29. BASALTS FROM THE EAST PACIFIC RISE: AN EXAMPLE OF TYPICAL OCEANIC CRUST DEPLETED IN HYGROMAGMAPHILE ELEMENTS[1]

P. Cambon and H. Bougault, Centre National pour l'Exploitation des Océans, Centre Océanologique de Bretagne
B.P. 337—29273 Brest Cedex, France
J. L. Joron, Laboratoire P. Sue, Groupe des Sciences de la Terre—Cen Saclay
B.P. no. 2—91190 Gif-Sur-Yvette, France
M. Treuil, Université P. et M. Curie, Laboratoire de Géochimie Comparée et Systématique, 4, place Jussieu,
Tour 24/25 E.3, 75230 Paris Cedex 05, France

ABSTRACT

Samples of basalt collected on Leg 65 near 22°N on the East Pacific Rise all display the depleted light rare-earth pattern of "normal" oceanic crust. Consequently the La/Ta ratio is close to 18, as opposed to the value of 9 associated with the flat or enriched patterns found along parts of the Mid-Atlantic Ridge and the Emperor Seamount chain. The Leg 65 samples are chemically similar to those from the CYAMEX area at 21°N and to the Leg 54 samples from 9°N, suggesting homogeneity of the upper mantle under the northern part of the East Pacific Rise over a minimum distance of about 1500 km. The geochemistry of the rocks and their field relationships with respect to depth and distance from the axis of the Rise show no pattern of distribution linked to the degree of fractional crystallization and thus cast doubt on any possible model involving large, long-lived magma chambers at the axis of the Rise.

INTRODUCTION

The East Pacific Rise was drilled for the first time near 9°N during Deep Sea Drilling Project (DSDP) Leg 54. During Leg 65, several holes were drilled immediately south of the Tamayo Fracture Zone at about 22°N, both on the eastern side of the Rise (Sites 482 and 485) and the western side (Site 483). Samples from close to the axis of the Rise were also obtained during the CYAMEX and RISE submersible expeditions in 1978 and 1979. In this paper, we present trace element data for the Leg 65 basalts—measured either by neutron activation analysis (NAA) or X-ray fluorescence spectrometry (XRF) in order to refine the definition of the basaltic units encountered in each hole. The geochemical properties of the basalts are also compared with data from Leg 54 and the CYAMEX expedition.

RESULTS

The major elements were analyzed on board the *Glomar Challenger* using the XRF unit from the Centre National pour l'Exploitation des Océans. In addition to the elements analyzed on earlier legs (e.g., Bougault, 1977; Melson et al., 1979), Na_2O was analyzed on board for the first time on Leg 65. A new TlAP crystal was used which enhances the light-element counting rates compared to those obtained with an ADP crystal. With the TlAP crystal, the Mg counting time can be cut at the same time that the analytical accuracy is improved, and Na_2O can be determined with an accuracy of $\pm 0.1\%$. Three trace elements (Ni, Zr, and Sr) were also measured on board (as on Legs 45, 46, and 55) to help discriminate between different magmatic units. Of these, Ni has a high crystal/liquid partition coefficient; Zr, which is a hygromagmaphile element, has a low partition coefficient; and Sr, although also a hygromagmaphile element, is more or less sensitive to plagioclase crystallization (or melting).

Table 1 presents the major and trace element data available for the four rocks chosen as standards by the shipboard party. The V, Cr, Co, Zn, Rb, Y, and Nb concentrations were determined on shore using the X-ray fluorescence techniques described by Bougault et al. (1977); Sc, Co, Ni, Cs, La, Eu, Tb, Hf, Ta, Th, and U concentrations were measured using the neutron activation analysis procedures outlined by Treuil et al. (1973). The major element data for the rocks recovered on Leg 65 are presented in Table 2 and the trace element data in Table 3. Tables 4 and 5 present the average trace element concentrations ($\bar{x}$) and standard deviations (σ) for the homogeneous "chemical types" defined at Sites 482 and 483, respectively. The tables showing trace element data include Ti, Mn, and Fe in order to have values shown in parts per million for all of the elements belonging to the first transition series presented together. The elements are arranged in order of increasing atomic number. The tables give Co and Ni concentrations from both XRF and NAA.

Data on trace elements confirm or refine the classification of the basaltic units identified on ship board. As far as possible, the "chemical types" defined by the shipboard party have been retained. Figures 1 and 2 show the distribution of these types versus depth for Sites 482 and 483. The chemical types defined by trace element studies correlate well with those established at sea, although some differences are noted in the lower parts of Holes 482B and 483B.

[1] Lewis, B. T. R., Robinson, P., et al., *Init. Repts. DSDP*, 65: Washington (U.S. Govt. Printing Office).

Table 1. Major and trace element composition of Leg 65 samples used as standards.[a]

Components \ Sample	482C-12-1, 92–118 cm	483B-8-3, 2–20 cm	483B-28-1, 42–59 cm	485A-25-1, 117–143 cm
Major elements (wt.%)				
SiO_2	49.82	47.52	49.08	48.79
Al_2O_3	14.66	16.24	14.03	14.34
Fe_2O_3	11.20	9.69	12.24	12.80
MnO	0.18	0.16	0.18	0.20
MgO	7.81	9.19	7.65	7.07
CaO	12.16	12.07	11.54	11.13
Na_2O	1.94	2.23	2.21	2.48
K_2O	0.07	0.04	0.10	0.08
TiO_2	1.28	1.05	1.79	2.14
P_2O_5	0.15	0.12	0.19	0.21
Loss on ignition 110°C	0.42	0.30	0.36	0.27
Loss on ignition 1050°C	0.42	1.38	0.64	0.35
Total	100.11	99.99	100.01	99.86
Trace elements (ppm)				
V	313	227	350	387
Cr	176	306	220	206
Co	43	45	45	44
Ni	55	96	166	59
Rb	< 1	< 1	< 1	< 1
Sr	92	135	108	103
Y	36	29	46	56
Zr	74	60	111	132
Nb	1	1	3.5	3.5

[a] Values determined by XRF analysis.

Site 482

Below Section 482B-18-2, for example, two different samples (482B-19-1, 96–100 cm and 482B-21-1, 62–64 cm) stand out because of their high concentrations of hygromagmaphile elements. The samples are respectively classified as Chemical Types C and E. Other samples from this interval are classified as Chemical Type D. Among these samples, however, there are differences which lead to some elements having standard deviations which are higher than those reported in Tables 4 and 5. The following subdivision of Chemical Type D is therefore proposed: Sample 482B-18-2, 99–101 cm has an Fe concentration of 82,000 ppm compared with 71,000 ppm for the mean value for D and is thus assigned to subunit D′. Samples 482B-20-3, 24–26 cm and 482B-24-1, 93–95 cm are assigned, in turn, to subunits D″, and D‴. Although these subdivisions may not be fundamental, they take into account differences (of 30 ppm in Sr content between subunits D″ and D‴, for instance) that are significant from an analytical viewpoint.

It is interesting to note that Sample 482B-21-1, 62–64 cm (Type E) and Sample 482D-10-3, 14–16 cm are geochemically the same except for their Cr contents, but occur at widely separated levels (205 m and 155 m, respectively). The only analyzed sample (Section 482F-4-3) from Hole 482F corresponds to this chemical type.

Site 483

Two chemical types, Types K and L, were defined by the shipboard party for grouping the basalts recovered from the lower part of Hole 483B, below Sample 483B-23-4, 63–71 cm. On the basis of the trace element data, however, all of the analyzed samples seem to be very similar: notable differences from Sections 483B-28-1 through 32-1 and the remaining samples only concern Cr, Ni, and the hygromagmaphile elements. We thus prefer to assign all of the samples to only one chemical type and to subdivide the subunits into K and K′. We include in subunit K Sections 483B-23-4 through 27-3 and Section 483B-32-3, and assign to K′ Sections 483B-28-1 through 32-1. The observed differences suggest that subunit K was derived from K′ by fractional crystallization or that K′ contains more ferromagnesian minerals than subunit K.

Similarly, in Hole 483, Chemical Type F defined on board ship incorporates the sequence from Section 20-1 through Section 23-2. We suggest that this unit should be divided into subunits F (Sections 483-20-1 through 21-2) and F′ (Sections 483-22-1 to 23-2). The comments made concerning subunits K and K′ in Hole 483B also apply to the subdivisions F and F′ in Hole 483. Section 25-1 in Hole 483 (near the 198 m level) belongs to Chemical Type A, which occurs at about the 110-m level in Holes 483 and 483B.

Site 485

Unlike the samples from Sites 482 and 483, the basalts from Hole 485A have not been grouped into chemical units. Except for the obvious difference between the uppermost sample (Section 485A-11-3) and the basalts obtained deeper in the section, the differences between samples are not clear enough to justify classification into different chemical types. The variable Ni concentrations observed could be the result of variations in olivine content.

TRACE ELEMENT GEOCHEMISTRY, FIELD DATA, AND SIZE OF MAGMA CHAMBERS

In a recent discussion on the East Pacific Rise at 22°N (RISE Project Group, 1980), it was noted that there is no correlation between the degree of fractionation of lavas and their age or distance from the Rise axis. From the present study, it is also evident that there is no clear relationship between fractionation and the vertical distribution of chemical units in the crust, at least in the holes drilled on Leg 65. In nearly all of the samples examined, the Ni concentration varies between 50 and 100 ppm. This range of variation can be attributed, in part, to variations in olivine content, but it also requires the removal of olivine by crystallization processes. For similar Ni concentrations, the Cr content varies between 190 ppm and 380 ppm. Once again, variations in the abundance of olivine, spinel, and clinopyroxene phenocrysts cannot entirely explain the observed values, and the removal of varying proportions of ferromagnesian minerals during fractional crystallization must also be invoked.

In addition, it was noted by the shipboard party that the uppermost unit of basalt in Hole 485A, represented by Sample 485A-11-3, 82–83 cm, is close in composition to a primitive liquid. This observation is confirmed by

Table 2. Major element composition of basalts, Leg 65.[a]

Sample (interval in cm)	SiO_2	TiO_2	Al_2O_3	Fe_2O_3[b]	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI[c]	Total	Chemical Type
Hole 482B													
10-7, 14-16	43.44	1.77	13.96	13.05	0.23	6.68	9.57	2.58	0.08	0.17	7.78	99.34	—
11-1, 23-25	48.98	1.76	13.93	11.39	0.20	7.48	11.96	2.36	0.08	0.17	1.61	99.92	A
12-2, 135-137	49.27	1.74	14.04	11.61	0.18	7.91	11.64	2.18	0.08	0.18	1.11	99.94	A
14-2, 121-124	48.86	1.39	14.42	11.07	0.18	7.80	12.01	2.19	0.05	0.13	1.47	99.57	F
15-1, 135-139	48.85	1.30	14.48	10.99	0.18	7.95	11.92	2.00	0.04	0.12	1.73	99.56	B
15-3, 117-119	49.30	1.26	14.29	10.95	0.16	7.80	12.16	2.17	0.05	0.11	1.33	99.58	B
16-1, 36-38	49.44	1.27	14.44	10.94	0.16	7.80	12.10	2.08	0.05	0.11	1.12	99.51	B
17-2, 111-113	49.36	1.30	14.27	11.35	0.19	7.73	12.36	1.98	0.02	0.12	1.04	99.72	B
18-1, 18-20	49.69	1.30	14.06	11.26	0.17	7.88	11.94	2.18	0.06	0.11	1.12	99.77	B
18-2, 99-101	48.91	1.54	14.10	11.81	0.19	7.55	12.05	2.03	0.04	0.13	1.10	99.45	D′
19-1, 96-100	47.99	2.20	16.09	11.56	0.12	7.14	7.12	3.04	0.06	0.21	3.77	99.30	C
20-3, 24-26	48.55	1.54	15.33	9.97	0.16	7.31	11.38	2.39	0.04	0.14	2.58	99.39	D″
21-1, 62-64	48.22	1.88	13.84	11.70	0.16	7.47	11.20	2.43	0.06	0.16	1.82	98.94	E
21-3, 74-76	49.00	1.61	15.16	10.65	0.17	7.15	12.03	2.37	0.03	0.16	1.40	99.73	D‴
22-2, 34-36	49.27	1.56	15.57	10.64	0.16	6.94	12.04	2.36	0.03	0.15	1.47	100.19	D‴
22-4, 34-36	48.61	1.51	14.87	10.37	0.16	6.68	11.88	2.24	0.06	0.14	2.79	99.31	D‴
24-1, 93-95	48.10	1.63	15.42	10.22	0.15	7.20	10.35	2.46	0.05	0.14	3.62	99.34	D‴
Hole 482C													
9-1, 121-123	48.71	1.77	14.25	11.58	0.20	7.57	11.63	2.06	0.08	0.17	1.96	99.98	A
10-2, 73-75	48.83	1.71	14.28	11.41	0.19	7.94	11.45	2.06	0.06	0.16	1.81	99.90	A
11-1, 138-139	48.78	1.73	14.34	11.08	0.17	7.82	11.82	2.27	0.07	0.17	1.46	99.71	A
11-1, 115-117	48.45	1.78	14.42	11.36	0.17	7.68	11.67	2.17	0.06	0.17	1.56	99.49	A
11-2, 16-18	47.76	1.32	13.45	10.58	0.15	9.57	9.21	2.53	0.07	0.14	4.66	99.44	F
11-2, 21-24	47.32	1.19	13.74	11.51	0.13	10.25	8.31	2.40	0.08	0.12	4.15	99.20	F
11-3, 141-143	49.17	1.79	13.85	11.66	0.18	7.75	11.62	2.22	0.07	0.17	1.46	99.94	A
12-1, 11-13	49.22	1.30	14.35	11.20	0.18	8.03	11.88	1.85	0.05	0.12	1.04	99.22	B
12-2, 95-97	49.49	1.30	14.41	11.33	0.18	7.81	12.15	1.98	0.03	0.11	1.19	99.98	B
13-1, 22-24	48.70	1.30	14.56	10.47	0.15	8.26	11.43	2.05	0.03	0.10	2.28	99.33	B
13-1, 125-127	49.23	1.29	14.21	11.13	0.17	7.79	12.05	2.02	0.04	0.11	1.33	99.37	B
13-3, 108-110	49.23	1.30	14.30	11.27	0.18	7.66	12.10	2.03	0.05	0.12	1.09	99.33	B
14-1, 40-42	49.40	1.28	14.27	11.06	0.17	7.67	12.16	1.97	0.04	0.12	1.31	99.45	B
14-4, 127-129	49.25	1.29	14.19	11.22	0.17	7.93	12.14	1.93	0.05	0.12	1.10	99.39	B
15-1, 44-46	49.41	1.29	14.20	11.19	0.18	7.74	12.09	2.05	0.04	0.11	1.11	99.41	B
15-2, 132-134	49.21	1.27	14.14	11.03	0.17	7.88	12.05	1.95	0.05	0.12	1.53	99.40	B
15-3, 97-99	49.52	1.27	14.35	11.16	0.18	7.81	12.12	1.95	0.02	0.12	1.18	99.68	B
15-4, 119-121	49.61	1.26	14.28	11.10	0.18	7.68	12.16	2.00	0.05	0.11	1.18	99.61	B
Hole 482D													
8-1, 30	46.24	1.79	14.35	10.90	0.25	6.40	10.56	2.08	0.46	0.17	5.61	98.81	A
8-1, 109-111	48.93	1.75	14.04	11.51	0.19	7.57	11.84	2.06	0.04	0.16	1.81	99.90	A
9-1, 48-50	49.21	1.78	13.86	11.59	0.20	7.70	11.80	2.17	0.03	0.17	1.46	99.97	A
9-3, 50-52	48.93	1.80	13.90	11.84	0.20	7.44	11.73	2.39	0.05	0.17	1.31	99.76	A
10-2, 52-55	49.31	1.76	13.84	11.60	0.19	7.64	11.78	2.42	0.05	0.17	1.39	100.15	A
10-2, 109-112	49.10	1.77	13.95	11.40	0.18	7.72	11.54	2.35	0.07	0.16	1.88	100.12	A
10-3, 14-16	49.36	1.90	13.89	11.92	0.19	7.51	11.33	2.65	0.04	0.17	1.32	100.27	E
10-3, 101-103	48.49	1.41	14.80	11.05	0.18	7.29	11.99	2.52	0.05	0.13	2.16	100.07	F
11-1, 135-137	48.65	1.41	14.32	11.10	0.18	7.86	11.91	2.35	0.04	0.12	1.73	99.67	F
12-1, 105-107	48.88	1.39	14.44	11.17	0.18	7.90	11.84	2.24	0.04	0.13	1.11	99.32	F
12-2, 50-52	49.09	1.29	14.15	11.24	0.18	8.09	12.10	2.26	0.03	0.11	1.25	99.79	B
12-2, 82-84	49.31	1.29	14.17	11.17	0.17	8.02	12.00	2.17	0.03	0.11	1.11	99.55	B
12-3, 118-120	49.35	1.27	14.43	11.06	0.17	7.64	12.18	2.24	0.03	0.11	1.04	99.52	B
13-1, 124-127	49.02	1.34	14.73	10.51	0.16	8.24	11.42	2.41	0.03	0.12	1.80	99.78	B
13-3, 4-6	49.07	1.31	14.13	11.16	0.17	8.67	11.57	2.36	0.06	0.11	1.60	100.2	B
Hole 482F													
4-3, 131-137	49.05	1.95	13.75	12.28	0.19	7.52	11.31	2.41	0.08	0.19	1.11	99.84	E
Hole 483													
13-4, 17-19	49.37	1.27	15.83	10.85	0.16	7.18	12.26	2.22	0.05	0.11	1.04	100.34	A
14-1, 35-37	48.25	1.18	14.48	10.54	0.23	8.23	12.23	2.38	0.07	0.11	2.08	99.78	B
14-2, 12-14	49.06	1.20	14.63	10.42	0.16	7.88	12.25	2.55	0.06	0.11	1.53	99.85	B
15-1, 21-24	49.01	1.19	14.59	10.49	0.17	8.43	12.44	2.44	0.05	0.11	1.04	99.96	B
15-2, 96-98	48.62	1.19	14.58	10.29	0.16	8.73	12.50	2.48	0.05	0.11	1.18	99.89	B
15-3, 7-9	49.75	1.37	14.38	10.87	0.17	7.59	12.09	2.47	0.04	0.10	1.18	100.01	C
16-1, 114-115	49.49	1.31	14.31	10.86	0.18	7.67	12.21	2.66	0.05	0.11	1.11	99.96	C
16-1, 133-134	49.23	1.34	14.29	11.16	0.18	7.64	12.02	2.47	0.05	0.11	1.18	99.67	C
16-2, 58-60	49.62	1.35	14.32	11.18	0.18	7.75	12.03	2.36	0.05	0.11	0.97	99.92	C
16-3, 10-12	49.54	1.25	14.45	10.60	0.16	8.28	11.66	2.57	0.05	0.11	1.46	100.13	—
17-1, 64-66	48.26	0.97	16.12	9.53	0.17	9.48	12.29	2.08	0.02	0.09	1.39	100.40	D
17-3, 16-18	48.28	0.95	16.31	9.47	0.16	9.31	12.63	1.98	0.02	0.08	1.39	100.58	D
18-4, 103-105	48.23	0.95	16.10	9.46	0.16	9.13	12.54	1.98	0.02	0.09	1.73	100.39	D
18-4, 140-142	49.05	1.72	14.89	10.27	0.15	6.97	11.87	2.70	0.13	0.19	1.11	99.05	E
19-1, 6-8	48.61	1.70	15.16	10.35	0.16	7.06	12.12	2.75	0.06	0.17	1.94	100.08	E
20-1, 39-40	48.96	1.88	14.26	12.31	0.20	7.04	11.56	2.53	0.11	0.18	0.83	99.86	F
20-1, 144-146	48.88	1.91	14.79	11.66	0.20	7.04	11.55	2.51	0.06	0.19	1.25	100.04	F
21-1, 86-88	49.04	1.86	14.70	12.15	0.22	6.95	11.64	2.41	0.08	0.17	0.69	99.91	F
21-2, 78-80	49.11	1.87	14.70	12.22	0.20	6.96	11.66	2.47	0.08	0.18	0.69	100.14	F
21-3, 53-55	48.58	1.78	14.59	12.01	0.22	7.23	11.81	2.38	0.06	0.18	1.18	100.02	G?
22-1, 40-42	48.78	1.72	14.36	11.76	0.20	7.24	11.91	2.33	0.10	0.16	0.76	99.32	F′
22-2, 84-87	49.00	1.65	14.76	11.38	0.19	6.97	12.24	2.38	0.11	0.15	1.18	100.01	F
22-3, 38-40	48.32	1.69	15.13	10.62	0.17	6.63	12.00	2.53	0.05	0.16	2.22	99.52	F′
22-4, 30-32	48.71	1.60	14.75	11.35	0.18	7.16	11.92	2.39	0.11	0.16	1.11	99.44	F′
23-1, 12-14	48.35	1.70	15.00	11.48	0.19	6.69	12.18	2.29	0.07	0.17	1.67	99.79	F′
23-1, 100-110	48.85	1.59	14.61	11.39	0.19	7.61	11.90	2.45	0.04	0.14	1.18	99.95	F′
23-2, 32-35	48.71	1.64	14.80	11.49	0.19	7.09	11.86	2.38	0.07	0.17	1.32	99.72	F′
24-2, 58-60	48.56	2.17	13.51	13.05	0.19	6.43	10.95	2.55	0.11	0.21	0.83	98.56	H
25-1, 3-5	48.96	1.27	15.70	10.77	0.19	6.87	12.51	2.34	0.06	0.12	0.97	99.76	H

Table 2. (Continued).

Sample (interval in cm)	SiO_2	TiO_2	Al_2O_3	Fe_2O_3[b]	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI[c]	Total	Chemical Type
Hole 483													
25-1, 67-69	48.48	2.17	14.58	11.81	0.18	7.07	11.01	2.58	0.07	0.22	1.87	100.04	H
26-1, 20-22	49.17	2.14	13.74	12.85	0.18	6.87	10.86	2.50	0.09	0.21	0.97	99.56	H
26-1, 128-130	48.27	2.19	14.39	12.01	0.19	7.02	10.75	2.66	0.11	0.21	1.88	99.68	H
26-3, 3-5	48.97	2.12	13.84	12.98	0.20	6.80	11.06	2.53	0.09	0.22	1.18	99.99	H
Hole 483B													
3-1, 49-50	49.16	1.24	15.55	10.97	0.17	7.23	12.34	2.35	0.05	0.10	0.69	99.85	A
3-1, 124-126	49.15	1.23	14.69	10.22	0.14	7.82	12.11	2.60	0.05	0.11	1.66	99.78	B
4-4, 50-53	49.24	1.21	14.85	9.95	0.17	7.70	12.70	2.64	0.06	0.12	1.32	99.96	B
7-2, 48-50	48.99	1.34	13.95	11.44	0.19	7.90	11.80	2.44	0.04	0.11	1.67	99.87	C
8-1, 46-48	48.08	0.95	15.99	9.47	0.16	9.37	12.15	2.24	0.03	0.08	1.88	100.40	D
9-1, 40-42	47.99	0.97	15.97	9.47	0.15	9.43	12.37	2.12	0.03	0.08	1.25	99.83	D
Bit-1, 1-3	48.50	1.56	14.95	11.32	0.19	7.23	11.99	2.44	0.08	0.15	1.53	99.94	I
12-1, 15-17	48.86	1.55	15.13	11.17	0.19	7.03	12.09	2.41	0.07	0.17	1.53	100.20	I
12-2, 94-96	48.01	1.72	14.17	11.69	0.21	7.38	11.96	2.52	0.04	0.14	1.66	99.50	I
13-1, 3-5	48.70	1.90	14.69	11.72	0.19	7.04	11.68	2.58	0.07	0.19	1.32	100.08	F
13-1, 145-147	48.40	1.83	14.31	12.09	0.19	6.91	11.55	2.38	0.14	0.18	1.18	99.16	F
13-2, 146-148	48.77	1.84	14.48	12.09	0.19	7.04	11.62	2.45	0.10	0.18	1.04	99.80	F
13-3, 135-137	48.94	1.83	14.48	12.17	0.19	6.98	11.63	2.50	0.13	0.17	1.25	100.27	F
14-2, 44-46	48.84	1.96	13.94	12.48	0.20	7.27	11.24	2.65	0.06	0.19	0.83	99.66	F
17-1, 85-87	48.50	2.16	13.56	12.89	0.20	6.50	11.20	2.59	0.05	0.20	1.53	99.38	H
17-3, 7-9	48.95	2.09	13.65	12.92	0.21	7.09	11.25	2.63	0.05	0.20	1.18	100.22	H
18-1, 30-32	48.31	2.13	13.38	12.39	0.22	6.88	11.16	2.67	0.08	0.21	1.81	99.19	H
18-3, 45-48	47.37	2.13	14.04	12.53	0.21	6.76	11.50	2.54	0.09	0.21	2.36	99.70	H
19-1, 123-125	49.00	2.19	13.79	12.38	0.19	6.84	11.09	2.68	0.10	0.21	1.32	99.79	H
19-2, 122-124	48.55	2.13	13.73	12.93	0.19	6.80	10.98	2.67	0.08	0.21	1.22	99.49	H
20-2, 137-139	48.06	2.03	13.93	12.35	0.20	7.20	11.55	2.48	0.07	0.20	1.73	99.80	H
21-2, 100-102	49.34	1.66	14.34	11.77	0.20	7.51	12.04	2.29	0.07	0.16	0.69	100.07	J
22-1, 115-117	48.34	1.67	13.90	11.64	0.19	6.86	11.97	2.43	0.06	0.15	1.11	98.28	J
23-1, 95-97	48.24	1.63	14.60	11.33	0.18	7.15	11.95	2.42	0.05	0.14	2.08	99.77	J
23-3, 29-31	48.81	1.63	14.57	11.54	0.19	7.42	12.01	2.37	0.06	0.14	1.11	99.85	J
23-4, 69-71	48.83	1.78	13.91	12.11	0.20	7.31	11.69	2.56	0.09	0.16	0.90	99.54	K
24-2, 11-14	47.90	1.88	14.62	10.66	0.20	6.92	11.68	2.66	0.10	0.18	3.34	100.14	K
25-3, 10-12	48.64	1.91	14.15	12.25	0.18	6.50	11.62	2.88	0.08	0.17	1.39	99.77	K
26-2, 96-100	47.71	1.87	14.71	11.19	0.17	6.79	11.07	2.88	0.12	0.16	3.06	99.73	K
26-2, 145-147	48.10	1.82	14.73	11.17	0.17	7.36	10.08	2.81	0.11	0.16	2.84	99.35	K
27-3, 85-87	49.30	1.85	13.94	12.42	0.18	7.06	11.47	2.48	0.08	0.16	1.11	100.05	K
28-1, 66-68	49.14	1.71	14.11	11.78	0.18	7.54	11.70	2.43	0.08	0.15	1.25	100.07	K'
30-1, 31-34	49.01	1.75	14.46	11.37	0.21	7.45	11.72	2.56	0.07	0.16	1.10	99.86	K'
31-2, 86-89	48.42	1.58	14.39	11.51	0.22	7.36	11.84	2.33	0.18	0.15	1.25	99.23	K'
32-1, 135-137	48.51	1.59	15.25	10.00	0.17	7.86	12.07	2.30	0.04	0.14	1.80	99.67	K'
32-3, 62-64	48.95	1.82	14.04	12.14	0.22	7.06	11.68	2.38	0.17	0.16	0.76	99.38	K
Hole 483C													
4-2, 110	49.77	1.32	14.39	11.22	0.17	7.57	12.26	2.53	0.04	0.11	0.90	100.28	—
4-5, 103-105	49.68	1.32	14.29	11.24	0.17	7.37	12.12	2.64	0.05	0.11	1.04	100.03	—
Hole 484													
7-1, 5-7	47.62	2.06	15.69	11.38	0.19	5.49	11.68	2.73	0.32	0.21	1.93	99.30	—
Hole 485A													
11-3, 82-83	47.06	1.42	15.42	10.27	0.15	9.62	11.34	2.44	0.02	0.10	1.80	99.64	—
12-1, 62-64	48.74	2.08	13.33	13.23	0.21	6.94	11.41	2.40	0.04	0.19	0.83	99.40	—
13-1, 103-105	48.59	1.95	13.58	12.85	0.20	6.90	11.46	2.31	0.05	0.18	1.32	99.39	—
17-1, 112-114	48.19	2.17	14.39	12.28	0.17	6.81	10.83	2.51	0.06	0.20	1.73	99.34	—
23-1, 118-120	48.21	2.16	14.25	12.63	0.18	6.86	10.93	2.48	0.08	0.20	1.46	99.44	—
24-1, 89-91	48.62	1.97	14.70	11.60	0.18	7.16	11.47	2.49	0.07	0.18	1.11	99.55	—
25-3, 14-16	48.33	2.10	14.00	12.49	0.20	7.33	11.14	2.36	0.07	0.20	1.46	99.68	—
29-2, 122-124	48.65	2.17	13.71	12.80	0.18	7.49	10.70	2.41	0.11	0.20	1.52	99.94	—
29-4, 62-64	48.52	2.17	12.98	13.09	0.21	7.53	10.92	2.30	0.07	0.19	1.59	99.57	—
30-1, 39-41	48.87	2.20	13.04	13.08	0.20	7.32	11.10	2.25	0.06	0.19	1.32	99.63	—
30-3, 103-105	48.62	2.04	14.58	12.35	0.19	6.48	10.92	2.55	0.07	0.20	1.18	99.18	—
31-2, 81-83	48.83	1.80	14.10	11.67	0.19	7.68	11.89	2.33	0.12	0.17	1.11	99.89	—
35-1, 83-85	49.14	1.72	14.29	11.86	0.17	7.72	11.72	2.38	0.05	0.18	0.65	100.22	—
35-6, 10-12	49.14	1.81	13.96	12.21	0.18	7.58	11.51	2.38	0.07	0.19	0.63	100.01	—
39-4, 8-10	48.69	1.80	14.77	12.03	0.18	7.33	11.29	2.17	0.19	0.19	0.63	99.90	—

[a] Values shown in wt.%.
[b] Fe_2O_3 as total iron.
[c] LOI = loss on ignition at 1050°C; heated to 110°C for 1 hr. prior to determination of loss on ignition.

the Cr and Ni concentrations (517 and 220 ppm, respectively), which are similar to the theoretical values for a primitive liquid and to observed concentrations in the most primitive glass samples recovered in the FAMOUS area (Cr: 600 ppm; Ni: 250 ppm; Bougault et al., 1979). Thus the process of fractional crystallization is observed through high partition coefficient elements (such as Cr and Ni), but the observed concentrations of these elements also indicate that some of the liquids have evolved along independent paths in terms of the proportions of olivine and clinopyroxene removed. These observations, together with the absence of a correlation between the degree of fractionation on the one hand and either the distance from the axis or the depth in the crust on the other seems to argue for the existence of several magma chambers rather than a single large magma chamber under the ridge (O'Hara, 1977; Bryan and Thompson, 1979).

It should also be noted that if all of the liquids represented by the basalts in this study had been derived from the same magma chamber, we should observe an inverse correlation between Mg, Ni, and Cr on the one hand

Table 3. Trace element composition of basalts.[a]

Sample (interval in cm)	Chemical Type	Sc	Ti	V	Cr	Mn	Fe	Co		Ni		Zn	Rb	Sr	Y	Zr	Nb	Cs	La	Eu	Tb	Hf	Ta	Th	U
								XRF	NAA	XRF	NAA					XRF									
Hole 482B																									
10-7, 14-16	A		10,620	335	281	1781	91,350	42		65		75	<1	107	44	103	2.5								
11-1, 23-25	A	40	10,560	344	292	1549	79,730	41	44	74	71	80	<1	111	47	119	3.0	0.06	3.08	1.38	0.9	3.11	0.14	0.08	0.04
12-2, 135-137	A		10,440	345	293	1394	81,270	41		73		70	<1	107	46	n.d.	2.0								
14-2, 121-124	F		8,340	293	260	1394	77,490	43		98		71	<1	91	37	84	1.5								
15-1, 135-139	B		7,800	324	192	1394	76,930	44		58		74	<1	92	37	80	1.0								
15-3, 117-119	B		7,560	307	184	1239	76,650	41		57		73	<1	94	35	81	2.5								
16-1, 36-38	B		7,620	309	176	1239	76,580	43		63		65	<1	93	35	84	1.3								
17-2, 111-113	B	38	7,800	309	187	1471	79,450	43	45	60	55	73	<1	94	36	79	1.8	0.01	1.79	1.14	0.67	1.98	0.08	0.05	
18-1, 18-20	B	41	7,800	314	178	1316	78,820	44	47	60	58	73	<1	93	35	83	1.5	0.04	2.14	1.06	0.71	2.13	0.09	0.05	0.06
18-2, 99-101	D'		9,240	339	197	1471	82,670	43		64		79	<1	90	43	101	1.0		2.38						0.03
19-1, 96-100	C		13,200	464	150	929	80,920	47		51		79	<1	119	50	151	2.0								
20-3, 24-26	D'		9,240	371	199	1239	69,790	43		67		81	<1	97	43	103	1.3								
21-1, 62-64	E		11,280	354	197	1239	81,900	40		67		69	<1	112	50	130	2.0								
21-3, 74-76	D'''	39	9,660	317	241	1316	74,550	39	42	62	62	74	<1	126	41	116	1.5	0.01	2.97	1.35	0.83	2.88	0.10	0.06	0.06
22-2, 34-36	D'''		9,360	305	228	1239	74,480	38		61		67	<1	125	41	116	1.5								
22-4, 34-36	D'''		9,060	296	263	1239	72,590	39		71		63	<1	125	40	106	1.0								
24-1, 93-95	D''	42	9,780	385	193	1162	71,540	46	46	63	66	80	<1	96	44	108	2.0	0.08	2.50	1.09	0.84	2.75	0.10	0.06	0.23
Hole 482C																									
9-1, 121-123	A		10,620	361	277	1549	81,060	40		67		85	<1	110	48	125	2.5								
10-2, 73-75	A	39	10,260	353	288	1471	79,870	42	43	72	72	73	<1	106	45	121	1.5	0.6	2.9	1.35	0.89	3.1	0.13	0.09	0.04
11-1, 115-117	A	40	10,680	365	323	1316	79,520	43	45	81	77	70	<1	114	48	127	3.0	0.06	2.9	1.42	0.91	3.05	0.14	0.09	
11-1, 138-139	A		10,380	344	357	1316	77,560	41		84		70	<1	111	48	122	2.5								
11-2, 16-18	F		7,920	292	361	1162	74,060	38		79		40	<1	92	36	88	0.5								
11-2, 21-24	F		7,140	261	376	1007	80,570	37		80		26	<1	84	30	75	1.0								
11-3, 141-143	A		10,740	329	294	1394	8,160	41		72		67	<1	113	48	120	1.5								
12-1, 11-13	B		7,800	310	182	1397	78,400	42		59		75	<1	93	35	81	1.0								
12-2, 95-97	B		7,800	305	172	1397	79,310	41		58		69	<1	94	36	87	2.0								
13-1, 22-24	B	39	7,800	325	177	1162	73,290	42	44	55	57	65	<1	93	36	80	2.0	0.2	1.84	1.03	0.68	2.05	0.09	0.06	0.20
13-1, 125-127	B		7,740	311	175	1316	77,910	40		56		71	<1	93	35	76	2.5								
13-3, 108-110	B		7,800	307	172	1394	78,890	43		57		70	<1	93	36	78	2.0								
14-1, 40-42	B		7,680	287	163	1316	77,420	40		54		64	<1	94	36	81	1.0								
14-4, 127-129	B		7,740	306	195	1316	78,540	41		57		59	<1	92	36	75	1.5								
15-1, 44-46	B		7,620	305	180	1394	78,330	40		58		68	<1	92	35	80	2.0								
15-2, 132-134	B		7,620	292	170	1316	77,210	41		59		72	<1	92	35	75	1.0								
15-3, 97-99	B		7,620	307	174	1394	78,120	41		56		65	<1	94	35	74	1.5								
15-4, 119-121	B		7,560	305	191	1394	77,700	40		60		65	<1	92	34	82	2.0								
Hole 482D																									
8-1, 30	A		10,740	340	306	1936	76,300	38		60		75	4.4	104	44	111	2.0								
8-1, 109-111	A		10,500	355	268	1471	80,570	43		70		74	<1	111	46	119	2.0								
9-1, 48-50	A		10,680	357	301	2549	81,130	42		73		83	<1	107	46	120	2.5								
9-1, 50-52	A	41	10,800	357	293	1549	82,880	43	44	71	71	72	<1	109	48	124	3.0	0.11	3.1	1.5	0.86	3.36	0.14	0.1	0.05
10-2, 53-55	A		10,560	341	288	1471	81,200	40		71		79	<1	108	47	127	2.5								
10-2, 109-112	A		10,620	346	287	1394	79,800	41		73		76	<1	106	46	122	2.0								
10-3, 14-16	E	42	11,400	360	265	1471	83,440	42	45	65	66	80	<1	108	51	133	1.5	0.05	3.3	1.31	1.07	3.52	0.15	0.12	
10-3, 101-103	E	38	8,460	306	279	1394	77,350	43	46	99	98	73	<1	91	38	91	1.5	0.08	2.26	1.23	0.75	2.38	0.09	0.06	0.23
11-1, 135-137	F	36	8,460	307	266	1394	77,700	44	44	86	87	77	<1	94	37	91	1.5	0.06	2.0	1.10	0.73	2.23	0.10	0.07	
12-1, 105-107	F		8,340	303	253	1394	78,190	42		96		74	<1	97	38	84	3.0								
12-2, 50-52	B		7,740	316	198	1394	78,680	43		63		73	<1	93	36	78	3.0								
12-2, 82-84	B		7,740	317	188	1316	78,190	44		63		66	<1	91	35	79	2.0								
12-3, 118-120	B	38	7,620	293	164	1316	77,420	41	45	59	57	65	<1	95	35	83	2.5		2.05	0.98	0.68	2.21	0.08	0.04	
13-1, 127-129	B	40	8,040	340	188	1239	73,570	43	45	64	57	79	<1	99	36	80	1.0	0.03	1.90	0.98	0.68	2.09	0.09	0.05	
13-3, 4-6	B		7,860	314	163	1316	78,120	43		61		70	<1	95	37	85	2.5								
Hole 482F																									
4-3, 131-137	E	40	11,700	360	212	1471	85,960	43	44	64	59	80	<1	113	51	135	2.5	0.04	3.2	1.61	1.00	3.4	0.15	0.10	0.07
Hole 483																									
13-4, 17-19	A		7,620	311	174	1,239	75,950	40		70		73	<1	993	34	74	1								
14-1, 35-37	B	37	7,080	267	369	1,781	73,780	42	45	69	65	80	<1	110	30	78	2.5	0.14	1.72	1.04	0.59	1.84	0.10	0.04	
14-2, 12-14	B		7,200	275	373	1,239	72,940	43		73		62	<1	114	31	75	2								
15-1, 21-24	B		7,140	256	380	1,316	73,430	42		71		56	<1	113	31	77	1								
15-2, 96-98	B		7,140	261	378	1,239	72,030	40		68		59	<1	114	30	78	2								
15-3, 7-9	C		8,220	298	241	1,316	76,090	44		57		73	<1	97	36	79	1.5								
16-1, 114-115	C		7,860	288	258	1,394	76,020	43		58		62	<1	94	34	75	1.5								
16-1, 133-134	C		8,040	291	242	1,394	78,120	42		57		70	<1	94	36	75	1.5								
16-2, 58-60	C		8,100	304	238	1,394	78,260	45		57		74	<1	94	36	80	1.5								
16-3, 10-12			7,500	300	320	1,239	74,200	44		61		69	<1	103	33	72	1.5								
17-1, 64-66	D		5,820	217	358	1,316	66,710	44		107		52	<1	97	26	57	0.5								
17-3, 16-18	D		5,700	208	333	1,239	66,290	44		106		51	<1	134	25	61	0.5								
18-4, 103-105	D		5,700	215	348	1,239	66,220	43		112		58	<1	101	25	60	0.0								
18-4, 140-142	E		10,320	288	300	1,161	71,890	41		89		73	<1	166	41	124	3								
19-1, 6-8	E		10,200	303	296	1,239	72,450	42		88		73	<1	166	41	128	3								
20-1, 39-40	F		11,280	354	188	1,549	86,170	43		68		86	<1	101	49	132	2								
20-1, 144-146	F		11,460	385	192	1,549	81,620	45		66		90	<1	106	51	138	3.5								
21-1, 86-88	F		11,160	372	198	1,704	85,050	43		67		91	<1	101	49	131	3								
21-2, 78-80	F		11,220	370	205	1,549	85,540	43		67		88	<1	101	50	134	2.5								
21-3, 53-55	G?		10,680	362	222	1,704	84,070	43		68		85	<1	100	47	124	2.5								
22-1, 40-42	F'		10,320	337	274	1,549	82,320	42		78		83	<1	98	46	123	2								
22-2, 84-87	F'		9,990	340	297	1,471	79,660	42		82		81	<1	96	45	116	3								
22-3, 38-40	F'		10,140	350	316	1,316	74,340	44		89		86	<1	102	46	126	2.5								
22-4, 30-32	F'		9,600	321	283	1,394	79,450	41		91		78	1	99	42	105	2.5								
23-1, 12-14	F'		10,200	335	248	1,471	80,360	41		77		81	<1	103	45	120	2								
23-1, 108-110	F'		9,540	311	278	1,471	80,360	41		98		68	<1	99	43	113	1.5								
23-2, 32-35	F'	39	9,840	333	258	1,471	80,430	42	44	77	82	80	<1	101	44	118	2.5	0.05	3.1	1.06	0.81	3.12	0.16	0.14	
24-2, 58-60	H	41	13,020	390	162	1,471	91,350	44	46	70	71	90	<1	105	54	155	3		4.5	1.38	1.09	3.94	0.23	0.19	0.07
25-1, 3-5	A	38	7,620	293	180	1,471	75,390	40	44	64	64	70	<1	89	33	71	1.5	0.04	1.77	0.95	0.60	2.04	0.08	0.06	0.04
25-1, 67-69	H		13,020	440	169	1,394	82,670	48		77		98	<1	114	56	156	4								
26-1, 20-22	H		12,840	395	163	1,394	89,950	42		68		88	<1	104	55	158	4								
26-1, 128-130	H	43	13,140	430	182	1,471	84,070	46	47	67	70	95	<1	109	56	156	3.5	0.04	4.3	1.59	1.15	3.98	0.22	0.19	0.28
26-3, 3-5	H		12,720	386	155	1,549	90,860	43		63		87	<1	104	55	150	3.5								

Table 3. (Continued).

Sample (interval in cm)	Chemical Type	Sc	Ti	V	Cr	Mn	Fe	Co		Ni		Zn	Rb	Sr	Y	Zr	Nb	Cs	La	Eu	Tb	Hf	Ta	Th	U
								XRF	NAA	XRF	NAA					XRF									
Hole 483B																									
3-1, 49-50	A	36	7,440	290	176	1,316	76,790	40	44	65	62	68	<1	88	33	67	1.5	0.06	1.7	1.09	0.66	1.97	0.08	0.05	0.04
3-1, 124-126	B		7,380	280	370	1,084	71,540	42		71	68	58	<1	116	31	75	2								
4-4, 50-53	B		7,260	270	381	1,316	69,650	43		72		51	<1	114	32	75	2								
7-2, 48-50	C		8,040	281	243	1,471	80,080	42		60		65	<1	105	35	78	2								
8-1, 46-48	D		5,700	207	351	1,239	66,290	44		115		55	<1	93	26	62	1								
9-1, 40-42	D		5,820	199	336	1,162	66,290	42		107		50	<1	98	24	58	0.5								
Bit-1, 1-3	I		9,360	307	209	1,471	79,240	43		74		72	<1	116	40	104	3.5								
12-1, 15-17	I		9,300	312	221	1,471	78,190	42		75		74	<1	117	40	106	2.5								
12-2, 94-96	I	43	10,320	355	213	1,626	81,830	43	46	66	66	81	<1	115	44	113	4	0.02	2.9	1.3	0.93	2.95	0.15	0.11	
13-1, 3-5	F		11,400	379	211	1,471	82,040	45		71		88	<1	106	51	135	2.5								
13-1, 145-147	F		10,980	348	209	1,471	84,630	43		75		77	<1	102	48	135	2								
13-2, 146-148	F		11,040	363	214	1,471	84,630	42		67		84	<1	102	50	140	3								
13-3, 135-137	F	41	10,980	354	210	1,471	85,190	41	45	69	72	83	1	105	50	136	3.5	0.06	3.7	1.52	1.05	3.62	0.19	0.16	
14-2, 44-46	F		11,760	390	216	1,549	87,360	45		66		88	<1	102	52	140	4.5								
17-1, 85-87	H		12,960	387	166	1,549	90,230	44		64		87	<1	107	55	156	3.5								
17-3, 7-9	H		12,540	385	176	1,626	90,440	44		65		83	<1	105	54	153	3.5								
18-1, 30-32	H		12,780	412	165	1,704	86,730	43		62		87	<1	107	55	157	4								
18-3, 45-48	H		12,780	425	171	1,626	87,710	46		65		92	<1	108	56	156	4.5								
19-1, 123-125	H		13,140	410	158	1,471	86,660	44		59		91	<1	109	58	161	4								
19-2, 122-124	H		12,780	401	166	1,471	90,510	44		65		96	<1	105	56	155	5								
20-2, 137-139	H		12,180	403	249	1,549	86,450	44		69		91	<1	100	53	147	3								
21-2, 100-102	J		9,960	351	225	1,549	82,390	44		63		83	<1	108	42	108	2								
22-1, 115-117	J		10,020	340	215	1,471	81,480	44		59		76	<1	107	41	107	2								
23-1, 95-97	J		9,780	334	218	1,394	79,310	43		54		78	<1	108	41	106	2								
23-3, 29-31	J	38	9,780	336	218	1,471	80,780	44	44	69	74	79	<1	109	40	106	2.5	0.04	3.3	0.99	0.80	2.73	0.15	0.11	0.18
23-4, 69-71	K		10,680	361	205	1,549	84,770	45		67		81	<1	109	45	118	2.5								
24-2, 11-14	K		11,280	394	195	1,549	74,620	46		68			<1	119	48	121	2.5								
25-3, 10-12	K		11,460	359	154	1,394	85,740	43		54		85	<1	114	48	130	2.5								
26-2, 96-100	K		11,220	390	197	1,316	78,330	46		66		92	<1	119	47	121	3								
26-2, 145-147	K		10,920	379	198	1,316	78,190	48		68		85	1	115	46	117	3.5								
27-3, 85-87	K		11,100	353	166	1,394	86,940	43		61		84	<1	112	48	126	3								
28-1, 66-68	K'		10,260	332	233	1,394	82,460	41		80		68	1	109	45	117	3.5								
30-1, 31-34	K'	39	10,500	359	265	1,626	79,590	45	47	109	111	83	<1	112	45	118	3		3.7	1.47	0.9	3.05	0.18	0.15	0.34
31-2, 86-89	K'		9,480	321	358	1,703	80,570	46		128		74	2.7	110	41	99	3.5								
32-1, 135-137	K'	38	9,540	333	354	1,316	70,000	44	48	123	125	76	<1	121	41	110	2		3.2	1.12	0.75	2.66	0.17	0.19	0.13
32-3, 62-64	K		10,920	374	185	1,703	84,980	46		68		93	2.9	106	47	122	2								
Hole 483C																									
4-2, 110		41	7,920	298	179	1,316	78,540	42	48	67	60	65	<1	109	34	89	2	0.05	2.04	1.24	0.7	2.18	0.08	0.05	
4-5, 103-105			7,920	288	169	1,316	78,680	43		70		64	<1	108	34	84	1								
Hole 484A																									
7-1, 5-7		46	12,360	320	275	1,471	79,660	41	44	101	102	86	2.2	161	47	140	7	0.08	6.5	1.69	1.0	3.76	0.58	0.45	0.73
Hole 485A																									
11-3, 82-83		36	8,520	244	517	1,162	71,890	47	49	220	230	62	<1	135	35	90	1.5	20	2.5	1.28	0.65	2.37	0.07		0.05
12-1, 62-64		42	12,480	432	167	1,626	92,610	46	45	69	62	92	<1	90	57	134	3.0		3.5	1.62	1.07	3.72	0.12	0.05	
13-1, 103-105		41	11,700	408	177	1,549	89,950	44	46	76	72	90	<1	107	53	132	2.0	0.7	2.8	1.70	1.10	3.42	0.12	0.05	
17-1, 112-114		43	13,020	426	252	1,316	85,960	46	46	101	95	92	<1	105	55	151	3.5	0.12	3.5	1.55	1.14	4.00	0.16	0.12	
23-1, 118-120			12,960	381	212	1,394	88,410	43		84		80	<1	109	56	145	3.4								
24-1, 89-91			11,820	385	276	1,394	81,200	42		90		74	<1	105	51	136	3.0								
25-3, 14-16		42	12,600	384	230	1,549	87,430	43	44	91	86	82	<1	155	55	144	2.0	0.30	3.5	1.6	1.18	3.88	0.18	0.13	
29-2, 122-124			13,020	390	267	1,394	89,600	43		91		85	1.9	94	57	142	2.5								
29-4, 62-64		46	13,020	419	294	1,626	91,630	42	45	65	62	88	1.0	94	57	143	2.0	0.17	3.95	1.62	1.16	3.83	0.18	0.11	
30-1, 39-41			13,200	411	335	1,549	91,560	40		59		87	<1	97	57	142	2.0								
30-3, 103-105		38	12,240	348	266	1,471	86,450	40	42	75	78	74	<1	106	56	151	1.0	0.11	3.60	1.41	1.09	3.81	0.17	0.13	0.03
31-2, 81-83		43	10,800	351	458	1,471	81,690	40	44	102	105	77	2	96	49	119	4.5	0.26	3.2	1.26	0.87	3.22	0.14	0.01	
35-1, 83-85			10,320	337	262	1,316	83,020	41		67			<1	99	45	108	1.7								
35-6, 10-12			10,860	347	253	1,394	85,470	42		74			<1	98	47	110	2.4								
39-4, 8-10			10,800	342	210	1,394	84,210	44					<1	100	46	112	1.4								

Note: XRF = X-ray fluorescence; NAA = neutron activation analysis.
[a] Values shown in ppm.

and Ti and the hygromagmaphile elements on the other: this is obviously not the case. The absence of such a correlation was interpreted by Rhodes et al. (1979) to result from the mixing of a new primitive liquid with differentiated liquids. Such an explanation is possible, but it cannot apply to large, long-lived magma chambers (Bryan and Thompson, 1979) which are continually fractionating and being refilled by new primitive liquid. Such a process would imply higher and higher concentrations of hygromagmaphile elements: since these elements are trapped in the liquid, long-life magma chambers would be factories for hygromagmaphile element enrichment.

Finally, we note that the spectrum of hygromagmaphile elements observed in the cores recovered during Leg 65 from a portion of the East Pacific Rise where the opening rate is about 6 cm/y. is very similar to the spectrum observed at 22°N in the Atlantic Ocean (opening rate: 2 cm/y.). The idea of the lifetime of a magma chamber as a function of spreading rate is therefore not supported by evidence from trace element geochemistry.

In summary, trace element studies of the basalts recovered on Leg 65 provide the following:

1) Evidence of the removal of olivine, spinel, and(or) clinopyroxene in proportions which varied from unit to unit;

2) No evidence of a clear correlation between the degree of fractionation and either distance from the axis or depth in the crust; and

3) A spectrum of hygromagmaphile elements similar to that observed for the Mid-Atlantic Ridge at 22°N. Qualitatively, these observations support the existence of discrete magma chambers. Until they have been quantified, however, we would not like to say that large

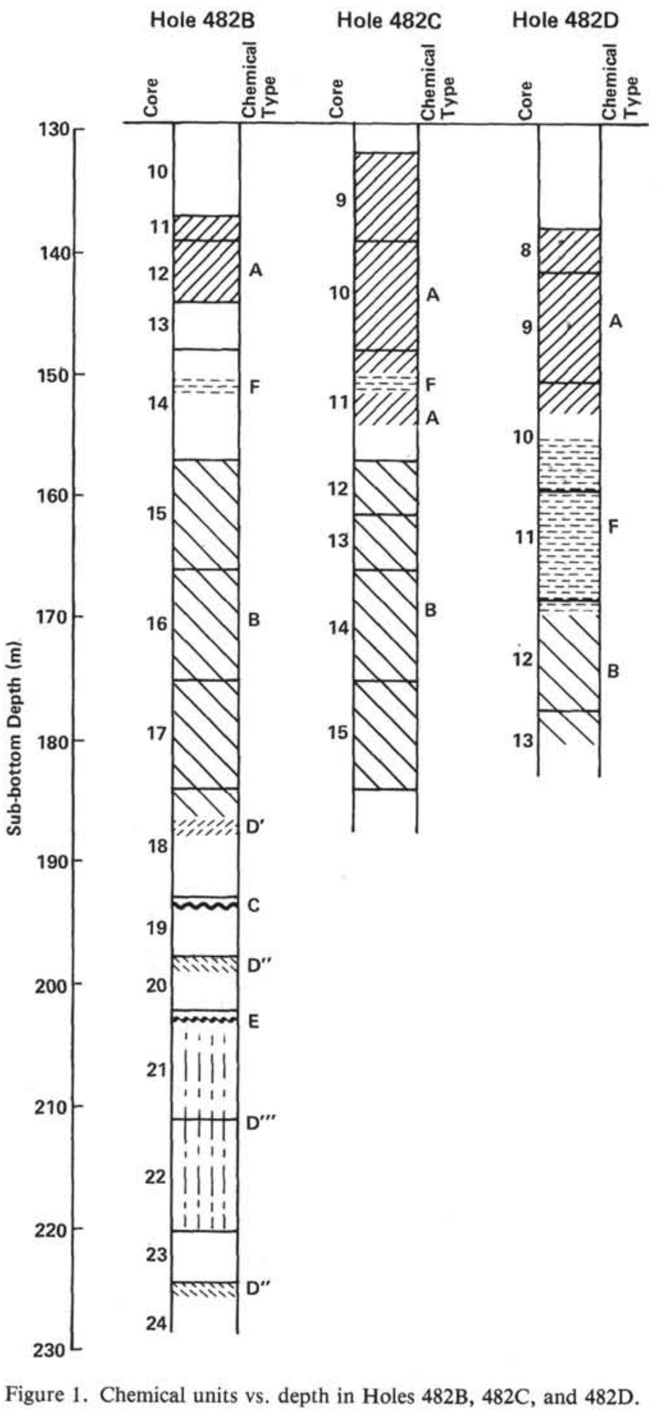

Figure 1. Chemical units vs. depth in Holes 482B, 482C, and 482D.

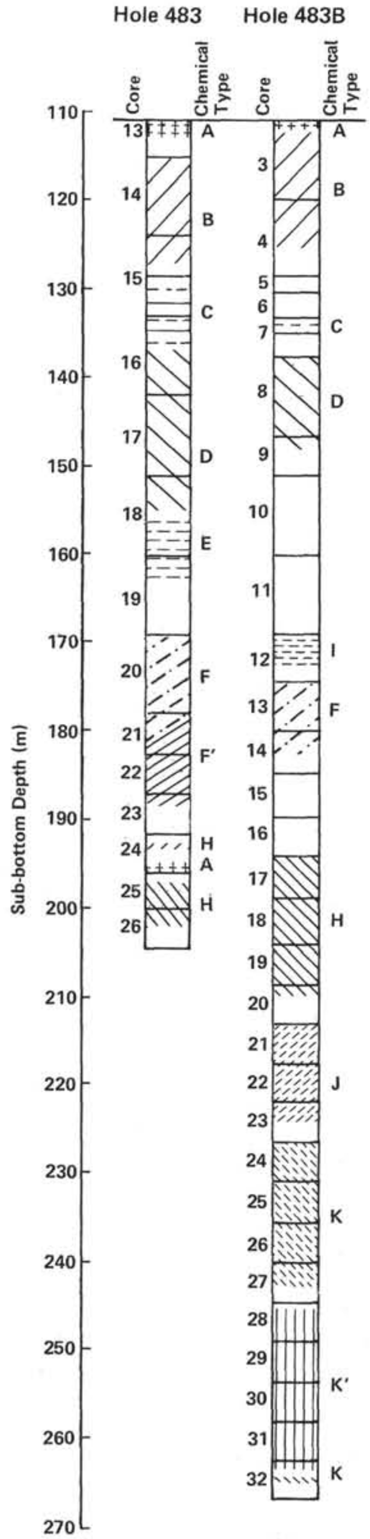

Figure 2. Chemical units vs. depth in Holes 483 and 483B.

magma chambers living for a long period of time do not exist. Nevertheless, any model involving large magma chambers will have to account for the apparently incompatible distribution of some of the elements observed in this study and for the field relationships observed between chemical types.

HYGROMAGMAPHILE ELEMENT GEOCHEMISTRY

On the basis of the classification scheme for the hygromagmaphile elements proposed by Bougault et al. (1979) and their chemical properties, the elements in the pairs Nb-Ta, Zr-Hf, and Y-Tb fractionate very little with respect to each other during magma genesis; this property is well known for Y, the position of which coincides with that of Tb in Coryell-Masuda rare-earth element diagrams. The Nb/Ta, Zr/Hf, and Y/Tb ratios in the basalts are close to the ratios observed in "primordial chondritic earth" material (17, 40, and 46, respectively).

From Tables 4 and 5, in which the average trace element compositions of the chemical types at each site are reported, it is readily seen that all of the Zr/Hf ratios lie between 38 and 40, which confirms that the ratio found previously for oceanic tholeiites is independent of mantle heterogeneity. The Y/Tb ratio is close to 50, which is higher than the presently accepted mean value of 46 for chondrites. We note that this ratio is the same as that which can be deduced from the Leg 54 data (Joron et al., 1980). Nonetheless, before any explanation of this apparent difference is attempted, we must examine for possible sources of analytical error.

A single Nb determination by XRF techniques is accurate to about ± 1 ppm: for this reason, it is not possible to calculate a Nb/Ta ratio from a single analysis if the sample has an Nb concentration of between 1 and 4 ppm. The average Nb value for each homogeneous unit is known to about 0.5 ppm, but this precision is still not sufficient for a Nb/Ta calculation. The Nb/Ta ratio can be determined statistically, however, from the average values for each type using the least-squares method as indicated in Figure 3. The Nb/Ta ratio found by this method is 16.4, which is very close to the value of 17 observed in the Atlantic Ocean, indicating that this ratio is also independent of any mantle heterogeneity.

Except for the small discrepancy observed for the Y/Tb ratio (which is probably analytical), the ratios of the pairs of elements which do not fractionate during magma genesis (Nb/Ta, Zr/Hf, and Y/Tb) are the same for the Atlantic and Pacific Oceans and represent the ratios for a primordial homogeneous Earth of chondritic composition.

Two different La/Ta ratios have been found to date: 9, which corresponds to a rare-earth element distribution which is either flat or reflects light rare-earth element enrichment, and 18, which reflects light rare-earth element depletion. In the Atlantic, a ratio of 9 has been found for the FAMOUS area, for 45°N, and for the Reykjanes Ridge, and a value of 18 has been found on each side of the Mid-Atlantic Ridge at 22°N (Legs 45 and 46) and at 25°N on 110 m.y. old crust (Legs 51, 52, and 53). In the Pacific Ocean, a value of 9 has been found for rocks from the Emperor Seamount chain (Leg 55, Cambon et al., 1980) and 18 was measured on the East Pacific Rise (Leg 54, Joron et al., 1980). The average values of the La/Ta ratio for the chemical types at Sites 482 and 483 are plotted in Figure 4: the value of 20 determined by the least-squares method is close to that associated with the Leg 54 basalts at 9°N and indicates light rare-earth element depletion.

Recently, the classification of those elements whose ions have a rare-gas electron structure has been improved by taking theoretical considerations into account (Bougault, 1980) and by incorporating the results of comparative geochemical studies. The hygromagmaphile character of an element not only depends upon its ion size but also upon its ability to form complexes in the liquid (Ringwood, 1955; Treuil, 1973). The hygromagmaphile character, Φ, of an element is described by the relation,

$$\Phi = [a(\Delta R_i)^2 + 1] + \phi, \qquad (1)$$

Table 4. Average trace element composition, $\bar{x}$, of chemical types at Site 482.[a]

Chemical Type		Sc	Ti	V	Cr	Mn	Fe	Co XRF	Co NAA	Ni XRF	Ni NAA	Zn	Rb	Sr	Y	Zr	Nb	Cs	La	Eu	Tb	Hf	Ta	Th	U
A	$\bar{x}$	40	10,570	351	295	1,405	80,333	41.3		72.8		75.9	<1	108.6	46.6	122.6	2.4	—	3.0	1.41	0.89	3.16	0.14	0.09	0.04
	σ		155	8	24	156	1,925	1.4		5.2		5.1		2.7	1.3	3.0	0.5		0.1	0.07	0.02	0.14	0.01	0.01	
B	$\bar{x}$	39.2	7,737	309	179	1,335	77,812	42		58.7		68.7	<1	93.1	35.5	79.7	1.8	—	1.94	1.04	0.68	2.09	0.09	0.05	
	σ	1.3	113	12	10	73	1,291	1.4		2.6		4.3		1.1	0.8	3.0	0.6		0.15	0.07	0.02	0.09	0.01	0.01	
F	$\bar{x}$	38	8,400	301	264	1,394	77,682	43		95		73.7	<1	93.2	37.5	87.5	1.5	—	2.1	1.15	0.74	2.3	0.1	0.07	
	σ		69	6	11		367			6		2.5		2.9	0.6	4.0									

[a] Values shown in ppm; σ represents one standard deviation.

Table 5. Average trace element composition, $\bar{x}$, of chemical types at Site 483.[a]

Chemical Type		Sc	Ti	V	Cr	Mn	Fe	Co XRF	Co NAA	Ni XRF	Ni NAA	Zn	Rb	Sr	Y	Zr	Nb	Cs	La	Eu	Tb	Hf	Ta	Th	U
A	$\bar{x}$	36	7500	300	175	1300	76200	40		67		70	<1	90	33	70	1	—	1.7	1.1	0.66	1.97	0.08	0.05	
B	$\bar{x}$	37	7200	268	375	1300	72230	42		71		60	<1	113.5	31	76.3	1.9	—	1.7	1.04	0.6	1.84	0.1	0.4	
	σ		107	9	5		1520			2				2	0.8	1.5	0.5								
C	$\bar{x}$		8052	292	244	1400	77715	43.2		58		70	<1	95	35.4	77	1.5								
	σ		130	9	8		1700	1.3		1.3					0.9	2									
D	$\bar{x}$		5750	210	345	1250	66300	43		109		53	<1	97	25.4	60	0.5	—							
	σ		66	7	10					4				3	0.9	2	0.4								
F	$\bar{x}$		11250	368	205	1500	84750	43		68.4		87	<1	103	50	136	2.9	—	3.7	1.52	1.05	3.62	0.19	0.16	
	σ		256	15	10			1.4		3				2	1	3	0.8								
F'	$\bar{x}$		9934	332	279	1450	80000	42		84		80	<1	99	44.4	117	2.3	—	3.1	1.06	0.81	3.12	0.16	0.14	
	σ		300	12	23			1		8				2	1.5	7	0.5								
H	$\bar{x}$		12825	405	166	1500	88135	44		66		90	<1	106	55	155	3.9	—	4.4	1.5	1.12	3.96	0.22	0.19	
	σ		270	18	8		2860	1.6		5		4		3	1	3.6	0.5								
J	$\bar{x}$		9885	340	219	1500	80500	44		61		79	<1	108	41	107	2.3	—	3.3	0.99	0.8	2.73	0.15	0.11	
	σ		123	7	4					6				1	1	1	0.5								
K	$\bar{x}$		11150	374	186	1400	83000	45		64		87	<1	114	47	123	2.7	—							
	σ		212	16	19			2.5		6		5		5	0.8	5	0.5								

[a] Values shown in ppm; σ represents one standard deviation.

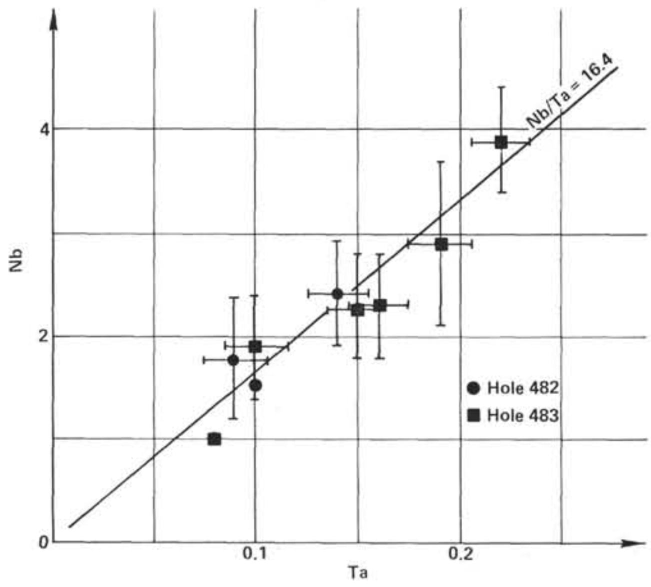

Figure 3. Least-squares determination of Nb/Ta ratio for Sites 482 and 483, using average values for each chemical type.

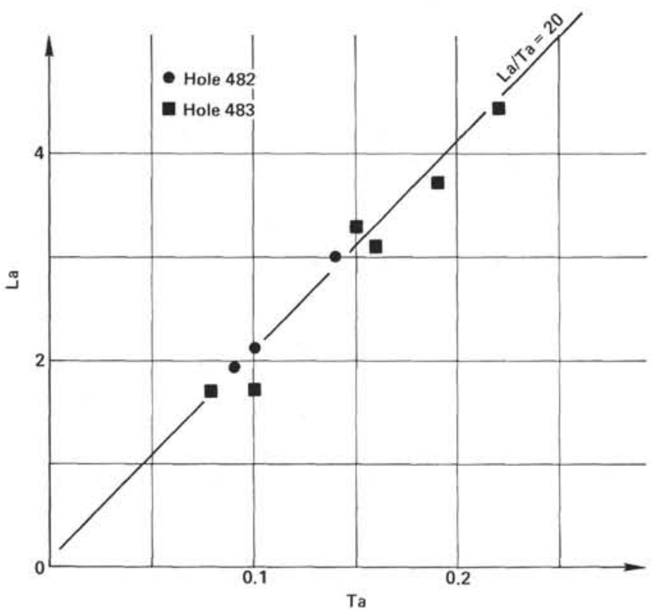

Figure 4. Least-squares determination of La/Ta ratio for Sites 482 and 483, using average values for each chemical type.

where ΔR_i is the difference between the major and trace element ionic radii, ϕ is the ionic potential of the trace element, and a is a parameter which defines the relative importance of the two functions, ΔR_i and ϕ, which are responsible for the hygromagmaphile character of the element. According to this relation, ΔR_i is thus a measure of the inability of an element to enter into a crystal structure and ϕ is a measure of its ability to form complexes in a magma. This theoretical approach, which is in perfect agreement with the results of comparative geochemical studies, leads to the classification of hygromagmaphile elements indicated on the x axis of Figure 5. This classification is also in agreement with the classification chosen by Wood (1979). In an extended Coryell-Masuda diagram, which includes both rare-earth elements and nonrare-earth elements, it can be observed not only that Y has to be plotted very close to Tb, but that Hf, Zr, and Ti plot close to Sm and that Ta and Nb plot close to La. It can also be seen that V is the least hygromagmaphile and Th the most hygromagmaphile element. In this diagram, the nonrare-earth elements plot on the same continuous line as the rare-earth elements and with the same precision.

As can be seen in Figure 5, Chemical Types A and B at Site 482 show a typical "light rare-earth" depleted pattern consistent with the La/Ta ratios discussed above. For these patterns, the normalized concentrations of Ta and Nb are lower than the La normalized concentrations by a factor of 2. Sample 482B-19-1, 96–100 cm has the highest absolute concentrations of hygromagmaphile elements; although only XRF data are available, it is evident from the Nb concentration that this sample also shows the characteristic "light rare-earth" depleted pattern. Chemical Types B, D, H, and J at Site 483 are plotted in Figure 6. Types H and J very probably show a negative Eu anomaly. Type D, for which only XRF data are available, also shows a "light rare-earth" depleted character, its Nb value being the lowest in Hole 483. The most primitive basalt encountered in Hole 485 (Sample 483-11-3, 82–83 cm) and another representative sample from the same hole are plotted in Figure 7.

It can be concluded that all of the samples recovered during Leg 65 were derived from typical mantle material depleted in the highly hygromagmaphile elements: their La/Ta ratios are close to 18; the samples are similar in all respects to the basalts collected during the CYAMEX expedition (1981); and they show the same extended Coryell-Masuda patterns as the Leg 54 samples from 9°N.

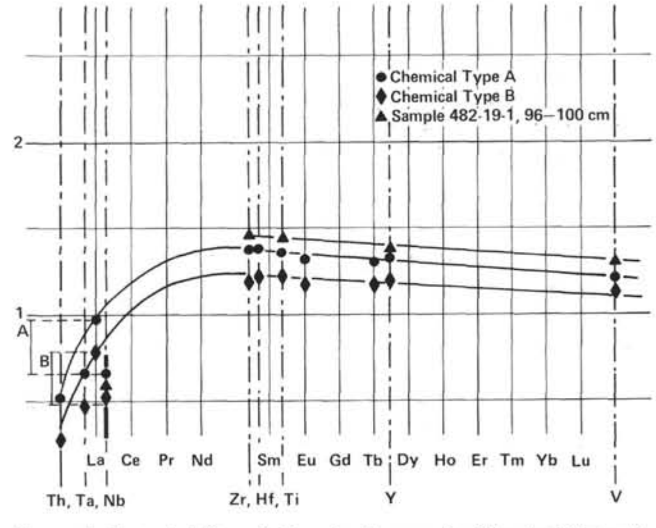

Figure 5. Extended Coryell-Masuda diagram for Chemical Types A, B, and C at Site 482. (Values shown for A and B represent average concentrations; Type C is represented only by Sample 482-19-1, 96–100 cm, for which only XRF data are available. The ordinate positions for Nb-Ta and La are shown on the left of the figure for Types A and B. The error bar for Nb is shown for Sample 482-19-1, 91–100 cm as a vertical bar.)

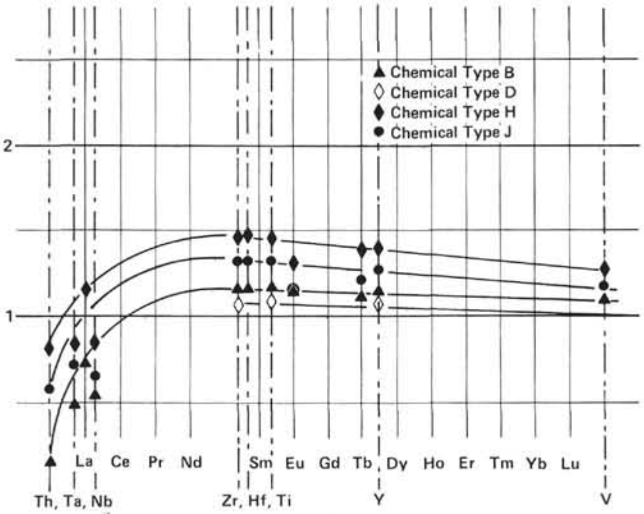

Figure 6. Extended Coryell-Masuda diagram for Chemical Types B, D, H, and J at Site 483. (Values shown represent average concentrations.)

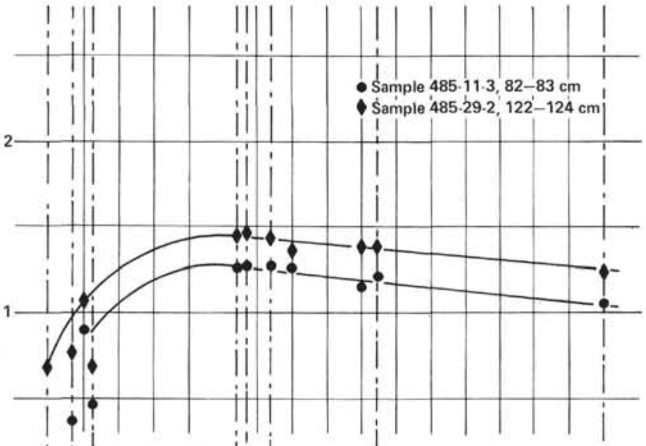

Figure 7. Extended Coryell-Masuda diagram for Samples 485-11-3, 82–83 cm and 485-29-2, 122–124 cm.

These results, when compared with those from the Atlantic, suggest that large regions of the mantle are chemically homogeneous.

CONCLUSIONS

From the major and trace element data presented above, it has been possible to draw several important conclusions concerning the origin and evolution of basaltic magmas in the mouth of the Gulf of California.

First, the trace element data have refined and confirmed the shipboard classification of the Leg 65 basalts based on major element data. The vertical correlation between the chemical units observed in the various holes drilled at Sites 482 and 483 is remarkable. When considered with the drilling results from earlier legs, it should be possible to put constraints on possible volumes of homogeneous lavas emitted during single volcanic events.

Second, the limited role of fractional crystallization, the range of variation of the hygromagmaphile elements, and the field data at the mouth of the Gulf all appear to be inconsistent with the existence of a large magma chamber under the ridge for any extended period of time.

Finally, the Nb/Ta, Zr/Hf, and Y/Tb ratios measured for the Leg 65 basalts show the commonly encountered values of 17, 40, and 50, respectively, and extended Coryell-Masuda plots of the data show a characteristic light rare-earth depleted pattern and a La/Ta ratio close to 18 (as opposed to the ratio 9 observed in material with a flat to light rare-earth enriched pattern). These results are very similar to the results obtained for samples from the East Pacific Rise at 21°N and 9°N and tend to demonstrate the chemical homogeneity of the mantle in this part of the ocean.

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