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L.B. Gray, D.R. Sherrod, and R.M. Conrey

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POTASSIUM-ARGON AGES FROM THE NORTHERN OREGON CASCADE RANGE

LEDA BETH GRAY — *U.S. Geological Survey, Menlo Park, CA 94025*
DAVID R. SHERROD — *U.S. Geological Survey, Vancouver, WA 98661*
RICHARD M. CONREY — *Washington State University, Pullman, WA 99164*

INTRODUCTION

We report nine ages and geochemical data, from volcanic rocks near Mount Hood in the Cascade Range of northern Oregon. The ages are mostly late Miocene and younger, and predate construction of the modern composite Mount Hood stratocone. This investigation is part of a larger study of the eruptive history of Mount Hood, undertaken by the U.S. Geological Survey to assess potential volcanic hazards at the volcano. Rock units in this area are often indistinguishable with respect to lithology and chemistry, thus radiometric age data allow correlation over long distances or across areas where units cannot be traced. The data supplement earlier work which primarily focused on Mount Hood (near center of fig. 1) or on strata of the Columbia River Basalt Group (exposed only in a few deep canyons).

ANALYTICAL TECHNIQUES

Sample preparation and K-Ar analytical procedures were conducted at U.S. Geological Survey laboratories in Menlo Park, Calif. Five whole-rock samples and four feldspar separates were analyzed. Two of the whole-rock samples were crushed to between 35 and 60 mesh and treated with 5 percent HF for 2 minutes followed by 14 percent HNO_3 for 30 minutes to remove fine-grained alteration minerals and glass. The other three were crushed to between 9 and 20 mesh but were not acid-treated. Three plagioclase separates and one sanidine separate were prepared using standard magnetic separation techniques. Feldspar separates were between 60 and 140 mesh in size, and plagioclases were given the same acid treatment used on the whole rock samples to remove adhering material.

Potassium analyses on powdered splits were performed using flame photometry as described by Ingamells (1970). Argon analyses were made by standard isotope dilution procedures (Dalrymple and Lanphere, 1969). The sanidine sample (S5-28) was fused with a few grams of fused basalt glass as flux to promote complete outgassing of the radiogenic ^{40}Ar, as sanidine is commonly quite refractory. No independent criteria exist by which to determine whether outgassing was complete, therefore, although this age appears consistent with the geology, it should be considered a minimum age.

Table 1 lists ages and analytical data for each of the runs. Assigned errors for individual analyses are estimates of analytical precision at one standard deviation, calculated by the method of Cox and Dalrymple (1967), except that error in spectrometer mass discrimination was also taken into account. For samples with replicate Ar analyses, weighted mean ages were calculated, with weighting proportional to the inverse of the variances of individual analyses (Taylor, 1982). The mean square of weighted deviates (MSWD, McIntyre and others, 1966) was calculated in order to determine if experimental error accounted for the dispersion of replicate analyses, as suggested by Fleck (oral comm., 1994). Errors accompanying the weighted means are the greater of (1) the uncertainty of the weighted mean shown in Taylor (1982) or (2) the same multiplied by the square root of the MSWD, thereby taking into account observed dispersion.

Major- and trace-element analyses (table 2) were conducted at the Department of Geology, Washington State University, Pullman, Wash., or at U.S. Geological Survey laboratories in Menlo Park, Calif., and Denver, Colo. Washington State University analyses were performed by R.M. Conrey on an automated Rigaku 3370 spectrometer using a single fused disk (ratio of lithium tetraborate to rock powder is 2:1). Each element is fully corrected for line interference and matrix effects of all other analyzed elements. U.S. Geological Survey analyses were completed using X-ray spectroscopy for major elements. Trace elements were analyzed by energy-dispersive X-ray fluorescence except Cr, which was analyzed by wavelength-dispersive X-ray fluorescence.

Remanent magnetization was determined for each unit sampled, using a portable fluxgate magnetometer. These polarity determinations and ages of samples are shown on the paleomagnetic time scale of Cande and Kent (1992) (fig. 2).

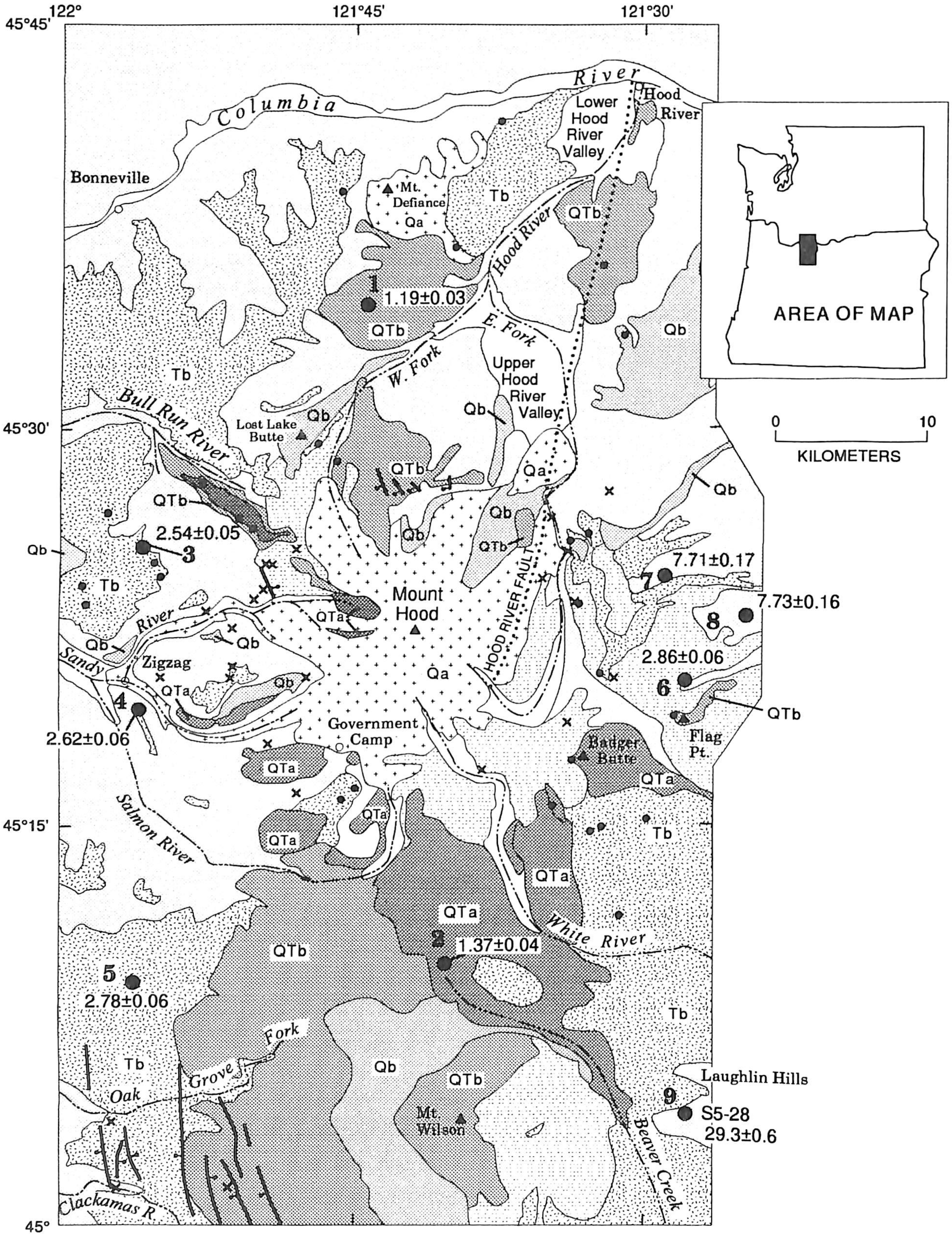

FIGURE 1. Generalized geologic map showing locations of K-Ar samples from the Mount Hood area, northern Oregon (from Sherrod and Smith, 1989, and Sherrod and Scott, 1995).

	Alluvium (Holocene and Pleistocene)
Qa	Andesite (Holocene and Pleistocene)—Chiefly lava flows and pyroclastic deposits at Mount Hood
Qb	Basaltic andesite (Pleistocene)—Chiefly lava flows. Age less than 0.78 Ma
QTa	Andesite (Pleistocene and Pliocene)—Chiefly lava flows. Older than 0.78 Ma; oldest part of unit was erupted at Badger Butte about 2 Ma
QTb	Basalt and basaltic andesite (Pleistocene and Pliocene)—Lava flows. Age mostly older than 0.78 Ma but some flows east of Lost Lake Butte are younger. Unit may be as old as 2.5 Ma in southwest corner of map area; elsewhere not older than about 2 Ma
Tb	Basalt (Pliocene)—Lava flows. Most ages range from 2 to 4.5 Ma
	Andesite, dacite, and rhyolite (Pliocene and upper Miocene)—Chiefly lava flows. Age ranges from 2 to 8 Ma
	Older rocks (upper Miocene to Oligocene)— Chiefly upper Miocene Dalles Formation and middle Miocene Rhododendron Formation and Columbia River Basalt Group. Also, includes lower Miocene and Oligocene volcanic rocks in southeast and southwest corners of map area
	Contact
	Fault—Dotted where concealed. Ball and bar on downthrown side. Not shown are structures older than about 11 Ma
5 ● 2.78±0.09	Sample location—Showing map number and age (Ma); see table 1 for analytical data
	Other dated samples
•	Localities of Conrey and others (in press)
×	Localities of Wise (1969), Priest and others (1982), or Keith and others (1985)

Figure 1 explanation.

UPPER MIOCENE AND PLIOCENE ANDESITE, DACITE, AND RHYOLITE

A sequence of upper Miocene andesite, dacite, and rhyolite is exposed south of Lost Lake Butte and east of Mount Hood. Judging from the map pattern (Unit Ta in fig. 1), the sequence is inferred to be continuous beneath Mount Hood. Ages of ~5.8 and ~6.3 Ma were determined from exposures near Lost Lake Butte (Lolo Pass area) by Wise (1969) and Keith and others (1985), respectively. We determined an age of 2.86 ± 0.06 Ma from the youngest part of this sequence east of the Cascade Range crest (sample 6, fig. 1). Silicic domes in the Flag Point area (east-central part of fig. 1) shed pyroclastic flows eastward into the Tygh Valley area. These pyroclastic deposits and coeval sedimentary rocks are considered to be between ~3 and 5 Ma in age for the following reasons: they underlie the 2.86-Ma andesite (sample 6), contain a tuff that yielded an age of 4.9 ± 0.5 Ma (Farooqui and others, 1981), and overlie an andesite that has an age of 5.1 ± 0.5 Ma (Farooqui and others, 1981).

PLIOCENE BASALT

Mafic lava flows (olivine basalt and basaltic andesite) along the west side of the Cascade Range crest overlie previously dated strata of the 14- to 11-Ma Rhododendron Formation or locally-occurring andesite lava about 11 to 9 Ma in age (Wise, 1969; Priest and others, 1982; Keith and others, 1985). The mafic rocks dated for this study yield ages between about 2.9 and 2.5 Ma (samples 3, 4, 5), but the sequence ranges in age from about 4 Ma to as young as 2 Ma (Conrey and others, 1996).

These Pliocene volcanic rocks (unit Tb) are as thick as 350 m in the northwest part of the map area (fig. 1) and greater than 1,000 m in the southwest part. They have been carved by streams and glaciers to form the narrow ridges and deeply incised canyons characteristic of the Western Cascades geomorphic province. A striking example of inverted topography produced by the canyon-cutting process is found at Hunchback Mountain (sample 4, south of Zigzag; fig. 1), where an ancestral intracanyon lava flow (2.62 ±

TABLE 1. New K-Ar ages from the Cascade Range, north-central Oregon.

Map number	Sample number	Location Lat. (N)	Location Long. (W)	Rock type	Material dated	K_2O (wt %)[1]	$^{40}Ar_{rad}$ (10^{-12}mol/g)	Percent $^{40}Ar_{rad}$	Calculated age (Ma)[2]	Weighted mean age (Ma)[3]
1.	S5-32	45°33.75'	121°45.70'	Basaltic	Whole rock	(1.095)				1.19±0.03
				andesite	(9-20 mesh)	1.097	1.885	23.3	1.20±.04	
						1.088	1.863	19.7	1.18±.04	
						1.103				
						1.093				
2.	S5-44	45°09.43'	121°39.15'	Andesite	Whole rock	(1.427)				1.37±0.04
					(35-60 mesh	1.417	2.741	30.7	1.33±0.04	
					HF, HNO_3)	1.439	2.905	51.2	1.41±0.04	
						1.419				
						1.433				
3.	S5-47	45°25.62'	121°55.54'	Basalt	Whole rock	(1.619)				2.54±0.05
					(9-20 mesh)	1.612	5.998	41.0	2.57±0.07	
						1.608	5.860	46.6	2.51±0.07	
						1.633				
						1.624				
4.	S88-22	45°19.65'	121°55.90'	Basalt	Whole rock	(0.7148)				2.62±0.06
					(35-60 mesh	0.723	2.671	22.8	2.59±0.08	
					HF, HNO_3)	0.716	2.722	18.2	2.64±0.08	
						0.712				
						0.708				
5.	S5-26	45°09.40'	121°56.45'	Basaltic	Whole rock	(0.8475)				2.78±0.06
				andesite	(9-20 mesh)	0.843	3.468	32.8	2.84±0.08	
						0.843	3.324	19.0	2.72±0.08	
						0.846				
						0.858				
6.	S88-25	45°20.45'	121°27.45'	Andesite	Plagioclase	(0.9905)				2.86±0.06
						0.984	4.176	77.7	2.93±0.07	
						0.986	3.920	60.7	2.75±0.07	
						0.996	4.122	38.7	2.89±0.07	
						0.996				
7.	S88-23	45°24.39'	121°27.78'	Dacite	Plagioclase	(0.2240)				7.71±0.17
						0.221	2.525	28.5	7.81±0.24	
						0.220	2.459	33.7	7.61±0.23	
						0.226				
						0.229				
8.	S88-24	45°23.26'	121°20.05'	Dacitic	Plagioclase	(0.2503)				7.73±0.16
				diamictite		0.249	2.780	34.6	7.70±0.23	
						0.249	2.797	28.1	7.75±0.23	
						0.255				
						0.248				
9.	S5-28	45°03.91'	121°27.90'	Rhyolitic	Sanidine	(7.083)				29.3±0.6[4]
				ash-flow tuff	(with fused	7.14	301.1	82.8	29.3±0.6	
					basalt flux)	7.15				
						7.02				
						7.02				

Notes:

[1]For multiple determinations, value in parentheses is arithmetic mean used in age calculation.

[2]K-Ar ages were calculated using the constants for the radioactive decay and abundance of ^{40}K recommended by the International Union of Geological Sciences Subcommission on Geochronology (Steiger and Jäger, 1977). These constants are:

$\lambda_\varepsilon = 0.581 \times 10^{-10}yr^{-1}$, $\lambda_\beta = 4.962 \times 10^{-10}yr^{-1}$, and $^{40}K/K_{total} = 1.167 \times 10^{-4}$ mol/mol.

[3]Mean ages are weighted by the inverse of the variance of individual runs (Taylor, 1982). Errors are the estimates of standard deviation of analytical error (Cox and Dalrymple 1967), and where dispersion is greater than is accounted for by experimental error, the mean square of weighted deviates (MSWD) is used to calculate an overall error which takes that dispersion into account (Fleck, pers. comm.).

[4]This age should be considered a minimum age due to possible insufficient outgassing of radiogenic ^{40}Ar. Fused basalt glass was added as a flux but there are no independent criteria on which to judge whether outgassing was complete.

TABLE 2. Major- and trace-element analyses of newly dated samples from the Cascade Range, northern Oregon. All data from Washington State University except No. 7 and major elements for Nos. 6 and 8, which are from U.S. Geological Survey.

Table 1 no.	1	2	3	4	5	6	7	8
Sample no.	S5-32	S5-44	S5-47	S88-22	S5-26	S88-25	S88-23	S88-24
Age (Ma)	1.19 ± 0.04	1.37 ± 0.03	2.54 ± 0.80	2.26 ± 0.06	2.78 ± 0.09	2.86 ± 0.04	7.71 ± 0.17	7.73 ± 0.16
Major-element analyses (weight percent)								
SiO_2	54.55	62.53	50.98	49.84	54.51	61.80	62.30	61.80
Al_2O_3	17.48	17.55	16.10	16.67	17.71	16.80	17.20	16.80
Fe_2O_3	—	—	—	—	—	2.77	2.88	2.19
FeO	7.98	5.91	10.00	11.03	8.69	2.64	2.20	2.69
MgO	5.20	2.45	7.98	7.57	4.77	2.31	2.08	2.31
CaO	8.05	5.45	8.60	9.27	7.95	5.34	5.52	5.30
Na_2O	3.93	4.31	3.45	3.05	3.88	3.94	4.09	3.34
K_2O	1.06	1.44	1.59	0.70	0.89	2.03	1.17	2.03
TiO_2	1.36	0.93	2.09	1.33	1.35	0.83	0.70	0.66
P_2O_5	0.34	0.23	0.58	0.19	0.46	0.22	0.18	0.15
MnO	0.13	0.10	0.16	0.18	0.15	0.09	0.08	0.08
H_2O^+	—	—	—	—	—	0.33	0.43	1.65
H_2O^-	—	—	—	—	—	0.49	0.59	0.55
CO_2	—	—	—	—	—	0.08	0.06	0.68
Total	100.08	100.91	101.52	99.83	100.36	99.67	99.48	100.23
SiO_2, normalized water- and CO_2-free	54.51	61.97	50.21	49.92	54.32	62.57	63.31	63.48
Trace-element analyses (parts per million)								
Ni	79	19	166	82	62	24	14	30
Cr	89	13	234	161	82	33	28	31
Sc	26	15	26	34	24	11	—	10
V	173	89	180	189	166	107	—	87
Ba	334	278	661	229	412	377	320	353
Rb	10	17	34	8	10	47	22	35
Sr	854	524	616	610	556	499	465	414
Zr	169	187	281	122	199	221	160	172
Y	20	22	26	27	26	21	16	15
Nb	14	13	22	6.4	16	14.6	10	11.7
Ga	19	19	19	15	17	19	—	21
Cu	85	55	82	52	94	24	74	35
Zn	89	74	98	96	105	66	74	64
Pb	—	—	—	5	—	4	—	5
La	—	—	—	20	—	34	<30	19
Ce	—	—	—	58	—	78	<30	61
Th	—	—	—	0	—	7	—	3

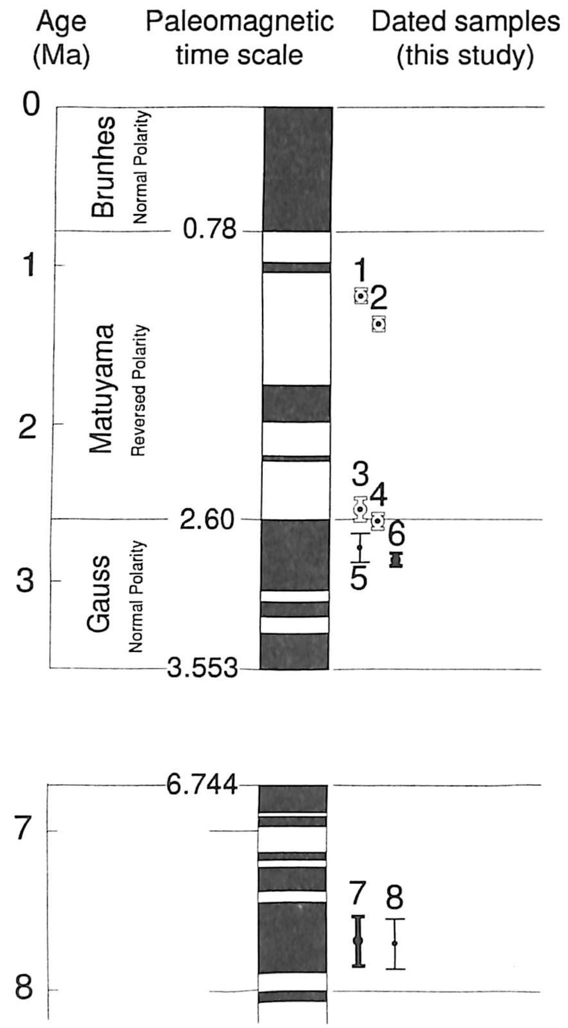

FIGURE 2. Correlation of dated samples with paleomagnetic time scale. Patterned to show remanent magnetization: dark fill, normal polarity; white fill, reversed polarity. Bars showing age and standard deviation are similarly patterned. Thin unpatterned bar shows sample of unknown magnetic polarity. Remanent magnetization was determined using portable fluxgate magnetometer. Time scale from Cande and Kent (1992).

0.06 Ma) has been left perched as a narrow ridge-capping lava flow on the interfluve between the Salmon and Zigzag Rivers. Based on this age determination and a depth of incision of ~300 m, the rate of incision has averaged 11-12 cm per 1,000 yr over the last 2.6 million years.

Similar mafic rocks, less than 200 m thick, are exposed on the east side of the range crest but have not been as deeply incised. Isotopic ages from the east side range from ~2 to 3 Ma (Conrey and others, 1996).

LOWER QUATERNARY LAVA FLOWS

We obtained ages of 1.19 ± 0.03 Ma (sample 1) and 1.37 ± 0.04 Ma (sample 2) from lower Quaternary lava flows (parts of units QTb and QTa, respectively, fig. 1) which in places overlie Pliocene lava flows. Most of these flows possess reversed-polarity magnetization, so they were known to be at least early Quaternary in age. They are lithologically similar to Pliocene lava, however, so isotopic dating is the only means to correctly show the limited extent of Quaternary volcanism. These Quaternary flows have been mapped separately in order to better understand the rate of volcanism and tectonism in the northern Oregon Cascade Range (Sherrod and Scott, 1995).

AGE OF THE DALLES FORMATION

The Dalles Formation is one of the better-known Cascade Range stratigraphic units. It consists chiefly of andesitic lithic block-and-ash flows and laharic deposits exposed on the east side of Mount Hood and basinward 40 km northeast to the Columbia River. The Dalles Formation was previously thought to be an east side equivalent of the Rhododendron Formation, mainly on the basis of lithology and stratigraphic position: both are volcaniclastic units and overlie the Columbia River Basalt Group. A chemical correlation between the Rhododendron and Dalles Formations also had been suggested (Gannett, 1982).

A growing body of isotopic ages suggests, however, that much of the Dalles Formation ranges in age from about 8 to 6 Ma and therefore is temporally distinct from the 14- to11- Ma Rhododendron Formation. We obtained an age of 7.73 ± 0.16 Ma on a plagioclase from a frothed dacitic clast in a monolithologic deposit midway through the Dalles Formation at Fifteenmile Creek (sample 8, fig. 1).

The Dalles Formation becomes increasingly rich in block-and-ash deposits toward its inferred source area along the East Fork of Hood River. Andesitic and dacitic domes there have yielded ages of 8.18 ± 0.06, 7.0 ± 0.8, and 6.2 ± 1.3 Ma (Keith and others, 1985; Wise, 1969; P.E. Hammond in Fiebelkorn and others, 1983). Our age of 7.71 ± 0.17 Ma (sample 7) from the dacite dome at Fivemile Butte fits with this sequence.

ROCKS IN THE LAUGHLIN HILLS

The oldest age obtained in this study is from a welded tuff in the southeast part of the map area (sample

9, fig. 1). This tuff is interbedded in a thick sequence of andesite lava flows exposed in the Laughlin Hills, which forms the northerly dipping flank of an east-trending fold capped by lava of the Columbia River Basalt Group. The andesite flows were mapped previously as Clarno Formation (Waters, 1968) on the basis of lithologic similarity to other andesite flows 70 km to the east near Clarno, Oregon. Assignment of the Laughlin Hills lava to the Clarno Formation would suggest their age is at least 39 Ma.

In contrast, we obtained an age of 29.3 ± 0.6 Ma from soda-sanidine in the tuff (sample 9). Although the age is presented as a minimum age owing to the possibility of incomplete outgassing of the sanidine during gas extraction in the laboratory, we prefer this age to the older age assignment implied by Water's (1968) mapping. McDowell (1983) found that most laboratories using basalt flux when fusing alkali feldspars were recovering all but a few percent of radiogenic argon, which would have an effect of less than a half million years on this sample.

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SAMPLE DESCRIPTIONS

1. *S5-32*
Basaltic andesite. Gently southeast-dipping flow in roadcut (unsectioned but probably SE 1/4 S13,T1N, R8E; Forest Rd 1310-650, 4,000 ft elevation, Wahtum Lake 7.5′ quad., Hood River Co., OR). Porphyritic intergranular basaltic andesite; 1% clinopyroxene phenocrysts; 1-2% olivine phenocrysts; seriate plagioclase. Reversed-polarity thermal remanent magnetization (TRM)
K-Ar (Whole Rock) 1.19 ± 0.03 Ma

2. *S5-44*
Andesite flow. Roadmetal quarry (north-center S10, T5S,R9E; US Hwy 26, 3,360 ft elevation, 300 m west of jct with Forest Rd 43, Wapinitia Pass 7.5′ quad., Wasco Co., OR). Porphyritic two-pyroxene andesite; 5% plagioclase phenocrysts; 1-2% total pyroxene phenocrysts; ≤1% olivine phenocrysts. Reversed-polarity TRM.
K-Ar (Whole Rock) 1.37 ± 0.04 Ma

3. *S5-47*
Basalt flow. Quarry on south flank of Thimble Mountain (NE 1/4 S3,T2S,R7E; Forest Rd 1200-055, 3,840 ft elevation, Hickman Butte 7.5′ quad., Clackamas Co., OR). Porphyritic intergranular basalt; 5% olivine phenocrysts. Reversed-polarity TRM.
K-Ar (Whole Rock) 2.54 ± 0.05 Ma

4. *S88-22*
Basalt flow. Frost-heaved outcrop at west end of Hunchback Mountain (center S10,T3S,R7E; Hunchback Mountain trail, 3,400 ft elevation, Rhododendron quad., Clackamas Co., OR). Porphyritic basalt; 5% olivine phenocrysts; seriate plagioclase phenocrysts. Reversed-polarity TRM where sampled in adjacent outcrops.
K-Ar (Whole Rock) 2.62 ± 0.06 Ma

5. *S5-26*
Basaltic andesite flow. Roadcut (NW 1/4 S10,T5S, R7E; Forest Rd 4610-240, 4,800 ft elevation, High Rock quad., Clackamas Co., OR). Porphyritic intergranular basaltic andesite; ≤1% clinopyroxene phenocrysts; seriate plagioclase phenocrysts. Polarity unmeasured.
K-Ar (Whole Rock) 2.78 ± 0.06 Ma

6. *S88-25*
Platy andesite flow. Outcrop above road near Three Bear Spring (NW 1/4 S5,T3S,R11E; Forest Rd 2730-200, 4,760 ft elevation, Flag Point quad., Wasco Co., OR). Porphyritic inclusion-rich two-pyroxene andesite; 10% plagioclase phenocrysts; 1-2% total pyroxene phenocrysts. Normal-polarity TRM.
K-Ar (Plagioclase) 2.86 ± 0.06 Ma

7. *S88-23*
Dacite flow. Roadcut (SW 1/4 S7,T2S,R11E; Forest Rd 4400-120, 4,400 ft elevation, Fivemile Butte quad., Wasco Co., OR). Porphyritic two-pyroxene dacite. 5% plagioclase phenocrysts. Normal-polarity TRM.
K-Ar (Plagioclase) 7.71 ± 0.17 Ma

8. *S88-24*
Debris-flow deposit (diamictite). Roadcut (NW 1/4 S20,T2S,R12E; Forest Rd 4421, 2,500 ft elevation, Wolf Run quad., Wasco Co., OR). Dacite clast from monolithologic deposit. Clasts range from 4 to 60 cm

across; sampled clast was 60 cm. Porphyritic; 10% plagioclase phenocrysts; ≤1% orthopyroxene phenocrysts; ≤1% olivine phenocrysts.

K-Ar (Plagioclase) 7.73 ± 0.16 Ma

9. *S5-28*

Rhyolitic welded ash-flow tuff. Outcrop near road S-509 on Warm Springs Indian Reservation (NE 1/4 S7,T6S,R11E; 2,880 ft elevation, Foreman Point quad., Wasco Co., OR). Pale yellow-brown flattened pumice lapilli (fiamme) in moderately porphyritic light-brown groundmass; 10% feldspar phenocrysts; <1% biotite phenocrysts.

K-Ar (Sanidine with basalt flux) 29.3 ± 0.6 Ma

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