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Ninety basalt samples from eight locations in central Oregon and one location in the Willamette Valley were analyzed for Si and Al. Fourteen basaltic rock specimens (> 1 kg each) from four buttes in the Willamette Valley were sampled and analyzed for Si, Al, Fe, Na, K, Mn, Cr, Co, Sc, and La. All analyses were carried out via instrumental neutron activation analysis to precisions of about 15% for K, 20% for La, 40% for Cr, and about 2-4% for the remaining elements.

The average abundances of all locations were compared with the average abundances of Picture Gorge, Yakima, and Late Yakima basalts, the three subtypes of Columbia River basalt. The five Willamette Valley averages were also compared with those of normal continental tholeiites and the Siletz River tholeiites and alkalic basalts.

The Si abundance averages for Emigrant Creek, Highway 27, Madras, Bond Butte, and Coburg Quarry locations were found to

match within limits those of Picture Gorge basalt. The Al averages were somewhat lower than in Picture Gorge for the Madras site and somewhat higher for the remaining four sites.

The average values obtained for the lower six Klickitat River flows were found to agree with average values for Yakima basalt.

Abundance averages of Locke Lake, Rock Creek Canyon, the upper nine Klickitat River flows, Hay Creek Canyon, Hale Butte, and Knox Butte were all found to agree within limits with average values of Late Yakima basalt. From the field relations, the basalts from Hay Creek Canyon are believed to be of Yakima type.

The individual abundances obtained from the Locke Lake and Rock Creek sites suggest that four of the flows from each site may be laterally equivalent with each other.

The abundance averages for Saddle Butte suggest that the flows which make it up are probably not related to Columbia River basalt.

No significant relationship between any of the Willamette Valley sites and the Siletz River tholeiitic or alkalic basalts was established, except for Hale Butte, whose average abundances appear to fit into the abundance ranges for the Siletz River alkalics.

Elemental Abundances in Selected Oregon Basalts

by

Barry Howard Nicholson

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INTRODUCTION

Basalts

General

Basalts are igneous rocks, classified by their fine-grained texture and chemical and mineralogical composition, which is based on a predominance of plagioclase feldspar and (usually) absence of quartz. There is present also a significant amount of mafic minerals (olivine, pyroxenes, and other minerals containing Mg or Fe). Basalts are generally extrusive rocks, that is, formed from lava flows. However, in some cases, as is believed for the Willamette Valley buttes studied in this work, rocks of basaltic composition may form intrusive bodies as well.

The study of basalts is very important for an overall understanding of global geology, and of extraterrestrial geology as well. Most of the rocks gathered on the Apollo lunar missions are of grossly basaltic nature (2, 3). The basement crust of the earth is believed to be basaltic, underneath both the oceans and the continents. Both types are thought to be tholeiitic, which means that they have relatively low concentrations of certain elements, notably K, Ti, and P, among others (14).

Samples of oceanic tholeiites taken from widely scattered areas in each of the three largest oceans all appear very similar in chemical and mineralogical composition (12, 13, 15). However, the oceanic and continental tholeiites differ somewhat in composition, notably in their potassium abundances, which are about 0.2% K_2O for oceanic tholeiites and 0.9% K_2O for continental tholeiites (14).

There are two basic types of continental basalts, the already-mentioned continental tholeiites and the continental alkalic basalts, which have on the average over 1.2% K_2O (14). The alkalic basalts, which contain more lighter-colored, less-dense minerals than the tholeiites, are generally found stratigraphically above associated tholeiitic basalt, if any is present. They are believed to be the products of extensive magmatic differentiation (14).

For many years there has been considerable interest in the study of the various basalt flows in Oregon and Washington. One group of basalt flows in particular, known as Columbia River basalt (Figure 1), is believed to have been formed principally during the Miocene epoch (13-25 million years ago). Columbia River basalt may be divided into at least three subtypes, separated in time and space and differing slightly, but significantly, in chemical composition. The oldest subtype is called Picture Gorge basalt; the next subtype, Yakima; and the youngest subtype, Late Yakima. These subtypes are all described by A. C. Waters (42), who has done extensive work on the Columbia River basalt.

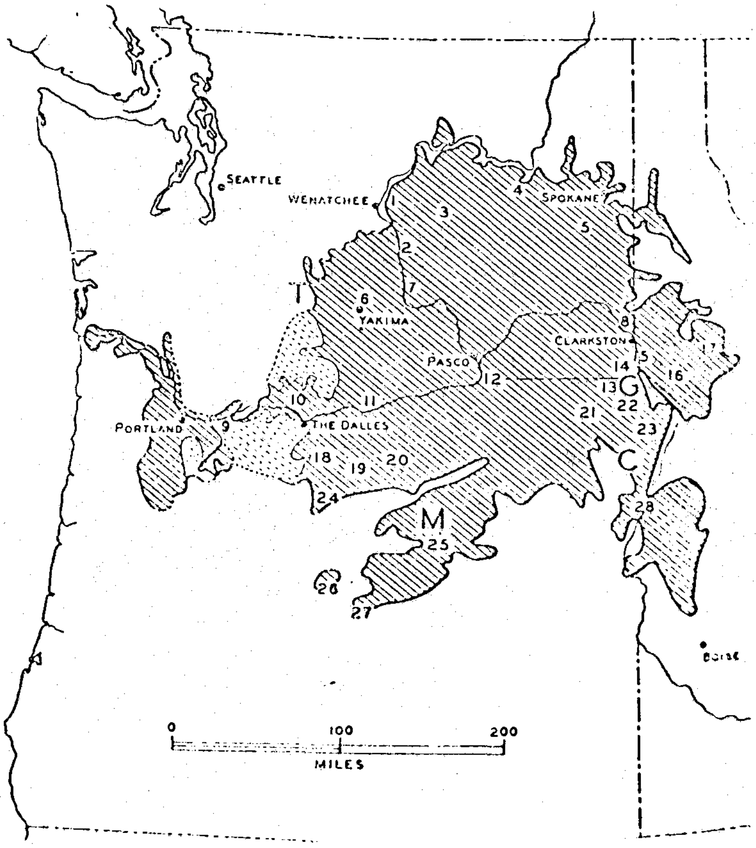

Figure 1. Columbia River basalt. Stipple indicates areas covered by younger basalts of Cascade Range. Letters are locations of dike swarms. Numbers are sampling locations used by Waters. Taken from Waters (42), Figure 1.

Another group of basalts in Oregon which has come under intensive study is the basalt of the Coast Range, one group in particular being the Eocene Siletz River Volcanics. Much work has been done on these by Snavely, MacLeod, and Wagner (36). Like the Columbia River basalt, this group has also been subdivided, in this case into two subgroups, an upper and lower. These in turn have been subdivided further into two or more units each, four of which are listed in Table 8. Note that three of these are tholeiitic basalt, and all are believed to be of Eocene age (36-58 million years).

Analysis

There are several ways in which basalts may be analyzed. One is the bulk chemical analysis, which leads to the normative mineral analysis as described by Shand (35). In this method, all major elements[1] are reported as oxides, and then each element is reported as part of a standard mineral. This method provides only an estimate of the actual mineral content in the rock, and its chief difficulty is that it does not consider many minerals that may actually be present in the rock undergoing analysis.

Another method for mineral analysis is modal analysis, in which the minerals and their proportions present in the rock under study are determined by direct observation of thin sections. This

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[1] In this work, an element is defined as major if it is greater than 1.0% abundant; as minor if it is between 0.01% and 1.0%; and trace if it is less than 0.01% abundant. (Potassium is defined as major, as it generally exceeds one percent in the basalts studied here).

analysis should always supplement the normative analysis in a complete petrological study.

In this work, basalt samples from eight locations in Central Oregon were analyzed for Si and Al, and these abundances, together with those obtained by Osawa and Goles (29), were compared with the abundances of the Columbia River basalt as obtained by Waters (42 and Table 8). Also, samples from five sites in the Willamette Valley were analyzed for ten selected elements. These abundances were compared with those of the Columbia River basalt, with normal tholeiites, and also with the Siletz River basalts of the Oregon Coast Range (36 and Table 8). All elements were analyzed by instrumental neutron activation analysis (INAA). The theory and general procedures of this analytical technique are discussed by Osborn (30).

Purpose

The purposes of this study are as follows:

1. To determine the abundances of Si and Al in a significant number of basalt samples from selected locations in central Oregon and a quarry in the Willamette Valley. Ninety samples from these nine locations, all studied by Osawa and Goles (29), were analyzed.

2. To determine the abundances of Si, Al, Fe, Na, K, Mn, Cr, Co, Sc, and La in basalt samples from previously-unstudied sites in the central Willamette Valley. Fourteen samples from four sites

were analyzed.

3. To compare abundances of basalts from all sampling sites with those reported for Columbia River basalts, to determine whether any of the sites sampled could represent Columbia River basalts, and if so, to which subgroup they may belong.

4. To compare the abundances from the Willamette Valley sites with normal tholeiites and also with the Eocene Siletz River Volcanics of the Oregon Coast Range, and establish any possible relationship.

EXPERIMENTAL

Sampling

Fourteen basaltic rock specimens (> 1 kg each) were obtained from four locations in western Oregon, in addition to 90 basaltic samples received from the Center for Volcanology, University of Oregon, through the courtesy of Drs. Gordon G. Goles and Masumi Osawa. The four sites sampled were Hale, Knox, Saddle, and Bond Buttes, as shown in Figure 2 and Table 1. The fifth western site, Coburg Quarry, was sampled by Goles and R. L. Beyer, and the eight other sites in central Oregon by Goles and Osawa, with occasional help from others. A digest of field notes for each of these sites and samplings is shown in the Appendix.

Sample Preparation

Each of the 14 large specimens was reduced to chunks approximately 5 cm thick or less, using a steel sledge, and any weathered areas removed, using a rock saw. The chunks were then crushed to small chips in a large rock crusher, crushed again between alumina plates in a small jaw crusher, and ground to fine powder in a pulverizer equipped with alumina faces. At least 300-500 grams were ground at one time, in order to reduce contamination to a minimum from the saw, crushers, and grinder. Cross-contamination was

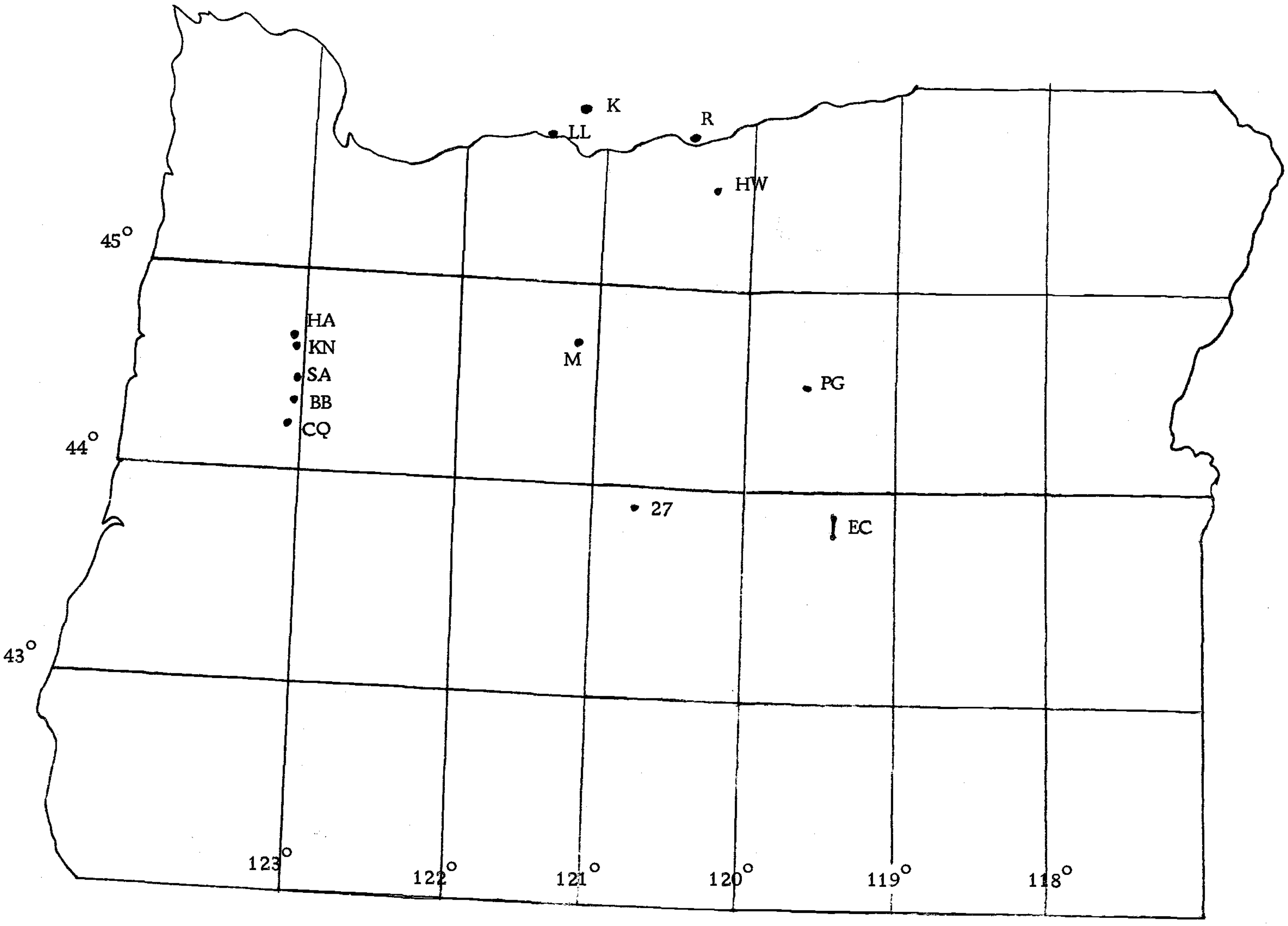

Figure 2. Sampling locations.

reduced to a minimum by carefully cleaning all tools between samples. In addition, the faces of the small crusher and pulverizer were thoroughly washed with acetone after each use.

Table 1. Sampling locations.

Source	Coordinates	Sample Designation	No. of Samples
Klickitat River Valley	45°49' N, 121° 10-13' W	K	18
Locke Lake	45°42' N, 121° 24' W	LL	7
Rock Creek Canyon	45°42' N, 120° 26' W	R	8
Hay Creek Canyon	45°28' N, 120° 19' W	HW	10
Picture Gorge	44°32' N, 119° 38' W	PG	20
Emigrant Creek	43°49-56' N, 119° 25' W	EC	13
Madras	44°43' N, 121° 12' W	M	1
Highway 27	43°58' N, 120° 45' W	27	7
Hale Butte	44°43' N, 123° 3' W	HA	3
Knox Butte	44°39' N, 123° 1' W	KN	3
Saddle Butte	44°27' N, 123° 3' W	SA	5
Bond Butte	44°19' N, 123° 3' W	BB	3
Coburg Quarry	44° 7' N, 123° 2' W	CQ	6

For each of the 90 samples from University of Oregon, 1-2 gram aliquants of the powder were prepared in snap-top half-dram polyethylene vials. In addition, for the 14 specimens prepared in our laboratory at the Oregon State University Radiation Center, similar 1-2 gram aliquants were prepared, along with two other samples of each, one in snap-top two-dram polyvials, weighing 11-15 grams each, and one in 180 ml plastic cups with snap-in covers. These aliquants ranged from 250-300 grams each. For the 1-2 gram and 11-15 gram samples, appropriate standards were also prepared in the same manner. Because geometry is critical in all of these determinations, care was taken to be sure that all the containers were completely filled, in order that all the samples be the same shape and size. All sample vials were heat sealed.

Methods of Analysis

All of the 1-2 gram rock samples prepared were analyzed for Al, and most samples also for Si. Due to equipment failure, however, not all of the 90 samples obtained from Eugene could be analyzed for Si. In addition, the samples from the 14 specimens which I collected were analyzed by INAA for Na, Mn, K, Fe, Cr, Co, Sc, and La.

A pneumatic rapid transfer system (rabbit) coupled to a 14-MeV Neutron Generator at the Radiation Center was used for the Si determinations. Neutrons are produced by the reaction $T(d,n)^4He$, in which 150-keV deuterons are accelerated onto a tritium target, producing 14-MeV neutrons. The sample is transferred into the irradiation head by remote control, and then brought back directly in front of a 3" x 3" NaI (Tl) detector. Transfer time is about four seconds. Two-dram polyvials were used as rabbits, and to insure good geometry, the half-dram vial containing the sample was positioned in the center of the rabbit by sandwiching it between two cut halves of a second empty half-dram vial. Care was taken to insure that the height of the sample below the bottom of the rabbit was constant for all vials, since the neutron flux at the head is very irregular. Also, since the flux varies from one run to the next, a double system was used. In one transfer tube, a known rock standard was run; in the other, the sample. Then both were counted simultaneously by using two 3" x 3" NaI(Tl) detectors coupled to two 400-channel TMC pulse height analyzers. Mean clock times were never found to vary more than two seconds, thus giving good accuracy for counting 2.3-m ^{28}Al. Rock standards, obtained from the U.S. Geological Survey, were a basalt (BCR-1), an andesite (AGV-1), and a granodiorite (GSP-1).

A rabbit system was also used in the Al analysis, and the methods here are similar to those used by Loveland, Schmitt, and Fisher (25). The flux in the Oregon State TRIGA Reactor (OSTR) is about 7×10^{11} neutrons cm^{-2}sec^{-1} at 250 kW. A power level of 3-5 watts was used for these determinations. Since the Al abundances in these samples were generally up to ten times higher than those analyzed by Loveland et al. and the Mn content was about the same or less (2500 ppm), the Mn correction for photopeak contribution to the 1.78-MeV ^{28}Al photopeak by the 1.81-MeV ^{56}Mn photopeak was found to be trivial (0.1% or less). The Si correction due to the fast neutron reaction ^{28}Si (n,p)^{28}Al was very small ($\leq$ 1%), but it was estimated by using a sample of spec-pure SiO$_2$ as a standard. This sample was wrapped in Cd foil to stop all but fast neutrons, in order that any Al present as an impurity would not be activated. Copper slugs (1-2 gm) were used with all runs to monitor the flux for each run. The slug was placed the same distance below the sample in every run, thus minimizing any effect of vertical flux gradients as discussed by Osborn (30). Data reduction was done with the aid of a computer program ALANAL, and the results were then corrected for flux variations.

The methods employed in the Na and Mn determinations are similar to those used by Osborn (30). Copper discs (~45 mg) were used to monitor the flux, and were placed in the bottom of two-dram polyvials which also held the half-dram sample vials. A Kimwipe was wrapped around each sample, as was done by Osborn, to hold the sample in the center of the TRIGA tube, in order to minimize effects of the radial flux gradient in the OSTR. Before counting, the samples were wiped with a Kimwipe and transferred to clean two-dram polyvials.

In the K determinations, naturally occurring ^{40}K was counted in large (250-300 gram) samples. A 3" x 3" NaI (Tl) detector coupled to a 400-channel pulse height analyzer was used. Counting times ranged from 13-24 hours. The 1.46-MeV photopeak of ^{40}K was used. All samples were corrected for background, as well as Compton contribution. Counting was done for all samples relative to sample

KN-2. This sample, which had the highest K:Na ratio, was then activated in the OSTR along with two rock standards and a primary standard of reagent-grade potassium acid phthalate (KHP) dried at 110° C. for 24 hours. As with the Na and Mn determinations, ~45-mg Cu foil discs were used again to monitor the neutron flux. By this method, an absolute K abundance was established for KN-2, and the abundances for the other samples were then found by comparison of the relative ^{40}K activities.

The methods for Fe and the trace elements were similar to those employed by Schmitt, Linn, and Wakita (33), and the parameters for these and the other determinations may be found in Table 2. Data reduction was done with the aid of SPECTRA, a computer program designed for gamma-ray spectrum analysis (7).

Accuracy and Precision

The abundances obtained for the U. S. Geological Survey rock standards BCR-1 and W-1 gave good agreement with the abundances in (16), (17), and (33). Comparisons with the values in (33) are shown in Table 7. From values listed in (33) accuracies of this work were estimated as: Si, 2%; Al, 7%; Na, 1%; K, 27%; Mn, 0.4%; Cr, 11%; Co, 31%; Sc, 6%; and La, 9%. The K value obtained for BCR-1 in this work appears to be about 27% lower than the corresponding K value in (33), so the actual K abundances of the basalt samples analyzed in this

Table 2. Experimental parameters.

Element	Sample Wt. (gm)	Primary Standards Used	Reactor power level or generator beam current[a]	Activation Time	Delay Time[b]	Count Time (min)	Isotope Generated	Photopeak Used (MeV)	Type of Detector Used
Si	1-2	BCR-1, AGV-1	0.4-0.6 ma	30 s	1 m	1	^{28}Al	1.78	3 x 3 NaI (Tl)
Al	1-2	Al foil in spec-pure $CaCO_3$	5 W	1 m	1.5 m	1	^{28}Al	1.78	3 x 3 NaI (T1)
Na[c]	1-2	$NaNO_3$[d]	1 kW	30 m	24 h	4	^{24}Na	2.75	3 x 3 (NaI (Tl)
Mn	1-2	$Mn(NO_3)_2$[d]	1 kW	30 m	4 h	1	^{56}Mn	0.84	3 x 3 NaI (Tl)
K	1-2	Reag. Gr. KHP	2 kW	30 m	24 h	167	^{42}K	1.52	30 cc Ge (Li)
Fe[c]	11-15	W-1	250 kW	2 h	15 d	100	^{59}Fe	1.10	20 cc Ge (Li)
Cr	11-15	$Cr(NO_3)_3$[d]	250 kW	2 h	15 d	100	^{51}Cr	0.32	20 cc Ge (Li)
Co	11-15	$Co(NO_3)_2$[d]	250 kW	2 h	15 d	100	^{60}Co	1.17 & 1.33[e]	20 cc Ge (Li)
Sc	11-15	$Sc(NO_3)_3$[d]	250 kW	2 h	15 d	100	^{46}Sc	1.12	20 cc Ge (Li)
La	11-15	$La(NO_3)_3$[d]	250 kW	2 h	15 d	100	^{140}La	1.59	20 cc Ge (Li)

[a] Reactor neutron flux is $\sim 2.8 \times 10^{6}$ $cm^{-2} sec^{-1} watt^{-1}$.

[b] Time from end of activation time to start of counting time.

[c] Na and Mn, and Fe, Cr, Co, Sc and La abundances were determined in two separate activations.

[d] Aqueous solutions.

[e] Co abundances are averages of calculated abundances for both photopeaks.

work may be about 27% too low. The relative differences between samples, however, are real differences.

Precisions were estimated to be: Si, 3.7%; Al, 2.1%; Fe, 1.8%; Na, 3.0%, K, 15%, Mn, 2.5%; Cr, 40%; Co, 4.5%; Sc, 3%; and La, 20%. The precisions for Cr and La could be improved by longer counting times.

DATA

Table 3. Central Oregon basalts.**

Location	Si (%)	Al (%)
Klickitat River Valley:		
K-1		7.0 ± .2
K-1A	23.5 ± .7	6.9 ± .2
K-1B	24.0 ± .7	6.6 ± .1
K-2		6.8 ± .2
K-3		7.0 ± .2
K-4	22.1 ± .7	6.7 ± .2
K-5		6.7 ± .1
K-6		7.0 ± .2
K-7	22.7 ± .7	6.8 ± .2
K-8		6.8 ± .2
K-9	23.0 ± .8	6.9 ± .2
K-10		7.4 ± .2
K-11	23.4 ± .7	7.5 ± .2
K-11B		7.5 ± .2
K-12	24.9 ± .9	7.2 ± .2
K-13		7.4 ± .2
K-14		7.4 ± .2
K-15	24.2 ± .7	7.1 ± .2
Locke Lake:		
LL-1		6.8 ± .1
LL-2	22.5 ± .7	6.5 ± .1
LL-3		6.7 ± .2
LL-4		7.2 ± .2
LL-5		6.9 ± .2
LL-6A	24.0 ± .7	6.6 ± .1
LL-6B		6.6 ± .1
Rock Creek Canyon:		
R-1	22.5 ± .7	7.2 ± .2
R-2		6.8 ± .2
R-2N		6.9 ± .2
R-3		6.3 ± .2
R-4	22.1 ± .7	6.8 ± .2
R-5		7.0 ± .2
R-6		6.8 ± .2
R-6N	20.8 ± .6	6.5 ± .2

Table 3 Continued.

Location	Si (%)	Al (%)
Hay Creek Canyon:		
HW-1	23.5 ± .1	6.9 ± .1
HW-2	22.0 ± 1.3	6.7 ± .1
HW-3	23.8 ± .3	6.7 ± .1
HW-3B	24.1 ± .3	6.8 ± .1
HW-4	23.3 ± .4	6.5 ± .1
HW-4B	23.8 ± .7	6.4 ± .1
HW-5	21.2 ± .6	7.6 ± .1
HW-6	26.2 ± .8	6.9 ± .1
HW-7	24.8 ± .7	7.1 ± .1
HW-8	22.1 ± .7	6.7 ± .1
Picture Gorge:		
PG-1	23.9 ± .8	7.5 ± .2
PG-2		8.0 ± .2
PG-3		8.1 ± .2
PG-4		7.7 ± .2
PG-5	21.6 ± .6	7.6 ± .2
PG-6		7.8 ± .8
PG-7	23.1 ± .7	8.1 ± .2
PG-8		7.7 ± .2
PG-9		7.9 ± .2
PG-10	22.6 ± .7	8.5 ± .3
PG-11		7.9 ± .4
PG-12	19.9 ± .17	8.4 ± .3
PG-13		8.2 ± .3
PG-14	20.9 ± .6	7.9 ± .3
PG-15		8.1 ± .3
PG-16		8.1 ± .3
PG-17	20.5 ± .6	8.1 ± .3
PG-18A		7.8 ± .4
PG-18B	21.5 ± .6	8.4 ± .3
PG-19		8.2 ± .3

Table 3 Continued.

Location	Si (%)	Al (%)
Emigrant Creek:		
EC-1	19.4 ± .9	8.1 ± .1
EC-2	20.8 ± .8	8.9 ± .1
EC-2A	22.0 ± .9	8.5 ± .1
EC-3	21.4 ± 1.0	8.1 ± .1
EC-4	21.8 ± .6	9.0 ± .2
EC-5	21.9 ± .4	8.2 ± .1
EC-6	18.4 ± 2.3	8.9 ± .6
EC-7	23.7 ± .4	7.8 ± .6
EC-8	23.3 ± .1	9.3 ± .2
EC-9	21.7 ± .3	8.5 ± .1
EC-10	24.8 ± 1.3	8.8 ± .2
EC-P	23.2 ± .8	8.7 ± .2
EC-PA	22.1 ± .5	8.5 ± .2
Madras:		
M-1	22.9 ± .7	7.4 ± .3
Highway 27:		
27-A	21.6 ± .8	9.4 ± .3
27-B		9.4 ± .3
27-C	24.0 ± .8	9.1 ± .3
27-D		9.1 ± .3
27-E		9.3 ± .3
27-F	22.4 ± .8	10.2 ± .4
27-G		9.6 ± .3

**One standard deviation due to counting statistics is indicated by ± values.

Table 4. Central Oregon basalts-averages*.

	Location										
Element	K(1-9)	K(10-15)	LL	R	HW	PG(1-9)	PG(10-19)	EC	M	27(A-E)	27(F-G)
This work											
Si (%)	23.1	24.2	23.3	21.8	23.5	22.9	21.1	21.9	22.9	22.8	22.4
	± .4	± .5	±1.0	± .6	± .5	± .8	± .6	± .5	± .7	±1.7	± .8
Al (%)	6.8	7.4	6.8	6.8	6.8	7.9	8.2	8.6	7.4	9.3	9.9
	± .2	± .2	± .2	± .3	± .4	± .2	± .3	± .4	± .3	± .3	± .4
Other work											
Fe (%)**	10.5	8.6	na	na	na	8.8	7.8	na	na	6.5	na
	± .1	± .1				± .2	± .1			± .4	
Cr (ppm)	28	31	na	na	na	63	177	175	19	202	na
	± 4	± 4				± 9	± 5	±41[d]	± 1	± 42	
Co (ppm)	39	38	na	na	na	40	42	na	na	40	na
	±4	±4				±4	±4			±4	
Sc(ppm)	34	33	na	na	na	40	42	na	na	31	na
	±2	±2				±2	±1			±4	
La(ppm)	24.2	19.1	24	23.8	22.4	11.3	7.6	9.7	11.0	12	na
	± .5	± .4	±2[a]	± .6[b]	±.3[c]	± .5	± .2	±1.4[d]	± .1	±4	

*Sample standard deviations are indicated by ± values.

**Osawa and Goles (29). Individual abundances are given in this paper.

na = Not available at this time

[a] Average of samples 4 and 5

[b] Averages of samples 2 and 5

[c] Averages of samples 2, 4B and 8

[d] Average of samples 1, 5 and 7

Table 5. Willamette Valley Buttes and Quarries--major elements.*

Location	Si (%)	Al (%)	Fe (%)	Na (%)	K (%)
Hale Butte:					
HA-1	21.2 ± .8	7.7 ± .2	9.8 ± .2	2.87 ± .09	0.7 ± .1
HA-2	21.9 ± .8	7.3 ± .1	10.0 ± .2	2.68 ± .08	0.6 ± .1
HA-3	21.7 ± .8	7.6 ± .2	9.7 ± .2	2.72 ± .08	0.6 ± .1
Knox Butte:					
KN-1	22.5 ± .8	7.0 ± .1	8.6 ± .2	2.17 ± .07	1.5 ± .2
KN-2	23.2 ± .8	6.9 ± .1	10.4 ± .2	2.13 ± .06	1.6 ± .1
KN-3	22.4 ± .8	6.9 ± .1	10.7 ± .2	2.07 ± .06	1.3 ± .2
Saddle Butte:					
SA-1	26.6 ± 1.2	8.3 ± .2	8.2 ± .2	2.81 ± .08	1.0 ± .1
SA-2	25.7 ± .9	7.6 ± .2	8.4 ± .2	2.62 ± .08	0.9 ± .1
SA-3A	25.1 ± 1.2	8.7 ± .2	6.6 ± .1	2.90 ± .09	1.4 ± .2
SA-3B	25.7 ± .9	7.9 ± .2	7.5 ± .1	2.84 ± .09	1.3 ± .2
SA-4	24.3 ± .9	8.0 ± .2	6.3 ± .1	2.78 ± .08	1.1 ± .2
Bond Butte:					
BB-1	23.0 ± .8	9.7 ± .2	7.5 ± .1	1.96 ± .06	0.6 ± .1
BB-2	23.0 ± .8	8.7 ± .2	7.0 ± .1	1.87 ± .06	0.8 ± .1
BB-3	22.8 ± .8	9.3 ± .2	6.8 ± .1	1.85 ± .06	0.9 ± .1
**Coburg Quarry:					
CQ-15		11.1 ± .3	5.4 ± .3	1.53 ± .01	ND
CQ-17	22.4 ± .8	11.3 ± .3	5.9 ± .3	1.59 ± .01	ND
CQ-18		7.5 ± .4	9.6 ± .4	2.17 ± .02	ND
CQ-19		14.2 ± .2	4.9 ± .3	1.71 ± .02	ND
CQ-20		10.9 ± .4	5.8 ± .3	1.58 ± .01	ND
CQ-21	21.2 ± .7	10.9 ± .2	5.9 ± .3	1.16 ± .01	ND

*Abundances in percent ± one standard deviation due to counting statistics.

**All Coburg Quarry Abundances except Si and Al from Robert L. Beyer, University of Oregon.

ND = Not Determined.

Table 6. Willamette Valley Buttes and Quarries--minor and trace elements.*

Location	Mn (ppm)	Cr (ppm)	Co (ppm)	Sc (ppm)	La (ppm)
Hale Butte:					
HA-1	1510 ± 40	50 ± 30	41 ± 2	37 ± 1	18 ± 3
HA-2	1510 ± 60	30 ± 10	49 ± 2	38 ± 1	18 ± 3
HA-3	1530 ± 40	80 ± 30	48 ± 1	34 ± 1	20 ± 4
Knox Butte:					
KN-1	1940 ± 50	80 ± 40	46 ± 2	31 ± 1	29 ± 4
KN-2	1940 ± 50	100 ± 40	43 ± 2	33 ± 1	30 ± 4
KN-3	1740 ± 40	110 ± 40	49 ± 2	34 ± 1	33 ± 4
Saddle Butte:					
SA-1	1310 ± 30	70 ± 40	33 ± 2	34 ± 1	22 ± 4
SA-2	1140 ± 30	30 ± 20	31 ± 2	33 ± 1	23 ± 5
SA-3A	1210 ± 30	90 ± 40	28 ± 2	33 ± 1	26 ± 4
SA-3B	1410 ± 30	50 ± 30	33 ± 1	31 ± 1	24 ± 4
SA-4	1250 ± 30	70 ± 40	30 ± 2	30 ± 1	24 ± 4
Bond Butte:					
BB-1	1160 ± 30	110 ± 20	51 ± 2	29 ± 1	10 ± 3
BB-2	1140 ± 30	100 ± 20	49 ± 2	28 ± 1	5 ± 3
BB-3	1110 ± 40	120 ± 20	42 ± 2	30 ± 1	12 ± 4
**Coburg Quarry:					
CQ-15	1080 ± 50	210 ± 20	28 ± 2	26 ± 1	5 ± 1
CQ-17	960 ± 40	210 ± 20	30 ± 2	28 ± 1	7 ± 1
CQ-18	1470 ± 60	ND	40 ± 2	40 ± 1	10 ± 1
CQ-19	840 ± 50	260 ± 30	33 ± 2	29 ± 1	6 ± 1
CQ-20	1000 ± 50	200 ± 20	31 ± 2	26 ± 1	8 ± 1
CQ-21	1010 ± 50	210 ± 20	32 ± 2	27 ± 1	9 ± 1

*Abundances in ppm ± one standard deviation due to counting statistics.

**All Coburg Quarry abundances from Robert L. Beyer, University of Oregon.

ND = Not Detected (< 20 ppm)

Table 7. Willamette Valley Buttes and Quarries--averages*.

Element	HA	KN	SA	BB	CQ[1]	BCR-1		W-1	
						this work	other**	this work	other**
(%)									
Si	21.6 ± .8	22.7 ± .8	25.5 ± .9	22.9 ± .8	21.8 ± .8	25.4 ± .4	25.0 ± .6	---	---
Al	7.5 ± .2	6.9 ± .1	8.1 ± .2	9.2 ± .4	11.0 ± 2.1	7.1 ± .1	7.6 ± .2	---	---
Fe	9.8 ± .1	9.9 ± .8	7.4 ± .5	7.1 ± .2	6.3 ± .8	---	---	(2)	7.75 ± .15
Na	2.76 ± .07	2.12 ± .04	2.79 ± .05	1.89 ± .04	1.62 ± .15	2.52 ± .08	2.54 ± .06	---	---
K	0.6 ± .1	1.5 ± .2	1.1 ± .1	0.8 ± .1	ND	1.04 ± .05	1.42 ± .06	---	---
(ppm)									
Mn	1520 ± 40	1870 ± 80	1260 ± 50	1140 ± 30	890 ± 130	1500 ± 40	1490 ± 30	---	---
Cr	50 ± 20	100 ± 20	60 ± 20	110 ± 10	220 ± 10	---	---	120 ± 20	111 ± 2
Co	46 ± 3	46 ± 2	31 ± 1	47 ± 3	32 ± 2	---	---	56 ± 2	42 ± 1
Sc	36 ± 1	33 ± 1	32 ± 1	29 ± 1	29 ± 2	---	---	35 ± 1	33 ± 1
La	19 ± 2	31 ± 2	23 ± 2	9 ± 3	8 ± 1	---	---	13 ± 3	12***

*Sample standard deviations are indicated by ± values.

**Schmitt, Linn, and Wakita (33).

***Fleischer (17)--error not given.

ND = Not Determined.

[1] All abundances except Si and Al by Robert L. Beyer, University of Oregon.

[2] Used as Fe standard in this work.

Table 8. Average abundances of Columbia River basalt and other basalts.

Element	Picture Gorge Basalt[1]	Yakima Basalt[1]	Late Yakima and Ellensburg[1]	Normal Continental Tholeiites[1]	Lower Siletz River[2] Tholeiites (1A)	Lower Siletz River[2] Tholeiites (1B)	Upper Siletz River Tholeiites[3]	Upper Siletz River Alkalics[3]
(%)								
Si	23.0	25.1	23.4	23.7	22.9	22.6	22.3	21.5-24.0
Al	8.3	7.4	7.2	7.5	7.7	7.7	8.0	6.7-9.3
Fe	8.5	9.0	11.0	9.0	8.7	10.3	9.8	7.7-9.8
Na	2.0	2.2	2.2	1.65	1.7	1.9	2.0	2.0-4.6
K	0.4	1.2	1.2	0.68	.14	.12	0.48	0.41-1.6
Mn	0.15	0.15	0.19	0.14	.15	.19	0.16	0.15-0.16
(ppm)								
Cr[4]					150-300	30-200	15-150	0-500
Co					50-70	30-70	30-70	24-50
Sc					15-50	15-70	15-40	17-50

[1] Waters (42), Table 5.

[2] Snavely *et al*. (36), Table 3, Cols. 1A and 1B

[3] Snavely *et al*. (36), Table 7

[4] All trace element ranges in ppm from Snavely *et al*., Table 4. All other values calculated from oxide abundances.

RESULTS AND DISCUSSION

Central Oregon Basalts

The Si and Al abundances for the individual basaltic samples are listed in Table 3, and the averages of these and other elements are shown in Table 4.

Klickitat River Section

Two separate averages of this group of flows were determined, one of the top nine flows, which are of Late Yakima type, and one of the lower six flows, which are of Yakima type (29). Aluminum abundances appear to bear out differences between the two sets of flows, and both tend to agree with the averages found by Waters (42). However, the Si abundances and the Al average for the Late Yakima type seem to be systematically lower than the values given by Waters. This discrepancy can possibly be explained by noting that the analyses by Waters are the standard, classical techniques of analysis for Si and Al, which almost always result in high values, due to coprecipitation and other difficulties. Iron abundances, as determined by Osawa and Goles (29), also tend to agree with Waters' values, except they are again both slightly lower than Waters' values. Again, this could be explained by possible analytical error by classical techniques leading to systematically high values.

Locke Lake and Rock Creek Sections

These two sections will be considered together, not only because they are both Late Yakima basalts (29), but also because the Al abundance data suggest that both these basalt samplings may be part of one group of flows. Locke Lake basalts are numbered from the bottom up (see Appendix) and Rock Creek from the top down, and inspecting the data in Table 3 shows that samples LL-4, LL-3, LL-2, and LL-1 appear to correlate with samples R-1, R-2 & 2N, R-3, and R-4 respectively, as follows.

Table 9. Correlation of Locke Lake and Rock Creek basalt flows.

LL-4	7.2% Al	7.2% Al	R-1
LL-3	6.7	6.8	R-2
		6.9	R-2N
LL-2	6.5	6.3	R-3
LL-1	6.8	6.8	R-4

Note: R-2 and R-2N were samplings of the same flow.

Abundances in the samples I propose to correlate agree within the error limits shown in Table 3. As with the Klickitat River specimens, the values all tend to be systematically lower than Waters' values (Table 8), except for the Si averages of the Locke Lake specimens, which are about the same as those of Waters. The relatively large spread in the average is due to the fact that only two of the seven samples were analyzed for Si.

Hay Creek Canyon Section

This group of basalt flows is described as Yakima type by Osawa and Goles (29), and the Si averages show reasonable agreement with Waters (Table 8), if sufficient allowance for error is considered. Interestingly enough, however, the Al abundance average is lower than Waters' value of 7.4%; in fact the average for these basalts is identical with those of the Locke Lake, Rock Creek, and the upper nine flows of the Klickitat River section, all of which are known to be Late Yakima basalts. The La average of 22.4 ppm appears about mid-way between that of known Yakima and Late Yakima basalt flows (Table 4, K 1-9 and K 10-15). Possibly these basalts were late enough to mix with magma of Late Yakima type, a suggestion which could explain the low Al content and relatively high La content.

Picture Gorge and Emigrant Creek Series

The Si and Al abundances appear to be in agreement with Waters' values (Table 8), but are slightly lower in all cases, again possibly attributable to high values by classical techniques. The Al abundances, as well as the Cr (Table 4), appear to bear out the distinctions between two separate series of Picture Gorge flows. The lower group (10-19) appears richer in both Cr and Al and depleted in Si, Fe, and La relative to the upper group (1-9). The individual Al abundances (Table 3) seem to reflect differences in the two groups and place the boundary between PG-9 and PG-10, in agreement with the trace element data by Osawa and Goles.

The Si abundances for the Emigrant Creek series appear in agreement with those of the Picture Gorge basalts. The Al average is somewhat higher than that of the lower group of Picture Gorge flows, although many of the individual Emigrant Creek abundances are close to the individual Picture Gorge abundances. The Cr and La averages are also very close to those for the lower group of Picture Gorge flows, suggesting that these basalts may have come from a common magma source. The field notes (Appendix) indicate that sample EC-6 may be from a mud flow deposit; this suggestion may explain its relatively low Si content. The available data seem to lend support to the idea that these basalts may be of Picture Gorge type, but clearly more field work and petrographic studies of these flows need to be conducted.

Madras and Highway 27 Series

The Si and La abundances for the single Madras sample appear identical with the average of the upper Picture Gorge unit. However, the Al and Cr abundances are lower, the Al abundance being identical with the average for the lower six flows of the Klickitat River series, which are known to be Yakima basalts. This observation could suggest some mixing that may have taken place between the latest Picture Gorge and the earliest Yakima flows. The Cr abundance is lower than that of any of the other basalts studied in this work and is unexplained. Certainly more sampling, field work, and petrographic studies should be made of the flows in this area before any conclusions are drawn.

The Highway 27 flows, mapped by Walker _et al_. (41) as "questionable" Columbia River basalts, seem to be even more questionable after looking at the Al data. The Si and Co averages appear in agreement with those of Picture Gorge basalts. However, all samples are considerably higher in Al and Cr, and depleted in Fe and Sc relative to the lower group of the Picture Gorge series, even if samples F and G are not considered. Flows from which F and G were taken are separated from those from which A through E were taken by tuffaceous sediments (29), and their Al abundances are higher than those of specimens from the underlying flows. The data available at this time seem to suggest that none of these flows is Columbia River basalt, but more petrographic studies will have to be undertaken in order to draw any definite conclusions.

Willamette Valley Basalts

Individual abundances for these sites are shown in Tables 5 and

6, and averages in Table 7. Abundances of two rock standards are also shown to illustrate the good reproducibility of INAA.

Hale Butte

The Si and K abundances appear to be similar to those of Picture Gorge basalts, but the Al content is lower and the Fe content higher, suggesting possibly Yakima or Late Yakima affinities. The Na average is higher than that of any Columbia River basalt, and trace element contents seem to be somewhere in between Picture Gorge and Yakima basalts (Table 4, Klickitat flows 10-15). Petrographic studies are in progress, and clearly more field work needs to be done before any conclusions can be drawn. Most of the rock in this quarry was badly weathered, and sampling was difficult. However, the rocks sampled for this study were relatively fresh in appearance, as compared to the bulk of the rocks in the quarry. The relative uniformity of elemental abundances (except Cr) in the three samples also suggests that these samples were reasonably fresh.

Knox Butte

As with Hale Butte, the Si abundances correspond to Picture Gorge type, while the Al and Fe correspond to Late Yakima type. In this intrusive body, however, the Na, K, and Mn abundances also appear to match Late Yakima averages (Table 8). The only disagreement is Cr, which is higher than the Late Yakima flows analyzed by Osawa and Goles (Klickitat River flows 1-9), but this could be due to a local enrichment in Cr. This butte is different from the other buttes sampled in that the basaltic rock which makes it up is much coarser in texture, and microscopic examination shows small vesicles with "whiskers" of labradorite plagioclase (37). It also contains a fair amount of plagioclase phenocrysts ($\sim$5%), while the samplings from the other buttes do not contain any phenocrysts. The preliminary analyses seem to indicate a possible connection with Late Yakima basalts, but more field work and petrographic studies will have to be undertaken.

Saddle Butte

The high Si abundance in every sample seems to indicate that this intrusive body is not related to Columbia River basalts. Sodium is also higher than in any type of Columbia River basalt. The individual Fe, Mn, and Cr abundances vary quite a bit between samples, as was expected from the varying nature of the samples (see Appendix). High Fe concentration was expected in SA-2, since it, unlike the other samples, contained numerous vesicles filled with chlorophaeite. Manganese was enriched in SA-1 and SA-3B as expected, since they were sampled from the scree, and would have undergone more alteration. The other trace elements (Co, Sc, La) seem to be reasonably uniform throughout the samples, but do not appear to agree with any one type of Columbia River basalt. This evidence also reinforces the field work done on this intrusive body (19), which shows that it is probably not connected with Columbia River basalt. More sampling will have to be done on this body, as it is a very complex formation, appearing to be a network of flows and brecciated intrusions, and presents a very complicated problem in petrogenesis.

Bond Butte

Field work on this intrusive body has suggested that it may have affinities with Picture Gorge basalts, and the data seem to support this hypothesis, although Al is somewhat higher and Fe lower than in the older Picture Gorge unit. The data on this intrusion seem to show the same differences with the Picture Gorge subtypes as the Highway 27 series does (i.e., higher Al and lower Fe). The Cr content, however, is about the same or less than the older Picture Gorge unit (Table 4, PG 10-19). Manganese is somewhat lower than Waters' value (Table 8), but cannot be compared to any other Picture Gorge samples, as data are not available yet. The trace element data seem to agree within error limits with the data by Osawa and Goles on the Picture Gorge. The low La concentration appears especially significant, in light of the higher La concentrations that the other buttes show.

Coburg Quarry

The data for this intrusion (except Si and Al) were made available by Robert L. Beyer (5), who has been conducting field work and geochemical and petrographic studies on this site. Samples 15, 17, 20, and 21 all appear fairly similar in practically all the elements considered here, except that 21 appears somewhat depleted in Na. Samples 18 and 19 show marked differences, however, especially in Al. Their physical appearances are also different (see Appendix). The abnormally high concentration of Al in all these samples (except 18) can be explained by the large volume of plagioclase phenocrysts found in five of the six samples. Sample 18 was sampled on the edge of the intrusion, and contained few phenocrysts (5, 19). The two samples analyzed for Si appear to agree with values obtained for Picture Gorge basalts. Also, since sample 18 contained relatively few phenocrysts, its abundances are essentially those of the fine-grained matrix, and excepting Fe, also appear to agree within limits with the averages for the younger Picture Gorge basalts (Table 4, PG 1-9, and Table 8). If this is a valid comparison, then the Fe abundance in this particular sample is abnormally high for a typical Picture Gorge basalt. Sample 19 was labeled as a "fracture" sample (19), and was taken from inside the intrusion (5). The higher abundances of Al and Cr and lower content of Fe and Mn seem to indicate that this sample may have had an even higher percentage of phenocrysts than the other four similar samples. Of course, modal analyses of these samples are necessary before one may draw any conclusions regarding the percentage of plagioclase phenocrysts in each sample. Owing to the great abundance of large phenocrysts in many of these samples, proper modal analyses will require examination of several standard-sized thin sections per specimen.

Comparisons with the Coast Range Alkalics

Since the basalts of this study are clearly non-tholeiitic in nature ($K \geq 0.6\%$), they are obviously not related to any of the Oregon Coast Range tholeiites as found in (36) and Table 8. From this bulk compositional data, there does not appear to be any relationship between Knox, Saddle, and Bond buttes and the youngest Siletz River Alkalic basalts. However, the abundances in Hale Butte appear to match closely the bulk abundances in the youngest Siletz River alkalic basalts. Of course, more field work needs to be done before relationships with any other basaltic bodies can be confirmed.

SUMMARY AND CONCLUSION

Ninety basalt samples from eight locations in central Oregon and south central Washington and one quarry in the Willamette Valley were analyzed for Si and Al. Fourteen basaltic rock specimens gathered from four buttes in the Willamette Valley were also sampled and analyzed for Fe, Na, K, Mn, Cr, Co, Sc, and La in addition to Si and Al. Precisions ranged from about 2-4% for the major elements, Mn, Co, and Sc, 15% for K, 20% for La, and 40% for Cr. The precisions for the last two elements could be improved by counting for longer times.

The Si and Al averages obtained for the Klickitat River, Locke Lake, and Rock Creek specimens were found to agree reasonably well with Late Yakima values, except for the lower six Klickitat flows which agree with Yakima values. The Al abundances also show that the Locke Lake and Rock Creek flows may be part of one sequence of flows laterally equivalent to one another.

The Si and Al averages found for the Hay Creek Canyon specimens appear to agree with Late Yakima values, although these basalts are thought to be of Yakima type.

The Si and Al averages obtained for the Picture Gorge specimens were found to agree with previous values, and also to corroborate the suggestion of two separate groups of flows in the Picture Gorge section.

The Emigrant Creek specimens yielded Si values which suggest that they are also varieties of Picture Gorge basalt. However, the higher Al values indicate that they are probably not closely related to the flows at Picture Gorge.

The single Madras sample appears to be related to Picture Gorge basalt, but its Al and Cr contents are both lower than those found at Picture Gorge.

The Highway 27 series of flows A through E were found to have Si abundances in agreement with those of Picture Gorge basalt. In this case, however, the Al and Cr abundances appear higher than those in any known Columbia River basalt. Clearly more study is warranted in this area, as well as the Madras and Emigrant Creek areas, before any valid conclusions can be drawn.

Of the buttes sampled in the Willamette Valley, Hale and Knox Buttes showed agreement with Late Yakima abundances, except that they were found to be depleted in Si relative to Late Yakima type. Hale Butte also had considerably more Na than the average Late Yakima basalt.

Saddle Butte yielded abundance averages which indicate that it is probably not related to the Columbia River basalt. Similar conclusions have been obtained from field work involving lithologic studies.

Bond Butte and Coburg Quarry samples were found to agree very closely with abundances of the Picture Gorge basalt, except that the Al abundances were higher for Bond Butte and, for the single aphanitic sample from Coburg Quarry, lower than the average Al abundances of the Picture Gorge basalts. The opposite trend was observed for the Fe abundances.

No significant relationship was established between any of these buttes and the Coast Range tholeiitic and alkalic basalts shown in Table 8, except for the abundances of the Hale Butte samples. These bulk abundances were found to match the bulk compositional ranges of the Coast Range alkalic basalts.

It must be emphasized that these abundances are whole-rock, bulk analyses, and as such do not give any information about the actual mineral content. For this reason, these data can only imply certain affinities, not confirm them. As stated before, field work, modal analyses, and other petrographic studies are necessary to definitely establish an affinity with Columbia River or with any other type of basalt.

It is hoped that this study, along with other studies of basalts, has shown that INAA is both an accurate and precise analytical technique for determining elemental concentrations in rock samples, and that further studies on basalts in Oregon and elsewhere may serve to reveal some clues about the origin of the Earth's crust and upper mantle.

SUGGESTIONS FOR FURTHER STUDIES

1. Determination of Ca, Mg, and Ti content and normative mineral analyses. As Mg is very difficult, if not impossible, to determine by INAA, other analytical techniques, such as atomic absorption, would probably be suitable for finding both Mg and Ca.
2. Determination of the rare earth elements in the butte samples for further comparison with Columbia River basalt.
3. Ages of selected samples by the K:Ar or Rb:Sr method.
4. More sampling and field work at certain sites, particularly the Willamette Valley buttes and the Madras quarry area.
5. Modal mineral analyses.

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APPENDIX

Field Notes on Basalt Samples Analyzed

Central Oregon Basalts

K series: Klickitat River section of Waters (42); taken along "new" road west of Klickitat River and southwest of section sampled by Waters, beginning in Section 28, T3N, R 13E, at 45°49' N, 121° 10-13' W. Sampling began at top, about on the boundary between Sections 19 and 30. Fifteen flows were sampled, many with pronounced pillow structures; much palagonitization was noted. Flows seem to dip largely along present topographic contours; they may well have been deposited in a valley ancestral to the present tributary of the Klickitat. Waters (personal communication) pointed out that there is much landsliding in this area.

LL series: Taken along old highway leading off to the ENE of Washington State Highway 14 at Locke Lake, at 45°42' N, 121° 24' W. Samples were taken from individual basalt flows, numbered from the bottom up. The second flow from the top was conspicuously thin, and can be seen easily from the turnoff onto the old highway. The top flow is located some distance from the others along the road, and seems to be separated from underlying flows by a moderately thick sedimentary interbed.

R series: Rock Creek Canyon section, across from Goodnoe Hills (45°42' N, 120° 26' W), sampled from the top of Walker Grade on down. Flow #2 was quite thin. Thick sedimentary interbeds are present near the top of the section, and again between flows 4 and 5. Flow #6 was sampled along Rock Creek, in a road cut south of Walker Grade; this flow has a reddish vesicular top which is well exposed.

HW series: Hay Creek Canyon (just north of the Sixmile section of Waters), west of Mikkalo, at 45°28' N, 120°19' W. Eight flows were sampled from the top down on the west side of the canyon. Flow #3 has abundant vesicles filled with chlorophaeite, some of which was sampled independently.

PG series: Taken from junction of U.S. Highway 26 and Oregon State Highway 19, at 44°32' N, 119°38' W. Samples are numbered in descending stratigraphic order, with known cases of replicate sampling from a single flow indicated by suffixed letter designations (29). There is some repetition of the section at the bottom, owing to a small east-west fault approximately along Highway 26.

EC series: Emigrant Creek Canyon, south of Whiskey Mountain, at 43° 49-56' N, 119° 25' W. Exposed flows are supposedly Picture Gorge basalts. Sampled from the top down, but note that the relations between flows are not well exposed.

EC-2: Poorly exposed on north side of road at relatively high elevation.

EC-2A: May be gabbroic basal layer of EC-2 flow.

EC-3 is definitely below EC-2A.

EC-6 is apparently a mud flow deposit of basalt fragments in a palagonitized matrix.

EC-P (for "pillow") and EC-PA are not necessarily in sequence in the section as is also the case for EC-9 and EC-10. EC-P, EC-PA, and EC-9 may all be from the same flow (?)

27 series: Taken along Oregon State Highway 27, about six miles north of U.S. Highway 20, at 43°58' N, 120° 45' W. Sampled, using letter designations, from bottom up.

M series: Collected from a quarry along U.S. Highway 26 just southeast of the Deschutes River near Warm Springs, Oregon, at 44°43' N, 121° 12' W. (Quoted from Osawa and Goles, 29).

Willamette Valley Basalts

CQ series: Sampled from an intrusion just east of Interstate Highway 5, near Coburg, Oregon (44° 7' N, 123° 2' W). Sampling done by Robert L. Beyer. The following notes on preliminary petrography are from Dr. Gordon Goles:

CQ-15: Abundant plagioclase phenocrysts, some very large, in "fine" groundmass.

CQ-17: Similar to CQ-15.

CQ-18: Slightly trachytic texture, few phenocrysts, some of reasonably fresh olivine. Groundmass rich in opaques.

CQ-19: Similar to CQ-15.

CQ-20: Mostly phenocrysts, some huge. Like CQ-19.

CQ-21: Like CQ-20.

(Above information from Dr. Gordon Goles and Robert L. Beyer, University of Oregon).

HA series: Sampled from Hale Butte quarry just east of Interstate Highway 5, northeast of Albany, Oregon (44° 43' N, 123° 3' W). All samples were taken from the scree on the east side of the quarry. Most of the rocks there were badly weathered, and sampling was difficult.

HA-1: From the northern section of the quarry.

HA-2: From the middle section.

HA-3: From the southern section.

KN series: Sampled from Knox Butte, just east of Albany (44° 39' N, 123° 1' W). All samples were taken from large boulders along the roadside. Samples were found to contain some fairly large plagioclase phenocrysts (up to about 5 mm in length).

KN-1: West side of butte; from west side of road about 15 m north of bend in road.

KN-2: South side of butte; from south side of road about 30 m east of bend.

KN-3: West side of butte, about halfway down from top. Taken at the side of the road.

Samples 1 and 2 were taken around the topmost exposed part of the butte.

SA series: Taken from quarry, due east of Shedd, Oregon and just east of Interstate Highway 5 at 44° 27' N, 123° 3' W. This quarry presents an incredibly complicated network of basalts and brecciated intrusions, and it was very difficult to sample. The first four samples were taken from the northwest quarry, and the fifth from the southeast quarry.

SA-1: From scree at north end.

SA-2: Northeast side; highly vesicular with much chlorophaeite. Taken <u>in situ</u>.

SA-3A: Southeast side about 8 m south of contact with breccia, also *in situ*.
SA-3B: Same position as 3A except from scree at bottom.
SA-4: Taken *in situ*.

BB series: Sampled from quarry located just east of Interstate Highway 5, on a parallel located about halfway between Halsey and Harrisburg, Oregon, at 44° 19' N, 123° 3' W. All samples were taken *in situ* and showed generous amounts of chlorophaeite deep inside. Outcrops displayed excellent columnar jointing, with the columns oriented generally north-south in the horizontal plane. The intrusion is presumably a near-surface feeder dike.

BB-1: Sample taken from east quarry.
BB-2: West quarry, taken 3 m below top of outcrop.
BB-3: Taken 12 m below BB-2.