21. PRELIMINARY GEOCHEMICAL STUDIES OF THE SEDIMENTS FROM DSDP LEG 26, SOUTHERN INDIAN OCEAN

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ABSTRACT

The sediments collected on Leg 26 of the Deep Sea Drilling Project provide a varying suite of lithologies for a geochemical study. Preliminary analyses, by carbon-arc-emission spectrography, of 91 samples from the nine sites show that the overall geochemistry of the sediments is broadly the same as that of the ocean-bottom sediments of today, though the average manganese, strontium, barium, and molybdenum values are distinctly lower (for the lithogenous sediments 0.21%, 58 ppm, 414 ppm, and 7 ppm, respectively, compared with average values for ocean bottom sediments of today of 0.37%, 180 ppm, 2300 ppm, and 27 ppm). Variations in the elemental concentrations within the lithological units are present. Concentrations of the rare-earth elements are consistent with the suggestion that the Ninetyeast Ridge may be the surface expression of a former mantle plume. The rare-earth data for a sample from the Naturaliste Plateau, from the bottom of Hole 258, were found to follow the same trend as those for the Ninetyeast Ridge samples.

INTRODUCTION

There is little published work on the inorganic geochemistry of sediments collected by the Deep Sea Drilling Project. Analyses are presented in Lisitzen et al. (1971), Bostrom et al. (1972), and Donnelly and Nalli (1973), and standard laboratory reports of silicon, oxygen, aluminum, iron, and magnesium determinations by neutron activation analysis appear in early volumes of the Initial Reports. The basal ferruginous sediments of the eastern Pacific have been studied in detail (e.g., von der Borch et al., 1971; Cronan et al., 1972; Cronan, 1973; and Cronan and Garrett, 1973).

The calcareous and lithogenous sediments collected on Leg 26 of the DSDP, along with samples of an atypical volcanic ash sequence deposited in a shallow-water environment, provide a varying suite of sediments for a geochemical study which may be expected to show elemental variations at a site not only between differing lithologies but also with variation in depth in a particular lithology. They also provide data for geochemical comparison of buried sediments with those found on the ocean bottom today.

As a first step in such a study a survey using analyses of some of the collected samples obtained by carbon-arc-emission spectrography was carried out, and the results are reported here. Certain samples were also analyzed for the rare-earth elements by neutron activation analysis. The purpose of this was twofold. First, to ascertain whether some basal sediments, thought to be derived from basalt, contained, as whole sediments, the rare-earth elements in concentrations similar to those found in ocean basalts; the probable origins of clay fractions from the central Atlantic have been indicated by such means (Copeland et al., 1971). Secondly, it was hoped to identify the geochemical affinities of the ash sequence at Site 253 and of the basalts from which any of the sediment samples might prove to have been derived.

Further work is being carried out using atomic-absorption spectrophotometry and neutron-activation analysis on these and other samples. Determinations of the H_2O+ and carbonate contents of the samples will also be undertaken.

GENERAL PREPARATION OF SAMPLES

Prior to preparation for specific analytical techniques, the samples were dried in an oven at 105°-110°C for sufficient time to enable them to be ground in an agate pestle and mortar to less than 195μ. The ground samples were stored in polyethylene tubes until required.

CARBON-ARC-EMISSION SPECTROGRAPHY

Method

Ninety-one samples representing the sediments cored at the nine sites of Leg 26 were analyzed by carbon-arc-emission spectrography. First, they were chosen to be representative of the major lithological units, and second, to sample each hole at approximately uniform intervals. No consideration has been given to the ages of the samples at this stage, but these will be taken into account in future work

Direct-reading spectrography was used to analyze the samples. This was carried out using a quantitative system which must nevertheless be regarded as semi-

quantitative for the purpose of the present study. It is calibrated using argillaceous and siliceous standards. Computerized conversion of the results obtained by the spectrograph to elemental concentrations is based on controlling factors which relate to argillaceous and siliceous sediments. When a sample contains more than about 15% calcium, the conversion program does not allow sufficiently for the matrix and other effects, often causing the recorded concentrations, notably of silicon and aluminum, to be well below those which are considered to be within the useful working range for the element. Such samples are shown by an asterisk in Table 1. The results that are given for the calcium-rich samples will be affected by the unsuitability of the conversion factors of the computer program, but are given here for comparison at a particular site. Analysis of these sediments by other methods is planned, including analysis for sodium which is not determined by this method.

Results and Discussion

Table 1 shows the elemental contents of each sample, the average elemental contents of a particular lithology at a site, the average elemental contents of a particular lithology at all sites, and some published values for comparison. The values given for trace element concentrations have been rounded off to a whole number, except where the values obtained are less than 0.5 ppm and within the working range, when they have been rounded up to 0.5 ppm. Because of the analytical problems mentioned above, a rigorous examination of the results cannot be undertaken until the further analytical work using other methods is completed. However, the main geochemical features of the sediments are described below Site by Site, in most instances under three headings:

1) Major elements
2) Trace elements
3) Enriched trace elements, i.e., those trace elements in which the sediments, at a particular site, are enriched relative to near-shore sediments and igneous rocks. The measured values are compared with collected published data for pelagic sediments (Chester, 1965; Riley and Chester, 1971).

Site 250

1. Major elements: the titanium, aluminum, calcium, and magnesium contents of the detrital clay, the lower lithological unit, and all the manganese values, except at a depth of about 700 meters, are low compared with lithogenous pelagic sediments. The iron concentration decreases with depth, but has a relatively high value (6.9%) in the sample adjacent to the basalt.

2. Trace elements: the concentrations of beryllium, scandium, vanadium, chromium, gallium, silver, cadmium, tin, and lead do not vary significantly and are similar to published data. The strontium, barium, and zinc values vary, with zinc concentrated more in the upper lithologic unit; the average values of these elements and those of molybdenum are low compared to other deep-sea clays.

3. Enriched trace elements: cobalt, nickel, and copper, whose concentrations are greatest in the highest samples from each lithological unit, have relatively high values at about 700 meters, as does manganese.

Site 251

1. Major elements: all the sediments from this site are calcareous and contain over 15% calcium; therefore, the analyses are considered unreliable for the reasons explained above. Titanium, iron, and manganese are relatively enriched in the basal sample, probably as a result of the presence of metasomatic garnets in the basal micarb chalk, described elsewhere (Kempe and Easton, this volume, Chapter 25).

2. Trace elements: the lead and barium concentrations in the basal sample, relative to the other samples, are respectively enriched and depleted. The copper values are the only others to vary significantly.

Site 252

1. Major elements: the average aluminum (4.5%) and manganese (0.08%) contents are low compared to noncalcareous pelagic sediments (Al, 9.3%, Mn, 0.38%). The uppermost sample contains a high percentage of iron.

2. Trace elements: the lithium, beryllium, strontium, barium, scandium, vanadium, chromium, gallium, silver, cadmium, and tin contents of the samples are all consistent with the lithologic nature of the sediments, but the average value for molybdenum (3 ppm) is low compared with the published value (27 ppm).

3. Enriched trace elements: cobalt, nickel, copper, zinc, and lead, all of which, except zinc which is more highly enriched, are present in concentrations similar to those found in Atlantic deep-sea clays.

Site 253

The uppermost lithologic unit consists of nannoplankton oozes and chalks. The high calcium contents of the samples from this unit affect the analyses which include apparently consistently low manganese and titanium values. The lower unit is a sequence of altered vitric volcanic ash, the geochemistry of which is consistent with an igneous provenance and admixture of fossil fragments and is dealt with elsewhere (McKelvey and Fleet, this volume, Chapter 22).

Site 254

1. Major elements: as at Site 253, calcareous oozes make up the upper lithological unit and show low concentrations of manganese and titanium. Beneath these occur sediments which are considered to be volcaniclastic and of basaltic provenance. The presence of macrofossils causes low silicon and aluminum and high calcium concentrations in two of the upper three samples of this unit. The titanium and iron contents are consistently high, in the latter case increasing with depth, but the manganese values are very low, being highest in the sample adjacent to the basalt.

2. Trace elements: the average barium (30 ppm), molybdenum (2 ppm), and lead (1 ppm) concentrations

TABLE 1
Composition of DSDP Leg 26 Sediments Obtained by Direct-Reading Spectography[a]

Lithology	Core-Section, Interval in cm	Depth Below Sea Floor (m)	Si (%)	Ti (%)	Al (%)	Fe (%)	Mn (%)	Ca (%)	Mg (%)	K (%)	Li (ppm)	Be (ppm)	Sr (ppm)	Ba (ppm)	Sc (ppm)	V (ppm)	Cr (ppm)	Co (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Ga (ppm)	Mo (ppm)	Ag (ppm)	Cd (ppm)	Sn (ppm)	Pb (ppm)	Stratigraphic Age
	Hole 250A																											
Nanno ooze and Detrital Silty Clay	1-3, 23-25	58	18.5	0.21	6.1	7.8	0.11	0.3	1.3	3.2	78	3	66	487	16	98	101	170	530	132	159	22	9	–	1	12	41	Quaternary
	5-6, 28-30	157	25.2	0.24	6.7	6.2	0.05	0.2	1.4	2.6	68	4	31	247	10	153	146	77	101	276	149	17	3	–	–	9	34	U. Pliocene
	8-4, 8-9	297	23.3	0.29	8.0	5.5	0.08	0.4	1.6	2.7	70	3	72	376	24	108	120	49	88	83	149	21	3	–	1	14	33	U. Miocene
	11-6, 119-121	472	18.3	0.22	6.4	5.2	0.03	0.2	1.2	2.0	46	3	28	167	10	81	98	25	42	49	97	15	2	–	–	–	11	M. Miocene
	Average		21.3	0.24	6.8	6.2	0.07	0.3	1.4	2.6	66	3	49	319	15	110	116	80	190	135	138	19	4	–	<1	<9	30	
Detrital Clay	16-3, 102-104	638	25.4	0.36	5.5	4.7	0.04	0.3	1.6	2.9	53	2	45	141	18	135	129	210	297	112	61	19	–	–	–	12	25	L. Miocene
	18-2, 20-22	655	25.5	0.29	5.9	4.3	0.10	0.2	1.6	3.1	46	3	44	121	16	112	137	41	83	78	130	20	1	–	–	13	28	L. Miocene
	20-2, 80-82	674	19.6	0.26	4.3	4.4	0.04	0.2	1.4	3.2	29	3	30	83	16	107	125	28	52	52	67	15	1	–	–	9	9	?
	22-4, 75-77	696	23.9	0.11	1.4	3.3	0.52	0.1	1.2	1.3	19	2	66	+	6	102	45	80	70	101	10	7	1	–	–	5	87	Coniacian
	23-2, 73-75	703	26.1	0.14	3.0	3.1	0.52	0.2	1.3	2.0	5	2	144	+	9	132	60	111	74	220	54	13	6	–	–	18	215	Coniacian
	25-1, 50-52	720	27.9	0.24	4.6	6.9	0.04	0.2	2.2	3.2	63	3	28	52	16	94	110	41	78	131	124	22	–	–	–	17	29	?
	Average		24.2	0.23	4.1	4.5	0.21	0.2	1.6	2.6	36	3	60	>400	13	114	101	73	109	116	74	16	<1	–	–	12	65	
	Hole 251																											
	2-1, 40-42	2*	–	0.05	–	0.6	0.03	+	0.4	0.2	16	–	+	564	–	–	–	–	6	39	–	2	2	1	–	19	–	Quaternary
	7-6, 46-48	58*	–	0.06	–	1.1	0.02	+	0.6	0.4	21	–	+	503	–	–	6	4	14	38	–	3	3	1	–	22	–	U. Pliocene
	Hole 251A																											
Nanno ooze and Chalk	5-6, 19-21	124*	–	0.07	–	0.9	0.02	+	0.7	0.5	69	–	+	373	–	–	11	3	10	35	–	4	6	1	–	12	6	L. Pliocene
	10-6, 24-26	171*	–	0.04	–	0.7	0.04	+	0.6	0.4	35	–	+	324	–	–	5	23	39	105	–	2	3	–	–	19	5	U. Miocene
	13-5, 60-62	256*	–	0.07	–	1.0	0.06	+	0.7	0.5	18	–	+	469	–	–	9	–	15	50	–	4	2	1	–	38	10	U. Miocene
	16-6, 140-142	343*	–	0.04	–	0.6	0.02	24.4	0.4	0.3	37	–	+	340	–	–	6	–	5	27	–	–	3	1	–	6	-	M. Miocene
	20-6, 130-132	400*	–	0.08	–	1.6	0.03	+	0.9	0.7	52	–	+	538	–	–	19	11	22	62	15	5	5	1	–	13	8	M. Miocene
	26-4, 142-144	454*	–	0.07	–	1.3	0.02	24.8	0.8	0.6	31	–	+	476	–	–	16	6	16	28	–	3	2	1	–	3	–	L. Miocene
	27-2, 8-10	460*	–	0.07	–	1.7	0.05	22.6	1.2	1.4	43	–	+	769	–	–	27	14	34	40	–	6	2	–	–	23	10	L. Miocene
	29-2, 130-132	480*	–	0.11	–	3.0	0.07	+	0.9	0.2	30	–	+	54	–	–	19	2	24	33	–	7	5	1	–	25	48	L. Miocene
	Average		–	0.07	–	12.5	0.04	+	0.7	0.5	35	–	+	441	–	–	<12	<7	19	46	–	<3	3	<0.5	–	18	<7	
	Site 252																											
Radiolarian Clay	2-6, 147-149	9	28.6	0.40	4.2	7.0	0.06	1.3	2.0	1.6	34	3	110	+	13	109	75	97	85	163	212	18	5	–	–	13	40	Quaternary
	5-3, 120-122	150	17.5	0.56	4.9	3.2	0.07	1.3	1.5	2.3	33	–	307	+	21	127	89	59	60	73	82	14	3	–	–	23	45	U. Miocene
	7-2, 13-15	239	29.8	0.53	4.4	4.5	0.10	1.6	1.6	1.6	20	1	208	1000	16	116	77	73	81	185	135	15	2	–	–	18	38	U. Miocene
	Average		25.3	0.50	4.5	4.9	0.08	1.4	1.7	1.8	29	<1	208	+	17	118	80	76	76	140	143	16	3	–	–	18	41	
	Site 253																											
Nanno ooze and Chalk	1-6, 145-147	9*	–	0.02	–	0.6	0.01	+	0.3	0.2	9	–	+	345	–	–	–	–	8	36	–	–	–	1	–	29	–	Quaternary
	5-6, 29-31	45*	–	0.02	–	0.6	0.02	+	0.3	0.2	15	–	+	325	–	–	–	–	7	32	11	–	–	2	–	28	–	Miocene
	13-6, 80-82	122*	–	0.03	–	0.6	0.02	+	0.2	0.2	8	–	+	203	–	–	–	–	5	27	–	–	1	1	–	26	–	U. Eocene
	16-6, 127-129	151*	–	0.06	–	0.7	0.02	+	0.1	0.2	3	–	+	13	–	–	–	–	7	27	–	–	2	–	–	25	3	M. Eocene
	Average		–	0.03	–	0.6	0.02	+	0.3	0.2	9	–	+	221	–	–	–	–	7	31	–	–	<1	<1	–	27	–	

TABLE 1 – *Continued*

Lithology	Core-Section, Interval in cm	Depth Below Sea Floor (m)	Si (%)	Ti (%)	Al (%)	Fe (%)	Mn (%)	Ca (%)	Mg (%)	K (%)	Li (ppm)	Be (ppm)	Sr (ppm)	Ba (ppm)	Sc (ppm)	V (ppm)	Cr (ppm)	Co (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Ga (ppm)	Mo (ppm)	Ag (ppm)	Cd (ppm)	Sn (ppm)	Pb (ppm)	Stratigraphic Age
Altered	17-2, 60-62	153	15.4	0.61	1.4	4.8	0.53	0.8	1.6	2.1	47	–	78	189	8	103	23	50	24	38	64	10	2	–	–	15	–	M. Eocene
Vitric	19-2, 9-11	172	2.4	0.24	–	4.4	0.11	10.9	1.7	1.9	35	–	213	153	4	61	66	18	31	40	43	7	1	–	–	18	11	M. Eocene
Volcanic	20-2, 90-92	182	–	0.12	–	3.8	0.05	13.5	1.6	0.7	53	–	349	85	–	24	16	17	22	38	–	5	–	–	–	18	–	M. Eocene
Ash	21-2, 58-60	192	18.2	0.02	1.5	3.5	0.02	0.3	2.5	0.9	83	2	33	9	–	–	–	2	–	6	24	6	–	–	–	5	–	M. Eocene
	21-4, 112-114	195	18.4	0.50	2.7	3.4	0.06	2.8	2.5	1.9	119	–	87	11	9	110	28	42	16	73	52	14	–	–	–	17	–	M. Eocene
	23-2, 86-88	211	14.4	0.13	3.1	3.4	0.10	5.7	2.5	1.7	35	2	68	22	9	125	179	30	77	64	57	7	–	–	–	9	–	M. Eocene
	26-2, 23-25	239	25.5	0.37	4.3	3.9	0.06	1.0	3.0	1.9	96	3	40	18	17	281	136	71	77	141	127	20	–	–	–	22	15	M. Eocene
	28-2, 18-19	252	5.4	0.10	–	1.3	0.18	3.4	1.7	1.1	45	1	22	9	–	109	67	20	26	79	13	7	–	–	–	–	–	M. Eocene
	30-1, 120-122	271	4.9	0.12	–	8.5	0.06	13.5	2.0	2.5	41	–	774	27	–	33	39	12	23	30	56	9	–	–	–	31	10	M. Eocene
	36-1, 93-95	327	24.6	0.09	3.0	2.0	0.01	0.6	2.5	1.3	23	–	461	+	–	–	10	62	5	35	–	–	1	–	–	3	–	M. Eocene
	41-1, 100-102	375	19.3	1.17	3.2	7.3	0.10	2.2	2.2	2.3	28	–	+	+	–	–	10	33	10	37	–	4	3	1	–	14	–	M. Eocene
	44-2, 80-82	405	4.3	0.14	0.2	3.1	0.02	3.2	1.6	1.3	11	1	31	6	4	75	45	24	22	38	18	4	–	–	–	–	–	M. Eocene
	45-2, 110-113	415	16.7	0.49	1.7	8.3	0.05	2.4	2.6	1.4	49	1	+	190	–	–	14	–	10	33	–	5	4	2	–	30	8	M. Eocene
	46-5, 110-112	429	10.3	0.31	1.4	3.8	0.06	2.7	2.2	2.7	54	7	29	292	19	197	37	68	91	29	51	14	2	1	–	4	24	M. Eocene
	48-2, 91-94	443	16.2	0.18	2.2	2.4	0.07	1.1	2.6	1.9	32	1	44	156	10	93	77	18	20	20	51	10	1	–	–	15	52	M. Eocene
	52-2, 50-52	481	15.5	0.34	3.7	4.4	0.07	4.0	2.7	1.7	4	1	512	53	15	130	89	35	33	63	90	9	–	–	–	15	–	M. Eocene
	53-2, 137-140	491	16.0	0.10	2.5	6.6	0.11	2.1	2.4	0.3	–	2	8	9	10	91	91	35	58	78	114	6	–	–	–	–	–	M. Eocene
	54-5, 115-117	505	17.0	0.14	–	1.2	0.03	1.7	1.1	0.9	17	1	46	22	3	85	22	21	12	44	–	2	–	–	–	–	–	M. Eocene
	56-2, 50-52	519	18.0	0.14	3.4	2.5	0.05	0.8	2.9	0.9	16	3	26	16	13	212	209	57	99	110	25	11	–	7	–	11	2	M. Eocene
	57-2, 85-88	547	12.4	0.78	2.7	2.2	0.10	4.6	2.8	2.3	9	–	69	36	16	154	36	29	23	87	90	14	–	–	–	23	5	M. Eocene
	Average		<14.0	0.30	<2.1	4.0	0.09	3.9	2.2	1.6	<40	<1	>244	>165	<8	<95	<60	<32	<34	54	<46	<8	–	–	–	<13	–	
	Site 254																											
Foram	1-3, 110-112	4*	–	0.02	–	0.6	0.01	+	0.4	0.2	17	–	+	86	–	–	–	–	7	28	–	–	1	–	–	27	–	Quaternary
Namo ooze,	7-6, 50-52	61*	–	0.02	–	0.7	0.01	+	0.4	0.2	–	–	+	164	–	–	–	–	7	34	22	–	–	1	–	44	2	M. Miocene
Calcite ooze,	18-5, 94-96	155*	–	0.07	–	0.6	0.01	+	0.5	0.3	27	–	+	77	–	–	–	–	4	24	–	–	3	0.5	–	18	–	L. Miocene
and	20-6, 130-133	176*	–	0.07	–	0.9	0.02	+	0.6	0.2	36	–	940	17	–	–	8	5	11	25	15	3	3	0.5	–	19	–	Oligocene
Namo ooze	Average		–	0.05	–	0.7	0.01	+	0.4	0.2	<21	–	+	86	–	–	–	–	7	28	<14	–	<2	<0.5	–	27	–	
Sandy and	24-1, 100-102	211	8.3	0.92	3.0	6.1	0.07	1.8	2.0	1.6	42	3	56	57	26	321	175	64	59	121	59	25	5	0.5	–	15	3	?
silty clays,	26-1, 140-142	230	16.1	1.24	5.8	8.6	0.06	0.3	1.6	1.5	60	3	130	26	29	332	298	74	71	151	154	29	1	0.5	–	25	–	?
and fine-	28-1, 130-132	249	4.9	1.51	4.2	6.1	0.07	7.3	1.8	1.6	31	–	238	4.5	4.0	226	176	33	45	82	76	18	3	0.5	–	40	–	?
grained	30-1, 130-132	268	17.9	1.06	7.3	9.6	0.04	0.6	0.9	0.5	19	10	15	17	43	562	192	122	111	139	82	30	1	–	–	22	3	?
silty sands,	32-1, 120-122	287	13.7	1.29	9.2	10.5	0.08	0.3	0.4	0.3	82	5	5	37	41	425	469	73	160	87	102	35	1	0.5	–	25	–	?
with some	33-1, 62-65	301	16.4	1.53	16.2	12.2	0.07	0.5	0.7	0.5	24	–	21	14	64	336	74	42	86	73	338	39	3	0.5	2	36	14	?
pebble	33-1, 67-69	301	15.5	1.39	8.2	6.7	0.12	0.3	1.0	0.7	21	–	15	11	43	330	401	77	150	83	97	22	–	0.5	–	21	–	?
conglom-	Average		13.3	1.28	7.7	8.5	0.07	1.6	1.2	1.0	40	<7	68	30	41	362	255	69	97	105	130	28	<2	<0.5	–	26	–	
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	Site 255																											
Nanno	3-1, 130-132	24*	–	0.02	–	0.6	0.01	+	0.2	0.1	33	–	+	71	–	–	4	–	8	27	–	3	2	1	–	25	–	Miocene
Foram	5-1, 120-122	43*	–	0.06	–	0.8	0.14	+	0.5	0.2	29	–	+	52	–	–	3	67	92	36	–	3	5	–	–	28	18	Miocene
ooze	Average		–	0.04	–	0.7	0.08	+	0.4	0.2	28	–	+	62	–	–	4	<34	50	31	–	3	3	<0.5	–	27	<10	

	Site 256																										
Detrital Clay	1-5, 87-89	7	17.2	0.16	2.8	6.8	0.53	0.6	1.4	1.9	73	6	44	124	11	182	92	200	225	224	47	20	37	–	–	8	92	Pliocene
	3-2, 95-97	50	10.2	0.14	5.1	1.4	0.18	0.3	1.3	1.7	167	4	50	100	11	168	69	53	64	129	23	20	11	–	–	4	58	Pliocene
	4-2, 94-96	88	18.5	0.29	11.5	5.5	0.53	0.5	1.6	1.6	372	8	49	118	13	264	114	103	146	147	112	32	39	–	–	17	91	Pliocene
	4-6, 127-129	94	22.9	0.29	9.7	9.3	0.53	0.6	1.7	1.5	489	9	76	395	24	271	99	301	270	165	186	29	39	–	1	26	92	Pliocene
	5-4, 37-39	128	27.7	0.39	9.1	6.7	0.37	0.4	1.8	4.4	161	9	97	108	22	727	98	86	116	148	323	26	4	–	1	25	66	?
	7-3, 78-80	216	28.8	0.29	2.8	5.4	0.10	0.2	1.4	2.5	35	2	64	260	9	69	57	65	74	109	25	8	0.5	–	–	15	24	U.Cretaceous
	9-1, 133-135	248	9.8	0.11	0.1	2.5	0.18	4.2	1.3	1.2	22	–	74	485	–	26	27	19	20	58	–	2	3	–	–	–	–	L.Cretaceous
	Average		19.3	0.24	5.9	5.4	0.35	1.0	1.5	2.1	189	<5	65	227	<13	244	80	118	131	140	<98	20	19	–	–	<14	<61	
	Site 257																										
Detrital Clay	1-2, 93-95	2	19.7	0.21	4.4	5.6	0.53	0.6	1.6	1.8	36	6	76	258	18	180	58	76	134	123	64	15	13	–	–	14	59	Quaternary
	2-2, 124-126	12	19.2	0.14	3.2	6.6	0.53	0.3	1.2	1.6	62	6	35	141	8	234	88	79	94	153	39	16	18	–	–	6	58	?
	3-2, 94-95	50	16.8	0.10	5.3	4.0	0.11	0.3	1.2	2.3	228	6	37	84	9	175	88	29	74	98	103	28	7	0.5	–	7	53	?
	4-4, 27-29	90	26.1	0.18	3.9	5.0	0.27	0.3	1.5	1.8	55	4	42	245	6	71	33	30	52	124	106	14	2	–	–	–	25	Cretaceous
	5-2, 83-85	126	22.4	0.13	5.9	4.3	0.46	0.4	1.5	1.6	45	6	129	176	14	134	63	61	69	107	74	17	10	–	–	7	47	Cretaceous
Coccolith Detrital clay, clayey coccolith ooze Clayey coccolith Chalk	7-2, 96-98	201	15.4	0.12	3.3	3.5	0.22	2.0	1.4	1.5	56	4	68	281	6	105	82	62	64	77	36	16	2	–	–	4	39	M. Albian
	8-2, 72-74	239	17.5	0.13	4.5	2.7	0.46	3.9	1.9	2.5	124	2	107	139	6	103	51	69	124	134	65	14	2	–	–	17	61	M. Albian
	Average (2 samples)		16.4	0.12	3.9	3.1	0.34	3.0	1.7	2.0	90	3	87	210	6	104	66	65	94	105	51	15	2	–	–	11	50	
	9-3, 63-65	251	22.4	0.10	3.3	1.2	0.04	0.1	1.4	1.1	58	14	22	124	5	+	260	53	78	72	57	14	–	–	–	–	10	?
Detrital Clay	10-1, 127-129	258	22.4	0.08	1.6	7.3	0.14	0.7	1.4	1.1	46	6	23	270	15	201	35	67	92	27	–	12	1	4	–	–	15	?
	15-1, 29-31	298	14.1	0.08	0.6	7.4	0.10	2.2	2.8	1.4	40	5	35	832	9	151	105	92	140	75	31	13	1	–	–	–	6	?
	Average (all 8 detrital clay samples)		20.4	0.13	3.5	5.2	0.27	0.6	1.6	1.6	71	7	50	266	10>	268	91	61	91	97	<60	16	7	–	–	<6	34	
	Site 258																										
Nanno oozes and Chalks	1-5, 105-107	7*	–	0.04	–	0.8	0.02	+	0.9	0.3	34	–	+	187	–	–	8	–	8	27	–	3	3	–	–	25	3	Quaternary
	3-6, 120-122	56*	–	0.04	–	0.6	0.01	+	0.3	0.2	60	1	+	589	–	–	9	3	6	28	17	4	3	1	–	17	–	Pliocene
	6-5, 130-132	148*	–	0.04	–	0.7	0.02	+	0.5	0.1	38	–	710	+	–	–	9	27	9	37	–	4	4	1	–	6	–	Coniacian
	10-2, 75-77	202*	–	0.04	–	0.9	0.01	+	0.8	0.3	35	2	369	+	–	7	24	60	34	132	–	10	2	–	–	–	–	Coniacian
	12-6, 90-92	243*	14.5	0.03	–	0.7	0.09	18.9	0.7	0.7	16	–	639	+	–	–	11	63	9	45	–	2	1	–	–	16	–	Turanian
	Average		–	0.04	–	0.7	0.03	+	0.6	0.5	37	–	<723	+	–	–	12	<31	13	54	–	4	2	–	–	16	–	
Clays and Chalks	15-2, 105-107	285	15.6	0.09	2.2	1.5	0.04	1.0	0.9	1.4	57	2	85	+	–	57	78	28	37	116	13	13	–	–	–	–	7	U. Albian
Detrital Clay	16-2, 1-3	303	21.9	0.10	3.3	4.8	0.02	1.6	1.1	1.1	48	5	48	+	–	105	107	50	106	90	76	15	–	0.5	–	–	20	U. Albian
	17-5, 68-70	327	13.0	0.07	1.6	1.9	0.01	3.4	0.9	0.6	30	3	46	+	–	34	43	27	31	61	33	8	–	–	–	–	–	U. Albian
	18-4, 116-118	345	23.8	0.06	1.2	2.4	0.01	3.4	0.9	0.5	33	3	90	+	–	49	50	31	37	60	34	9	0.5	0.5	–	–	–	U. Albian
	21-1, 130-132	407	26.3	0.12	4.4	2.5	0.01	1.1	0.9	0.8	48	3	47	798	3	65	66	28	44	48	431	12	0.5	0.5	–	–	13	M. Albian
	22-5, 120-122	442	22.5	0.11	4.5	3.2	0.01	2.4	1.0	0.8	31	4	68	+	–	91	87	29	42	61	41	16	0.5	0.5	–	–	23	M. Albian
	23-2, 123-125	475	23.7	0.14	9.2	3.2	0.01	0.9	1.3	1.6	67	6	71	624	12	165	138	36	69	109	105	25	–	0.5	1	8	51	M. Albian
	24-2, 130-132	513	30.1	0.09	5.4	3.8	0.01	0.9	1.3	0.4	50	5	34	49	5	64	76	20	52	67	114	15	2	0.5	1	–	22	M. Albian
	Average (7 detrital clay samples)		23.0	0.09	4.2	3.1	0.01	2.0	1.1	0.8	44	4	58	+	–	82	81	32	54	71	119	14	<1	<0.5	–	–	19	

TABLE 1 – *Continued*

Lithology	Core-Section, Interval in cm	Depth Below Sea Floor (m)	Si (%)	Ti (%)	Al (%)	Fe (%)	Mn (%)	Ca (%)	Mg (%)	K (%)	Li (ppm)	Be (ppm)	Sr (ppm)	Ba (ppm)	Sc (ppm)	V (ppm)	Cr (ppm)	Co (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Ga (ppm)	Mo (ppm)	Ag (ppm)	Cd (ppm)	Sn (ppm)	Pb (ppm)	Stratigraphic Age
Glauconitic Detrital Silty Clay	25-4, 58-60	525	12.5	0.77	6.8	8.6	0.03	0.6	1.1	0.8	192	6	22	45	33	299	281	77	79	111	27	23	1	–	–	13	–	M. Albian
Average Values																												
Nanno Oozes and Chalks from Sites 251, 253, 254, 255, 258 (25 samples)			–	0.05	–	0.9	0.03	+	0.5	0.4	<28	–	+	>377	–	–	<8	<12	16	41	–	<3	<3	<0.5	–	21	–	
Nanno Ooze and Clay, etc. from Sites 250, 257, 258 (7 samples)			19.1	0.18	5.3	4.6	0.14	1.2	1.4	2.3	71	3	65	>385	<11	101	97	87	141	124	95	17	3	–	–	<9	32	
Radiolarian Clay from Site 252 (3 samples)			25.3	0.50	4.5	4.9	0.08	1.4	1.7	1.8	29	<1	208	+	17	118	80	76	76	140	143	16	3	–	–	18	41	
Detrital Clay from Sites 250, 256, 257, 258 (28 samples)			21.9	0.17	4.4	4.6	0.21	1.0	1.4	1.7	86	<5	58	>414	<10	>182	88	70	96	105	<88	16	<7	–	–	<9	<44	
Miscellaneous																												
Altered Vitric Volcanic Ash from Site 253 (20 samples)			<14.0	0.30	<2.1	4.0	0.09	3.9	2.2	1.6	⟨40	⟨1	⟩244	⟩165	⟨8	⟨95	⟨60	⟨32	⟨34	54	⟨46	⟨8	–	–	–	⟨13	–	
Sands, silts, and clays from Site 254 (7 samples)			13.3	1.28	7.7	8.5	0.07	1.6	1.2	1.0	40	⟨7	68	30	41	362	255	69	97	105	130	28	⟨2	⟨0.5	–	26	–	
Glauconitic silty clay from Site 258 (1 sample)			12.5	0.77	6.8	8.6	0.03	0.6	1.1	0.8	192	6	22	45	33	299	281	78	79	111	27	23	1	–	–	13	–	
Published Average Chemical Composition of Deep-Sea Sediments (Riley and Chester, 1971)																												
Major Elements																												
Calcareous sediments			12.6	0.20	4.8	2.77	0.26	20.40	0.80	1.23																		
Lithogenous sediments			25.9	0.44	10.7	5.80	0.37	1.11	2.12	2.71																		
Siliceous sediments			29.9	0.34	8.0	4.48	0.38	0.98	1.21	1.58																		
Oceanic Average			20.0	0.31	7.4	4.15	0.32	10.40	1.35	1.74																		
Trace Elements																												
Deep-sea carbonates											5	0.x	2000	190	2	20	11	7	30	30	35	13	3	0.0x	0.0x	0.0x	9	
Deep-sea clays											57	2.6	180	2300	19	120	90	74	225	250	165	20	27	0.11	0.42	1.5	80	
Direct-Reading Spectograph: Useful Working Range																												
Upper Limit			46.0	2.0	15.0	15.0	1.0	25.0	3.5	5.0	1000	100	1000	1000	100	1000	1000	1000	1000	1000	1000	100	100	100	100	100	1000	
Lower Limit			4.0	0.001	0.7	0.1	0.001	0.0	0.03	0.1	3.0	0.4	2.0	5.0	3.0	5.0	2.0	1.0	2.0	2.0	10.0	1.5	0.3	0.2	0.5	3.0	2.0	

Note:
- * Sample containing more than 15% Ca (See text);
- \+ Result greater than the upper limit of the useful working range for the direct-reading spectrograph (see above);
- – Result less than the lower limit of the useful working range for the direct-reading spectrograph (see above);
- > Prefix of average calculated using upper limit value of the useful working range for the direct-reading spectrograph in place of result(s) shown as above upper limit, hence actual average is greater than that shown;
- < Prefix of average calculated using lower limit value of the useful working range for the direct-reading spectrograph in place of result(s) shown as below lower limit, hence actual average is less than that shown; and
- x An estimate of order of magnitude

[a] For these sediments, this method must be regarded as, at best, semi-quantitative.

in the volcaniclastic sediments are low and not typical of deep-sea sediments.

3. Enriched trace elements: the concentrations of vanadium, cobalt, nickel, copper, and zinc are typical of deep-sea sediments, but the chromium values and the higher vanadium values are unusual because chromium is not normally enriched in pelagic sediments, and, even in the Pacific, the average vanadium content is only 330 ppm.

Site 255

The two samples from this site which were analyzed are calcareous oozes and apparently contain titanium, iron, and manganese in low concentrations, with the two manganese values differing greatly.

Site 256

1. Major elements: typical deep-sea clays were sampled at this site, though the lowest sample is calcium rich and contains relatively little silicon, titanium, iron, and aluminum. The average manganese content is consistent with this view, but the manganese values of the samples vary between 0.53% and 0.10%.

2. Trace elements: beryllium, strontium, scandium, chromium, gallium, silver, and cadmium all occur in amounts to be expected in pelagic clays, but the average lithium concentration (189 ppm) is high compared with the average value for pelagic clays (57 ppm); also, the barium and molybdenum values are low and vary, as do those of lithium.

3. Enriched trace elements: vanadium, cobalt, nickel, zinc, copper, and lead are all enriched, and the values of the first four of these vary distinctly from sample to sample, vanadium attaining a high value of over 700 ppm in one sample. The degree of enrichment of vanadium and cobalt is similar to that in Pacific clays, but the other elements are enriched as in Atlantic clays.

Site 257

1. Major elements: the Site 257 samples, coming from a similar geologic setting, are like those of Site 256. In general, the titanium and aluminum values are low, the aluminum values being exceptionally so in the lowest two samples. The iron and manganese concentrations at the top and the iron concentrations at the bottom of the sequence are relatively high. Samples taken at 201 and 239 meters, with high calcium and low silicon contents, represent mixtures of clays and coccolith oozes.

2. Trace elements: the lithium, beryllium, scandium, chromium, gallium, silver, and cadmium values are typical, and, as at Site 256, the barium and molybdenum values are generally low, while the tin concentrations are lower than elsewhere.

3. Enriched trace elements: as at Site 256, vanadium, cobalt, nickel, copper, zinc, and lead are enriched, though beneath 250 meters the lead results are distinctly low. Vanadium obtains a higher maximum value than at Site 256 (>1000 ppm).

Site 258

1. Major elements: the upper lithological unit, as the calcareous sediments at other sites, contains low concentrations of titanium, iron, and manganese. In the underlying detrital clay the titanium, aluminum, iron, and manganese contents are low; the manganese values vary little and have an average value of 0.01%, compared with an average value for lithogenous pelagic sediments of 0.37%.

2. Trace elements: the results for lithium, beryllium, barium, chromium, gallium, and strontium are generally typical of deep-sea sediments, but those for scandium, vanadium, molybdenum, and tin are low compared with other sites. The barium concentrations vary, being atypically high in the calcareous sediments but very low in the bottom two samples. Nickel and lead are not enriched relative to near-shore sediments and igneous rocks.

3. Enriched trace elements: cobalt, copper, and zinc are enriched to a lesser extent at this site than at Sites 256 and 257, with the degree of enrichment being similar to that of the Atlantic.

4. Basal glauconitic sandy lithological unit: this is of basaltic provenance (B. C. McKelvey, personal communication) and is a geochemically distinct unit containing more titanium, iron, vanadium, chromium, cobalt, nickel, and copper than the overlying clays.

Conclusions

Because of their unreliability, little will be said here of the results for the nannoplankton oozes and chalks. However, it is worth noting the apparently low average iron and manganese contents of the oozes (0.8% and 0.4%, respectively), compared with average iron and manganese concentrations of calcareous pelagic sediments of (2.77% and 0.26%). The average major element concentrations in the other three major lithologic types, which are all basically clays, are generally similar, bearing in mind their somewhat variable components. The average compositions of these clays are in most respects the same as the average published analyses. Of the major elements, the determined titanium and aluminum average values are about half the published values. The average iron content is lower than that published (about 4.6% compared with about 6.0%) and there is, on the average, approximately 0.2% manganese in these samples compared with a published average of about 0.4%.

The measurements of the lithium, beryllium, scandium, chromium, gallium, silver, and cadmium contents yield average values similar to the published values, but those of strontium, molybdenum, and notably barium are low. The existing data concerning tin are inconclusive, giving values of about 1.0 or 20 ppm; the figures obtained here are generally between these values.

The clays are enriched in vanadium, cobalt, nickel, copper, lead, and zinc, relative to near-shore sediments and igneous rocks in the manner characteristic of pelagic clays (Chester, 1965; Riley and Chester, 1971). The average vanadium, cobalt, and nickel values are greater than those of the Atlantic but less than those of the Pacific, while the average copper and lead values are similar to those of the Atlantic. It would seem significant that these trace elements, normally considered to be

associated with the hydrogenous components (e.g., ferromanganese nodules and iron and manganese oxides) of deep-sea sediments (Riley and Chester, 1971), and iron are present in the Leg 26 samples in concentrations similar to those in sediments from on and just below the present-day ocean bottom, while the average manganese concentration in the drilled samples is about half that of the ocean-bottom sediments.

In order to study the partitioning of the iron, manganese, and trace elements between the various components of the sediments, some of the samples will be subjected to chemical treatment as described by Chester and Hughes (1967). Continuing work will provide chemical analyses of these and other samples, together with specific mineralogical investigations. These studies will provide data for comparison with present-day pelagic sediments, and, hopefully, elucidate elemental variations at particular sites, with possible implications for the oceanic sediment pile as a whole.

NEUTRON ACTIVATION ANALYSIS

Method

Duplicate samples of the Leg 26 material and of USGS standard rock BCR-1 of known weight, along with elemental standards, were irradiated in the University of London Reactor at a thermal neutron flux of about 0.9×10^{12} n cm $^{-2}$ sec^{-1}. For the determination of cerium, neodymium, europium, gadolinium, terbium, holmium, thulium, ytterbium, and lutetium, the samples were irradiated for 15 hr and allowed to cool for about 3 weeks. For lanthanum and samarium, the irradiation was for 7.5 hr with a cooling period of 4 to 5 days. The activity, in the case of the former group of elements, was detected by means of a low-energy ultra-pure germanium detector (Princeton Gamma Tech.) with the following measured specifications: resolution (FWHM) of 538ev at 122 kev; active area 200 mm^2; 5-mm thick; 5-mil Be window. The detector was coupled via a pulsed optical feedback preamplifier and amplifier to an Intertechnique SA40B 400 channel analyzer. For the determination of lanthanum and samarium, a germanium-lithium detector (Princeton Gamma Tech.), with the following measured specifications: resolution (FWHM) of 1.81 kev at 1.33 Mev; efficiency (relative to sodium iodide [Tl] detector) 8.1%; 42-cm^3 active volume; drift depth 16 mm, was used. This was connected via a preamplifier and a Tenelec 205 amplifier to an AEP 4096 channel analyzer based on a Nova computer. A pulse generator was used to enable a correction for dead time to be made.

Results and Discussion

The rare-earth contents of six samples are shown in Table 2, along with the enrichment factors relative to chondrites. Table 3 compares the values determined for the USGS BCR-1 standard with the published values (Flanagan, 1973).

The enrichment factors, relative to chondrites, for the rare-earth elements of oceanic sediments and ridge basalts are distinct; a plot of these factors (Figure 1) shows that, while the enrichment factors of the ele-

TABLE 2
Rare-earth Element Data

Sample	Rare-earth Contents of Samples (ppm)												Rare-earth Enrichment Factors Relative to Chondrites [a]											
	La	Ce	Nd	Sm	Eu	Gd	Tb	Ho	Tm	Yb	Lu		La	Ce	Nd	Sm	Eu	Gd	Tb	Ho	Tm	Yb	Lu
250A-25-1, 50-52 cm	17.1	27.9	18.3	2.9	0.9	4.1	0.8	1.5	0.5	1.6	0.1		57.0	33.2	31.6	13.8	12.2	12.8	16.3	20.5	15.2	9.4	3.2
253-26-2, 23-25 cm	7.1	19.8	16.0	3.0	1.0	4.3	0.9	1.1	0.7	2.9	0.4		23.7	23.6	27.6	14.3	13.5	13.4	18.4	15.1	21.2	17.1	12.9
253-57-2, 85-88 cm	13.7	36.3	27.5	5.3	1.9	6.0	1.1	2.0	1.0	3.2	0.5		45.7	43.2	47.4	25.2	25.7	18.8	22.4	27.4	30.3	18.8	16.1
254-33-1, 67-69 cm	8.3	29.5	15.4	6.5	1.8	5.0	1.2	1.4	1.2	4.6	0.8		27.7	35.1	26.6	31.0	24.3	15.6	24.5	19.2	36.4	27.1	25.8
257-10-1, 127-129 cm	23.7	84.2	27.8	4.5	1.4	7.7	1.3	1.4	0.7	2.5	0.01		79.0	100.2	47.9	21.4	18.9	24.1	26.5	19.2	21.2	14.7	0.3
258-25-4, 58-60 cm	14.5	34.7	29.2	7.2	3.6	12.0	2.2	2.0	2.6	6.0	0.8		48.3	41.3	50.3	34.3	48.6	37.5	44.9	27.4	78.8	35.3	25.8

[a] Values used for the chondrites are from Haskin et al. (1968)

TABLE 3
Rare-earth Contents of U.S.G.S. BCR-1 Standard

	This Study	Published Value (Flanagan, 1973)
La	17.9	26[a]
Ce	40.9	53.9
Nd	29.7	29
Sm	4.6	6.6[a]
Eu	2.1	1.94
Gd	6.2	6.6
Tb	1.0	1.0
Ho	1.4	1.2[b]
Tm	0.8	0.6
Yb	3.2	3.36[a]
Lu	0.2	0.55

[a]Average
[b]Magnitude

ments with atomic numbers greater than that of europium are of similar value, those factors of the elements with atomic numbers less than 63 have progressively divergent plots with decreasing atomic number. The results for the three analyzed basalt samples from Sites 250, 257, and 258 are shown in Figure 1. Those for Samples 250A-25-1, 50-52 cm and 257-10-1, 127-129 cm plot as oceanic sediments, but the trend of the results for Sample 258-254, 58-60 cm is different. In Figure 2 the results for the three samples from the Ninetyeast Ridge are plotted. Samples 253-26-2, 23-25 cm and 253-57-2, 85-88 cm are altered volcanic ashes (McKelvey and Fleet, this volume, Chapter 22), and Sample 254-33-1, 67-69 cm consists of volcaniclastic sediments. The Ninetyeast Ridge samples plot with trends similar to those obtained by Thompson et al. (in press) for basalts from Sites 214, 215, and 216; by Frey and Sung (Chapter 23, this volume) for basalts from Sites 253 and 254; and by Schilling (1973) for basalts from the Reykjanes Ridge near Iceland, and its extension over the island. Thompson et al. claim their results are consistent with the idea of the Ninetyeast Ridge being the surface expression of a former mantle plume. This hypothesis is further supported by consideration of the ratio of the lanthanium and samarium enrichment factors $(La/Sm)_{E.F.}$ relative to chondrites. The ratios for the basalts studied by Schilling fall into three groups. The ratios for the ridge basalts over 400 km southwest of Iceland on the Reykjanes Ridge are less than 0.5, while those basalts from within 200 km of Iceland, on the ridge and from the landward extension of the ridge, have ratios between 0.8 and 1.4. In Figure 3 the $(La/Sm)_{E.F.}$ ratio ranges for these two groups of basalt, and an intermediate group from on the ridge are shown diagrammatically, along with the $(La/Sm)_{E.F.}$ range for the oceanic sediments analyzed by Wildeman and Haskin (1965). It can be seen that the $(La/Sm)_{E.F.}$ ratios for the Ninetyeast Ridge samples are similar to those for the basalts from Iceland and the Ridge within 200 km of Iceland, whose compositions are considered by Schilling (1973) to be influenced by a primordial hot mantle plume rising beneath Iceland. The $(La/Sm)_{E.F.}$ ratio of the sample from Site 258 is also within this group, but the basal sediments from Sites 250 and 257 have

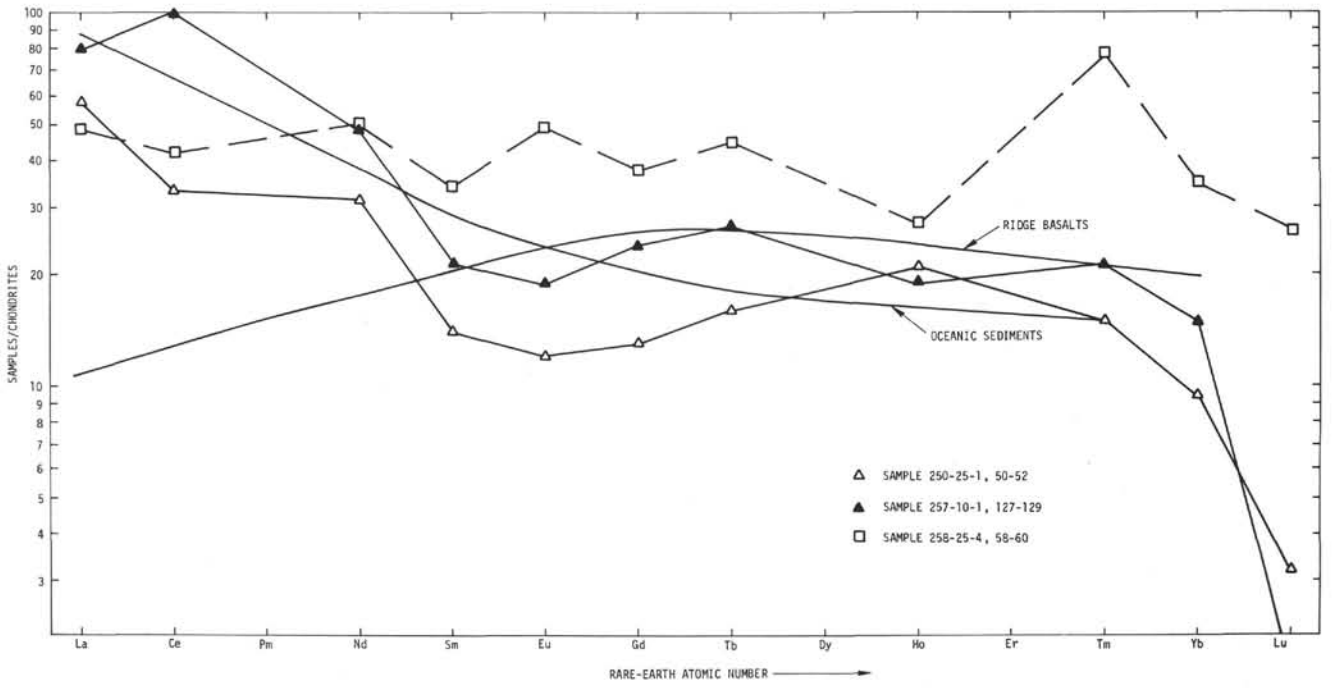

Figure 1. *Rare-earth element enrichment factors relative to chondrites of some basal sediments. Values for ridge basalts: Haskin et al. (1968). Values for oceanic sediments: Wildeman and Haskin (1965).*

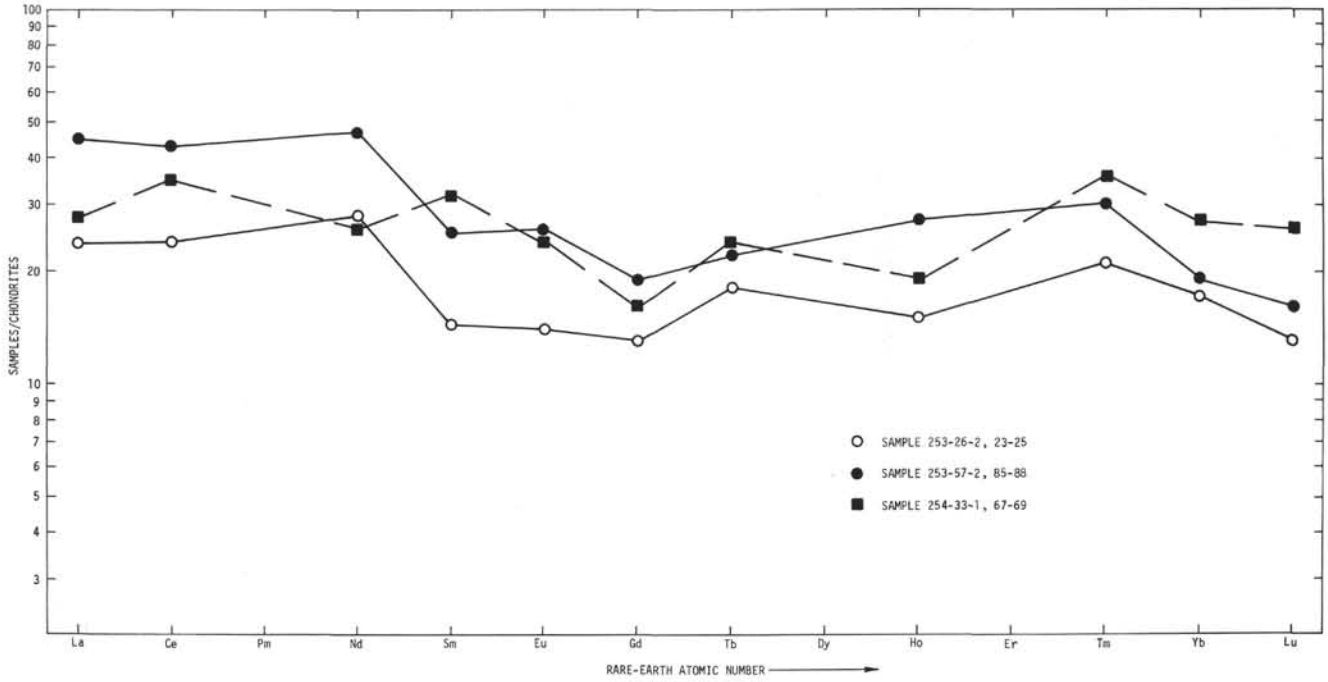

Figure 2. *Rare-earth element enrichment factors relative to chondrites of samples from the Ninetyeast Ridge.*

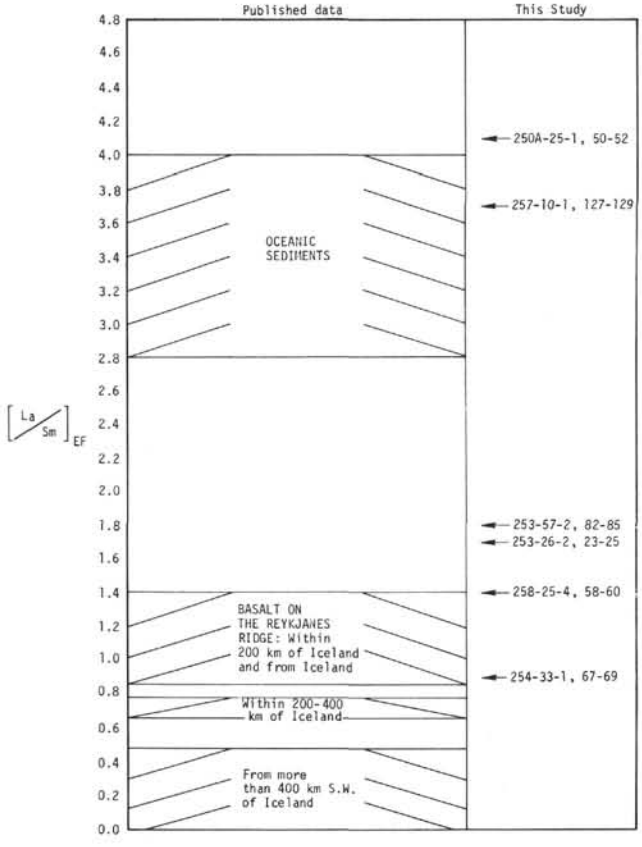

Figure 3. *Diagram comparing [La/Sm]$_{E.F.}$ ratios from published data with those obtained in this study. Values for oceanic sediments: Wildeman and Haskin (1965). Values for Reykjanes Ridge: Schilling (1973).*

(La/Sm)$_{E.F.}$ ratios consistent with their being normal deep-sea sediments, on the basis of whole sediment analysis.

Work is being carried out to verify the trends which are reported above and to fully evaluate the errors involved. Unfortunately, no basalt was obtained from Site 258 or from Site 264 (Leg 28) on the Naturaliste Plateau. Any further work must, therefore, be undertaken on the apparently volcanically derived sediments from the base of Site 258, and this is, in fact, planned.

Note added in press: These samples have been reanalyzed, together with six others. The trends reported above are confirmed. The enrichment factors for Sample 258-24-2, 130-132 cm plot as do those for sediments, but the sample from the clay interval in the basalt of Core 15 at Site 257 (Sample 257-15-1, 29-31 cm), which is of problematical origin, plots similarly to Sample 258-25-4, 58-60 cm. The new (La/Sm)$_{E.F.}$ ratios fall into three groups:

>3.4	Samples:	250-25-1, 50-52 cm
		256-9-1, 133-135 cm
		257-10-1, 127-129 cm
		258-24-2, 130-132 cm
1.6-0.9	Samples:	253-17-2, 60-62 cm
		253-26-2, 23-25 cm
		254-26-1, 140-142 cm
		254-33-1, 67-69 cm
		257-15-1, 29-31 cm
		258-25-4, 58-60 cm
2.3-2.5	Samples:	253-36-1, 93-95 cm
		253-57-2, 85-88 cm

The last two samples in this list are significantly enriched in lanthanum relative to cerium, as is the case

with no other of the samples, and come from the lower magnesium-rich half of the Site 253 altered-ash sequence (see McKelvey and Fleet, Chapter 22, this volume).

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