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DISTRIBUTION AND GEOCHRONOLOGY OF STEENS MOUNTAIN-TYPE BASALTS FROM THE NORTHWESTERN GREAT BASIN

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INTRODUCTION

Basaltic volcanism in the major physiographic provinces of the northwestern United States defines periods of varied volcanic output that can be tied closely to tectonic events occurring along the western margin of the North American plate (e.g., Atwater, 1970; Christiansen and McKee, 1978; Barrash and Venkatakrishnan, 1982). A major pulse of basaltic volcanism at 16 ± 1 m.y. is well defined by the main volume of Columbia River quartz tholeiites. During this period another large-volume basalt-extrusion event was occurring to the south of the Columbia River Plateau, leading to the formation of the 1,000-m-thick section of tholeiites exposed at Steens Mountain in southeastern Oregon (e.g., Baksi and others, 1967; McKee and others, 1977). Based on age information (Hart and Mertzman, 1982) together with paleomagnetic (e.g., Larson and others, 1971; Watkins and Baksi, 1974) and chemical data (Carlson and Hart, 1983; this study), thick basalt sequences exposed over a wide area of the northern Great Basin appear to derive from the Steens magmatic event. If so, flows emanating from the feeder dikes exposed in the general area of Steens Mountain may cover an area greater than 20,000 km^2 of the northern Great Basin.

In an ongoing study of the processes controlling volcanism in the northwestern United States, we have attempted to better define the areal extent and age of basalts with chemical and petrographic characteristics similar to those exposed at Steens Mountain. Compositionally, Steens-type basalts are similar to many basalts of the Columbia River Group in that they are relatively fractionated (i.e. most have low Mg/Fe) and have many major- and trace-element characteristics similar to typical "continental tholeiites." The chronologic and compositional characteristics of the Steens-type basalts can be compared with basalts of the Columbia River Group to further illuminate the mechanism of formation of basaltic volcanism in the northwestern United States, the influence the crustal provinces through which these basalts were erupted may have had on their differentiation history, and the relationships between basalt formation and the interaction of the North American and oceanic plates to the west.

Constants used in calculating the ages are: $\lambda_\epsilon = 0.581 \times 10^{-10}$ yr^{-1}; $\lambda_\beta = 4.962 \times 10^{-10}$ yr^{-1}; $^{40}K/K = 1.167 \times 10^{-4}$ mol/mol.

RESULTS AND DISCUSSION

We report 24 new K-Ar ages for basalts compositionally similar to those of Steens Mountain and andesites correlative with the Steens Mountain andesite series as well as 2 new K-Ar ages on lavas from the Owyhee Mountains unrelated to Steens-type magmatism (samples CH82-34 and CH82-42). The K-Ar data are given below, with numbers corresponding to sample locations in figure 1 and major-element chemical analyses in table 1. Every attempt was made to collect the freshest material available, but at some localities alteration-free material could not be obtained. Alteration typically causes ^{40}Ar loss and K gain, resulting in low measurement of the apparent age of the sample as well as the potential for sample inhomogeneity. In cases where clays have caused trapping of excess atmospheric argon, the opposite effect is observed (Baksi, 1974). In both cases, low yield of radiogenic argon ($^{40}Ar^*$) will be characteristic. Additional criteria for evaluating the reliability of the K-Ar data are the observed degree of alteration in thin section, particularly of K-bearing phases such as feldspar, glass and mesostasis, and the total volatile content of the sample. In an effort to minimize the effects of alteration, all samples were crushed to 10–30 mesh, ultrasonically washed in deionized water and methanol, then baked at 200–250°C under vacuum for approximately 12–18 hours prior to argon extraction. All K_2O concentrations are the averages of at least two separately analyzed aliquots powdered from the washed 10–30-mesh material.

Five samples (CH82-20A, CH83-22, H9-47, CH82-32, CH82-61) were run in duplicate to test the reproducibility of the technique as well as the data for altered samples. Three out of the five duplicate analyses agree within analytical uncertainty with the original determination. Two samples (H9-47 and CH82-61) show significant discrepancies. The first run of H9-47 yielded 76.96% $^{40}Ar^*$ whereas the second run yielded 25.28% $^{40}Ar^*$. The low yield of $^{40}Ar^*$ in the second run may indicate trapped excess atmospheric argon. Thus we prefer the original data giving an age of 13.3 m.y. for this sample. Both runs of CH82-61 produced relatively high yields (64.89–68.50%) of $^{40}Ar^*$, but the two ages calculated are different by over 3 m.y. We suggest that sample heterogeneity due to interstitial secondary clay and the abundant phyric plagioclase combined with Ar loss (or K gain) due to alteration may explain this. Based on field relations and the higher $^{40}Ar^*$ of the second run, we prefer the age of 15.9 m.y. but note the potential imprecision for this sample.

The chemical and chronologic data presented in this paper, in Hart and Mertzman (1982), and in Carlson and Hart (1983) indicate that basalts erupted from the area of Steens Mountain may have flowed as far west as Abert and Polker Jim Rims and as far south and east as the Santa Rosa Range and the Black Rock Desert. Other flows, chemically similar to those at Steens Mountain, appear to have been derived from more local eruptive centers as widely dispersed as the Santa Rosa, Owyhee, and Jarbidge mountain ranges (map numbers 5, 6, 9, 17–19, 22, 23). The K-Ar data presented here show that these dispersed Steens-type basalts erupted over a considerably longer time interval than assumed for the basalts of the type section exposed at Steens Mountain (e.g., Baksi and others, 1967). In particular, besides the concentration of ages around 16 ± 1 m.y. (as seen at Steens Mountain), another clustering of ages occurs around 12 ± 1 m.y. Surprisingly, this younger age group includes one of the stratigraphically

TABLE 1. Major element data. All values in weight %.

Map no.	1	2	3	4	5	6	7	8	9	10	11	11	12
Sample no.	CH83-3A	CH83-4A	CH83-5	CH82-20A	CH82-9	CH82-11	CH82-13	CH82-17	CH83-22	CH82-23A	CH82-24A	CH82-24E	CH83-60B
SiO_2	46.9	52.0	49.3	49.7	49.5	50.3	58.7	44.4	51.5	47.6	55.4	49.3	49.0
TiO_2	1.74	1.71	1.56	2.26	1.85	2.43	1.02	1.34	2.29	1.77	1.13	1.81	1.50
Al_2O_3	17.3	16.3	18.4	15.4	15.1	14.8	16.5	10.4	14.8	16.9	17.2	13.9	20.4
Fe_2O_3[1]	11.4	11.4	10.3	10.6	13.5	14.1	6.55	15.3	11.8	13.2	7.36	12.1	9.10
MnO	0.15	0.16	0.14	0.14	0.20	0.21	0.08	0.21	0.17	0.18	0.08	0.17	0.12
MgO	6.01	4.97	4.26	5.34	5.60	4.40	2.93	18.3	3.85	5.98	1.67	8.51	3.49
CaO	8.84	7.81	9.85	9.47	8.87	7.78	5.08	6.89	6.98	9.14	6.62	9.89	10.2
Na_2O	2.83	3.30	3.08	2.88	2.80	3.00	3.59	1.73	3.17	2.94	4.10	2.37	3.12
K_2O	0.78	1.50	1.05	0.69	1.36	1.67	3.39	0.35	1.89	0.59	1.93	0.76	0.65
P_2O_5	0.28	0.39	0.28	0.29	0.40	0.70	0.45	0.16	0.52	0.22	0.34	0.22	0.21
L.O.I.[2]	2.62	0.23	0.93	1.23	0.23	-0.07	1.23	0.77	1.39	0.47	3.85	-0.15	0.47
TOTAL	98.85	99.77	99.15	98.00	99.41	99.32	99.52	99.85	98.36	98.99	99.68	98.88	98.26

Map no.	12	13	14	15	16	17	18	19	19	20	21	22	23
Sample no.	CH83-60F	CH83-59	CH83-55	CH83-48	CH83-41	H9-47	CH82-26	CH82-32	CH82-34	CH82-42	CH82-58	CH82-61	CH82-65B
SiO_2	47.6	49.2	48.1	52.5	49.9	49.4	50.6	47.6	57.0	48.6	48.1	48.4	50.4
TiO_2	1.80	1.96	2.45	1.66	1.91	2.32	2.62	2.28	1.03	1.79	1.96	1.88	0.97
Al_2O_3	15.5	15.8	14.8	15.6	16.0	15.2	13.6	15.5	17.3	14.6	15.4	18.3	15.7
Fe_2O_3[1]	12.2	12.0	13.4	10.8	12.4	13.2	13.5	12.5	6.44	11.9	13.6	11.8	9.65
MnO	0.17	0.17	0.21	0.19	0.18	0.19	0.18	0.15	0.06	0.17	0.19	0.17	0.14
MgO	7.18	5.59	5.43	5.05	5.96	4.69	4.06	5.58	2.46	7.64	5.65	4.17	6.66
CaO	10.2	10.1	9.07	8.21	8.66	9.05	7.67	8.41	6.57	9.45	8.52	7.96	9.39
Na_2O	2.60	2.72	2.96	2.96	2.80	3.19	2.95	2.86	4.71	2.38	2.68	3.73	2.45
K_2O	0.47	0.67	1.17	1.28	0.86	0.92	1.46	0.94	2.02	0.45	1.18	1.56	0.64
P_2O_5	0.29	0.24	0.77	0.64	0.50	0.43	0.49	0.34	0.46	0.24	0.43	0.48	0.25
L.O.I.[2]	0.31	0.00	0.39	1.54	0.39	1.53	1.70	3.16	1.70	2.00	0.93	1.16	3.16
TOTAL	98.22	98.45	98.75	100.43	99.56	100.13	98.83	99.32	99.75	98.22	98.64	99.61	99.41

[1] Fe_2O_3 = total Fe as Fe_2O_3
[2] L.O.I. = % loss on ignition

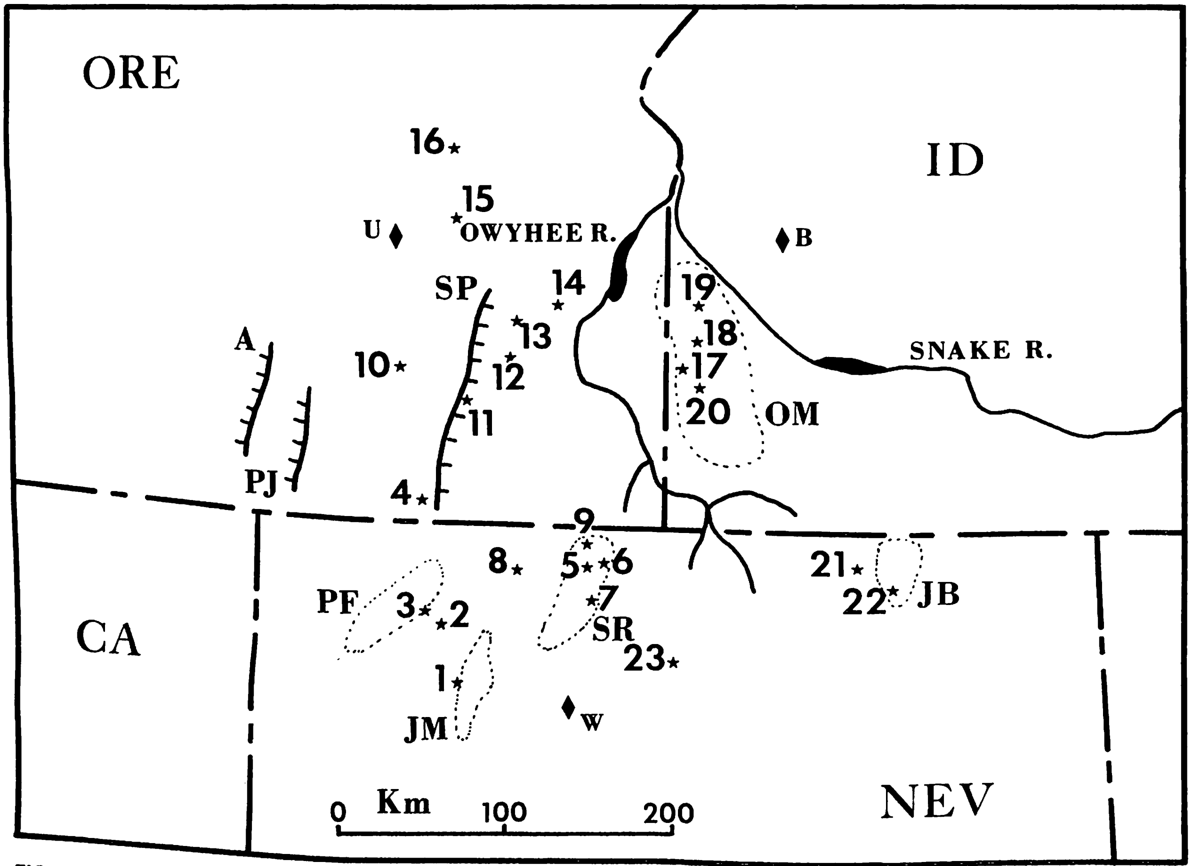

FIGURE 1. Map of northwestern Great Basin. Sample localities are numbered and correspond to the data in table 1 and in the sample descriptions. Major fault blocks (A-Abert Rim; PJ-Polker Jim Rim; SP-Steens-Pueblo) and mountain ranges (JB-Jarbidge; JM-Jackson; OM-Owyhee; PF-Pine Forest; SR-Santa Rosa) are indicated. B = Boise, ID; U = Burns, OR; W = Winnemucca, NV.

older flows from the Pueblo Mountains, the southern extension of the Steens Mountain horst. Additional work in the Pueblo Mountains area is in progress to confirm and investigate the implications of this result, which indicates that even in the area of Steens Mountain, volcanism occurred over a much longer time interval than recognized previously. Based on the data reported here, the Steens magmatic episode began about 18 m.y. ago, peaked in output at 15.5 m.y., and then continued with diminished intensity until about 11 m.y. ago. The occurrence of Steens-type basalts north of Steens Mountain (map numbers 13–16) extending towards the boundary of the Columbia River Province and the general overall chronologic and chemical similarities between Steens and Columbia River lavas suggests that the processes controlling the formation and evolution of these two large-volume basalt eruptions were similar. As evidenced by Dickinson's (1979) summary discussions and maps of the volcano-tectonic development of the northwestern United States, the concept that both Steens-type and Columbia River volcanism represents a single identifiable episode of flood basalt volcanism has been suggested previously. Additional analyses of the regional tectonic significance of this finding and of the implications of the similarities and differences in the chemical and isotopic characteristics of the Columbia River and Steens-type basalts are in progress.

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SAMPLE DESCRIPTIONS

1. *CH83-3A* K-Ar

Basalt (41°2′N,118°41′W; top flow in eastern fault block along "Devil's Ridge," eastern margin Black Rock Desert; Humboldt Co., NV). Medium-grained matrix of subophitic to intergranular Ti-rich augite, plagioclase, altered olivine, oxide, and interstitial clay/calcite; abundant porphyritic and glomeroporphyritic plagioclase (An_{62-64}) up to 7 mm × 4.5 mm (some with secondary calcite) and microphenocrysts of clay-altered olivine. *Analytical data:* Sample weight = 3.9430 gm; K_2O = 0.677 (wt)%; $^{40}Ar^*$ = 1.559 × 10^{-11} moles/gm; $^{40}Ar^*$ = 35.61%.

(whole rock) 15.9 ± 0.9 m.y.

2. *CH83-4A*

Basalt (S28,T42N,R30E; top flow overlying volcanic breccia at The Mesa, western margin Black Rock Desert; Humboldt Co., NV). Fine-grained matrix of ophitic/subophitic to intergranular plagioclase, Ti-rich augite, olivine, oxide, and interstitial oxide-rich mesostasis (trace glass); porphyritic and glomeroporphyritic plagioclase phenocrysts and laths up to 6 mm × 4 mm with poikilitic olivine and oxide and fresh to slightly iddingsitized olivine microphenocrysts. *Analytical data:* Sample weight = 3.0418 gm; K_2O = 1.400 (wt)%; $^{40}Ar^*$ = 3.368 × 10^{-11} moles/gm; $^{40}Ar^*$ = 58.55%.

(whole rock) 16.6 ± 0.9 m.y.

3. *CH83-5* K-Ar

Basalt (S18,T42N,R30E; basalt flow overlying a second volcanic breccia along small stream valley WNW of sample 83-4A at The Mesa; Humboldt Co., NV). Fine- to medium-grained, diktytaxitic matrix of subophitic to intergranular plagioclase, Ti-rich augite, iddingsitized olivine, oxide, and interstitial oxide-rich mesostasis (trace glass); porphyritic and glomeroporphyritic plagioclase laths and phenocrysts (An_{58-60}) up to 10 mm × 6 mm with poikilitic olivine and oxide and microphenocrysts of iddingsitized olivine. *Analytical data:* Sample weight = 4.6192 gm; K_2O = 1.000 (wt)%; $^{40}Ar^*$ = 2.220 × 10^{-11} moles/gm; $^{40}Ar^*$ = 29.43%.

(whole rock) 15.4 ± 1.0 m.y.

4. *CH82-20A* K-Ar

Basalt (SE/4,S14,T41S,R34E; lowest exposed basalt flow unconformably overlying metamorphic sequence on SW side Denio Creek, Pueblo Mountains; Harney Co., OR). Fine- to medium-grained matrix of ophitic/subophitic to intergranular plagioclase, titanaugite, and altered olivine; interstitial oxide, oxide-rich mesostasis, glass and clay alteration; porphyritic and glomeroporphyritic plagioclase (An_{58-60}) up to 7 mm × 6 mm (some resorbed and altered to clay/sericite) and microphenocrysts of iddingsitized/nontronitized olivine. *Analytical data:* Sample weights = 5.1290 gm, 5.3051 gm; K_2O = 0.603 (wt)%, 0.603 (wt)%; $^{40}Ar^*$ = 1.037 × 10^{-11} moles/gm, 1.091 × 10^{-11} moles/gm; $^{40}Ar^*$ = 28.12%, 26.33%.

(whole rock) 11.9 ± 0.7 m.y.
(whole rock) 12.5 ± 0.7 m.y.

5. *CH82-9* K-Ar

Basalt (SE/4,S15,T44N,R39E; columnar-jointed dike[?] exposure N side Lye Creek, Santa Rosa Range; Humboldt Co., NV). Fine-grained, aphyric, intergranular to subophitic plagioclase, olivine, and clinopyroxene; interstitial oxide, oxide-rich mesostasis, and minor calcite/clay. *Analytical data:* Sample weight = 5.5673 gm; K_2O = 1.406 (wt)%; $^{40}Ar^*$ = 2.733 × 10^{-11} moles/gm; $^{40}Ar^*$ = 81.68%.

(whole rock) 13.5 ± 0.7 m.y.

6. *CH82-11* K-Ar

Basalt (SE/4,S23,T44N,R39E; large domelike exposure of highly fractured and jointed basalt plug[?], Chocolate Mountain, Santa Rosa Range; Humboldt Co., NV). Very fine grained assemblage of intergranular plagioclase, mafic microlites, and oxide; some scattered, highly altered/relict olivine up to 0.8 mm and larger plagioclase laths up to 1.8 mm. *Analytical data:* Sample weight = 5.6900 gm; K_2O = 1.714 (wt)%; $^{40}Ar^*$ = 3.577 × 10^{-11} moles/gm; $^{40}Ar^*$ = 50.77%. *Comment:* Abundant basaltic xenoliths enclosed in host basalt.

(whole rock) 14.4 ± 0.8 m.y.

7. *CH82-13* K-Ar

Andesite (SW/4,S3,T42N,R39E; flow along Big Cottonwood Creek, E side Santa Rosa Range; Humboldt Co., NV). Very fine grained, intergranular-intersertal matrix of plagioclase laths, clinopyroxene, orthopyroxene with clinopyroxene rims, minor oxide, and fresh to altered glass (some patches are oxide rich); scattered, highly resorbed phenocrysts of plagioclase up to 4 mm; matrix is altered in patches. *Analytical data:* Sample weight = 3.1105 gm; K_2O = 3.428 (wt)%; $^{40}Ar^*$ = 9.720 × 10^{-11} moles/gm; $^{40}Ar^*$ = 84.84%.

(whole rock) 19.6 ± 0.9 m.y.

8. *CH82-17* K-Ar
Basalt (S17,T44N,R38E; eroded flow top in valley E of Bilk Creek Mountains; Humboldt Co., NV). Coarse-grained olivine cumulate; abundant phenocrysts of olivine up to 4 mm with veins and rims of iddingsite; intercumulus ophitic clinopyroxene, plagioclase, oxide, and minor altered mesostasis. *Analytical data:* Sample weight = 5.6669 gm; K_2O = 0.401 (wt)%; $^{40}Ar^*$ = 1.460 × 10^{-11} moles/gm; $^{40}Ar^*$ = 42.55%.

(whole rock) 14.3 ± 0.9 m.y.

9. *CH83-22* K-Ar
Basalt (NE/4,S22,T45N,R39E; flow midway up basalt section along Canyon Creek, W side Santa Rosa Range; Humboldt Co., NV). Very fine grained matrix of intergranular (some subophitic patches) plagioclase, clinopyroxene, olivine, and oxide; abundant interstitial oxide-rich mesostasis (trace glass) and scattered interstitial clay/calcite after glass and plagioclase; scattered phenocrysts and glomeroporphyritic clumps of resorbed plagioclase up to 4 mm. *Analytical data:* Sample weights = 3.0236 gm, 3.0465 gm; K_2O = 1.551 (wt)%, 1.551 (wt)%; $^{40}Ar^*$ = 2.446 × 10^{-11} moles/gm, 2.540 × 10^{-11} moles/gm; $^{40}Ar^*$ = 16.36%, 17.33%.

(whole rock) 11.4 ± 0.9 m.y.
(whole rock) 11.3 ± 0.9 m.y.

10. *CH82-23A* K-Ar
Basalt (SE/4,SE/4,S4,T32S,R32E; top flow from fault scarp W of Frenchglen; Harney Co., OR). Fine-grained, slightly diktytaxitic, intergranular to subophitic assemblage of Ca-plagioclase, Ti-rich augite, iddingsitized olivine, and oxide; minor oxide-rich mesostasis. *Analytical data:* Sample weight = 6.0263 gm; K_2O = 0.616 (wt)%; $^{40}Ar^*$ = 1.319 × 10^{-11} moles/gm; $^{40}Ar^*$ = 53.05%.

(whole rock) 14.8 ± 0.8 m.y.

11. *CH82-24A* K-Ar
Basaltic andesite (border S5–8,T34S,R34E; basal flow directly above thick sequence of ash along Little Alvord Creek valley, E face Steens Mountain; Harney Co., OR). Cryptocrystalline oxide-rich matrix exhibiting light and dark banding; abundant microphenocrysts of resorbed and embayed plagioclase with clay/calcite alteration up to 1.5 mm; laths of orthopyroxene with altered clinopyroxene rims; scattered microphenocrysts of fresh and altered clinopyroxene (some twinned, up to 1 mm) and oxide; minor glomeroporphyritic clumps of clinopyroxene and plagioclase. *Analytical data:* Sample weight = 5.0690 gm; K_2O = 1.990 (wt)%; $^{40}Ar^*$ = 6.839 × 10^{-11} moles/gm; $^{40}Ar^*$ = 56.98%.

(whole rock) 23.7 ± 1.3 m.y.

11. *CH82-24E* K-Ar
Basalt (same location as above [CH82-24A]; 4 flows above CH82-24A directly overlying plagioclase-phyric flow; Harney Co., OR). Fine-grained, holocrystalline intergranular matrix of plagioclase, clinopyroxene, iddingsitized olivine, and oxides; porphyritic and glomeroporphyritic plagioclase up to 5 mm and partially iddingsitized olivine up to 2.5 mm, some with picotite inclusions. *Analytical data:* Sample weight = 3.0249 gm; K_2O = 0.586 (wt)%; $^{40}Ar^*$ = 1.537 × 10^{-11} moles/gm; $^{40}Ar^*$ = 45.03%.

(whole rock) 18.1 ± 1.1 m.y.

12. *CH83-60B* K-Ar
Basalt (S4,T30S,R37E; third flow from top [flow no. 3] of uplifted rim exposing 34 basalt flows at W margin Sheepshead Mountains; Malheur Co., OR). Medium-grained, subophitic to intergranular matrix of plagioclase, augite, iddingsitized olivine, and oxide; interstitial oxide-rich mesostasis; porphyritic and glomeroporphyritic laths and phenocrysts of plagioclase (An_{64-66}) up to 12 mm × 5 mm, some resorbed with poikilitic olivine and oxide. *Analytical data:* Sample weight = 4.9806 gm; K_2O = 0.592 (wt)%; $^{40}Ar^*$ = 1.265 × 10^{-11} moles/gm; $^{40}Ar^*$ = 48.43%.

(whole rock) 14.8 ± 0.8 m.y.

12. *CH83-60F* K-Ar
Basalt (same location as above [CH83-60B]; basal flow [flow no. 34] above talus; Malheur Co., OR). Very fine grained, vesicular, holocrystalline, equigranular assemblage of intergranular plagioclase, clinopyroxene, iddingsitized olivine, and oxide. *Analytical data:* Sample weight = 5.0747 gm; K_2O = 0.410 (wt)%; $^{40}Ar^*$ = 1.010 × 10^{-11} moles/gm; $^{40}Ar^*$ = 51.15%.

(whole rock) 17.0 ± 1.1 m.y.

13. *CH83-59* K-Ar
Basalt (NW/4,S35,T28S,R37E; mesa capping flow NE of Follyfarm; Malheur Co., OR). Medium-grained, diktytaxitic, nearly equigranular assemblage of intergranular to subophitic plagioclase (An_{66-68}), Ti-rich augite, iddingsitized olivine, and oxide; scattered microphenocrysts and glomeroporphyritic clumps of plagioclase and olivine; minor interstitial oxide-rich mesostasis. *Analytical data:* Sample weight = 4.0705 gm; K_2O = 0.560 (wt)%; $^{40}Ar^*$ = 1.298 × 10^{-11} moles/gm; $^{40}Ar^*$ = 46.68%.

(whole rock) 17.3 ± 1.0 m.y.

14. *CH83-55* K-Ar
Basalt (NW/4,S26,T26S,R39E; top flow of 3 flows, due W of Crowley Ranch; Malheur Co., OR). Very fine to fine-grained, diktytaxitic matrix of intergranular to ophitic plagioclase, titanaugite, iddingsitized olivine, oxides, and minor scattered patches of calcite/zeolite and interstitial oxide-rich mesostasis; porphyritic and glomeroporphyritic phenocrysts and microphenocrysts of plagioclase (An_{62-64}) up to 10 mm × 20 mm and iddingsitized olivine up to 3 mm × 3 mm. *Analytical data:* Sample weight = 3.0465 gm; K_2O = 1.093 (wt)%; $^{40}Ar^*$ = 1.786 × 10^{-11} moles/gm; $^{40}Ar^*$ = 28.42%.

(whole rock) 11.3 ± 0.8 m.y.

15. *CH83-48* K-Ar
Basalt (SW/4,S29,T21S,R34E; top flow of 2 exposed basalts along Little Pine Creek, N of U.S. Highway 20; Harney Co., OR). Fine- to medium-grained, nearly equigranular assemblage of intergranular plagioclase, augite, iddingsitized olivine, oxide, and interstitial oxide-rich mesostasis and clay; some scattered

microphenocrysts of fresh and clay-altered olivine. *Analytical data:* Sample weight = 3.2987 gm; K_2O = 1.186 (wt)%; $^{40}Ar^*$ = 1.970 × 10^{-11} moles/gm; $^{40}Ar^*$ = 47.07%.

(whole rock)11.5 ± 0.7 m.y.

16. *CH83-41* K-Ar
Basalt (NE/4,S5,T17S,R33½E; flow underlying basaltic andesite along Malheur National Forest Road 1630 following Crooked Creek, southern Strawberry Mountains area; Malheur Co., OR). Medium-grained, diktytaxitic, nearly equigranular assemblage of intergranular to subophitic plagioclase (An_{60-62}), Ti-rich augite, iddingsitized olivine, and oxide; abundant interstitial oxide-rich mesostasis. *Analytical data:* Sample weight = 4.0965 gm; K_2O = 0.820 (wt)%; $^{40}Ar^*$ = 1.404 × 10^{-11} moles/gm; $^{40}Ar^*$ = 36.44%.

(whole rock)11.9 ± 0.7 m.y.

17. *H9-47* K-Ar
Basalt (NW/4,NW/4,T6S,R5W; "Lower Basalt" flow E side Jordan Creek near Connors Spring, Owyhee Mountains; Owyhee Co., ID). Fine-grained matrix of ophitic plagioclase and titanaugite, intergranular and glomeroporphyritic plagioclase (An_{58-62}), and highly altered (iddingsite and clay) olivine up to 2 mm; minor patches of clay and chalcedony; some vesicles lined with calcite. *Analytical data:* Sample weights = 5.0567 gm, 3.1102 gm; K_2O = 0.963 (wt)%, 0.963 (wt)%; $^{40}Ar^*$ = 1.851 × 10^{-11} moles/gm, 2.830 × 10^{-11} moles/gm; $^{40}Ar^*$ = 76.96%, 25.28%.

(whole rock)13.3 ± 0.6 m.y.
(whole rock)15.0 ± 0.9 m.y.

18. *CH82-26* K-Ar
Basalt (SE/4,S31,T4S,R4W; "Lower Basalt" cut by road to Silver City, just W of DeLamar; Owyhee Co., ID). Very fine grained, intergranular/intersertal matrix of plagioclase, clinopyroxene, olivine, oxide, glass, and oxide-rich mesostasis; scattered porphyritic plagioclase; glomeroporphyritic plagioclase and highly altered mafics (olivine?); patches of clay and calcite in matrix. *Analytical data:* Sample weight = 3.5165 gm; K_2O = 1.537 (wt)%; $^{40}Ar^*$ = 2.717 × 10^{-11} moles/gm; $^{40}Ar^*$ = 9.55%.

(whole rock)12.2 ± 1.3 m.y.

19. *CH82-32*
Basalt (middle S24,T2S,R5W; "Lower Basalt" flow along road S of Squaw Butte, Owyhee Mountains; Owyhee Co., ID). Fine-grained, ophitic to intergranular/intersertal matrix of clinopyroxene, plagioclase, olivine, oxide, and altered glass; scattered 5-mm plagioclase laths and minor microphenocrysts of relict olivine completely altered to clay; abundant interstitial clay mainly after glass and olivine. *Analytical data:* Sample weights = 5.1208 gm; 3.0640 gm; K_2O = 0.950 (wt)%, 0.950 (wt)%; $^{40}Ar^*$ = 2.163 × 10^{-11} moles/gm, 2.267 × 10^{-11} moles/gm; $^{40}Ar^*$ = 60.24%, 52.96%.

(whole rock)15.7 ± 0.7 m.y.
(whole rock)16.5 ± 0.8 m.y.

19. *CH82-34* K-Ar
Andesite (SE/4,S23,T2S,R5W; platy flow exposed along road S of Squaw Butte, Owyhee Mountains; Owyhee Co., ID). Very fine grained, intergranular matrix of pilotaxitic plagioclase, mafic microlites, oxides, and schlieren; scattered microphenocrysts of subcalcic augite and xenocrysts of disequilibrium quartz and K-feldspar up to 2 mm × 2 mm. *Analytical data:* Sample weight = 4.0628 gm; K_2O = 1.884 (wt)%; $^{40}Ar^*$ = 7.582 × 10^{-11} moles/gm; $^{40}Ar^*$ = 89.45%.

(whole rock)27.7 ± 1.4 m.y.

20. *CH82-42*
Basalt (SE/4,S36,T7S,R5W; flow cut by road along South Mountain Creek, NE of South Mountain; Owyhee Co., ID). Fine-grained, intergranular matrix of plagioclase, clinopyroxene, altered olivine, oxide, and patches of secondary clay; scattered microphenocrysts of plagioclase and clay-altered olivine. *Analytical data:* Sample weight = 4.3004 gm; K_2O = 0.390 (wt)%; $^{40}Ar^*$ = 7.608 × 10^{-12} moles/gm; $^{40}Ar^*$ = 34.09%.

(whole rock)13.5 ± 1.0 m.y.

21. *CH82-58* K-Ar
Basalt (S17,T45N,R55E; domelike exposure of highly fractured and jointed dike[?] basalt, N of Point of Rocks; Elko Co., NV). Very fine grained matrix of intergranular clinopyroxene, plagioclase, oxide, and abundant oxide-rich mesostasis; porphyritic and glomeroporphyritic plagioclase laths (some with resorbed cores) up to 2.5 mm and fresh to completely clay-altered olivine up to 1 mm; patches of alteration to calcite and clay. *Analytical data:* Sample weight = 4.1339 gm; K_2O = 1.223 (wt)%; $^{40}Ar^*$ = 2.568 × 10^{-11} moles/gm; $^{40}Ar^*$ = 18.52%. *Comment:* Abundant xenoliths of crustal material in host basalt.

(whole rock)14.5 ± 1.1 m.y.

22. *CH82-61* K-Ar
Basalt (border S29–32,T45N,R58E; eroded, highly fractured hill of Seventy Six Basalt along road from Jarbidge to Charleston in Copper Basin, southern Jarbidge Mountains; Elko Co., NV). Very fine grained, intergranular to ophitic matrix of plagioclase, titanaugite, clay-altered olivine, and oxide; abundant interstitial clay; large (some resorbed) phenocrysts and laths of plagioclase generally 5 mm × 5 mm, some as large as 9 mm in length; scattered 1-mm microphenocrysts of fresh olivine; glomeroporphyritic clumps of plagioclase + plagioclase and plagioclase + olivine. *Analytical data:* Sample weights = 4.1110 gm, 2.9514 gm; K_2O = 1.515 (wt)%, 1.515 (wt)%; $^{40}Ar^*$ = 2.715 × 10^{-11} moles/gm, 3.483 × 10^{-11} moles/gm; $^{40}Ar^*$ = 64.89%, 68.50%. *Comment:* Abundant rounded mafic xenoliths as large as 60 cm × 60 cm in host basalt.

(whole rock)12.4 ± 0.7 m.y.
(whole rock)15.9 ± 0.8 m.y.

23. *CH82-65B* K-Ar
Basalt (SW/4,NW/4,S8,T38N,R45E; flow exposed in basal section of Owyhee Bluffs and cut by Sawtooth dike, Midas Trough; Elko Co., NV). Fine-grained, intergranular to subophitic, nearly equigranular assemblage of plagioclase, clinopyroxene, clay-altered/iddingsitized olivine, and oxide; abundant oxide-rich mesostasis pervasively altered to clay; minor glomeroporphyritic clumps of plagioclase. *Analytical data:* Sample weight = 3.0908 gm; K_2O = 0.669 (wt)%; $^{40}Ar^*$ = 1.229 × 10^{-11} moles/gm; $^{40}Ar^*$ = 54.59%.

(whole rock)12.7 ± 0.8 m.y.

REFERENCES

Atwater, T. (1970) Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of American Bulletin, v. 81, p. 3513–3536.

Baksi, A. K. (1974) Isotopic fractionation of loosely held atmospheric argon component in the Picture Gorge basalts: Earth and Planetary Science Letters, v. 21, p. 431–438.

Baksi, A. K., York, D., and Watkins, N. D. (1967) The age of the Steens Mountain geomagnetic polarity transition: Journal of Geophysical Research, v. 72, p. 6299–6308.

Barrash, W., and Venkatakrishnan, R. (1982) Timing of late Cenozoic volcanic and tectonic events along the western margin of the North American plate: Geological Society of America Bulletin, v. 93, p. 977–989.

Carlson, R. W., and Hart, W. K. (1983) Geochemical study of the Steens Mountain flood basalt: Carnegie Institution of Washington Year Book 82, p. 475–481.

Christiansen, R. L., and McKee, E. H. (1978) Late Cenozoic volcanic and tectonic evolution of the Great Basin and Columbia intermontane regions, *in* Smith, R. B. and Eaton, G. P., eds., Cenozoic tectonics and regional geophysics of the Western Cordillera: Geological Society of America Memoir 152, p. 238–311.

Dickinson, W. R. (1979) Cenozoic plate tectonic setting of the Cordilleran region in the United States, *in* Armentrout, J. M., Cole, M. R., and Terbest, H., eds., Cenozoic Paleogeography Symposium 3, p. 1–13.

Hart, W. K., and Mertzman, S. A. (1982) K-Ar ages of basalts from south-central and southeastern Oregon: Isochron/West, no. 33, p. 23–26.

Larson, E. E., Watson, D. E., and Jennings, W. (1971) Regional comparison of a Miocene geomagnetic transition in Oregon and Nevada: Earth and Planetary Science Letters, v. 11, p. 391–400.

McKee, E. H., Swanson, D. A., and Wright, T. L. (1977) Duration and volume of Columbia River basalt volcanism, Washington, Oregon, Idaho [abstract]: Geological Society of America, Abstracts with Programs, v. 9, p. 463–464.

Watkins, N. D., and Baksi, A. K. (1974) Magnetostratigraphy and oroclinal folding of the Columbia River, Steens, and Owyhee basalts in Oregon, Washington, and Idaho: American Journal of Science, v. 274, p. 148–189.