ELEMENTAL ABUNDANCES IN METEORITIC AND TERRESTRIAL MATTER

Annual Progress Report September 1, 1973-August 31, 1974

to the

National Aeronautics and Space Administration

By

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Personnel

During the past year the following postdoctoral, graduate students have been supported and involved in this meteorite and related terrestrial research program.

Dr. W. V. Boynton, postdoctoral student
Dr. Patricia Starzyk, postdoctoral student
Dr. D. B. Curtis, received his Ph.D. in October, 1973
D. A. Miller, received his M.S. degree in November, 1973
D. W. Hill, received his M.S. degree in September, 1974
C. A. Palmer, received his M.S. degree in October, 1974
R. A. Conard, second year graduate student

Dr. Boynton completed three years of postdoctoral studies with our group and has joined Professor John T. Wasson's lunar research group at the Institute of Geophysics and Planetary Physics, University of California, Los Angeles. Dr. Starzyk joined our group during July, 1974. She completed her Ph.D. at the University of Chicago, under Professor Nathan Sugarman's guidance and has had subsequent employment at the Argonne National Laboratory.

Dr. Curtis has joined Prof. G. J. Wasserburg's group at the California Institute of Technology as a postdoctoral student. Mr. Miller is continuing his education in Portland, Oregon. Mr. Hill is now employed by General Atomic Co., San Diego. Mr. Palmer has joined the staff of Prof. Roy Filby at the Nuclear Radiation Center, Washington State University, Pullman, and finally, Miss Conard is well along with her meteoritic and terrestrial research program.

Publications September 1, 1973 to August 31, 1974

1. "Elemental Composition of Individual Chondrules from Carbonaceous Chondrites, Including Allende" Geochim. Cosmochim. Acta, 38, 1359-1378 (1974) by T. W. Osborn, R. G. Warren, R. H. Smith, H. Wakita, D. L. Zellmer and R. A. Schmitt.

2. "Chemical Composition of Apollo 15,16 and 17 Samples" Proc. Fourth Lunar Sci. Conf. Geochim. Cosmochim. Acta. Suppl. 4, 2 1349-1367 (1973) by J. C. Laul and R. A. Schmitt.

Papers in Press

1. "Fractionation in The Solar Nebula: Condensation of Yttrium and The Rare Earth Elements" Geochim. Cosmochim. Acta., by W. V. Boynton.

2. "Chemical Composition of Boulder - 2 Rocks and Soils, Apollo 17, Station 2" Earth and Planet. Science Letters, by J. C. Laul and R. A. Schmitt.

3. "Chemical Studies of Apollo 16 and 17 Samples" Proc. Fifth Lunar Science Conf. Geochim. Cosmochim Acta. Suppl. 5, 2, (1974) by J. C. Laul, D. W. Hill and R. A. Schmitt.

Papers in Preparation

1. "Enstatite Achondrites: Bulk and Trace Element Studies" by W. V. Boynton and R. A. Schmitt.

2. "Chemical Studies of Hypersthene, Olivine and Olivine Pigeonite Achondrites" by W. V. Boynton and R. A. Schmitt.

3. "A Chemical Study of Minerals from L6 Chondrites" by D. B. Curtis and R. A. Schmitt.

4. "The Chemical Composition Studies of Marginal Rift, Coastal and Plateau Basalts, Layered Gabbros, Xenoliths, and Mineral Separates from The Saudi Arabia-Red Sea Area" by R. G. Coleman, C. A. Palmer, D. G. Coles, D. A. Miller and R. A. Schmitt.

5. "Oregon and Washington Coastal Basalts: A Chemical Study" by D. W. Hill, M. J. Dudas and R. A. Schmitt.

6. "Rare Earth Patterns and Other Trace Elements in Pallasites" by T. D. Cooper, W. V. Boynton, and R. A. Schmitt.

Papers at Meetings

1. "Fractionated Rare Earth Abundances in an Allende Inclusion: A Sample of a Fractionated Nebular Gas" 37th Annual Met. Soc. Meeting (Los Angeles, August, 1974) by W. V. Boynton.

Geochimica et Cosmochimica Acta, 1974, Vol. 38, pp. 1359 to 1378. Pergamon Press. Printed in Northern Ireland

Elemental composition of individual chondrules from carbonaceous chondrites, including Allende

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(*Received* 23 *February* 1973; *accepted in revised form* 8 *March* 1974)

Abstract—Major and trace element analyses of over 180 individual chondrules from 12 carbonaceous chondrites are reported, including individual analyses of 60 chondrules from Pueblito de Allende. Siderophile elements in most chondrules are depleted, compared to the whole chondrite. Correlations of Al–Ir and Ir–Sc among chondrules high in Ca and Al were observed. A Cu–Mn correlation was also found for chondrules from some meteorites. No correlation was observed between Au and other siderophile elements (Fe, Ni, Co and Ir). It is suggested that these elemental associations were present in the material from which the chondrules formed. Compositionally, chondrules appear to be a multicomponent mixture of remelted dust. One component displaying an Al–Ir correlation is identified as Allende-type white aggregates. The other components are a material chemically similar to the present matrix and sulfides-plus-metal material. Abundances of the REE (rare earth elements) were measured in 'ordinary' Allende chondrules and were 50% higher than REE abundances in Mokoia chondrules; REE abundances in Ca–Al rich chondrules were similar to REE abundances in Ca-rich white aggregates.

INTRODUCTION

THIS PAPER presents the results of Si, Fe, Al, Na, Sc, Cr, Mn, Ir, Co, Ni, V, Ca, Ti, Cu, Au and REE (rare earth elements) analyses of individual chondrules from a suite of carbonaceous chondrites, with special attention to chondrules from Allende. The analytical method was non-destructive, instrumental neutron activation analysis (INAA) for most elements and radiochemical neutron activation analysis for REE measurements. The analysis of whole chondrules yields information concerning the chondrules as a total subsystem of the whole chondrite.

Initial compositional studies on individual whole chondrules were made by SCHMITT *et al.* (1965) using NaI(Tl) gamma-ray detectors. OSBORN *et al.* (1973) reported on the analyses of chondrules from the H, L and LL chondrites and established a systematic compositional variation among chondrules from different petrologic types which were consistent with the classification of VAN SCHMUS and WOOD (1967).

OSBORN and SCHMITT (1971), WARREN *et al.* (1971) and OSBORN *et al.* (1973) reported correlations in chondrules between Al–Ir and Sc–Ir which these authors attributed to a high-temperature fractionation process. SCHMITT *et al.* (1968)

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Chemical composition of Apollo 15, 16, and 17 samples

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Abstract—The abundances of the bulk elements, TiO_2, Al_2O_3, FeO, MgO, CaO, Na_2O, K_2O, MnO, and Cr_2O_3, and the trace elements Sc, V, Co, Zr, Hf, Th, U, Ba, Ta, and nine REE, La, Ce, Nd, Sm, Eu, Tb, Dy, Yb, and Lu, and the siderophile elements Ni, Ir, and Au elements have been determined by sequential instrumental neutron activation analysis (INAA) in 53 lunar soils and rocks. Two basalts 15643 and 15388 show positive Eu anomalies; these probably represent mesostasis-poor Ap 15 mare basalts. REE patterns of Apollo 15 basalts suggest six lava flows at the Palus Putredinis site. Apollo 15 soils contain 5 to 18% norite-KREEP contribution. Luna 20 metaigneous rocks are feldspathic and are similar to Apollo 16 metaigneous rocks. Luna 20 soil is derived by ≈33% Luna 20 metaigneous rocks and ≈65% anorthositic gabbroic breccias like 15418. Apollo 16 anorthosites, all low K-group, show the same positive Eu enrichment similar to low K-group anorthosites from other sites. Anorthosite 60015 (97% pl) is *identical* to 15415 anorthosite. Likewise, anorthosite 60025 is identical to 69955. The dark clast (glass) 60015,54 seems to be splashed molten breccia rock ejecta by meteoritic impact onto a relatively pure anorthositic rock. Breccia 67031 is compositionally identical to breccia 60017 and both probably represent North Ray Crater material which is more feldspathic, lower in REE and other trace elements, including the siderophile elements compared to breccias ejected from the South Ray Crater. Cobalt is a diagnostic indicator between the North and South Ray materials and is enriched in the latter. Breccia 68516 is similar to the recrystallized 68415 rock and both lack Eu anomalies. Apollo 16 breccias are not compacted soils. The Apollo 16 highland soils are anorthositic gabbroic and are rather uniform in bulk and REE compositions. All Apollo 16 soils show negative Eu anomalies (avg. Sm/Eu ≈ 5.1). About 5% norite-KREEP component seems plausible for the Apollo 16 soils. Four Apollo 17 soils from Stations 5 and 9 in the valley and Station 8 on the Sculptured Hills are very similar and nearly match the Apollo 11 soil in bulk and trace elemental composition, including the siderophiles, and in their similar REE patterns. The absolute REE abundances in Apollo 17 soils are lower by a factor of ≈2 relative to the Apollo 11 soil. Compositional data of the 72501 soil (Station 2 on the South Massif avalanche) indicate that the South Massif may be composed of predominantly anorthositic gabbroic material. Anorthositic gabbro78155 is similar to 10085,11,146. The FeO/MnO correlation, observed previously for maria, is also found for highland samples; this correlation suggests a homogeneous accretion of the moon.

Fractionated Rare Earth Abundances in an Allende Inclusion: A Sample of a Fractionated Nebular Gas

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The condensation of Y and the rare earth elements (REE) from the solar nebula may be controlled by thermodynamic equilibrium between gas and condensed solids. Highly fractionated REE patterns may result if condensates are removed from the gas before condensation is complete. It is found that the fractionation is not a smooth function of REE ionic radius but varies in an extremely irregular pattern. Both Yb and Eu are predicted to be extremely depleted in the early condensate without the requirement of condensation in the divalent state. The model is discussed with respect to a highly fractionated pattern observed by Tanaka and Masuda (1973) in a pink Ca-Al-rich inclusion from the Allende meteorite and can account for the abundances of each REE determined.

According to the model, this inclusion may be a condensate from a previously fractionated gas rather than from a gas of solar composition. Before the condensation of the Allende inclusion, an earlier condensate may have formed and been isolated from equilibrium with the gas. The REE abundances in the inclusion represent a sample of the fractionated gas ramaining after the isolation of this initial condensate. It should be noted that the fractionated REE pattern provides strong evidence that this inclusion did not condense from a plasma as suggested by Arrhenius and Alfvèn (1971) since the ionization potentials of the REE vary smoothly with atomic number and would not yield an irregular pattern.

Because the REE, with similar geochemical behavior, have different cosmochemical properties, their abundance patterns may become an important tool in understanding chemical processes in the early solar system.

Arrhenius, G. and Alfvén, H. (1971) Earth Planet. Sci. Lett. 10:253-267.

Tanaka, T. and Masuda, A. (1973) Icarus 19:523-530

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Chemical Composition Studies of Oregon and Washington Coastal Basalts*

Dale W. Hill

Basalts of both Eocene and Miocene age from several groups along the Oregon and Washington coasts have been analyzed for some major, minor, and trace elements using instrumental neutron activation analysis (INAA). The rare earth element (REE) patterns observed in these samples are used for comparisons within the groups studied and for comparisons with other types of basalts. The three groups of Miocene basalts from the coast have been shown to be nearly identical chemically to three chemical types defined in the Columbia River Plateau basalts as follows: Depoe Bay Basalt ≡ Lower Yakima Basalt (high and low Mg types), Cape Foulweather Basalt ≡ Frenchman Springs Basalt, and Pack Sack Lookout Basalt ≡ Pomona Basalt. Possible models for the origin of these basalts erupted from vents over 500 km apart are also discussed. The Eocene basalts from the Oregon coast are found to be most similar to the basalts from the Hawaiian Islands, whereas the Metochosin Formation basalts on southern Vancouver Island are found to be more similar to ocean ridge tholeiites. The basalts from the Crescent Formation on the Olympic Peninsula show a variety of chemical compositions and REE patterns which do not allow a simple classification of this formation.

* Abstracted from D. W. Hill M.S. Thesis, September 3, 1974.

Table 1. INAA Scheme.

Counting Sets

1. 15 min decay, 200 sec count Ge (Li)
2. 3 hr decay, 800 sec count Ge (Li)
3. 1 day decay, 400 sec count Ge (Li)
4. 3 day decay, 10K sec count Ge (Li)
5. 1 week decay, 4K-20K sec count Ge (Li)
6. 2 week decay, 10K-20K sec count Ge (Li)
7. 6 week decay, 20K-40K sec count Ge (Li)

Activation	Isotope	Half Life*	E γ(keV)*	Counting Set
25 kW for 2	Ti - 51	5.79 min	320	1
min,	Mg - 27	9.46 min	1014	1
"Rabbit Run"	V - 52	3.75 min	1434	1
(7.5 x 10^{10} n/	Al - 28	2.33 min	1779	1
cm^2/sec)	Ca - 49	8.80 min	3084	1
	Dy - 155	2.32 hr	95	2
	Mn - 56	2.38 hr	847	2
	Na - 24	15.0 hr	1369, 2754	3
1 MW for 3	K - 42	12.4 hr	1525	4
hr,	Sm - 153	46.8 hr	104	5, 6
"Long Lived"	Lu - 177	6.74 day	208	5, 6
(3 x 10^{12} n/	Yb - 175	101 hr	396	5, 6
cm^2/sec)	Ba - 131	12.1 day	496	5, 6
	Nd - 147	11.1 day	91, 531	5, 6
	La - 140	40.2 hr	1596	5, 6
	Eu - 152	12.7 yr	122, 1408	6, 7
	Tb - 160	72.1 day	299	6, 7
	Th(Pa - 233)	27.0 day	312	6, 7
	Cr - 51	27.8 day	320	6, 7
	Fe - 59	45.6 day	1099	6. 7
	Sc - 46	83.9 day	1121	6, 7
	Ta - 182	115 day	1221	6, 7
	Co - 60	5.26 yr	1332	6, 7
	Ce - 141	32.5 day	145	7
	Hf - 181	42.5 day	482	7
	Cs - 134	2.05 yr	797	7
	Zr - 95	65.5 day	757	7

*Values obtained from: Gamma Ray Energy Tables for Neutron Activation Analysis. 1970. Compiled and edited by R.H. Filby, A. I. Davis, K. R. Shah, G. G. Wainscott, W. A. Haller, and W. A. Cassatt, Washington State University, Pullman.

Table 4. Miocene Basaltic Stratigraphy. (Not all plateau chemical types have Coast Range equivalents.)

K-Ar Dates	Coast Range Basalts	Yakima Basalts	K-Ar Dates
	---	UPPER YAKIMA (chemical types)	
	---	Ice Harbor	
	---	Elephant Mountain	
9.0 ± 1.4 m.y.[a] 12.9 ± 2 m.y.[b]	Basalt of Pack Sack Lookout	Pomona	
	---	MIDDLE YAKIMA (chemical types)	13.4 ± 0.4 m.y.[c] 16.5 ± 0.8 m.y.[b]
	---	Umatilla	
	---	Roza	
	Cape Foulweather Basalt	Frenchman Springs	
16 ± 0.65 m.y.[d] 14.5 ± 1.0 m.y.[e] 15.2 ± 0.6 m.y.[e] 14 ± 2.7 m.y.[e]	DEPOE BAY BASALT (chemical types)	LOWER YAKIMA (chemical types)	15.3 ± 0.8 m.y.[e] 15.2 ± 0.7 m.y.[b] 16.4 ± 0.6 m.y.[b]
	High Mg	High Mg	
	Low Mg	Low Mg	

[a] R. F. Denison (written communication to Snavely et al., 1973).

[b] Holmgren (1970).

[c] Evernden and James (1964).

[d] J. Obradovich (written communication to Snavely et al., 1973).

[e] Turner (1970).

Table 5. Low Mg Lower Yakima and Depoe Bay Basalts.

	Lower Yakima Ave. (Snavely)*	Depoe Bay Ave. (Snavely)*	LOWER YAKIMA			DEPOE BAY
			Nathan & Fruchter+ Ave.	U of O[x] Ave.	This Work	This Work Ave.
TiO_2 (%)	2.0 - 2.0	2.0	2.20	2.04	2.0	1.9
Al_2O_3	14.2 - 13.6	14.0	13.76	13.39	13.3	12.7
FeO^{++}	11.5 - 12.1	12.1	12.30	11.8	11.6	12.0
MgO	4.2 - 4.2	3.6	3.38	3.13	3.8	3.6
CaO	7.9 - 7.9	7.1	7.11	6.76	6.8	6.3
Na_2O	3.0 - 3.0	3.3	3.27	3.03	3.0	3.2
K_2O	1.3 - 1.4	1.4	1.78	2.07	1.7	1.5
MnO	0.21 - 0.18	0.21	0.21	0.207	0.174	0.172
Cr_2O_3 (ppm)			15	17	32	18
Sc			31	31	33	31
V					350	320
Co			34	35	37	35
Zr					110	160
Ba			~600	645	590	580
La			24	24.1	24.2	24.3
Ce					48	49
Nd					28	25
Sm			6.9	6.8	6.3	6.4
Eu				1.9	1.81	1.79
Tb					1.00	1.00
Dy					6	6
Yb				2.9	3.8	3.3
Lu			0.59	0.56	0.50	0.50
Hf					4.6	4.8
Ta					0.73	0.75
Th			5.8	6.2	4.5	5.3
Cs					1.4	1.6

* Snavely et al. (1973).

\+ Nathan and Fruchter (1974).

x Average of analyses obtained from Frachter (private communication).

++ Total Fe was calculated as FeO for all data tables in this paper.

Table 6. High Mg Lower Yakima and Depoe Bay Basalts.

	YAKIMA			DEPOE BAY
	Nathan & Fruchter Ave.[+]	U. of O.[x] Ave.	This Work Ave.	This Work Ave.
TiO_2 (%)	1.78	1.76	1.9	1.9
Al_2O_3	14.33	14.09	13.4	13.3
FeO	11.42	11.46	11.0	11.9
MgO	4.90	4.77	5.8	4.6
CaO	8.72	8.43	[illegible]	7.9
Na_2O	2.84	3.0	2.9	3.0
K_2O	1.17	1.22	1.2	0.8
MnO	0.20	0.188	0.185	0.196
Cr_2O_3 (ppm)	36	55	66	37
Sc	33	35	38	37
V			[illegible]20	320
Co	38	38	41	38
Zr			150	170
Ba	~500	488	440	420
La	19	18.4	18.5	[illegible].1
Ce			38	41
Nd			22	24
Sm	5.3	5.76	5.6	5.9
Eu		1.71	1.71	[illegible]
Tb			0.90	[illegible]0
Dy			6	
Yb		2.7	3.1	[illegible].1
Lu	0.40	0.49	0.47	0.47
Hf		3.8	3.9	4.2
Ta			0.60	0.69
Th	3.5	3.6	3.0	3.3
Cs			0.6	0.9

[+] Nathan and Fruchter (1974).

[x] Average of analyses obtained from Fruchter (private communication).

Table 7. Frenchman Springs and Cape Foulweather Basalts.

	FRENCHMAN SPRINGS				CAPE FOULWEATHER	
	Snavely* Ave.	Nathan & Fruchter+ Ave.	U. of O.x Ave.	This Work	Snavely* Ave.	This Work Ave.
TiO_2 (%)	3.0 - 3.4	3.00	2.93	2.8	3.0	3.0
Al_2O_3	13.6 - 13.0	13.71	13.05	12.5	13.9	12.5
FeO	14.0 - 14.7	14.16	14.23	13.6	14.1	14.0
MgO	4.5 - 4.6	4.19	4.21	4.3	3.9	3.6
CaO	8.3 - 8.5	8.46	8.22	7.5	7.9	7.5
Na_2O	2.9 - 2.7	2.[illegible]	2.87	2.9	3.0	3.0
K_2O	1.2 - 1.3	1.33	1.29	1.0	1.0	1.1
MnO	0.24 - 0.24	0.24	0.21	0.180	0.22	0.181
Cr_2O_3 (ppm)		30	49	74		31
Sc		34	35	38		36
V				430		330
Co		39	40	40		39
Zr				170		180
Ba		~ 550	566	470		480
La		24	24.0	23.5		24.3
Ce				50		52
Nd				31		30
Sm		7.4	7.78	7.3		7.7
Eu			2.18	2.18		2.28
Tb				1.14		1.17
Dy				6		7
Yb			3.3	3.4		3.6
Lu		0.47	0.55	0.53		0.53
Hf			5.2	5.0		4.8
Ta				0.87		0.89
Th		3.7	3.9	3.8		3.9
Cs				0.7		1.0

*Snavely *et al.* (1973).

+Nathan and Fruchter (1974).

xAverage of analyses obtained from Fruchter (private communication).

Table 8. Pomona and Pack Sack Lookout Basalts.

	POMONA				PACK SACK LOOKOUT	
	Snavely* Ave.	U. of O.[x] Ave.	This Work Ave.	This Work & U. of O.[+] 73-5	Snavely* Ave.	This Work Ave.
TiO_2 (%)	1.7		1.7	1.5	1.6	1.65
Al_2O_3	15.1		13.4	13.6	15.1	13.8
FeO	10.8	11.4	11.5	10.9	10.3	10.6
MgO	7.0		6.7	7.8	6.9	6.5
CaO	10.9		10.0	9.9	10.6	10.5
Na_2O	2.3	2.29	2.5	2.4	2.3	2.4
K_2O	0.62		0.8	0.7	0.56	0.5
MnO	0.20		0.173	0.166	0.18	0.161
Cr_2O_3 (ppm)		131	127	1[illegible]1		144
Sc		38	37	36		35
V			300	270		270
Co		48	42	43		41
Zr			140	130		100
Ba		280	220	200		220
La		20.0	19.1	17.2		17.0
Ce			40	37		35
Nd			24	24		21
Sm		5.38	5.6	5.1		5.1
Eu		1.8	1.68	1.57		1.49
Tb			0.87	0.75		0.82
Dy			5	5		5
Yb		3.55	3.0	2.9		2.6
Lu		0.61	0.43	0.40		0.40
Hf			3.9	3.5		3.4
Ta			0.80	0.73		0.68
Th		3.3	2.7	2.7		2.5
Cs			0.2	0.2		0.2

*Snavely *et al.* (1973).

[x] Average of analyses obtained from Fruchter (private communication).

[+] Average of duplicate analyses of sample 73-5.

Table 9. Chemical Composition Ranges in Metchosin and Crescent Formation and Umpqua Volcanics.

	Metchosin	Crescent	Umpqua*
TiO_2 (%)	1.0 - 2.5	0.8 - 2.9	---
Al_2C_3	12.0 - 14.0	13.0 - 17.4	13.9 - 15.4
FeO	10.7 - 15.5	8.5 - 14.4	9.9 - 13.1
MgO	5.2 - 8.6	3.5 - 8.6	5.1 - 8.2
CaO	7.6 - 11.9	6.9 - 11.2	9.6 - 13.1
Na_2O	1.9 - 2.8	2.2 - 4.6	2.0 - 3.8
K_2O	<0.1 - 0.3	<0.1 - 0.3	0.053 - 0.39
MnO	0.167 - 0.272	0.147 - 0.219	0.146 - 0.241
Cr_2O_3 (ppm)	36 - 290	7 - 480	190 - 690
Sc	42 - 49	31 - 47	40 - 50
V	310 - 430	240 - 380	---
Co	39 - 49	31 - 49	46 - 53
Zr	<60 - 190	<60 - 230	---
Ba	<30 - 60	<30 - 220	70 - 140
La	2.9 - 11.3	2.5 - 20.6	8.0 - 13
Ce	7 - 27	7 - 39	21 - 34
Nd	<8 - 26	<10 - 26	---
Sm	2.5 - 8.0	1.8 - 7.6	3.2 - 5.1
Eu	0.89 - 2.6	0.67 - 2.3	1.3 - 1.9
Tb	0.58 - 1.8	0.39 - 1.5	0.62 - 1.0
Dy	4 - 11	3 - 10	---
Yb	2.4 - 7.4	1.6 - 7.5	2.1 - 3.0
Lu	0.36 - 1.12	0.24 - 1.14	0.34 - 0.52
Hf	1.8 - 6.1	1.8 - 7.3	2.4 - 4.2
Ta	0.17 - 0.67	0.17 - 1.45	0.20 - 1.3
Th	<0.3 - 0.7	<0.3 - 1.5	0.55 - 1.7
Sr	---	---	65 - 380

*These samples were analyzed by M. J. Dudas for all elements except Al_2O_3.

Table 10. Chemical Composition Ranges* in the Tillamook and Siletz River Volcanics and the Eocene Alkalics.

	Tillamook	Eocene Alkalic	Siletz River Older Unit	Siletz River Younger Unit
Al_2O_3 (%)	11.3 - 15.4	15.0 - 18.2	14.8 - 15.2	12.2 - 15.2
FeO	10.8 - 13.8	8.0 - 12.8	10.7 - 11.7	12.9 - 15.1
MgO	4.9 - 7.7	0.95 - 6.5	7.6 - 7.9	4.6 - 6.3
CaO	10.4 - 11.9	3.4 - 6.6	10.0 - 11.5	9.4 - 11.7
Na_2O	2.4 - 3.9	2.9 - 4.5	1.8 - 2.2	2.6 - 2.8
K_2O	0.14 - 0.28	1.3 - 1.7	0.095 - 0.10	0.13 - 0.72
MnO	0.156 - 0.272	0.137 - 0.174	0.170 - 0.198	0.181 - 0.239
Cr_2O_3 (ppm)	59 - 480	9 - 140	420 - 480	73 - 290
Sc	32 - 42	8.7 - 18	38 - 42	37 - 41
Co	44 - 64	11 - 42	46 - 50	43 - 52
Ba	70 - 140	420 - 600	$<$50 - 70	$<$60 - 200
La	7.2 - 35	46 - 98	5.8 - 6.7	10.2 - 32.8
Ce	22 - 84	101 - 216	15 - 18	26 - 81
Sm	3.8 - 7.7	10 - 14	3.2 - 3.9	4.9 - 11.5
Eu	1.3 - 2.2	2.6 - 3.9	1.03 - 1.28	1.6 - 3.0
Tb	0.68 - 1.2	1.3 - 1.5	0.57 - 0.75	0.86 - 1.9
Yb	2.0 - 3.2	2.9 - 4.3	1.9 - 2.3	2.4 - 5.5
Lu	0.34 - 0.50	0.41 - 0.54	0.34 - 0.39	0.42 - 0.84
Hf	2.4 - 6.3	8.4 - 10.9	2.1 - 2.9	3.3 - 9.5
Ta	0.40 - 2.5	2.8 - 6.2	0.49 - 0.80	1.1 - 3.8
Th	0.67 - 6.8	5.3 - 13	0.50 - 0.60	0.8 - 3.5
Sr	140 - 330	440 - 840	200 - 206	150 - 190

*The samples in this table were analyzed by M. J. Dudas for all elements except Al_2O_3.

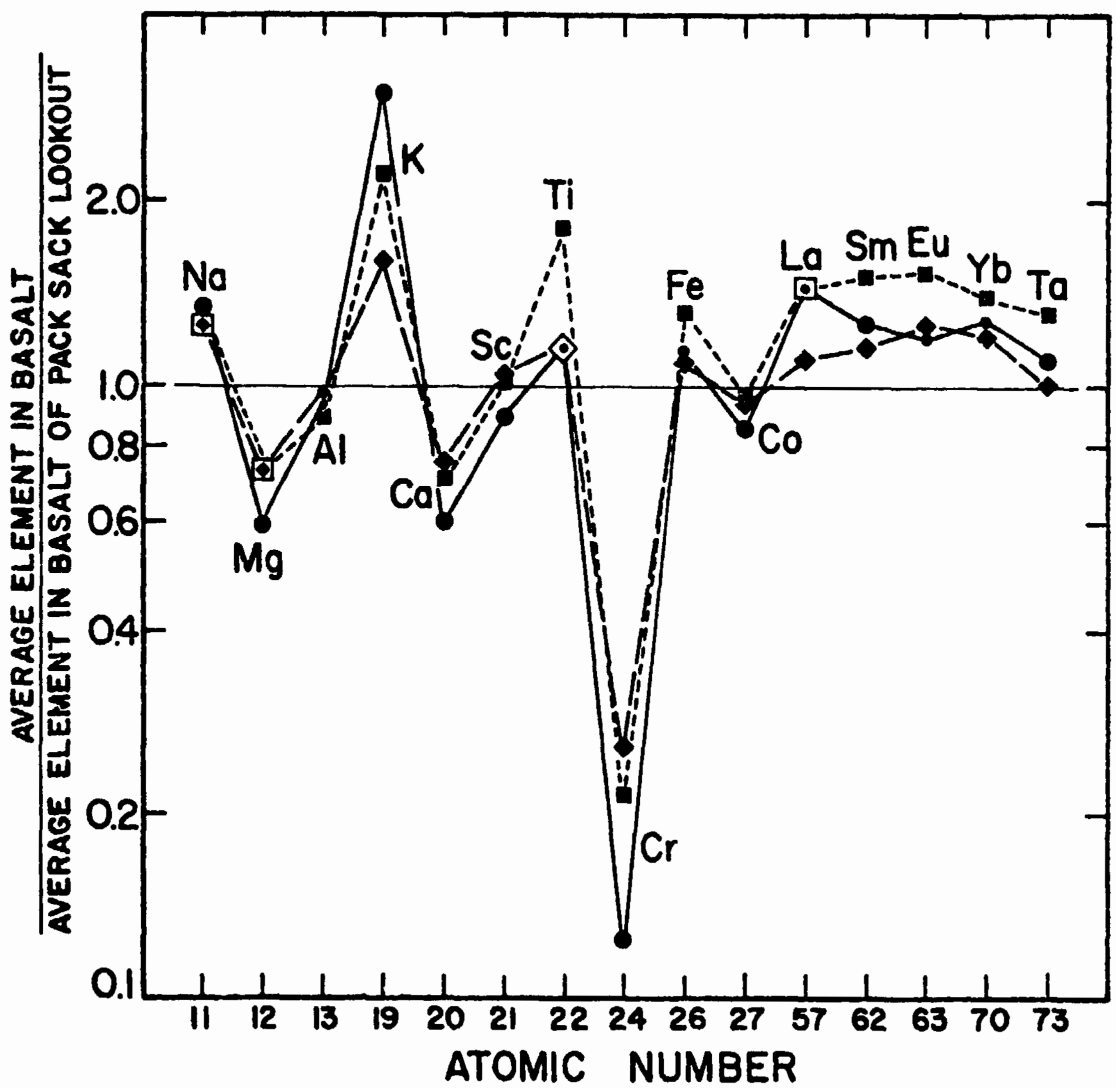

Figure 2. Average abundances of several representative elements in low (●) and high (♦) Mg Depoe Bay basalts and Cape Foulweather basalts (■) are normalized to the average abundances of the basalt of Pack Sack Lookout.

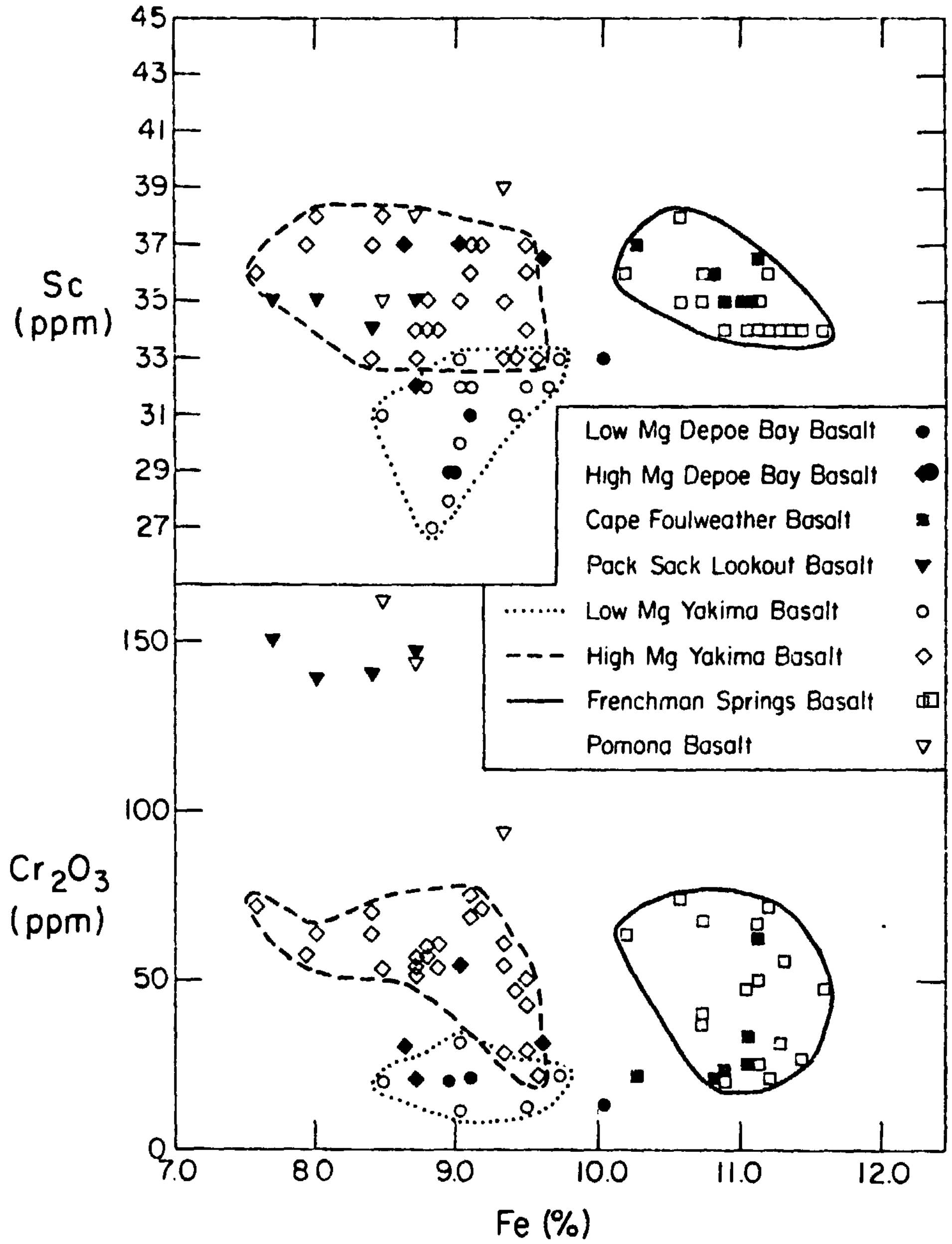

Figure 3. Variation diagram of Fe versus Sc and Cr_2O_3. Solid symbols are for the coastal basalts, and open symbols are for the plateau basalts. Sample representations are as follows: o, ●, low Mg, ◇ , ◆, high Mg Lower Yakima and Depoe Bay basalts; □, ■, Frenchman Springs and Cape Foulweather basalts; ▽, ▼, Pomona basalt and basalt of Pack Sack Lookout. The regions for low Mg and high Mg Lower Yakima and Frenchman Springs basalts are designated by dotted, dashed, and solid lines, respectively. No region for Pomona basalt is designated due to lack of sufficient data.

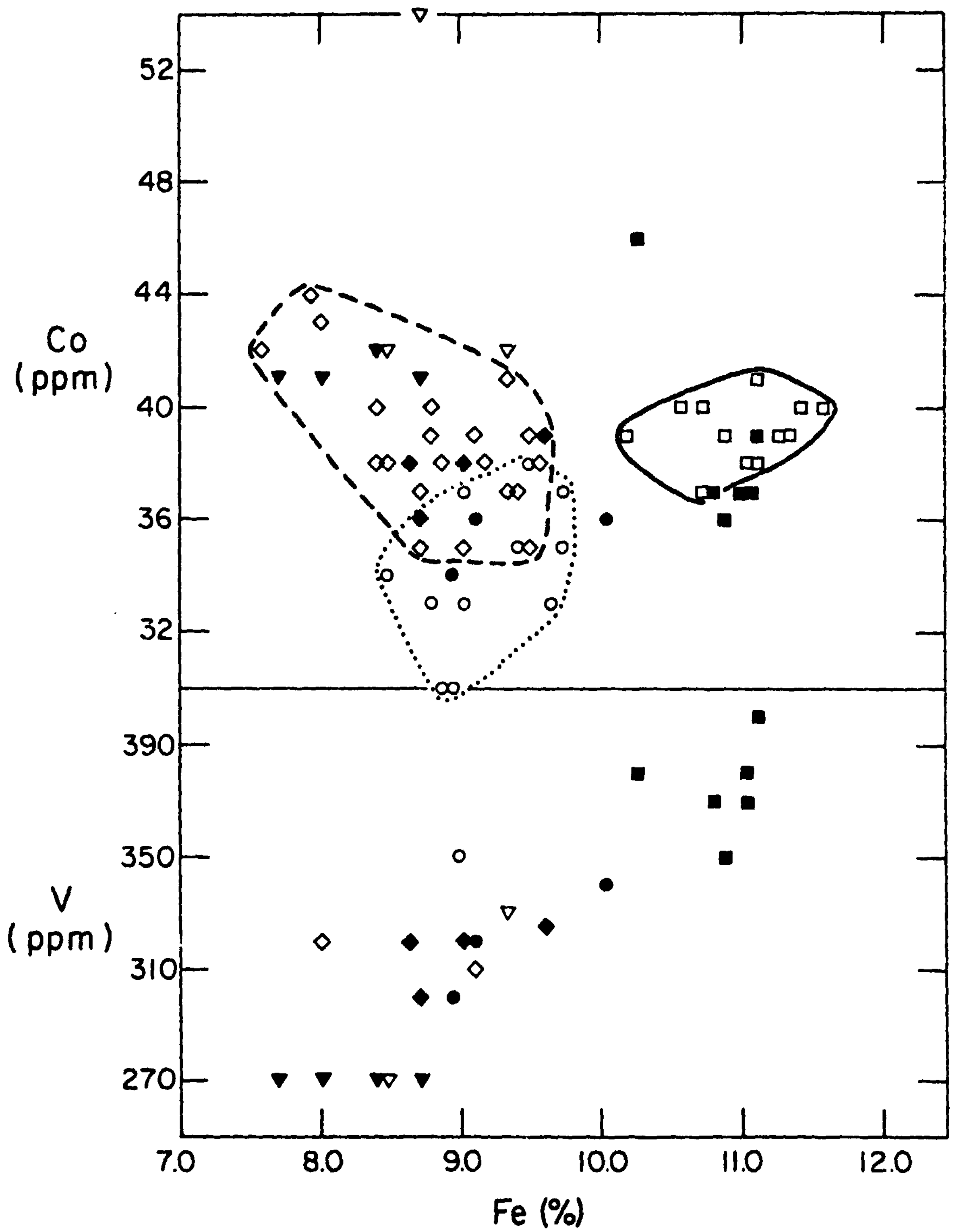

Figure 4. Variation diagram of Fe versus Co and V. Symbols are same as in Figure 3.

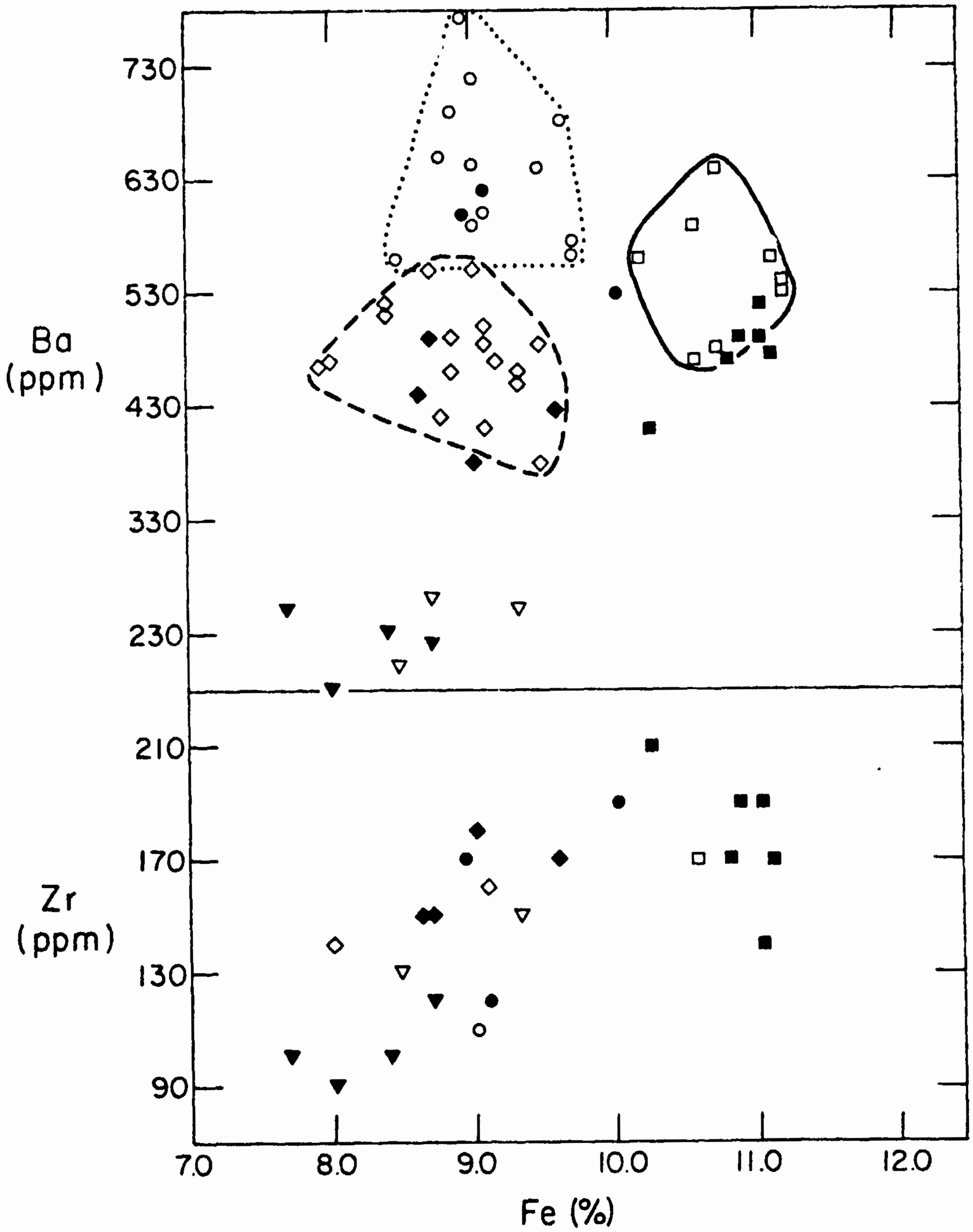

Figure 5. Variation diagram of Fe versus Ba and Zr. Symbols are same as in Figure 3.

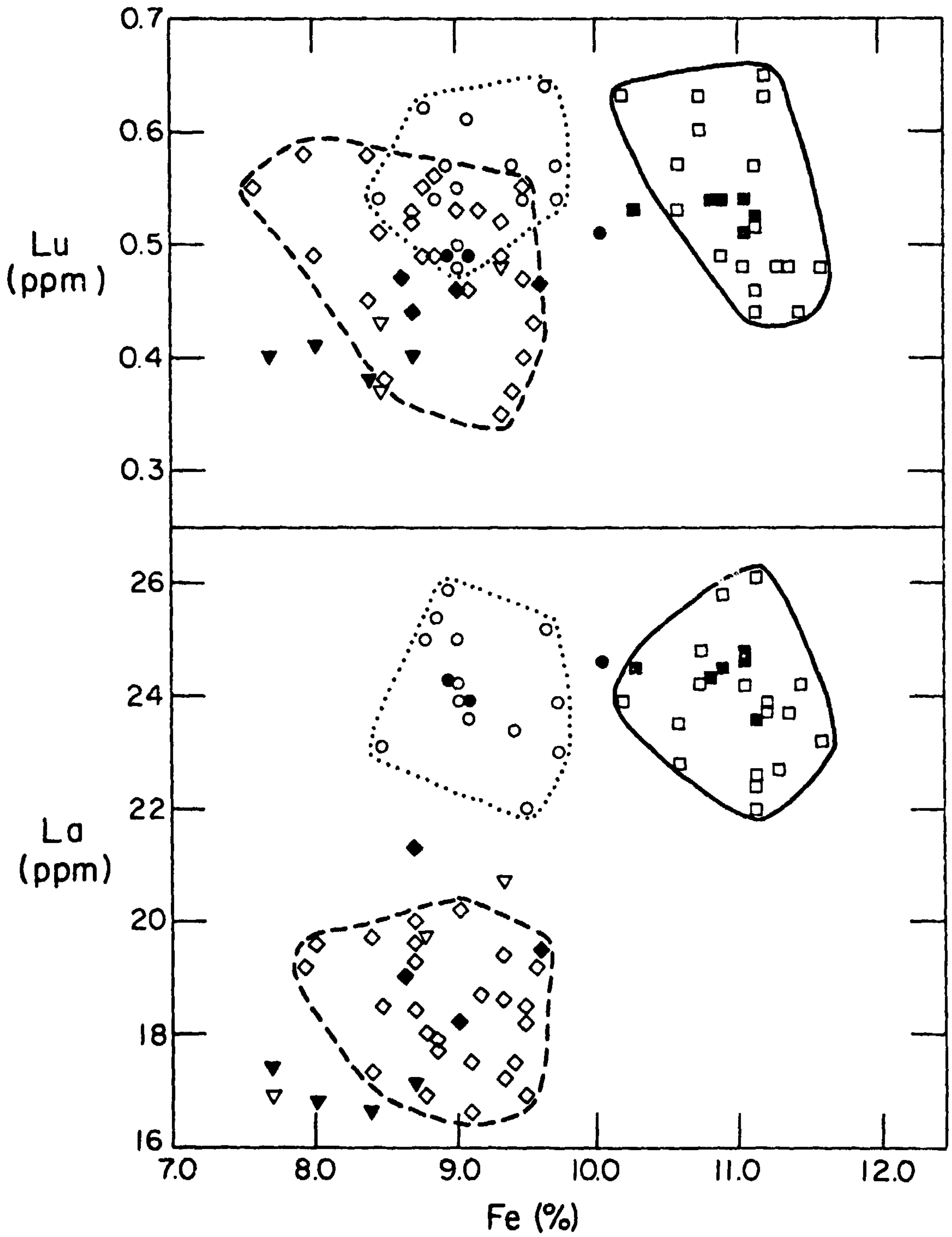

Figure 6. Variation diagram of Fe versus La and Lu. Symbols are same as in Figure 3.

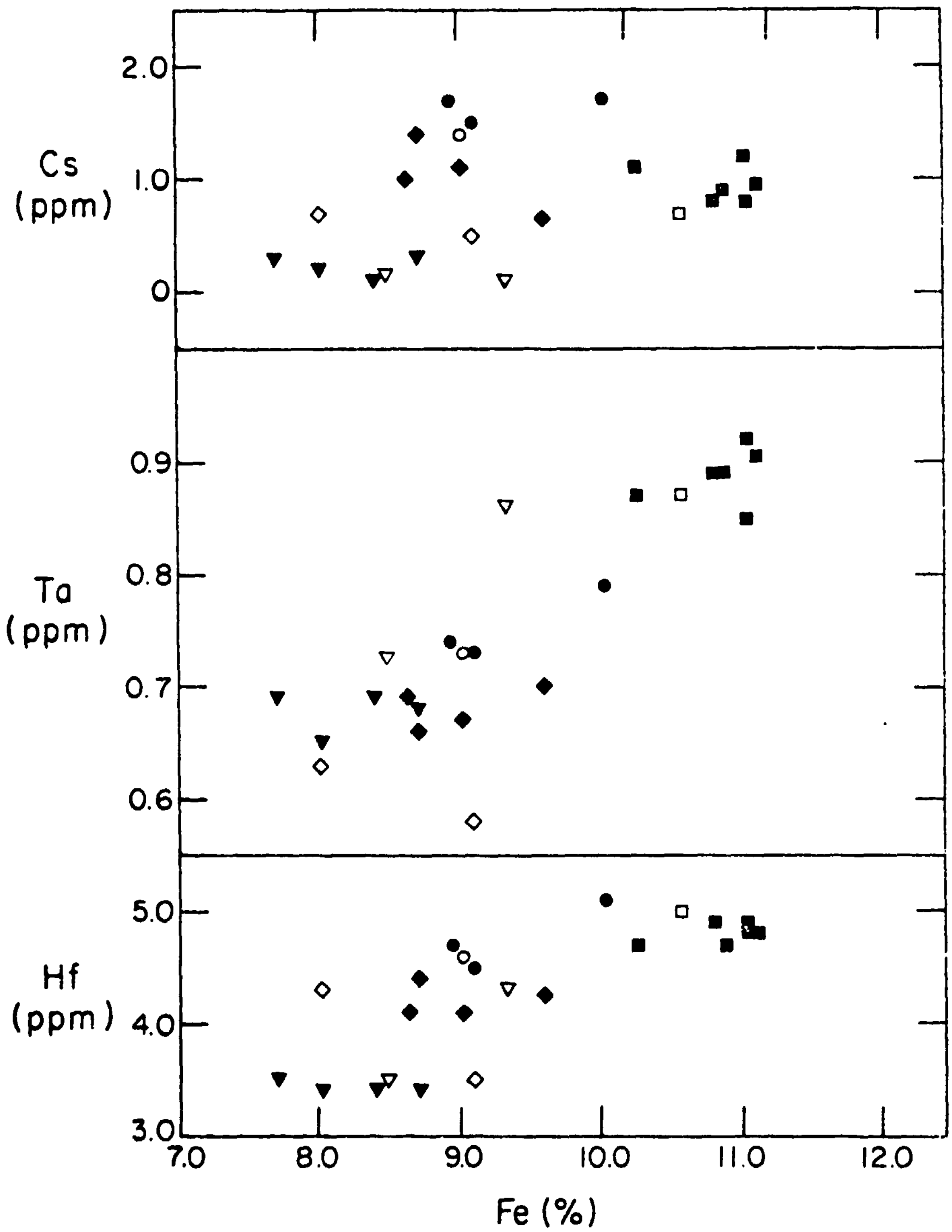

Figure 7. Variation diagram of Fe versus Cs, Ta and Hf. Symbols are same as in Figure 3.

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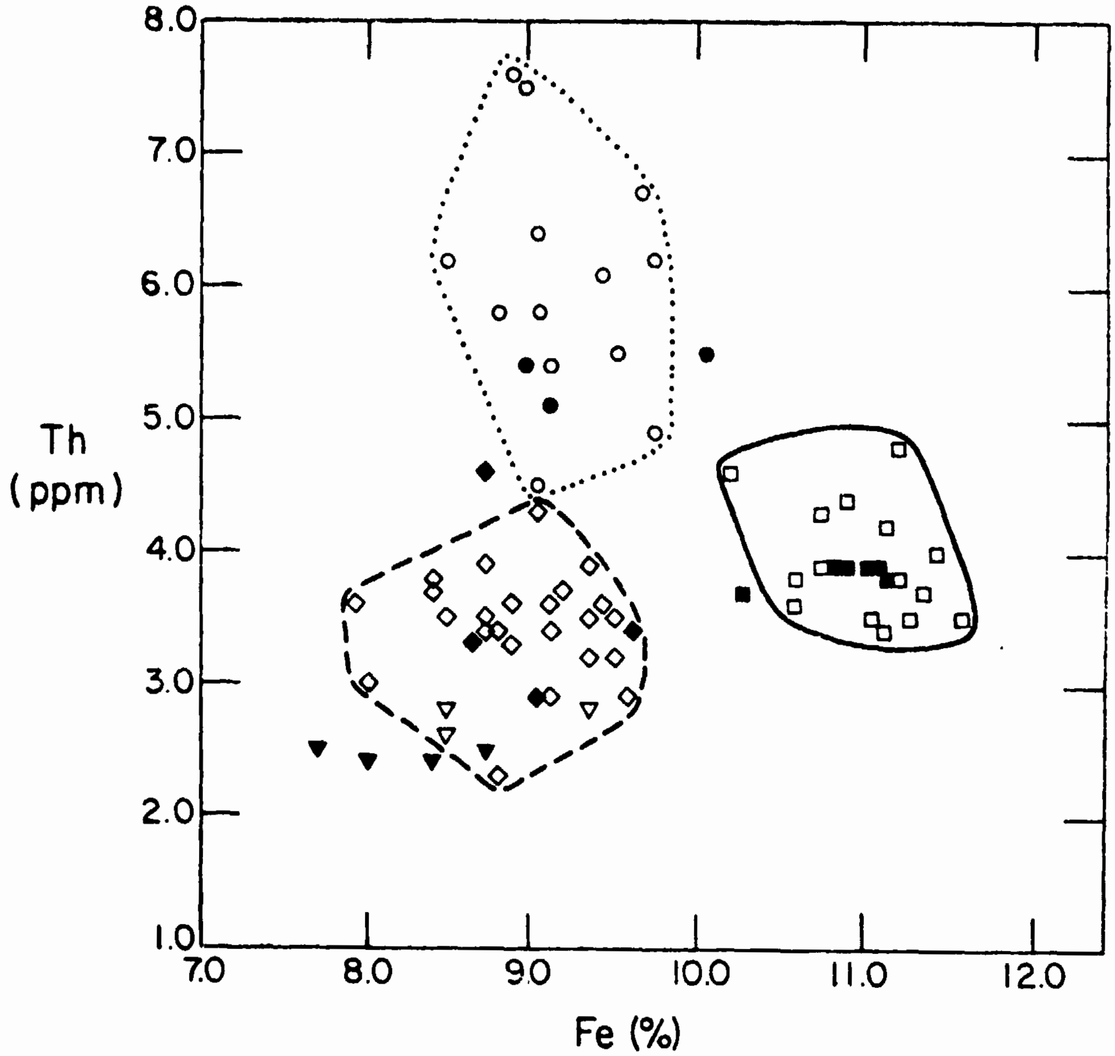

Figure 8. Variation diagram of Fe versus Th. Symbols are same as in Figure 3.

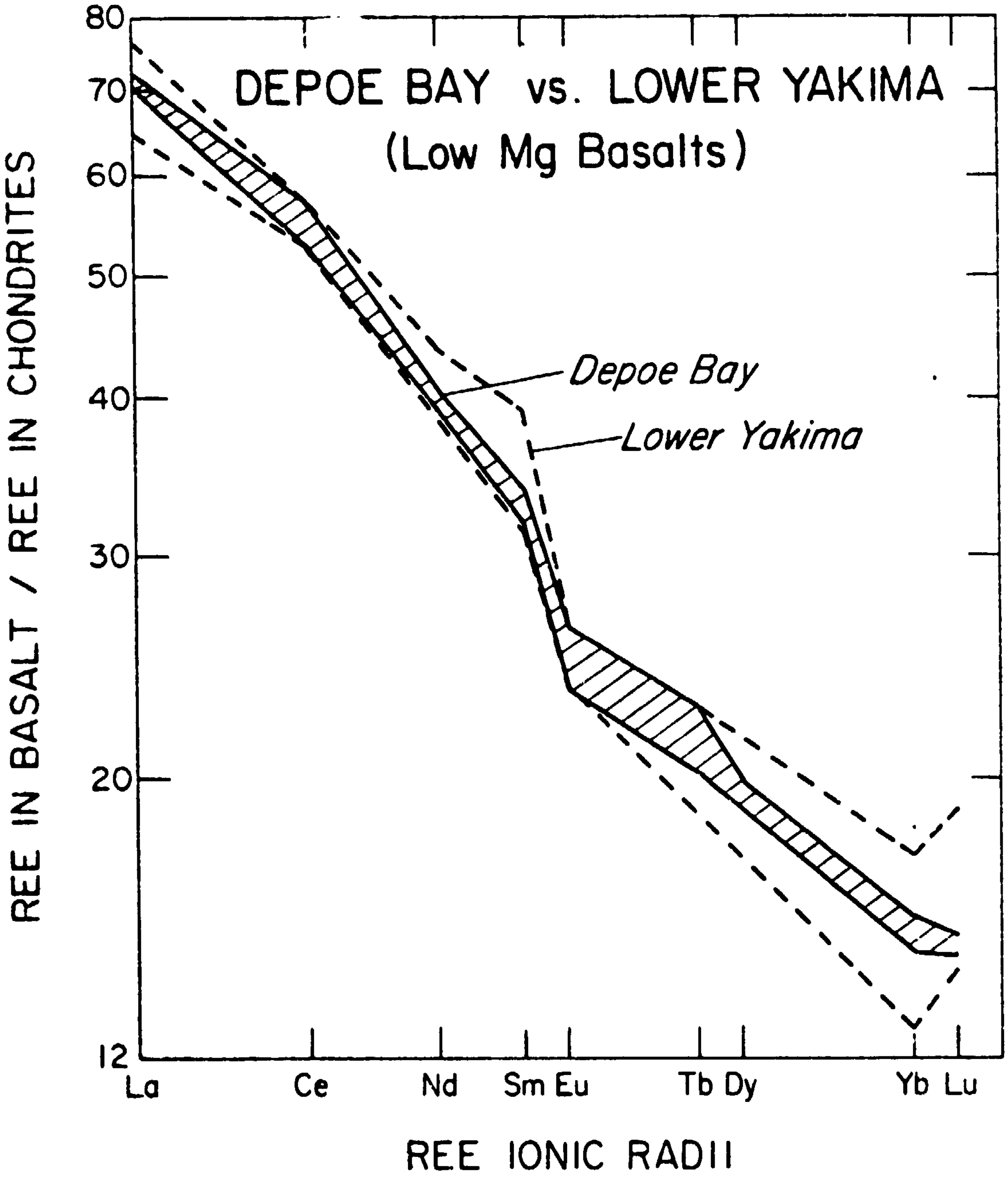

Figure 9. Abundance ranges of REE in low Mg Lower Yakima and Depoe Bay basalts are normalized to the average abundances in ordinary chondrites.

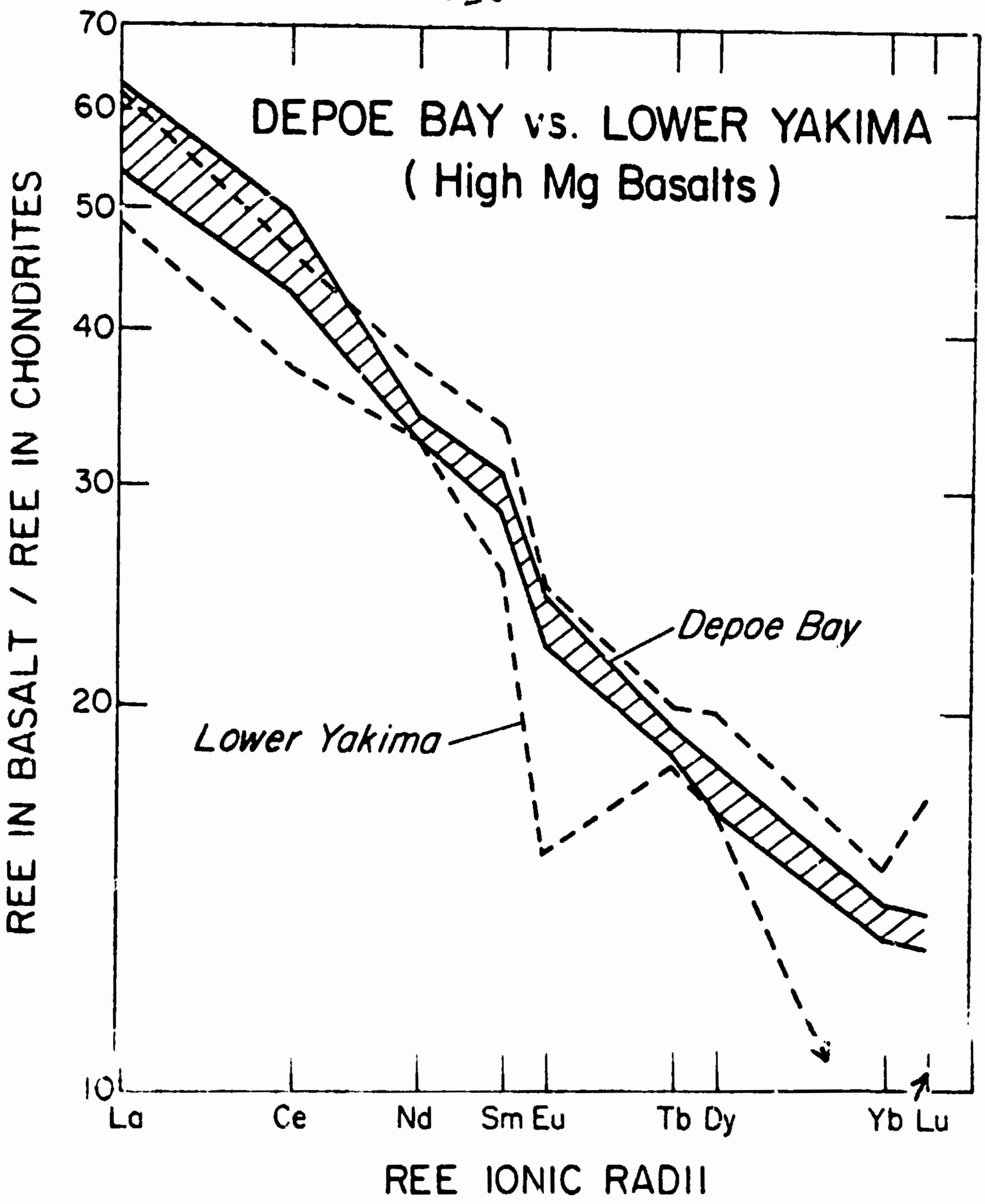

Figure 10. Abundance ranges of REE in high Mg Lower Yakima and Depoe Bay basalts are normalized to chondrites.

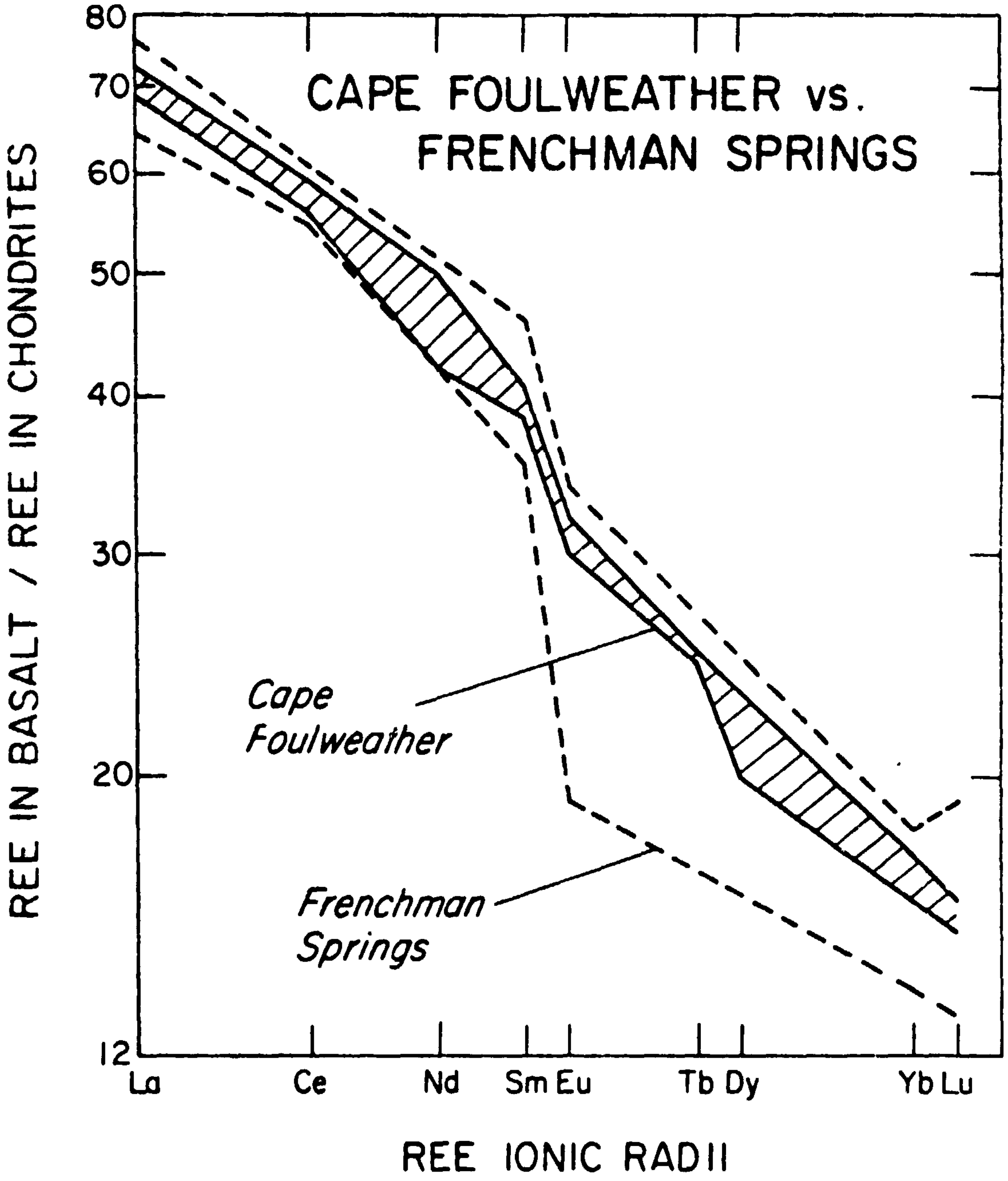

Figure 11. Abundance ranges of REE in Frenchman Springs and Cape Foulweather basalts are normalized to chondrites.

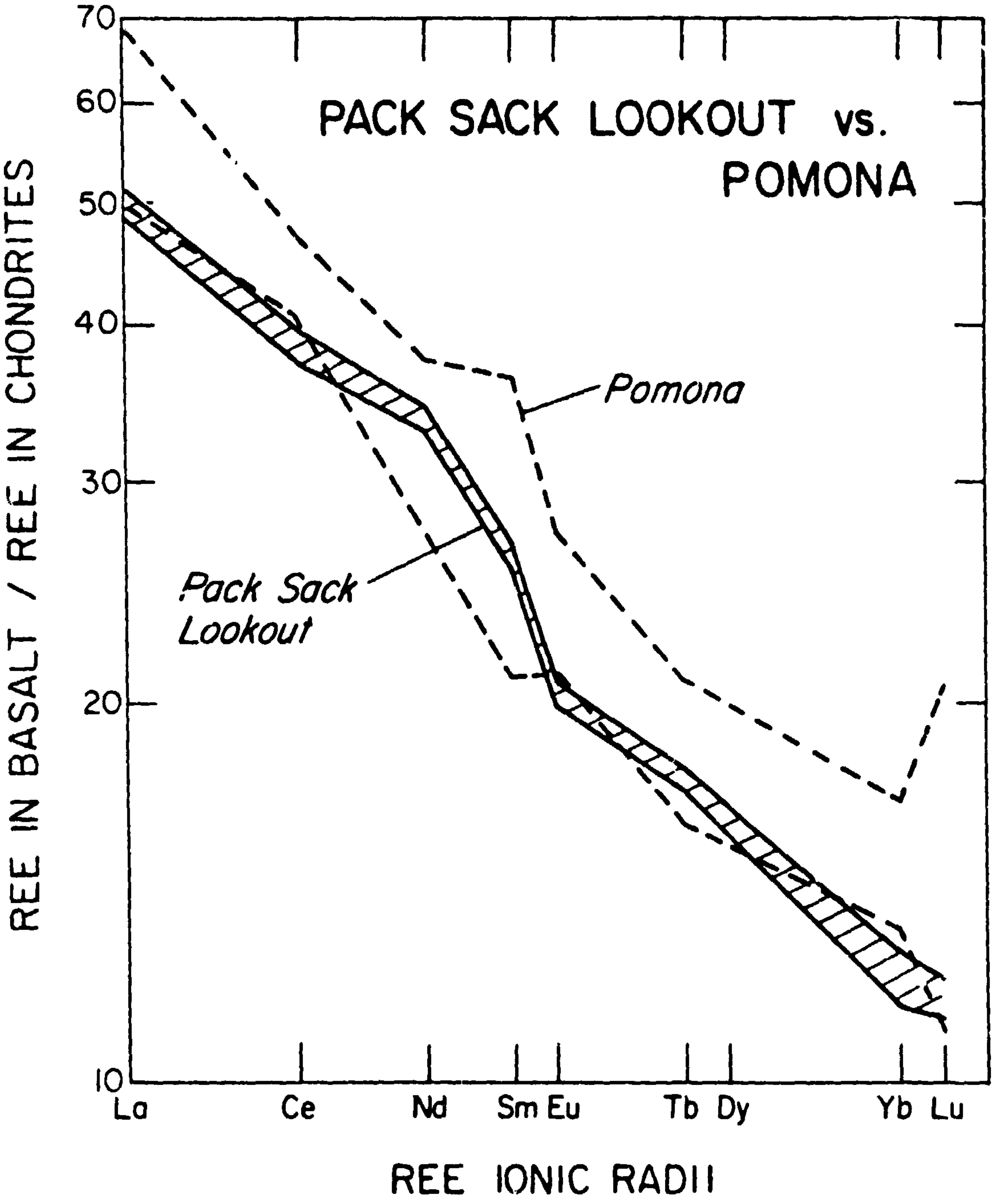

Figure 12. Abundance ranges of REE in Pomona basalt and basalt of Pack Sack Lookout are normalized to chondrites.

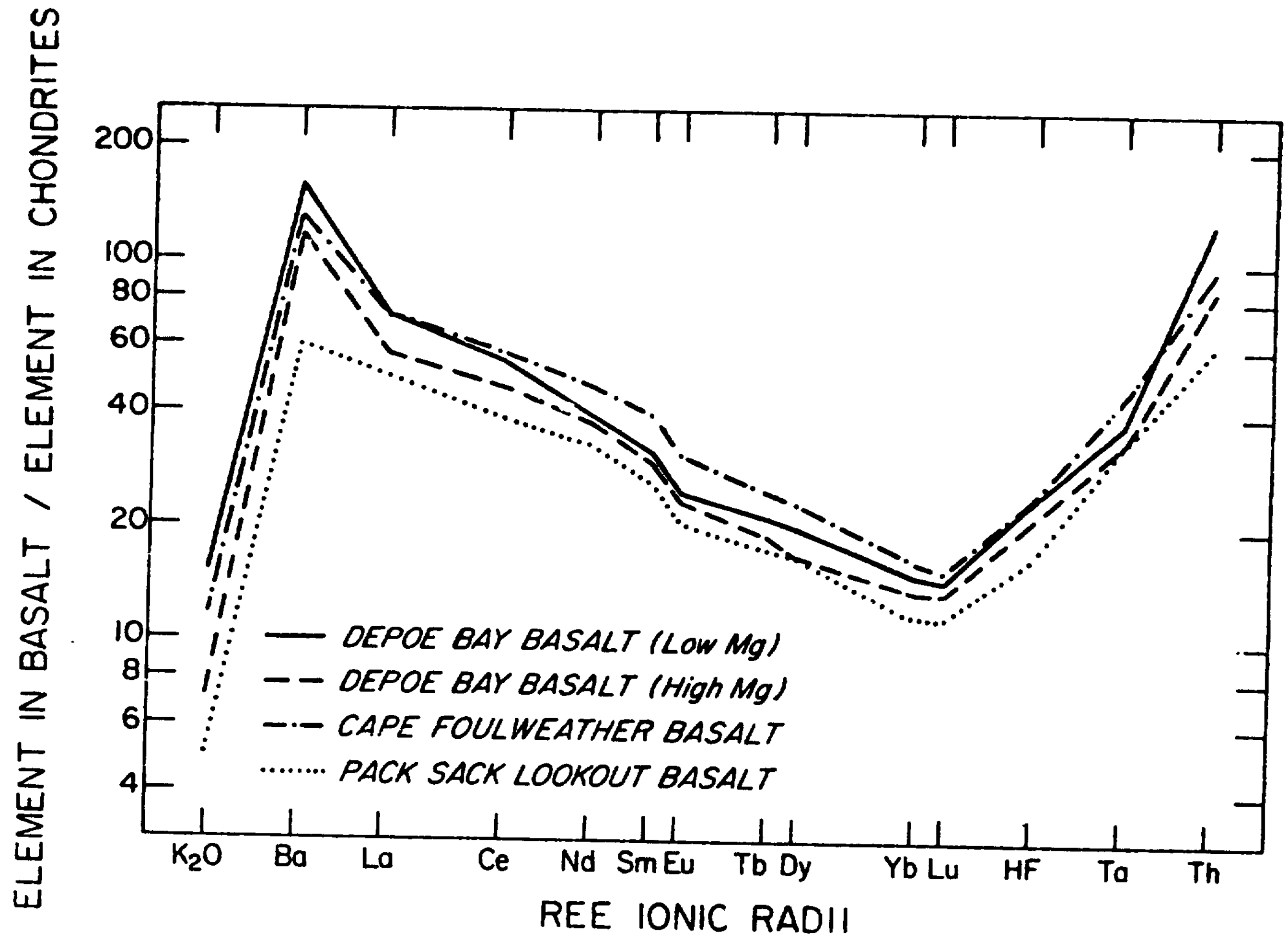

Figure 13. Average abundances of REE, K_2O, Ba, Hf, Ta and Th in the low and high Mg Depoe Bay and the Cape Foulweather basalts and the basalt of Pack Sack Lookout are normalized to the average abundances in ordinary chondrites.

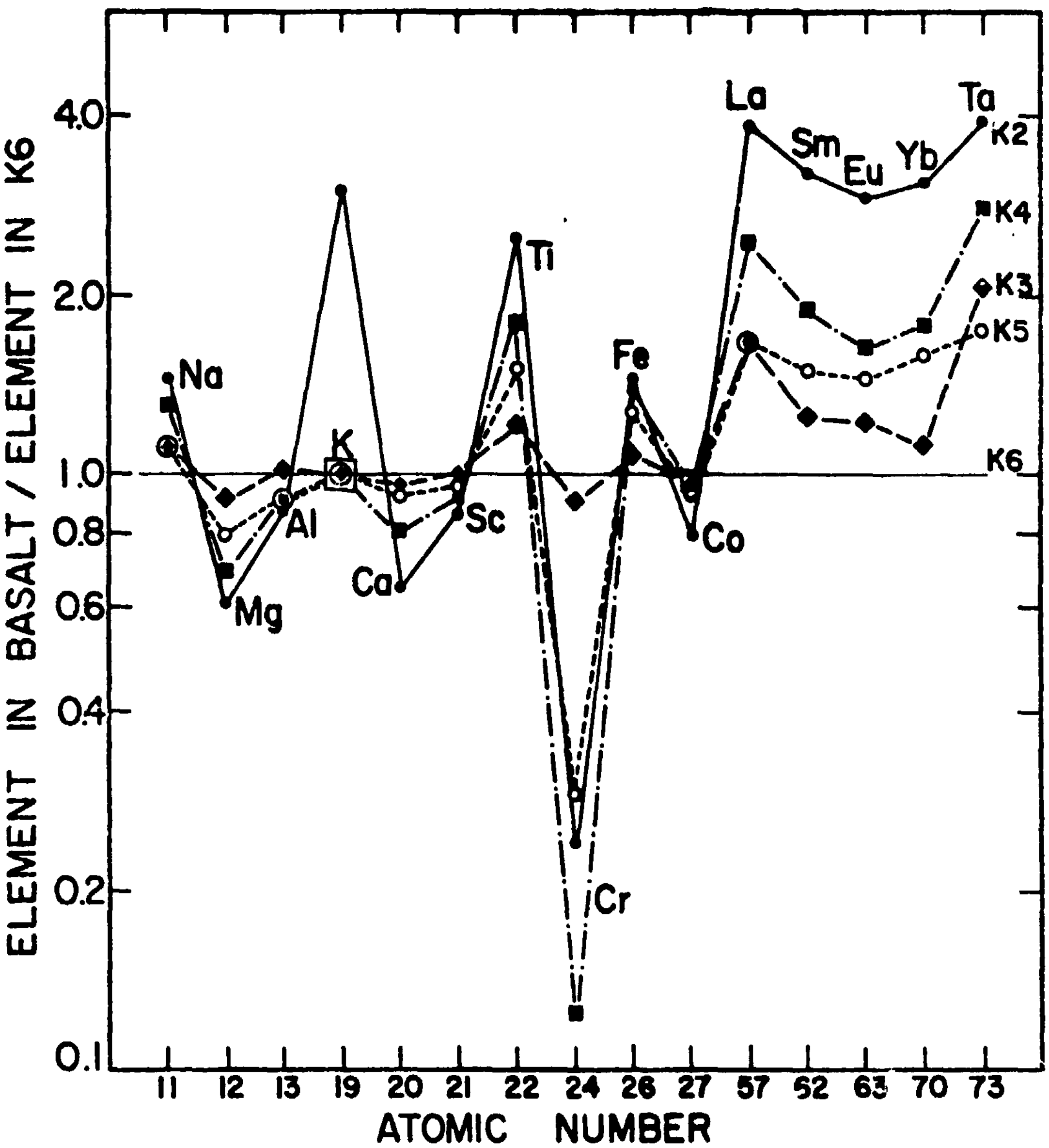

Figure 15. Abundances of several representative elements in four Metchosin Formation samples are normalized to the abundances of the fifth.

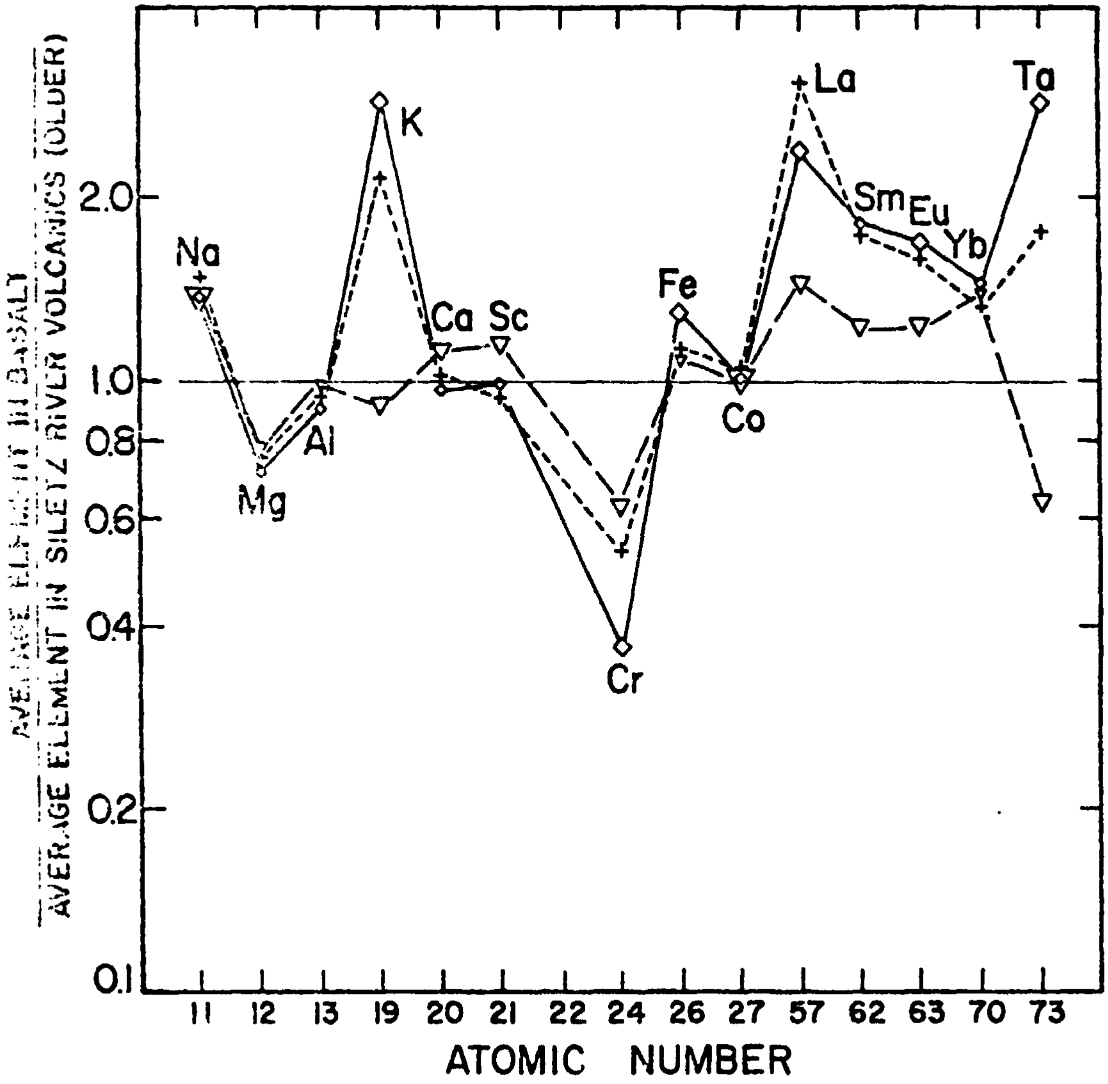

Figure 16. Average abundances of several representative elements in the Tillamook (+), Umpqua (▽), and Siletz River Volcanics (younger unit) (◇) are normalized to the average abundances of the Siletz River Volcanics (older unit).

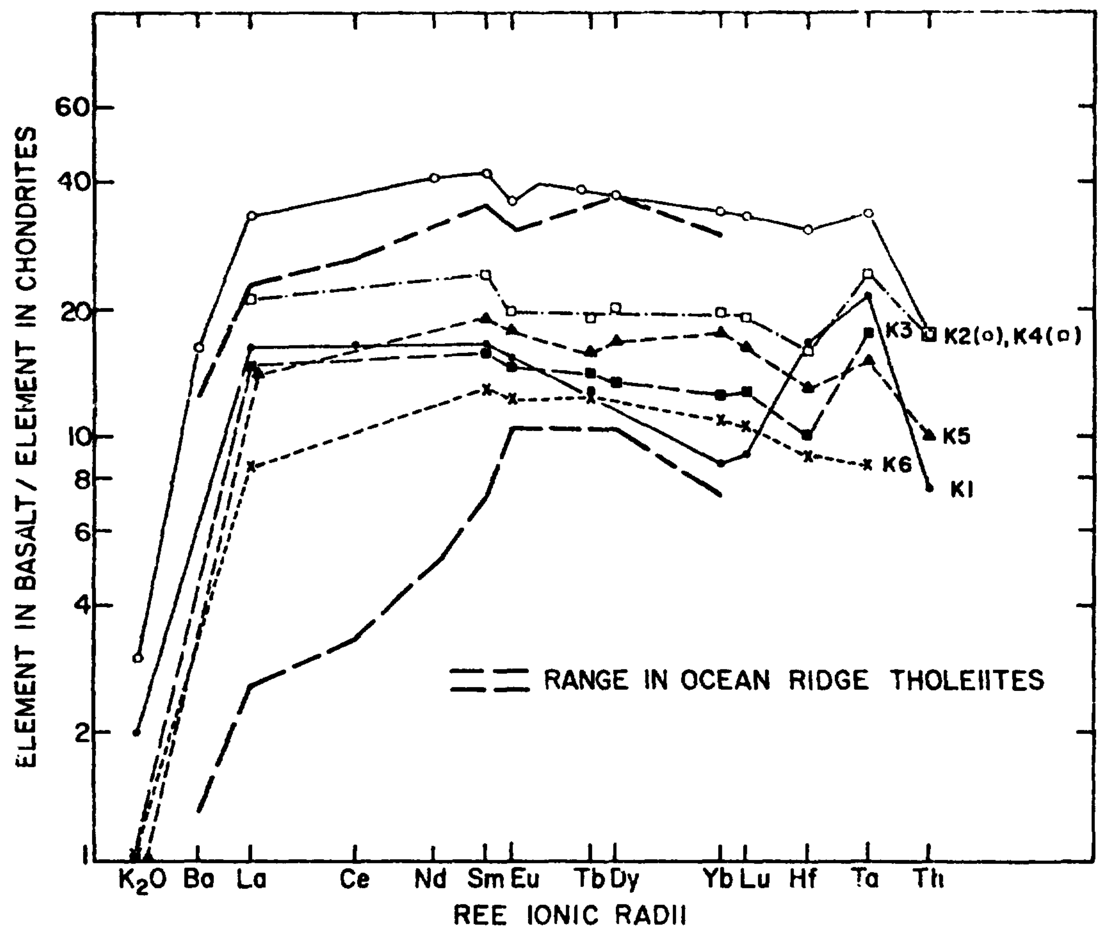

Figure 17. REE, K_2O, Ba, Hf, Ta and Th abundances in Karmutsen (K1) and Metchosin (K2-K6) Formation basalts are normalized to the average abundances in ordinary chondrites The abundance range in ocean ridge tholeiites is plotted for comparison (Kay et al., 1970).

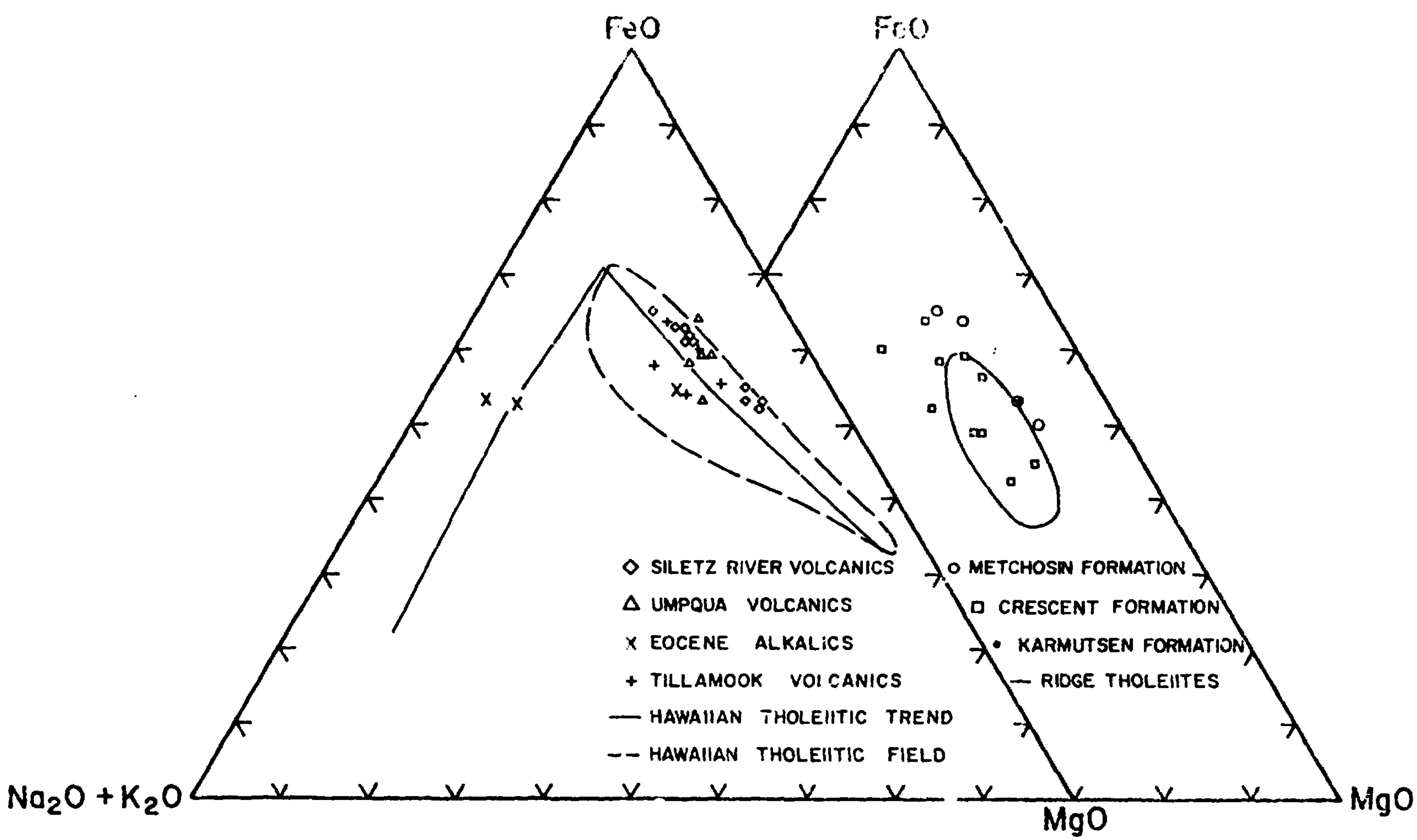

Figure 18. AFM (total alkalies vs. FeO (total Fe) vs. MgO) diagrams for the Eocene coastal basalts. Outlines of the fields in which the oceanic tholeiites (Glassley, 1973) and Hawaiian tholeiites (MacDonald and Katsura, 1964) are shown as well as the Hawaiian tholeiite trend line. The symbols are explained on the figure.

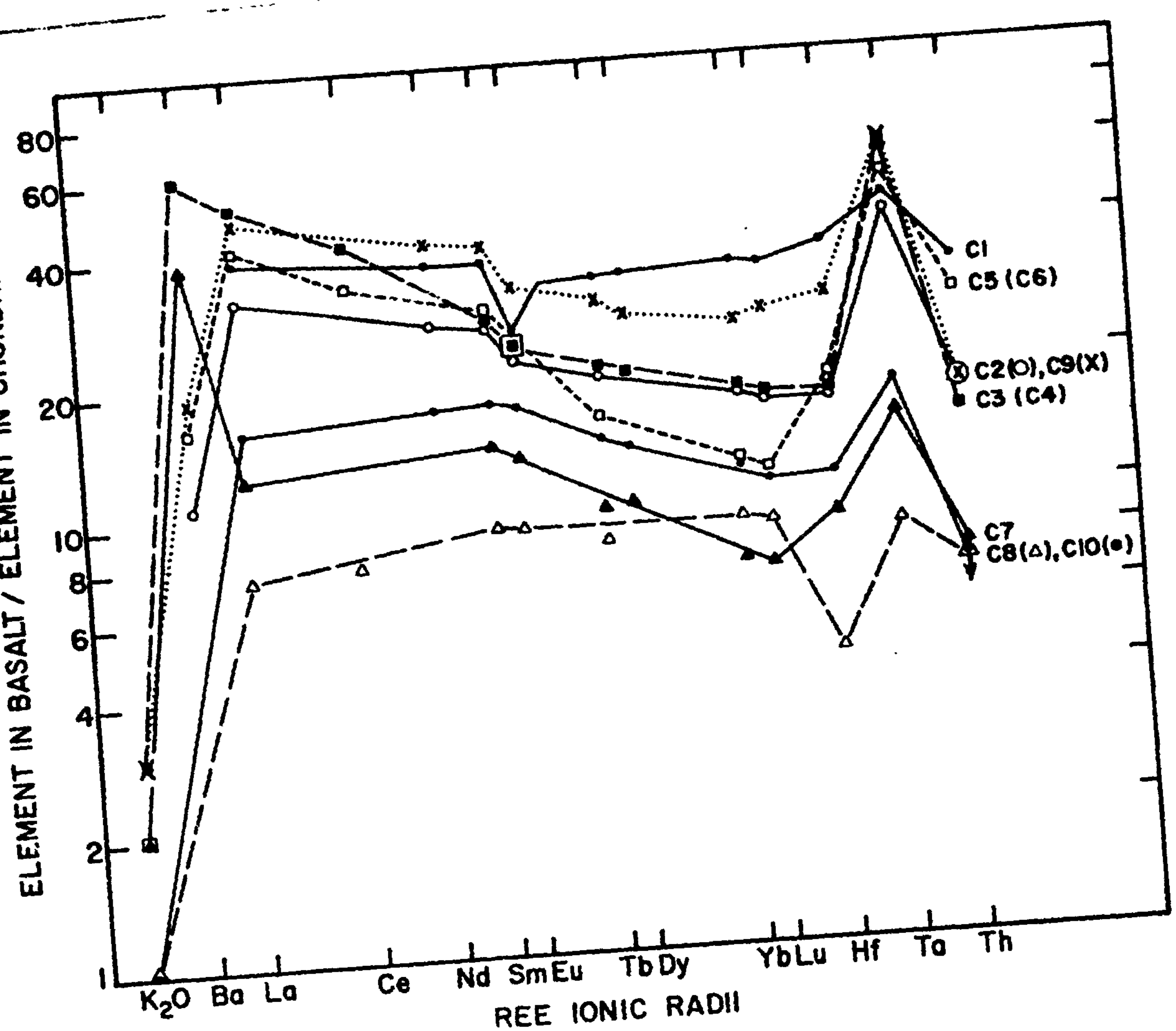

Figure 19. REE, K_2O, Ba, Hf, Ta, and Th abundances in Crescent Formation basalts are normalized to chondrites.

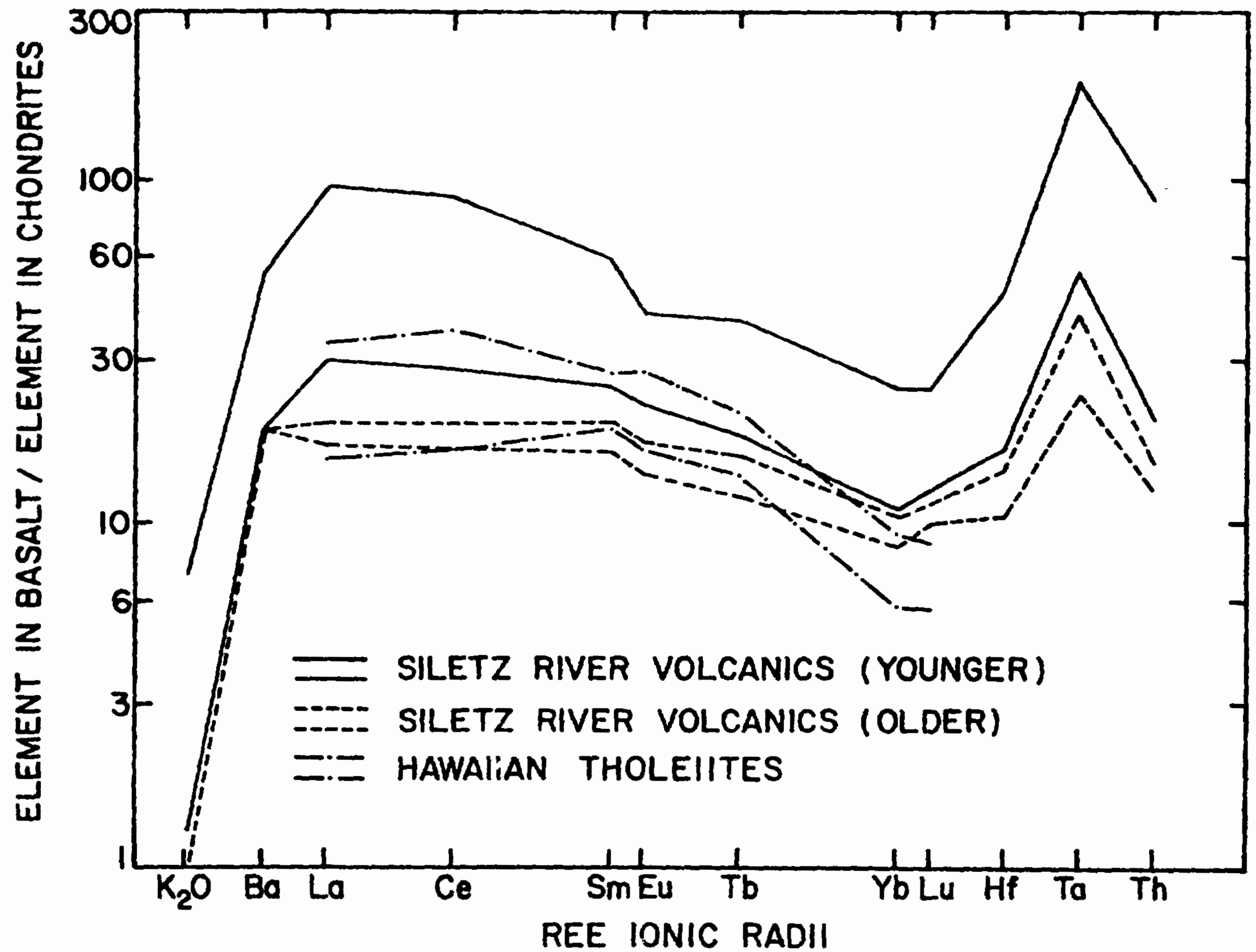

Figure 20. Ranges in abundances of the REE, K_2O, Ba, Hf, Ta and Th in the Siletz River Volcanics are normalized to chondrites. The abundance range in Hawaiian tholeiites is plotted for comparisons (Schilling and Winchester, 1969).

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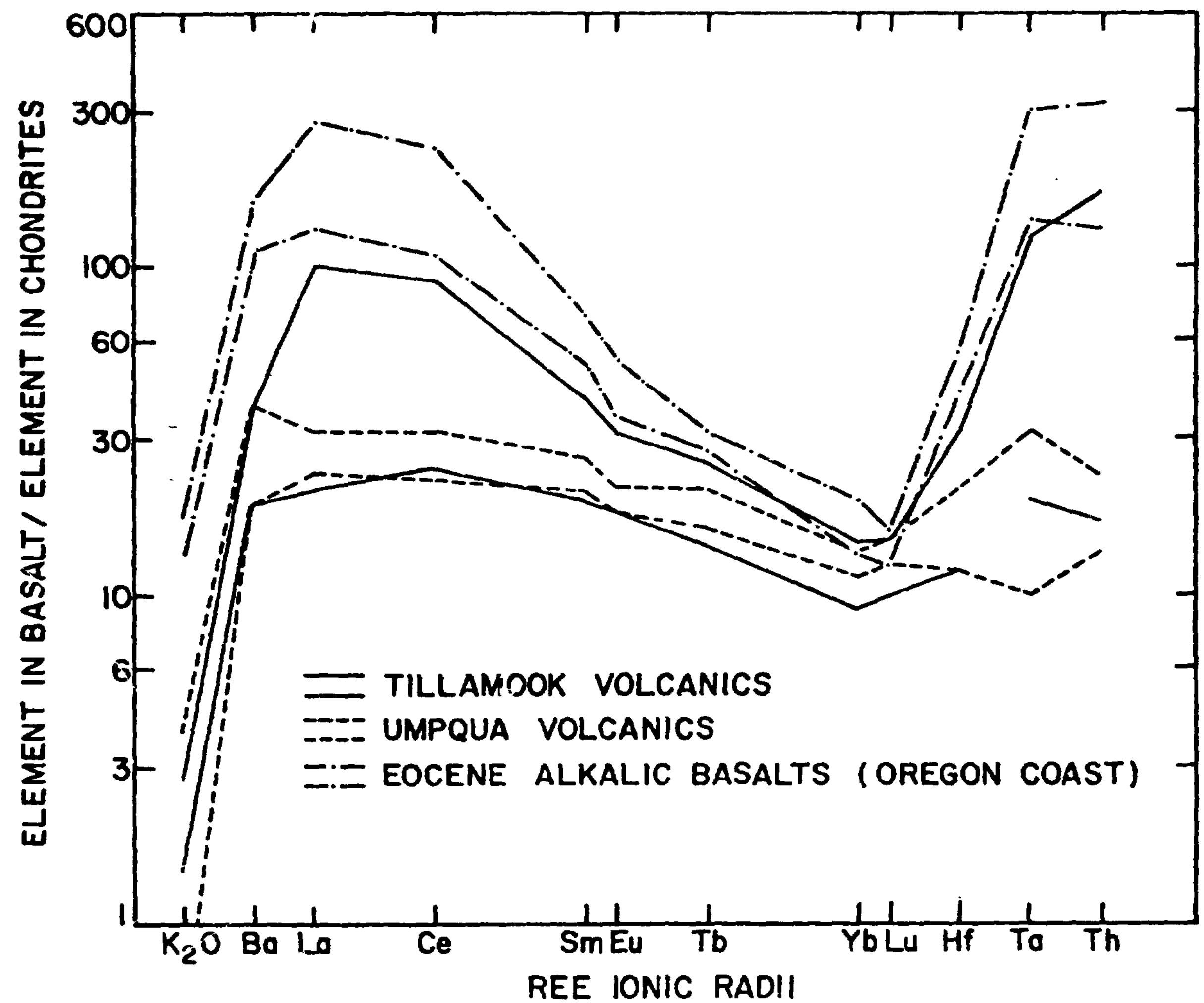

Figure 21. Ranges in abundances of the REE, K_2O, Ba, Hf, Ta and Th in the Eocene Alkalic basalts and the Tillamook and Umpqua Volcanics are normalized to chondrites.

Table 11. Depoe Bay Basalt.

	Low Mg			High Mg				
	D1	D2	D5	D3	D4	D6a	D6b	D7
TiO_2 (%)	2.0	1.8	2.0	1.9	2.0	1.8	1.9	1.8
Al_2O_3	12.7	13.4	13.8	13.1	13.5	13.8	13.2	14.0
FeO	12.9	11.5	11.7	11.2	11.6	12.2	12.5	11.1
MgO	3.9	3.3	3.5	4.4	5.0	4.8	5.0	4.2
CaO	6.3	6.5	6.1	7.1	7.7	7.7	7.8	8.3
Na_2O	3.2	3.2	3.2	3.2	3.2	3.0	3.0	3.0
K_2O	1.3	1.5	1.8	--	0.4	1.0	1.0	0.8
MnO	0.200	0.171	0.180	0.170	0.206	0.187	0.180	0.255
Cr_2O_3 (ppm)	14	20	21	21	54	33	32	31
Sc	33	29	31	32	37	36	37	37
V	340	300	320	300	320	330	320	320
Co	36	34	36	36	38	38	40	38
Zr	190	170	120	150	180	170	170	150
Ba	530	600	620	490	380	420	430	440
La	24.6	24.3	23.9	21.3	18.2	19.5	19.5	19.0
Ce	52	48	48	45	40	43	42	39
Nd	25	26	25	24	24	24	24	23
Sm	6.6	6.2	6.4	5.6	5.7	6.0	6.0	5.9
Eu	1.92	1.72	1.74	1.65	1.68	1.76	1.80	1.72
Tb	1.07	0.97	0.95	0.87	0.89	0.91	0.91	0.89
Dy	6	6	6	5	5	5	5	5
Yb	3.4	3.4	3.2	2.9	3.0	3.1	3.1	3.1
Lu	0.51	0.49	0.49	0.44	0.46	0.46	0.47	0.47
Hf	5.1	4.7	4.5	4.4	4.1	4.2	4.3	4.1
Ta	0.79	0.74	0.73	0.66	0.67	0.69	0.71	0.69
Th	5.5	5.4	5.1	4.6	2.9	3.2	3.6	3.3
Cs	1.7	1.7	1.5	1.4	1.1	0.5	0.8	1.0

Sample #	USGS Designation	Sample #	USGS Designation
D1	WCF59-1	D5	SR59-6
D2	SR63-141	D6a	GM61-27
D3	MR69-145	D6b	GM61-27
D4	SR61-30	D7	SR63-79

Table 12. Cape Foulweather Basalt.

	CF1	CF2	CF3	CF4	CF5	CF6a	CF6b
TiO_2 (%)	3.1	3.0	3.1	3.0	2.9	2.8	2.8
Al_2O_3	13.1	12.9	12.9	13.1	13.1	13.1	12.7
FeO	13.2	14.2	13.9	14.0	14.2	14.0	14.6
MgO	3.2	3.6	3.8	3.1	3.3	4.2	4.1
CaO	7.7	6.7	7.6	7.2	6.8	8.1	8.1
Na_2O	3.0	3.0	3.1	2.9	2.9	3.0	2.8
K_2O	0.6	1.3	0.9	1.3	1.1	1.1	1.2
MnO	0.164	0.201	0.182	0.189	0.206	0.202	0.201
Cr_2O_3 (ppm)	22	33	21	23	25	63	62
Sc	37	35	36	35	35	36	37
V	380	370	370	350	380	400	400
Co	46	37	37	36	37	39	39
Zr	210	190	170	190	140	160	180
Ba	410	490	470	490	520	480	470
La	24.5	24.8	24.3	24.5	24.6	23.5	23.6
Ce	53	54	52	53	52	51	51
Nd	29	32	28	27	32	33	30
Sm	7.8	7.8	7.8	7.9	7.7	7.5	7.5
Eu	2.31	2.34	2.31	2.31	2.28	2.19	2.20
Tb	1.18	1.17	1.17	1.17	1.17	1.20	1.16
Dy	7	7	7	7	7	6	6
Yb	3.8	3.6	3.6	3.5	3.6	3.7	3.7
Lu	0.53	0.51	0.54	0.54	0.54	0.52	0.53
Hf	4.7	4.9	4.9	4.7	4.8	4.7	4.9
Ta	0.87	0.92	0.89	0.89	0.85	0.90	0.91
Th	3.7	3.9	3.9	3.9	3.9	3.8	3.8
Cs	1.1	0.8	0.8	0.9	1.2	0.8	1.1

Sample #	USGS Designation
CF1	SR64-23
CF2	SR61-123
CF3	YC-129
CF4	Mtil 68-37
CF5	SR59-32B
CF6a	SR66-12B
CF6b	SR66-12B

Table 13. Basalt of Pack Sack Lookout and Standard Basalts.

	P1	P2	P3	P4	BCR-1	CRB
TiO_2 (%)	1.6	1.7	1.7	1.6	2.3	--
Al_2O_3	14.3	14.6	14.4	14.3	--	14.0
FeO	10.8	9.9	10.3	11.2	--	12.3
MgO	6.7	6.2	6.8	6.1	3.6	--
CaO	10.3	10.4	11.1	10.1	6.7	--
Na_2O	2.5	2.5	2.2	2.3	--	--
K_2O	0.4	0.7	0.4	0.6	--	1.7
MnO	0.161	0.164	0.166	0.196	--	--
Cr_2O_3 (ppm)	140	150	140	150	18	15
Sc	34	35	35	35	--	32
V	270	270	270	270	400	--
Co	42	41	41	41	--	35
Zr	100	100	90	120	170	180
Ba	230	250	180	2[illegible]	--	580
La	16.6	17.4	16.8	17.1	25.5	25.3
Ce	35	36	35	34	55	53
Nd	21	21	21	22	--	30
Sm	5.1	5.2	5.0	5.1	--	6.7
Eu	1.47	1.52	1.46	1.49	1.91	1.91
Tb	0.82	0.83	0.80	0.82	1.00	0.97
Dy	5	5	5	5	6	--
Yb	2.6	2.8	2.5	2.6	3.4	3.4
Lu	0.38	0.40	0.41	0.40	0.51	0.49
Hf	3.4	3.5	3.4	3.4	5.1	5.0
Ta	0.69	0.69	0.65	0.68	--	0.73
Th	2.4	2.5	2.4	2.5	5.7	5.6
Cs	0.1	0.3	0.2	0.3	1.2	1.3

Sample #	USGS Designation	Sample #	USGS Designation
P1	SR65-130	BCR-1	USGS standard rock
P2	SR63-32	CRB	Research group standard rock
P3	GM61-109		
P4	SR59-6		

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Table 14. Columbia River Plateau Basalts.

	TY4	TY6	TY15	TY18	TY20	CR1	73-5	± Error*
TiO_2 (%)	2.3	2.0	1.9	1.8	2.8	1.9	1.5	0.3
Al_2O_3	13.4	13.3	14.0	13.6	12.9	13.8	14.0	0.6
FeO	12.5	11.6	10.3	11.7	13.6	12.0	10.9	0.4
MgO	4.7	3.8	5.5	6.2	3.9	5.7	7.7	0.6
CaO	7.7	6.8	7.9	8.7	7.5	10.2	9.9	0.7
Na_2O	3.3	3.0	2.9	2.9	2.9	2.6	2.4	0.1
K_2O	1.9	1.7	1.1	1.0	1.0	0.9	0.7	0.2
MnO	0.233	0.188	0.184	0.193	0.180	0.191	0.170	0.005
Cr_2O_3 (ppm)	19	32	64	69	74	93	160	3
Sc	37	33	38	37	38	39	35	2
V	320	350	320	310	430	330	270	10
Co	28	37	43	39	40	42	42	2
Zr	120	110	140	160	170	150	130	50
Ba	2210	590	470	410	470	250	200	50
La	25.4	24.2	19.6	17.5	23.5	20.7	17.4	0.5
Ce	51	48	42	34	50	43	37	4
Nd	39	28	24	21	31	24	24	7
Sm	9.3	6.3	5.9	5.3	7.3	6.1	5.1	0.3
Eu	3.60	1.81	1.81	1.61	2.18	1.81	1.54	0.07
Tb	1.33	1.00	0.95	0.85	1.14	0.98	0.75	0.06
Dy	7	6	6	5	6	5	5	2
Yb	4.1	3.8	3.2	3.0	3.4	3.1	2.9	0.2
Lu	0.61	0.50	0.49	0.46	0.53	0.48	0.37	0.04
Hf	4.1	4.6	4.3	3.5	5.0	4.3	3.5	0.3
Ta	0.49	0.73	0.63	0.58	0.87	0.86	0.73	0.08
Th	3.6	4.5	3.0	2.9	3.8	2.8	2.6	0.3
Cs	2.0	1.4	0.7	0.5	0.7	0.1	0.2	0.4

TY: Tygh River (numbered from bottom up)
CR: Columbia River (Yakima Type)
73-5: 1973, #5

*Cited errors are the estimated maximum error in the abundances in Tables 10 through 15 and 21. See experimental section (II) for details on error determination.

Table 15. Karmutsen and Metchosin Formation Basalts.

	K1	K2	K3	K4	K5	K6
TiO_2 (%)	1.4	2.5	1.2	1.8	1.5	1.0
Al_2O_3	15.4	12.0	14.0	12.5	12.6	13.7
FeO	10.5	15.5	11.5	14.8	13.6	10.7
MgO	7.2	5.2	7.9	5.9	6.8	8.6
CaO	12.1	7.6	11.5	9.6	11.1	11.9
Na_2O	1.8	2.8	2.1	2.5	2.1	1.9
K_2O	0.2	0.3	0.1	<0.1	0.1	0.1
MnO	0.182	0.272	0.180	0.255	0.212	0.167
Cr_2O_3 (ppm)	490	70	260	36	84	290
Sc	37	42	49	45	46	49
V	290	390	340	430	420	310
Co	45	39	48	48	46	49
Zr	<60	190	160	<70	<60	70
Ba	<40	60	<30	<50	<40	<30
La	5.5	11.3	4.9	7.1	4.9	2.9
Ce	15	27	12	16	12	7
Nd	13	26	<10	21	15	<8
Sm	3.2	8.0	3.1	4.7	3.7	2.5
Eu	1.10	2.61	1.09	1.45	1.29	0.89
Tb	0.59	1.78	0.65	0.90	0.74	0.58
Dy	4	11	4	6	5	4
Yb	1.9	7.4	2.7	4.3	3.8	2.4
Lu	0.31	1.12	0.43	0.64	0.55	0.36
Hf	3.3	6.1	2.0	3.4	2.6	1.8
Ta	0.43	0.67	0.35	0.48	0.30	0.17
Th	0.3	0.7	<0.3	0.7	0.4	<0.3
Cs	--	--	--	--	--	--

Sample #	USGS Designation	Sample #	USGS Designation
K1	MV71-29	K4	MV71-16
K2	MV71-13A	K5	MV71-17
K3	MV71-14	K6	MV71-25

Table 16. Crescent Formation Basalts.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
TiO_2 (%)	1.6	1.9	1.8	2.0	2.1	1.3	1.2	0.8	2.9	1.4
Al_2O_3	13.1	14.1	15.1	13.6	13.6	14.4	15.0	17.4	13.0	15.2
FeO	12.2	11.8	11.4	11.2	13.1	10.3	8.8	8.5	14.4	11.6
MgO	3.5	8.3	8.0	5.8	6.2	4.5	8.6	8.2	4.8	6.5
CaO	6.9	8.4	7.5	9.6	10.7	9.0	10.9	11.2	7.5	11.1
Na_2O	4.6	3.8	3.6	4.1	2.7	2.6	3.1	2.2	3.1	2.5
K_2O	<0.1	<0.1	0.3	0.2	0.2	0.2	0.2	0.1	0.3	0.1
MnO	0.187	0.150	0.161	0.172	0.219	0.275	0.147	0.152	0.217	0.168
Cr_2O_3 (ppm)	35	310	310	223	44	120	440	480	7	150
Sc	31	47	38	42	40	36	40	38	38	44
V	310	370	300	380	360	280	240	240	290	320
Co	31	43	42	36	49	43	40	41	34	47
Zr	230	150	90	110	90	50	<60	<90	160	120
Ba	<30	40	220	<30	60	80	140	<30	70	<40
La	13.1	10.7	17.4	20.6	13.9	14.3	4.2	2.5	15.9	5.[illegible]
Ce	32	22	37	39	30	28	10	7	36	14
Nd	23	17	24	26	22	18	9	<10	26	11
Sm	7.0	5.0	5.2	5.9	5.4	4.3	2.7	1.8	7.6	3.4
Eu	1.83	1.58	1.70	1.85	1.69	1.37	0.95	0.67	2.30	1.24
Tb	1.53	0.92	0.96	1.03	0.74	0.72	0.46	0.39	1.35	0.66
Dy	10	6	6	7	4	4	3	3	8	4
Yb	7.5	3.8	3.9	4.5	2.7	2.9	1.6	2.0	5.5	2.6
Lu	1.14	0.56	0.58	0.66	0.39	0.43	0.24	0.30	0.89	0.37
Hf	7.3	3.3	3.4	3.8	3.7	2.7	1.8	0.9	5.6	2.2
Ta	0.92	0.84	1.21	1.45	1.02	0.99	0.30	0.17	1.24	0.35
Th	1.3	0.7	0.6	1.5	1.1	1.2	0.3	<0.3	0.7	<0.3
Cs	--	--	--	--	--	--	--	--	--	--

Sample #	USGS Designation	Sample #	USGS Designation
C1	HR-17	C6	SR61-163
C2	HR-25	C7	MR71-166
C3	HR-27	C8	MR71-187
C4	HR-28	C9	MR71-191
C5	SR60-4	C10	J101-104

Table 17. Tillamook Volcanics.*

	80	81	82	83	84
Al_2O_3 (%)	13.4	14.0	15.1	11.3	15.4
FeO	12.5	12.8	10.8	13.1	13.8
MgO	5.1	5.9	5.8	7.7	4.49
CaO	10.4	11.2	11.3	10.4	11.9
Na_2O	3.9	2.4	3.2	2.7	2.6
K_2O	0.16	0.27	0.19	0.15	0.28
MnO	0.272	0.261	0.199	0.156	0.232
Cr_2O_3 (ppm)	110	170	350	480	59
Sc	38	42	41	33	32
Co	44	51	46	64	47
Ba	140	70	70	70	135
La	13	12	7.2	35	26
Ce	33	32	22	84	60
Sm	5.4	5.4	3.8	7.7	7.5
Eu	1.6	1.6	1.3	2.2	2.2
Tb	1.0	1.0	0.68	0.69	1.2
Yb	2.7	3.2	2.5	2.0	2.9
Lu	0.50	0.47	0.46	0.34	0.49
Hf	3.8	3.7	2.4	6.1	6.3
Ta	0.51	0.54	0.40	2.5	1.4
Th	1.2	1.5	0.67	6.8	3.1
Sr	230	190	160	140	330

Sample Locations:

#80 - SE 1/4 sec. 8, T1S, R8W, Blaine, Ore.

#81 - NE 1/4 sec. 24, T1N, R8W, Enright, Ore.

#82 - SE 1/4 sec. 26, T2N, R5W, Timber, Ore.

#83 - SE 1/4 sec. 28, T1N, R9W, Nehalem, Ore.

#84 - SW 1/4 sec. 29, T2N, R9W, Nehalem, Ore.

*These samples were analyzed by M. J. Dudas via INAA and atomic absorption analysis. Al_2O_3 was determined via INAA in this work.

Table 18. Umpqua Volcanics.*

	89	90	91	92	93	94a
Al_2O_3 (%)	15.4	13.9	14.7	14.1	14.6	14.6
FeO	13.1	12.5	12.3	13.0	10.9	9.9
MgO	5.1	6.1	5.9	6.0	6.5	8.2
CaO	12.0	10.9	13.1	11.0	12.8	9.6
Na_2O	2.1	3.2	2.4	2.8	3.0	3.8
K_2O	0.053	0.10	0.075	0.061	0.16	0.39
MnO	0.146	0.225	0.241	0.192	0.239	0.152
Cr_2O_3 (ppm)	240	190	270	210	430	690
Sc	40	45	46	44	50	42
Co	48	46	50	49	53	51
Ba	70	120	70	70	140	7[illegible]
La	10.8	8.0	8.4	8.4	8.6	13
Ce	29	23	21	21	23	34
Sm	5.1	4.2	3.9	4.0	4.0	3.2
Eu	1.6	1.3	1.3	1.3	1.4	1.9
Tb	0.97	0.76	0.76	1.0	0.91	0.62
Yb	2.5	2.7	2.6	3.0	2.6	2.1
Lu	0.43	0.50	0.47	0.52	0.47	0.34
Hf	4.2	3.1	2.4	3.3	3.1	3.1
Ta	0.64	0.44	0.20	0.41	0.32	1.3
Th	0.94	0.55	0.74	0.71	0.74	1.7
Sr	65	270	300	120	180	380

Sample Locations:

#89 - SW 1/4 sec. 34, T22S, R4W, Anlauf, Ore.

#90 - NE 1/4 sec. 25, T27S, R6W, Roseburg, Ore.

#91 - SW 1/4 sec. 24, T28S, R8W, Camas Valley, Ore.

#92 - NW 1/4 sec. 26, T29S, R12W, Coquille, Ore.

#93 - NW 1/4-NE 1/4 sec. 30, T28S, R12W, Coquille, Ore.

#94a- NE 1/4 sec. 3, T25S, R12W, Coos Bay, Ore.

*These samples were analyzed by M. J. Dudas via INAA and atomic absorption analysis. Al_2O_3 was determined via INAA in this work.

Table 19. Siletz River Volcanics (Older Unit).*

	45	46	47	49	BCR-1
Al_2O_3 (%)	15.2	14.8	14.9	15.0	13.1
FeO	11.7	10.7	10.9	11.7	13.0
MgO	7.6	7.9	7.9	7.9	3.4
CaO	11.5	11.2	10.5	10.0	6.5
Na_2O	2.0	1.9	1.8	2.2	3.4
K_2O	--	0.10	--	0.095	1.66
MnO	0.190	0.170	0.186	0.198	0.196
Cr_2O_3 (ppm)	480	420	420	450	19
Sc	42	40	38	41	32
Co	50	46	48	50	37
Ba	70	<50	<50	<50	730
La	6.4	5.8	5.8	6.7	25.4
Ce	18	16	15	18	58
Sm	3.4	3.4	3.2	3.9	7.0
Eu	1.14	1.16	1.03	1.28	1.9
Tb	0.75	0.57	0.72	0.63	1.01
Yb	2.1	1.9	1.9	2.3	3.5
Lu	0.39	0.38	0.34	0.37	0.60
Hf	2.4	2.2	2.1	2.9	5.0
Ta	0.80	0.49	0.56	0.70	1.2
Th	0.50	0.52	0.50	0.60	6.6
Sr	200	--	206	--	280

Sample Locations:

#45 - (SR59-28) SE 1/4 sec. 36, T10S, R5W, Benton Co., Ore.

#46 - (SR59-28) Same as sample 45 (200 yds. south).

#47 - (SR59-22) SW 1/4 sec. 27, T11S, R6W, Benton Co., Ore.

#49 - SW 1/4 sec. 7, T11S, R5W, Benton Co., Ore.

*These samples were analyzed by M. J. Dudas via INAA and atomic absorption analysis. Al_2O_3 was determined via INAA in this work.

Table 20. Siletz River Volcanics (Younger Unit).*

	39	40	41	42	43	44
Al_2O_3 (%)	12.8	12.2	15.2	13.7	13.5	13.5
FeO	14.7	15.1	12.9	15.3	13.3	14.7
MgO	5.8	4.6	5.5	6.3	5.7	5.3
CaO	10.0	9.4	11.7	10.2	10.4	10.4
Na_2O	2.6	2.8	2.6	2.8	2.7	2.8
K_2O	0.26	0.72	0.14	0.13	0.20	0.22
MnO	0.239	0.213	0.181	0.220	0.205	0.234
Cr_2O_3 (ppm)	160	140	290	73	160	160
Sc	38	38	41	40	37	39
Co	48	43	53	52	48	46
Ba	140	200	70	<60	100	100
La	15.6	32.8	10.2	12.4	18.4	15.3
Ce	39	81	26	30	46	39
Sm	6.3	11.5	4.9	6.1	7.3	6.6
Eu	1.9	3.0	1.6	1.9	2.4	1.7
Tb	0.99	1.9	0.86	1.01	1.20	1.09
Yb	3.0	5.5	2.4	2.9	3.2	3.1
Lu	0.47	0.84	0.42	0.50	0.54	0.53
Hf	4.6	9.5	3.3	4.6	5.2	5.2
Ta	1.9	3.8	1.1	1.5	2.1	2.2
Th	1.6	3.5	0.8	1.1	1.6	1.6
Sr	165	150	155	165	190	175

Sample Locations:

#39 - NE 1/4 sec. 28, T11S, R6W, Benton Co., Ore.

#40 - (SR52-25) SW 1/4 sec. 26, T10S, R6W, Benton Co., Ore.

#41 - NE 1/4 sec. 22, T10S, R6W, Benton Co., Ore.

#42 - (SR60-86) SW 1/4 sec. 25, T7S, R6W, Polk Co., Ore.

#43 - (SR65-81) SE 1/4 sec. 4, T7S, R6W, Polk Co., Ore.

#44 - (SAB59-1) NW 1/4 sec. 18, T10S, R5W, Benton Co., Ore.

*These samples were analyzed by M. J. Dudas via INAA and atomic absorption analysis. Al_2O_3 was determined via INAA in this work.

Table 21. Eocene Alkalic Basalts.*

	86	88	50	BCR-1
Al_2O_3 (%)	18.2	15.0	17.3	14.0
FeO	9.0	12.8	8.0	13.1
MgO	1.8	6.5	0.95	3.2
CaO	5.5	6.6	3.4	6.3
Na_2O	4.5	2.9	4.4	3.4
K_2O	1.70	1.30	1.63	1.51
MnO	0.174	0.170	0.137	0.186
Cr_2O_3 (ppm)	15	140	9	20
Sc	8.7	18	17	32
Co	15	42	11	37
Ba	600	420	460	730
La	98	46	60	26
Ce	216	101	130	61
Sm	14	10	12	7.1
Eu	3.9	2.6	3.3	1.9
Tb	1.5	1.3	1.5	1.1
Yb	4.3	2.9	4.1	3.8
Lu	0.54	0.41	0.51	0.62
Hf	9.4	8.4	10.9	5.0
Ta	6.2	2.8	3.5	1.0
Th	13	5.3	7.9	7.3
Sr	840	440	450	270

Sample Locations:

#86 - SE 1/4 sec. 36, T5S, R11W, Hebo, Ore.

#88 - SW 1/4 sec. 25, T6S, R10W, Hebo, Ore.

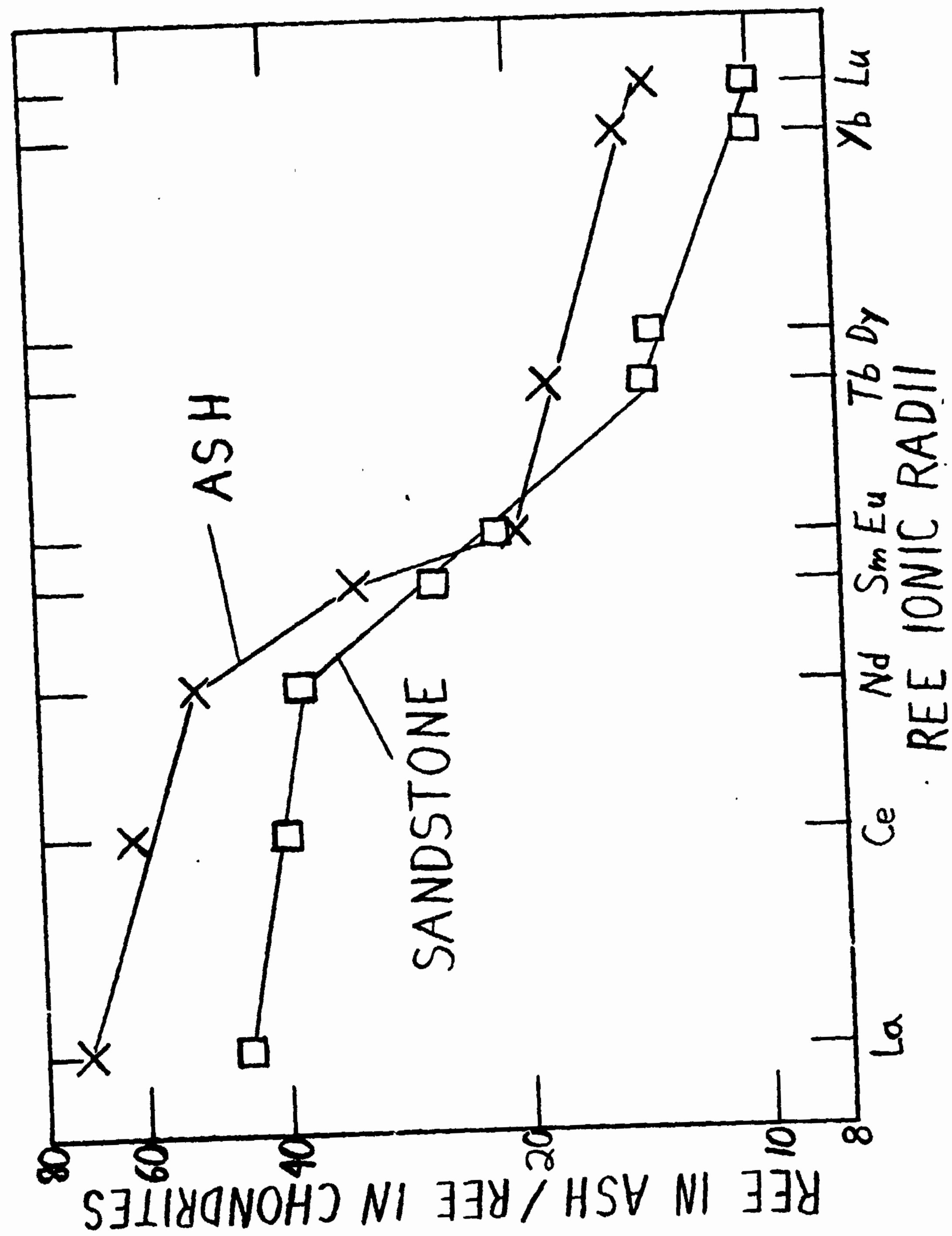
#50 - Neptune State Park, Ore. Hwy. 101, 124° 7' X 44° 16'.

*These samples were analyzed by M. J. Dudas via INAA and atomic absorption analysis. Al_2O_3 was determined via INAA in this work.

Table 22. Cove Palisades Volcanic Ash.*

	CPL	CPD	CPa	CPb
TiO_2 (%)	0.5	0.5	1.2	0.8
Al_2O_3	14.8	15.1	17.7	15.8
FeO	3.4	3.0	8.2	4.3
MgO	1.4	0.9	4.3	1.8
CaO	2.3	2.0	7.7	2.8
Na_2O	4.1	3.8	3.6	4.2
K_2O	3.4	3.6	1.1	2.3
MnO	0.085	0.080	0.141	0.100
Cr_2O_3 (ppm)	7	7	87	19
Sc	10	9	25	13
V	20	10	200	60
Co	3.3	2.4	25	7.2
Zr	230	220	60	260
Ba	600	590	400	590
La	22.8	24.8	15.1	24.2
Ce	57	58	36	55
Nd	32	33	24	33
Sm	5.7	6.3	5.0	6.8
Eu	1.39	1.29	1.55	1.72
Tb	0.81	0.82	0.64	0.89
Dy	4	7	4	6
Yb	3.1	3.1	2.2	3.5
Lu	0.46	0.49	0.36	0.55
Hf	7.2	7.3	3.3	6.3
Ta	0.80	0.87	0.39	0.80
Th	5.1	5.1	1.1	3.1
Cs	2.1	2.2	0.5	1.5

*Sample designations are explained in text.


ASH
SANDSTONE
La
Ce
Nd
Sm
Eu
Tb
Dy
Yb
Lu
REE IONIC RADII
80
60
40
20
10
8
REE IN ASH / REE IN CHONDRITES

Elemental Abundances Studies in Allende Inclusions

Roberta L. Conard

High temperature inclusions from the Allende meteorite were analyzed by INAA for major and trace elements. Five of the samples (B-28, B-30, A-2, B-32-1, B-32-2) were obtained from Professor G. J. Wasserburg (Cal. Tech.). These were reserve portions of the samples analyzed at Cal. Tech. and published by Gray et al. (1973). A separation of B-32 into dark matrix and white friable material was made before analysis. Analyses were also made of the mineral melilite (separated by Nagasawa, University of Tokyo), a bulk Allende sample (NMNH #3496), Leedey and BCR (see Table 1).

Leedey does not appear to be a particularly representative sample as evidenced by the high Fe and Co concentrations of 30% and 1700 ppm compared to the expected 22% Fe and 550 ppm Co (Mason, 1971). This may be a result of the very small sample size (17 mg) which was rather coarsely powdered. Also the Fe-Ni ratio for Leedey is 10 instead of the expected 20 usually found in chondrites. Using the same standards, the Ni-Co ratios for the Allende samples (excepting B-32-2) are around 20. The Ni-Co ratio of B-32-2 is also 10.

Comparison of the Allende bulk sample with published values shows good agreement between this analysis and other work (Clark, 1970).

The Allende REE abundances range from 0.47 - 15 ppm for La and 0.03 - 0.69 ppm for Lu. Most show a flat normalized REE pattern with a small positive Eu anomaly (see figure 1). Sample B-32-2 appears flat from La to Sm and then drops abruptly to a ratio of 1 for Yb and Lu. B-30 appears to have anomalous Eu and Yb abundances but the lack of data points between Eu and Yb prevents a definite answer.

Future plans include RNAA for REE abundance determinations in order to define further these strange REE patterns.

Clark, Jr., Roy S., E. Jarasewich, B. Mason, J. Nelen, M. Gomey, J. R. Hyde (1970). The Allende, Mexico meteorite shower. Smithsonian Contrib. Earth Sci., c. 1970, No. 5.

Gray, C. M., D. A. Papanastassiou, G. W. Wasserburg (1973). The Identification of Early Condensates from the Solar Nebula. Icarus 20, 213.

Mason, B. ed. (1971). Handbook of Elemental Abundances in Meteorites. Gordon and Breach Science Publishers (New York).

Table 1. Elemental abundances of Allende meteorite high temperature inclusions[a]

Element		Allende bulk analysis	B-28	B-30	A-2	B-32-1	B-32-2	Melilite	Leedey	BCR
	Sample Wt (mg)	18.48	22.25	13.13	19.46	13.92	11.20	29.44	16.70	13.77 15.09 avg.
TiO_2	(%)	0.3	3.3	1.6	2.2	0.5	0.7	0.7	0.5	4.8
Al_2O_3	(%)	2.9	26	52	25	3.7	37	26	2.0	13.5
FeO[b]	(%)	31	1.1	1.6	0.84	28	5.1	0.089	39	12.2
MnO	(%)	0.19	0.0035	0.0095	0.0040	0.17	0.027	0.0015	0.29	0.017
MgO	(%)	26	11	10	15	30	8	4	24	3.0
CaO	(%)	2.6	26	16	25	2.9	12	40	1.6	6.9
Na_2O	(%)	0.47	0.25	0.99	0.13	0.52	6.8	0.043	0.90	3.15
K_2O	(%)	0.034	0.009	0.052	0.0051	0.030	0.31	0.003	0.076	1.65
Ni	(%)	1.42	0.21	<0.01	0.088	1.65	0.025	0.085	1.6	-
Co	(ppm)	710	86	4.5	40	800	27	32	1700	40
Cr	(ppm)	3740	420	320	450	3700	340	48	3600	11
Sc	(ppm)	11	133	111	19	62	50	30	6.6	31
V	(ppm)	104	810	180	800	110	89	184	76	442
Ir	(ppm)	0.85	7.4	20	0.42	1.2	0.024	2.8	0.56	-
Au	(ppm)	0.13	0.11	0.081	0.076	0.23	0.015	0.011	0.25	-
Zn	(ppm)	114	53	600	50	120	820	20	-	-
La	(ppm)	0.47	4.6	4.3	2.8	0.50	15	3.9	0.33	26
Sm	(ppm)	0.30	3.0	2.8	2.1	0.29	9.1	2.4	0.18	6.7
Eu	(ppm)	0.16	1.41	0.40	1.17	0.18	0.20	1.6	0.10	1.9
Yb	(ppm)	0.35	3.9	0.8	2.6	0.28	0.30	2.0	0.2	3.25
Lu	(ppm)	0.05	0.65	0.69	0.12	0.10	0.03	0.36	-	0.52

a Estimated error range due to counting statistics: Al_2O_3, FeO, Na_2O, Co, Cr, Sc, Ir, Au, La, Sm, Eu 1-5%; MnO, MgO, CaO, Ni, V 1-10%; Yb, Lu 1-20%; TiO_2 1-30%; K_2O, Zn 10-30%; low error numbers in the error ranges are generally associated with higher abundance value.

b Total iron abundance in sample calculated as FeO. Total abundances of other elements are also obtained by INAA.

Figure 1. REE DISTRIBUTION IN Allende