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K-Ar AGES OF OLIGOCENE SALMON CREEK VOLCANICS, OWYHEE MOUNTAINS, IDAHO

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GEOLOGIC SETTING

The Cenozoic geologic history of the northwestern United States is dominated by continental volcanism related to tectonic interactions between North America and the oceanic plates off its western coast. Early Tertiary activity comprised mainly intermediate-composition volcanism commonly attributed to eastward subduction of the Pacific and Farallon plates at a shallow angle beneath the continent. Sizable volumes of calc-alkaline andesite flows, rhyodacite and quartz latite tuffs, and lesser alkaline lavas erupted from large volcanic centers across western Montana, Idaho, and Oregon. By the middle Miocene the character of the volcanism had changed to basaltic or to a bimodal rhyolite-basalt association following constriction of the arc to the continental margin and evolution of most of the region in a complex back-arc setting (Christiansen and McKee, 1978).

These broad relations are known with some certainty but a detailed understanding of the timing of these changes, and of how the style of magma evolution correlates with tectonic environment requires close study of relatively small areas. In this regard, the Owyhee Mountains of southwestern Idaho provide a particularly good opportunity to examine the temporal evolution of Cenozoic volcanism in the northern Basin and Range province. These mountains are constructed of Cretaceous granitic rocks covered by thick sections of Cenozoic volcanics and lesser terrigenous sediments. Minor pre-Cretaceous metamorphic rocks are exposed locally. The Cenozoic volcanics consist of: (i) *Eocene* rhyodacite tuff and minor lava flows of quartz latite that are correlative with the Challis volcanics of central Idaho; (ii) *Oligocene* andesite and basalt flows with interbedded pyroclastic breccias; and (iii) a *Miocene to Pleistocene* bimodal sequence of basalt flows intercalated with voluminous rhyolite ash-flow tuffs and lava flows (Ekren, et al., 1981, 1984). Similar bimodal activity during the late Tertiary was widespread across the western U.S., including the Snake River Plain which borders the Owyhee range on the north and east, the Oregon Plateau to the west, and the Basin and Range to the south.

The rhyolites and basalts of the Owyhee area and the Snake River Plain are relatively well-characterized although many details of their petrogenesis remain obscure (see, e.g., Ekren, et al., 1984; Leeman, 1982; Bonnichsen, 1982). The Challis volcanics have also received considerable attention recently (Fisher, et al., 1983; McIntyre, et al., 1982; Hardyman, et al., 1985). However, rocks of Oligocene age are uncommon in the northern Basin and Range province and only limited data are available on the nature of the volcanism during this time. As part of our petrologic and geochemical studies of these rocks we present here three new K-Ar age determinations on whole rock samples of the Salmon Creek volcanics (SCV) from the northern Owyhee Mountains. These data bracket the age range of Oligocene activity in this area as 30.9 to 26.0 ± 0.3 m.y. ago (Ma).

The SCV comprise lava flows of andesite and basalt, pyroclastic breccias, and andesite dikes that cut the pyroclastic units and apparently fed a small number of upper flows which are only locally preserved (figs. 1, 2). Compositionally these lavas evolved from basaltic to andesitic with time. Flows of basalt, then andesite were followed by eruptions of pyroclastic breccias characteristic of near-vent facies deposits, and finally by a small volume of differentiated andesite lava. The exposed volume of SCV is estimated to be 10–20 km^3.

Most of the SCV lavas can be classified as medium- to high-potassium andesites based on their K_2O-SiO_2 relations, TiO_2 contents, and Fe/Mg (after Gill, 1981). Representative major and trace element analyses are given in table 1. These lavas constitute by far the largest volume of intermediate-composition lava exposed in the Owyhee range, and, in fact, are the only true andesites exposed in the area. These rocks provide the most direct evidence for active subduction beneath this region during the mid-Cenozoic. Their presence demonstrates that subduction-related magma sources were active some 700 km inland at a time when the Western Cascades were beginning to rise on the continental margin to the west (Robinson, et al., 1984).

The basal olivine-phyric lavas are potassium-rich basalts, but they do not have the high alumina contents typical of continental arc basalts (table 1). The SCV basalts and some of the more basic andesites are mildly alkaline whereas most of the andesites are calc-alkaline according to the criteria of Irvine and Baragar (1971). The alkaline nature of the SCV basalts is corroborated by their small amount of normative nepheline (assuming Fe^{3+}/Fe^{2+} = 0.15) and their lack of iron enrichment with increasing silica (not shown). Pliocene age basalts with major and trace element compositions virtually identical to the SCV basalts are found in southern Nevada and in the southern Cascades (Hedge and Noble, 1971; Walker and Naslund, 1986). In the Cascades they often constitute the base of the High Cascade series where the contact with High Cascade lavas is exposed (Priest, et al., 1983). At the Klamath River Gorge the volcanic sequence also evolved from mildly alkaline basalt to calc-alkaline basalt and finally to calc-alkaline andesite through time (Walker and Naslund, 1986).

Compositional and petrographic variations in the SCV suite are broadly consistent with evolution of these magmas to progressively higher volatile contents and more evolved compositions. However, detailed sampling and subsequent geochemical analyses through the andesite section shows several compositional cycles. Early stages of andesitic activity become less siliceous and more magnesian upsection. Higher in the section these trends are reversed (fig. 3). We interpret these compositional cycles in terms of dynamic magma chamber processes. The trends toward more mafic compositions in the lower cycles may document replenishment of relatively evolved magma reservoir(s) with more primitive magma. Later

Salmon Creek volcanic sequence, Idaho

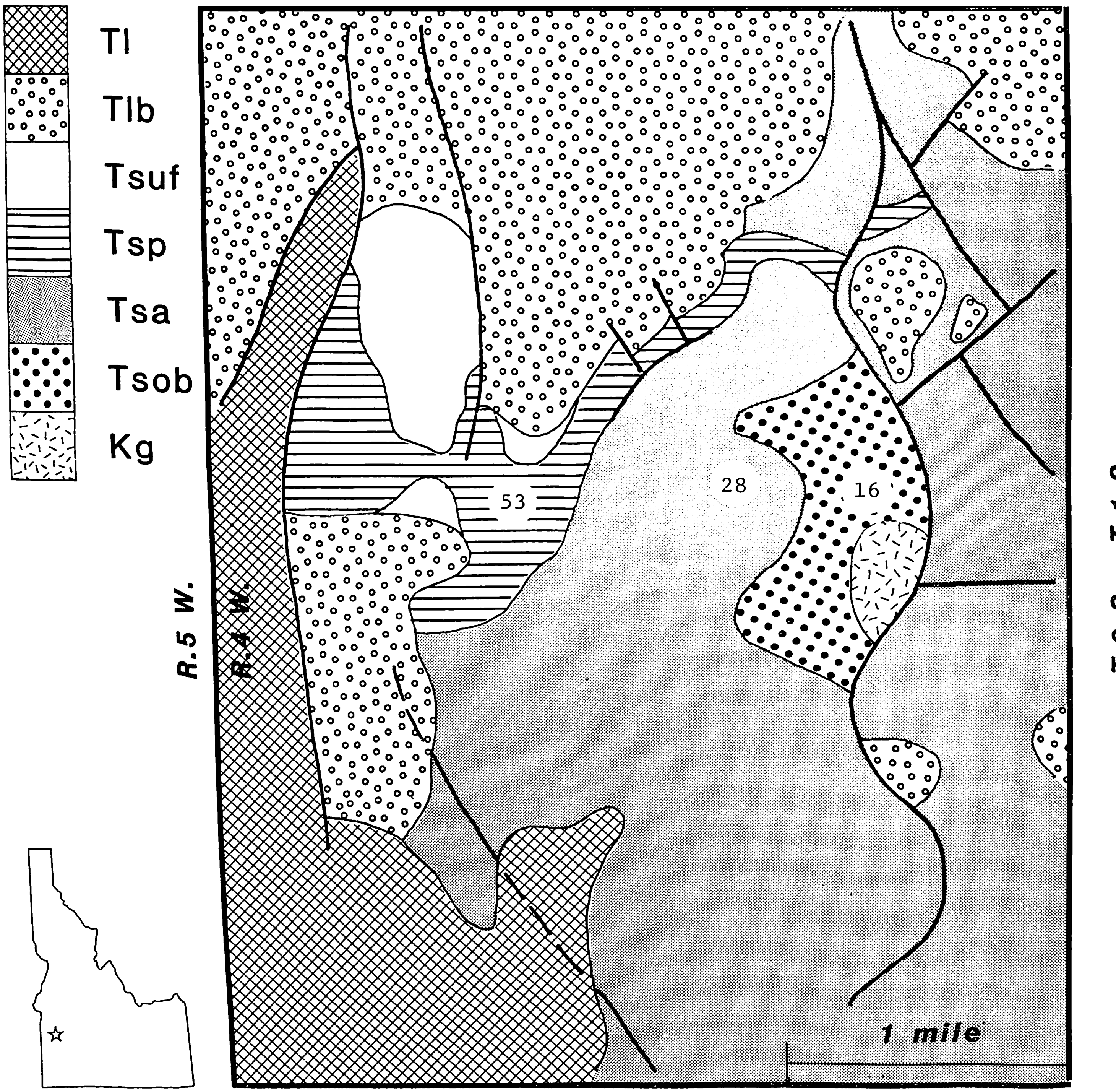


FIGURE 1. Geologic map of the Salmon Creek study area in the Owyhee Mountains of southwestern Idaho. Not shown on this map are several dikes that cut the pyroclastic rocks in the vicinity of the upper andesite flows. An explanation of the map units is given in figure 2.

Stratigraphic units of the Salmon Creek volcanic sequence

AGE (Ma)	THICKNESS (m)	MAP UNITS	LITHOLOGY AND CHEMISTRY
Miocene		Tl	Ferrolatite lava flows and tuffs. Phenocrysts of plagioclase, pyroxene, and olivine, plus xenoliths of granite, quartz, and feldspar in glassy to intersertal matrices. Compositionally variable: SiO_2 54-69%, K_2O 2.0-4.6%, Fe/Mg* 4.2-7.8, Sr 100-530 ppm.
	1325	Tlb	Lower basalt flows and tuffs. Includes Hoot Nanny (Thn) and Toll Gate (Ttg) units of McIntyre (1972). Phenocrysts of olivine and plagioclase ± Fe-Ti oxides in ophitic to intergranular matrices. SiO_2 48-49%, K_2O 0.3-0.8%, Fe/Mg 1.3-2.7, Sr 415-515 ppm.
26.0	1225	Tsuf Tsd	SCV dikes and upper flows. Olivine-pyroxene and hornblende andesites petrographically and geochemically similar to Tsa.
Oligocene	1000	Tsp	SCV pyroclastic lapilli tuff and ash tuff breccias erupted from multiple vents within the study area. A matrix of slightly welded, vesicular cinders or ash carries blocks and bombs of andesite lava. Extensive and locally variable alteration of the matrix.
28.7 30.6	700	Tsa	Main sequence of SCV andesite lava flows. Sparse phenocrysts of pyroxene, magnetite ± ilmenite, olivine, hornblende, and rarely plagioclase in trachytic, intergranular, or hyalopilitic matrices. Also rare xenocrysts of quartz, plagioclase, and oxide. Compositions show cyclic variations upsection within the ranges SiO_2 53-61%, K_2O 1.7-2.3%, Fe/Mg 1.5-2.5, Sr 910-1500 ppm.
30.9	150	Tsob	SCV olivine basalt flows. Phenocrysts of olivine, magnetite, and ilmenite, plus rare xenocrysts of quartz and plagioclase in trachytic textured matrices. SiO_2 48-52%, K_2O 1.4-1.8%, Fe/Mg 1.4-1.5, Sr 1040-1680 ppm.
Cretaceous	0	Kg	Coarse-grained granodiorite related to the Idaho batholith. SiO_2 67-75%, K_2O 1.9-3.6%, Fe/Mg 2.8-5.4, Sr 615-670 ppm.

*Fe/Mg = Fe_tO_3/MgO where Fe_tO_3 represents total iron.

FIGURE 2. *A summary of the map units shown on figure 1.*

TABLE 1. Representative major and trace element analyses of SCV lavas. The major elements have been normalized to 100%.

Sample:	SCV 16	SCV 28	SCV 38	SCV 53	SCV 58
Unit:	Tsob	Tsa	Tsa	Tsd	Tsuf
SiO_2	48.31	54.11	58.74	56.42	60.60
TiO_2	2.07	1.66	1.06	1.88	1.01
Al_2O_3	15.47	16.63	17.41	18.37	16.44
Fe_2O_3	10.93	8.75	6.51	6.65	5.91
MnO	0.15	0.10	0.17	0.07	0.11
MgO	8.02	3.69	2.93	2.10	3.33
CaO	8.83	8.00	6.10	6.54	5.21
Na_2O	3.88	4.77	4.49	4.37	4.40
K_2O	1.40	1.71	2.08	2.48	2.48
P_2O_5	0.95	0.58	0.51	1.13	0.50
Sr	1559	1272	1209	1689	992
Ba	968	795	1296	1848	1003
Y	19	17	23	23	15
Zr	178	149	155	236	155
Sc	20.5	18.3	12.5	11.5	10.2
Co	39	27	24	26	21
V	250	225	151	235	125
Ni	99	54	29	26	42
Cr	206	97	95	27	70

cycles are clearly dominated by crystal fractionation, eventually culminating in the volatile build-up that led to the pyroclastic eruptions.

Samples for dating were taken from one of the lowermost olivine basalt flows, from an olivine-pyroxene andesite that marks the base of the first well-defined fractionation cycle within the main sequence of flows, and from one of the hornblende andesite dikes that cut the pyroclastic units. The determined ages thus bracket the span of SCV activity and are consistent with an age of 30.6 ± 1.0 Ma given by Ekren, et al. (1981) for the lowermost andesite flow.

METHODS

Samples for K-Ar dating were selected on the basis of thin section examination, and conventional K-Ar techniques (Dalrymple and Lanphere, 1969) were used to determine the ages reported here. The rock samples were sawed to remove any weathered surfaces, and then crushed to 0.84–2.00 mm size fraction. The crushed samples were washed in distilled water, dried and split into two aliquots: one was used for Ar-analysis and the other was powdered and used for K-analysis. K concentrations were measured by atomic absorption spectrophotometry. Ar isotope concen-

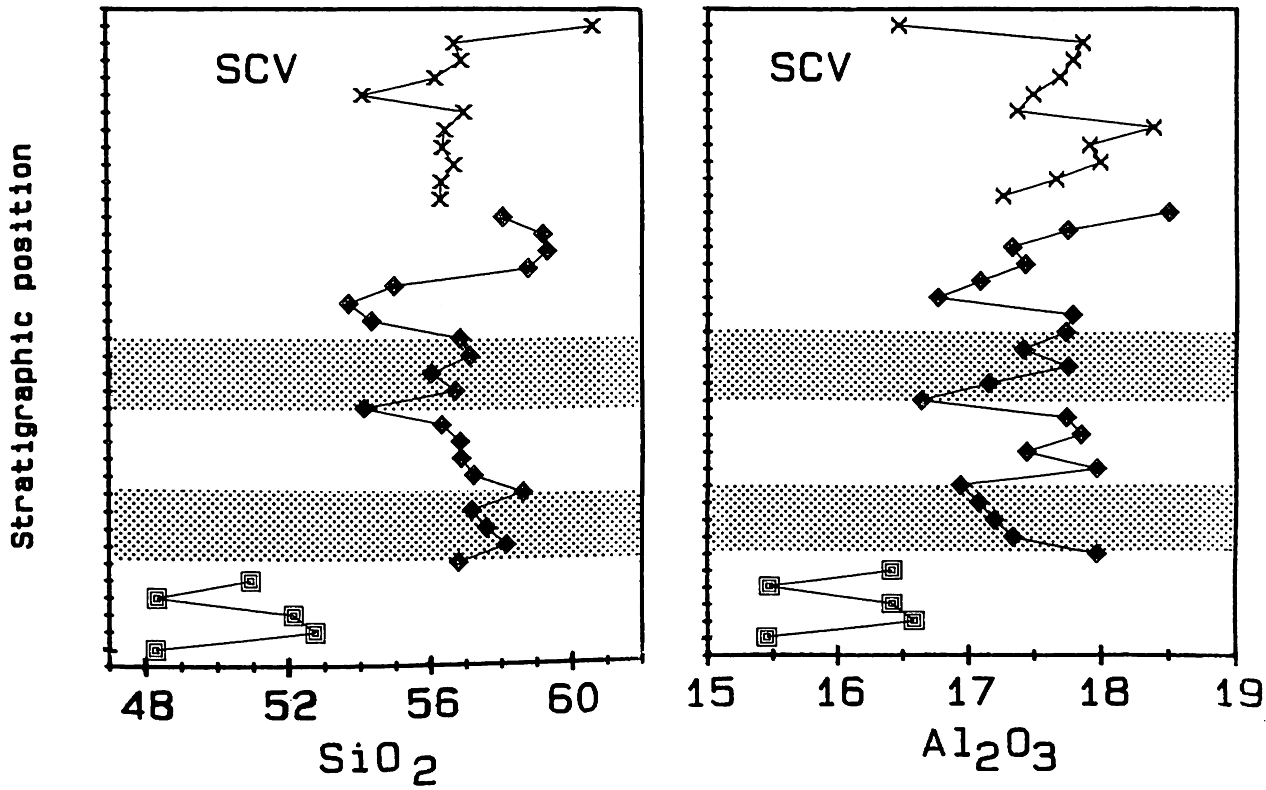
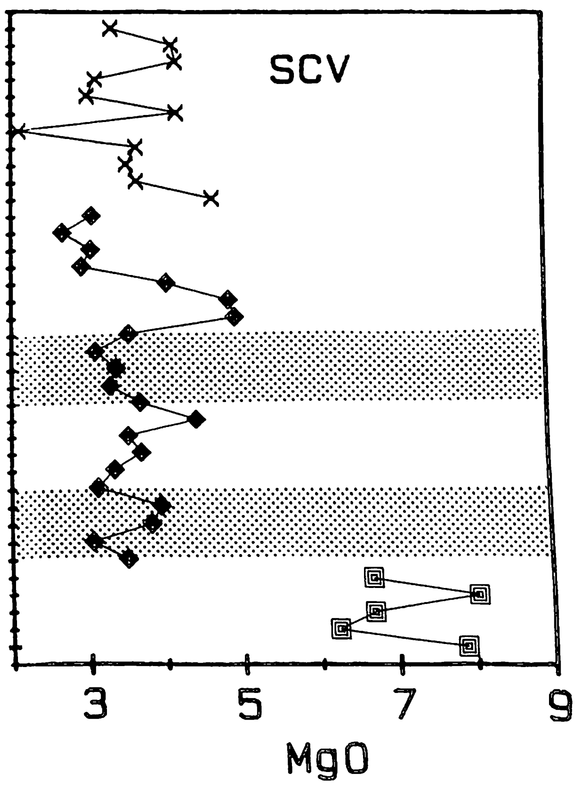


FIGURE 3. Compositions of the SCV lavas plotted as a function of relative stratigraphic position. Squares represent Tsob, diamonds are Tsa, and X's are Tsd and Tsuf. Note the sharp break between the basal basalts and the andesites, and the compositional cycles within the main sequence of andesites. Stippling highlights these cycles.



trations were measured by ^{38}Ar isotope dilution with an AEI-MS10 mass spectrometer equipped with two in-line high vacuum extraction systems.

The major and trace element analyses presented in table 1 were obtained by inductively-coupled plasma emission spectrometry (ICP) at Rice University. Solutions were prepared by fusion of rock powders with a mixed lithium metaborate-lithium tetraborate flux, and dissolution of the glass fusion bead in dilute nitric acid. Details of our analytical procedures will be published elsewhere.

SAMPLE DESCRIPTIONS

1. *SCV 16* — K-Ar

   Flow of olivine phyric basalt near the base of the SCV section (43°17′15″N,116°49′20″W; ID). Phenocrysts of olivine (to 3mm) and Fe-Ti oxide (to 0.05 mm) in a pilotaxitic to trachytic matrix of plagioclase laths (to 0.10 mm long) and interstitial clinopyroxene, oxide, and olivine with accessory biotite, apatite, and glass. A trace of secondary hematite and calcite is present and olivines are slightly altered along cracks and grain edges. *Analytical data:* K = 1.11%; ^{40}Ar = 1.30 × 10^{-6} cc/gm; $^{40}Ar^{rad}/^{40}Ar^{TOT}$ = 84.5%.

   (whole rock) 30.9 ± 0.3 m.y.

2. *SCV 28* — K-Ar

   Olivine-phyric andesite flow from the lower third of the andesite pile (43°17′22″N,116°49′51″W; ID). Matrix is holocrystalline intergranular with randomly oriented laths and sheaves of plagioclase and interstitial clinopyroxene, olivine, and oxide with accessory biotite and apatite. Most of the olivine phenocrysts are altered, probably by deuteric interaction with the hydrous magma. *Analytical data:* K = 1.39%; $^{40}Ar^{rad}$ = 1.56×10^{-6} cc/gm; $^{40}Ar^{rad}/^{40}Ar^{TOT}$ = 96.7%.

(whole rock) 28.7 ± 0.3 m.y.

3. *SCV 53* K-Ar

Hornblende andesite dike that cuts pyroclastic breccia (43°17'19"N,116"51'24"W; ID). Phenocrysts of hornblende (to 5 mm long), clinopyroxene (to 0.4 mm long), plagioclase, and apatite in a hyalopilitic to trachytic matrix of small plagioclase laths surrounded by brown mesostasis. *Analytical data:* K = 1.81%; $^{40}Ar^{rad}$ = 1.84×10^{-6} cc/gm; $^{40}Ar^{rad}/^{40}Ar^{TOT}$ = 65.3%.

(whole rock) 26.0 ± 0.3 m.y.

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