23. LEG 55, EMPEROR SEAMOUNTS: TRACE ELEMENTS IN TRANSITIONAL THOLEIITES, ALKALI BASALTS, AND HAWAIITES—MANTLE HOMOGENEITY OR HETEROGENEITY AND MAGMATIC PROCESSES

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INTRODUCTION

Three seamounts of the Emperor Seamount chain were sampled during Leg 55:

Ōjin seamount, Hole 430A, 37° 59.29 N 170° 35.86 E
Nintoku seamount, Hole 432A, 41° 20.03 N 170° 22.74 E
Suiko seamount, Hole 433A, 44° 46.60 N 170° 01.26 E
Hole 433C, 44° 46.63 N 170° 01.23 E

Oceanites, ankaramites, transitional tholeiites, alkali basalts, and hawaiites were recovered from these seamounts. The purpose of this study is the fractionation of trace elements according to their physicochemical properties and partition coefficient classification; fractionation of the elements observed in these samples is compared with their fractionation in mid-oceanic ridge tholeiites. Some preliminary conclusions are presented with regard to mantle heterogeneity or homogeneity and magmatic processes.

DESCRIPTION OF RESULTS

Ōjin Seamount: Hole 430A. Shipboard chemical analyses (major elements and Ni, Zr, Sr, and Ba) were performed on 13 samples. Major-element data have been completed for Na_2O (Table 1); trace-element data, obtained either through X-ray fluorescence spectrometry or neutron activation analysis (or both) are shown in Table 2. Shipboard Ba data were obtained without any matrix effect correction; precision should be within 15 per cent, and comparison neutron activation analysis data are given. Except Samples 4-1, 68–70 cm (sandstone) and 6-4, 143–146 cm (tholeiite), all samples have been defined as hawaiites, and show homogeneous results for all elements investigated. Ni and Cr (high-partition-coefficient elements) concentrations are low (15 and 7 ppm, respectively), and low-partition-coefficient elements concentrations are high (e.g., Nb =46 ppm, Ta = 3.2 ppm).

Nintoku Seamount: Hole 432A (Tables 3 and 4). Sample 1-1, 35–38 cm has been defined as a hawaiite; it shows the highest values for low-partition-coefficient elements (e.g., Nb = 86 ppm, Ta = 5.4 ppm). The five other analyzed samples characterized as alkali basalts also show high concentrations for low-partition-coefficient elements, even if lower than in hawaiites of Hole 430A (e.g., Nb = 40 ppm, Ta =2.7 ppm). Ni and Cr concentrations are higher than in hawaiites (about 60 and 80 ppm, respectively).

Suiko Seamount: Holes 433A, 433B, and 433C. The five samples analyzed for Hole 433A (alkali basalts) are very similar both for major elements (Table 5) and trace elements (Table 6), and probably represent different samples of the same flow unit. The sample from Hole 433B is also very close to samples from Hole 433A. According to the concentrations of low-partition-coefficient elements, the samples from Hole 433C (Tables 7 and 8) can be classified as follows: oceanites (Nb ~ 5 ppm, Ta ~ 0.35 ppm), ankaramites (Nb ~ 11 ppm, Ta ~ 0.75 ppm), transitional tholeiites and (or) transitional alkali basalts (Nb = 11–17 ppm, Ta = 0.75–1.1 ppm), and one alkali basalt (Nb = 26.3 ppm, Ta = 1.79 ppm), which is close to alkali basalts of Holes 433A and 433B. Oceanites and ankaramites present high Ni and Cr concentrations because of olivine and pyroxene accumulation. From this general description, good agreement is observed between the shipboard classification of samples and low-partition-coefficient element concentrations; in order of increasing concentrations, this classification is: oceanite, ankaramite, "transitional" tholeiites (or "transitional alkali basalts"), alkali basalts, and hawaiites.

Y/Tb, Zr/Hf, and Nb/Ta RATIOS: CHONDRITIC PRIMORDIAL MANTLE

From physicochemical properties of the elements and oceanic basalt data, the studied elements have been classified according to their partition coefficients $D_V > D_Y \cong D_{Tb} > D_{TC} > D_{Zr} \alpha D_{Hf} > D_{Nb} \cong D_{Ta} \neq D_{La} > D_{Th}$ (Bougault et al., in press). One of the important results is that elements of each pair Y–Tb, Zr–Hf, and Nb–Ta belonging to groups III, IV, and V have equal or very similar partition coefficients. These pairs of elements are plotted Figure 1 (Y–Tb), Figure 2 (Hf–Zr), and Figure 3 (Nb–Ta). We do observe in each diagram that one element of one pair versus the other plots following very closely a straight line. The ratios Y/Tb (40), Zr/Hf (40), and Nb/Ta (15) are very close to those found for the Atlantic Ocean (42.5, 39, and 17, respectively) (Bougault et al., in press) and to those for the East Pacific Rise (Joron et al., in press). These values correspond to

TABLE 1
Hole 430A, Ōjin Seamount: Major Elements

Sample (Interval in cm)	4-1, 68–70	4-2, 139–142	5-1 (#1), 5–7	5-1 (#2A), 16–19	5-2 (#6C), 120–123	5-5 (#10D), 127–129	6-1 (#2B), 33–35	6-2 (#10), 102–105	6-2 (#13), 133–136	6-3 (#6), 68–70	6-4 (#1B), 8–11	6-4 (#18), 143–146	10,CC, 28–30
Rock Type	Volcanic Sandstone	Hawaiite	Hawaiite	Hawaiite	Hawaiite	Hawaiite	Hawaiite	Hawaiite	Hawaiite	Hawaiite	Hawaiite	Tholeiite	Hawaiite
SiO_2	49.77	49.03	49.96	49.10	49.50	49.81	49.60	49.29	49.80	50.02	49.56	48.38	49.63
TiO_2	2.93	3.16	3.13	3.13	3.00	3.03	3.02	2.88	2.87	2.90	2.83	2.79	2.86
Al_2O_3	15.16	15.96	16.09	16.17	15.57	15.84	15.72	15.99	15.98	16.05	15.75	15.44	15.76
$Fe_2O_{3(T)}$	14.04	13.02	12.41	13.28	12.87	12.22	12.31	12.39	12.00	11.72	12.35	13.07	12.46
MnO	0.07	0.09	0.08	0.09	0.13	0.10	0.11	0.13	0.12	0.12	0.14	0.18	0.14
MgO	6.87	3.78	3.73	3.09	4.78	4.31	4.12	4.74	4.76	4.11	4.58	5.41	4.71
CaO	3.41	6.96	7.01	7.17	6.95	7.24	7.18	6.85	7.02	7.02	6.80	11.05	6.99
Na_2O	4.10	4.30	4.40	4.20	4.10	4.20	4.10	4.40	4.20	4.30	4.10	2.80	4.00
K_2O	2.67	1.85	1.79	1.77	1.60	1.66	1.66	1.68	1.73	1.73	1.72	0.36	1.70
P_2O_5	0.35	1.27	1.26	1.25	1.19	1.31	1.27						1.29
Total	99.37	99.42	99.66	99.25	99.69	99.72	99.09	99.70	99.84	99.29	99.11	99.81	99.54
L.O.I.	25.77	4.26	4.16	4.44	3.15	3.61	3.29	3.81	3.55	3.20	3.53	1.08	2.82
H_2O^+	2.69	1.04	0.89	0.91	1.59	1.45	1.34	1.67	1.54	1.41	1.55	0.38	1.23
CO_2	0.15	0.15	0.04	0.18	0.03	0.05	0.07	0.07	0.06	0.07	0.05	0.03	0.05

chondritic values. This means that whatever the magmatic processes giving rise to tholeiites, "transitional" tholeiites, alkali basalts, and hawaiites, and whatever the history of the mantle, these ratios have been kept constant and characterize the primordial chondritic character of the mantle.

Ta–Th, La–Ta: MANTLE SOURCES

Nb, Ta, Th, and La are very low-partition-coefficient elements. Nb and Ta physicochemical properties are very similar. La, Th, and Ta ionic charges and sizes are different, which leads to different absolute values for their partition coefficients. The consequence is an easier fractionation of these elements compared with the Nb–Ta pair. Two different values have been observed for the La/Ta ratio (~9 and ~18), and several values for the Ta/Th ratio in oceanic tholeiites. For Leg 55 samples (tholeiites, alkali basalts, and oceanites), we did not observe an important fractionation of Ta/Th and La/Ta (Figures 4 and 5). La/Ta ratios, 9 to 11 for alkali basalts and tholeiites and 12 for oceanites, are in agreement with the value 9 found for tholeiites in the Atlantic samples recovered from topographic highs or "platforms". The almost unique Ta/Th ratio for tholeiites and alkali basalts of Leg 55, compared with the possible variation in tholeiites (Bougault et al., in press) and the small difference observed for hawaiites, suggests that the sources of these materials are not much different.

Tb/Ta: PARTIAL MELTING

Looking at Figure 1 (Y–Tb), Figure 2 (Hf–Zr), and Figure 3 (Nb–Ta), even if the ratios of the elements of the different pairs are constant or almost constant, the relative positions of tholeiites, alkali basalts of Site 433, alkali basalts of Site 432, and hawaiite of Site 430 are not the same in each diagram. The best classification of these different rock types is made through the lowest-partition-coefficient elements Nb–Ta (or Th–Ta as well); the tholeiitic sample recovered in Hole 430A (6-4, 143–146 cm) lies in the upper field of the tholeiites; according to the position of the different rock types, only one sample of Hole 433C can be classified as "alkali basalt": 4-1, 39–41 cm; it lies very close to alkali basalts of Holes 433A and 433B.

With increasing partition coefficients from Nb–Ta to Hf–Zr to Y–Tb, alkali basalts plot closer and closer to the tholeiitic field; alkali basalts of Site 432 plot in the middle part of the tholeiitic field (with some fractionation) in the Y–Tb diagram (Figure 1).

This feature is easier to see in Figure 6, where two elements of the same transition series (with different partition coefficients) are plotted (Tb–Ta). If we admit from La/Ta and Th/Ta data that the mantle sources, parents of these different rocks, are very similar, then the only way to explain such Tb/Ta fractionation is partial melting. It can be the extent of partial melting: in this case, except for the hawaiite sample of Hole 432A, it can be stated that the lowest partial melting is related to alkali basalts of Hole 432A. It can also be melting of a residue; in this second possibility, tholeiites (or transitional tholeiites) would be the result of melting of a residue, alkali basalts being produced through melting a more primitive source. Both hypotheses, related to partial melting, can account for the relative values of Tb/Ta ratios in tholeiites and alkali basalts.

V, Ti: FRACTIONAL CRYSTALLIZATION

According to their partition coefficients, V and Ti are the closest to Y and Zr, respectively. In respect of "non-fractionation" availability, V–Y and Ti–Zr are plotted in Figures 7 and 8. We indeed observe very little fractionation between the elements of these pairs for tholeiites and alkali basalts. But for hawaiites, a large fractionation is observed, these two diagrams showing the biggest difference between hawaiites and alkali or tholeiite basalts. This fractionation is interpreted as the result of titanomagnetite fractionation (see petrographic description in this volume).

CONCLUSION

According to the classification of the elements which was made previously from the samples recovered in the Atlantic Ocean, with regard to their physicochemical

TABLE 2
Hole 430A, Nintoku Seamount: Trace Elements

Sample (Interval in cm)	Sc NAA	Ti XRF	V XRF	Cr XRF	Mn XRF	Fe XRF	Co XRF	Co NAA	Ni XRF	Ni NAA	Rb XRF	Rb NAA	Sr XRF
4-1, 68–70	27	17600	287	177	540	98280	31	35		72			
4-2, 139–142	20.9	18960	188	6.3	690	91140	34	35	21	13	28.2	30	710
5-1, 5–7	19.1	18780	191	7.8	620	86870	42	37.7	20	13	26.3	21.5	705
5-1, 16–19	21.0	18780	185	6.0	690	92960	36	40.8	19	15	25.5	28.5	706
5-2, 120–123	17.7	18000	184	8.2	1000	90090	34	32.2	19	11	25.1		661
5-5, 127–129	19.7	18180	184	5.9	770	85540	33	33.7	16	12	25.0	27.1	685
6-1, 33–35	18.7	18120	179	8.3	850	86170	32	32.6	16	12	24.5	24.3	667
6-2, 102–105	17	17280	176	8.3	1010	86730	29	29.8	16	9.5	18		652
6-2, 133–136	17.7	17220	172	5.4	930	84000	29	29.7	15	7.2	22.1	21.8	676
6-3, 68–70	18.5	17400	168	6.4	930	82040	30	31.1	14	10	24.2	24.2	683
6-4, 8–11	16.9	16980	165	7.2	1080	86450	32	30.3	17	11	25.3	25	651
6-4, 143–146	29.4	16740	305	86	1390	91490	47	44.5	59	59	2.2	3.2	428
10,CC	18.2	17160	167	7.9	1080	87220	33	32.3	12	11	26.5	27.7	683

Sample (Interval in cm)	Y XRF	Zr XRF	Nb XRF	Sb NAA	Cs NAA	Ba XRF	Ba NAA	La NAA	Eu NAA	Tb NAA	Hf NAA	Ta NAA	Th NAA	U NAA
4-1, 68–70				0.12	0.13		169	18.9	2.6	1.12	6.69	1.97	1.68	0.52
4-2, 139–142	67.8	479	46	0.11	0.12	330	379	43.7	5.9	2.19	12.2	3.57	3.65	1.23
5-1, 5–7	64.7	478	44.7	0.09	0.08	337	257	41.8	5.9	1.95	10.7	3.28	2.97	1.15
5-1, 16–19	66.4	473	45.1	0.11	0.12	327	386	42.5	5.9	2.15	12.3	3.54	3.54	1.16
5-2, 120–123	62.7	461	43.1	0.09	0.09	315	327	36.7	4.8	1.81	10.4	3.02	3.02	1.01
5-5, 127–129	65.7	496	47.1	0.08	0.07	325	363	42.2	5.7	2.08	11.8	3.41	3.41	1.11
6-1, 33–35	64.5	474	46.0	0.04	0.07	320	342	38.5	5.5	1.95	11.1	3.19	3.23	1.03
6-2, 102–105	66.1	477	46.0	0.05	0.04	328	340	39.9	5.0	1.89	10.7	3.15	3.18	0.79
6-2, 133–136	65.3	486	46.0	0.06	0.04	335	363	41.1	5.7	2.03	11.5	3.29	3.41	0.95
6-3, 68–70	65.8	481	47.0	0.08	0.08	340	398	42.6	5.8	2.13	11.8	3.41	3.57	1.04
6-4, 8–11	64.8	476	46.5	0.09	0.10	330	340	38	5.18	1.91	10.8	3.16	3.21	1.09
6-4, 143–146	34.6	171	16.7	0.03	0.04	75	94	12.4	2.24	0.94	4.39	1.18	0.97	0.28
10,CC	63.1	484	46.7	0.09	0.11	335	369	42.2	5.8	2.02	11.4	3.32	3.60	1.18

TABLE 3
Hole 432A, Nintoku Seamount: Major Elements

Sample (Interval in cm)	1-1, 35–38	2-1 (#8B), 83–85	2-2 (#11E), 100–102	3-2, 106–108	4-4 (#6B), 84–86	5-1 (#3B), 128–130
Rock Type	Hawaiite	Alkali Basalt	Alkali Basalt	Alkali Basalt	Alkali Basalt	Alkali Basalt
SiO_2	48.35	46.75	47.49	46.64	47.91	47.69
TiO_2	2.84	2.65	2.51	3.01	3.38	3.01
Al_2O_3	20.38	16.35	18.38	15.54	17.40	15.72
$Fe_2O_{3(T)}$	10.95	13.19	12.78	14.58	15.58	14.47
MnO	0.07	0.16	0.12	0.19	0.27	0.17
MgO	2.13	6.21	3.10	5.79	3.94	5.52
CaO	7.39	10.19	9.97	8.36	5.87	8.30
Na_2O	4.70	3.10	3.40	3.50	3.30	3.30
K_2O	1.64	0.95	1.28	1.19	1.41	1.09
P_2O_5	1.12	0.52	0.58	0.49	0.54	0.48
Total	99.59	100.08	99.62	99.29	99.59	99.75
L.O.I.	7.15	4.14	4.62	1.38	7.79	2.7
H_2O^+	2.66	1.97	1.63	2.62	3.15	1.85
CO_2	0.46	0.29	0.31	0.48	0.07	0.10

properties and partition coefficients, the following items can be formulated from the study of the Emperor Seamount samples drilled during Leg 55:

1) The chondritic nature of the "primordial" mantle is confirmed through Y/Tb, Zr/Hf, and Nb/Ta ratios.

2) The value 9 for the La/Ta ratio has been found related to topographic highs or platforms in the Atlantic Ocean (the value is 18 in other cases, corresponding to typically "depleted" tholeiites). The values close to 9 found for Emperor Seamount samples independently of their petrographic classification (tholeiite, alkali basalts, or hawaiite) tend to confirm the correlation of this ratio to topography.

3) The single Th/Ta ratio observed in tholeiites, alkali basalts, and hawaiites suggests similar mantle sources for these different rock types.

4) The transition elements belonging to the same series, characterized by different partition coefficients, show a fractionation. This fractionation can be interpreted as the result of partial melting.

5) Ti and V are fractionated in hawaiites as a consequence of titanomagnetite crystallization.

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TABLE 4
Hole 432A, Nintoku Seamount: Trace Elements

Sample	Sc	Ti	V	Cr	Mn	Fe	Co		Ni		Rb		Sr	Y	Zr	Nb	Sb	Cs	Ba		La	Eu	Tb	Hf	Ta	Th	U
(Interval in cm)	NAA	XRF	XRF	XRF	XRF	XRF	XRF	NAA	XRF	NAA	XRF	NAA	XRF	XRF	XRF	XRF	NAA	NAA	XRF	NAA	NAA	NAA	NAA	NAA	NAA	NAA	NAA
1-1, 35–38	13.6	17040	117	10.4	540	76650	45	45.8	20	14	13.2		1059	40.6	303	86.5	0.18	0.06	761	770	56	3.35	1.09	6.02	5.37	5.87	1.50
2-1, 83–85	22.1	15900	248	92.8	1240	92330	45	44.1	81	75	14.4	14.5	638	23	175	35.1	0.05	0.06	284	307	22.8	2.30	0.76	3.77	2.44	2.19	0.57
2-2, 100–102	20	15060	233	79.6	330	89460	39	37.4	70	72	20	18.3	761	25.9	181	37.2	0.05	0.14	388	401	23.7	2.36	0.78	3.79	2.57	2.38	0.63
3-2, 106–108	21.8	18060	223	82.6	1470	102060	41	40	51	51	20.3		540	30.1	204	40.0	0.04	0.11	308	346	24.4	2.28	0.85	4.72	2.87	2.53	0.76
4-4, 84–86	24.3	20280	247	91.4	2090	109060	45	43.8	62	56	22	22	453	31.9	226	41.0	0.02	0.23	326	332	26.6	2.6	1.00	5.08	3.08	2.72	0.80
5-1, 128–130	22.4	18060	220	79.0	1316	101290	41	39.1	53	47	16.8	17.7	514	30.5	194	37.9	0.02	0.09	299	328	23.9	2.36	.92	4.62	2.75	2.46	0.80

TABLE 5
Holes 433A and 433B, Suiko Seamount: Major Elements

Sample (Interval in cm)	433A-20-1 (#1d), 36–38	433A-20-2 (#1b), 10–12	433A-20-2 (#2e), 49–51	433A-21-2 (#2c), 84–86	433A-21-4 (#15), 138–140	433B-5-2 (#3c), 81–83
Rock Type	Alkali Basalt	Alkali Basalt	Alkali Basalt	Alkali Basalt	Alkali Basalt	Alkali Basalt
SiO_2	47.18	47.08	46.93	47.32	47.70	47.46
TiO_2	3.16	3.33	3.17	3.19	3.21	3.18
Al_2O_3	14.33	14.82	13.91	14.29	14.55	14.42
$Fe_2O_{3(T)}$	15.16	15.40	15.49	15.05	14.96	14.98
MnO	.18	.16	.21	.19	.18	0.18
MgO	5.06	4.60	5.39	5.57	5.07	5.45
CaO	9.51	8.92	9.77	9.21	9.36	9.88
Na_2O	3.30	3.40	3.10	3.20	3.20	3.10
K_2O	.97	1.07	1.03	.93	.97	0.86
P_2O_5	.46	.44	.48	.46	.45	0.44
Total	99.31	99.22	99.47	99.41	99.65	99.95
L.O.I.	1.67	2.93	3.16	2.45	2.27	1.27
H_2O^+	.71	.93	.95	1.10	.99	0.72
CO_2	.09	.29	.83	.10	.09	0.42

TABLE 6
Holes 433A and 433B, Suiko Seamount: Trace Elements

Sample	Sc	Ti	V	Cr	Mn	Fe	Co		Ni		Rb		Sr	Y	Zr	Nb	Sb	Cs	Ba		La	Eu	Tb	Hf	Ta	Th	U
(Interval in cm)	NAA	XRF	XRF	XRF	XRF	XRF	XRF	NAA	XRF	NAA	XRF	NAA	XRF	XRF	XRF	XRF	NAA	NAA	XRF	NAA	NAA	NAA	NAA	NAA	NAA	NAA	NAA
Hole 433A																											
20-1, 36–38	31.4	18960	365	44.7	1390	106120	46	43.6	49	44	14.4		404	40.1	217	28.5	0.03	0.06	171	220	21.2	2.49	1.03	5.44	2.01	1.86	0.50
20-2, 10–12	32.2	19980	385	44.4	1240	107800	46	44.8	53	46	15.3		420	38.3	223	28.8	0.05	0.11	180	224	20.5	2.58	1.02	5.33	2.01	1.89	0.48
20-2, 49–51	30.6	19020	357	43.3	1626	108360	47	44	50	46	20.6	19.5	391	39.7	212	29.1	0.05	0.97	170	202	19.6	2.40	1.04	5.1	1.99	1.86	0.55
21-2, 84–86	32	19140	362	43.0	1470	105350	47	45.1	48	48	14	12.8	384	38.3	218	28.7	0.02	0.06	165	199	20	2.59	1.01	5.42	2.02	1.94	0.56
21-4, 138–140	31.7	19260	364	40.5	1390	104720	46	43	50	43	14.8	13.4	409	38.1	221	28.3	0.01	0.01	181	228	21	2.58	1.03	5.52	2.05	1.93	0.40
Hole 433B																											
5-2, 81–83	32.8	19080	370	51.5	1390	104860	47	46.6	50	50	13.3	12.2	411	37.1	217	28.5	0.02	0.06	173	203	20.1	2.49	0.98	5.27	1.98	1.87	0.40

TABLE 7
Hole 433C, Suiko Seamount: Major Elements

Sample (Interval in cm)	4-1 (#2C), 39–41	10-1 (#1A), 7-9	10-2 (#3A), 16–18	10-2 (#7), 58–60	10-3 (#10A), 105–107	10-4 (#8B), 118–121	10-5 (#13), 118–120	11-1 (#9C), 135–137	11-3 (#2A), 29–31	11-4 (#14), 110–112	12-3 (#1E), 51–53
Rock Type	Alkali Basalt	Ankaramite	Ankaramite	Ankaramite	Ankaramite	Ankaramite	Tholeiite	Tholeiite	Tholeiite	Alkali Basalt (Transitional)	Tholeiite
SiO_2	46.99	46.86	46.70	46.16	45.96	45.94	47.78	47.00	48.00	48.73	48.91
TiO_2	2.92	1.70	1.85	1.91	1.97	1.15	1.89	1.89	1.92	2.40	2.35
Al_2O_3	13.73	12.74	13.09	14.10	14.76	8.81	14.14	14.86	15.00	15.33	14.36
$Fe_2O_{3(T)}$	14.93	14.15	14.16	14.63	14.95	14.10	15.70	13.35	13.03	12.71	12.30
MnO	0.19	0.16	0.15	0.13	0.15	0.19	0.07	0.18	0.12	0.11	0.14
MgO	7.39	14.05	14.09	11.34	9.23	20.39	10.81	8.02	8.25	6.95	7.43
CaO	9.72	7.71	6.54	7.84	8.95	6.70	4.82	10.95	10.54	10.25	11.30
Na_2O	2.80	1.90	2.00	2.30	2.20	1.40	2.80	2.50	2.50	2.50	2.50
K_2O	0.79	0.40	0.47	0.44	0.71	0.28	0.83	0.32	0.23	0.63	0.20
P_2O_5	0.40	0.25	0.21	0.24	0.25	0.15	0.23	0.24	0.22	0.28	0.28
Total	99.86	99.92	99.26	99.09	99.13	99.11	99.07	99.31	99.81	99.89	99.77
L.O.I.	1.28	6.49	10.40	6.59	7.83	14.00	8.74	7.24	5.41	5.66	3.38
H_2O^+	1.12	4.17	4.62	3.56	2.98	5.52	3.26	2.28	2.19	1.72	1.12
CO_2	0.05	0.20	0.20	0.17	0.37	1.76	0.17	1.31	0.51	0.56	0.47

TABLE 7 – *Continued*

Sample (Interval in cm)	13-2 (#1H), 53–55	14-3 (#4A), 55–57	14-4 (#1B), 21–23	15-1 (#13), 115–118	15-4 (#4), 46–48	15-6 (#1C), 31–32	19-2 (#2F), 56–58	19-4 (#1B), 17–19	20-2 (#13), 132–134	21-4, 40–42	22-1 (#10), 94–96
Rock Type	Tholeiite	Alkali Basalt (Transitional)	Tholeiite	Tholeiite	Tholeiite	Tholeiite	Tholeiite	Tholeiite	Tholeiite	Tholeiite (Plag. Phyric)	Alkali Basalt (Transitional)
SiO_2	48.00	48.26	48.62	47.78	47.62	47.91	48.31	48.83	48.24	47.26	47.47
TiO_2	2.26	2.68	2.53	2.65	2.54	2.57	2.45	2.10	2.83	2.71	2.77
Al_2O_3	14.22	15.50	15.23	14.75	13.39	13.87	14.93	15.13	15.80	15.73	15.24
$Fe_2O_{3(T)}$	13.16	13.97	13.55	14.32	16.88	14.50	13.26	11.98	12.32	12.92	13.31
MnO	0.17	0.09	0.14	0.12	0.11	0.18	0.13	0.13	0.11	0.11	0.16
MgO	7.90	7.20	7.00	7.35	8.30	6.50	7.33	7.70	7.25	7.58	6.96
CaO	11.16	7.39	9.63	8.84	6.59	10.77	10.22	10.72	9.50	9.16	9.21
Na_2O	2.30	3.20	2.90	2.90	2.80	2.50	2.70	2.70	2.90	3.00	2.90
K_2O	0.47	0.80	0.22	0.46	1.24	0.24	0.30	0.24	0.30	0.45	0.64
P_2O_5				0.33	0.24	0.28	0.27	0.26	0.29	0.29	0.31
Total	99.92	99.40	100.12	99.50	99.71	99.32	99.90	99.79	99.54	99.21	98.97
L.O.I.	2.47	4.64	3.37	3.28	6.56	1.33	2.78	2.86	3.57	3.67	3.52
H_2O^+	1.42	1.93	1.13	1.37	1.97	0.42	1.21	1.23	1.50	1.41	1.70
CO_2	0.14	0.26	0.19	0.17	0.12	0.09	0.28	0.24	0.30	0.27	0.30

TABLE 7 – *Continued*

Sample (Interval in cm)	24-1 (#2), 12–15	23-1 (#5D), 102–104	23-5 (#1B), 16–19	24-7 (#3G), 141–144	25-2 (#1B), 22–25	26-1 (#2A), 42–45	26-5 (#1H), 82–85	26-6 (#7A), 114–117	27-2 (#6B), 131–134	28-2 (#1D), 19–21	28-5 (#6E), 107–109
Rock Type	Tholeiite (Oceanite)	Tholeiite	Tholeiite	Tholeiite (Oceanite)	Tholeiite	Tholeiite	Tholeiite	Tholeiite	Tholeiite (Oceanite)	Tholeiite	Tholeiite
SiO_2	46.10	48.45	49.11	44.73	47.40	47.88	46.94	46.65	44.00	49.00	49.35
TiO_2	1.33	2.32	1.69	1.24	2.10	2.10	2.10	2.37	1.08	2.57	2.78
Al_2O_3	9.76	13.27	12.84	8.88	14.71	14.70	13.04	14.75	8.04	13.97	14.11
$Fe_2O_{3(T)}$	14.24	16.00	12.31	14.04	12.98	12.98	13.67	13.32	14.67	13.24	13.71
MnO	0.18	0.08	0.15	0.17	0.14	0.14	0.16	0.15	0.18	0.16	0.16
MgO	19.60	9.61	12.54	22.00	9.56	8.29	12.66	10.88	26.02	6.89	6.52
CaO	6.25	5.01	8.03	5.33	9.67	10.30	8.98	8.47	4.29	10.29	10.61
Na_2O	1.20	2.60	2.20	1.60	2.40	2.50	2.00	2.50	1.00	2.50	2.60
K_2O	0.13	1.08	0.27	1.08	0.16	0.22	0.14	0.14	0.13	0.19	0.21
P_2O_5	0.13	0.06	0.18	0.14	0.21	0.23	0.23	0.24	0.11	0.25	0.33
Total	98.92	98.48	99.32	99.11	99.33	99.34	99.92	99.47	99.52	99.06	100.38
L.O.I.	6.10	8.54	6.33	4.31	4.12	3.09	4.82	3.14	5.89	1.11	1.44
H_2O^+	4.89	3.28	2.86	3.36	2.27	1.48	3.47	3.11	4.46	0.59	0.59
CO_2	0.52	0.25	0.47	0.24	0.20	0.18	0.36	0.38	0.34	0.17	0.10

TABLE 7 – *Continued*

Sample (Interval in cm)	29-3 (#2C), 25–27	31-1 (#1D), 15–18	32-1 (#3D), 98–101	32-5 (#1C), 72–75	34-7, 95–98	35-6 (#1D), 27–29	36-2 (#1D), 16–19	36-3 (#1J), 79–82	36-4 (#1F), 49–52	36-5 (#4M), 119–122	37-3 (#1F), 101–103
Rock Type	Tholeiite (Transitional)	Tholeiite	Tholeiite (Oceanite)	Tholeiite (Oceanite)	Tholeiite	Tholeiite	Tholeiite (Transitional)	Tholeiite (Transitional)	Tholeiite	Tholeiite	Tholeiite
SiO_2	48.33	46.75	42.90	46.96	47.50	48.46	48.45	48.17	48.23	48.33	49.50
TiO_2	2.95	2.74	0.95	1.78	2.45	2.39	2.31	2.24	2.25	2.34	2.24
Al_2O_3	14.33	14.21	6.55	11.86	14.03	13.48	13.34	12.89	12.92	13.71	13.88
$Fe_2O_{3(T)}$	13.24	14.02	14.35	13.84	12.50	13.31	13.38	13.20	12.94	13.15	12.52
MnO	0.20	0.17	0.16	0.19	0.26	0.17	0.14	0.16	0.17	0.14	0.15
MgO	6.88	8.70	30.50	15.93	9.47	8.65	9.55	11.20	11.31	10.15	7.30
CaO	10.27	9.95	3.63	7.24	10.13	9.98	8.82	8.58	8.32	8.88	10.69
Na_2O	2.60	2.60	0.60	1.60	2.50	2.40	2.50	2.40	2.30	2.50	2.40
K_2O	0.65	0.41	0.04	0.10	0.44	0.33	0.51	0.35	0.32	0.22	0.42
P_2O_5	0.34	0.35	0.10	0.19	0.31	0.32	0.26	0.22	0.24	0.27	0.26
Total	99.79	99.90	99.78	99.69	99.59	99.49	99.26	99.41	99.00	99.69	99.36
L.O.I.	2.27	1.17	7.43	6.15	4.25	2.22	10.18	5.25	4.23	5.21	3.14
H_2O^+	0.89	1.03	6.01	4.54	1.43	1.11	1.91	2.47	2.54	2.09	0.76
CO_2	0.19	0.21	0.41	0.31	0.45	0.12	0.26	0.26	0.30	0.24	0.21

TABLE 7 – *Continued*

Sample (Interval in cm)	38-1 (#1G), 76–79	38-5, 97–100	39-5 (#1C), 102–104	40-2 (#1G), 111–113	41-1 (#1C), 19–21	42-1 (#1G), 2–6	42-3 (#1B), 14–16	42-5 (#1F), 37–39	45-5 (#1A), 6–8	46-3, 72–74	47-5 (#6B), 87–89	49-2 (#1D), 31–36
Rock Type	Tholeiite	Tholeiite	Tholeiite	Tholeiite	Tholeiite	Tholeiite	Tholeiite	Tholeiite	Tholeiite	Tholeiite	Alkali Basalt	Tholeiite (Transitional)
SiO_2	46.60	47.56	48.16	47.80	48.96	49.26	48.80	48.86	48.72	48.96	45.45	46.70
TiO_2	2.18	2.37	2.22	2.12	2.39	2.37	1.88	2.02	2.16	2.19	3.12	2.84
Al_2O_3	13.13	14.85	13.20	12.76	14.00	13.89	16.25	15.40	14.47	14.72	14.00	15.44
$Fe_2O_{3(T)}$	13.88	13.10	13.15	13.13	13.28	12.91	11.33	11.85	12.90	13.17	14.80	14.40
MnO	0.17	0.15	0.16	0.16	0.12	0.13	0.13	0.14	0.21	0.13	0.19	0.16
MgO	12.55	8.82	10.50	11.77	7.68	7.68	7.72	6.98	6.69	6.75	6.76	6.19
CaO	8.50	9.97	9.71	9.29	10.07	10.14	10.26	10.94	11.15	9.58	10.92	9.77
Na_2O	2.30	2.40	2.10	2.10	2.60	2.70	2.70	2.50	2.60	2.80	2.60	2.90
K_2O	0.45	0.18	0.22	0.20	0.24	0.25	0.25	0.23	0.18	0.65	0.89	0.52
P_2O_5	0.23	0.27	0.25	0.24	0.26	0.26	0.24	0.23	0.21	0.26	0.33	0.32
Total	99.99	99.67	99.67	99.57	99.60	99.59	99.56	99.15	99.29	99.21	99.06	99.24
L.O.I.	3.44	4.05	2.16	2.36	3.08	2.89	2.62	2.33	2.26	3.60	4.65	3.97
H_2O^+	2.49	2.21	1.58	2.09	1.08	1.02	1.31	0.88	0.81	1.24	1.74	1.84
CO_2	0.27	0.24	0.18	0.13	0.20	0.22	0.21	0.30	0.32	0.19	1.06	0.22

TABLE 8
Hole 433C, Suiko Seamount: Trace Elements

Sample (Interval in cm)	Sc NAA	Ti XRF	V XRF	Cr XRF	Mn XRF	Fe XRF	Co XRF	Co NAA	Ni XRF	Ni NAA	Rb XRF	Rb NAA	Sr XRF	Y XRF	Zr XRF	Nb XRF	Sb NAA	Cs NAA	Ba XRF	Ba NAA	La NAA	Eu NAA	Tb NAA	Hf NAA	Ta NAA	Th NAA	U NAA
4-1, 39–41	30.5	17520	338	197	1470	104510		51.3	122	127	13.4	11.5	371	34.9	203	26.3	0.04	0.07	161	204	18.4	2.19	0.92	4.81	1.79	1.71	0.47
10-2, 16–18	25.7	11100	261	752	1160	99120	69	72.1	516	517	6.2	6.6	162	23.6	114	10.9	0.02	0.04		177		1.35	0.59	2.73	0.75	0.8	0.25
10-2, 58–60	27.3	11460	265	664	1010	102410	65	63.1	401	410	3.5	5	216	23.7	118	12.1	0.09	0.02		79	8.9	14.1	0.60	2.86	0.78	0.77	0.08
10-3, 105–107	29	11820	277	575	1160	104650	58	57.6	329	304	6.0	6.4	235	26.5	120	12.1	0.13	0.04		171	9.1	1.46	0.63	2.95	0.84	0.85	0.24
10-4, 118–121	18	6900	169	1328	1470	98700	100	104	1391	1208	5.1	4.3	102	14.0	70	6.6	0.02	0.07		34	4.8	0.8	0.34	1.60	0.43	0.48	0.19
10-5, 118–120	27.7	11340	242	427	540	109900	64	61.2	270	287	9.8	11.4	165	21.5	117	10.3	0.02	0.09		59	7.8	1.47	0.60	2.80	0.70	0.68	0.42
10-1, 7–9	25.7	10200	244	752	1240	99050	73	71.5	520	510	5.8	7.2	179	22.4	103	11.4	0.01	0.02		60	8.4	1.36	0.57	2.55	0.72	0.71	0.13
11-1, 135–137	29.6	11340	268	375	1390	93450	52	52.1	168	160	2.5	1.6	267	25.5	123	10.5	0.01	0.04		86	8.4	1.63	0.71	2.97	0.71	0.70	0.25
11-3, 29–31	30.1	11520	269	407	930	91210	56	54.9	188	187	2.7		294	25.8	124	9.7		0.07		38	8.8	1.47	0.63	2.90	0.73	0.75	0.16
11-4, 110–112	34.3	14400	326	329	850	88970	46	46.6	124	129	11.2	11.4	305	30.9	145	13.8	0.01	0.21		51	10.6	1.90	0.82	3.68	0.97	0.90	0.22
12-3, 51–53	32.3	14100	314	279	1080	86100	47	48.3	107	112	0.4		304	32.7	147	14.4				71	9.8	1.77	0.80	2.73	0.97	0.86	0.24
13-2, 53–55	34.2	13560	328	232	1320	92120	48	46.7	100	96	5.4	4.4	304	28.2	143	15.3	0.02	0.03		103	10.9	1.66	0.72	2.47	1.07	1.03	0.22
14-3, 55–57	34.0	16080	322	73	700	97790	49	45.7	53	49	9.3	8.5	307	38.2	165	15.3	0.05	0.11		86	9.9	2.01		4.04	0.97	0.90	0.51
14-4, 21–23	32.4	15180	320	77	1080	94850	47	46.6	48	47	1.8		308	31.1	158	14.3				55	9.9	1.83	0.82	3.80	0.95	0.85	0.15
15-1, 115–118	33.4	15900	328	65.0	930	100240	51	48.7	45	48	2		296	35.4	160	14.5				65	10.4	2.11	0.90	4.06	1.01	0.92	0.39
15-4, 46–48	31.8	15240	310	69.5	850	118160	49	45.9	50	55	18	17.6	242	27.8	159	13.3	0.02	0.19		54	10.4	1.81	0.78	3.77	0.92	0.84	0.26
15-6, 31–32	35.2	15420	338	75.3	1390	101500	52	48.8	54	59	1.5		308	35.2	168	13.3				77	10.4	2.04	0.92	4.29	0.90	0.90	0.23
19-2, 56–58	32.6	14700	301	128	1010	92820	46	45.3	80	76	1.9		301	32.8	154	12.3				45	9.9	1.99	0.82	3.89	0.90	0.79	0.22
19-4, 17–19	31.7	12600	271	270	1010	83860	45	45.2	112	108	1.6		287	28.8	135	10.4	0.02			42	8.1	1.59	0.73	3.24	0.74	0.70	0.12
20-2, 132–134	31.4	16980	308	190	850	86240	47	46.6	98	94	0.4	2.6	351	35.6	179	15.9	0.02			91	11.5	2.20	0.97	4.38	1.09	1.02	0.14
21-4, 40–42	28	16260	276	176	850	90440	49	48.3	126	130	2.1		353	32.7	170	14.4	0.02	0.01		87	11.6	1.91	0.87	4.42	1.07	0.95	0.27
22-1, 94–96	34.6	16620	275	169	1240	93170	48	57.8	110	158	2.6	4.4	350	33.8	176	16.1	0.04	0.02		94	13.2	2.49	1.07	4.87	1.22	0.99	0.30
23-1, 102–104	28.8	16240	235	267	1390	112000	59	57.6	276	276	18.2	18.2	196	18.7	138	11.4	0.03	0.24		41	9.9	1.78	0.57	3.37	0.82	0.72	0.21
23-5, 16–19	26.3	10140	226	703	620	86170	63	64	489	468	2.6	3.8	184	26.3	95	7.4		0.04		30	5.2	1.29	0.60	2.29	0.048	0.45	0.12
24-1, 12–15	21	7980	183	875	1160	99680	92	91.2	1049	1014	2.1		114	18.2	79	5.5		0.06			4.6	0.83	0.43	1.77	0.35	0.26	
24-7, 141–144	19.6	7440	165	908	1320	98280	96	97	1068	1139	15.0	15	131	16.3	69	5.3	0.01	0.07		44	3.4	0.92	0.41	1.63	0.35	0.32	
25-2, 22–25	29.5	12600	271	347	1080	90860	54	53	156	154	1.2		266	28.1	128	10.8	0.01			30	8.2	1.66	0.71	3.03	0.71	0.65	
26-1, 42–45	29.6	12600	263	286	1080	90860	49	49.7	114	109	1.2		268	28	120	10.1				58	8.2	1.70	0.71	3.10	0.71	0.61	0.11
26-5, 82–85	27	12600	250	596	1240	95690	65	65.5	438	417	1.6	2.2	263	24.6	125	11.0	0.02	0.04		20	7.5	1.59	0.72	3.05	0.72	0.57	0.10
26-6, 114–117	30.1	14220	273	471	1160	93240	59	55.8	232	230	0.7	2.6	269	29.0	145	11.4	0.02			57	8.9	1.80	0.78	3.48	0.82	0.71	0.17
27-2, 131–134	11.1	6480	145	1186	1390	102690	109	111	1335	1434	3.7	2.6	89	14.8	63	4.6	0.01	0.11		9	3	0.84	0.37	1.16	0.31	0.35	
28-2, 19–21	34.4	15420	313	148	1240	92680	47	47.7	71	66	1.8	2.9	303	33.6	153	13.0	0.02			68	9.8	2.05	0.89	3.97	0.94	0.85	0.21
28-5, 107–109	33.3	16200	307	134	1240	95970	45	45.3	68	68	1.6		324	37.0	184	16.3	0.03	0.02		48	11.7	2.04	0.95	4.65	1.08	0.93	0.26
29-3, 25–27	28.2	17700	334	167	1550	92680	45	44.2	79	80	8.6	8.8	316	40.6	189	16.3		0.06		60	12.2	2.55	1.12	4.80	1.12	1.02	0.12
31-1, 15–18	28.2	16440	264	206	1320	98140	58	55.5	184	201	4.6	3.4	344	35.2	171	14.6	0.02	0.06		82	11.2	2	0.93	4.51	1.06	0.84	0.21
32-1, 98–101	14.6	5700	129	1100	1240	100450	117	112	1614	1628	1.5		57	11.8	59	4.4		0.05		11	3.4	0.57	0.27	1.28	0.27	0.24	0.07
32-5, 72–75	24	10680	229	822	1470	96880	74	74	606	579	0.8	2.5	168	22.2	97	9.3		0.04		29	6.6	1.36	0.56	2.64	0.59	0.52	0.11
34-7, 95–98	31.3	14700	302	443	2010	87500	55	54.5	267	275	2.2		293	32.8	161	13.6	0.01	0.03		43	11.2	1.97	0.86	4.01	0.94	0.82	0.16
35-6, 27–29	30.3	14340	267	379	1320	93170	54	51.9	217	218	1.7	2.9	283	31.9	169	16.0	0.02	0.02		75	18	2.07	0.85	4.18	0.99	0.92	0.24
36-2, 16–19	29.7	13860	274	522	1080	93660	50	52.4	287	285	4.9	3.9	251	32.2	145	11.2	0.03	0.06		66	9.5	1.73	0.82	3.68	0.87	0.77	0.25
36-3, 79–82	29.9	13440	273	592	1240	92400	57	58.8	367	370	3.0	4.1	230	29.5	147	12.7	0.02			48	7.8	1.75	0.77	3.63	0.85	0.75	0.22
36-4, 49–52	29.3	13500	275	554	1320	90580	56	55.2	338	325	3.0	3.7	223	30.6	147	12.4	0.02	0.03		69	9.2	1.76	0.77	3.57	0.84	0.72	0.22
36-5, 119–122	30.1	14040	281	502	1080	92050	53	52.4	274	260	1.5		258	31.8	151	14.5	0.02			43	9.5	1.89	0.82	3.64	0.88	0.79	0.03
37-3, 101–103	31	13440	283	344	1160	87640	48	48.8	167	167	6.1	6.5	283	29.8	133	10.1	0.02	0.02		47	8.6	1.70	0.72	3.53	0.79	0.67	0.24
38-1, 76–79	26.7	13080	254	452	1320	97160	67	68.2	448	491	4.2	2.9	268	26.0	137	11.3	0.02	0.06		58	5.6	1.63	0.63	3.35	0.75	0.66	
38-5, 97–100	28.8	14220	282	295	1160	91700	52	51.4	163	156	0.2		293	30.9	145	13.9	0.03			54	9	1.73	0.76	3.68	0.85	0.68	0.14
39-5, 102–104	28.4	13320	263	451	1240	92050	56	56	315	322	1.1		263	28.2	135	12.8	0.02	0.04		53	8.5	1.60	0.72	3.52	0.80	0.66	0.18
40-2, 111–113		12720	261	452	1240	91910	60		409		1.5		243	27.7	134	11.0											
41-1, 19–21	33.7	14340	300	219	930	92960	48	46.6	87	85	1.5	2.2	275	34.6	148	11.0	0.03			29	8.9	1.79	0.83	3.61	0.81	0.72	0.18
42-1, 2–6	33.1	14220	316	215	1010	90370	46	45.5	86	89	1.9		277	30.4	136	11.3	0.02			20	8.1	1.71	0.77	3.46	0.77	0.63	0.18
42-3, 14–16	29.1	11280	258	279	1010	79310	43	42.5	91	84	2.4		275	25.7	108	8.2				17	5.5	1.47	0.64	2.69	0.58	0.51	0.16
42-5, 37–39	31.3	12120	267	257	1080	82950	43	44.8	87	85	0.9	–	276	28.2	118	8.6				40	7	1.67	0.71	3.16	0.67	0.59	0.12
45-5, 6–8	33.1	12960	307	201	1630	90300	48	48.6	86	81	1.7	2.7	278	30.5	121	9.5	0.02	0.03		41	6.9	1.71	0.74	3.23	0.65	0.55	0.11
46-3, 72–74	31.4	13140	290	198	1010	92190	47	47	83	89	4.8	3.7	269	32.2	145	18.2	0.01			46	7.8	1.71	0.82	3.67	0.76	0.70	0.12
47-5, 87–89	31.2	18720	315	252	1470	103600	67	67.1	195	195	12.2	12.4	308	40.5	193	14.7	0.03	0.43		61	12.4	2.34	1.03	4.80	1.17	1.03	0.38
49-2, 31–36	25.4	17040	290	205	1240	100800	51	41.2	138	93	2.9	–	338	34.1	175		0.02			98	10.9	1.94	0.89	3.88	0.98	0.94	0.17

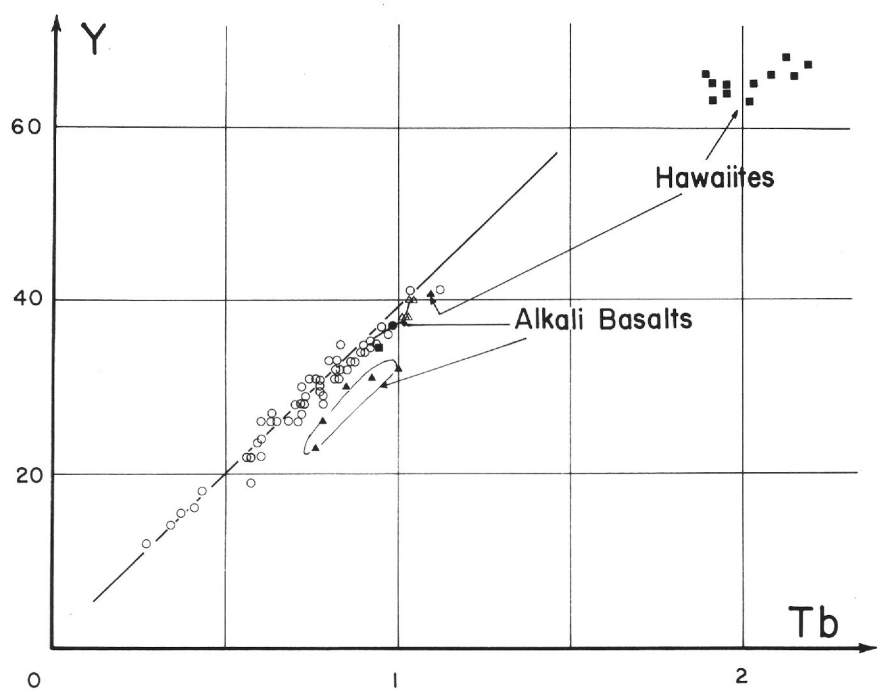

Figure 1. *Y versus Tb: black squares correspond to samples from Hole 430A, black triangles to Hole 432A, open triangles to Hole 433A, black dot to Hole 433B, and open circle to Hole 433C. Alkali basalts belonging respectively to Sites 432 and 433 are delimited. All open circles (433C) except one sample (alkali basalt) are tholeiites or transitional tholeiites, including oceanites and ankaramite. One sample from Hole 330A (black squares) is a tholeiite.*

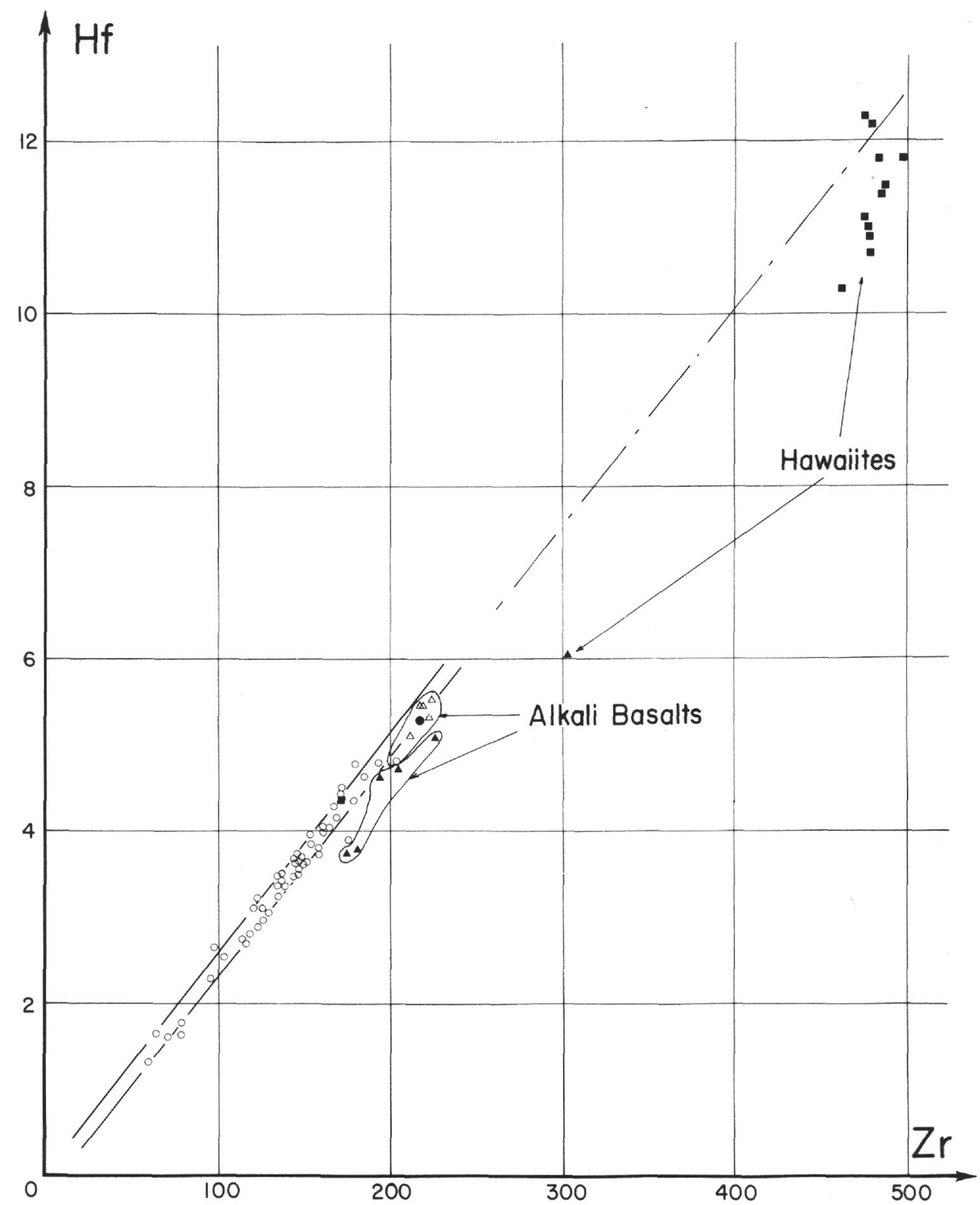

Figure 2. *Hf versus Zr: same symbols as in Figure 1.*

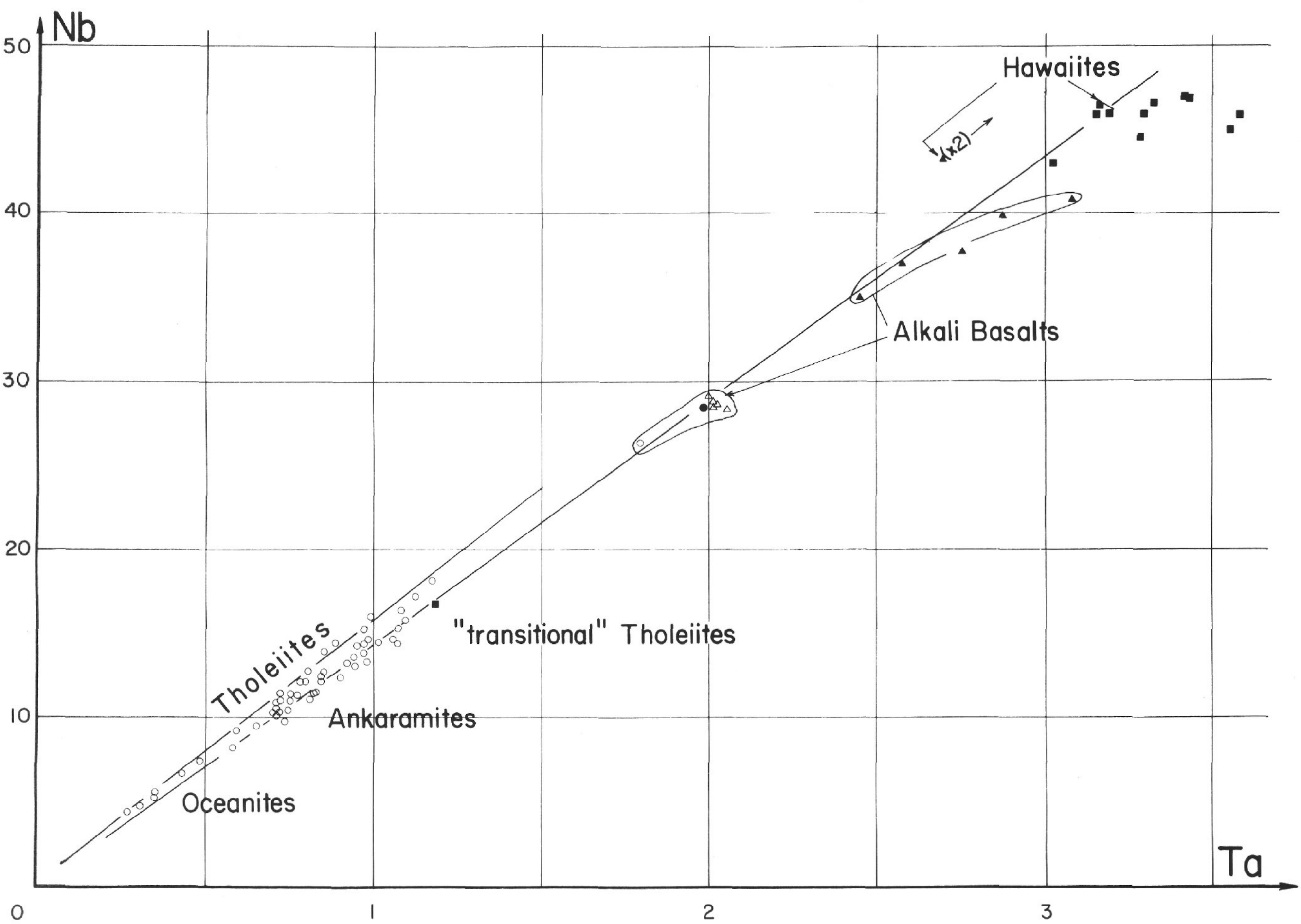

Figure 3. *Nb versus Ta: same symbols as in Figure 1. The sample mentioned (×2) has concentrations twice higher than corresponding to the plot.*

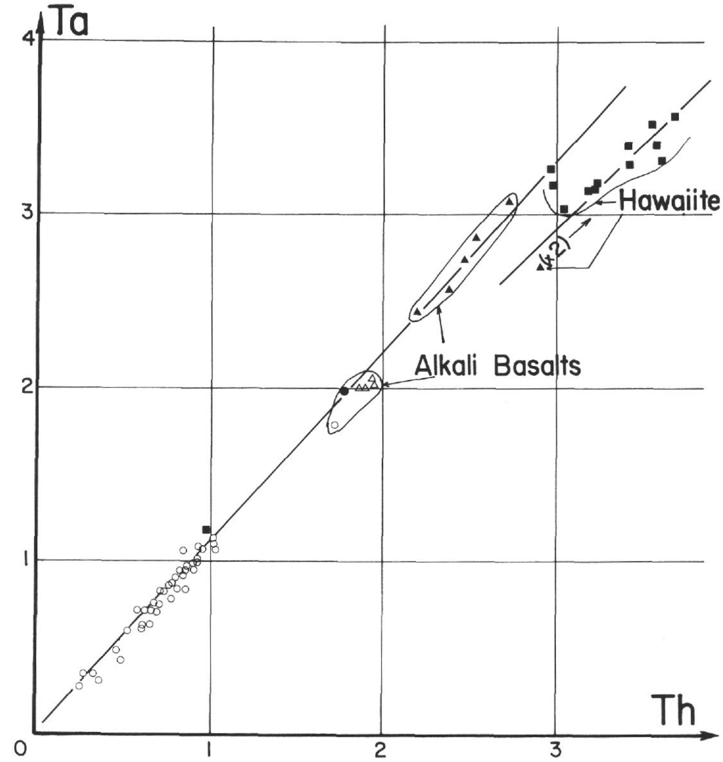

Figure 4. *Ta versus Th: same symbols as in Figure 1. The sample mentioned (× 2) has concentrations twice higher than corresponding to the plot.*

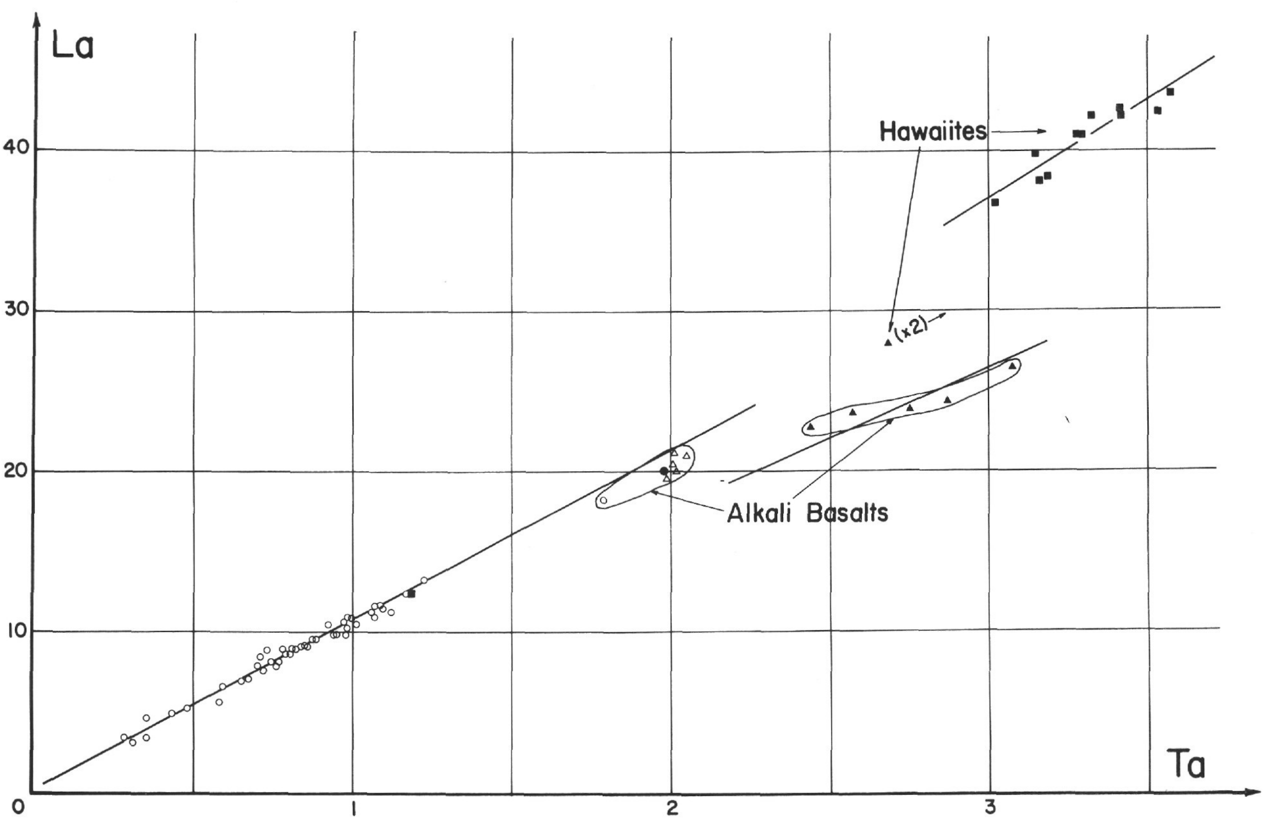

Figure 5. *La versus Ta: same symbols as in Figure 1. The sample mentioned (× 2) has concentrations twice higher than corresponding to the plot.*

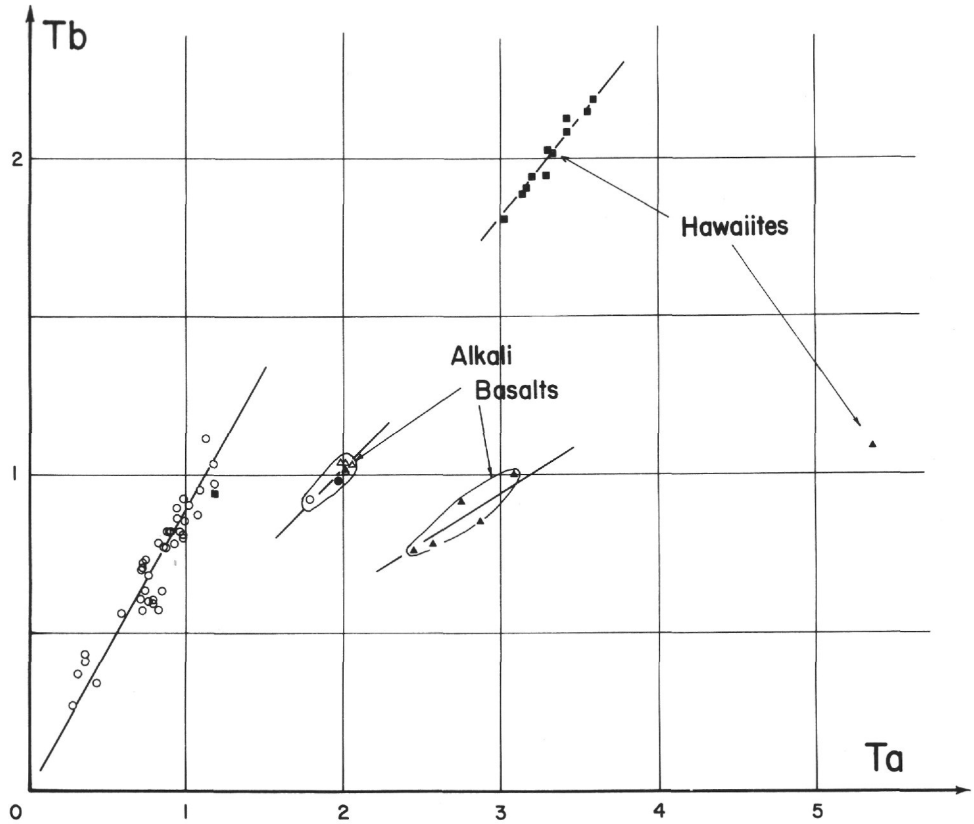

Figure 6. *Tb versus Ta: same symbols as in Figure 1.*

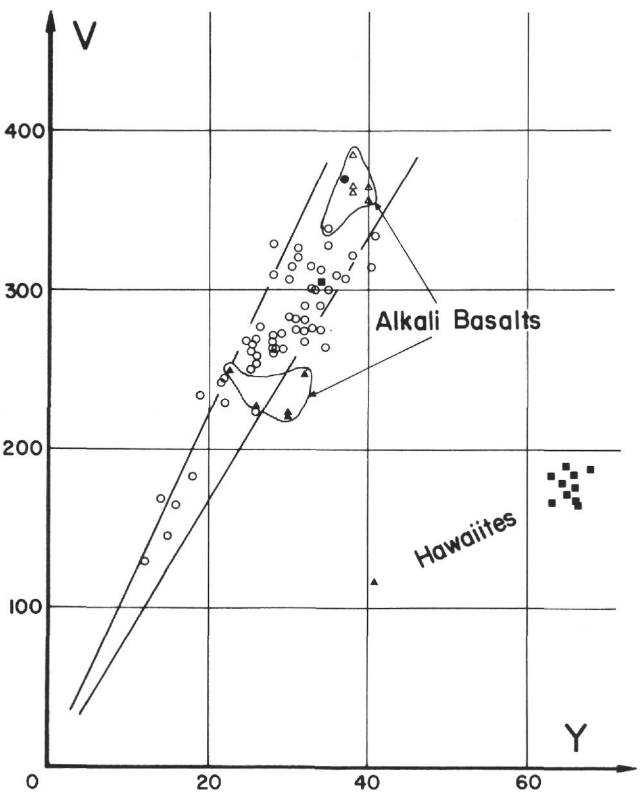

Figure 7. *V versus Y: same symbols as in Figure 1.*

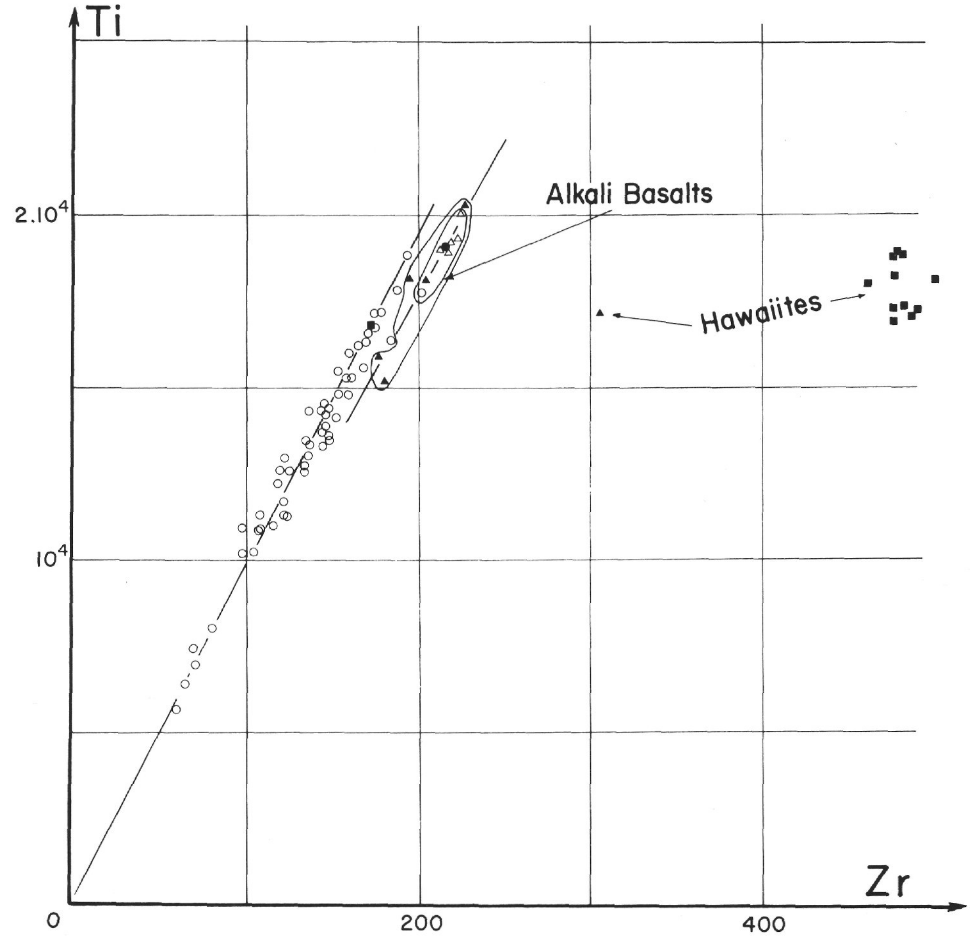

Figure 8. *Ti versus Zr: same symbols as in Figure 1.*