13. MAJOR AND MINOR ELEMENTS IN HYDROTHERMAL AND PELAGIC SEDIMENTS OF THE GALAPAGOS MOUNDS AREA, LEG 70, DEEP SEA DRILLING PROJECT¹

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INTRODUCTION

Interaction between young basaltic crust and seawater near the oceanic speading centers is one of the important processes affecting the chemical composition of the oceanic layer. The formation of metalliferous hydrothermal sediments results from this interaction.

The importance of the interaction between seawater and basalt in determining the chemical composition of pore waters from sediments is well known. The influence of mineral solutions derived from this interaction on ocean water composition and the significant flux of some elements (e.g., Mn) are reported by Lyle (1976), Bogdanov et al. (1979), and others. Metal-rich sediments found in active zones of the ocean basins illustrate the influence of seawater-basalt interaction and its effect on the sedimentary cover in such areas. The role of hydrothermal activity and seawater circulation in basalts with regard to global geochemistry cycles has recently been demonstrated by Edmond, Measures, Mc-Duff, McDuff et al. (1979), and Edmond, Measures, Mangum (1979).

In the area of the Galapagos Spreading Center the interaction of sediments and solutions derived from interaction of seawater and basalt has resulted in the formation of hydrothermal mounds. The mounds are composed of manganese crusts and green clay interbedded and mixed with pelagic nannofossil ooze. These mounds are observed only in areas characterized by high heat flow (Honnorez, et al., 1981) and high hydrothermal activity.

Hydrothermal mounds were studied by deep-tow (Sclater and Klitgord, 1973; Lonsdale, 1977), by the submersible *Alvin* (Corliss et al., 1979), and by direct drilling during Leg 54 (Hekinian et al., 1978; Natland et al., 1979; Rosendahl, Hekinian et al., 1980) of the Deep Sea Drilling Project (DSDP). Green clay and Mn-crust sampled from Galapagos mounds are very similar to those observed in the FAMOUS area (Hoffert et al., 1978, 1980).

The first analytical data on samples obtained from these expeditions show a significant difference between green clays and Mn crusts from the Galapagos hydrothermal mounds and metalliferous sediments recovered from the mid-oceanic ridges, especially the East Pacific Rise (Boström and Peterson, 1969; Bender et al., 1971; Sayles and Bishoff, 1973; Bonatti, 1975; Cronan, 1976, Migdisov, Girin et al., 1979).

The metalliferous sediments from mid-oceanic ridges directly cover basaltic basement; they consist of Fe and Mn hydroxides and Fe smectites and are enriched by many minor and trace elements (Ba, Ni, Cu, Zn, Cd, Sb, Mo, REE, etc.). Th, Ce, Rb, Cr, and some other elements were depleted in these sediments relative to the deep oceanic clays. In contrast, hydrothermal sediments from the Galapagos mounds are poor in all these elements (Hekinian et al., 1978; Hoffert et al., 1980) and are both vertically and laterally restricted (Honnorez et al., 1981).

Various hypotheses on the origin of the hydrothermal mounds sediments were proposed by Hoffert et al. (1980) and Dymond et al. (1980). They are as follows:

1) Deposition from solution, resulting in wide-spreading sedimentary layers.

2) Interaction of pelagic oozes in the mounds area sedimentary cover with upward percolating hydrothermal solutions which replace the pelagic ooze by green clays.

3) Upward flux of hydrothermal solutions from locally permeable zones of basement through the sedimentary cover, with the formation of minerals resulting from an advancing oxidation gradient, without any interaction of solutions with pelagic sediments.

On Leg 70 of the Deep Sea Drilling Project (DSDP), a more detailed series of holes was drilled in 30 to 40 meters of sedimentary cover, both on mounds and in an off-mounds area. Regions of low heat flow without mound occurrences were also investigated. The hydraulic piston corer (HPC) was used, and detailed sampling of undisturbed sedimentary sections was accomplished.

Data obtained on Leg 70 (Honnorez et al., 1981) suggest that the hydrothermal sediments are local in regional extent, which allows us to exclude the first hypothesis. Some aspects of the third hypothesis also are questionable given the data obtained from Leg 70. For example, differences in thickness of pelagic ooze from mounds, off-mounds, and low heat-flow area sedimentary sections were observed. The evidence of microfossil tests, replacement, and infilling by smectite (Honnorez et al., 1981; Schrader et al., 1980) also casts doubt on the third hypothesis. However, data on the element distribution in sediments indicate that the hypothesis offered by Dymond et al. (1980) may be correct—namely, element differentiation through a redox-potential gradient in sedimentary sections. The data of Schrader et

¹ Honnorez, J., Von Herzen, R. P., et al., *Init. Repts. DSDP*, 70: Washington (U.S. Govt. Printing Office).

al. (1980) maybe taken to suggest that in the mounds smectite textures have been produced both by replacement of pelagic sediments and by open space filling. The authors recognized "complete replacement of Foraminifera tests" in all mounds holes of Leg 54. They noted that this type of texture is not common statistically and is "often obscured by overgrowth of additional green clay." Open space filling textures have been observed as "zoned and sequential infillings of void spaces," implying "controlled deposition." The authors suggested that either types of smectite formation are concurrent or the process of replacement may be assumed to be slightly later. At the same time the relative role of both processes in smectite generation in mounds is not yet clear, and geochemical data supporting void infilling processes are absent.

The problem of the redistribution of major elements in the pelagic ooze during their dissolution and replacement has also not been resolved.

In light of these problems, the purpose of this chapter is the following:

1) To study changes with depth in the mineralogical and chemical composition of sediments in mounds cores.

2) To compare and correlate changes in the distribution of major and minor elements on mounds, offmounds, and in low heat-flow areas.

3) To speculate on the origin of hydrothermal sediments on the basis of obtained data.

METHODS OF ANALYSES

Prepared samples were washed to remove marine salts before analysis. Different techniques were used for determination of major and minor elements.

Data on major elements were obtained both by X-ray fluorescence (XRF) and chemical techniques. Samples were heated to 105° C prior to analysis. The chemical technique used, including determination of volatile components (H₂O⁺, CO₂) and the oxidation state of Fe, is discussed by Migdisov, Girin et al. (1979).

XRF analyses were performed on a 28-channel PW-1600 "Philips" machine. A description of the procedure is given in Tsameryan et al. (1980).

Data on the major elements, determined by two independent techniques, were very similar and are presented in Tables 1–6. Numbers represent the mean value of the two analyses.

Minor and trace elements were determined by XRF, atomic absorption, and instrumental neutron activation. Cr and V were analyzed by XRF during major element determination. Li, Rb, Sr, Ni, Zn, Cu, and Pb were analyzed by the atomic absorption method using Perkin Elmer-405 and Perkin Elmer-603 machines. For Pb determination, a graphitic cuvette HGA-76 B machine was used in some cases (Sedyh et al., 1980). Neutron activation analyses were carried out using the technique described by Migdisov et al. (1980). A 40-cm³ Ge(Li) detector and Nokia LP 4900 channel analyzer were used. In some cases radiochemical concentrations of rare earth elements (REE) were examined.

Mineralogical and structural anomalies of the hydrothermal clay minerals were also studied. Measurements were made on a diffractometer DRON-2, with Fe-radiation filtered with Ni using a common sample treatment technique.

MAJOR ELEMENTS

The data obtained are shown in Tables 1–10 and Figures 1–17. Figure 1 presents the distribution of some elements with depth at two mounds sites, 507 and 509. An inverse relationship in Fe and Mn concentrations exists within the hydrothermal sediments. The iron-rich smec-

tites lack Mn, which is concentrated in the uppermost layer of the mound in the form of Mn crusts. In turn, very little Fe is found in the manganese crusts.

There are some cases where full fractionation of Fe and Mn is not observed. These are: (1) in oxidized smectites which are localized directly underneath the Mn crusts (these smectites contain much higher Mn concentrations relative to deeper layers, but one cannot exclude some contamination by Mn oxides); (2) in some finegrained smectites from burrows mixed with pelagic ooze (Sample 509B-5-2, 35-37 cm [1]). Mn enrichment of pelagic oozes alternating with green clays and the low Fe₂O₂/MnO₂ ratio (0.5) in these sediments must also be noted (Samples 509B-5-2, 35-37 cm [2] and 509B-5-1, 86-90 cm): (3) in the oxidized Fe-Mn sediments brown carbonate and siliceous ooze with Fe-Mn nodules and crusts occur in the uppermost horizons of the mounds. We noted the similarity of the composition of micronodules separated from the uppermost mound sediments to the Fe-Mn crusts and nodules from these oozes and to the carbonate-free basis composition of the uppermost pelagic sediments in the mounds. We therefore classified all these materials as "upper crusts" in contrast to "lower crusts" which occur farther down in the mound section and are characterized by a lower Fe-Mn ratio and by lower iron, silica, and alumina concentrations. The least differentiated type of Fe-Mn oxide sediments was sampled as a dark brown nonconsolidated mud in a layer of pelagic ooze (Sample 509B-2-3, 12-14 cm) within the unit of the hydrothermal sediments. The $Fe_2O_3/$ MnO₂ ratio in the analyzed sample is approximately 1/2.

In the pelagic oozes from the low heat-flow areas and the off-mounds sedimentary sections, higher Fe and Mn concentrations relative to normal oceanic carbonate sediments (Turekian and Wedepohl, 1961) are observed. Further, the Fe and Mn concentrations (on a carbonatefree basis) approach the Fe and Mn concentrations found in deep ocean red clays (Turekian and Wedepohl, 1961: Strakhov, 1976; Migdisov, Bogdanov et al., 1979). The highest concentrations of these elements, especially Mn, are found in the upper oxidized surface layers of the pelagic sediments (Lynn and Bonatti, 1965). The layers of pelagic ooze occurring between hydrothermal layers or from lower in the mounds sections have relatively higher concentrations of Mn and Fe than do the off-mounds and low heat-flow, nonmounds, sedimentary sections (Tables 7-9).

At the same time, significant inhomogeneity of the elements in the pelagic ooze on the mounds (Tables 1–3) must be taken into account. For example, there are samples (e.g., Sample 509-2-2, 127–131 cm) with high concentrations of iron (15% Fe₂O₃) with average or low concentrations of Mn (0.34% MnO), and there are other examples (e.g., Sample 509B-5-2, 35–37 cm [2]) where the concentrations of these elements run opposite: e.g., 11% MnO and 5.76% Fe₂O₃.

Iron in hydrothermal nontronitic smetites is mainly in an oxidized state (Rateev et al., 1980; Hoffert et al., 1980). However, the FeO concentrations in the smectites (Tables 1-3, 7-9) fluctuate from below the determina-

Table 1. Major and minor elements in sediments from Hole 507D, DSDP Leg 70.

Sample	1-1, 14-20 cm	1-1, 18–20 cm	2-1, 18-19 cm	2-1, 22-26 cm	2-1, 91-95 cm	2-2, 6-10 cm	4-2, 130-135 cm	5-1, 78-80 cm	6-3, 7–9 cm	6-3, 94-98 cm	10-2, 116-119 cm
Component	no. 13	no. 14	no. 15	no. 16	no. 17	no. 18	no. 24	no. 25	no. 27	no. 28	no. 36
Major elemen	nt oxides (%)									
SiO ₂		21.5	2.5	48.95	52.1	53.4	53.65	57.30	52.7	18.7	8.65
TiO ₂		0.17	0.07	0.05	0.08	0.08	0.09	0.41	0.07	0.13	0.11
Al2O3		3.10	0.51	0.85	0.52	0.65	0.38	10.68	0.35	1.98	1.55
Fe2O3	9.4	4.51	4.10	35.52	35.82	125.00	32.15	112.14	122.00	9.16	2.52
FeO				0.42		135.98	0.88	}13.14	32.90	1.06	0.56
MnO		40.90 ^a	39.74 ^a	0.515	0.082	0.065	0.035	0.138	0.055	0.164	0.210
MgO		2.20	0.95	3.09	3.49	3.85	3.82	3.24	5.05	2.04	0.81
CaO	3.8	8.48	2.32	0.51	0.32	0.35	0.23	1.16	0.38	33.47	46.18
Na ₂ O	2.2	1.53	4.26	1.32	2.51	1.83	1.12	2.20	1.51	0.26	0.30
K2Õ		0.82	0.37	1.36	1.34	1.29	3.16	2.61	2.37	0.50	0.34
P205		0.210	0.224	0.096	0.069	0.081	0.058	0.112	0.078	0.102	0.066
H20+		5.05		6.65	07/2/07/20		4.89			4.21	2.11
CÕ2		12.14		0.08						26.68	35.93
Total		100.58		99.41			100.46			98.46	99.34
Minor elemen	ts (ppm)										
Li	9	9		10			6	40		75	7.5
Rb	5	8	6	25			62	90		18	9
Cs	_	13.8	11.4			<u>19</u>	1.8	34	64.56		13
Sr	705	545	300	104			36	270		1070	1496
Co	24	25	10.5	3.6	_		0.6	12		47	49
Ni	780	590	51	10	_	_	5	76	73	22	21
Cr	,00	26	40	31	10	10	20	37	20	21	28
v	1.1	60	31	51	10	10	20	100	20	21	20
Cu	185	170	44	36			5	153	14	50	51
Zn	456	406	50	92			21	300	25	08	61
Sh	18 7	12.2	11 7	1.2			1.0	1.8	25	0.6	0.5
Ph	9	1.2	<0.5	18	_	_	<0.5	1.0	0.5	0.0	0.5
Sc	28	7.1	1.7	2.8		N	1.0	12	0.5	47	3.1
La	13	11 1	5 44	5 77		_	0.74	20 44		14.5	14 46
Ce	12	12.9	1.6	5.6	_	_	1.47	22.44		9.6	10.05
Sm	20	2 22	4.0	5.0		_	0.174	1 10	322	2.5	1.64
En	2.0	0.300	0.74	0.98			0.1/4	4.10		2.5	0.360
Th	5332	0.390	0.210	0.444	_		0.10/	0.903		0.04	0.309
Vh	20	0.432	0.213	0.047	-	—	0.0/4	0.039		1 220	1 112
10	2.0	1.090	0.560	0.947		_	0.213	1.933	2.14	0.100	0.174
Lu		0.300	0.095	0.170	—	—	0.062	0.356		0.190	0.174

a Expressed as MnO2.

tion limit to greater than 3%. The highest FeO concentration is observed in a fine-grained smectite mixed with pelagic ooze. The fluctuation of FeO content in the smectites is not random but shows a distinct trend, increasing from the top to the bottom of the hydrothermal units. As shown in Figure 2, the degree of iron reduction in the smectites increases with depth in the cores. Comparing Figures 2 and 3, we can conclude that at the offmounds sites and in the low heat-flow areas, the increase in FeO/Fe₂O₃ with depth is very similar to this ratio increase of the smectites in the mounds. The areas with high heat flow (Holes 509 and 509B) are assumed to have the greater gradient of FeO/Fe₂O₃, with the ratio increasing with depth.

Elements that do not depend on the redox gradient also vary with depth in the mounds. For example, potassium content in smectites is shown versus depth in Figure 4. Average concentrations of the major elements in the smectites from the "upper," "middle," and "lower" parts of mounds hydrothermal units are given in Tables 7 and 8. Although such a division of the smectites into three groups is quite arbitrary and different limits for such division can be chosen, the increase in K_2O with depth, along with changes in relative abundances of most of the major elements, suggests alteration in the compositions of the smectites.

XRD investigations of the smectite samples support the regularity of their alteration with depth. Rateev et al. (1980) have shown that the green hydrothermal clays are the K-Fe smectites close to nontronite. Smectite can be defined "as a mixed-layer mineral in which typically montmorillonitic spaces filled with hydroxyl ions alternate with spaces filled with potassium." The authors suggest that this may be the result of glauconitization or celadonitization by influence of hydrothermal solutions. Fe- and K-rich glauconite-like mica in variable proportions tends to occur in the later stages of these processes. Smectite samples analyzed in this work are characterized by higher Fe and K and lower Al content, with the lower smectites assumed to be in a higher level of celadonitization, as compared to the previously cited work. Hoffert et al. (1980) nevertheless concluded on

\mathbf{i}			Hole 507F		Hol	e 507C	Hole 507H		
Sample	1-1, 5-7 cm	2-1, 14-17 cm	2-2, 132-134 cm	3-3, 41-45 cm	6-3, 55-59 cm	1-2, 59-62 cm	1-4, 141-145 cm	6-1, 53-55 cm	6-8, 115-119 cm
Component	no. 105	no. 107	no. 101	no. 103	no. 108	no. 37	no. 39	no. 40	no. 43
Major element	oxides (%)								
SiOn	17.9	27.3	52 40	14.45	9.55	26.8	23.90	12.2	13.90
TiOn	0.13	0.21	0.07	0.12	0.11	0.12	0.18	0.18	0.26
Ala	2 50	4 14	0.41	2.11	2.00	2.12	3.98	2.18	4 02
FeaOa	2 21	4.14	33 73	2.57	1.76	0.88	2 22	1.23	1.51
FeO	2.21	7.12	0.33	0.70	0.58	0.63	0.97	0.72	0.99
MnO	2 92*	0 279	0.33	0.778	0.146	0.341	0.240	0.129	0.172
MaO	0.92	2.02	2.49	0.270	0.740	0.341	1.15	0.150	1.04
CaO	0.00	2.02	3.48	2.23	0.76	0.80	1.15	0.78	1.04
CaO	30.75	29.58	0.18	41.09	44.61	33.87	34.03	42.85	41.79
Na ₂ O	0.64	0.89	1.14	0.33	0.27	0.38	0.55	0.23	0.56
K20	0.33	0.56	1.95	0.32	0.29	0.29	0.53	0.26	0.65
P2O5	0.125	0.119	0.050	0.074	0.078	0.080	0.085	0.078	0.112
H_2O^+	4.53	_	5.72	3.27	2.29	2.98	3.46	4.23	1.65
CO ₂	28.41	—	_	31.79	35.00	26.87	26.97	33.34	31.76
LOI	1.02		-		1.43	3.00	1.78		1.04
Total	98.34	—	99.49	99.33	98.87	99.21	100.64	98.42	99.45
Minor elements	(ppm)								
Li	7	16	6	6	8	_	9	7.5	10
Rb	9.5	17	47	11	9		13	9	14
Cs	2.2		1 26		0.6	197	1.2	20	1.26
Ba	120		00		148		70		125
Da	1201	080	90	410	140	1010	1025	1259	1000
Co	1201	980	57	410	1514	1010	1025	1256	1000
CO		12	0.7		4.0	10	0.1	0.0	1.2
INI C	_	190	4.8	107	21	1	134	00	52
Cr	15		10		18	_	18	100	12
Cu		23	19	76	50		96	65	57
Zn	225	489	29	184	125		206	150	75
Cd	0.057	100	0.27			1000	100		_
Sb	1.0	_	0.7		0.4	1.6	3.8		0.6
As		—	-		3.1		—		9.3
Pb		48	< 0.5	30	44		30		—
Sc	4.8	7	0.7	3.8	3.3	4.8	5.7	4.5	6.8
La	10.10	17.20	1.27	-	10.15	8.70	10.30	-	18.80
Ce	6.28		11.90		8.80		7.52		15.02
Sm	1.612	1.700	0.930	1.450	1.270	1.650	1.540	1.040	2.136
Eu	0.432	0.450	0.214		0.301		0.501		0.553
Tb	0.393		0.198	_	0.269		0.310		0.462
Yh	1.270	1 300	0.451	1 360	1 274	1 040	1.300	1.130	1 404
Lu	0 209	1.505	0.069	1.500	0.175	1.040	0 233		0 213
ALC: LA	0.409		0.003		0.175		0.433		0.41.0

Table 2. Major and minor elements in sediments from Holes 507F, 507C, and 507H, DSDP Leg 70.

^a Expressed as MnO₂.

the basis of X-ray diffractograms that the green clays had a smectite structure and contained a mica phase with a *d*-spacing equal to 10 Å.

Our XRD investigation has shown that the green clays are represented by mixed-layered minerals which contain a high iron (Fe-montmorillonite-nontronite series) three-layer structure. This conclusion is based on d_{060} spacing values of diffractograms which vary from 1.502 to 1.505 Å (Fig. 5). The ratio of the secondary reflection (002) of the smectite and the basal mica reflection (001) is significant. There is 80-90% smectite in the mixed-layer structure of Sample 66 which is from the upper smectite layers (2.8 m sub-bottom depth) of Sample 509-1-2, 126-129 cm. An equal and possibly greater smectite content is found in the upper green clay layers of Samples 507D-2-1, 22-26 cm and 91-95 cm (1.2-1.9 m sub-bottom depth). Approximately half as much smectite (40-50%) is found within the mica-smectite mineral from Hole 507D (Table 1: no. 24; Sample 507D 4-2, 130-135 cm), which was sampled at 12.8 meters subbottom. The minimum content of smectite structures (30-40%) and maximum mica-layer content are found in the deepest hydrothermal sediment layer at 19.6 meters sub-bottom in Hole 509B. The structural alterations observed (Fig. 6) are in agreement with the increase of

 K_2O concentration with depth in the mounds sections from 1.3 to 5.0% (Fig. 4).

Some green clays from the mounds sections (Samples 507D-5-1, 78-80 cm and 509B-3-2, 104-109 cm) which alternated with pelagic-ooze layers differ significantly from the Fe-rich and Al-poor clays previously discussed. They have a higher concentration of Al, and their compositions are close to that of a beidellite-nontronitic type of smectite.

As was noted previously (Honnorez et al., 1981) a distinct gradient change of amorphous SiO₂ concentration with depth in all but Hole 509 and the off-mounds sections was observed. A typical example of the siliceous microfossil test distribution through the sedimentary sections is shown in Figure 7. It can be seen that these tests are lacking in the lower horizons of the mounds and that they are nearly absent in the hydrothermal units. At the same time, the concentrations of siliceous tests within the sediments does not differ with depth in the low heat-flow regions (Fig. 7). Their preservation here is much better than in the pelagic oozes found in the mounds areas. CaCO₃, which is the main component in the pelagic sediments, is absent in greenclay layers (Tables 1-8). In addition, this mineral is observed only in fine-grained smectites which are mixed

with pelagic oozes. Minor amounts of C_{org} and S_{pyr} are observed in the mixed layers, but they are practically absent in granular pure smectites.

One main peculiarity of the mounds hydrothermal sediments is that they are poor in alumina (Tables 7 and 8). Boström and Peterson (1969) have also reported aluminium-poor and Fe-Mn rich metalliferous sediments in areas of high heat flow near mid-ocean rises. Aluminium is one of the most stable elements under sedimentary conditions, and the change in the ratios of various elements to alumina is used to estimate the input rate of sediments from hydrothermal sources. Comparison of the element ratios to alumina in the mounds and off the mounds to those which are not affected by hydrothermal solutions (Hole 508) may give a rough estimation of the elemental input from hydrothermal solutions and an approximate scale of the redistribution of the elements.

The results of this comparison show the distinct geochemical differences between hydrothermal sediments occurring at different levels within the mounds sections. The upper crusts differ from the lower crusts and from the Fe-Mn oxide mud, but they have significant similarity to the uppermost oxidized layers of the off-mound pelagic oozes in the high heat-flow area (Fig. 8). The Fe-Mn oxide sediments differ from all Mn-crusts and from oxidized off-mound oozes by their significant enrichment in Fe and Si. At the same time all oxidized sediments of the high heat-flow area share a common peculiarity: They are strongly enriched in manganese in comparison with the low heat-flow area pelagic oozes. All the hydrothermal crusts are enriched in Mn, K, Na, Mg, and, in some cases, in Fe and Si (for the Fe-Mn oxide sediment) relative to pelagic oozes.

The comparison of iron-rich smectites from different levels of the mounds sections with the mound pelagic oozes and the pelagic sediments from the low heat-flow area is shown in Figure 9. High ratios of SiO₂, Fe₂O₃, FeO, K, Na, and Mg to alumina in smectites are evident. There is also the enrichment in Fe₂O₃ and K in the mound pelagic oozes (both in basal sediments and in oozes alternating with smectites). A high manganese to alumina ratio is characteristic of pelagic oozes interlayering with hydrothermal sediments. The high alumina smectites, scattered as thin layers or patches in these pelagic oozes, are similar to the host sediments in elemental ratios, but they differ significantly from hydrothermal iron-rich and alumina-poor green clays. In other words, interpreting obtained data relative to the least mobile alumina, we can suggest significant input.

A more accurate estimation of elemental input or subtraction caused by hydrothermal activity can be obtained by evaluating the absolute masses of elements or oxides in the mound sequence with respect to those in the low heat-flow sedimentary sequences. In these estimates, the physical properties of sediments (porosity and density) which were ignored in calculations of ratios to alumina have to be considered.

Unfortunately, data on physical properties were not available for all samples analyzed; thus we used shipboard measurements for intervals close to the analyzed samples or average values for each type of sediment in the hole if physical properties had not been measured near our samples.

The results of the calculations are presented in Table 10. They show a high input of silica in the hydrothermal layers. The mass of silica in smectite is up to five times as large as in pelagic ooze found in the low heat-flow area. At the same time, silicon is depleted up to twothirds from the basal pelagic oozes in the mounds section. Silica flux is a maximum in the lower smectites and decreases in the upper smectite layers. The same trends exist for iron. Iron input in the lower smectites is 20 times higher than in pelagic sediments. Both ferric and ferrous iron supply is a maximum in these lower smectites. Estimates of iron mass in the mounds pelagic sediments show a distinct increase. As a rule, the iron increase in pelagic layers alternating with smectites is greater than in basal sediments. Within the smectites, alumina mass values differ from each other and from that of pelagics by a factor of three. In the upper smectites at Hole 509B, alumina mass values are the same as in pelagic sediments from low heat-flow areas. At the same time the middle and lower smectites in Hole 509B and all the smectites in Hole 507D are depleted in alumina masses respective to low heat-flow sediments. The variations of alumina masses in smectites presumably result both from the significant role of the pore infilling texture of smectites in some layers and from the inhomogeneity of alumina masses in parent pelagic oozes being replaced by smectite. Actually, pelagic ooze from the mounds sequences at Hole 507D contains only half as much alumina mass as low heat-flow pelagic sediments.

MINOR ELEMENTS

The distribution of minor elements and their relations with major elements in hydrothermal sediments differs from pelagic ooze.

As a rule, element concentrations in pelagic sediments are higher than in hydrothermal sediments, especially when values obtained are calculated on a carbonate-free basis (Tables 7–9). It can be shown that only the upper crust and Fe-Mn oxide sediments are close to the pelagic sediments in some minor element concentrations. High alumina smectites also contain higher concentrations of minor elements when compared to the hydrothermal sediments.

Differences in relationships of elements are observed between pelagic and hydrothermal sediments. For example, in Figure 10 the Mn and Ni contents in the offmounds pelagic ooze show a nice correlation. This relationship is worse in mounds pelagic sediments and it is absent in hydrothermal smectites and Mn crusts. Similar trends exist between Ni plotted against Sb (Fig. 11). Correlations between Ni, Co, and Cu are observed in all the sediments. Zn correlates with Fe in Mn crusts (Fig. 12). The relationship between K and Rb within hydrothermal and pelagic sediments is shown in Figure 13. There is a nice correlation between these elements in pelagic oozes and in the smectites replacing them. In contrast, this correlation is absent in Mn crusts.

The average concentrations of rare-earth elements (REE) in hydrothermal sediments are one order of mag-

Table 3. Major and mind	r elements in sediments	from Hole 509B,	Leg 70.
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Sample	1-1, 40-42 cm	1-1, 84–87 cm	I-1, 108-110 cm	1-2, 48-52 cm	1-2, 126-129 cm	2-1, 90-93 cm	2-1, 109-111 cm	2-1, 124-126 cm	2-2, 40-42 cm	2-2, 112-115 cm	2-2, 127-131 cm	2-3, 12-14 cm	2-3, 16-18 cm
Component	no. 96	no. 99	no. 64	no. 65	no. 66	no. 67	no. 68	no. 100	no. 69	no. 70	no. 71	no. 97	no. 72
Major element of	oxides (%)												
SiO ₂	3.9	17.3	10.5	1.5	50.8	16.4	6.4	49,50	45.10	51.9	35.55	32.75	23.65
TiO ₂	0.10	0.16	0.13	0.08	0.07	0.24	0.15	0.16	0.22	0.24	0.32	0.18	0.08
AlpÕa	0.90	3.07	2.08	0.71	0.30	3.88	1.87	1.39	4.26	4.12	5.51	5.38	0.82
Fe2O3	0.91	3.70	5.46	0.56	34.20	4.00	1.69	29.10	23.02	28.4	9.33	3.03	17.76
FeO	_	_	_	_	-				-	_	0.69	0.33	
MnO	47.97a	9.81 ^a	36.08 ^a	78 34 ^a	1.16	34.76 ^a	42.15 ^a	4.06 ^a	9.88 ^a	0.270	0.220	0.705	35.00 ^a
MgO	1.49	1.24	2.46	3 42	3 72	3.02	3.44	3.56	3.68	4.07	2.65	1.04	3.56
CaO	3.61	32.7	15.76	1.68	0.23	9 35	6.53	0.88	0.74	1.00	21.4	28.24	3.88
NapO	_	0.71	1 27	1 53	1 24	1.16	1.05	0.94	1.21	1.58	0.91	1.21	1.29
K2O	0.49	0.42	0.41	1.14	1.81	0.70	0.47	2.14	1.60	1.72	0.96	1.43	1.11
PaOs	0.105	0.147	0.186	0.118	0.073	0.160	0.130	0.065	0.129	0.115	0.110	0.090	0.187
H ₂ O+	_	5 62	-	7 74	5.88		_	7.11	8.10	_	7.41	3.46	8.64
CO2		27 43		3 93	n d			0.68	1.69		14.91	20.33	4.43
L.O.I.		n.d.		n.d.	n.d.			n.d.	n.d.	-	n.d.	1.81	n.d.
Total	-	99.31		100.80	99.48	_	-	99.59	99.63	-	99.97	99.99	100.41
Minor elements	(ppm)												
Li	1.9	8	5	<2	5	6	10	11	15	15	20	9	8
Rb	1.9	10	6	7	30	6	14	40	34	41	26	31	10
Cs	7.7	- <u>-</u> -	1	8.8		<u> </u>			1.7	-	_	1.7	
Sr	890	2440	820	680	47	545	750	200	795	270	730	876	645
Co	22	10		14	1.7	14	28		16	-		3.4	156
Ni	146	144	175	60	5.5	132	153	12	48	14	88	53	840
Cr	12	16	10	-	30	30	61	20	40	20	_	15	40
Cu	50	152	144	27		70	122	61	130	50	78	48	321
Zn	173	220	220	37	27	88	98	55	70	85	270	134	690
Sb	15.4	10		10	0.5	_	8.2		1.9	_		0.9	25.2
Pb	<15	8.5	1.5	<1	1.7	<1	<1	3.2	2.6	< 0.5		30	<1
Sc	6.5	4.5	-	1.6	0.5	3.5	10.4	3.4	8.2	—		5.6	6.2
La	3.17	10.7		2.62	0.45	9.2	_	3.3	13.6	$\sim - 1$		12.0	5.04
Ce	3.05	9		3.5	0.88	10.0		_	16.3	-		11.4	4.52
Sm	0.85	1.5		0.78	0.16	1.4	_	0.85	2.48			2.3	0.85
Eu	0.299	0.43	_	0.167	0.033	0.44		1000 C	0.572	—	-	0.572	_
Tb	0.233	0.40		0.141	0.027	0.44			0,495	-		0.439	_
Yb	0.805	1.2	-	0.437	0.087	1.5			1.504	_	_	1.274	0.612
Lu	0.134	0.18		0.063	0.017	-		-	0.296	V		0.218	0.090

a Mn and MnO2.

nitude less than their average concentrations in carbonate-free pelagic ooze material (Tables 7 and 8). For minimal concentrations of REE in hydrothermal smectites, they differ by about two orders of magnitude. The REE distribution pattern in pelagic ooze and hydrothermal sediments as a rule is much the same. The main difference is the cerium deficiency. This peculiarity reflects the role of seawater in the REE pattern of this sediment formation (Piper, 1974; Piper and Graef, 1974; Bender et al., 1971; Migdisov, Bogdanov et al., 1979). Smectites containing the lowest REE concentration are characterized by different patterns (Figs. 14, 15). They are similar to basalt REE distribution patterns and are close to the smectite found in veins and in basalt alteration zones (Fig. 16) recovered from the deep part of Hole 504B, Costa Rica Rift and described by Sharaskin et al. (in press). These patterns are assumed to be caused by hydrothermal solutions circulating through the basalts.

The minor element concentrations in the mounds sediments are localized at different depths in much the same manner as the major element distributions—for example, in the upper layer of the mounds sediments in Hole 507D are concentrated sufficiently higher amounts of Ni, Co, Cu, Zn, Pb, and REE as compared with the lower Mn crusts. These concentrations also approach the values found in the upper oxidized layer of pelagic ooze (Tables 7 and 8).

The distribution of minor elements in the smectites also varies with depth. Rb content increases from the top to the bottom of the hydrothermal unit in the mounds sections. Figure 17 plots zinc content against ferrous iron, which also increases with depth. It should be mentioned that higher concentrations of Zn, as well as sulfide sulfur, occurred in smectites mixed with pelagic ooze. It is these varieties of smectite, characterized by higher concentrations of these minor elements, which are enriched in the pelagic sediments (Tables 1, 3, 7, and 8). Their concentrations in mixed smectites are intermediate between pure smectite and pelagic sediments.

In a number of cases the data on minor element distribution present evidence for redistribution of elements near the contact between smectite and pelagic sediment. For example, in Hole 509B, a smectite-infilled burrow surrounded by pelagic ooze was studied (Table 3; Sample 509B-5-2, 35-37 cm). Enrichment of iron, manganese (3% MnO), and a high concentration of Ni (600 ppm) in the smectite was observed with more than 30%CaCO₃. On a carbonate-free basis, Zn and Cu content in the pelagic ooze near the contact with smectite is three to four times and Ni concentration is nearly one-tenth as large as in the smectites. Enrichment of Co, Sb, and REE near the contact between the smectites and pelagic ooze was also observed.

Inhomogeneity of minor element distribution in the pelagic ooze interlayers within hydrothermal zones and in the lower pelagic ooze units also suggests a redistribution of elements. For example, Ni content in the mounds pelagic ooze differs from 5 to 180 ppm (on a

Table 3. (Continued).

3-1, 86-89 cm	3-2, 104-109 cm	3-3,	4-1,	4-2, 98-103 cm	4-3 21-26 cm	5-1 86-90 cm	5-2 35-37 cm (1)	5-2 35-37 cm (2)	5-3 80-82 cm	6-3	7-2 70-74 cm	8-1 93-98 cm	8-3 52-78 cm
no. 73	no. 74	no. 75	no. 98	no. 76	no. 77	no. 78	no, 79	no. 80	no. 81	no. 82	no. 83	no. 84	no. 85
				122121									
52.45	53.25	53.10	52.80	54.10	53.15	10.0	33.75	10.50	47.85	8.80	11.15	13.85	11.75
0.08	0.42	0.08	0.08	0.23	0.08	0.10	0.11	0.16	0.08	0.06	0.18	0.22	0.20
0.45	7.68	0.69	0.60	3.29	0.22	1.30	1.54	2.14	1.00	1.85	2.11	3.28	2.30
32.10	19.66	31.06	31.98	26.40	32.10	1.19	16.56	1.37	26.91	1.07	1.43	2.01	1.73
-	0.85	0.85	0.56	_	-		0.94	0.39	1.70	0.39	0.50	0.46	0.97
0.530	0.212	0.068	0.224	0.065	0.058	2.070ª	3.255ª	2.690 ^a	0.072	0.550	0.240	0.232	0.245
3.92	4.64	3.98	3.82	4.38	4.22	0.92	3.67	1.09	4.44	0.88	0.88	1.30	1.29
0.54	0.98	0.33	0.36	0.85	0.29	45.27	17.32	42.66	4.46	46.67	44.14	41.44	44.46
1.01	1.10	1.03	0.86	0.75	0.86	0.17	0.55	0.32	0.73	0.27	0.28	0.36	0.30
2.98	1.94	3.38	3.20	2.69	2.74	0.15	2.35	0.28	4.63	0.36	0.36	0.43	0.32
0.048	0.125	0.065	0.030	0.080	0.034	0.075	0.060	0.084	0.050	0.080	0.097	0.108	0.090
6.13	7.26	5.81	5.85	6.50	5.91	2.17	4.63	2.84	5.64	1.68	2.54	4.06	2.56
0.26	n.d.	0.19	0.21	n.d.	n.d.	35.10	14.84	33.54	3.24	37.17	33.31	30.69	33.86
n.d.	0.53	n.d.	n.d.	n.d.	n.d.	100		0.83		—	0.53	0.53	
100.50	98.65	100.64	100.57	99.34	99.66	98.52	100.02	98.89	100.80	99.83	98.41	98.97	100.08
3	26	9	5		<12	6	12	0	12	5	7		
50	50	70	75	11	<12	6	13	10	115	12	11	_	11
39	50	70	15	65	00	5	/6	10	115	12		_	11
51	440	64	60	245	47	1470	520	1480	222	450	1464		1022
4	940	04	00	343	2.0	14/0	330	1460	4.0	439	5.9	_	0.2
	50	0	- 5	-	5.0	126	10	12.5	4.0	3.1	5.0	_	7.0
10	49	20	10	22	0.4	125	035	08	30	< 5	180	_	12
24	126	50	30	33	16	02	10	20	10	3	10.4	_	42
24	217	21	1.5	60	10	160	169	176	104	40	222	_	119
24	10	21	34	23	0.7	100	108	1/5	104	40	223	_	0.4
1.0	1.0	-0.5		-	-0.5		2.0	1.0	1.0	20	20		22
1.0	0.9	< 0.5	_	0.8	< 0.5		24	-	1.9	30	30	_	33
1.0	10.6	1.00		7.8	0.7		2.0	10.0	4.0	1.0	4.0	200	0.3
	10.5			7.0		_	7.0	10.9	2.22	11.07	14		12.3
	7.8			10	_			9.5	3.18	3.95	15.7		9.0
	2.81		—	1.9	_	—	1.1	2.0	0.055	1.75	3.5		1.9/
125	0.000	100		_		_	-	0.42	-	0.000	0.67	_	0.484
10.0	0.552	100	-	_	-	_	0.00		0.000	0.293		-	0.418
	1.387	_		_		_	0.96	1.27	0.383	1.283	1.9	_	1.364
	0.238		—	_		_	March 1	-	0.091	0.086	0.30	_	0.222

Table 4. Major and minor elements in sediments from Hole 509, DSDP Leg 70.

Sample	1-1, 4-7 cm	1-1, 82-86 cm	3-1, 50-52 cm	4-1, 80-84 cm	5-1, 85-89 cm	6-1, 91-95 cm	7-2, 62-66 cm	8-2, 19-21 cm
Component	no. 47	no. 48	no. 44	no. 49	no. 50	no. 51	no. 52	no. 53
Major element o	oxides (%)							
SiO ₂	18.10	18.50	23.60	21.20	15.1	13.1	11.3	12.10
TiO ₂	0.16	0.12	0.26	0.18	0.18	0.15	0.17	0.17
Al2O3	2.93	1.73	3.69	3.54	2.38	2.37	1.96	2.92
Fe ₂ O ₃	2.22	2.52	1.86	2.46	1.38	1.08	0.78	1.49
FeO		0.70	0.76	0.79	0.68	0.80	0.68	0.60
MnO	5.130	0.288	0.484	1.420	0.346	0.311	0.203	0.194
MgO	0.86	1.12	1.21	1.36	0.91	0.87	0.75	0.78
CaO	35.23	38.23	34.98	34.64	41.16	42.51	43.67	42.86
Na ₂ O	0.52	0.31	0.48	0.53	0.35	0.37	0.41	0.33
K ₂ Õ	0.35	0.27	0,42	0.46	0.32	0.28	0.26	0.33
P2O5	0.139	0.130	0.100	0.089	0.085	0.108	0.090	0.178
H_2O^+	5.32	3.77	4.63	3.63	4.90	3.31	2.74	2.98
CO ₂	28.58	30.19	27.33	27.78	32.43	32.98	33.54	33.68
L.O.1.		0.86	0.22	—	-	-	2.17	_
Total	99.54	98.74	100.02	98.08	100.22	98.24	98.72	98.61
Minor elements	(ppm)							
Li	10	8	10	12	8	9	8	10
				22	10	10		1000
Rb	9	15	14	23	10	10	9.5	10
Rb Cs	9	15 2.3	14	23	10	10	9.5	10
Rb Cs Ba	9	15 2.3 90	14	23	10	10	9.5	10 1.1 151
Rb Cs Ba Sr	9 1160	15 2.3 90 1120	14	1200	1290	1460	9.5	10 1.1 151 1460
Rb Cs Ba Sr Co	9 1160 25	15 2.3 90 1120 8.0	14 1180 7.5	1200 9	1290 5	1460 5	9.5 1460 10.7	10 1.1 151 1460 7.5
Rb Cs Ba Sr Co Ni	9 1160 25 245	15 2.3 90 1120 8.0 111	14 1180 7.5 145	23 1200 9 165	1290 5 105	1460 5 82	9.5 1460 10.7 77	10 1.1 151 1460 7.5 67
Rb Cs Ba Sr Co Ni Cr	9 1160 25 245	15 2.3 90 1120 8.0 111 24	14 1180 7.5 145	23 1200 9 165 21.6	1290 5 105 15	1460 5 82 15	9.5 1460 10.7 77 13	10 1.1 151 1460 7.5 67 19
Rb Cs Ba Sr Co Ni Cr V	9 1160 25 245	15 2.3 90 1120 8.0 111 24	14 1180 7.5 145	23 1200 9 165 21.6 16	1290 5 105 15	1460 5 82 15	9.5 1460 10.7 77 13	10 1.1 151 1460 7.5 67 19
Rb Cs Ba Sr Co Ni Cr V Cu	9 1160 25 245 124	15 2.3 90 1120 8.0 111 24 105	14 1180 7.5 145	23 1200 9 165 21.6 16 122	1290 5 105 15 84	1460 5 82 15 72	9.5 1460 10.7 77 13 120	10 1.1 151 1460 7.5 67 19
Rb Cs Ba Sr Co Ni Cr V Cu Zn	9 1160 25 245 124 220	15 2.3 90 1120 8.0 111 24 105 220	14 1180 7.5 145 106 193	23 1200 9 165 21.6 16 122 185	1290 5 105 15 84 175	1460 5 82 15 72 170	9.5 1460 10.7 77 13 120 126	10 1.1 151 1460 7.5 67 19 105 93
Rb Cs Ba Sr Co Ni Cr V Cu Zn Sb	9 1160 25 245 124 220 3,3	15 2.3 90 1120 8.0 111 24 105 220 1.0	14 1180 7.5 145 106 193	23 1200 9 165 21.6 16 122 185	1290 5 105 15 84 175	1460 5 82 15 72 170	9.5 1460 10.7 77 13 120 126 1.7	10 1.1 151 1460 7.5 67 19 105 93 0.3
Rb Cs Ba Sr Co Ni Cr V Cu Zn Sb Sc	9 1160 25 245 124 220 3.3 6.4	15 2.3 90 1120 8.0 111 24 105 220 1.0 2.8	14 1180 7.5 145 106 193	23 1200 9 165 21.6 16 122 185 5.2	1290 5 105 15 84 175	1460 5 82 15 72 170	9.5 1460 10.7 77 13 120 126 1.7 5.0	10 1.1 151 1460 7.5 67 19 105 93 0.3
Rb Cs Ba Sr Co Ni Cr V Cu Zn Sb Sc La	9 1160 25 245 124 220 3.3 6.4 12.7	15 2.3 90 1120 8.0 111 24 105 220 1.0 2.8 11.03	14 1180 7.5 145 106 193	23 1200 9 165 21.6 16 122 185 5.2 10.7	1290 5 105 15 84 175	1460 5 82 15 72 170	9.5 1460 10.7 77 13 120 126 1.7 5.0 7.7	10 1.1 151 1460 7.5 67 19 105 93 0.3 8.17
Rb Cs Ba Sr Co Ni Cr V Cu Zn Sb Sc La Ce	9 1160 25 245 124 220 3.3 6.4 12.7 11.8	15 2.3 90 1120 8.0 111 24 105 220 1.0 2.8 11.03 7.19	14 1180 7.5 145 106 193	23 1200 9 165 21.6 16 122 185 5.2 10.7 8.6	1290 5 105 15 84 175	1460 5 82 15 72 170	9.5 1460 10.7 77 13 120 126 1.7 5.0 7.7 7.9	10 1.1 151 1460 7.5 67 19 105 93 0.3 8.17 6.70
Rb Gs Ba Sr Co Ni Cr V Cu Zn Sb Sc La Ce m	9 1160 25 245 124 220 3.3 6.4 12.7 11.8 2.4	15 2.3 90 1120 8.0 111 24 105 220 1.0 2.8 11.03 7.19 1.722	14 1180 7.5 145	23 1200 9 165 21.6 16 122 185 5.2 10.7 8.6 1.7	1290 5 105 15 84 175	1460 5 82 15 72 170	9.5 1460 10.7 77 13 120 126 1.7 5.0 7.7 7.9 1.6	10 1.1 151 1460 7.5 67 19 105 93 0.3 8.17 6.70 1.41
Rb Cs Ba Sr Co Ni Cr V Cu Zn Sb Sc La Ce Sm Eu	9 1160 25 245 124 220 3.3 6.4 12.7 11.8 2.4 -	15 2.3 90 1120 8.0 111 24 105 220 1.0 2.8 11.03 7.19 1.722 0.357	14 1180 7.5 145 106 193	23 1200 9 165 21.6 16 122 185 5.2 10.7 8.6 1.7 0.4	1290 5 105 15 84 175	1460 5 82 15 72 170	9.5 1460 10.7 77 13 120 126 1.7 5.0 7.7 7.9 1.6 0.4	10 1.1 151 1460 7.5 67 19 105 93 0.3 8.17 6.70 1.41 0.355
Rb Ba Sr Co Ni Cr V Cu Zn Sb Sc La Sc La Sm Eu Tb	9 1160 25 245 124 220 3.3 6.4 12.7 11.8 2.4 	15 2.3 90 1120 8.0 111 24 105 220 1.0 2.8 11.03 7.19 1.722 0.357 0.323	14 1180 7.5 145	23 1200 9 165 21.6 16 122 185 5.2 10.7 8.6 1.7 0.4 0.4	1290 5 105 15 84 175	1460 5 82 15 72 170	9.3 1460 10.7 77 13 120 126 1.7 5.0 7.7 7.9 1.6 0.4 0.4	10 1.1 151 1460 7.5 67 19 105 93 0.3 8.17 6.70 1.41 0.355

Table 5. Major and minor elements in sediments from Holes 508 and 508C, DSDP Leg 70.

Sample					Hole 508						Hole	508C
	1-1, 39-43 cm	2-1, 61-65 cm	3-1, 123-127 cm	4-2, 80-84 cm	5-1, 82-86 cm	6-2, 25-29 cm	7-2, 123-128 cm	8-2, 33-35 cm	8-3, 54-56 cm	8-3, 63-64 cm	1-1, 24–28 cm	1-2, 15-19 cm
Component	no. 1	no. 2	no. 3	no. 4	no, 5	no. 6	no. 7	no. 8	no. 9	no. 10	no. 11	no. 12
Major elemen	nt oxides (%)										
SiO ₂	17.8	27.5	19.4	21.8	12.7	9.7	16.20	18.65	14.0	17.6	8.3	7.8
TiO ₂	0.12	0.19	0.19	0.12	0.15	0.13	0.14	0.16	0.13	0.13	0.13	0.13
Al ₂ O ₃	1.81	4.71	3.75	2.42	2.37	2.01	2.63	3.25	2.20	2.25	1.89	1.71
Fe2O3	3.11	12.21	2 69	1.71	1.24	1	1.14	2.52	1.58	1.16	1.94	2.71
FeO	0.60	12.21	2.38	1.71	0.42	1.21	0.49	0.70	0.54	0.71	0.41	
MnO	0.312	0.921	0.378	0.282	0.388	0.249	0.180	0.173	0.153	0.140	0.214	0.226
MgO	1.33	1.01	1.01	0.84	0.83	0.62	0.84	1.44	1.23	4.47	1.62	1.84
CaO	37.92	31.95	38.09	37.56	43.70	47.77	41.88	37.33	44.61	41.64	45.79	47.84
NapO	0.29	0.60	0.60	0.43	0.42	0.32	0.36	0.35	0.87	0.26	0.15	0.20
K2Ô	0.26	0.91	0.45	0.32	0.30	0.29	0.34	0.41	0.13	0.04	0.27	0.31
PoOs	0.099	0.116	0.116	0.096	0.106	0.114	0.099	0.104	0.100	0.103	0.122	0.166
HoO+	3.13	3.50	3.0	3.02	2 75	0.50	2.55	3 43	0.65	1.65	1.71	0.5
COn	29.22	25 20	30.0	29.56	34 45	37 60	31.49	28.07	30.69	27 47	35.62	37.37
LOI	3.56	20.20	50.0	0.66	54.45	57.00	1.71	2.21	3.07	1.30	1.33	51101
Total	98.92	98.82	99.57	98.82	99.67	100.51	100.05	98.79	99.95	98.92	99.49	100.81
Minor elemen	its (ppm)											
Li	7.5			7.2			9.5	5	3	16	6	
Rb	7			8.5			10	11	4	2.5	6	
Cs	2.0			0.5			10			2.0	0.9	
Ba	100									82	51	
Sr	1130			1260			1190	1120	1170	1130	780	
Co	10			10			5.5	6.0	6.5	5.5	3.6	
Ni	143			116			78	86	55	52	30	
G	18 5			110			78	15.2	55	12.6	8.5	
Cu	118			07			77	87	15	6	49	
Zn	215			174			130	180	85	38	48 5	
Sh	1.2			1/4			139	1 7	65	0.8	40.5	
50	1.2			040			2.0	1.7	2.2	4.5	2.0	
SC	4 7 0			4			3.8	4.9	2.5	4.5	5.0	
La	7.8			11.2			9.4	7.0	10.5	11.0	0.5	
Ce	9.0						1.72			8.9	4.0	
Sm	1.559			2.0			1.65	2.5	2.5	1.416	1.086	
Eu	0.309									0.468	0.242	
Tb				1017-0027						0.290	0.242	
Yb	0.907			1.67					1.63	1.222	0.851	
Lu	0.234									0.240	0.171	

carbonate-free basis [CFB], Ni content = 31-798 ppm), Co concentration varies from 4.6 to 58 ppm (28-257 on CFB), and zinc ranges from 48 to 223 ppm (295-989 on CFB). In all but the Mn-rich oxidized layers of the mounds sediments, the distribution of the elements is more homogeneous and varies more than two to four times. The most homogeneous distribution of minor elements is in the off-mounds area and in the low heat-flow areas.

The increase in the homogenization of elements in the pelagic oozes from the mounds to the off-mounds and to the low heat-flow areas is attributed to the decreased influence of hydrothermal activity.

Data on minor element to alumina ratios (Figs. 8, 9) and the absolute masses of minor elements in the smectites and the pelagic oozes (Table 10) suggest an increase and redistribution of a number of elements within the sediments studied. There are significant concentration increases in Ni, Co, Zn, Sb, Cu, and Cs relative to alumina in the upper manganese crusts (Fig. 8) in comparison with pelagic ooze from the low heat-flow areas. Elements concentrated in minor amounts in the oxidized pelagic ooze layer (Li, Rb, and Cr) and REE to alumina ratios are close to low heat-flow area sediments. In the lower crusts the list of enriched elements is clearly different. Rb and Cr are enriched relative to alumina while the transition, rare-earth elements, and Sc are not.

The Fe-Mn oxide sediments have a significant enrichment in Ni, Co, Zn, and Cu relative to alumina as well as upper crusts and oxidized layers, but higher ratios of Rb and Cr to alumina are observed when comparing Fe-Mn oxide sediments to the pelagic oozes.

Minor element to alumina ratios (Fig. 9) and mass calculations (Table 10) in the smectites indicate a great increase of Li, Rb, Cs, and Sb in these sediments. Depletion of Sr, Ni, Co, Cu, and Zn in mounds sediments are noted and observed both in the smectites and in the pelagic oozes which alternate with smectites. Redistribution and local fluctuations of these elements are observed in the smectites which are mixed with pelagic oozes and in the basal pelagic oozes.

CONCLUSIONS

Some conclusions follow from the data that we have presented:

1) Mn crusts and alumina-poor and iron-rich smectites differ in major and minor element distribution

Table 6. Major and minor elements in sediments from Hole 510, DSDP Leg 70.

Sample	2-2,	2-6,	5-5,	8-2,
Component	no 54	no 56	155-137 cm	/3-/8 cm
	110. 54	110. 50	110.00	110. 05
Major element	oxides (%)			
SiO ₂	27.05	20.6	23,40	23.6
TiO ₂	0.11	0.13	0.10	0.12
Al ₂ O ₃	2.10	2.50	1.23	2.49
Fe ₂ O ₃	0.96	0.95	0.29	0.76
FeO	0.61	0.55	0.61	0.53
MnO	0.225	0.201	0.100	0.158
MgO	0.94	0.69	0.46	1.05
CaO	35.10	38.74	39.21	37.33
Na ₂ O	0.32	0.47	0.29	0.32
K ₂ O	0.31	0.38	0.20	0.27
P2O5	0.102	0.116	0.040	0.170
H_2O^+	3.31	2.71	2.90	2.81
CO_2	27.13	30.68	30.78	28.62
LOĨ	1.04	0.72	0.60	1.50
Total	99.31	99.44	100.21	99.73
Minor elements	(ppm)			
Li	12.5	9	6.5	22
Rb	14	12.5	6.5	10
Cs	1.2			0.9
Sr	1090	1250	1200	1190
Co	8	6.7	5.2	5.9
Ni	132	74	51	45
Cr	16	<u> </u>		14.2
Cu	81	74	77	63
Zn	198	136	93	106
Sb	1.0	_		0.5
Sc	4	5.5	3.4	3.7
La	10.1	16.4	9.8	7.6
Ce	5.9		_	6.2
Sm	1.112	3.2	2.3	1.77
Eu	0.265			0.411
Tb	0.276	-	_	0.358
Yb	0.850	1.76	1.4	1.074
Lu	0.135	—	-	0.181

from the pelagic sediments and surely have a different origin, but both must be attributed to hydrothermal activity.

2) A significant additional input of a number of elements (Si, Fe, Mn, K, Rb, Li, etc.) to the mounds location are evident. There is a strong similarity between this list of elements and those that enriched the thermal solution sampled at the axis zone of Galapagos Rift (Edmond, Measures; McDuff, 1979; Edmond, Measures, Mangum, 1979).

3) The data strongly suggest interaction of pelagic ooze with hydrothermal solutions. This interaction leads to intensive redistribution of elements and to subtraction of some elements from mounds sediments (Ni, Co, Cu, REE, Sr, etc.). These are the elements that are depleted in thermal solutions from the axis zone of Galapagos Rift.

4) Hydrothermally derived solutions rich in elements appear to differentiate in the mound section. This may result from a redox gradient encountered during the upward percolation of hydrothermal solutions through the sediment cover. 5) The similarities in element distribution between upper Mn crusts and Fe-Mn oxides and the off-mounds upper oxidized layers of pelagic oozes (enrichment of Ni, Co, Cu, Zn, etc.) reflect the influence of seawater on their composition.

In light of the foregoing disscussion, it appears that the mounds form as the result of percolating solutions rich in Si, Fe, and Mn which emanate from the basement through fracture zones and react with seawater and with the overlying sediment layer. Available data give us no opportunity to resolve the problem of whether the input of iron was synchronous with that of manganese or whether the elements arrived separately. A great deal of data indicate a manganese influx to the water column above the Galapagos Spreading Center (Bolger et al., 1978; Lyle, 1976; Klinkhammer et al., 1977; Edmond et al., 1979 a,b). At the same time observations show that significant iron input also takes place and that Fe and Mn fractionation occurs during oxidation in the seawater (Gordeev et al., 1979).

The occurrence of the Fe-Mn oxide sediment in the mounds sections is assumed to reflect incomplete separation of these elements, and the correlation of the redox gradient with Mn and Fe separation suggests the possibility of synchronous iron and manganese input.

Data on different ferrous iron masses at different levels in the mounds section show that iron arrives at these levels in solution and is incompletely oxidized. This assumption agrees well with data from Edmond et al. on the composition of hydrothermal solutions from the axis of the Galapagos Rift. From the data presented above and other work (Honnorez et al., 1981), it appears that infiltration of oxygen-bearing waters into a mound is one of the main oxidizing factors. Proton formation and carbonate dissolution follow from the reaction of ferrous iron oxidation and its combination with SiO2 and H2O. It is obvious that carbonate dissolution leads to a largescale redistribution of elements. It is likely that most dissolved and redistributed elements are washed out of mounds sediments by circulating water. Large amounts of oxygen are required for the precipitation of manganese in the form of todorokite, which was fixed in the course of manganese and iron separation in the upper layers of the mounds sequence. The uppermost crusts in oxidized pelagic ooze, which were subjected to contact with seawater, have a similar elemental pattern as the pelagic oxidized layer. In contrast, the lower manganese crusts have the characteristics of rapidly accumulating manganese formations (Moor and Vogt, 1976) and are similar to the smectites from the standpoint of minor element distribution. Fe-Mn oxide sediment is assumed to have accumulated rapidly as a result of the simultaneous oxidation of both elements. Its composition demonstrates seawater influence. Direct deposition of this sediment from open seawater is possible.

Comparison of the different types of Galapagos hydrothermal mounds sediments with other products of hydrothermal activity in oceans and ophiolite zones of continents is interesting. The distribution of REE, reflecting the influence of different source material, can be chosen for this comparison. In Figure 16 is shown

Table 7.	Average	composition	of hydrothermal	and pelagi	c sediments	(carbonate-fi	ree basis) i	in mounds and	d off-mounds :	sedimentary	sections,	Site
507.												

Hole		507A		507A, F		507A			5071	507C, H	
Lithology	Upper Mn Crust	Lower Mn Crust	Upper Smectites	Middle Smectites	Lower Smectites	Fine-Grained Smectite Mixed with Pelagic Ooze	Al- Smectites	Lower Pelagic Ooze	Upper Oxide Layer of Pelagic Ooze	Mound Slope Pelagic Ooze	Off-Mound Pelagic Ooze
						Sub-bottom Dep	oth (m)				
Component	0-0.2	1.2	1.25	1.9-5.2	12.8-19.1	20.0	15.3	38.2	0.0-0.7	2.5-23.6	2.1-31.1
Major element oxid	des (%)										
SiO ₂	26.89	2.50	48.95	52.60	53.18	48.81	57.30	50.2	53.93	54.04	59.86
TiO2	0.21	0.07	0.05	0.08	0.08	0.34	0.41	0.64	0.39	0.49	0.64
Al2Õ2	3.90	0.51	0.85	0.53	0.36	5.16	10.68	9.0	7.53	9.05	10.26
FeoOa	7.50	4 1	35.52	34.94	32.15	23.91	13.14	14.6	6.66	11.32	4.84
FeO	_		0.42	0.33	0.88	2.77		3.25	_	1.89	2.78
MnO	51 15a	48 76 ^a	0.515	0.059	0.045	0.43	0.138	1.22	8.80	0.80	0.70
MgO	2 75	0.95	3.09	3.61	4 44	5.32	3.24	4.70	2.65	5.56	3.18
NapO	2.00	4 26	1 32	1.82	1.32	0.68	2.20	1.74	1.93	1.51	1.40
KaO	1.03	0.37	1.36	1 53	2 77	1 31	2.61	1.97	1.00	1.30	1.45
P2O5	0.26	0.22	0.10	0.066	0.068	0.27	0.112	0.38	0.38	0.32	0.30
Minor elements (p	pm)										
Li	10		10	6	6	20	40	-	21	33	32
Rb	8	6	25	42	62	47	90	_	29	42	42
Cs	14	11.40		1.3	1.8		3.4	7.50	6.60		4.0
Cr	32	40	31	10	20	55	37	162	45	100	46
Co	28	10.5	3.60	0.7	0.60	12.30	12	28	33	26	25
Ni	759	51	10	4.8	6.20	57	76	122	-	306	280
Cu	199	44	36	19	9.50	131	153	296	_	198	253
Sb	17	12	1.2	0.7	1.20	1.60	1.8	2.9	3.0	2.1	5.4
Zn	482	50	92	29	23	255	390	354	678	795	498
Sc	5.80	1.70	2.80	0.6	5.0	12.30	12.0	18	14.50	16	18
La	13.40	5.40	5.80	1.27	0.74	37.80	20.4	83.9	30.40	47.3	40.50
Ce	14.60	4 60	5.60		1.47	25	33.50	58.30	18.90	30.5	38.60
Sm	2 45	0.74	0.98	0.93	0.17	6 50	4.18	9.52	4.80	5.2	5.30
Eu	0.49	0.27	0.44	0.21	0.11	1.70	0.963	2.14	1.30	0.32	1.71
Tb	0.52	0.21	_	0.19	_	_	0.639	2.04	1.18		
Yh	2.06	0.56	0.95	0.45	0.21	3.48	1.93	6.46	3.83	4.83	4.13
Lu	0.38	0.10	0.17	0.07	0.06	0.50	0.356	1.01	0.63	0.30	0.70
No. of samples	2	1	1	3	2	1	1	1	1	3	4

^a Mn as MnO₂.

North American shale normalized REE distributions in hydrothermal products. The lowest concentrations of REE are characteristic of both vein smectites from basaltic basement and some samples of Galapagos mound smectites. REE patterns of this product are shown in Figure 16 (no. 1 and 3) and are assumed to be attributable to the hydrothermal source which produces these minerals. The same relationships are typical for some oceanic and ophiolitic formations (Fig. 16, no. 2, 4). These formations do not have any REE additions from the depositional environment. In contrast, the interaction of hydrothermally derived formations during their deposition with the surrounding environments tends to change initial REE distribution. For example, much of Galapagos hydrothermal smectites as well as lower manganese crusts have distinct cerium depletion and slight increases in REE concentrations (Fig. 16, no. 5-7). In the upper crusts of the Galapagos mounds, REE concentrations are further increased and the pattern of their distribution demonstrates a further similarity with seawater (Fig. 16, no. 9). The same concentrations and patterns in REE (Fig. 16, no. 8) were observed in the hydro-

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thermal pyrite that was oxidized by seawater near the Mid-Atlantic Ridge (Bonatti, Honnorez-Guerstein et al., 1976).

The maximum REE content and the typical seawater distribution pattern are reported from the East Pacific Rise metalliferous sediments and Cyprus ochres and umbers (Piper and Graef, 1974; Piper, 1974; Robertson and Fleet, 1976), which are supposed to be precipitated directly from open seawater (Fig. 16, no. 10, 11).

It appears that hydrothermally derived sediments from active ocean zones are close to ophiolitic zones in REE distribution. It is also suggested that the interaction of hydrothermal solutions with the surrounding environments (e.g., seawater, pore water, sediments) leads to the increase in REE concentration in the resulting products and to changes in the initial REE distribution patterns.

This comparison also suggests that both replacement of sediments and minor scale infilling of voids without significant interaction with the sediments has taken place during the formation of smectite in the Galapagos mounds.

38 ar 1

Table 8.	Average composition of hydrothermal and pelagic sediments (carbonate-free basis) in mounds and off-mounds sedimentary se	ections, Site
509.		

			Hole 509									
Lithology	Upper Mn Crust	Lower Mn Crust	Fe-Mn Oxide Sediment	Upper Smectites	Middle Smectites	Lower Smectites	Fine- Grain Mixed Smectites	Al- Smectites	Pelagic Ooze in Hydrothermal Unit	Lower Pelagic Ooze	Oxidized Pelagic Ooze	Off-Mound Pelagic Ooze
						Sub-b	ottom Dept	h (m)				
Component	0-1.20	1.20-2.70	6.16	2.7-5.6	8.2-11.8	12.2-20.0	18.1	9.2	5.8-18.1	23.0-33.0	0.09	5.9-29
Major element oxi	des (%)											
SiO ₂	14.40	1.55	23.65	51.35	52.78	52,68	49.75	53.45	57.67	52.74	55.84	57.28
TiO2	0.21	0.08	0.08	0.16	0.08	0.12	0.16	0.42	0.49	0.70	0.42	0.69
AlaOa	3.12	0.71	0.82	2.21	0.57	1.28	2 27	7.68	9.29	11.43	7.00	10.28
FeoOa	3.71	0.50	17.76	29.68	31 40	29 34	24 41	19.66	9.68	6.97	7.26	5.39
FeO	_	_			0.85	1 19	1 39	0.85	1.22	3.03	1.16	2.71
MnO	55.37a	78 34a	35 00 ^a	0.72	0.30	0.106	4 754	0.212	3.69	1.86	11.93	1.62
MgO	3.08	3.42	3.56	3.90	3.95	4 72	5 41	4 64	3 69	5.09	3.05	3.46
NanO	1.97	1 48	1 29	1 41	1.02	0.82	0.81	1.10	1.69	1.43	1.24	1.52
KaÓ	0.66	1 14	1 11	1.76	3 18	3 40	3 46	1.94	1.84	1.76	0.94	1.27
P2O5	0.192	0.118	0.187	0.094	0.056	0.049	0.088	0.125	0.23	0.446	0.41	0.42
Minor elements (p)	om)											
T i	R 1	~2	0	10	4	10	10	26	20	21.7	27	36
Rh	10	7	10	36	64	81	115	50	42	57.5	38	45
Cs	77		10	50	04	01	115	50	3 3	01.0	7.6	5.0
Cr	16	70	40	25	20	25	15	48	36	98	79	64
Co	23.8	14	156	23	20	-37	22.6	40 6 A	28.0	109	48	28
Ni	198	60	840	0.8	9 5	~17	03.6	50	206	336	526	377
Cu	143	27	321	50	19.5	15 6	110	126	256	277	346	382
Sh	14.8	0	25.2	0.5	10	0.85	2.0	1.0	4.2	1.8	62	4.6
Zn	211	37	600	56	22	52	2.9	217	480	610	671	482
Sc	8 2	16	6.2	1.0	60	12	240	11	13.2	21.4	13.6	19.6
La	12.6	5.3	5.0	0.5	0.0	4.2	5.0	10.5	13.2	50.0	36	34.3
Ca	12.5	4.00	4.52	0.5		4.0	10.5	7.9	41.1	44.8	28 4	30.4
Sm	2.11	4.99	4.52	0.04		1.29	1.60	2.01	8 40	11.8	6.2	6.2
En	0.64	0.107	0.85	0.14		1.20	1.00	0.655	2.08	2 11	1.29	1.54
Th	0.59	0.107		0.033	1.00	_		0.055	1.50	1.87	0.88	1.57
Vb	1 00	0.141	0.61	0.00		0.74	1.42	1 20	4.88	7 45	3 90	5 35
Lu	0.20	0.003	0.01	0.133		0.14	1.42	0.329	1.00	0.66	0.62	1.02
No of samples	5	1	1	2	2	0.135	2	1	1.09	3	2	6
rto. or samples	5	2.11.5	1	2	2	4	2	1		3	2	0

^a Mn as MnO₂.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Drs. P. Borella, J. Honnorez, Yu. Balashov, and G. Zakariadze for discussions and critical reviews. We also express our appreciation to Rosemary Amidei and Drs. P. Borella and A. Sharaskin for their invaluable assistance in improving the English version of this manuscript.

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Table	9.	Average	composition	of	pelagic
sec	lim	ents from	low heat-flow	are	eas (car-
bo	nat	e-free bas	is).		

	Hole 508	Hole 510				
	Sub-bottom Depth					
Component	0.4-32.5	41.5-113.8				
Major element oxid	des (%)					
SiO ₂	59.45	71.56				
TiO ₂	0.53	0.35				
Al2O3	9.56	6.25				
Fe2O3	5.50	2.21				
FeO	1.69	1.75				
MnO	1.086	0.511				
MgO	4.69	2.34				
Na ₂ O	1.63	1.08				
K2Ô	1.18	0.88				
P205	0.39	0.32				
Minor elements (pr	om)					
Li	26.5	37.2				
Rb	23.4	32.3				
Cs	4.5	2.9				
Cr	47	42				
Co	23.8	19.5				
Ni	285	223				
Cu	212	224				
Sb	3.7	2.0				
Zn	452	337				
Sc	15.5	12.7				
La	31.8	33.8				
Ce	28.1	23.3				
Sm	3.81	6.57				
Eu	0.950	1.546				
Tb	0.781	1.437				
Yb	3.560	3.957				
Lu	0.744	0.649				
No. of samples	10	4				



Figure 1. Distribution of Mn, Fe2O3, Ni, Cu, Zn, and Sb, recalculated on carbonate-free basis, Holes 507D, 507F, and 509B.

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Figure 2. FeO/Fe₂O₃ ratio in smectites plotted against sub-bottom depth in mounds sections. (Circles with dots = Hole 509B; double circles = Hole 507D.)



Figure 3. FeO/Fe₂O₃ ratio in pelagic oozes in Holes 509B, 509, and 508 plotted against sub-bottom depth. (Open squares = Hole 509; open circles = Hole 508; solid circles = Hole 509B.) (Data for the deepest samples from Hole 508, in and near the lithified layer, were removed.)



Figure 4. K_2O concentration in smectites plotted against sub-bottom depth in mounds sections. (Open circles = Hole 509B; solid circles = Hole 507D.)



Figure 5. X-ray diffractograms of <0.001-mm fractions of hydrothermal green clays from Holes 507D and 509B. (Sample numbers in Tables 1, 3 and text; a = air-dried samples; b = ethylene-glycol saturated samples.)



Figure 6. Content of smectite layers in analyzed mixed-layered micasmectite minerals. (Relationships between the $d(\text{\AA})$ of basal mica (001) and secondary smectite (002) reflections and the content of smectite layers are given by Gradusov, 1971.)



Figure 7. Variation in content of siliceous microfossils in Holes 507D, 507F, and 508 on the basis of smear-slide data. (See site summaries, this volume.)



Figure 8. Element-to-alumina ratios in Mn crusts of mounds and in uppermost oxidized layers of pelagic oozes, normalized to ratios in average low heat-flow area sediments, Hole 508. (1 = lower Mn crusts; 2 = Fe-Mn oxide sediment; 3 = upper Mn crusts; 4 = uppermost oxidized layers of high heat-flow area pelagic oozes (offmounds sediments); 5 = uppermost oxidized layers of low heatflow area pelagic oozes.)



Figure 9. Element-to-alumina ratios in mounds smectites and pelagic oozes, normalized to ratios in average low heat-flow sediments, Hole 508. (1 = lower smectites; 2 = middle smectites; 3 = upper smectites (some contamination by Mn crusts may take place); 4 = lower pelagic sediments in mound sections; 5 = pelagic oozes alternating with smectite in mounds sections; 6 = Al-rich smectite.)

Hole	507A	509B	507A	509B	507A	509B	507D	509B	509B	507D	509B	507C, H	509	508
Lithology	U	pper	Lo Sm	ower ectites	Mi Sme	xed ctites	Al	-Rich ectites	Pelagic Ooze from Hydrothermal Unit	Mo Lo Pel O	ound wer agic oze	Off-M Pela Oc	found agic oze	Low Heat-Flow Area Sediment
Major elemen	t oxides (mg/cm ³)												
SiO ₂	455	477	827	490	83.0	245	96.8	187	120	46.7	55.2	110	88.8	112
TiO2	0.46	1.5	1.24	1.1	0.58	0.80	0.69	1 47	1.03	0.59	0.76	1.17	1.07	1.00
AlpÓa	7.91	20.6	5.6	11.9	8.79	11.2	18.05	26.9	19.3	84	12.0	18.9	15.9	18.0
Fe2O2	330	276	500	273	40.6	120	22.2	68.8	20.1	13.6	73	9.0	84	10.3
FeO	3.9	_	13.7	11.1	4.7	10.1		3.0	2.5	3.0	3.2	5.1	4 2	3.2
MnO	4.8	6.7	0.70	0.99	0.73	23.6	0.23	0.74	77	1.1	19	13	2.5	2.0
MgO	28.7	36.3	69.0	39.2	9.1	26.6	5.5	16.2	77	A A	5 3	5.8	5.4	8.8
NapO	12.3	13.1	20.5	7.6	1.2	4.0	37	3.0	3.5	1.6	1.5	2.6	24	3.1
KaO	12.6	16.4	43 1	31.6	2.2	17.0	4.4	6.8	3.8	1.8	1.8	2.0	2.0	2.2
P2O5	0.93	0.87	1.1	0.46	0.45	0.44	0.19	0.44	0.48	0.36	0.49	0.55	0.65	0.73
Minor elemen	ts (10 ⁻⁴	% mg/cm	³)											
Li	93	93	93	93	33	94	68	91	63	41	33	58	56	50
Rb	232	335	964	753	80	566	152	175	88	49	61	76	70	44
Cs		_	28	100	00	500	57	175	7	7	01	7	8	-
Sr	967	1469	560	1609	4778	3842	456	4092	9714	8278	6799	,	7903	
Cr	288	233	311	233	03	73	63	168	76	151	103	85	99	88
Co	33		9	< 34	21	116	20	22	44	27	113	46	43	45
Ni	93	91	96	<158	08	4606	178	175	454	113	352	516	584	536
Cu	335	465	148	331	222	587	250	441	400	275	290	466	592	300
Sh	11.2	4.6	18 7	7 9	27	14.5	200	2 5	400	213	1.8	0.0	71	7.0
Zn	856	521	358	484	135	1218	650	760	000	320	637	015	747	850
Sc	26	9	78	30	435	1210	20	20	299	17	22	22	30	20
La	53.0	47	11.5	42.0	64.7	50.8	24 5	36.0	20	70 1	67.6	74.6	52.2	50.9
Ce	52.1	7.9	22.0	61 4	42.6	50.8	54.5	30.0	91.0	54.2	47.0	71.1	47.1	52.0
Sm	0.1	1.0	26	11.0	42.0	8.0	50.0	21.3	85.5	54.5	47.0	0.7	47.1	52.0
En	4.00	0.21	1.71	11.9	2.84	8.0	1.1	9.8	17.5	0.9	12.4	2.15	9.0	1.2
Th	4.09	0.51	1./1	1000	2.84		1.03	2.30	0.0	1.99	2.21	5.15	2.40	1.0
Vh	8 84	1.25	2.27	6.00	5.00	7.0	1.08	1.93	4.59	1.90	7.0	7.60	2.40	6.7
In	0.04	1.23	0.02	0.90	5.90	7.0	3.20	4.80	10.10	0.01	1.0	1.00	0.50	0.7
Lu	1.38	_	0.93	1.20	0.84		0.60	0.83	2.30	0.94		1.28	1.60	1.4

Table 10. Average absolute masses of elements in mounds, off-mounds, and low heat-flow area sediments.



Figure 10. Ni vs. Mn correlation in hydrothermal and pelagic sediments of mounds areas. (Open circles = off-mounds and crossed circles = mounds pelagic sediments; large open circles = Mn crusts and Fe-Mn oxide sediment; solid circles = Fe-rich smectites.)



Figure 11. Sb vs. Ni correlation in hydrothermal and pelagic sediments (symbols as in Fig. 11).



Figure 12. Zn vs. Fe correlation in manganese crusts and in Fe-Mn oxide sediment. (Open circles = Hole 507D; solid circles = Hole 509B.)



Figure 13. Rb vs. K₂O content in hydrothermal and pelagic sediments (symbols as in Fig. 11).



Figure 14. Distribution of rare earth elements in hydrothermal sediments, Hole 507D, normalized on North American shale (NAS) distribution.



Figure 15. Distribution of rare earth elements in hydrothermal sediments, Hole 509B, normalized on North American shale (NAS) distribution.



Figure 16. NAS-normalized distribution of rare earth elements in hydrothermally derived products from ocean spreading zone and continental ophiolite sediments. (1 = smectites with low rare-earth element concentrations from Galapagos hydrothermal mounds (average of three samples); 2 = Fe-rich hydrothermally derived product from northeast Pacific [Piper et al., 1975]; 3 = vein smectites from Hole 504B basalts, Costa Rica Rift (Sharaskin et al., in press); 4 = Mn-enriched sediments, Malinelo deposit, Italy [Bonatti, Zerbi, et al., 1976]; 5 = Fe-Mn oxide sediment from Galapagos mounds; 6 = lower Mn crusts of Galapagos mounds; 7 = Fe-rich smectites of Galapagos mounds; 8 = oxidized hydrothermal pyrite concretions from Romanch deep (Bonatti, Honnorez-Guerstein, et al., 1976); 9 = upper manganese crusts of Galapagos mounds; 10 = metalliferous sediments from the East Pacific Rise [Piper and Graef, 1974]; 11 = metalliferous sediments of Troodos massif, Cyprus [Robertson and Fleet, 1976].)



Figure 17. Zn vs. FeO content in mounds smectites carbonate-free basis. (Open circles = Hole 509B; triangles = Hole 507D.)