95	3.90
7	265	92	38	8	29	16	840	3	5.40	3.70
7	280	100	40	8	32	17	880	3	5.50	3.50
8	0	112	46	22	43	18	1020	11	5.40	3.00
8	1	100	46	14	42	20	710	3	5.25	3.45
8	9	98	38	13	42	16	1070	4	5.10	2.75
8	23	106	46	12	50	17	700	3	5.40	3.70
8	50	106	42	12	46	18	760	3	5.55	3.80
8	146	88	40	8	36	18	820	4	5.30	3.65
8	190	100	38	8	36	17	910	3	5.90	3.50
9	0	148	58	19	68	14	1410	12	4.95	1.60
9	3	154	66	16	70	15	1630	4	5.30	1.70
9	50	166	62	14	75	17	680	3	5.70	2.20
9	100	96	36	11	34	16	780	3	5.50	3.35
9	132	102	40	8	38	18	880	4	5.85	3.80
10	0	192	74	20	98	17	9800	8	5.40	1.70
10	10	176	74	20	92	18	4600	6	5.50	1.80
10	50	182	68	18	82	16	960	3	5.65	1.60
10	100	186	70	18	89	20	1030	3	5.85	1.80
10	150	106	52	12	53	18	950	4	5.00	5.30
12	0	112	52	12	58	20	1420	4	5.55	3.10
12	6	104	40	8	40	18	880	3	5.80	3.25
12	14	130	90	19	111	29	4100	4	5.10	2.25
12	30	126	64	14	63	23	1870	2	4.20	7.40
12	50	106	48	6	46	19	760	3	5.10	3.30
12	100	106	40	7	33	18	840	3	5.50	2.95
12	150	78	28	8	28	14	800	2	5.15	3.70
13	0	112	66	18	84	24	2750	3	4.85	2.65
13	15	148	74	18	96	34	840	2	6.70	4.40
13	50	134	74	18	80	28	940	3	5.60	3.30
13	100	122	62	11	73	27	920	3	5.30	6.10
13	150	108	54	12	76	22	790	4	4.10	14.40
13	160	144	90	20	122	28	860	3	5.60	1.60
13	162	320	1400	340	540	490	29500	2	12.20	1.65
14	0	198	114	22	178	29	7500	11	4.90	2.40
14	5	182	116	18	130	32	5900	3	5.00	2.70
14	16	190	114	19	100	26	1770	2	5.80	3.20
14	25	200	114	17	120	22	890	3	5.75	4.20
14	50	102	50	10	64	20	760	3	4.90	3.80
14	95	84	30	8	31	14	850	4	5.00	3.40
14	102	66	22	7	26	13	740	4	4.70	3.90
14	110	91	36	7	32	17	880	3	5.50	3.70
14	150	106	40	9	38	18	940	5	6.45	2.85
14	190	88	40	11	44	17	800	4	5.60	2.70
15	0	255	98	22	178	32	14000	19	5.40	1.70
15	2	240	102	22	122	34	5900	3	5.60	2.40
15	17	290	104	20	133	22	1020	3	5.70	2.50
15	50	108	40	10	39	20	1000	4	6.10	3.20
15	100	122	66	11	59	24	1320	4	5.65	4.85
15	115	140	60	13	72	26	1760	4	5.00	5.20
16	0	300	126	64	200	36	19500	21	4.90	2.50
16	2	290	126	22	190	30	17000	10	4.40	2.90
16	11	320	134	20	144	22	1620	3	5.60	4.00
16	50	128	56	14	72	18	890	2	5.90	2.90
16	86	76	28	8	41	12	680	4	4.80	2.70
16	90	76	40	12	43	14	670	3	4.60	2.85
17	0	170	68	14	104	19	5950	9	5.25	2.75
17	2	104	42	9	56	16	1070	5	5.70	2.45
17	8	290	120	14	225	31	27000	12	5.00	2.30
17	17	325	128	17	156	24	1840	3	5.60	3.60
17	50	108	46	10	78	20	930	4	5.70	2.30
17	100	114	46	14	56	17	900	3	6.10	3.00
17	140	72	28	8	40	14	660	3	4.45	2.65
17	143	60	28	7	36	12	660	4	4.20	3.35
17	145	94	46	10	48	18	950	2	5.55	3.80
18	0	300	126	21	250	30	33500	48	4.90	1.70
18	3	255	118	18	176	28	19800	7	4.60	2.40
18	16	290	130	18	136	22	1780	2	4.40	3.50
18	49	225	92	14	116	20	1090	4	5.40	3.90
18	99	94	40	8	60	18	830	4	5.70	2.40
18	125	106	46	9	56	16	880	5	5.90	2.70
19	0	212	112	12	206	28	13800	26	5.40	2.20
19	4	250	140	18	250	32	29000	35	4.70	1.70
19	14	260	118	20	118	22	1220	4	5.30	2.10
19	50	124	58	10	87	22	1000	5	5.80	5.10
19	100	96	38	10	52	16	800	4	5.90	2.40
19	150	92	34	8	50	15	760	5	5.90	2.20
19	200	100	42	9	54	16	820	5	6.10	2.55
19	218	108	46	15	58	18	1720	4	5.90	2.50
20	0	96	44	12	56	18	1440	4	4.65	3.40
20	2	102	46	8	52	20	960	4	5.30	3.20
20	7	158	112	12	205	34	7000	7	4.90	2.65
20	12	144	110	18	116	39	4000	3	5.30	4.40
20	30	104	36	6	66	18	720	3	6.20	2.25
20	50	104	48	7	53	20	800	4	6.20	4.70
20	91	64	20	7	26	12	740	4	4.60	4.50
20	105	42	14	8	20	10	570	3	3.50	4.50
20	130	98	50	8	50	20	860	5	6.40	2.50
20	155	102	46	10	40	18	940	4	6.30	4.10
20	182	68	26	9	30	14	800	3	5.00	4.40
21	0	98	46	9	49	20	945	6	5.50	3.95
21	4	110	66	9	46	18	1050	12	4.95	4.35
21	10	102	42	7	44	19	930	4	5.75	3.80
21	18	152	112	17	235	35	7400	8	4.90	3.50
21	28	124	82	16	78	30	1950	4	5.20	8.50
21	34	102	48	13	62	16	750	3	5.90	3.25
21	50	92	38	9	44	16	800	3	5.30	4.60
21	100	110	54	10	62	22	860	5	6.10	2.80
21	157	106	84	14	59	28	1300	4	5.00	11.80
22	2	108	54	10	58	21	710	6	6.30	3.00
22	25	106	44	9	49	20	880	4	6.20	3.10
22	35	152	106	17	100	35	3500	3	5.70	2.70
22	43	138	84	17	88	35	2950	4	5.45	4.30
22	49	136	48	12	94	18	670	3	6.65	2.25
22	100	102	84	10	59	20	780	3	6.45	2.70
22	150	118	48	10	53	20	970	4	6.35	3.70
22	200	74	30	11	39	16	755	3	4.90	3.90
22	250	104	50	12	58	19	830	3	6.30	2.70
22	300	88	36	9	38	16	875	4	5.35	3.90
23	4	86	38	11	47	16	770	4	5.20	3.20
23	12	174	114	20	245	32	11000	14	5.45	2.30
23	19	170	126	22	118	39	4300	5	5.65	3.50
23	32	152	84	15	88	18	850	3	5.70	8.30
23	50	92	84	10	59	17	750	5	5.60	3.80
23	100	96	38	9	45	17	1200	5	5.60	3.10
23	147	80	34	9	48	17	800	4	4.70	4.40
23	200	102	54	10	53	22	1400	3	6.00	5.40
23	250	120	56	13	69	22	1700	3	5.45	7.45
23	300	114	52	11	59	20	1250	3	5.80	3.85
24	1	148	100	19	180	25	6800	7	5.35	2.30
24	10	150	88	16	94	25	1900	3	5.45	4.70
24	19	118	66	14	102	19	740	3	6.40	3.10
24	50	88	42	11	52	17	740	4	5.55	3.10
24	100	86	42	10	51	15	740	4	5.35	2.80
24	150	106	38	11	48	19	970	3	6.20	3.40
24	200	102	54	10	53	20	1000	3	6.50	3.00
24	250	86	42	10	45	17	895	5	5.65	3.80
24	297	96	52	11	64	20	890	4	5.95	3.15
25	4	92	38	10	40	16	880	4	5.70	3.50
25	9	170	138	18	250	36	8200	9	5.75	2.70
25	23	156	124	19	128	54	5600	6	5.80	6.00
25	36	132	50	10	64	18	945	3	6.30	5.00
25	50	120	52	9	62	18	870	4	6.50	4.45
25	100	98	40	9	52	18	810	3	5.70	3.20
25	150	110	54	8	43	20	925	3	5.95	3.15
25	200	102	52	9	57	20	765	3	5.95	2.55
25	250	116	52	9	48	22	930	5	6.40	3.45
25	287	801	38	10	35	17	765	3	5.00	4.20
26	0	224	160	14	290	48	13600	7	5.40	4.80
26	1	250	186	19	345	45	18000	20	5.00	3.70
26	8	188	142	15	73	46	9700	3	5.20	8.50
26	12	188	172	20	188	48	11500	3	5.10	4.40
26	28	186	136	16	169	44	9200	5	4.60	9.40
26	45	134	88	15	126	49	6700	5	3.90	15.20
26	58	116	80	10	75	30	1500	3	4.20	16.00
26	100	98	50	9	73	21	1300	3	4.00	15.60
26	112	66	52	10	49	19	1750	4	2.80	23.00
26	147	124	126	17	73	28	2350	4	4.30	11.60
26	157	192	64	20	121	35	1500	3	5.90	5.60
26	170	168	108	12	94	30	1150	3	5.80	1.75
26	185	124	240	20	122	46	2400	5	4.40	16.20
26	204	66	62	10	57	19	2200	1	2.70	23.00
27	0	118	68	16	81	24	2600	4	4.70	7.30
27	1	112	62	11	75	25	1850	3	5.00	11.20
27	5	164	114	18	200	33	8850	5	4.20	5.80
27	12	148	112	16	108	39	4500	4	4.30	7.60
27	27	144	54	11	89	22	1150	2	6.40	5.00
27	50	116	42	10	64	29	1250	3	6.45	3.10
27	100	110	82	16	78	31	1600	5	4.50	11.80

CORE	DEPTH CM	ZN	CU	PB	NI	CO	MN	MO	FE %	CA %
27	129	112	62	14	76	26	1000	2	5.10	6.70
27	135	128	48	11	94	28	1150	3	5.95	3.10
27	146	88	62	14	51	16	910	4	3.50	15.00
27	162	70	42	13	47	13	930	3	2.65	20.00
27	170	172	104	13	88	30	1200	3	6.20	1.80
27	178	92	54	12	60	29	980	3	4.20	16.00
27	200	134	140	15	81	32	1200	2	5.45	5.50
27	225	162	78	18	80	34	940	3	5.25	6.20
27	240	210	136	24	107	39	895	5	5.70	1.80
28	0	90	92	14	89	39	4100	8	3.40	13.80
28	2	74	76	11	64	31	3150	7	3.00	21.00
28	6	148	172	21	200	60	9500	9	5.20	6.70
28	14	84	94	12	88	49	3600	7	3.25	17.80
28	26	64	68	12	44	23	930	4	2.90	22.00
28	50	52	48	13	42	20	970	3	2.25	28.00
28	66	118	120	19	103	54	5200	5	4.10	11.80
28	80	182	118	19	88	30	1300	4	4.90	1.70
28	106	50	46	11	48	23	1950	4	2.20	27.00
28	130	86	76	16	68	29	1700	5	3.60	16.20
28	145	130	124	20	84	37	1600	3	5.40	2.05
28	165	70	80	15	68	37	2100	4	2.90	22.00
28	170	100	100	16	81	35	1950	4	4.25	13.60
28	200	134	158	20	134	70	5200	3	5.30	3.10
28	220	120	126	18	96	46	3400	3	4.90	8.40
28	235	78	78	14	70	39	3600	5	3.30	18.00
29	0	124	122	15	134	45	6500	11	4.10	14.00
29	15	46	50	11	43	23	2150	5	2.10	23.00
29	50	142	176	23	190	79	13000	8	4.85	8.70
29	55	154	126	20	99	56	4500	6	5.35	5.50
29	68	230	198	24	185	124	13000	9	6.00	1.30
29	81	245	108	17	98	31	1050	7	6.40	1.35
29	100	188	134	24	107	34	880	7	6.30	1.20
29	120	118	116	24	72	24	1500	6	4.90	7.60
29	140	66	84	11	72	43	3650	3	2.50	24.00
29	170	64	54	13	49	18	1400	4	2.80	21.80
29	195	52	42	12	32	10	830	4	2.30	27.00
29	235	134	122	17	79	35	1850	3	5.80	1.65
29	275	134	128	17	94	51	2850	4	5.50	1.60
29	305	100	106	17	96	65	5950	7	3.70	14.00
29	345	138	156	19	98	49	3800	3	5.85	2.10
29	360	142	138	20	84	39	2100	4	5.80	1.80
29	380	118	122	19	85	39	2600	5	4.70	7.70
29	395	118	120	16	78	39	2300	3	4.85	7.00
29	440	100	92	16	79	35	3400	4	4.20	11.00
29	450	124	126	18	129	59	6300	4	5.50	2.90
29	475	126	122	19	97	39	2900	3	4.90	6.70
29	500	148	192	21	148	60	5200	4	5.40	2.00
29	525	96	134	16	118	63	5500	5	3.50	16.40
29	540	94	88	14	72	36	3200	5	3.30	18.00
29	575	78	68	13	48	16	980	5	3.10	20.30
31	1	200	136	15	295	35	12000	13	5.20	1.65
31	15	154	88	16	94	24	2100	4	5.50	3.00
31	20	188	74	12	102	19	670	4	6.55	2.50
31	50	100	48	11	69	19	670	3	5.45	1.80
31	67	116	58	11	68	21	870	5	5.90	3.85
31	83	112	56	9	63	22	780	4	6.65	2.15
31	105	98	46	9	52	19	750	4	5.65	2.50
32	0	260	46	22	295	34	24500	24	5.30	1.55
32	15	250	66	21	149	32	1300	3	5.55	2.90
32	50	156	54	12	108	22	900	3	5.80	4.40
32	73	110	62	9	69	20	860	4	5.15	2.90
32	104	108	40	10	66	22	815	4	6.50	2.50
32	112	104	56	10	66	22	800	2	5.45	2.40
33	0	220	90	20	115	22	7000	8	4.75	2.10
33	6	245	92	19	116	22	3100	3	5.20	2.35
33	14	235	100	20	137	28	14500	8	4.90	1.80
33	18	260	104	20	116	22	1700	2	5.30	2.05
33	35	250	104	19	120	24	1700	3	5.35	1.80
33	120	142	76	13	90	32	4000	3	5.20	5.00
33	136	134	76	14	73	34	8300	4	5.55	5.00
33	158	112	50	10	42	23	1300	3	5.90	2.90
33	170	110	52	9	44	20	1200	3	5.70	2.70
34	0	112	72	20	140	28	1520	2	7.60	3.00
34	3	118	50	12	62	19	700	3	4.50	3.10
34	5	130	60	13	74	20	2700	4	4.95	3.10
34	9	126	54	12	72	16	730	3	5.20	3.70
34	16	116	54	9	69	20	680	4	5.45	3.60
34	31	72	30	9	45	15	570	4	4.20	2.40
34	50	100	50	10	49	18	825	5	5.70	2.80
34	83	76	40	8	43	16	710	4	5.00	3.90
34	109	104	50	14	48	18	940	4	5.20	4.75
35	0	146	70	16	92	22	4450	7	4.85	3.80
35	22	156	76	15	90	20	700	5	5.15	5.90
35	42	132	66	15	77	20	810	2	5.00	5.30
35	59	88	42	8	49	19	740	4	4.70	3.50
36	0	220	82	16	115	19	8750	7	4.80	2.20
36	4	148	60	10	73	16	935	2	4.55	2.00
36	10	260	104	15	140	20	18500	11	4.45	1.60
36	15	310	118	18	124	15	1400	3	4.75	1.70
36	50	182	80	13	104	19	1300	5	5.30	3.80
36	87	78	36	9	54	14	690	4	4.60	2.70
37	0	205	80	15	104	18	6100	8	4.75	2.10
37	3	290	108	18	139	22	4300	4	5.10	2.10
37	18	310	118	18	172	24	21000	7	5.30	1.50
37	24	305	110	19	139	18	1900	3	5.55	1.80
37	50	290	112	18	150	22	1400	4	5.45	1.60
37	98	80	38	10	54	18	1650	3	4.40	2.50
37	114	102	52	11	57	20	1100	4	5.60	2.95
37	143	80	38	11	52	17	745	3	4.80	2.50
37	160	104	36	16	44	18	760	4	5.55	2.10
37	181	106	50	17	42	17	810	5	5.50	2.70
38	0	250	94	22	124	20	13000	15	5.10	2.50
38	1	240	96	20	124	24	5100	7	5.75	3.80
38	4	300	116	22	172	24	26500	14	5.55	1.75
38	11	300	108	23	125	19	4400	5	5.45	2.00
38	50	310	120	23	150	29	1850	4	5.65	1.75
38	66	235	114	22	150	28	1850	3	6.10	2.70
38	76	240	104	18	140	24	1700	3	5.70	4.65
38	100	94	42	12	69	20	855	2	5.30	2.50
38	123	116	60	15	70	28	1900	3	5.45	4.50
38	138	120	72	16	71	33	4700	4	4.85	7.20
38	203	76	34	16	42	18	690	4	4.70	2.80
39	0	268	136	20	92	28	34000	15	5.40	1.60
39	10	295	140	22	172	24	35500	14	4.95	1.70
39	22	355	114	28	179	24	4650	5	5.75	2.50
39	30	350	156	23	179	24	4700	4	5.80	2.80
39	50	340	160	28	169	30	2800	4	6.30	3.10
39	90	182	86	20	104	32	2550	5	5.30	6.30
39	110	112	52	17	50	30	1500	5	5.20	3.85
40	0	232	136	20	196	26	23200	6	6.40	2.20
40	4	335	134	27	184	28	31000	11	5.25	1.95
40	21	365	118	26	182	26	3150	3	5.60	2.40
40	70	275	134	22	152	27	2950	4	6.05	4.10
40	110	126	68	18	70	34	4100	4	5.00	6.85
41	0	200	92	17	109	29	3300	7	5.10	2.80
41	15	170	86	16	110	24	2000	3	5.25	2.60
41	50	340	152	23	186	24	38000	26	5.20	1.40
41	58	370	126	24	172	29	5850	4	5.70	2.60
41	100	140	88	16	92	26	1550	5	5.70	2.30
41	150	100	54	10	59	19	1000	4	5.60	2.30
41	200	108	66	9	42	19	2500	4	4.60	8.25
41	234	68	34	14	54	25	750	3	4.30	3.05
41	285	110	56	11	69	22	990	4	5.65	1.85
42	0	144	64	24	100	20	2640	2	5.20	2.00
42	1	200	72	19	96	20	4550	4	4.95	1.50
42	2	290	76	17	109	18	865	2	5.60	2.00
42	18	142	76	16	93	19	540	2	5.10	4.10
42	48	88	40	16	43	16	510	2	4.75	2.65
43	0	134	60	24	79	18	2750	4	5.10	1.80
43	10	88	48	14	57	17	470	3	4.70	7.70
43	15	94	42	16	50	18	480	3	5.90	3.20
43	50	98	36	17	38	18	540	4	5.45	2.10
43	100	94	40	17	50	17	460	4	5.50	3.20
44	0	530	64	18	78	19	1500	4	4.80	2.65
44	1	178	60	17	78	19	1700	4	4.90	2.80
44	6	138	56	15	78	19	675	3	4.90	2.95
44	50	106	36	16	42	20	630	5	5.45	2.30
44	100	58	24	11	40	20	575	3	3.90	3.10
44	133	98	42	18	38	19	545	4	5.40	2.40