37. *DATA REPORT*: TRACE-ELEMENT GEOCHEMISTRY OF THE LOWER SHEETED DIKE COMPLEX, HOLE 504B (LEG 140)[1]

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ABSTRACT

Rocks of the lower sheeted dike complex of Hole 504B, sampled during Leg 140, were analyzed for trace element compositions (Li, Sc, Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Nb, Mo, REE, Hf, Ta, Bi, Th, U, and Cs) using a multielement ICP-MS (inductively coupled plasma mass spectrometry) method. The rocks are relatively uniform in composition and similar to the shallower dikes in Hole 504B. Previous investigations showed systematic depletions in centimeter-sized patches for REE, Zr, Y, TiO_2, and P_2O_5. Data of this study similarly show that Nb, Hf, Sc, Mo, and, to a lesser extent, Li, and Th are also depleted relative to the host rocks. Whereas Rb shows a systematic increase in centimeter-sized patches, elements such as Cr, Co, Ni, Zn, Ga, and Sr show no significant changes compared to adjacent less altered diabases.

INTRODUCTION

The only oceanic drill hole that clearly penetrates through the lavas of Layers 2A and 2B into the sheeted dike complex of Layer 2C is Deep Sea Drilling Project (DSDP)/Ocean Drilling Program (ODP) Hole 504B, located in 5.9-m.y.-old crust, 201 km south of the Costa Rica Rift (1°13.611′N, 83°43.818′W). Late in 1991, Leg 140 returned to Hole 504B and drilled the hole 379 m deeper into the sheeted dike complex to a total depth of 2000.4 meters below seafloor (mbsf) (Shipboard Scientific Party, 1992). Earlier investigations showed a relatively uniform chemical and mineralogical composition of the drilled section (i.e., Hubberten et al., 1983; Emmermann, 1985; Alt et al., 1986). Only the REE, Y, Zr, TiO_2, and P_2O_5 are depleted in centimeter-sized patches relative to the surrounding rocks (Zuleger et al., 1995). The mineralogical description is given in detail in Alt et al. (1995). To explain this phenomenon, a multielement ICP-MS method was developed to determine other genetically important trace elements. This chapter presents the data obtained from this investigation.

The main purpose of this report is to provide other investigators with a more complete data set from Hole 504B. A more detailed discussion of the data will be presented elsewhere together with new trace element data from the upper part and the lower part of the hole (W. Bach and E. Zuleger, unpubl. data).

ANALYTICAL METHOD

Sample Preparation

This report is based on chemical data obtained for 84 whole-rock samples, representing 62% of the 59 lithologic units recovered during Leg 140. Forty samples represent the freshest possible rocks (i.e., the macroscopically least-altered basalts), which are dark gray in color and have no visible veins or alteration discoloration. More intensively altered portions of the rocks or veins in the rocks were systematically removed by sawing before grinding for analysis. Throughout this report, these samples are referred to as "fresh rocks," and are listed as "D" (for dark gray) in Table 1. Another 16 samples exhibit a slightly lighter gray color and are affected by more intensive background alteration. These are listed as "L" (for light gray) in Table 1. Many of the latter are from fine-grained dike margins with abundant veins, and the more intensive alteration may actually represent coalescing of alteration halos around multiple veins. Twenty-three samples represent highly altered rocks, that is, light gray to greenish alteration halos along veins and alteration patches ("H" and "P," respectively, in Table 1). Six samples were cut so that both the intensively altered patch or halo and the immediately adjacent dark gray host rock could be analyzed (labeled A and B in Table 1).

After the samples were washed with distilled water, dried, and crushed to <1 mm, they were powdered in an agate mill to a grain size <30 µm.

Sample Dissolution

Samples were dissolved using a $HF/HNO_3/HClO_4$-digestion in closed Teflon beakers as described in Garbe-Schoenberg (1993) before ICP-MS measurements. The final solution contains 250 mg of sample in 50 mL of 2% nitric acid (1:200).

ICP-MS Technique

A Fisons VG Plasmaquad 2 Plus ICP-MS was used for the determination of 35 trace elements. The operation parameters are listed in Table 2. The instrument was optimized using an acidified (2% HNO_3) solution containing 50 µg/L Co, Be, La, U, In, and Bi to give maximum sensitivity while minimizing interferences. A multielement procedure, analyzing 33 elements simultaneously in a 1:2000 diluted sample solution, was used (Table 3), followed by a multielement procedure analyzing 26 elements simultaneously in a 1:400 diluted sample solution (Table 3). Table 3 also presents the selected isotopes used for these multielement methods and Table 4 shows the concentrations of the standard solutions. In and Be (50 µg/L) were added as internal standards to monitor instrumental instability and recalibrations were performed after every fifth sample for maximum precision. All results represent duplicate measurements and depending on the concentrations the results were taken from either one of the

[1]Alt, J.C., Kinoshita, H., Stokking, L.B., and Michael, P.J. (Eds.), 1996. *Proc. ODP, Sci. Results,* 148: College Station, TX (Ocean Drilling Program).

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Table 1. Trace-element compositions of Hole 504B diabases recovered during Leg 140.

Leg:	137	137	137	137	137	137	137	140	140	140	140	140	140	140	140	140	140
Hole:	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B
Core, section:	173R-1	173R-1	174R-2	177R-1	181M-1	181M-2	186R-2	187R-1	187R-1	189R-1	189R-1	189R-1	189R-2	190R-1	193R-1	193R-1	193R-1
Interval (cm):	54–57	73–76	23–26	48–51	6–10	95–97	30–32	59–63A	59–63B	85–88	90–94A	90–94B	15–17	14–10	22–24	44–46	58–60B
Piece no.:	6	9	5	13	1	7B	8	14	14	19	20	20	3	2	7	13A	14
Depth (mbsf):	1570.5	1570.7	1578.0	1605.0	1622.8	1620.0	1628.1	1632.6	1632.6	1651.9	1651.9	1651.9	1653.5	1655.2	1674.7	1675.0	1675.1
Lithologic unit:	193	193	195	202	204	208	213	216	216	218	218	218	218	218	220	220	220
Alteration type:	D	L	D	D	D	P	D	D	P	D	D	H	P	L	P	H	P
Li	1.67	1.94	1.22	1.33	1.24	1.19	1.75	1.07	0.64	1.44	1.50	1.75	1.55	1.47	1.55	1.47	0.97
Sc	45	40	34	45	44	45	45	42	40	41	44	42	38	34	39	41	35
Cr	242	253	221	169	233	333	385	278	231	255	277	203	347	300	234	278	384
Co	46	44	44	45	44	44	45	41	47	45	45	44	39	36	44	54	39
Ni	92	92	86	85	86	97	138	88	90	91	97	98	117	98	93	97	103
Cu	82	23	81	65	77	126	11	48	8	252	100	66	102	13	28	102	4
Zn	67	64	78	72	69	59	48	53	57	71	69	70	59	60	71	65	61
Ga	15.7	13.9	15.1	15.8	15.4	14.6	15.3	14.5	15.0	15.3	15.7	14.7	13.3	13.1	14.5	14.7	12.8
Rb	0.11	0.13	0.12	<0.1	0.10	<0.1	0.13	<0.1	<0.1	0.11	0.13	0.19	0.16	0.22	0.13	0.16	0.22
Sr	46	53	46	46	44	45	66	50	53	47	48	58	54	32	55	51	41
Y	23.9	17.0	ND	25.9	24.5	21.9	24.6	23.6	20.4	24.3	24.2	19.6	15.7	14.7	17.9	23.5	13.2
Nb	0.30	0.22	0.32	0.29	0.26	0.25	0.78	0.30	0.25	0.28	0.31	0.28	0.19	0.18	0.22	0.30	0.14
Mo	0.18	0.08	0.09	0.05	0.07	0.07	0.06	0.07	<0.05	0.07	0.06	0.11	0.07	0.07	0.08	0.07	0.08
La	1.03	0.75	1.08	1.05	1.03	0.90	1.65	0.89	0.83	1.06	1.02	0.96	0.64	0.56	0.73	1.22	0.65
Ce	3.98	2.66	4.11	4.17	3.84	3.50	5.72	3.58	3.29	4.02	3.91	3.34	2.41	2.22	2.75	4.65	2.17
Pr	0.78	0.54	0.82	0.83	0.81	0.70	1.09	0.74	0.63	0.82	0.79	0.67	0.49	0.45	0.57	0.96	0.46
Nd	4.73	3.38	5.00	5.29	5.15	4.56	6.50	4.72	4.22	5.02	4.95	3.99	3.01	2.75	3.62	5.54	2.63
Sm	1.98	1.43	2.11	2.21	2.10	1.87	2.37	2.04	1.71	2.13	2.05	1.65	1.28	1.19	1.53	2.36	1.14
Eu	0.80	0.60	0.78	0.84	0.75	0.71	0.83	0.80	0.83	0.79	0.78	0.71	0.58	0.67	0.62	0.87	0.74
Gd	3.03	2.11	3.14	3.34	3.16	2.78	3.28	3.22	2.68	3.23	3.14	2.63	1.98	1.90	2.30	3.19	1.71
Tb	0.59	0.40	0.64	0.68	0.61	0.54	0.62	0.63	0.54	0.64	0.62	0.52	0.42	0.39	0.48	0.64	0.35
Dy	4.21	3.13	4.54	4.73	4.62	4.07	4.63	4.45	3.90	4.51	4.49	3.61	2.94	2.75	3.40	4.41	2.46
Ho	0.91	0.67	1.00	1.01	0.99	0.88	0.97	0.97	0.80	0.98	0.96	0.79	0.63	0.60	0.72	0.96	0.51
Er	2.72	2.06	2.95	3.04	3.02	2.64	3.00	2.90	2.56	2.93	2.94	2.40	1.95	1.80	2.24	2.83	1.65
Tm	0.39	0.30	0.43	0.46	0.45	0.39	0.43	0.43	0.36	0.43	0.41	0.36	0.29	0.27	0.32	0.41	0.23
Yb	2.66	2.04	2.79	2.97	2.96	2.69	2.85	2.84	2.48	2.95	2.89	2.31	1.89	1.81	2.11	2.80	1.60
Lu	0.41	0.32	0.46	0.45	0.46	0.40	0.44	0.43	0.35	0.44	0.42	0.35	0.30	0.26	0.32	0.41	0.23
Hf	1.07	0.80	1.14	1.22	1.17	0.90	0.92	1.01	0.94	1.27	1.30	0.98	0.79	0.83	0.84	1.06	0.63
Ta	0.032	0.018	0.045	0.032	0.030	0.029	0.057	0.034	0.021	0.035	0.030	0.031	0.031	0.023	0.021	0.057	0.022
Bi	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Th	0.028	0.016	0.020	0.025	0.025	0.021	0.052	0.016	0.015	0.018	0.018	0.016	0.014	0.019	0.015	0.021	0.011
U	0.015	<0.01	<0.01	0.010	0.012	<0.01	0.016	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zr (XRF)	35	48	50	50	49	44	65	48	39	50	49	39	32	29	37	46	26
Zr/Hf	43.97	44.99	44.01	41.12	41.74	49.11	70.88	47.34	41.62	39.25	37.72	39.67	40.56	34.90	44.15	43.36	41.27
Zr/Nb	156.95	161.07	158.23	170.07	185.61	173.91	83.23	161.07	154.76	178.57	157.56	139.78	172.04	164.77	170.51	155.93	184.40
La/Ta	32.03	41.39	23.89	32.88	34.30	31.10	28.91	26.12	39.29	30.14	33.90	30.90	20.68	24.43	34.81	21.39	29.64
La/Nb	3.44	3.34	3.40	3.58	3.90	3.57	2.11	2.98	3.30	3.77	3.27	3.43	3.45	3.19	3.37	4.13	4.62
Nb/Ta	9.31	12.39	7.02	9.19	8.80	8.72	13.70	8.76	11.90	8.00	10.37	9.00	6.00	7.65	10.33	5.18	6.41
Rb/Sr	0.0023	0.0025	0.0026		0.0023		0.0020			0.0022	0.0027	0.0033	0.0030	0.0068	0.0023	0.0031	0.0055
Th/Ta	0.875	0.889	0.444	0.781	0.833	0.724	0.912	0.471	0.714	0.514	0.600	0.516	0.452	0.826	0.714	0.368	0.500
Th/Hf	0.026	0.020	0.018	0.021	0.021	0.023	0.057	0.016	0.016	0.014	0.014	0.016	0.018	0.023	0.018	0.020	0.017
Th/U	1.867			2.500	2.083		3.250										
Sum REE	28.2	20.4	29.8	31.1	29.9	26.6	34.4	28.6	25.2	29.9	29.4	24.3	18.8	17.6	21.7	31.2	16.5

Table 1 (continued).

Leg:	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
Hole:	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B
Core, section:	194R-1	194R-1	195R-1	196R-1	197R-1	197R-1	197 R01	198R-1	198R-1	199R-1	199R-1	200R-1	200R-2	200R-2	200R-3	200R-4	202R-1
Interval (cm):	36–40	42–46	1–3	21–26	29–31	116–120	123–126	50–54	79–82	54–57	89–92	35–39	53–57	116–119	115–117	16–19	9–12
Piece no.:	7	8	1	4	7	26	27	14	20	13	21	8	7B	18	18	4	3
Depth (mbsf):	1680.8	1680.8	1690.3	1696.7	1703.1	1704.0	1704.0	1712.7	1713.0	1719.9	1720.3	1729.0	1730.6	1731.3	1732.8	1733.3	1747.3
Lithologic unit:	220	220	221	222	222	223	223	223	224	226	226	227	227	227	227	227	229
Alteration type:	D	P	D	D	H	D	D	D	L	D	D	D	D	D	D	L	D
Li	1.72	1.13	1.51	1.51	1.29	2.14	2.05	1.33	0.50	1.47	1.61	1.81	1.75	1.27	1.82	1.45	1.10
Sc	41	33	41	41	40	40	41	41	40	36	37	35	29	37	36	36	42
Cr	330	313	259	251	254	369	382	367	440	395	373	416	433	383	390	265	353
Co	43	42	43	41	44	45	49	46	44	42	42	42	42	47	44	46	45
Ni	104	111	91	91	88	140	156	144	114	155	147	155	160	155	183	164	126
Cu	81	5	71	114	13	95	116	102	9	88	95	87	88	ND	73	89	96
Zn	69	71	76	57	58	57	68	65	54	65	76	60	63	75	89	69	66
Ga	15.3	13.2	15.0	15.2	14.6	14.1	14.0	14.0	16.0	13.7	13.2	13.7	13.2	13.6	13.1	13.8	14.7
Rb	<0.1	0.12	<0.1	0.15	<0.1	0.11	<0.1	<0.1	<0.1	0.10	<0.1	0.10	<0.1	<0.1	<0.1	0.12	<0.1
Sr	47	47	50	48	54	49	52	50	61	63	64	62	67	62	61	67	56
Y	22.9	12.7	22.1	23.0	20.0	20.3	20.7	20.1	20.9	18.4	17.6	17.2	ND	17.7	16.5	17.4	21.4
Nb	0.28	0.14	0.26	0.29	0.21	0.29	0.24	0.24	0.26	0.36	0.32	0.32	0.29	0.31	0.27	0.28	0.30
Mo	0.06	<0.05	0.06	0.10	0.07	0.11	0.09	0.10	0.28	0.07	0.06	0.07	0.09	<0.05	0.15	0.06	0.10
La	0.98	0.46	0.93	1.03	0.70	0.88	0.82	0.91	0.81	1.00	0.98	0.94	0.97	1.18	0.92	1.08	0.92
Ce	3.86	1.77	3.67	3.95	2.93	3.32	3.25	3.52	3.18	3.69	3.55	3.57	3.62	4.93	3.16	3.56	3.50
Pr	0.78	0.37	0.74	0.80	0.60	0.70	0.66	0.71	0.64	0.72	0.68	0.69	0.70	0.68	0.60	0.73	0.69
Nd	4.80	2.36	4.65	4.88	3.88	4.21	4.29	4.38	3.98	4.25	4.15	4.20	4.09	4.19	3.75	3.98	4.38
Sm	2.06	1.05	1.97	1.99	1.68	1.82	1.80	1.84	1.74	1.73	1.65	1.68	1.67	1.66	1.47	1.62	1.77
Eu	0.79	0.52	0.76	0.81	0.69	0.75	0.71	0.72	0.82	0.70	0.68	0.69	0.68	0.70	0.59	0.70	0.72
Gd	3.10	1.61	3.00	3.15	2.53	2.71	2.66	2.80	2.75	2.47	2.47	2.48	2.39	2.48	2.24	2.40	2.77
Tb	0.62	0.33	0.59	0.64	0.50	0.58	0.55	0.56	0.55	0.50	0.30	0.49	0.48	0.48	0.44	0.47	0.54
Dy	4.45	2.33	4.24	4.44	3.63	3.81	3.90	3.87	3.98	3.45	3.38	3.37	3.42	3.39	3.07	3.25	3.93
Ho	0.92	0.50	0.91	0.96	0.79	0.84	0.86	0.83	0.84	0.74	0.72	0.73	0.72	0.73	0.67	0.71	0.86
Er	2.90	1.55	2.72	2.88	2.34	2.50	2.58	2.49	2.59	0.10	2.12	2.15	2.16	2.18	2.00	2.21	2.60
Tm	0.43	0.22	0.41	0.43	0.35	0.39	0.39	0.37	0.37	0.33	0.30	0.33	0.30	0.28	0.26	0.29	0.38
Yb	2.83	1.49	2.68	2.85	2.33	2.45	2.56	2.47	2.49	2.13	2.12	2.11	2.08	2.12	1.99	1.97	2.57
Lu	0.42	0.21	0.41	0.42	0.35	0.39	0.39	0.38	0.38	0.32	0.30	0.31	0.34	0.29	0.27	0.29	0.39
Hf	1.14	0.63	1.07	1.10	0.93	0.68	0.67	0.64	0.96	0.96	1.02	1.00	0.91	0.95	0.96	0.92	1.02
Ta	0.020	0.051	0.035	0.030	0.028	0.061	0.042	0.052	0.042	0.063	0.034	0.032	0.040	0.038	0.031	0.031	0.026
Bi	<0.05	<0.05	<0.05	<0.05	<0.05	0.054	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Th	0.021	<0.01	0.014	0.027	0.011	0.021	0.015	0.016	0.024	0.028	0.022	0.027	0.018	0.029	0.022	0.021	0.017
U	<0.01	<0.01	<0.01	0.014	<0.01	<0.01	<0.01	<0.01	<0.01	0.011	<0.01	0.011	<0.01	<0.01	<0.01	<0.01	<0.01
Zr (XRF)	48	25	45	49	39	41	41	43	44	43	42	42	42	43	38	41	44
Zr/Hf	41.96	40.00	42.13	44.67	42.12	60.47	61.38	66.87	45.74	44.65	41.14	41.87	46.10	45.07	39.42	44.61	43.01
Zr/Nb	172.04	179.86	173.08	167.24	182.24	139.93	173.00	176.23	169.88	118.46	132.08	130.43	146.34	136.94	141.26	146.95	148.15
La/Ta	49.20	8.94	26.49	34.27	24.93	14.44	19.55	17.42	19.17	15.84	28.85	29.47	24.13	31.05	29.68	34.68	35.23
La/Nb	3.53	3.28	3.57	3.51	3.26	3.01	3.46	3.71	3.11	2.75	3.08	2.93	3.36	3.76	3.42	3.85	3.08
Nb/Ta	13.95	2.73	7.43	9.77	7.64	4.80	5.64	4.69	6.17	5.76	9.35	10.06	7.18	8.26	8.68	9.00	11.42
Rb/Sr		0.0025		0.0031		0.0023				0.0017		0.0017				0.0017	
Th/Ta	1.050		0.400	0.900	0.393	0.344	0.357	0.308	0.571	0.444	0.647	0.844	0.450	0.763	0.710	0.677	0.654
Th/Hf	0.018		0.013	0.025	0.012	0.031	0.022	0.025	0.025	0.029	0.022	0.027	0.020	0.030	0.023	0.023	0.017
Th/U				1.929						2.545		2.455					
Sum REE	28.9	14.8	27.7	29.2	23.3	25.3	25.4	25.8	25.1	22.1	23.4	23.7	23.6	25.3	21.4	23.2	26.0

Table 1 (continued).

Leg:	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
Hole:	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B
Core, section:	202R-1	203R-1	204R-1	204R-1	205R-1	207R-1	208R-1	208R-1	208R-2	208R-3	209R-1	209R-1	209R-1	209R-1	209R-2	210R-1	210R-1
Interval (cm):	23–25	12–14	0–4	15–19	21–23	22–26	88–91	110–114	0–6	7–10	35–41A	35–41B	98–102	129–132	68–70	33–37	80–87
Piece no.:	7	4	1	4	3	6	19	23	1	1	6A	6A	14	15	10	4C	12
Depth (mbsf):	1747.4	1749.1	1756.5	1756.7	1757.2	1768.6	1778.9	1779.1	1779.5	1781.1	1787.9	1787.9	1788.5	1788.8	1789.6	1795.2	1795.7
Lithologic unit:	229	231	232	232	232	236	239	239	239	239	240	240	240	240	240	241	241
Alteration type:	H	D	L	L	L	D	H	D	L	P	D	P	P	D	D	D	D
Li	1.70	1.30	1.22	1.25	1.01	0.61	1.54	1.44	1.35	0.63	1.64	1.09	0.93	1.84	1.41	0.89	1.44
Sc	42	45	38	43	38	45	39	48	32	29	35	34	30	39	43	30	45
Cr	339	381	336	370	346	271	383	400	369	364	355	366	391	416	438	372	402
Co	45	45	44	44	40	44	52	49	42	59	41	42	67	45	47	41	43
Ni	119	108	136	127	141	93	117	105	111	124	135	130	136	121	128	109	108
Cu	522	160	7	6	10	54	179	109	84	5	129	33	6	113	97	84	74
Zn	57	58	46	41	56	48	64	62	55	54	50	53	64	53	53	61	48
Ga	14.2	14.7	15.2	15.3	14.2	15.1	14.6	14.9	14.1	12.2	15.2	14.3	12.9	14.4	14.6	14.0	14.3
Rb	<0.1	0.14	<0.1	0.14	0.12	0.10	<0.1	<0.1	0.10	0.15	<0.1	<0.1	0.13	<0.1	<0.1	0.12	<0.1
Sr	52	53	64	72	62	53	54	59	55	62	60	53	57	59	62	57	53
Y	ND	23.3	22.3	23.8	21.9	25.1	19.1	21.0	ND	13.7	18.6	14.3	11.4	18.5	17.8	ND	22.0
Nb	0.27	0.33	0.73	0.73	0.66	0.46	0.26	0.29	0.26	0.18	0.28	0.20	0.38	0.27	0.30	0.29	0.30
Mo	0.13	0.26	0.10	0.09	0.05	0.06	0.07	0.07	ND	0.05	0.08	<0.05	0.33	0.08	0.07	0.10	0.09
La	0.95	0.99	1.38	1.26	1.22	1.18	0.92	0.95	0.93	0.84	0.97	0.56	0.47	0.87	0.82	0.95	0.87
Ce	3.47	3.85	5.14	4.98	4.68	4.49	3.58	3.60	3.53	2.76	4.20	2.32	1.65	3.38	3.16	3.60	3.44
Pr	0.68	0.76	0.97	0.97	0.90	0.90	0.70	0.73	0.71	0.55	0.67	0.45	0.39	0.68	0.62	0.75	0.69
Nd	4.38	4.64	5.61	5.75	5.45	6.46	4.32	4.55	4.26	3.15	4.24	3.00	2.41	4.09	3.90	4.40	4.34
Sm	1.87	2.02	2.09	2.19	2.11	2.20	1.75	1.86	1.74	1.09	1.66	1.20	1.07	1.71	1.60	1.83	1.85
Eu	0.73	0.79	0.85	0.95	0.77	0.87	0.70	0.71	0.72	0.56	0.61	0.56	0.70	0.67	0.60	0.73	0.72
Gd	2.81	2.97	2.89	3.23	3.07	3.31	2.63	2.78	2.48	1.79	2.56	1.85	1.50	2.54	2.36	2.68	2.86
Tb	0.55	0.59	0.58	0.62	0.59	0.66	0.50	0.55	0.50	0.35	0.48	0.36	0.29	0.50	0.46	0.54	0.57
Dy	3.98	4.20	4.06	4.34	4.18	4.66	3.70	3.83	3.51	2.35	3.49	2.71	2.11	3.46	3.22	3.91	4.09
Ho	0.89	0.92	0.89	0.94	0.91	1.00	0.79	0.81	0.77	0.51	0.73	0.57	0.45	0.72	0.69	0.83	0.87
Er	2.67	2.80	2.65	2.78	2.75	2.94	2.30	2.46	2.20	1.57	2.25	1.71	1.32	2.19	2.04	2.43	2.60
Tm	0.37	0.43	0.39	0.42	0.40	0.44	0.34	0.35	0.33	0.21	0.29	0.22	0.18	0.31	0.30	0.36	0.41
Yb	2.75	2.77	2.69	2.69	2.65	2.91	2.26	2.32	2.22	1.53	2.13	1.67	1.33	2.14	2.02	2.39	2.65
Lu	0.38	0.42	0.40	0.41	0.40	0.43	0.34	0.34	0.34	0.19	0.31	0.24	0.18	0.32	0.30	0.38	0.39
Hf	1.05	1.12	1.00	1.03	0.91	1.09	0.97	1.01	0.90	0.67	0.91	0.70	0.53	0.89	1.03	0.95	0.85
Ta	0.036	0.052	0.066	0.076	0.056	0.039	0.030	0.031	0.033	0.038	0.026	0.017	ND	0.053	0.052	0.034	0.039
Bi	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Th	0.024	0.038	0.054	0.059	0.048	0.032	0.018	0.018	0.014	0.014	0.016	0.010	0.011	0.016	0.022	0.017	0.019
U	<0.01	0.016	0.012	0.017	<0.01	0.014	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.011	<0.01	<0.01
Zr (XRF)	44	46	62	60	62	53	45	47	44	31	43	32	25	43	40	45	45
Zr/Hf	41.98	41.22	62.25	58.31	68.13	48.76	46.25	46.58	49.00	46.48	47.05	45.98	46.90	48.31	39.02	47.32	52.88
Zr/Nb	160.58	138.97	84.93	82.19	93.37	114.22	176.47	163.19	167.30	174.16	151.94	161.62	65.10	157.51	131.58	157.34	148.51
La/Ta	26.47	19.10	20.88	16.61	21.84	30.21	30.80	30.71	28.06	22.11	37.23	32.76		16.49	15.79	27.97	22.36
La/Nb	3.48	3.00	1.89	1.73	1.84	2.54	3.62	3.31	3.52	4.72	3.42	2.81	1.22	3.20	2.70	3.33	2.88
Nb/Ta	7.61	6.37	11.06	9.61	11.86	11.90	8.50	9.29	7.97	4.68	10.88	11.65		5.15	5.85	8.41	7.77
Rb/Sr		0.0026		0.0019	0.0019	0.0019			0.0019	0.0024			0.0022			0.0021	
Th/Ta	0.667	0.731	0.818	0.776	0.857	0.821	0.600	0.581	0.424	0.368	0.615	0.588		0.302	0.423	0.500	0.487
Th/Hf	0.023	0.034	0.054	0.057	0.053	0.029	0.018	0.018	0.016	0.021	0.018	0.014	0.021	0.018	0.021	0.018	0.022
Th/U		2.375	4.500	3.471		2.286									2.000		
Sum REE	26.5	28.1	30.6	31.5	30.1	32.4	24.8	25.8	24.2	17.5	24.6	17.4	14.0	23.6	22.1	25.8	26.3

Table 1 (continued).

Leg:	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
Hole:	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B
Core, section:	211R-1	213R-1	214R-1	214R-1	214R-1	215R-1	215R-1	215R-1	216R-1	218R-1	220R-1	222R-1	222R-1	222R-1	224R-1	224R-1	225R-1
Interval (cm):	70–74	64–68	24–28	36–40	73–76	39–43	59–63	81–85	54–56	7–9	23–26	69–73	115–120A	115–120B	38–42	71–74	107–109
Piece no.:	16	19	5A	5	8	11	12	20	12	2	6	12A	22	22	8	13	27
Depth (mbsf):	1799.2	1813.1	1818.9	1819.0	1819.3	1823.5	1823.6	1823.8	1828.4	1847.0	1865.7	1885.3	1885.8	1885.8	1904.1	1904.4	1913.3
Lithologic unit:	241	243	244	244	244	244	244	244	245	247	252	254	256	256	258	258	259
Alteration type:	D	D	P	D	P	L	D	D	D	L	D	D	D	P	D	L	L
Li	1.51	1.65	0.91	1.46	0.12	1.28	1.21	1.43	2.52	1.42	1.73	2.63	2.05	1.47	1.63	0.33	0.62
Sc	43	42	39	38	27	41	42	43	41	41	44	40	47	43	41	41	43
Cr	386	365	*274	*359	*329	351	344	369	347	*232	283	341	*434	*366	318	250	426
Co	48	46	58	39	39	43	44	46	42	46	48	49	43	47	44	40	44
Ni	137	136	166	144	131	123	126	113	107	89	96	180	155	160	102	101	121
Cu	111	80	5	13	2	85	98	93	90	38	86	20	47	22	88	18	79
Zn	47	44	46	42	35	50	55	62	67	48	75	44	40	38	60	31	35
Ga	14.4	14.2	13.7	13.7	11.3	13.8	14.2	14.7	14.5	15.8	14.8	14.6	15.6	15.0	14.5	14.5	14.8
Rb	<0.1	<0.1	0.11	<0.1	0.19	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sr	52	51	55	56	49	51	54	53	54	55	54	62	68	84	54	53	77
Y	20.8	19.5	15.8	16.8	12.0	19.2	20.1	22.0	20.7	24.1	23.7	22.7	25.6	25.7	22.3	23.7	22.2
Nb	0.29	0.26	0.20	0.24	0.17	0.23	0.26	0.33	0.27	0.46	0.31	0.66	0.77	0.82	0.31	0.43	0.26
Mo	0.05	<0.05	<0.05	0.06	0.07	0.08	0.26	0.19	0.09	<0.05	0.06	0.06	0.07	<0.05	0.15	0.07	0.06
La	0.84	0.77	0.70	0.76	0.66	0.82	0.92	0.99	0.90	1.16	1.08	1.32	1.36	1.30	0.97	1.17	1.20
Ce	3.27	2.98	2.41	2.54	2.11	3.15	3.29	3.82	3.49	4.41	4.08	4.88	5.14	5.05	3.74	4.34	4.73
Pr	0.66	0.61	0.49	0.55	0.43	0.63	0.64	0.77	0.68	0.85	0.80	0.93	1.02	1.02	0.75	0.85	0.94
Nd	4.17	3.78	3.11	3.28	2.47	3.93	4.10	4.76	4.28	5.27	4.97	5.50	6.15	6.05	4.62	5.17	5.57
Sm	1.71	1.60	1.29	1.39	1.05	1.66	1.71	1.98	1.76	2.12	2.04	2.14	2.28	2.25	1.93	2.13	2.23
Eu	0.69	0.67	0.62	0.56	0.70	0.73	0.71	0.77	0.70	0.84	0.81	0.75	0.79	0.79	0.76	0.78	0.88
Gd	2.64	2.50	1.94	2.19	1.72	2.53	2.57	2.93	2.67	3.11	3.07	3.08	3.36	3.28	2.82	3.18	3.04
Tb	0.53	0.49	0.38	0.45	0.31	0.50	0.50	0.59	0.56	0.63	0.63	0.61	0.65	0.63	0.58	0.64	0.61
Dy	3.68	3.46	2.86	3.15	2.29	3.64	3.73	4.15	3.87	4.42	4.36	4.31	4.70	4.55	4.14	4.51	4.20
Ho	0.80	0.76	0.58	0.69	0.49	0.79	0.82	0.87	0.83	0.95	0.95	0.89	1.02	0.99	0.88	0.97	0.91
Er	2.44	2.31	1.85	2.17	1.63	2.38	2.42	2.59	2.48	2.92	2.86	2.71	3.03	2.97	2.72	2.89	2.62
Tm	0.36	0.34	0.26	0.31	0.22	0.36	0.32	0.40	0.38	0.41	0.43	0.42	0.43	0.43	0.41	0.43	0.39
Yb	2.53	2.21	1.83	2.14	1.48	2.36	2.40	2.62	2.51	2.86	2.94	2.67	2.91	2.86	2.75	2.89	2.59
Lu	0.35	0.34	0.27	0.31	0.21	0.36	0.33	0.39	0.38	0.43	0.43	0.41	0.43	0.43	0.42	0.44	0.39
Hf	0.69	0.62	0.81	0.86	0.61	0.65	0.73	0.80	0.98	0.96	1.32	0.80	0.94	0.93	0.82	0.81	1.03
Ta	0.041	0.042	0.036	0.028	0.023	0.024	0.037	0.037	0.045	0.040	0.039	0.061	0.065	0.064	0.035	0.051	0.029
Bi	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.134	0.085	<0.05	<0.05	<0.05
Th	0.014	0.013	0.019	0.013	0.010	0.012	0.014	0.015	0.021	0.033	0.028	0.038	0.047	0.047	0.015	0.031	0.018
U	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.013	<0.01	0.010	<0.01	0.010	<0.01	<0.01	<0.01	<0.01
Zr (XRF)	43	39	26	36	23	40	42	48	44	54	50	58	64	64	47	55	58
Zr/Hf	62.41	62.50	32.18	41.96	37.46	61.63	57.69	59.70	44.76	56.19	37.88	72.96	68.09	0.00	57.04	67.57	56.09
Zr/Nb	150.88	152.94	130.00	153.19	136.09	170.94	164.71	144.14	162.36	118.42	159.74	87.88	83.01	0.00	152.60	127.02	223.94
La/Ta	20.39	18.26	19.31	27.25	28.57	33.96	24.89	26.76	20.07	28.90	27.72	21.62	20.89	20.31	27.63	22.90	41.21
La/Nb	2.93	3.01	3.48	3.25	3.89	3.48	3.61	2.97	3.33	2.54	3.45	2.00	1.76	1.59	3.14	2.70	4.61
Nb/Ta	6.95	6.07	5.56	8.39	7.35	9.75	6.89	9.00	6.02	11.40	8.03	10.82	11.86	12.78	8.80	8.49	8.93
Rb/Sr			0.0021		0.0039												
Th/Ta	0.341	0.310	0.528	0.464	0.435	0.500	0.378	0.405	0.467	0.825	0.718	0.623	0.723	0.734	0.429	0.608	0.621
Th/Hf	0.020	0.021	0.024	0.015	0.016	0.018	0.019	0.019	0.021	0.034	0.021	0.048	0.050	0.050	0.018	0.038	0.017
Th/U									1.615		2.800		4.700				
Sum REE	24.7	22.8	18.6	20.5	15.8	23.8	24.5	27.6	25.5	30.3	29.4	30.6	33.3	32.6	27.5	30.4	30.3

Table 1 (continued).

Leg:	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
Hole:	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B	504B
Core, section:	225R-2	225R-2	225R-2	226R-3	227R-1	227R-1	229R-1	230R-1	231R-1	233R-1	235R-1	235R-1	236R-1	237R-1	238R-1	238R-1
Interval (cm):	29–32	68–72A	68–72B	30–34	40–46	67–70	31–33	11–14	0–3	16–18	21–24A	21–24B	26–28	17–19	4–7	8–9
Piece no.:	5	13	13	3	7	8B	10	3	1	5	7	7	5	5	2	3
Depth (mbsf):	1914.0	1914.4	1914.4	1923.2	1924.9	1925.2	1943.8	1953.1	1953.5	1960.1	1976.3	1976.3	1981.0	1983.9	1992.0	1992.0
Lithologic unit:	260	260	260	260	260	260	265	265	265	266	269	269	269	269	269	269
Alteration type:	D	D	H	D	D	P	L	L	L	L	D	H	P	D	D	D
Li	0.86	1.04	0.63	1.32	1.16	0.82	0.29	0.41	0.18	0.65	1.39	0.73	0.72	1.02	1.11	0.79
Sc	43	43	40	30	38	37	40	43	40	40	38	38	33	37	40	39
Cr	372	*410	398	323	380	383	416	151	184	273	*371	372	438	348	*386	*368
Co	49	47	47	44	45	48	39	44	46	42	41	41	46	44	47	42
Ni	131	151	140	145	142	152	104	88	86	93	114	111	152	112	116	113
Cu	94	86	12	144	39	9	6	57	4	45	111	26	6	129	113	20
Zn	68	50	39	44	41	47	33	38	35	38	43	41	41	44	57	38
Ga	14.4	14.9	13.7	14.4	13.4	13.3	14.1	15.5	15.4	14.6	14.6	14.1	13.4	14.1	14.4	13.4
Rb	<0.1	<0.1	<0.1	0.14	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sr	56	56	51	55	55	59	52	50	46	50	63	56	62	58	61	56
Y	20.6	21.3	19.6	16.5	16.7	13.7	20.0	25.6	21.7	21.3	20.0	18.8	15.4	19.1	20.6	16.7
Nb	0.29	0.29	0.28	0.33	0.22	0.14	0.39	0.33	0.27	0.42	0.26	0.24	0.17	0.26	0.30	0.20
Mo	0.10	0.09	0.07	0.13	0.07	0.24	0.06	0.06	<0.05	0.08	0.08	0.07	0.07	0.06	0.35	0.08
La	0.84	0.92	0.81	0.96	0.68	0.64	1.10	1.05	0.79	1.06	1.33	0.87	0.73	0.91	0.98	0.75
Ce	3.31	3.48	3.14	3.61	2.65	2.22	3.76	3.91	3.21	3.90	4.40	3.35	2.61	3.48	3.75	2.95
Pr	0.67	0.70	0.63	0.72	0.53	0.46	0.71	0.80	0.68	0.75	0.79	0.69	0.55	0.70	0.75	0.59
Nd	4.25	4.19	3.99	4.32	3.31	2.71	4.36	5.00	4.38	4.76	4.78	4.19	3.28	4.41	4.66	3.68
Sm	1.81	1.70	1.64	1.84	1.45	1.18	1.72	2.18	1.85	1.88	1.89	1.67	1.45	1.83	1.90	1.52
Eu	0.72	0.67	0.87	0.72	0.62	0.61	0.72	0.84	0.81	0.72	0.70	0.78	0.54	0.71	0.74	0.67
Gd	2.67	2.64	2.53	2.70	2.15	1.67	2.63	3.24	2.78	2.80	2.71	2.55	2.00	2.62	2.80	2.28
Tb	0.54	0.53	0.51	0.54	0.44	0.35	0.52	0.67	0.56	0.54	0.52	0.50	0.37	0.53	0.57	0.44
Dy	3.79	3.74	3.64	3.89	3.06	2.56	3.71	4.69	4.03	3.96	3.69	3.49	2.85	3.66	3.85	3.21
Ho	0.84	0.81	0.80	0.87	0.69	0.56	0.82	1.01	0.87	0.83	0.79	0.77	0.61	0.79	0.83	0.68
Er	2.51	2.47	2.39	2.53	2.02	1.66	2.43	3.05	2.62	2.61	2.37	2.27	1.83	2.30	2.45	2.07
Tm	0.37	0.35	0.35	0.38	0.31	0.24	0.35	0.45	0.37	0.37	0.34	0.32	0.26	0.35	0.36	0.30
Yb	2.48	2.39	2.37	2.52	2.07	1.70	2.40	3.00	2.49	2.50	2.19	2.15	1.76	2.32	2.45	2.02
Lu	0.37	0.36	0.36	0.40	0.32	0.25	0.35	0.45	0.37	0.36	0.34	0.32	0.25	0.34	0.36	0.30
Hf	0.96	0.83	0.90	0.93	0.79	0.63	0.80	0.99	0.90	0.77	0.85	0.81	0.82	0.79	0.80	0.73
Ta	0.038	0.034	0.028	0.038	0.034	0.017	0.041	0.037	0.035	0.043	0.030	0.029	0.019	0.039	0.036	0.022
Bi	<0.05	0.149	0.079	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.052	<0.05	<0.05	<0.05	<0.05	<0.05
Th	0.024	0.017	0.018	0.018	0.015	0.014	0.022	0.019	0.017	0.023	0.014	0.013	0.015	0.013	0.020	0.013
U	0.010	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zr (XRF)	42	42	40	45	34	28	48	52	44	49	43	46	34	44	48	36
Zr/Hf	43.57	50.66	44.35	48.44	43.15	44.44	60.30	52.63	49.11	63.80	50.89	56.58	41.51	55.77	59.85	49.11
Zr/Nb	143.34	144.83	142.86	135.14	153.85	195.80	122.45	158.05	164.79	118.07	168.63	193.28	206.06	167.94	161.07	177.34
La/Ta	22.18	26.91	28.79	25.16	19.94	37.41	26.93	28.49	22.69	24.63	44.33	29.97	38.47	23.21	27.17	34.14
La/Nb	2.88	3.16	2.88	2.87	3.07	4.45	2.82	3.20	2.97	2.55	5.22	3.65	4.43	3.45	3.28	3.70
Nb/Ta	7.71	8.53	10.00	8.76	6.50	8.41	9.56	8.89	7.63	9.65	8.50	8.21	8.68	6.72	8.28	9.23
Rb/Sr				0.0025												
Th/Ta	0.632	0.500	0.643	0.474	0.441	0.824	0.537	0.514	0.486	0.535	0.467	0.448	0.789	0.333	0.556	0.591
Th/Hf	0.025	0.021	0.020	0.019	0.019	0.022	0.028	0.019	0.019	0.030	0.017	0.016	0.018	0.016	0.025	0.018
Th/U	2.400															
Sum REE	25.2	24.9	24.0	26.0	20.3	16.8	25.6	30.3	25.8	27.0	26.8	23.9	19.1	24.9	26.4	21.5

Notes: Zr (XRF) indicates Zr data acquired by X-ray fluorescence analysis (Zuleger et al., 1995). Single asterisk (*) = different from the XRF values (Zuleger et al., 1995). A, B in interval number = sample divided in host rock and intensively altered patch or halo. Lithologic units are taken from Shipboard Scientific Party (1992). Alteration types as follows: D = macroscopically dark, less altered diabase; L = macroscopically light, high background alteration; H = diabase containing high percentage of halos around veins; P = samples with green patches or vugs and a high background alteration. ND = not determined. Values are given in ppm.

Table 2. Operating parameters used for the Fisons VG Plasmaquad 2 Plus (ICP-MS, GFZ Potsdam).

Parameter	Values	
RF generator	27.12 MHz	
Incident power	1348 W	
Reflected power	<1W	
Sample cone	Ni 1.0 mm	
Skimmer cone	Ni 0.7 mm	
Argon plasma	Cool flow 12 L/min Auxiliary flow 1.5 L/min Nebulizer flow 0.83 L/min	
Nebulizer	Meinhard TR-30-A3	
Quartz spray chamber	Water-cooled at 6°C	
Ion lenses	Optimized for the whole mass range on ^{59}Co, ^{9}Be, ^{238}U, ^{139}La, ^{209}Bi, ^{115}In	
Internal standard	50 ppb Be and In	
Sampling	Uptake 90 s, acquire 60 s, washout 180 s	
Mode	Peak jump	
Dwell time	10240 ms	
Points/peak	3	
Program	1:2000	1:400
Mass/sweep	58	42
Time/sweep	2.20 s	1.67 s

Table 3. Calculated detection limits and reproducibilities of selected isotopes for the two different multi-element procedures.

Elements	Measured isotopes 3σ (ppm)	Detection limit 1:2000 3σ (ppm)	Detection limit 1:400	Error 2σ (%)
Li	7	0.5		20
Sc	45	1	<10	
Cr	52	2		<10
Co	59	2		<10
Ni	60	2		<10
Cu	63	5	2	<10
Zn	68	2		<10
Ga	71	0.5		<10
Rb	85		0.1	<10
Sr	88	2		<10
Y	89	0.2		<10
Nb	93	0.1	0.02	<10
Mo	98	0.1	0.05	<15
La	139	0.3	0.10	<10
Ce	140	0.6	0.06	<10
Pr	141	0.1	0.01	<10
Nd	146	0.2	0.02	<10
Sm	149	0.05	0.01	<10
Eu	151	0.05	0.01	<10
Gd	157	0.05	0.01	<10
Tb	159	0.05	0.01	<10
Dy	163	0.05	0.02	<10
Ho	165	0.05	0.01	<10
Er	167	0.05	0.01	<10
Tm	169	0.05	0.003	<10
Yb	172	0.05	0.02	<10
Lu	175	0.05	0.004	<10
Hf	178	0.05	0.03	<10
Ta	181	0.05	0.004	<20
Bi	209	0.05	0.05	<30
Th	232	0.05	0.01	<20
U	238	0.05	0.01	<20
Ba	138	5	1.60	>50
Pb	208	4	2.80	>50
Cs	133		0.02	50

Notes: Error calculated from reference samples and multiple measurements of different samples; see also Tables 5–8. Detection limits calculated as 3σ of digestion blank, reported as concentrations in the solids.

Table 4. Multielement standard composition and concentration used for the multi-element procedures, 1:400 and 1:2000, in 2% nitric acid matrix.

Sample dilution 1:400 Element groups	Concentration (ppb)	Sample dilution 1:2000 Element groups	Concentration (ppb)
Rb, Cs	1	Sc, Ga	20
Pb, Bi, U, Th	1	Y, Li, Sr	20
REE + Ba	5	Zr	20
Nb, Mo, Hf, Ta	5	V, Cr, Co, Ni, Cu, Zn,Fe	20
V, Cr, Co, Ni, Cu, Zn,Fe	5	Rb, Cs	5
		Nb, Mo, Hf,Ta	5
		Pb, Bi, U, Th	5
		REE + Ba	5

two procedures. Trace elements like Sr, Cu, Zn Ga, Cr, Ni, Y, which were previously analyzed by XRF (Zuleger et al., 1995), are used as internal standards to check the dissolution efficiency. Instrumental detection limits were calculated as 3σ standard deviation of 20 determinations of the digestion blank, reported as apparent concentrations in the solids (Table 3).

RESULTS

Table 1 summarizes the results of the 84 whole-rock samples. The data set includes the first Li, Mo, and Bi data of lower oceanic crustal rocks. The average concentrations for Li and Mo are 1.28 ppm and 0.09 ppm, respectively. Bi contents range from <0.05 ppm to 0.15 ppm. The values for Cs (<20 ppb) were found to be below the detection limit of these multielement procedures. Ba and Pb could not be determined to better than a 50% uncertainty because of blank and memory problems. Therefore, these elements are not reported. The precision was tested by duplicate measurements of selected samples (Tables 5, 6). The accuracy was checked by analyzing the international reference rocks JB2 and JB3 and interlaboratory standards Bas 140 (Sparks and Zuleger, 1995) and So 62 G224 as unknown samples. The chemical results are given in Tables 7 and 8 along with the analytical errors and the recommended values (Govindaraju, 1989). With exception of some Cr values, the XRF data for Sr, Cu, Zn, Ga, Ni, and Y, reported in Zuleger et al. (1995), show good agreement with the ICP-MS results.

In general, the major constituents of the rocks cored during Leg 140 exhibit a relatively uniform chemical composition, similar to those of previously drilled sections (Hubberten et al., 1983; Emmermann, 1985). The samples studied in the present work represent moderately evolved mid-ocean-ridge basalts (MORB) unusually low in incompatible elements (TiO_2 = 0.42–1.1 wt%, Zr = 23–62 ppm) as reported in Zuleger et al. (1995). The rocks are also unusually low in many trace elements (Hf, Nb, Ta, Th, U, REE, Sc; Fig.1; Table 1) relative to normal MORB (Sun and McDonough, 1989; Floyd, 1991), and low in comparison to the upper part of Hole 504B (Kempton et al., 1985; Tual et al., 1985).

The highly altered "patches" show distinct depletions in TiO_2, CaO, Y, Zr, and total REE values compared to less altered rocks (fig. 5D–H in Zuleger et al., 1995). This study demonstrates that Sc, Hf, Nb, Mo, and, to a minor extent, Th and Li, are also depleted in the alteration patches, whereas Rb is enriched (Fig. 2; Table 9). Despite depletion of the patches in these elements, the patches show no significant differences in element ratios like Zr/Hf, Zr/Nb, Th/Hf, La/Ta, La/Nb, and Zr/Th relative to their parent rocks. Seven other sam-

Table 5. External reproducibility calculated by repeated measurements of selected samples from Hole 504B, using a sample dilution of 1:2000.

	Sample 140-504B-195R-1, 1–3 cm				Sample 140-504B-202R-1, 9–12 cm			
	N = 2/1			*N* = 4/2		*N* = 2/1		*N* = 4/2
Elements	Mean	2σ (%)	Mean	2σ (%)	Mean	2σ (%)	Mean	2σ (%)
Li 7	1.58	15.5	1.51	14.6	1.24	19.4	1.24	14.9
Sc 45	41	14.5	41	8.9	41	9.7	42	12.9
Cr 52	262	1.3	259	5.3	345	3.2	353	6.4
Co 59	45	15.3	43	14.5	44	8.2	45	12.1
Ni 60	94	1.7	91	9.9	122	6.0	126	14.8
Cu 63	73	2.9	71	7.3	94	11.5	96	12.6
Zn 68	77	5.6	76	4.3	64	1.6	66	12.2
Ga 71	15	3.6	15	3.6	14	4.5	15	12.8
Sr 88	51	3.8	50	4.2	59	2.3	56	2.1
Y 89	22	5.6	22	5.5	21	4.2	21	4.1
Nb 93	0.24	10.3	0.25	11.0	0.27	16.1	0.26	12.4
Mo 98	<0.1		<0.1		<0.1		<0.1	
La 139	0.92	11.6	0.93	11.6	0.98	10.3	0.92	10.2
Ce 140	3.67	16.1	3.67	11.3	3.68	6.6	3.50	14.4
Pr 141	0.73	14.2	0.73	10.8	0.72	4.2	0.69	8.1
Nd 146	4.67	11.8	4.65	10.2	4.48	7.6	4.38	7.0
Sm 149	2.02	12.3	1.97	15.2	1.80	3.3	1.77	6.7
Eu 151	0.75	16.8	0.76	11.5	0.74	7.1	0.72	10.1
Gd 157	3.00	12.5	3.00	16.1	2.80	0.0	2.77	3.0
Tb 159	0.59	16.0	0.59	14.5	0.55	4.6	0.54	5.1
Dy 163	4.25	10.1	4.24	13.0	3.94	3.4	3.93	2.3
Ho 165	0.89	9.9	0.91	13.7	0.88	2.4	0.86	5.4
Er 167	2.70	10.5	2.72	12.2	2.65	1.4	2.60	4.8
Tm 169	0.41	16.7	0.41	16.8	0.40	4.4	0.38	9.7
Yb 172	2.65	12.2	2.68	13.1	2.57	0.2	2.57	1.8
Lu 175	0.41	13.3	0.41	15.5	0.40	3.0	0.39	4.1
Hf 178	1.06	14.6	1.07	14.7	1.06	4.7	1.02	8.9

Note: *N* = number of measurements = number of digestions. Values are given in ppm.

Table 6. External reproducibility calculated by repeated measurements of selected samples from Hole 504B, using a sample dilution of 1:400.

	Sample 140-504B-198R-1, 79–82 cm				Sample 140-504B-202R-1, 23–25 cm			
		N = 2/1		*N* = 4/2		*N* = 2/1		*N* = 4/2
Elements	Mean	2σ(%)	Mean	2σ (%)	Mean	2σ(%)	Mean	2σ(%)
Cu 63	7.31	15.3	7.53	14.0	ND		ND	
Rb 85	<0.1		<0.1		<0.1		<0.1	
Nb 93	0.28	2.2	0.26	39.7	0.29	8.0	0.28	11.8
Mo 98	0.30	0.4	0.28	19.0	0.13	11.1	0.12	14.4
La 139	0.81	1.0	0.81	3.4	0.91	0.5	0.89	4.4
Ce 140	3.27	1.2	3.28	2.2	3.50	0.4	3.42	5.4
Pr 141	0.67	2.6	0.67	2.5	0.70	1.3	0.69	5.2
Nd 146	4.22	7.8	4.22	7.0	4.42	0.1	4.28	9.4
Sm 149	1.84	9.4	1.81	9.1	1.85	1.2	1.80	7.1
Eu 151	0.84	10.1	0.84	7.3	0.74	0.2	0.72	6.9
Gd 157	2.80	13.4	2.75	13.2	2.82	1.6	2.72	10.2
Tb 159	0.56	9.8	0.55	10.0	0.57	0.1	0.55	11.7
Dy 163	3.95	10.0	3.91	11.0	4.07	0.9	3.91	11.7
Ho 165	0.86	9.7	0.86	9.6	0.88	2.2	0.85	11.4
Er 167	2.60	12.5	2.58	13.3	2.67	2.1	2.56	10.7
Tm 169	0.38	10.4	0.38	9.4	0.39	2.1	0.38	9.7
Yb 172	2.58	13.2	2.56	11.1	2.70	3.6	2.59	10.6
Lu 175	0.39	12.3	0.39	10.4	0.40	0.6	0.39	8.1
Hf 178	1.08	8.8	1.03	12.7	1.09	1.3	1.04	11.4
Ta 181	0.04	18.1	0.04	20.0	0.03	14.5	0.03	20.3
Bi 209	<0.05		<0.05		<0.05		<0.05	
Th 232	0.02	19.9	0.02	19.3	0.02	21.2	0.02	23.0
U 238	0.01	25.5	0.01	21.5	0.01	7.2	0.01	9.6

Note: *N* = number of measurements = number of digestions. Values are given in ppm. ND = not determined.

ples deviate significantly from the vast majority of rocks recovered from Leg 140 as seen in Figure 1I–K, and Nb, Ta, and Th vs. Zr and Nb vs. Ta (Fig. 3). Note that this group contains only one "patch" and no "halo" sample and represents distinct lithologic units. Samples 140-504B-204R-1, 0–4 cm, 204R-1, 15–19 cm, and 205R-1, 21–23 cm, are part of lithologic Unit 232; 186R-2, 30–32 cm, is part of Unit 213, whereas the others belong to Units 254 (222R-1, 69–73 cm) and 256 (222R-1, 115–120 cm, A and B), respectively (Shipboard Scientific Party, 1992). The same grouping could be shown by the Zr/TiO_2 ratio in Zuleger et al. (1995).

The element ratios in relationship to normal MORB and to the upper part of Hole 504B (Tual et al., 1985) scatter in a wider range; and Zr/Hf, Zr/Nb, La/Nb, and La/Ta ratios are much higher than normal MORB, whereas Nb/Ta, Th/Ta, and Y/Tb are lower (Table 10).

ACKNOWLEDGMENTS

We are especially thankful to Heike Rothe for preparing the samples for the ICP-MS. We also wish to thank Martin Zimmer and Hans-Gerrit Plessen for their assistance in operating the ICP-MS and Wolfgang Bach for his numerous helpful discussions. We are grateful to the reviewers David Christie and Roger Nielsen for their critical and helpful contributions.

Table 7. Trace-element data for international reference rocks JB2 and JB3, and interlaboratory reference rocks Bas 140 and So 62 G224, using a sample dilution of 1:2000.

Sample:	JB 2			JB 3			Bas 140			So 62 G224		
Elements	N = 15 Mean	2σ (%)	Lit.	N = 4 Mean	2σ (%)	Lit.	N = 19 Mean	2σ (%)	XRF and ICP-AES	N = 17 Mean	2σ (%)	XRF and ICP-AES
Li 7	7.9	13.3	8	7.6	6.5	7.2	1.1	23.5	ND	5.2	12.0	ND
Sc 45	48	11.0	54	30	7.5	35	43	9.4	ND	40	7.0	ND
Cr 52	24	9.4	27.4	55	6.1	60.4	189	9.5	194	377	16.8	375
Co 59	36	8.8	39.8	33	7.7	36	55	13.3	ND	43	11.1	45
Ni 60	14	11.5	14.2	34	8.9	39	85	13.6	81	85	9.1	82
Cu 63	216	9.3	227	184	6.9	198	81	10.0	83	80	9.9	78
Zn 68	113	8.7	82	106	5.2	106	78	10.4	78	78	11.2	78
Ga 71	16.4	9.9	17	19.9	4.8	21	15.5	5.7	16	16.2	9.2	16
Rb 85	6.2	8.0	6.2	14.0	5.2	13	ND		ND	ND		ND
Sr 88	179	7.1	178	425	6.8	395	46	8.0	47	77	12.3	75
Y 89	20.7	19.1	26	24.0	6.4	28	24.7	6.4	27	27.2	12.7	30
Nb 93	0.48	10.5	0.8	1.91	5.2	2.3	0.56	8.1	ND	1.27	11.3	ND
Mo 98	0.96	12.5	1.1	1.05	6.4	1.1	0.20	27.9	ND	0.21	22.7	ND
Cs 133	0.85	9.2	0.9	1.01	11.3	1.1	ND		ND	ND		ND
La 139	2.3	9.2	2.4	8.7	7.5	9.1	1.0	12.6	1	2.0	10.9	2.2
Ce 140	6.6	8.6	6.5	22.0	4.6	20.5	3.8	7.1	4.8	6.7	10.2	8.4
Pr 141	1.16	9.4	1.2	3.27	5.7	3.2	0.78	11.1	ND	1.22	11.1	2.3
Nd 146	6.4	7.1	6.5	16.4	8.1	16.6	4.9	4.9	4.5	7.2	10.9	6.7
Sm 149	2.31	7.8	2.3	4.33	8.8	4.3	2.08	6.4	2	2.75	11.9	2.4
Eu 151	0.89	8.8	0.85	1.38	7.8	1.30	0.80	5.9	0.61	1.05	10.6	0.91
Gd 157	3.2	9.0	3.3	4.8	9.8	4.60	3.2	5.7	3.1	3.9	14.3	3.4
Tb 159	0.60	9.9	0.62	0.77	8.5	0.82	0.60	53.2	ND	0.71	48.2	ND
Dy 163	4.2	8.7	3.85	4.8	8.0	4.40	4.5	6.5	3.5	5.2	13.6	4.6
Ho 165	0.89	8.5	0.83	0.96	9.3	0.84	0.98	5.2	0.87	1.11	11.2	0.98
Er 167	2.7	9.7	2.4	2.8	5.1	2.50	3.0	6.3	2.6	3.3	13.1	3.1
Tm 169	0.39	6.7	0.5	0.40	9.6	0.50	0.44	11.4	ND	0.48	12.3	ND
Yb 172	2.6	7.8	2.5	2.6	3.6	2.40	2.9	7.2	2.5	3.2	13.6	2.7
Lu 175	0.40	9.0	0.4	0.38	10.1	0.38	0.45	9.5	0.4	0.48	12.2	0.44
Hf 178	1.58	9.4	1.4	2.96	9.1	2.70	1.24	6.8	ND	2.01	12.2	ND

Notes: Lit. = Govindaraju (1989); XRF and ICP-AES = data from University of Giessen, Federal Republic of Germany. N = number of dissolutions = number of measurements. ND = not determined. Values are given in ppm.

Table 8. Trace-element data for international reference rocks JB2 and JB3, and interlaboratory reference rocks Bas 140 and So 62 G224, using a sample dilution of 1:400.

Sample:	JB2			JB 3			Bas 140			So 62 G224		
Elements	N = 12 Mean	2σ (%)	Lit.	N = 4 Mean	2σ (%)	Lit.	N = 22 Mean	2σ (%)	ICP-AES and XRF	N = 17 Mean	2σ (%)	ICP-MS Kiel
Rb 85	ND		6.2	ND		13	0.06	43.5	ND	0.61	17.9	0.71
Nb 93	0.50	15.8	0.8	1.99	10.6	2.3	0.56	14.5	ND	1.27	17.3	1.30
Mo 98	0.94	14.3	1.1	1.12	9.2	1.1	0.18	12.7	ND	0.21	18.9	0.19
Cs 133	0.84	11.9	0.9	1.04	29.6	1.1	ND		ND	ND		0.01
La 139	2.26	13.0	2.4	ND		9.1	0.95	12.4	1	1.90	19.5	1.77
Ce 140	6.52	9.9	6.5	ND		20.5	3.78	12.0	4.8	6.43	18.9	6.08
Pr 141	1.15	11.7	1.2	ND		3.2	0.78	11.5	ND	1.19	20.6	1.11
Nd 146	6.32	9.2	6.5	ND		16.6	4.86	11.5	4.5	6.91	15.6	6.24
Sm 149	2.30	14.1	2.3	ND		4.3	2.07	11.2	2	2.64	15.8	2.42
Eu 151	0.90	14.4	0.85	1.55	26.0	1.3	0.80	12.1	0.61	1.02	16.7	0.92
Gd 157	3.04	11.6	3.3	4.93	13.5	4.6	3.07	12.4	3.1	3.66	16.1	3.26
Tb 159	0.59	16.5	0.62	0.79	15.0	0.82	0.62	12.9	ND	0.71	14.0	0.61
Dy 163	3.94	10.2	3.85	5.04	15.4	4.4	4.43	12.7	3.5	4.88	12.4	4.32
Ho 165	0.87	17.9	0.83	0.99	12.2	0.84	0.96	13.2	0.87	1.05	14.1	0.90
Er 167	2.56	12.9	2.4	2.83	12.3	2.5	2.90	13.0	2.6	3.11	13.0	2.68
Tm 169	0.39	17.2	0.5	0.40	11.7	0.5	0.43	12.5	ND	0.45	13.3	0.39
Yb 172	2.62	14.2	2.5	2.73	15.0	2.4	2.91	13.1	2.5	3.02	12.3	2.69
Lu 175	0.40	16.5	0.4	0.40	12.7	0.38	0.44	13.3	0.4	0.46	15.2	0.38
Hf 178	1.63	17.9	1.4	2.97	14.7	2.7	1.24	17.8	ND	1.98	14.3	1.62
Ta 181	0.05	21.4	0.2	0.16	16.1	0.15	1.43	13.1	ND	0.12	22.3	0.09
Bi 209	<0.05		0.03	<0.05		0.02	<0.05		ND	<0.05		<.01
Th 232	0.29	13.3	0.33	1.40	11.7	1.3	0.02	51.1	ND	0.10	21.0	0.08
U 238	0.17	14.6	0.16	0.53	14.7	0.46	<0.01	51.2	ND	0.06	10.9	0.05

Notes: Lit. = Govindaraju (1989); XRF and ICP-AES = data from University of Giessen, Federal Republic of Germany; ICP-MS Kiel = data from University of Kiel, Federal Republic of Germany, analyzed using a VG Plasmaquad. N = number of dissolutions = number of measurements. ND = not determined. Values are given in ppm.

This research was supported by the Deutsche Forschungsgemeinschaft, Bonn-Bad Godesberg, Federal Republic of Germany (Erz 123/7-1), to J. Erzinger.

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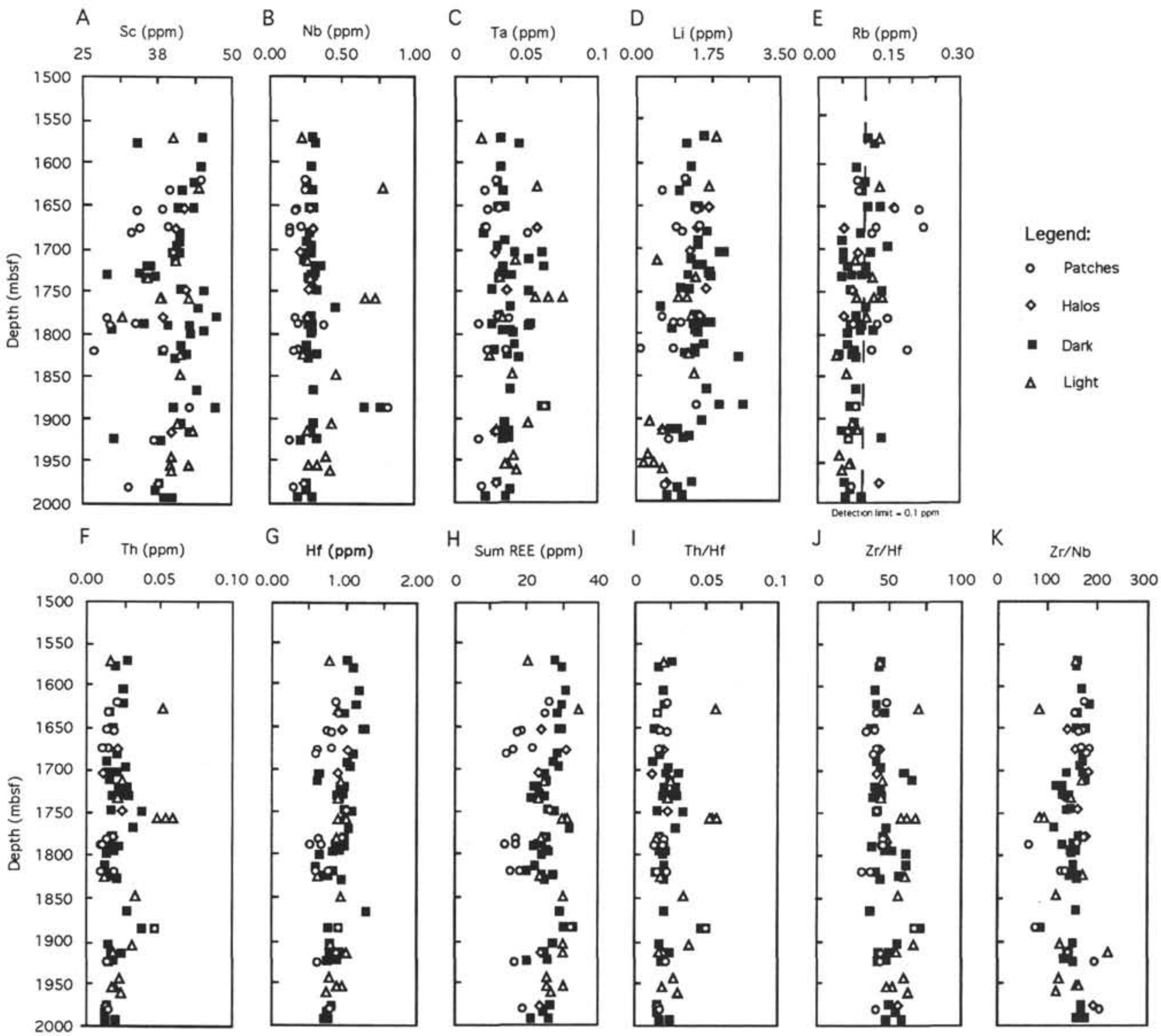

Figure 1. Downhole variations of Leg 140 diabases. **A.** Sc. **B.** Nb. **C.** Ta. **D.** Li. **E.** Rb. **F.** Th. **G.** Hf. **H.** $\sum$ REE. **I.** Th/Hf. **J.** Zr/Hf. **K.** Zr/Nb. Solid squares = macroscopically dark, less altered diabases; open triangles = macroscopically light, high background alteration; open diamonds = alteration halos around veins, and open circles = green to gray alteration patches.

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Date of initial receipt: 5 August 1994
Date of acceptance: 15 November 1994
Ms 148SR-112

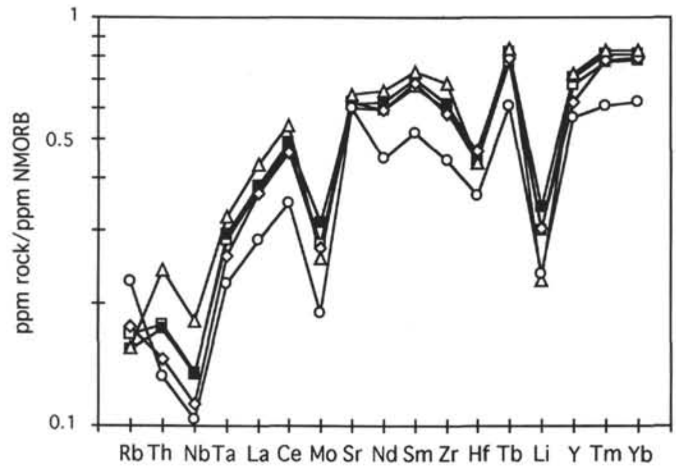

Figure 2. Spider diagram of average values for the different alteration types. Refer to Figure 1 for explanation of symbols; open squares = mean values of all samples. Values for N-MORB are from Sun and McDonough (1989).

Table 9. Average trace-element values for the different alteration types.

Alteration type (ppm)	Mean all N = 85	SD	Mean D N = 46	SD	Mean H N = 7	SD	Mean L N = 16	SD	Mean P N = 14	SD
Rb	0.09	0.04	0.09	0.02	0.10	0.05	0.09	0.03	0.13	0.05
Th	0.021	0.011	0.021	0.007	0.017	0.004	0.029	0.016	0.016	0.005
Nb	0.31	0.14	0.31	0.10	0.26	0.03	0.42	0.20	0.24	0.06
Ta	0.037	0.013	0.038	0.010	0.034	0.010	0.042	0.015	0.029	0.010
La	0.94	0.21	0.97	0.14	0.92	0.16	1.09	0.24	0.71	0.13
Ce	3.55	0.80	3.69	0.53	3.49	0.55	4.05	0.85	2.62	0.51
Mo	0.09	0.05	0.10	0.06	0.08	0.02	0.08	0.06	0.06	0.01
Sr	55	8	55	6	54	3	58	9	54	8
Nd	4.33	0.88	4.50	0.61	4.33	0.57	4.83	0.84	3.29	0.66
Sm	1.77	0.32	1.85	0.21	1.80	0.26	1.94	0.27	1.36	0.26
Zr	44	9	45	5	43	3	51	9	33	6
Hf	0.90	0.17	0.94	0.18	0.96	0.09	0.90	0.11	0.75	0.12
Tb	0.52	0.09	0.55	0.07	0.53	0.05	0.56	0.07	0.40	0.08
Li	1.28	0.49	1.47	0.41	1.30	0.45	0.98	0.55	1.01	0.40
Y	19	6	20	5	17	8	20	6	16	3
Tm	0.35	0.07	0.37	0.05	0.36	0.03	0.38	0.05	0.27	0.06
Yb	2.38	0.41	2.49	0.31	2.42	0.25	2.54	0.30	1.88	0.38
Sc	39	4	40	4	40	2	40	3	36	5

Notes: Alteration types: all = D + H + L + P; D = macroscopically dark, less altered diabase; L = macroscopically light, high background alteration; H = diabase containing high percentage of halos around veins; P = samples with green patches or vugs and a high background alteration. N = number of samples. SD = standard deviation.

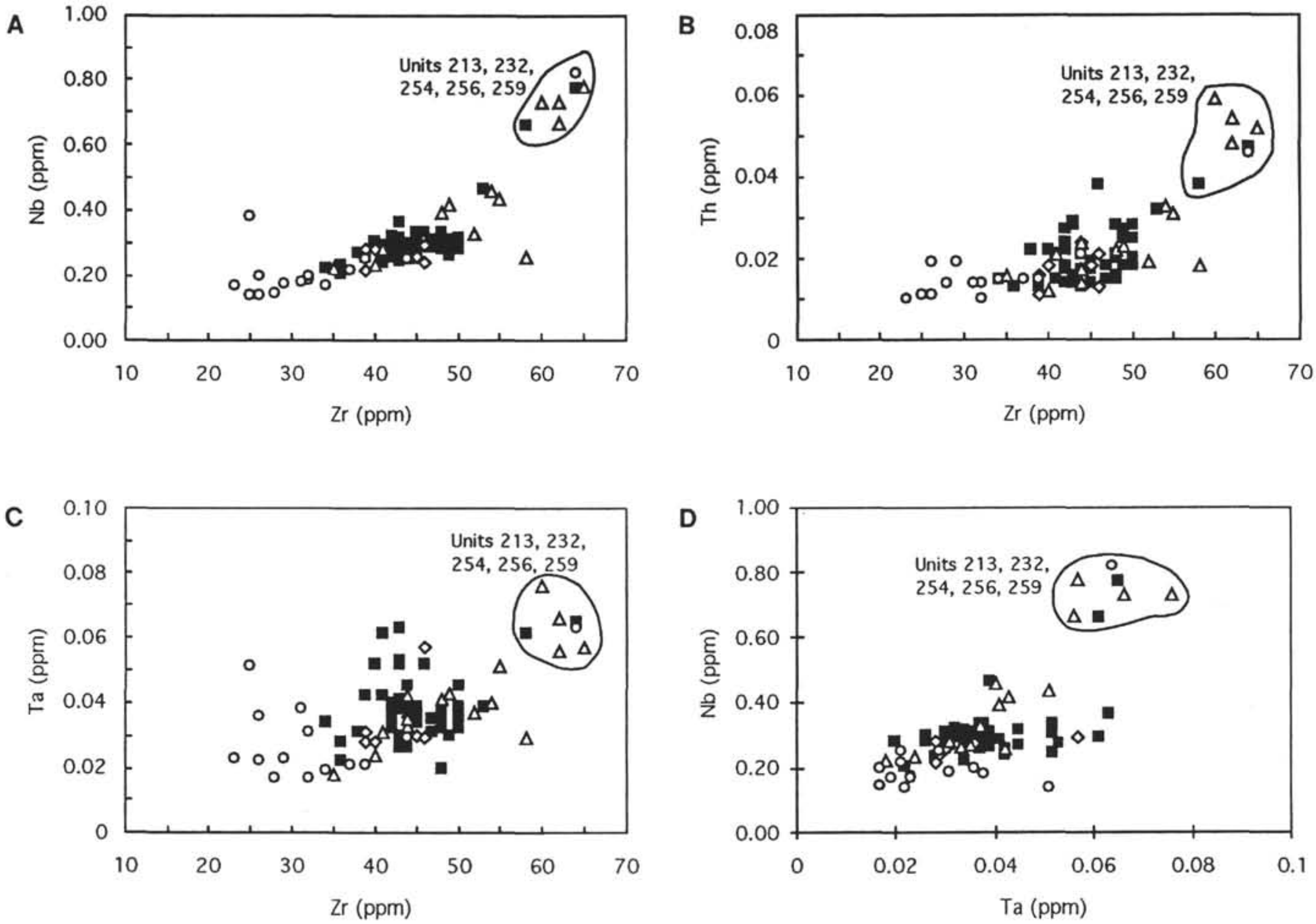

Figure 3. Nb (**A**), Th (**B**), and Ta (**C**) vs. Zr, and Nb vs. Ta (**D**) of selected Leg 140 diabases. Solid squares = macroscopically dark, less altered diabases; open triangles = macroscopically light, high background alteration; open diamonds = alteration halos around veins, and open circles = green to gray alteration patches. Refer to the text for explanation of the separate group of samples from lithologic Units 213, 232, 254, 256, and 259.

Table 10. Comparison of incompatible element ratios from MORB, diabases collected at Leg 140, and diabases from the upper part of Hole 504B.

Ratios	Mean Leg 140	N-MORB	Upper part Hole 504B
Zr/Hf	49 ± 9.4	36	39 ± 5
Zr/Nb	150 ± 30	>30	
Nb/Ta	8.5 ± 2.2	17	16 ± 1
Th/Ta	0.58 ± 0.19	0.9	
Y/Tb	37 ± 8		46
La/Ta	27 ± 7	18–20	
La/Nb	3.13 ± 0.7	>1	

Notes: N-MORB from Floyd (1991); upper part of Hole 504B data from Tual et al. (1985).