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# POTASSIUM-ARGON AGES FROM MOUNT HOOD AREA OF CASCADE RANGE, NORTHERN OREGON

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## INTRODUCTION

We report here on potassium-argon (K-Ar) ages from chiefly basalt and basaltic andesite lava flows in the Mount Hood area and northward to the Columbia River (fig. 1). This part of the Cascade Range forms a transitional zone across which Pliocene and Quaternary volcanoes diminish in number northward. The more numerous vents in northern Oregon erupted a nearly continuous cover of lava flows; whereas in Washington the cover is sporadic and the volcanoes stand isolated.

Our interest is directed toward the link between petrologic and tectonic evolution. Farther south in central Oregon, an along-arc graben developed about 5 Ma, synchronous with eruptions of basalt and basaltic andesite (for example, Smith and others, 1987). Less well understood is the timing and extent of faulting northward and its relation to volcanism. Previous studies in northern Oregon concentrated on Mount Hood itself and immediately adjacent areas (mainly Wise, 1969; Priest and others, 1982; Keith and others, 1985; Bargar and others, 1993). Until our work, little was known regarding the regional extent, composition, and age of Pliocene and Quaternary volcanic rocks.

## PROCEDURES

Samples were collected using a large sledgehammer to whittle chips from the cores of the freshest blocks at outcrop. We sampled chiefly basalt and basaltic andesite lava flows from areas where radiometric ages were largely lacking. Sites were chosen on the basis of geologic mapping, which is most complete south of lat. 45°30′ (Sherrod and Scott, 1995). In several cases, previously published chemical analyses by Wise (1969) influenced our choice of sampling locations (see sample descriptions for mention of Wise's sampling locations).

Sample preparation and analyses were conducted at the Geological Survey of Japan (GSJ) in Tsukuba, Japan. Whole-rock samples were crushed to between either 10- and 16-mesh or 16- and 30-mesh and then bathed in an ultrasonic distilled-water bath to remove adhering dust. Based on estimated age and $K_2O$ content we fused between 7 and 10 grams of material. A few samples were spiked with $^{38}Ar$ spike tubes prepared using the method described by Shibata (1968); most spikes were introduced from a spike reservoir. The reservoir was calibrated during the course of the experiments by repeated analyses of standard biotite JG-1 (Uto and others, 1995).

Potassium analyses on powdered splits were performed with flame photometry using internal Li standards to improve precision (Matsumoto, 1989). The pooled one sigma error in potassium determinations at the GSJ is 0.5 percent. Argon analyses were made by standard isotope dilution procedures as described by Dalrymple and Lanphere (1969). During the course of the experiments, the mass spectrometer was fitted for automatic control by a personal computer and data were collected digitally (Uto and others, 1995). This innovation significantly reduced analytical errors.

Potential sources of total analytical error were thoroughly evaluated. The reported one sigma error in age includes contributions from errors in determining spike volumes, atmospheric air ratios and potassium concentrations, least squares fitting of the $^{38}Ar/^{36}Ar$ and $^{40}Ar/^{36}Ar$ ratios, and errors due to poor radiogenic yields. In several cases, duplicate or triplicate analyses were made on single samples; for these we report each age and the weighted mean age of the experiments.

Magnetic polarity was measured with a fluxgate magnetometer at most sites. Given the freshness of these lava flows, the magnetization is likely the thermal remnant magnetization (TRM) imposed during emplacement. Aberrant declination and inclination create erratic signals when measured with a portable magnetometer (reported in the sample descriptions as indeterminate magnetic polarity). In one case, this problem was solved for us by drilling and alternating

current demagnetization of the cores (C.A. Gardner, oral commun., 1994).

## RESULTS

Ages and analytical data are reported in table 1. Weighted mean ages are also reported for duplicate or triplicate ages from each of six samples (map Nos. 2, 4, 13, 18, 24, and 28). Triplicate experiments on each of two low-K tholeiitic basalts (map Nos. 24 and 28) produced somewhat scattered results; weighted mean ages reported for these samples include all three measured ages. In both cases, two of the three ages are quite similar and the disparate ages had the lowest yields of radiogenic Ar (table 1). Calculations of weighted mean ages for these samples which do not include the disparate ages are not significantly different from the reported weighted mean ages. In the case of sample 28, an independent age determination by Anderson (1987) from the same or nearby outcrop agrees with the reported weighted mean age.

Three samples were collected near Grasshopper Point, the summit of a broad shield volcano south of Badger Butte. Two of the samples (11 and 15) are chemically and petrographically similar. They gave overlapping ages with small relative errors, but they span nearly 150 m stratigraphically from near the volcano's summit (sample 15, 2.23 ± 0.11 Ma) to its lowest exposures in Boulder Creek (sample 11, 2.07 ± 0.16 Ma). The volcano possesses reversed-polarity or indeterminate magnetization wherever sampled. Taken together, this evidence indicates that the volcano erupted during a short period of time between roughly 2.0 and 2.3 Ma (fig. 2). Sample 17 (W-115) from Rocky Butte, a small satellitic vent on the northeast flank of the Grasshopper Point shield gave a similar age of 2.28 ± 0.11 Ma.

## CORRELATION WITH MAGNETIC TIME SCALE

Most of our ages are in agreement with the paleomagnetic time scale (fig. 2). Two samples (4 and 24) disagree. Because sample 4 is reversely polarized, it is either too young as dated (0.57 ± 0.06 Ma, weighted mean age), or it was erupted during the short-lived Big Lost Reversed-Polarity Subchron (of Brunhes Normal-Polarity Chron), which has a similar age of 0.565 ± 0.014 Ma (Champion and others, 1988). Sample 24 is reversely polarized but has a weighted mean age (2.82 ± 0.11 Ma) that falls within the Gauss Normal-Polarity Chron. It is possible that either the sample was erupted during an undocumented short-lived reversed-polarity subchron, or the age is not correct.

Magnetic polarity serves as a check on the permissible ages for many samples. For example, sample 8 is probably 1.76 Ma or slightly older, on the basis of its normal-polarity magnetization (fig. 2). That evidence is in keeping with its measured age of 1.71 ± 0.08 Ma (an age of 1.76-1.79 Ma is acceptably within the analytical error). This method of constraining ages by polarity determinations is most effective when the analytical error is less than ± 0.20 m.y. In most cases, larger errors allow the age to span so many polarity subchrons that no constraint is provided by knowing a sample's magnetic polarity.

## AGE OF MAFIC VOLCANISM AND EXTENSION

Our results suggest a major pulse of mafic volcanism occurred in the northern Oregon Cascade Range between 2.1 and 4.4 Ma (during Pliocene time). Basalt and basaltic andesite were erupted from small to moderate-size shield volcanoes located mainly northwest and southeast of Mount Hood (fig. 1). Lava accumulated to thicknesses as great as 350 m near the shields. Extension that followed or possibly was associated with this pulse of Pliocene mafic volcanism led to displacement along the Hood River fault, which cuts lavas as young as 2.9 Ma. In the central Oregon Cascade Range, a similar pulse of mafic volcanism and extension was distinctly older and had culminated by 5 Ma (Smith and others, 1987). This 2.1 to 4.4 Ma pulse of mafic volcanism contrasts with the preceding ten million years, when andesitic eruptions dominated the northern Oregon Cascade Range (ages 14 to 5 Ma), and mafic lava was rarely extruded (Wise, 1969; Priest and others, 1982; Keith and others, 1985).

## ACKNOWLEDGMENTS

Potassium-argon ages were obtained by Conrey as part of a generous Japanese Agency for Industrial Science and Technology (AIST) fellowship. We thank the members of the AIST office in Tsukuba, the International Office of the Geological Survey of Japan (GSJ), and the Isotope Geoscience Section of the GSJ for assistance. Bill Wise (Univ. Calif. Santa Barbara) graciously loaned us his field aerial photographs, which

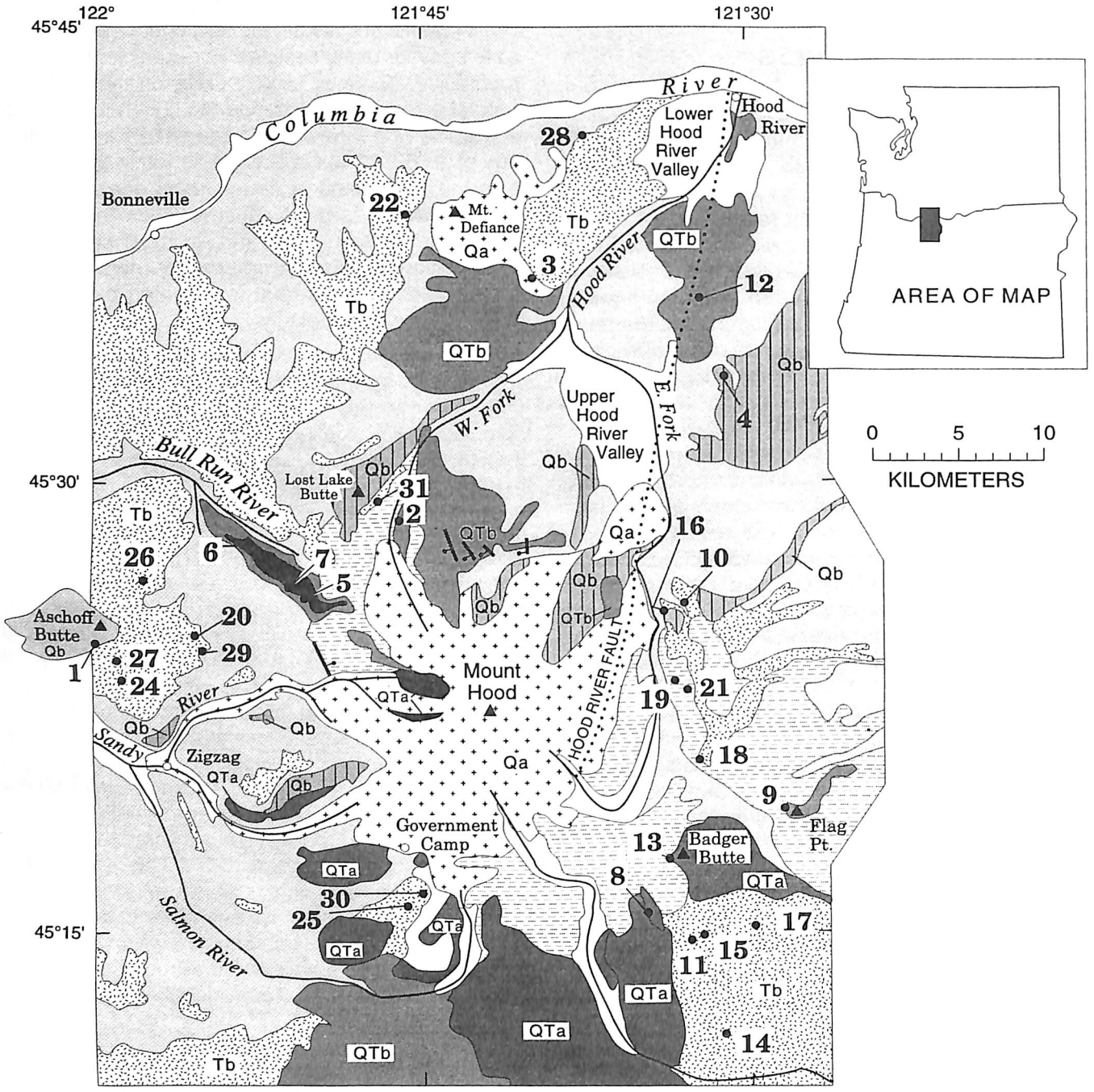


**FIGURE 1. Generalized geologic map showing locations of K-Ar samples from the Mount Hood area, northern Oregon (from Sherrod and Smith, 1989, and Sherrod and Scott, 1995).**

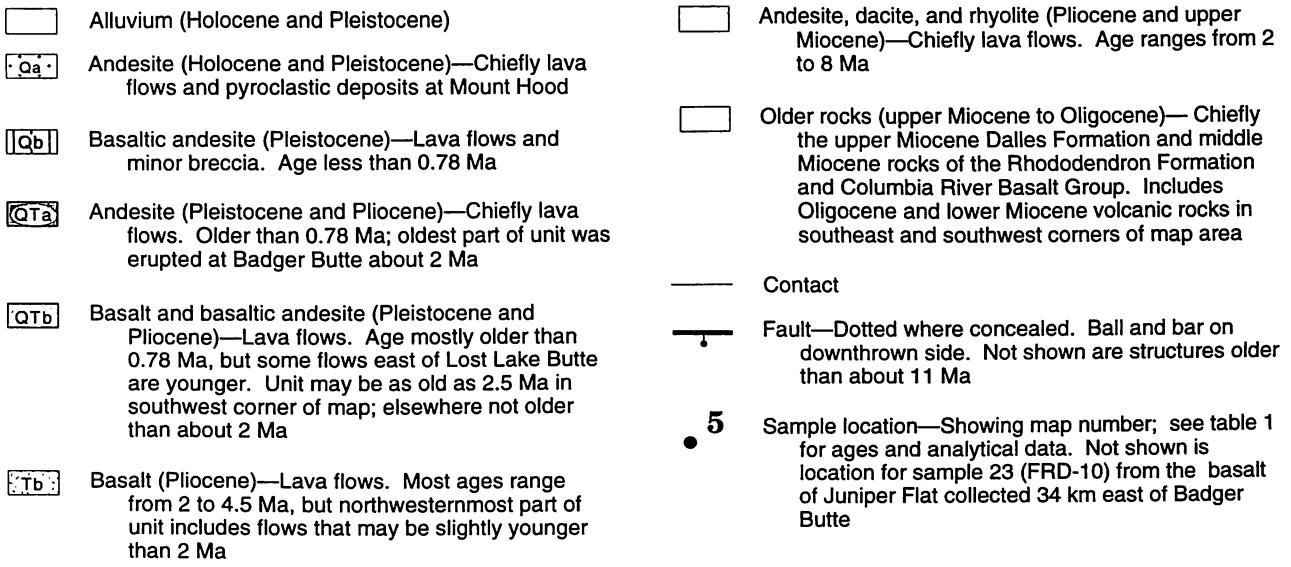


**Figure 1 explanation.**

we used to locate many of his sampling localities. Keith Bargar (USGS, Menlo Park, Calif.) likewise provided us with detailed field maps so we could pinpoint locations for samples previously dated as part of investigations by him, Terry Keith, and their coworkers. We are indebted to Cynthia Gardner (USGS, Vancouver, Wash.) for drilling the outcrop and measuring magnetization at locality 6. We thank George Priest for comments on the text and Jim Smith for his thorough review of the manuscript.

## SAMPLE DESCRIPTIONS

1. S91-H213 K-Ar
Quarry in lava flow erupted from youthful cinder cone Aschoff Butte (NE1/4 S7,T2S,R7E; Forest Rd 1200, 2,840 ft elevation, Hickman Butte 7.5′ quad., Clackamas Co., OR). Normal-polarity. Olivine (2-3%), augite (1-2%) and seriate plagioclase phenocrysts in an intergranular groundmass of plagioclase, pyroxene, and opaque minerals; olivine phenocrysts have traces of wispy iddingsite.
**0.20 ± 0.05 Ma**

2. *W-91* K-Ar
Roadcut in lava flow (NW1/4 S24,T1S,R8E; Forest Rd 18, 2,280 ft elevation, Bull Run Lake 7.5′ quad., Hood River Co., OR). Normal-polarity; erupted from vent on Blue Ridge. Corresponds to Wise locality 91 (Wise, 1969). Olivine (1%) phenocrysts in a fine-grained groundmass of plagioclase, augite, opaque minerals, and sparse brown glass; sample is essentially alteration free.
**Weighted mean age 0.22 ± 0.09 Ma**

3. *DPCK-1* K-Ar
Roadcut in lava flow from Mount Defiance (NE1/4 S2,T1N,R9E; south side of Dead Point Creek, Forest Rd 2820, 1,480 ft elevation, Dee 7.5′ quad., Hood River Co., OR). Normal-polarity. Seriate plagioclase (10%), augite (2-3%), and olivine (1-2%) phenocrysts in an intergranular groundmass of plagioclase, pyroxene, and opaque minerals; traces of alteration and oxidation are present in both olivine phenocrysts and groundmass.
0.50 ± 0.06 Ma

4. *FRMT-1* K-Ar
Roadcut in lava flow (north edge S24,T1N,R10E; Forest Rd 1710, W. Fork Neal Creek, 2,400 ft elevation, Parkdale 7.5′ quad., Hood River Co., OR). Reversed-polarity. Rare plagioclase phenocrysts in a trachytic-intergranular groundmass of plagioclase, pyroxene, and opaque minerals; traces of oxidation along fractures.
**Weighted mean age 0.57 ± 0.06 Ma**

**TABLE 1. New K-Ar whole-rock ages from Cascade Range, northern Oregon.**

| Map number | Sample number | Location | | Rock type | Material dated | $K_2O$ (wt %) | $^{40}Ar_{rad}$ ($10^{-7}$ ml/g) | Percent $^{40}Ar_{rad}$ | Calculated age (Ma)[1] | Weighted mean age (Ma) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Lat. (N) | Long. (W) | | | | | | | |
| 1. | S91-H213 | 45°24.93' | 121°59.10' | Basaltic andesite | Whole rock | 1.154 | 0.0738 | 8.9 | 0.20±0.05 | |
| 2. | W-91 | 45°28.43' | 121°46.17' | Basaltic andesite | Whole rock | 0.745 | 0.0606<br>0.0466 | 4.5<br>3.2 | 0.25±0.12<br>0.19±0.15 | 0.22±0.09 |
| 3. | DPCK-1 | 45°36.14' | 121°39.31' | Andesite | Whole rock | 1.164 | 0.1890 | 18.9 | 0.50±0.06 | |
| 4. | FRMT-1 | 45°33.82' | 121°31.11' | Basaltic andesite | Whole rock | 0.711 | 0.1533<br>0.1200 | 13.7<br>16.3 | 0.67±0.11<br>0.52±0.08 | 0.57±0.06 |
| 5. | W-85 | 45°26.32' | 121°50.35' | Basalt | Whole rock | 0.821 | 0.3296 | 7.4 | 1.24±0.69 | |
| 6. | S91-H206 | 45°28.01' | 121°52.41' | Andesite | Whole rock | 1.233 | 0.5316 | 10.9 | 1.34±0.24 | |
| 7. | W-92 | 45°26.68' | 121°50.96' | Basaltic andesite | Whole rock | 1.094 | 0.4908 | 52.1 | 1.39±0.06 | |
| 8. | S92-H273 | 45°15.55' | 121°34.22' | Andesite | Whole rock | 0.881 | 0.4851 | 37.0 | 1.71±0.08 | |
| 9. | S91-H199 | 45°19.17' | 121°28.16' | Basaltic andesite | Whole rock | 0.996 | 0.6234 | 46.5 | 1.92±0.20 | |
| 10. | S92-H265 | 45°26.01' | 121°32.73' | Basaltic andesite | Whole rock | 0.838 | 0.5577 | 44.4 | 2.06±0.08 | |
| 11. | S92-H284 | 45°15.11' | 121°32.64' | Basalt | Whole rock | 0.911 | 0.6083 | 22.3 | 2.07±0.16 | |
| 12. | BTH-1 | 45°37.40' | 121°31.56' | Basaltic andesite | Whole rock | 1.022 | 0.6835 | 6.8 | 2.07±0.60 | |
| 13. | W-55 | 45°17.45' | 121°33.88' | Andesite | Whole rock | 1.766 | 1.236<br>1.158 | 58.9<br>60.3 | 2.17±0.05<br>2.03±0.05 | 2.10±0.04 |
| 14. | BDRC-1 | 45°11.73' | 121°31.05' | Basaltic andesite | Whole rock | 1.090 | 0.7822 | 47.4 | 2.22±0.08 | |
| 15. | S92-H282 | 45°15.20' | 121°32.44' | Basalt | Whole rock | 0.921 | 0.6645 | 30.5 | 2.24±0.11 | |
| 16. | S92-H269 | 45°25.40' | 121°33.85' | Basaltic andesite | Whole rock | 0.868 | 0.6343 | 43.3 | 2.26±0.08 | |

**TABLE 1. New K-Ar whole-rock ages from Cascade Range, northern Oregon (continued).**

| Map number | Sample number | Location Lat. (N) | Location Long. (W) | Rock type | Material dated | $K_2O$ (wt %) | $^{40}Ar_{rad}$ ($10^{-7}$ ml/g) | Percent $^{40}Ar_{rad}$ | Calculated age (Ma)[1] | Weighted mean age (Ma) |
|---|---|---|---|---|---|---|---|---|---|---|
| 17. | W-115 | 45°15.15' | 121°30.11' | Basaltic andesite | Whole rock | 0.866 | 0.6363 | 46.7 | 2.28±0.11 | |
| 18. | S92-H271 | 45°20.76' | 121°32.13' | Basalt | Whole rock | 0.824 | 0.6140<br>0.7740 | 37.4<br>38.0 | 2.31±0.03<br>2.91±0.12 | 2.35±0.03 |
| 19. | S91-H47 | 45°23.75' | 121°33.56' | Basalt | Whole rock | 1.065 | 0.8362 | 50.3 | 2.43±0.14 | |
| 20. | S91-H210 | 45°25.42' | 121°55.42' | Basalt | Whole rock | 1.293 | 1.016 | 51.6 | 2.43±0.07 | |
| 21. | S91-H197 | 45°23.45' | 121°32.37' | Basalt | Whole rock | 1.144 | 0.9316 | 54.8 | 2.52±0.13 | |
| 22. | S92-H261 | 45°38.38' | 121°45.44' | Basalt | Whole rock | 0.698 | 0.5959 | 36.6 | 2.64±0.11 | |
| 23.[2] | FRD-10 | 45°13.58' | 121°07.50' | Basalt | Whole rock | 0.399 | 0.3614 | 15.5 | 2.81±0.36 | |
| 24. | S91-H214 | 45°23.68' | 121°57.99' | Basalt | Whole rock | 0.320 | 0.2963<br>0.2980<br>0.2122 | 11.4<br>13.2<br>9.8 | 2.87±0.51<br>2.88±0.12<br>2.05±0.44 | 2.82±0.11 |
| 25. | VDB-1 | 45°15.67' | 121°45.54' | Basaltic andesite | Whole rock | 0.946 | 0.8750 | 50.9 | 2.86±0.09 | |
| 26. | S91-H211 | 45°26.88' | 121°56.73' | Basalt | Whole rock | 0.810 | 0.8445 | 51.5 | 3.23±0.09 | |
| 27. | S91-H215 | 45°24.12' | 121°57.97' | Basalt | Whole rock | 1.553 | 1.657 | 46.8 | 3.30±0.22 | |
| 28. | WSP | 45°40.93 | 121°38.15' | Basalt | Whole rock | 0.409 | 0.4532<br>0.4420<br>0.5802 | 42.6<br>51.8<br>39.6 | 3.43±0.26<br>3.35±0.09<br>4.39±0.19 | 3.53±0.08 |
| 29. | S91-H208 | 45°24.51' | 121°54.36' | Basalt | Whole rock | 0.821 | 0.9679 | 52.2 | 3.65±0.25 | |
| 30. | VDB-2 | 45°16.25' | 121°44.70' | Basalt | Whole rock | 0.789 | 1.073 | 52.6 | 4.21±0.12 | |
| 31. | WHR-3 | 45°29.17 | 121°46.40' | Basalt | Whole rock | 0.622 | 0.8801 | 18.9 | 4.38±0.39 | |

Notes: [1]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:
$\lambda_\varepsilon = 0.580 \times 10^{-10}yr^{-1}$, $\lambda_\beta = 4.962 \times 10^{-10}yr^{-1}$, and $^{40}K/K_{total} = 1.167 \times 10^{-4}$ mol/mol.

[2]Not on figure 1. Sample is from the basalt of Juniper Flat collected 34 km east of Badger Butte.

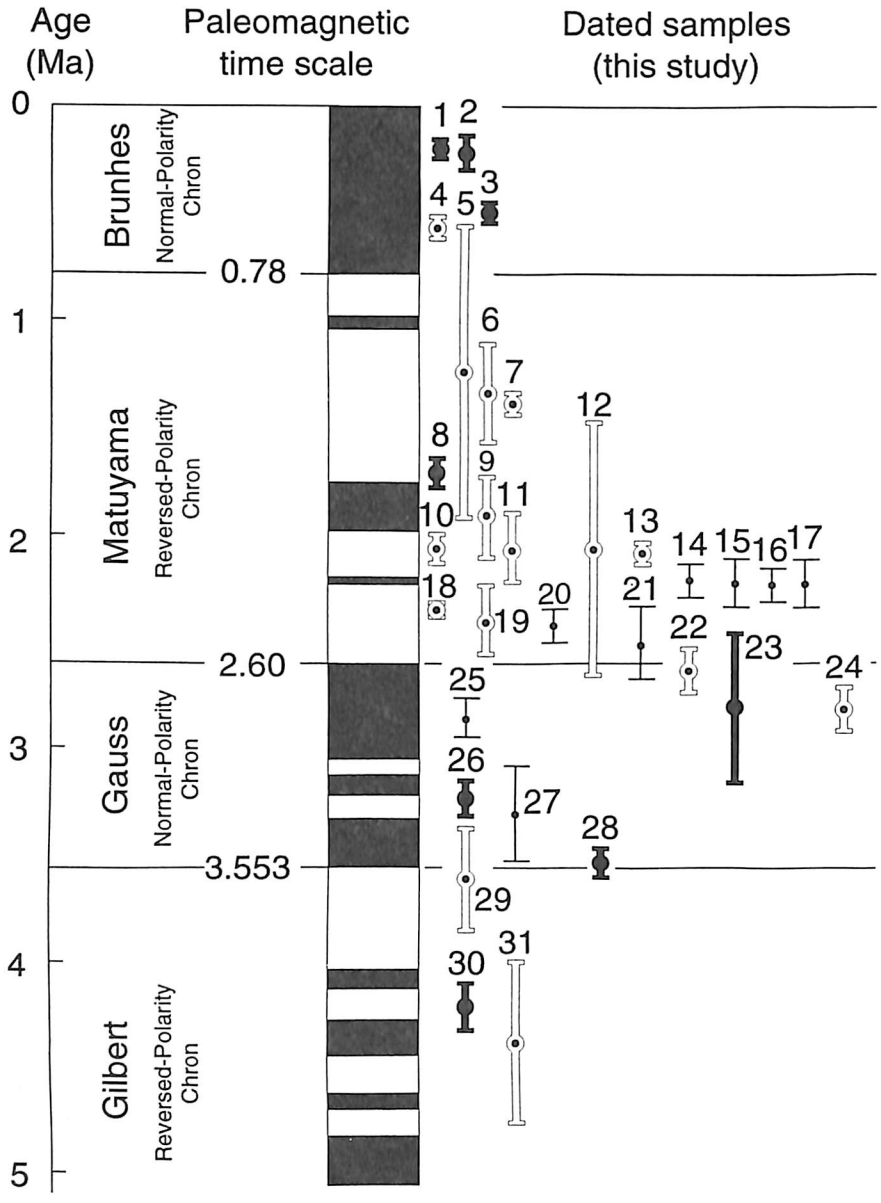


**FIGURE 2. Correlation of dated samples with paleomagnetic time scale. Patterned to show remnant magnetization: dark fill, normal polarity; white fill, reversed polarity. Bars showing age and standard deviation are similarly patterned. Thin unpatterned bars show samples of unknown or indeterminate magnetic polarity. Remnant magnetization was determined using fluxgate magnetometer (or in one case by drilling and alternating field demagnetization). Time scale from Cande and Kent (1992).**

5. *W-85* K-Ar

Lava collected in abandoned quarry above Forest Rd 1025 (west-center S33, T1S,R8E; 3,760 ft elevation [~300 ft upslope from road], Bull Run Lake 7.5′ quad., Clackamas Co., OR). Reversed-polarity. Corresponds to Wise locality 85 (Wise, 1969) and to sample 79LP1109 of Keith and others (1985). The latter is from a talus cone or slide block below our sampling locality and has a weighted mean age of 1.38 ± 0.10 Ma. Underlies andesite of Hiyu Mountain, which has a virtually identical weighted mean age of 1.38 ± 0.06 Ma. Olivine (2-3%) phenocrysts in an intergranular groundmass of plagioclase, augite, and opaque minerals; traces of alteration.

**1.24 ± 0.69 Ma**

6. *S91-H206* K-Ar
Andesite of Hiyu Mountain, roadcut in lava flow (SW1/4 S19,T1S,R8E; junction Forest Rds 1025 and 1025-110, 3,440 ft elevation, Bull Run Lake 7.5′ quad., Multnomah Co., OR). Reversed-polarity TRM measured using alternating-current demagnetization to remove induced component (C.A. Gardner, oral commun., 1994); fails to exhibit dipole behavior with fluxgate magnetometer. Plagioclase phyric (~20%), two-pyroxene, rare opaque mineral andesite with a very fine-grained intergranular groundmass of plagioclase, pyroxene, opaque minerals, and biotite(?); traces of hematite in groundmass.
**1.34 ± 0.24 Ma**

7. *W-92* K-Ar
Andesite of Hiyu Mountain, roadcut in lava flow (NE1/4 S32,T1S,R8E; Forest Rd 1025, 3,800 ft elevation, Bull Run Lake 7.5′ quad., Clackamas Co., OR). Unit has reversed-polarity TRM (see description for sample No. 6), although polarity indeterminate by fluxgate magnetometer at this site. Location corresponds to Wise sample locality 92 (Wise, 1969). Similar to sample No. 6 (S91-H206) but has a few large olivine phenocrysts with orthopyroxene rims.
**1.39 ± 0.06 Ma**

8. *S92-H273* K-Ar
Outcrop of thick lava flow exposed in headwall 200 m NW of Boulder Lake (SE1/4 S32, T3S,R10E; 4,880 ft elevation, Badger Lake 7.5′ quad., Hood River Co., OR). Normal-polarity. Seriate plagioclase-rich, two-pyroxene andesite with rare olivine surrounded by fine-grained opaque minerals and pyroxene; groundmass is holocrystalline with traces of oxidation.
**1.71 ± 0.08 Ma**

9. *S91-H199* K-Ar
Roadcut in lava flow at gate to Flag Point fire lookout (south-center S7,T3S,R11E; near end of Forest Rd 2730-200, Flag Point 7.5′ quad., Wasco Co., OR). Reversed-polarity. Flag Point is small vent for lava that flowed northeast into Tygh Creek drainage. Plagioclase (5%) and olivine (<1%) phenocrysts in an intergranular groundmass of plagioclase, augite, opaque minerals, and glass; rare alteration.
**1.92 ± 0.20 Ma**

10. *S92-H265* K-Ar
Outcrop in lava flow exposed on slope east of Dog River (SE1/4 S33,T1S,R10E; 3,600 ft elevation, Dog River 7.5′ quad., Hood River Co., OR). Reversed-polarity; corresponds to Wise sample locality 110 (Wise, 1969). This lava, erupted early in the Matuyama Reversed-Polarity Chron, is overlain by normally polarized lava (probably the Olduvai Normal-Polarity Subchron of the Matuyama) that forms the ramping surface traversed by Forest Rd 1700-680. Plagioclase (6-7%), olivine (1-2%), and augite (1-2%) phenocrysts in an intergranular groundmass of plagioclase, augite, opaque minerals, and traces of phlogopite; some olivine phenocrysts have faint wisps of iddingsite. Chemically and petrographically similar to sample No. 16 (S92-H269).
**2.06 ± 0.08 Ma**

11. *S92-H284* K-Ar
Outcrop of lava flow on slope ~500 ft below sample No. 15 (S92-H282) (NE1/4 S4,T4S,R10E; west side of Grasshopper Point, 4,600 ft elevation, Badger Lake 7.5′ quad., Wasco Co., OR). Reversed-polarity. May be same location as Wise sample 114 (Wise, 1969). Olivine (3%) and plagioclase (2%) phenocrysts in a very fine-grained intergranular groundmass of plagioclase, pyroxene, and opaque minerals; essentially free of alteration; similar chemically and petrographically to sample No. 15 (S92-H282).
**2.07 ± 0.16 Ma**

12. *BTH-1* K-Ar
Roadcut in lava flow (SE1/4 S26,T2N,R10E; Oregon Highway 35, 800 ft elevation, Parkdale 7.5′ quad., Hood River Co., OR). Reversed polarity. Probably a lava flow erupted from Booth Hill cinder cone, 3.5 km to the south. Olivine (4%) and augite (1-2%) phenocrysts in an intergranular-intersertal groundmass of plagioclase, pyroxene, opaque minerals, and brown glass; all olivine phenocrysts have iddingsite rims; traces of hematite in groundmass.
**2.07 ± 0.60 Ma**

13. *W-55* K-Ar
Roadcut in lava flow (SE1/4 S20,T3S,R10E; east of saddle, Forest Rd 4865, 5,280 ft elevation, Badger Lake 7.5′ quad., Hood River Co., OR). Reversed-polarity. Corresponds to Wise locality 55 (Wise, 1969). Highly plagioclase-phyric (30-35%), two-pyroxene andesite with rare opaque minerals and olivine phenocrysts in a very fine grained intergranular to holocrystalline groundmass; plagioclase and pyroxene phenocrysts

show evidence of disequilibrium; traces of alteration along fractures.

**Weighted mean age 2.10 ± 0.04 Ma**

14. *BDRC-1* K-Ar
Lava collected from roadcut (NW1/4 S26,T4S,R10E; Forest Rd 4870, 3,400 ft elevation, Post Point 7.5′ quad., Wasco Co., OR). Magnetic polarity unknown. Plagioclase (7-8%), olivine (2-3%), and augite (2-3%) phenocrysts in an intergranular groundmass of plagioclase, augite, and opaque minerals; most olivine phenocrysts have traces of iddingsite.

**2.22 ± 0.08 Ma**

15. *S92-H282* K-Ar
Outcrop of lava flow on slope ~500 ft above sample No. 11 (S92-H284) (NW1/4 S3,T4S,R10E; west side of Grasshopper Point, 5,140 ft elevation, Badger Lake 7.5′ quad., Wasco Co., OR). Indeterminate magnetic polarity by fluxgate magnetometer at this site. May be same location as Wise sample 113 (Wise, 1969). Olivine (3%) and plagioclase (2%) in a very fine-grained intergranular groundmass of plagioclase, pyroxene, and opaque minerals; most olivine phenocrysts affected by wispy iddingsite along fractures; similar chemically and petrographically to sample No. 11 (S92-H284).

**2.24 ± 0.11 Ma**

16. *S92-H269* K-Ar
Basalt lava near top of Polallie escarpment, east side of Hood River (SE1/4 S5,T2S,R10E; 3,560 ft elevation, Dog River 7.5′ quad., Hood River Co., OR). Second-highest lava in this cliffy exposure; highest lava is the basaltic andesite of Dog River, which is younger than 0.78 Ma (middle Pleistocene). Sampled lava (upper Pliocene) in turn overlies a conglomerate deposited on top of upper Miocene andesite (Wise, 1969; Keith and others, 1985). Magnetic polarity indeterminate at this site. Corresponds to Wise locality 112 (Wise, 1969). Essentially alteration-free sample is petrographically and chemically similar to sample No. 10 (S92-H265).

**2.26 ± 0.08 Ma**

17. *W-115* K-Ar
Outcrop in lava from Rocky Butte, a conduit-filling plug in eroded cinder cone on east side of Grasshopper Point shield volcano (on N-S section line between S1 and S2,T4S,R6E; 4,760 ft elevation, Badger Lake 7.5′ quad., Wasco Co., OR). Corresponds to Wise locality 115 (Wise, 1969). Polarity not measured. Age similar to sample No. 15 from main shield. Plagioclase (8-10%), olivine (<1%), augite (<1%), and rare opaque oxide phenocrysts in a seriate to very fine-grained groundmass of plagioclase, pyroxene, and opaque minerals; some olivine is strongly iddingsitized and some is fresh; opaque minerals are sporadically altered to hematite.

**2.28 ± 0.11 Ma**

18. *S92-H271* K-Ar
Roadcut in lava flow (SW1/4 S34,T2S,R10E; Forest Rd 3550, 5,720 ft elevation, Badger Lake 7.5′ quad., Hood River Co., OR). Reversed-polarity. Lava is lowest exposed in a sequence of several flows along Bennett Pass Road. Corresponds to Wise locality 104 (Wise, 1969). Olivine (2-3%) and plagioclase (<1%) phenocrysts in a subophitic-ophitic groundmass of plagioclase, augite, and opaque minerals with rare glass.

**Weighted mean age 2.35 ± 0.03 Ma**

19. *S91-H47* K-Ar
Roadcut in lava flow (SW1/4 S16,T2S,R10E; Forest Rd 44, 3,840 ft elevation, Dog River 7.5′ quad., Hood River Co., OR). Reversed-polarity. This flow overlies an andesite lava flow (same roadcut, 75 m south) with whole-rock K-Ar age of 2.70 ± 0.03 Ma (Keith and others, 1985, their sample No. 2). Olivine (3%) and resorbed plagioclase (2%) phenocrysts in an intergranular groundmass of plagioclase, augite, and opaque minerals; all olivine phenocrysts have a thin rind of iddingsite.

**2.43 ± 0.14 Ma**

20. *S91-H210* K-Ar
Roadcut in lava flow (SE1/4 S3,T2S,R7E; Forest Rd 1200-400, 1.6 km northwest of Hickman Butte, 3,800 ft elevation, Hickman Butte 7.5′ quad., Clackamas Co., OR). Magnetic polarity not measured. Olivine (3-4%) and plagioclase (<1%) phenocrysts in an intergranular groundmass of plagioclase, augite, opaque minerals, and phlogopite; most olivine phenocrysts have wispy traces of iddingsite.

**2.43 ± 0.07 Ma**

21. *S91-H197* K-Ar
Roadcut in lava flow near Horkelia Meadows (SW1/4 S15,T2S,R10E; at junction of Forest Rds 4410 and 4410-630, 4,920 ft elevation, Dog River 7.5′ quad., Hood River Co., OR). Magnetic polarity

not measured because roadcut is shattered by construction work. Augite (3-5%), olivine (2-3%), and plagioclase (<1%) phenocrysts in an intergranular groundmass of plagioclase, augite, opaque minerals, and traces of phlogopite; essentially alteration free.

**2.52 ± 0.13 Ma**

22. *S92-H261* K-Ar
Lava flow collected from outcrop 0.2 km south of North Lake (SE1/4 S24,T2N,R8E; 4,340 ft elevation, Carson 7.5′ quad., Hood River Co., OR). Reversed-polarity measured from adjacent outcrop 30 m south along strike, but dated sample is from outcrop too greatly frost-heaved to measure polarity. Two petrographically similar lava flows exposed successively downslope from this flow are also reversely polarized. Geomorphically, area sampled is part of the dissected remains of a shield volcano centered at Green Point Mountain. Plagioclase (3-4%) and olivine (3%) phenocrysts in an intergranular groundmass of plagioclase, augite, and opaque minerals; essentially alteration free.

**2.64 ± 0.11 Ma**

23. *FRD-10* K-Ar
Roadcut in lava flow of the basalt of Juniper Flat (NW1/4 S13,T4S,R13E; U.S. Highway 197, 1,560 ft elevation, boundary between Maupin and Tygh Valley 7.5′ quads., Wasco Co., OR). Normal-polarity. Plagioclase (2%) and olivine (2%) phenocrysts in a seriate, subophitic to ophitic groundmass of plagioclase, augite, olivine, opaque minerals, and cryptocrystalline material; most olivine phenocrysts have thin iddingsite selvages developed along fractures.

**2.81 ± 0.36 Ma**

24. *S91-H214* K-Ar
Roadcut in lava flow on west flank of North Mountain (SE1/4 S17,T2S,R7E; Forest Rd 1228, 3,480 ft elevation, Hickman Butte 7.5′ quad., Clackamas Co., OR). Reversed-polarity. Plagioclase (2%) and olivine (2%) phenocrysts in an ophitic, diktytaxitic groundmass of plagioclase, augite, opaque minerals, and glass or cryptocrystalline material; all olivine phenocrysts are affected by iddingsite; traces of hematite in groundmass.

**Weighted mean age 2.82 ± 0.11 Ma**

25. *VDB-1* K-Ar
Roadcut in lava flow, northeast slope of Veda Butte (SE1/4 S36,T3S,R8E; Forest Rd 2613, 4,240 ft elevation, Government Camp 7.5′ quad., Clackamas Co., OR). Magnetic polarity unknown. Sparse phenocrysts of olivine, plagioclase, and augite in an intergranular groundmass of plagioclase, augite, opaque minerals, glass, and apatite; rare patches of alteration.

**2.86 ± 0.09 Ma**

26. *S91-H211* K-Ar
Roadcut in lava flow (unsectioned [SE1/4 S28,T1S,R7E]; Forest Rd 12, 3,720 ft elevation, Hickman Butte 7.5′ quad., Clackamas Co., OR). Normal-polarity. Probably erupted from a shield volcano centered at an unnamed summit 2.9 km south of Big Bend Mountain. Seriate olivine (5%) and plagioclase (1-2%) phenocrysts in an intergranular groundmass of plagioclase, augite, opaque minerals, and traces of cryptocrystalline material or glass; all olivine phenocrysts have thin iddingsite rims.

**3.23 ± 0.09 Ma**

27. *S91-H215* K-Ar
Quarry in lava flow on northwest slope of North Mountain (NE1/4 S17,T2S,R7E; upslope from Forest Rd 1228, 3,540 ft elevation, Hickman Butte 7.5′ quad., Clackamas Co., OR). Indeterminate magnetic polarity by fluxgate magnetometer at this site. Seriate olivine (5%) and augite (3%) in a well-crystallized intergranular groundmass of plagioclase, augite, opaque minerals, and phlogopite; essentially alteration free.

**3.30 ± 0.22 Ma**

28. *WSP* K-Ar
Roadcut in lava flow upslope from Perham Creek Spring (south-center S1,T2N,R9E; 1600 ft elevation, Mount Defiance 7.5′ quad., Hood River Co., OR). Normal-polarity. An age of 3.67 ± 0.17 Ma was obtained previously from approximately the same location (Anderson, 1987); unit overlies and is down-faulted against middle Miocene rocks of the Columbia River Basalt Group. Sparse olivine phenocrysts in a subophitic groundmass of plagioclase, augite, opaque minerals, and cryptocrystalline material; traces of spotty iddingsite affect most olivine phenocrysts.

**Weighted mean age 3.53 ± 0.08 Ma**

29. *S91-H208* K-Ar
Roadcut in lava flow (SE1/4 S11,T2S,R7E; Forest Rd 1200-400 [Aschoff Road], 3,550 ft elevation, Hickman Butte 7.5′ quad., Clackamas Co., OR). Reversed-polarity. Sample collected from lowest

mafic lava exposed along road; overlies middle or upper Miocene andesite. Olivine (1-2%) and plagioclase (1-2%) phenocrysts in an intergranular groundmass of plagioclase, augite, and opaque minerals; many olivine phenocrysts have faint wispy traces of iddingsite.

**3.65 ± 0.25 Ma**

30. *VDB-2* K-Ar

Roadcut in lava flow (NW1/4 S36,T3S,R8 1/2E; Forest Rd 2613 [Sherar Burn Road], east slope of Eureka Peak, 4,000 ft elevation, Mount Hood South 7.5′ quad., Clackamas Co., OR). Collected from the lowest of the well-exposed roadcuts as road climbs southward towards Veda Butte. Normal-polarity. Large plagioclase (5%) and small, seriate olivine (3%) phenocrysts in an intergranular-subophitic groundmass of plagioclase, augite, olivine, opaque minerals, and glass; all olivine is rather heavily iddingsitized; traces of groundmass alteration.

**4.21 ± 0.12 Ma**

31. *WHR-3* K-Ar

Roadcut in lava flow (NW1/4 S13,T1S,R8E; Forest Rd 1340, 2,640 ft elevation, Bull Run Lake 7.5′ quad., Hood River Co., OR). Reversed-polarity. Sparse olivine and plagioclase and rare augite phenocrysts in an intergranular groundmass of plagioclase, augite, opaque minerals, and brown, oxidized orthopyroxene(?); most olivine phenocrysts are altered along margins and fractures to fine-grained micas(?) or cryptocrystalline material.

**4.38 ± 0.39 Ma**

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