Batiza, R., Storms, M.A., and Allan, J.F. (Eds.), 1995
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 142

12. *DATA REPORT:* TRACE ELEMENT GEOCHEMISTRY OF LEG 142 BASALTS BY INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS[1]

James F. Allan[2]

ABSTRACT

During Leg 142, two units of moderately evolved basalt were recovered from the East Pacific Rise axis at 9°30′N. Instrumental neutron activation analysis of seven samples from these units shows them to be light rare-earth-element (REE)-depleted, normal mid-ocean ridge basalt, with $(La/Sm)_N$ of 0.52–0.56, flat chondrite-normalized medium-to-heavy rare earth patterns, and slight negative europium anomalies. Unit 2 contains slightly higher amounts of REE and Hf and lower amounts of Cr than Unit 1, with both units similar in composition to the most-evolved samples previously collected from this section of the ridge crest.

INTRODUCTION

Drilling and coring at mid-ocean ridge spreading centers has been a long-standing goal in the earth science community. Fundamental petrological, hydrothermal, geochemical, structural, and geophysical problems of oceanic crustal formation can only be answered by direct observation and recovery of core. Site 864, located at 9°30′N on the East Pacific Rise (EPR), represented the initial attempt in a long-range plan to core the entire crustal section at the EPR. The principal scientific goal of Leg 142 was to core 100 m into the uppermost crust of this fast-spreading center (11 cm/year; Klitgord and Mammerickx, 1982). Though coring results fell well short of expectations (drilling and coring penetrated only 15 m into the crust at Site 864, Holes 864A and B), the samples recovered represent the initial benchmark in the suite of materials to be recovered at this site, and so are of crucial importance in establishing the crustal characteristics and magmatic processes operating at this portion of the EPR. This report presents the results of instrumental neutron activation analysis (INAA) of seven samples from Site 864.

Samples collected at the axial ridge crest of the EPR between the Clipperton Fracture Zone (≈10°N) and the offset spreading center at 9°03′N are remarkably homogenous in composition, with almost all representing moderately evolved, incompatible-element-depleted normal mid-ocean ridge basalt (N-MORB) (Batiza and Niu, 1992; Langmuir et al., 1986; Allan et al., 1989). X-ray fluorescence studies during Leg 142 (Storms, Batiza, et al., 1993) and INAA analytical results reported here reveal that the recovered samples from Holes 864A and 864B share these geochemical characteristics.

SAMPLE DESCRIPTION

Site 864 was located within the axial summit caldera on a flat, relatively unfissured lava flow at about 2581 m depth. Samples from Holes 864A and 864B took the form of bit recoveries, "junk basket" recoveries resulting from cleaning out of the holes, and cores. Details of sample recovery are given in Storms, Batiza, et al. (1993). Two lithological units were defined, based on slight differences in composition and mineralogy. Unit 1, about 7–12 m thick, consists of glassy, aphyric basalt comprised of massive and sheet/lobate flows, sparse phenocrysts of euhedral plagioclase, and very rare phenocrysts of euhedral clinopyroxene. Unit 2, of unknown thickness, is microcrystalline, aphyric to sparsely phyric, and contains up to 2% euhedral, glomerocrystic plagioclase phenocrysts and very rare, euhedral olivine. Further petrographic descriptions are given in Storms, Batiza, et al. (1993). Both Units 1 and 2 are moderately evolved N-MORBs, with average $Mg/(Mg + Fe^{2+})$ of 0.581 and 0.565, respectively (Storms, Batiza, et al., 1993), and compositions within the range previously reported by Batiza and Niu (1992) for samples from this section of the ridge.

ANALYTICAL METHODS

Analyses were obtained on splits of powders analyzed by X-ray fluorescence (XRF) during Leg 142 (Storms, Batiza, et al., 1993). Samples were prepared initially on ship by crushing clean, washed rock in teflon vessels by a press, followed by pulverization in an alumina ceramic barrel by a SPEX Shatterbox. Most of these powders were derived from clean, picked, relatively aphyric glass, with other powders originating from fresh, relatively aphyric, fine-grained samples; thus, they should closely approximate the erupted magmatic composition (e.g., Byerly et al., 1976). BAS142 represents an in-house standard derived from basaltic glass of Unit 1.

The INAA analyses were conducted at Texas A&M University using an on-campus TRIGA reactor for irradiation and counting facilities in the Center for Chemical Characterization for analysis. The NBS standard flyash SRM1633A was used as the multiple-element standard (Korotev, 1987), with its Tb content corrected to 2.53 ppm (L. Korotev, pers. comm., 1991). Samples were stacked three levels high in the cans used for sample irradiation. To compensate for flux variation in the reactor, each layer was individually calibrated to three samples of the SRM1633A flyash. Fifty-milligram samples were irradiated for 14 hours and counted for 6 hours apiece at 9 to 12 and 40 to 43 days using lead-shielded, Ortec coaxial intrinsic germanium detectors. These detectors have efficiencies of 22% to 24% relative to a 3 × 3-inch NaI detector crystal at a distance of 25 cm, with resolutions of 1.64 to 1.68 KeV at FWHM of the 1332 KeV line of ^{60}Co. Dead-time was kept below 5% during counting. Spectral anal-

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[1] Batiza, R., Storms, M.A., and Allan, J.F. (Eds.), 1995. *Proc. ODP, Sci. Results,* 142: College Station, TX (Ocean Drilling Program).

[2] Ocean Drilling Program and Department of Geology, Texas A&M University, College Station, TX 77845, U.S.A.

Table 1. Analyses of the standard AGV-1.

	AGV1-1	AGV1-2	AGV1-3	Average	Std dev	AGV-1 accepted	Std dev
Na (%)	3.04	nd	3.20	3.12	0.11	3.16	0.08
Fe (%)	4.57	4.65	4.83	4.68	0.13	4.73	0.12
Sc	11.6	12.0	12.2	11.9	0.3	12.2	1.1
Cr	13	11	12	12	1	10	2
Co	15.2	15.5	15.9	15.5	0.4	15.3	1.6
Ni		24		16	3		
Zn	89	87	93	90	3	88	9
Rb	64	59	71	65	6	67.3	0.9
Sr	668	745	725	713	40	662	9
Ba	1164	1166	1160	1163	3	1226	17
La	38.2	38.6	38.9	38.6	0.4	38	3
Ce	68.3	70.4	72.3	70.3	2.0	67	5
Sm	5.98	6.22	5.94	6.05	0.15	5.9	0.4
Eu	1.52	1.63	1.63	1.59	0.06	1.64	0.10
Tb	0.74	0.61	0.67	0.67	0.07	0.70	0.10
Yb	1.56	1.68	1.62	1.62	0.06	1.72	0.19
Lu	0.25	0.24	0.24	0.24	0.01	0.27	0.03
Hf	5.34	5.31	5.43	5.36	0.06	5.1	0.4
Ta	0.87	0.89	0.84	0.87	0.02	0.90	0.09
Th	6.27	6.32	6.59	6.39	0.17	6.5	0.5
U	1.91	2.09	1.57	1.86	0.26	1.92	0.15

Notes: Std dev = standard deviation. Accepted values for AGV-1 from Gladney et al. (1992).

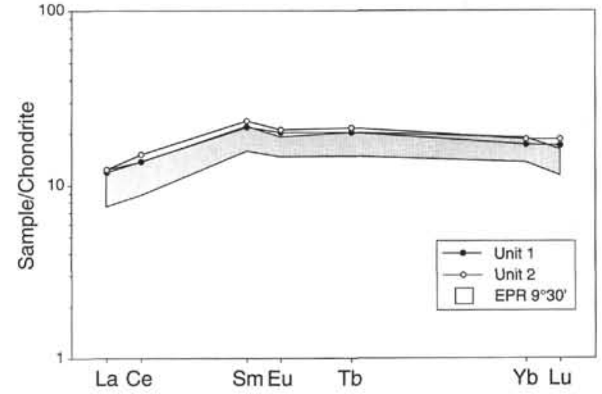

Figure 1. Comparison of the average REE contents of Leg 142 units with those of N-MORB samples collected previously from the EPR in the region of 9°30′N (EPR sample data shown by shaded area; data from Batiza and Niu, 1992). Chondrite normalizations follow Haskin et al. (1968). Slight reported differences in Lu contents between the two data sets may reflect differences in analytical procedure regarding the determination of INAA peak backgrounds.

ysis and peak-height evaluation was made using a software package by Nuclear Data, with U- and Th-series overlap and interference corrections done by hand (Landsberger and Simsons, 1987; Landsberger, 1986; Glascock et al., 1986).

To ensure historical run-to-run consistency, a sample of the international standard AGV-1 was run in each layer, with results given in Table 1. These results show excellent overall agreement with accepted values (Gladney et al., 1992); Ba is the only element whose concentration differs within analytical error.

RESULTS

Analytical results are presented in Table 2, with chondrite-normalized REE concentrations plotted in Figure 1. Unit 1 samples are uniform in their composition, as was noted with XRF-derived major and trace element analyses (Storms, Batiza, et al., 1993); the analytical standard deviations given for the Unit 1 samples in Table 2 are probably an excellent indication of the actual analytical uncertainty for the entire analysis procedure. Ta is curiously high in the Unit 2 Sample 142-864A-4Z1, Piece 2 (Table 2), perhaps reflecting contamination in this whole-rock sample from drillbit tungsten carbide teeth. In general, the INAA measurements match well with the shipboard XRF analyses, the exception being Zn (the average shipboard XRF Zn for samples from Units 1 and 2 are 92 and 93 ppm, respectively).

The two units overlap in composition in most elements, with Unit 2 containing slightly higher REE and Hf and lower Cr. These elemental variations are consistent with other XRF-derived major and trace element data that suggest that Unit 2 is slightly more evolved than Unit 1 (Storms, Batiza, et al., 1993). Th, U, Rb, and Ba are all below the analytical detection limits (<0.18, <0.14, <9, and <30 ppm, respectively). All Leg 142 samples are substantially depleted in the light REE, with flat chondrite-normalized medium-to-heavy REE patterns (Fig. 1; Table 2). Like other samples from this section of the EPR (Batiza and Niu, 1992), they contain slight negative europium anomalies (average Eu/Eu* is 0.96 for Unit 1 and 0.92 for Unit 2) that

Table 2. Analyses of Leg 142 samples.

Hole:	864A	864A	864A	864A	864B			864A	864A		
Section:	1M2	1M3	1M5	1M6	2W1			4Z1	5Z1		
Interval (cm) or piece number:	0–35	0–100	50–100	0–75	16–18			Piece 2	24–30		
Unit:	1	1	1	1	1	1	1	2	2	2	2
Comments:	Glass	BAS142 glass std	Glass	Glass	Whole rock	Average	Std dev	Whole rock	Whole rock	Average	Std dev
Na (%)	1.93	2.02	1.93	2.01	2.03	1.98	0.04	1.95	2.03	1.99	0.06
Fe (%)	8.32	8.23	7.83	8.36	8.12	8.17	0.19	8.28	8.53	8.41	0.18
Sc	44.6	44.2	42.2	44.8	44.0	44.0	0.9	43.3	43.9	43.6	0.4
Cr	239	249	227	241	241	239	7	195	167	181	19
Co	45.5	45.6	42.4	45.0	43.0	44.3	1.3	44.6	43.2	43.9	1.0
Ni	66	57	82	75	86	73	11	61	50	55	8
Zn	108	121	111	106	111	111	5	112	117	114	4
La	3.76	4.05	3.80	3.84	4.23	3.94	0.18	4.02	4.12	4.07	0.07
Ce	12.3	12.0	11.2	12.5	12.4	12.1	0.5	13.3	13.3	13.3	0
Sm	3.68	4.12	3.84	3.86	4.13	3.93	0.17	4.13	4.37	4.25	0.17
Eu	1.42	1.42	1.33	1.42	1.38	1.39	0.04	1.42	1.46	1.44	0.03
Tb	1.01	0.89	0.95	0.96	0.91	0.94	0.04	0.93	1.07	1.00	0.10
Yb	3.24	3.55	3.32	3.48	3.60	3.44	0.14	3.61	3.76	3.69	0.11
Lu	0.61	0.55	0.56	0.56	0.60	0.58	0.02	0.53	0.71	0.62	0.13
Hf	2.90	2.95	2.82	3.07	2.90	2.93	0.08	3.32	3.22	3.27	0.07
Ta	0.21	0.23	0.21	0.22	0.16	0.21	0.02	0.65	0.20	0.43	0.32
$(La/Sm)_N$	0.56	0.54	0.54	0.55	0.56	0.55	0.01	0.53	0.52	0.53	0.01

Notes: Samples in ppm; Na and Fe in wt%. Std dev = standard deviation. $(La/Sm)_N$ represents the chondritic normalization of La/Sm (Haskin et al., 1968). Average counting uncertainties (in ppm, unless noted) are: Na, 0.03%; Fe, 0.02%; Sc, 0.04; Cr, 2; Co, 0.1; Ni, 11; Zn, 3; La, 0.06; Ce, 0.5; Sm, 0.01; Eu, 0.03; Tb, 0.06; Yb, 0.05; Lu, 0.01; Hf, 0.12; and Ta, 0.04.

may be related to plagioclase fractionation. Overall, they represent N-MORB compositions (Sun and McDonough, 1989) and are similar in nature to the more evolved samples previously collected from this area of the ridge crest (Fig. 1; Batiza and Niu, 1992).

ACKNOWLEDGMENTS

I thank the SEDCO BP471 crew, the ODP engineers, and the ODP technical staff for their Herculean efforts to recover these samples. I am especially grateful to Rodey Batiza, who took me on as a green post-doc in 1985 and introduced me to the joys of EPR MORB petrology.

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Date of initial receipt: 12 August 1993
Date of acceptance: 3 November 1993
Ms 142SR-117

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[*] Abbreviations for names of organizations and publications in ODP reference lists follow the style given in *Chemical Abstracts Service Source Index* (published by American Chemical Society).