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K–Ar DATING, QUATERNARY AND NEOGENE VOLCANIC ROCKS OF THE SNAKE RIVER PLAIN, IDAHO†

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ABSTRACT. Ninety-eight K–Ar dates for lavas of the Snake River Plain (SRP) and vicinity provide calibration for the stratigraphic framework discussed by Malde and Powers (1962). The Idavada Volcanics, predominantly silicic volcanic rocks, are 9 to 13 m.y. old in the western SRP. Rocks of similar type and comparable stratigraphic position are 8 to 10 m.y. old in the central SRP and as young as 4 to 5 m.y. old in the eastern SRP. This time-transgressive silicic volcanic assemblage merges in the east with the silicic volcanic units erupted during the last 2 m.y. from Island Park, Yellowstone, and related volcanic centers. The Idaho Group, consisting of intercalated basalt flows and sedimentary deposits in the western half of the SRP, ranges in age from about 0.6 to 11.5 m.y. The name Banbury Basalt has been used for more than one basalt unit; one is older than the 8 to 9-m.y.-old Chalk Hills Formation. The type Banbury is not more than 6.25 m.y. old and may be a lateral equivalent of part of the Glenns Ferry Formation. In the western SRP Snake River Group basalts (0.54 m.y. and younger) overlie Bruneau Formation lavas and sediments (~1.4 m.y.), which in turn overlie Glenns Ferry Formation sediments and lavas (probably 4.4 to 6.2 m.y. old). Glenns Ferry Formation stratigraphy and K–Ar dates are inconsistent due to alteration of the lava flows. The beginning of the Blancan land mammal age may be as old as 6.2 m.y., 2 m.y. older than previously suggested.

General facies relations in the SRP for the last 10 m.y. have been, from east to west (or oldest to youngest in any local section): (A) silicic volcanic rocks, mostly ash-flow deposits, with minor basalt and sediment intercalations, (B) basalt flows with minor intercalated sediment and local silicious domes, and (C) lacustrine and fluviatile sediments complexly interstratified with basalt flows. These facies have shifted eastward across Idaho in a reasonably systematic manner at the rate of approximately 1° of longitude per 2 m.y. (~3.5 cm/yr).

The Bear River may have been diverted into Lake Bonneville 0.10 m.y. ago rather than 0.03 m.y. ago as dated by radiocarbon.

INTRODUCTION

The Snake River Plain is an arcuate depression of low topographic relief that extends more than 500 km across southern Idaho (fig. 1). Much of it is covered by basalt and interbedded continental sediments that dip gently, usually toward its central axis. Both faulting and downwarping have contributed to the subsidence of the region. In the west, especially on the north side, the Snake River Plain in graben-like, bounded by northwest-trending en echelon normal faults (Malde, 1959, 1965); at least part of the southwestern margin is downwarped rather than faulted (McIntyre, 1972). In the east, the Snake River Plain is a

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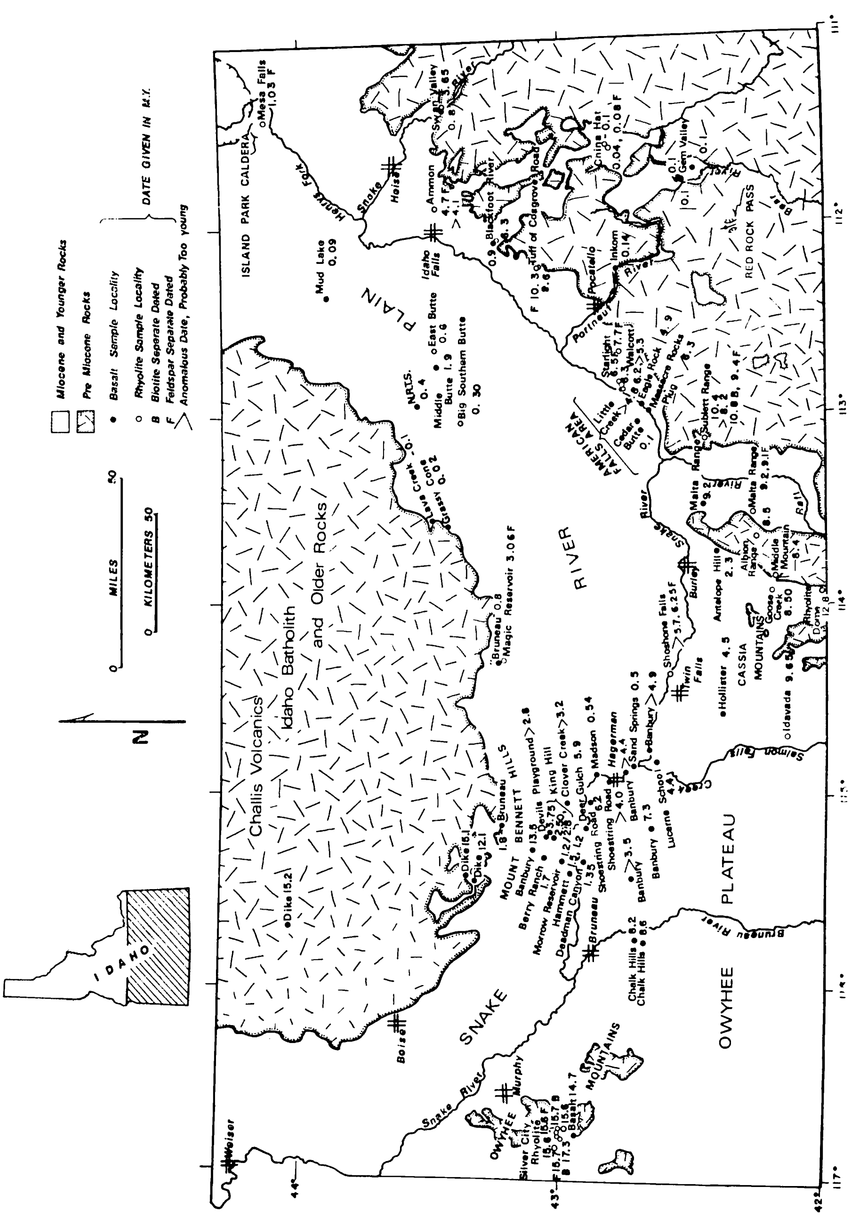

Fig. 1. Map of southern Idaho showing sample localities and extent of Miocene and younger volcanic rocks. Two sample localities are outside the area illustrated: the Lava Creek Member of the Yellowstone Tuff in Yellowstone Park and the Columbia River Basalt, north of Weiser.

simple structural downwarp in which faulting has played only a minor role (Kirkham, 1931).

Detailed stratigraphic work has been done in several areas of the Snake River Plain, but the restricted area covered by most units and abrupt facies changes have made regional correlations difficult. Local subdivisions are based on exposed stratigraphic relationships. Correlation between separated exposures has depended on similarity of stratigraphic sequence, degree of alteration, and fossils that are locally abundant but rarely precise indicators of age. The evolution of stratigraphic nomenclature in this region was reviewed by Malde and Powers (1962) and Ross (1962).

Long ago Stearns (1926) suggested that centers of silicic volcanism shifted eastward across the plain from southwestern Oregon (in Miocene time) toward the Yellowstone Plateau (currently active). Hamilton and Myers (1966) and Christiansen and Lipman (1972) have discussed the Snake River Plain in the context of the later Cenozoic tectonic and volcanic evolution of the western United States.

We have obtained K–Ar dates for a large number of rocks and mineral separates to facilitate the understanding of age relations and to make correlations of stratigraphic units between widely separated local stratigraphic successions. Our data bear on regional volcanic and tectonic history and provide control for paleontologic and paleomagnetic studies. We use the time scale of Evernden and others (1964) for the Cenozoic mammalian chronology of western North America, although their use of Pliocene (1.5-12 m.y. ago) does not conform to the European Pliocene which is now thought to be shorter (1.8-5.0 m.y. ago—Berggren, 1972). To use this paper to rectify this nomenclatural problem would probably only be confusing. Therefore, we follow previous nomenclature in the Snake River Plain and will avoid the word Pliocene wherever possible—using the less-ambiguous land-mammal ages or K–Ar dates.

GENERAL GEOLOGY

The Miocene and younger volcanic rocks of southern Idaho rest uncomformably upon deformed sedimentary and plutonic rocks ranging in age from Precambrian to Mesozoic and upon faulted remnants of latitic and rhyolitic rocks of early Tertiary age (Challis Volcanics [Ross, 1962] of middle Eocene age [Axelrod, 1966; Armstrong, 1974]). The structural grain produced during Mesozoic mountain building and Cenozoic block faulting, the latter being related to crustal extension of the Basin and Range province, is approximately north-south, nearly perpendicular to the axis of the Snake River Plain. Where older structures plunge under the plain on both sides, they are not deflected in any way that would suggest the presence of a Snake River downwarp as a significant tectonic feature before Miocene time. Indeed, Axelrod (1968) suggested that a volcanic highland extended uninterrupted from central Idaho to Nevada as recently as the Eocene. A gap in the stratigraphic record in southern Idaho, lasting from late Eocene through early Miocene time, clearly separates Snake River Plain deposits and tectonic evolution from earlier chapters in the geologic history of the region. Our study is concerned only with Miocene and younger rocks.

The generalized stratigraphic sequence of the western Snake River Plain, as summarized by Malde and Powers (1962) and shown in figure 2, begins with basalt and rhyolite exposed along the margins of the plain. These volcanics are interbedded with sediments of the Payette Formation and locally show the effects of hydrothermal alteration and mineralization. These older deposits are overlain unconformably by nonmineralized silicic volcanic rocks and interbedded sediments rich in volcanic ash, which together are the Idavada Volcanics. These are in turn overlain by interbedded basalt and sedimentary deposits of the Idaho Group. The top of the generalized sequence is the Snake River Group, predominantly unaltered basalt that blankets the eastern part of the Snake River Plain today and extends westward to the Hagerman area, and beyond, where it abuts and overlaps eroded deposits of the Idaho Group. Local stratigraphic relations in the Snake River Group are complex because of concurrent canyon cutting by the Snake River and repeated eruptions of basalt (Malde, 1972).

The boundaries of these units and many of their subdivisions are time-transgressive and stratigraphically complex because they are volcanic-sedimentary facies deposited synchronously in different areas. The different facies can be observed to occur in sequence within any small area. Our discussion of details proceeds from west to east, beginning in each instance with the oldest rocks of the local section.

As we discuss the K–Ar dates in the context of previous stratigraphic assignments, nomenclature problems will arise from the mixed usage of formation names. Previous usage has not always distinguished units that are time-stratigraphic formations such as individual basalt flows from formations and groups that are time-transgressive. The same name has been applied by different authors in different localities to units of distinctly different age, although the original intent was often to imply a time-stratigraphic correlation. We will describe this confusion, evident in hindsight, but not offer a revision of the nomenclature. That is best left to the next generation of mapmakers for the Snake River Plain.

TECHNIQUES

Our samples were mostly collected by Leeman and Armstrong using for guidance unpublished geologic maps by H. E. Malde, D. E. Trimble, and R. L. Armstrong and other published maps and reports. Several samples were supplied by other geologists as noted in table 1. Analytical work was done at Yale University by Armstrong. The most consistent dates were obtained on absolutely fresh material—a finding that underlines the necessity of rigorous screening of samples for K–Ar dating, especially where analyses are made of whole rocks. Such samples were crushed to ~5 mm chunks for Ar analyses and were powdered for K analysis. For many silicic rocks, feldspars were separated so that whole-

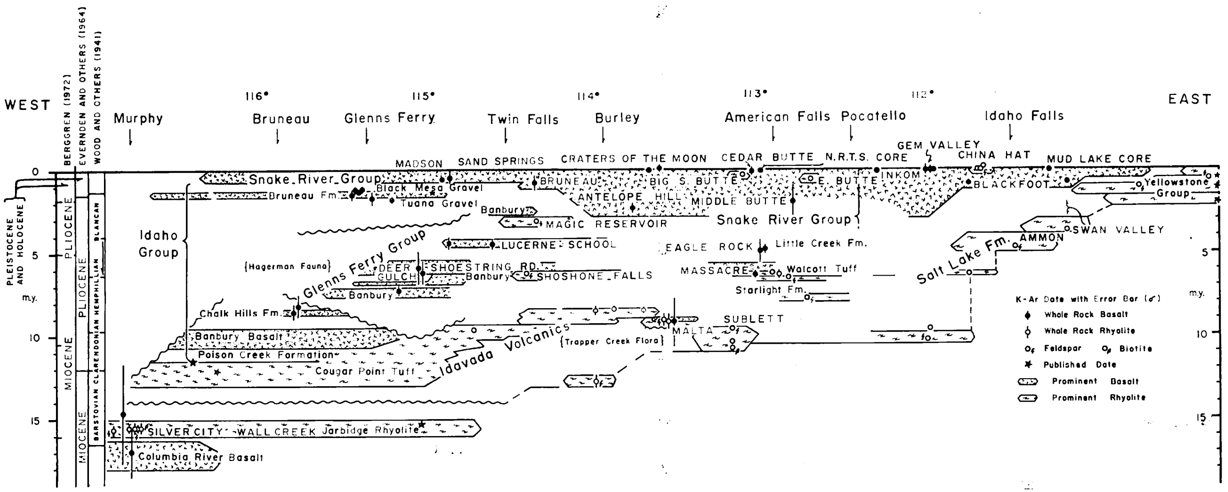

Fig. 2. Schematic stratigraphic-chronologic diagram for the Snake River Plain across Idaho. Local stratigraphy is much more complex and obscure than this figure would imply, because only selected units are shown, yet the diagram conveys the essence of the stratigraphic story. Unpatterned areas represent erosional intervals, sedimentary deposits, and other rock units unimportant to the text. Constructed on the basis of references and dates cited in the text. The stars indicate dates published by Coats (1968), Evernden and others (1964), and Christiansen and Blank (1972). The arrow on the time scale illustrates the possible revision, or time transgressive nature, of the Blancan-Hemphillian boundary as discussed in the text.

TABLE 1

K–Ar dates for Quaternary and Neogene volcanic rocks of the Snake River Plain and vicinity

Unit sampled	Sample number	Magnetic polarity	Material analyzed	Date (m.y.) and error (σ)	
Snake River Plain west of Twin Falls					
Snake River Group					
Sand Springs Basalt	69-52(L)	N	WR	0.5 ± 0.5	
Madson Basalt	69-53(L)	N	WR	0.54 ± 0.08	
Idaho Group-Bruneau Formation basalt flows					
"Bruneau" basalt flow near Magic Reservoir	69-39(L)	N	WR	0.8 ± 0.5	
Berry Ranch lava flow	70-7(L)	R	WR	1.7 ± 0.4	
King Hill lava flow	69-61(L)		WR	2.50 ± 0.05	Excess Ar suspected
King Hill lava flow	69-60(L)	R	WR	2.8 ± 0.2	
King Hill lava flow	59 P 79(HP)		WR	3.75 ± 0.1	
Morrow Reservoir lava flow	70-8(L)	R	WR	1.2 ± 0.2	
Hammett lava flow	70-4(L)	R	WR	1.5 ± 0.3	
Hammett lava flow	59 P 271(HP)		WR	1.2 ± 0.2	
Deadman Canyon lava flow	69-59(L)	R	WR	1.35 ± 0.07	
Basalt flow, north of Mt. Bennett Hills	70-13(L)	R	WR	1.8 ± 0.2	
Idaho Group-older basalt flows					
Lucerne School lava flow	69-51(L)	R	WR(a)	4.2 ± 0.4	4.4 ± 0.4
			WR(b)	5.0 ± 1.3	
Glenns Ferry Formation lava flow near Hollister	69-42(L)	R	WR	4.5 ± 0.3	
Deer Gulch lava flow	70-16(L)	R	WR	5.9 ± 1.0	
Shoestring Road lava flow	69-55(L)	N	WR	6.2 ± 0.7	
Shoestring Road lava flow	54 P 93(HP)		WR	4.0 ± 0.3	Ar loss suspected
Clover Creek lava flow	OB 9(HP)	R	WR	3.2 ± 2.0	
Devils Playground lava flow	70-10(L)	R	WR	2.8 ± 0.3	
Upper Banbury Basalt	70-44(L)	N	WR	4.4 ± 0.6	
Upper Banbury Basalt	59 P 318(HP)		WR	3.5 ± 0.6	
Lower Banbury Basalt	69-47(L)	N	WR	4.9 ± 0.6	
Banbury Basalt, Notch Butte	62 P 111(HP) USGS No I-4121		WR	7.3 ± 0.3	
Basalt of Chalk Hills Formation	70-3(L)		WR	8.2 ± 0.7	
Basalt of Chalk Hills Formation	69-50(L)	N	WR	8.6 ± 0.5	
Banbury Basalt, Mt. Bennett Hills	70-11(L)	N	WR	13.5 ± 1.5	

Columbia River Basalt and correlative basalt flows					
Yakima Basalt	64-44(F)		WR	17.0 ± 1.5	
Basalt dike, Anderson Ranch Dam	342 W(T)		WR	15.1 ± 0.7	
Basalt dike, Anderson Ranch Dam	339 (T)		WR	12.1 ± 1.2	
Basalt dike, west of Lowman	423 (T)		WR	15.2 ± 0.5	
Alkali olivine basalt, Silver City Region	A 350(P)		WR	14.7 ± 3.0	
Silicic volcanic rocks					
Rhyolite of Magic Reservoir (Asher, 1965)	69-40(L)		Fsp(a) Fsp(b)	3.0 ± 0.06 3.13 ± 0.06	3.06 ± 0.04
Idavada Volcanics, Shoshone Falls	69-45(L)		WR(a) WR(b) WR(c)	5.7 ± 0.3 5.8 ± 0.11 5.6 ± 0.2	5.7 ±0.1
			Fsp(a) Fsp(b)	6.0 ± 0.2 6.5 ± 0.16	6.25 ± 0.12
Idavada Volcanics, south of Hollister	69-43(L)	R	WR(a) WR(b)	9.7 ± 0.16 9.6 ± 0.14	9.65 ± 0.1
Silver City Region					
Rhyolite porphyry flow	A 325(P)		Fsp	15.7 ± 0.3	
Rhyolite vitrophyre flow	A 98(P)		Fsp	15.6 ± 0.3	
Rhyolite porphyry flow	A 26(P)		WR	15.6 ± 0.2	
Rhyolite porphyry flow	A 345(P)		Bi	15.7 ± 0.2	
Porphyritic rhyolite flow	A 45(P)		WR	15.6 ± 0.3	
Rhyolite porphyry flow	A 34(P)		Bi	17.3 ± 0.3	
Snake River Plain between Twin Falls and Idaho Falls					
Basalt flows					
Lava Creek flow (Anderson, 1929) near Craters of the Moon	69-22(L)	N	WR	—0.1 ± 0.2	
Grassy Cone flow near Craters of the Moon (Murtaugh, ms)	69-27(L)	N	WR(a) WR(b)	—0.02 ± 0.05 0.07 ± 0.09	0.02 ± 0.05
Porphyritic olivine basalt, Gem Valley	900(O)		WR	0.1 ± 0.03	avg of 13 Ar analyses
Porphyritic olivine basalt, Gem Valley	902(O)		WR	0.1 ± 0.3	
Porphyritic olivine basalt, Gem Valley	903(O)		WR	0.1 ± 0.4	
Basalt, lowest flow at Inkom	69-2(L)	N	WR(a) WR(b)	0.14 ± 0.06 0.14 ± 0.04	0.14 ± 0.03

TABLE 1 (continued)

Unit sampled	Sample number	Magnetic polarity	Material analyzed	Date (m.y.) and error (σ)	
Basalt 61 m below surface at NRTS	62 P 73(HP) USGS No I 4125		WR	0.4 ± 0.1	
Flow above Blackfoot River, east of Wapello	69-3(L)	N	WR	0.90 ± 0.2	
Basalt flow, north side Middle Butte	70-35(L)		WR	1.9 ± 1.2	
Olivine basalt, Antelope Hill	928(A)		WR	2.3 ± 0.3	
Ophitic olivine basalt, Malta Range	927(A)		WR	9.2 ± 1.5	
Silicic volcanic rocks					
Pumiceous rhyolite, China Hat	70-27(L)		WR	0.04 ± 0.02	
Perlitic rhyolite, China Hat	70-26(L)		Fsp	0.08 ± 0.04	
Pumiceous rhyolite, Middle Cone, near China Hat	70-28(L)		WR	—0.1 ± 0.1	
Rhyolite, Big Southern Butte	70-38(L)		WR	0.30 ± 0.02	
Crystal tuff, East Butte	70-36(L)		WR	0.6 ± 0.1	
Ash flow, Blackfoot River, east of Blackfoot	QTV 2(A)		WR	6.3 ± 0.1	
Crystal vitric tuff, Cosgrove Road	70-21(L)		WR	9.6 ± 0.1	
Crystal tuff, Cosgrove Road	TAV 1(A)		Fsp	10.3 ± 0.14	
Vitric ash flow, near top of section, Sublett Range	924(R)		WR	10.4 ± 0.14	
Vitrict ash flow, glass, middle of section, Sublett Range	922(R)		WR	8.2 ± 0.2	
Vitric ash flow, base of section, Sublett Range	921(R)		Bi	10.8 ± 0.2	
	921(R)		Fsp	9.4 ± 0.14	
Rhyolite vitrophyre flow, Malta Range	801(A)		WR	9.2 ± 0.5	
			Fsp	9.1 ± 0.4	
Tridymite-rich vitric ash flow, Albion Range	805(A)		WR	8.5 ± 0.2	
Vitric ash flow, north of Middle Mountain	929(A)		WR	8.4 ± 0.2	
Vitric ash flow, Trapper Creek Road, Goose Creek Reservoir	794(A)		WR	8.5 ± 0.3	
Rhyolite dome, east of Goose Creek, near Utah border	Alb 2490(A)		Fsp	12.8 ± 0.4	
American Falls area					
Basalt flows					
Cedar Butte, flow near base of volcano	69-13(L)	N	WR	0.1 ± 0.2	
Basalt of Eagle Rock (Massacre Volcanics)	70-45(L)	R	WR	4.9 ± 0.7	Ar loss suspected
Little Creek Formation	69-10(L)	R	WR	4.8 ± 0.3	

Massacre Volcanics, basalt plug, Massacre Rocks	69-41(L)	R	WR(b)	6.1 ± 0.2	6.3 ± 0.2
			WR(a)	6.5 ± 0.6	
Silicic volcanic rocks					
Walcott Tuff	776(A)		WR	6.3 ± 0.3	
Walcott (?) Tuff below American Falls Dam	69-11(L)		WR(a)	4.9 ± 0.17	5.3 ± 0.12; Ar loss suspected
			WR(b)	5.7 ± 0.21	
Obsidian pellets from ash flow above 69-11(L)	69-12(L)		WR	6.2 ± 0.09	
Starlight Formation, vitric crystal tuff in upper part	70-19 B(L)		Fsp	6.5 ± 0.1	
Starlight Formation, tuff of Arbon Valley, in middle of the formation	70-20(L)		Fsp	7.7 ± 0.1	
Snake River Plain between Idaho Falls and Yellowstone Park					
Basalt flows					
Flow 15.5 m below surface near Mud Lake	69 M 9(M)		WR	0.09 ± 0.14	
Flow, overlies 69-6, west of Swan Valley	69-8(L)	N	WR	0.8 ± 0.1	
Silicic volcanic rocks					
Yellowstone Group, Lava Creek Tuff	21(A)	N	Fsp	0.56 ± 0.04	
Welded ash flow tuff, probably Mesa Falls Tuff of Yellowstone Group	69-5(L)		Fsp(a)	0.94 ± 0.05	1.03 ± 0.03
			Fsp(b)	1.09 ± 0.04	
Felsic lava, west of Swan Valley	69-6(L)	R	WR	3.65 ± 0.10	
Welded ash flow, quarry east of Ammon	69-9(L)		WR(a)	4.10 ± 0.13	4.11 ±0.10
			WR(b)	4.13 ± 0.14	
			Fsp(b)	4.7 ± 0.10	

Details of sample localities and analytical data are included in a review of Idaho geochronometry that will appear in Isochron/West (Armstrong, ms)

Parenthetical letter after sample number designates the collector, as follows:

A—R. L. Armstrong
L—W. P. Leeman
F—C. W. Field
O—S. S. Oriel and L. Platt
P—A. J. Pansze, Jr.
R—L. Rychener
T—W. H. Taubeneck
M—H. E. Malde
HP—H. A. Powers

Samples collected by Malde and Powers were furnished Armstrong by G. T. Stone.

Polarity: N, normal; R, reversed. Material analyzed: WR, whole rock; Fsp, feldspar; Bi, biotite.

rock and feldspar dates could be compared. Many fresh glassy rocks gave nearly concordant results for such comparisons, but in general the glass gave slightly lower dates, as would be expected. We consider the dates on feldspar to be those in which the most confidence can be placed. Whole-rock dates, particularly those determined on older rocks, must always be viewed with suspicion.

The precision and accuracy of dates on young rocks depend almost entirely on the ability to measure the Ar^{36} to Ar^{40} ratio in gas extracted from the samples so that total argon may be corrected for atmospheric argon contamination. Most atmospheric argon comes from the samples and is not an analytical system blank. This is demonstrated by the varied amounts of atmospheric argon obtained for different samples and by reproducibility of the results for reruns of the same sample. In general the amount of atmospheric argon increases with age and with degree of alteration of the rock. As a consequence the observed percentage of radiogenic argon does not increase in proportion to the age of samples, and the percentage errors for dates from older rocks may be nearly as large as for very young samples. Atmospheric argon does not seem to be strongly correlated with vesicularity. Four samples were rejected because they were so grossly contaminated with atmospheric argon that the dates obtained had uncertainties of greater than 5 m.y.

In order to monitor our ability to make the correction for atmospheric argon, specimens known to be of young age were repeatedly analyzed. These should contain no radiogenic argon (presuming they were completely degassed at the time of eruption). The dates for these samples (Craters of the Moon shown on table 1 and the 1960 Kilauea lava) were all zero within one-sigma error limits. Even with samples of basalt that are relatively free of atmospheric argon, the analytical uncertainty due to the atmospheric argon correction seldom falls below 0.1 m.y. The K-rich siliceous glasses and feldspars give results with somewhat greater precision. We consider all dates with an uncertainty of more than 0.5 m.y. (or 10 percent for dates greater than 5 m.y.) as of dubious quality.

K–Ar dates for young volcanic rocks are inherently inaccurate because the amount of initial radiogenic argon is uncertain. The King Hill lava flow, discussed later, is apparently contaminated with radiogenic argon frozen in upon original cooling and crystallization, but it is an unusual magma both chemically and isotopically. There also exists a possibility that the Massacre Volcanics basalt plug is slightly contaminated with excess radiogenic argon. No other samples in the suite we dated seem to have excess radiogenic argon, but this cannot be proved. Many of the dates might actually be a bit too old, but experience has demonstrated that K–Ar dating usually gives reliable results for volcanic rocks. Tests of consistency help to weed out the rare discrepant results. These tests include stratigraphic order, multiple samples from the same unit, mineral separates compared with whole-rock dates, and in some cases, paleomagnetic correlation. The application of many such tests is discussed below.

The analytical techniques are the same as those described by Armstrong (1970)—isotope dilution for Ar, atomic absorption spectrophotometry for K. The precision of both K and total Ar analyses is 1 percent (σ), and the uncertainty of the atmospheric argon correction is 1 percent of the total argon. All dates are calculated using the constants: $K\lambda_\beta = 4.72 \times 10^{-10}$ yr^{-1}, $K\lambda_e = 0.584 \times 10^{-10}$ yr^{-1}, $^{40}K/K = 0.0119$ atom percent. Sample localities are shown in figure 1, and sample data given in table 1. Stratigraphic and chronologic relationships within the Snake River Plain are most easily followed on figure 2. Although schematic, it will make the following discussion much easier to comprehend.

Paleomagnetic measurements were obtained in the field using a portable flux-gate magnetometer with at least three independent observations for each reported polarity.

VOLCANIC CHRONOLOGY

Western Snake River Plain

Basalt and rhyolite older than Idavada Volcanics.—Columbia River Basalt and correlative basalt in eastern Oregon apparently were erupted during a relatively short span of time (14-18 m.y.) and are thus considered to be middle Miocene (mostly Barstovian, perhaps some a bit older) (Holmgren, 1970; Baksi and Watkins, 1973; Evernden and James, 1964). The wider range of time, 12.1 to 21.3 m.y., reported by Gray and Kittleman (1967) for basalts of the Clearwater Embayment (west-central Idaho) requires confirmation because it conflicts with the results of other workers. We have one date of 17 ± 1.5 m.y. for the Yakima petrologic type basalt near Hornet Reservoir (north of Weiser) and a date of 14.7 ± 3 m.y. for a basalt flow near Silver City that is overlain by rhyolite dated 15.65 m.y. In addition we dated three dikes thought by Taubeneck (1970) to be feeders for Columbia River Basalt. Of these, one date seems distinctly young (12.1 ± 1.2 m.y.); the other two (15.1 ± 0.7 and 15.2 ± 0.5 m.y.) are quite consistent with a Columbia River age.

North and northwest of Boise, Columbia River Basalt intertongues with lake deposits, bedded ash, and other sediments of the Payette Formation. In the Owyhee Mountains to the south, alkali basalt of similar age is overlain by locally altered and mineralized rhyolites from which we obtained ages clustering around 15.65 m.y. (rhyolites near Silver City). Rhyolite of similar age (15.4 m.y., 15 to 16 m.y.) overlies undated basalt in northeastern Nevada (Evernden and others, 1964; Coats, 1971); Axelrod (1964) reported a K–Ar date of 16.8 m.y. for the same unit.

Although the Columbia River basalt is older than and chemically distinct from basalts of the Snake River Plain (Powers, 1960), no major geographic or chronologic break separates the two volcanic provinces. Rather, near the western border of Idaho the eruption of Columbia

River and related basalts was synchronous with silicic volcanism that was the first step in the evolution of the Snake River Plain.

Idavada Volcanics.—Rhyolitic tuffs, ash flows, clastic sediments, and minor basalt flows unconformably overlie the mineralized volcanic rocks of Miocene age and older rocks in highlands north and south of the Snake River Plain. Similar rocks are locally exposed along the Snake River Canyon and its tributaries and in prominent buttes that project through the veneer of younger basalts in the eastern Snake River Plain. West of the Albion Range these rocks are called Idavada Volcanics (Malde and Powers, 1962); similar rocks are called Starlight Formation near American Falls (Carr and Trimble, 1963), and east of there the name Salt Lake Formation has been used (Mansfield, 1920, 1927). These rocks have been considered on paleontologic and stratigraphic grounds to decrease slightly in age as traced eastward, the Idavada Volcanics being Clarendonian and the silicic volcanics of the eastern Snake River Plain being Hemphillian in age. We will discuss the silicic rocks of the eastern Snake River Plain later.

Coats (1968) reported a date of 12.2 m.y. for the Cougar Point Welded Tuff and a date of 11.6 m.y. for the Circle Creek Rhyolite lekolith in the Owyhee region of northern Nevada. These dates are distinctly older than our dates of 9.7 m.y. for type Idavada and 8.4 to 8.5 m.y. for the volcanics near Goose Creek farther east. The dating is in agreement with previous estimates of age for these volcanics. Idavada Volcanics in the Mount Bennett Hills north of the Snake River Plain (Smith, ms) have not yet been dated.

Idaho Group.—The Idaho Group is recognized and mapped in detail only in the western Snake River Plain. Southwest of Boise the lowest unit, the Poison Creek Formation, of Clarendonian age, is composed of sediments and volcanic ash that lie between Idavada Volcanics and lava flows probably correlative with Banbury Basalt. Its age is bracketed by dates on the enclosing units.

Banbury Basalt along the southwestern margin of the plain near Murphy overlies Poison Creek Formation and underlies Chalk Hills Formation. We have dated basalt from the Hemphillian Chalk Hills Formation as at least 8.4 m.y. old, probably slightly older. E. H. McKee (written commun., 1971) reports that four dates on Banbury Basalt in the Owyhee-Jarbridge region range from 8.0 to 10.6 m.y., the older dates being preferred. On this basis, Poison Creek Formation is approximately 11 m.y. old. Banbury Basalt mapped at other localities is of various ages ranging from at least 10 to less than 3 m.y., but we will discuss that later.

The Glenns Ferry Formation consists of intertonguing lacustrine and fluviatile sediments containing volcanic marker beds (Powers and Malde, 1961; Malde and Powers, 1962; Malde, 1972), a number of which have been mapped and named. The basalt flows are pervasively altered, and fresh material is difficult to obtain. Many attempts to date them did not succeed because of the alteration and high atmospheric argon contamination levels, but we have selected what we consider the best results on the freshest material. Our dates are much greater than the widely quoted dates of 3.5 m.y. for the Deer Gulch lava flow and 3.3 m.y. and 3.2 m.y. for Glenns Ferry ash layers reported by Evernden and others (1964, samples KA 1173, KA 831, and KA 832, respectively). This disparity is a cause for concern because Glenns Ferry rocks are locally rich in fossils that have been extensively studied. The Evernden and others (1964) date was thought to be an excellent number for the Blancan land mammal age. The paleontologic interpretations were reviewed by Malde and Powers (1962) and Malde (1972). The mollusks were thought to be late Pliocene, the vertebrates Blancan—late Pliocene to early Pleistocene. Zakrzewski (1969) considered the mammals to be definitely late Pliocene. Reconsideration of the time ranges of the fossil invertebrates and mammals and of the land mammal ages would be required by acceptance of our dates. If our dates are correct, the Glenns Ferry represents the earliest appearance of many forms and assemblages, and a revision of the ages assigned to the Blancan zone would be necessary.

The Glenns Ferry K–Ar dates considered here to be most accurate range from 4.4 to 6.2 m.y., all being older than Blancan on the time scale of Evernden and others (1964). The lowest units that we succeeded in dating were the Deer Gulch lava flow and the immediately underlying Shoestring Road lava flow, 5.9 ± 1.0 m.y. and 6.2 ± 0.7 m.y., respectively. From stratigraphic evidence, these lava flows are virtually contemporaneous. The Shoestring Road lava flow is 215 m above the base of the Glenns Ferry Formation. A date of 4.0 ± 0.3 m.y. for a more altered Shoestring Road sample was rejected as was 3.2 ± 2.0 m.y. for an altered sample of the even older Clover Creek basalt flow and 2.8 ± 0.3 m.y. for slightly altered-looking Devils Playground basalt flow, considered on stratigraphic grounds to be the oldest Glenns Ferry basalt. For the Lucerne School lava flow, believed to be the youngest Glenns Ferry basalt in the type area on the basis of its elevation (perhaps 30 m stratigraphically above the Shoestring Road lava flow), we obtained 4.4 m.y. on a sample that appeared quite fresh. We thus conclude that the lower part of the Glenns Ferry sediments—the part that has yielded most of the late Pliocene fossils—is approximately 4.4 to 6 m.y. old, considerably older than previously thought.

The higher parts of the Glenns Ferry Formation, west of the area of these dated lava flows, include several beds of basaltic pyroclastic material that represent either products of phreatic eruptions or fragmental material dispersed from lava flows that entered a lacustine environment (Malde, 1972). These beds of basaltic material reach stratigraphic levels nearly 185 m above the Deer Gulch lava flow but have not been dated. Layers of silicic volcanic ash, also undated, occur even higher in the formation.

The change in placement (or the recognition of time-transgression) of the base of the Blancan suggested by these dates is illustrated in figure 2. The unusually long duration of the Hemphillian zone is shortened by this adjustment of the time scale. This shortening would imply a different rate of evolutionary change in Neogene vertebrate faunas than heretofore recognized.

The other Basalts called Banbury Basalt.—The type locality for Banbury Basalt is on the Snake River near the mouth of Salmon Falls Creek where altered basalt and interbedded sedimentary deposits underlie the Glenns Ferry Formation including the Lucerne School lava flow. The Banbury Basalt overlies Idavada volcanics in Salmon Falls Creek (Malde and Powers, 1972) and can be traced eastward to outcrops where the basalt overlies Idavada Volcanics exposed in the Snake River Canyon at Twin Falls (Malde, Powers, and Marshall, 1963). Our dates for fresh-looking samples of Banbury Basalt in the type locality are 4.4 ± 0.6 and 4.9 ± 0.6 m.y. A result of 3.5 ± 0.6 m.y. was obtained for a distinctly altered sample. We might suspect that all these dates were low due to alteration of the basalt. The rocks dated are bracketed by 4.4 m.y. for the overlying Lucerne School lava flow and 6.25 ± 0.13 for feldspar from the Idavada Volcanics at Shoshone Falls. Thus we believe that the type Banbury, although different from Glenns Ferry rocks in its greater degree of alteration and in the character of interbedded sediment, is of approximately the same age as parts of the Glenns Ferry Formation that lie to the north and west but is distinctly younger than the Banbury that underlies Chalk Hills Formation. The K–Ar dates for the type Banbury are inconsistent with dates for the Shoestring Road and Deer Gulch lava flows that lie stratigraphically higher (Malde and Powers, 1962, 1972; Malde, 1972). Our dates do not exclude the possibility that the type Banbury is only slightly older than Shoestring Road and Deer Gulch lava flows and thus has an age of about 6.2 m.y., but we do not believe it can be much older than that because of the feldspar date from Shoshone Falls.

There are more than just two Banbury Basalts! In the Mount Bennett Hills, the Banbury Basalt above Idavada Volcanics encloses sediments that contain early Hemphillian fossils. Coarse ash from the sediments was dated 10.0 m.y. by Everden and others (1964, sample KA 830). Our date for fresh-looking Banbury Basalt in the Mount Bennett Hills is a very imprecise 13.5 ± 1.5 m.y. (because of a large atmospheric argon correction). This suggests that the Banbury in this area is older than 10 m.y., ash dates being notoriously unreliable. More dates are urgently needed for these rocks. At Notch Butte, 37 km south of the town of King Hill, fresh Banbury Basalt gave a date of 7.3 ± 0.3 m.y. At the east end of the Mount Bennett Hills, on the northern side of the plain due north of Twin Falls, Banbury Basalt overlies the rhyolite of Magic Reservoir (Malde, Powers, and Marshall, 1963). An intrusion considered to be related to the rhyolite was dated 3.06 ± 0.04 m.y. on feldspar, and thus the basalt is only about 3 m.y. old.

We conclude, as surmized by Malde, Powers, and Marshall (1963) that the name Banbury has been used to designate basalts of several ages sandwiched between older silicic volcanic rocks and younger units.

Banbury Basalt, as thus far identified, may span most of the Idaho Group. In mapping, the name Banbury has been used to indicate either altered basalts below Glenns Ferry strata along the Snake River (and thus in places perhaps an alteration facies of basalts of Glenns Ferry age) or basalt of uplands to the north and south into which the Glenns Ferry and the Chalk Hills Formations are apparently incised. The Banbury Basalt does not, therefore, represent a formation of limited stratigraphic position nor a formation of limited range in age.

Bruneau Formation.—A gap in the stratigraphic record of the western Snake River Plain is indicated by erosion that preceded deposition of the Tuana Gravel (Malde and Powers, 1962). The Bruneau Formation is composed of lake and stream deposits and basaltic lava flows, many individually named, that accumulated in the western Snake River Plain after deposition of the Tuana Gravel. Evernden and others (1964, sample KA 1188) reported a date of 1.36 m.y. for the Berry Ranch lava flow, high in the Bruneau Formation. The related fossils are Irvingtonion—early to middle Pleistocene. The average of all our dates for named Bruneau basalt flows (except King Hill) is 1.41 m.y.; our most accurate date is 1.35 ± 0.07 m.y. for the Deadman Canyon lava flow–in excellent agreement with the result reported by Evernden and others. The results are not precise enough to compare dates with stratigraphic position, as no single date differs significantly from the average value.

Basalt from the King Hill lava flows, sandwiched stratigraphically between the Berry Ranch and Morrow Reservoir lava flows, yields dates that are erratic and anomalously old. The only reasonable explanation is that the lava contained radiogenic argon at the time of crystallization. The lava is unusually rich in K, and so the excess argon is more than two orders of magnitude greater than the small amounts of radiogenic argon measured in more recent basalts. The lava is characterized by anomalously high Sr^{87} content (Leeman and Manton, 1971) and is distinct in chemistry from most Snake River Plain basalts (Powers, 1960; Stone, ms), suggesting both contamination and fractionation in an environment with abnormally high partial pressure of radiogenic argon. This might easily occur if the magma stagnated in a chamber enclosed in Precambrian rocks.

Snake River Group.—Deposition of the Snake River Group, a sequence that includes eight identified upper Pleistocene formations (Stearns, Crandall, and Steward, 1938; Malde and Powers, 1962; Malde, 1971a) followed another break in the stratigraphic record of the western Snake River Plain marked by erosion, deposition of the Black Mesa Gravel, and renewed downcutting. During subsequent entrenchment of the Snake River to its present depth the several basaltic lava flows of the Snake River Group were erupted. The only accurate date we have is for the oldest lava of the Snake River Group, the Madson Basalt (0.54 ± 0.08 m.y.). A date of 0.5 ± 0.5 m.y. for the younger Sand Springs Basalt is compatible but not particularly informative. As will be seen later, the Snake River Group of the western Snake River Plain spans much less time than basalts mapped with the same designation in the eastern Plain. An upland lava flow near Magic Reservoir, which was mapped as Bruneau by Malde, Powers, and Marshall (1963), although isolated from sedimentary deposits of the Bruneau, is 0.8 ± 0.5 m.y. old and has normal remanant magnetism. It is probably correlative with Snake River Group basalts elsewhere on the Snake River Plain.

Eastern Snake River Plain

East of Twin Falls parts of the Snake River Plain are mantled by fresh basalts, some with well preserved flow surfaces suggesting an age no older than hundreds or thousands of years. The most famous of these young lavas are those of the Craters of the Moon, where relatively young flows approximately 2100 yr old have been dated by C^{14} (Bullard and Rylander, 1970; Bullard, 1971). A similar date for an eruption from the Kings Bowl rift farther south has been reported by Prinz (1970). The Craters of the Moon lava flows are too young to be dated accurately using the K–Ar technique; analyses of two samples from relatively old flows gave essentially zero dates, indicating a lack of inherited radiogenic argon. This result is encouraging but rather surprising considering the chemical and isotopic similarity of Craters of the Moon to the King Hill lava flows (Stone, ms; Leeman and Manton, 1971), which apparently have excess argon.

Older volcanic rocks of the eastern Snake River Plain are best exposed along the southern margin of the plain. They have been studied in greatest detail around the Albion Range (R. L. Armstrong, work in progress), between American Falls and Blackfoot (Carr and Trimble, 1963; D. E. Trimble, written commun. 1971), and in the National Reactor Test Site and Island Park area (Stearns, Bryan, and Crandall, 1939; Hamilton, 1960, 1963, 1965; Malde, 1971b; R. L. Christiansen, work in progress).

Twin Falls to the Sublett Range.—The various silicic volcanic rocks that are exposed east and west of the Albion Range and in the Sublett Range are not identical in age but collectively fall within the time span determined for Idavada Volcanics farther west. The oldest volcanic rock dated in this sector is a rhyolite dome exposed east of Goose Creek on the Idaho-Utah border. A feldspar date of 12.8 ± 0.4 m.y. suggests correlation with the Cougar Point Tuff farther west in northern Nevada. Next oldest are the ash flows of the Sublett Range, with dates of 9.4 m.y. for feldspar in the basal unit, 10.8 m.y. for biotite from the basal unit, and 10.4 m.y. for whole rock near the top of the section. The discordance among these dates must be due either to contamination of the whole rock and biotite or to an anomalously low feldspar date. Failure to extract all radiogenic argon from the feldspar is unlikely, inasmuch as it was fused to a clear, bubble-free glass with a flux for one determination and without flux in the other. The true age probably lies somewhere within the limits defined by these dates.

Dates on glassy whole rock and feldspar from the Malta (Cottrell) Range indicate an age of 9.1 m.y. for a thick west-dipping rhyolite flow (possibly a lekolith as defined by Coats, 1968). Capping this rhyolite is a very low-K basalt of essentially the same age (9.2 ± 1.5 m.y.).

The silicic volcanics exposed on Goose Creek, south of Burley, are rhyolite tuff and ash flows that lap onto the Albion Range. Although these rocks display considerable warping and small-scale faulting, they are not as steeply tilted or as much broken by faults as older volcanics to the east and west. In fact, the remnants of these younger volcanic rocks of Goose Creek scattered about in the mountains clearly show that the topography and relief of the Albion Range have scarcely changed since they were erupted. Piper (1923) and Mapel and Hail (1959) included them in the Salt Lake Formation, a name used by Mansfield (1920, 1927) farther east. Axelrod (1964) and Malde and Powers (1962) included the same ash flows and sedimentary deposits in the Idavada. Both glassy and devitrified samples yield an age of 8.5 m.y. for massive ash flows that cap the volcanic sequence near Goose Creek and in the Albion Range a few kilometers to the east.

These silicic volcanics of Goose Creek all plunge gently north under basalt of the Snake River Plain. Antelope Hill, a low shield volcano southeast of Burley, gave a date of 2.3 ± 0.3 m.y. No geologic study has been made to determine the relation of the basalt of Antelope Hill to rocks mapped as the Snake River Group, but loess-covered shield volcanoes of similar appearance south of the Snake River near Twin Falls (for example, Hub Butte) were mapped as part of the Glenns Ferry Formation (Malde, Powers, and Marshall, 1963).

An attempt to date Burley Butte, another loess-covered shield west of Burley was unsuccessful, because the sample was excessively contaminated with atmospheric argon.

Sublett Range to Idaho Falls.—The Starlight Formation near American Falls (Carr and Trimble, 1963) includes various rocks: bedded tuff breccia, tuffaceous sediments, marls, clastic sediments, basalt flows, and ash flows, some of which are traceable over large areas. The Starlight is overlain by massive impure rhyolitic tuff called the Neeley Formation, which is capped in turn by the Walcott Tuff, a distinctive glassy rhyolitic welded tuff. Dates on feldspar from ash flows in the Starlight Formation near American Falls are 6.5 and 7.7 m.y. The Walcott Tuff is approximately 6.2 m.y. old, ignoring one hydrated glassy sample whose dates (4.9 and 5.7 m.y.) reflect a considerable loss of argon. Our dates agree with a date of 6.1 ± 0.3 m.y. reported by Marvin, Mehnert, and Noble (1970) for the Walcott. East of Blackfoot, along Cosgrove Road, a tuff thought by D. E. Trimble (written commun., 1971) to correlate with a unit of the Starlight near American Falls (tuff of Arbon Valley dated as 7.7 m.y. old) gave a whole-rock date of 9.6 m.y. Suspecting contamination, we re-collected close to the same locality. Feldspar separated from this second sample gave a date of 10.3 m.y., in reasonable agreement with the first result. In the same area near Blackfoot the youngest widespread ash flow, thought to be Pleistocene (D. E. Trimble, written commun., 1971), gave a date of 6.3 m.y., which is nearly identical to the date for the Walcott Tuff. The age of silicic volcanic rocks of the region between American Falls and Blackfoot is thereby bracketed between 6 and 10 m.y. old. This result is consistent with the mid-Pliocene age assigned to mollusks from the interbedded sedimentary rocks (D. W. Taylor, *in* Carr and Trimble, 1963, p. 12).

The Little Creek Formation (Carr and Trimble, 1963), a sequence of tuffaceous deposits capped by a single lava flow of basalt, is exposed along the Snake River near American Falls. For the basalt a date of 4.8 ± 0.3 m.y. was obtained. Immediately younger vents and eruptive rocks of this area are part of the Massacre Volcanics (Stearns and Isotoff, 1956). All these basaltic volcanic rocks are stratigraphically younger than the Walcott Tuff. Carr and Trimble (1963) assigned the Little Creek Formation to the late Pliocene or early Pleistocene. The Massacre Rocks (vents for some of the Massacre Volcanics) have been inadvertently reported as being vents for some of the basalt of the Snake River Group (Malde and Trimble, *in* Richmond and others, 1965). This statement was not meant to suggest an age assignment but, rather, to indicate that the Massacre Rocks petrographically resemble basalts of the Snake River Plain (D. E. Trimble, oral commun., 1974). The date reported here for Massacre Rocks (6.3 m.y.) is inconsistent with Trimble's interpretation of the geologic relations (oral commun., 1974), because a flow that evidently issued from one of the vents at Massacre Rocks incorporates blocks that seemingly came from the basalt at Eagle Rock (for which a date of 4.9 ± 0.7 m.y. was obtained).

The dates for these basalts are internally discordant, suggesting either moderate argon loss from the basalt flows (with the true age of all basalts being nearly identical to the age of the Walcott Tuff) *or* excess of radiogenic argon in the basalt plug at Massacre Rocks. If such an excess exists, however, it is uniformly distributed, because two specimens of the plug gave dates of 6.1 ± 0.2 and 6.5 ± 0.6. Argon loss from the lava seems the probable cause of the discordant dates.

A much younger basalt flow, the Cedar Butte Basalt, is believed by Trimble and Carr (1961) to have dammed the Snake River near American Falls immediately prior to the Bonneville Flood (Malde, 1960, 1968). Our date of 0.11 ± 0.19 m.y. is consistent with this interpretation.

North of the American Falls several prominent buttes (volcanic domes of silicic lava) rise out of the middle of the basalt-covered plain (Walker, 1964). The dates for rhyolite from two of these (Big Southern Butte, 0.3 ± 0.02 m.y., East Butte, 0.6 ± 0.1 m.y.) were quite young but are not in conflict with known stratigraphic relations. The rise of Big Southern Butte uplifted and titled a section of basaltic lava flows on the order of 1 km thick (G. T. Stone, oral commun., 1974). Middle Butte is another topographic prominence nearby, but only basalt is exposed on its top; basalt scree mantles its flanks. The basalt, probably an older flow pushed up by a younger, still-concealed rhyolite dome, was not precisely datable because of an unusual degree of contamination with atmospheric argon but is nevertheless fairly young (1.9 ± 1.2 m.y.). Basalt from a depth of 61 m in a drill hole on the National Reactor Testing Station (NRTS) gave a more precise date of 0.4 ± 0.1 m.y.

Chase (1972) reported a number of K–Ar dates for volcanic rocks in and near the National Reactor Testing Station (NRTS). In general his results confirm the chronology we describe. In four cases where Chase dated the same unit as we did (East Butte, Middle Butte, and two samples from Big Southern Butte) our dates are consistently slightly younger and usually more precise. His results include one silicic volcanic rock about 9 m.y. old and numerous basalt flows ranging in age downward from 5.4 m.y.

Basalts temporally equivalent to the Snake River Group are commonly found in valleys marginal to the eastern Snake River Plain. Two large basaltic lava fields occur near the Blackfoot Reservoir in southeastern Idaho (Mansfield, 1927). These basalts are covered by thin loessal soil, and well-preserved lava-flow surface features suggest that the flows are rather young. Rhyolite domes in the Blackfoot lava field (for example, China Hat, Middle Cone) are older than the exposed basalts, but they contain xenoliths of still older basalts (Mansfield, 1927). Several intracanyon basalt flows, from vents in or near the Blackfoot lava field, are exposed along the Blackfoot River. Similar flows along the Portneuf River may have originated from vents near Alexander (Stearns, Crandall, and Steward, 1938). The Snake River valley above Heise was also filled by intracanyon basalt flows, which now form narrow benches above the river.

Basalts along the Blackfoot River gave a date of 0.90 ± 0.25 m.y.; a flow along the Portneuf River near Inkom gave 0.14 ± 0.04 m.y.; and the rhyolite domes of China Hat and Middle Cone gave ages of less than 0.1 m.y. A large number of analyses have given an age of 0.1 ± 0.03 m.y. for basalt flows in Gem Valley. All these lavas are thus Pleistocene in age.

Idaho Falls to Yellowstone Park.—Rhyolitic welded tuff near Ammon is so similar to the Walcott Tuff that Carr and Trimble (1963) suggested that the two units were correlative. Dates of 4.1 m.y. for glass, 4.7 m.y. for feldspar indicate that such a correlation is unlikely. A felsic volcanic rock of somewhat younger age, 3.65 ± 0.1 m.y., was collected near Swan Valley 50 km east of the Ammon locality. Together these silicic volcanic rocks are intermediate in age between the Starlight and Walcott Formations and the volcanism in the Island Park and Yellowstone volcanics.

The Island Park caldera and the Yellowstone Plateau are volcanic highlands consisting largely of rhyolitic welded tuffs and rhyolite flows (Hamilton, 1960, 1963, 1965; Boyd, 1961; Christiansen and Blank, 1972). Island Park Basin is a collapsed caldera approximately 29 km in diameter, rimmed by welded tuffs and partially filled by basalt flows. Hamilton (1960) and Boyd (1961) suggested that a caldera 50 km in diameter formed in Yellowstone Park and that during the later Pleistocene this caldera was filled by vast flows of viscous rhyolite. Some of these flows spilled westward into Island Park. Christiansen and Blank (1972) discussed this history in considerably greater detail.

The volcanic rocks of the Island Park-Yellowstone area have been dated extensively by J. D. Obradovich of the U.S. Geological Survey (Christiansen and Blank, 1972). Our dates for two widespread units, 1.03 ± 0.03 m.y. for the Mesa Falls Member of the Yellowstone Tuff and 0.56 ± 0.04 m.y. for the Lava Creek Member of the Yellowstone Tuff, agree with Obradovich's dates of 1.2 m.y. and 0.6 m.y. for the same units, respectively.

Eruption of rhyolite flows followed emplacement of ash-flow tuffs of the Yellowstone Group and has continued until relatively recent time (Richmond and Hamilton, 1960; Christiansen and Blank, 1972). There is no reason to believe that silicic volcanism northeast of the Snake River Plain has ceased.

The basalts of the northeastern end of the Snake River Plain are young, a flow in Swan Valley being 0.8 ± 0.1 m.y. old and a flow sampled at a depth of 15.5 m in a drill hole near Mud Lake being 0.09 ± 0.14 m.y. old.

Discordant Dates

The older basalts of the Idaho Group are commonly altered and are consequently difficult to sample for K–Ar dating. Even some of the freshest available samples have been disappointing, yielding dates that are either obviously too young or inconsistent with other results. The dates that we believe to be incorrect because of argon loss are listed in table 2. A matter of geologic interest is the convergence of discordant results toward 3.0 m.y., an observation in accord with stratigraphic evidence that places the time of maximum burial of these rocks between 2 and 4 m.y. ago. The period of most intense exposure to geothermally heated ground water may have occurred about 3 m.y. ago, and this cir-

TABLE 2

Discordant K–Ar dates for pre-Bruneau basalts and volcanic ashes of the Idaho Group

Sample	Estimated age m.y.	Date m.y.
Hydrated ash	6	3.2*
Deer Gulch lava flow	6	3.5*
Hydrated ash	6	3.3*
Shoestring Road lava flow	6	4.0 ± 0.3
Clover Creek lava flow	6	3.2 ± 2.0
Devils Playground lava flow	6	2.8 ± 0.3
Upper Banbury Basalt	6	3.5 ± 0.6
Upper Banbury Basalt	6	4.4 ± 0.6
Lower Banbury Basalt	6	4.9 ± 0.6
Basalts of Eagle Rock	6(?)	4.9 ± 0.7
Little Creek Formation	6(?)	4.8 ± 0.3

* Dates reported by Evernden and others (1964).

cumstance apparently resulted in resetting of the K–Ar clocks—even in some samples that appear to be only slightly if at all altered.

Baksi (1974) has demonstrated that atmospheric argon trapped in slightly altered basalts may be isotopically fractionated during sample bakeout so that the atmospheric correction is underestimated and the calculated K–Ar date too large. Although our bakeout procedure was very mild, this effect may be present in some of our dates with unusually large atmospheric argon corrections. In particular, the dates that we report for the Deer Gulch (70-16 L) and Shoestring Road (69-55 L) basalt flows and the Banbury Basalt of the Mt. Bennett Hills (70-11 L) may be a bit high. Dating now in progress at the University of British Columbia is designed to investigate this possibility.

Magnetic Polarity

Our data make no significant contribution to the magnetic polarity time scale of Cox (1969). Cox, Doell, and Dalrymple (1965) and Cox (Malde, 1971a) have studied the lavas of the classic stratigraphic units identified in the western Snake River Plain (Malde and Powers, 1962). Basalts of the Snake River Group west of Twin Falls are all normal and were erupted in the Brunhes epoch. Basalts in the Bruneau Formation are reversed, unambiguously dating from the Matuyama epoch. The results we have are entirely in agreement except for an isolated lava flow mapped as Bruneau near Magic Reservoir which is normal and younger than type Bruneau deposits (having formed either during the Jaramillo event or the Brunhes epoch). All Glenns Ferry basalts studied by Cox are reversed. We observed reversed polarity for all but the Shoestring Road lava flow. The several basalts mapped as Banbury are normal. Unfortunately, the dates for these older units are too inaccurate to define a polarity time scale. The polarities for rocks older than 2 m.y. are useful primarily for mapping purposes. The magnetic reversal coincident with the Snake River Group—Bruneau Formation boundary can be used as a stratigraphic marker throughout the Snake River Plain (Leeman, work in progress).

Bonneville Flood chronology.—The Bonneville Flood (Malde, 1960, 1968, 1971a; Stearns, 1962; Trimble and Carr, 1961) resulted from the overflow of Lake Bonneville at Red Rock Pass, south of Pocatello. The problem of the age of the flood and events leading up to it is discussed in detail by Malde (1968, p. 10-11). Based on radiocarbon dates, the Bear River was diverted into Lake Bonneville as a result of basalt eruptions 34,000 to 27,000 yrs ago in Gem Valley (Bright, 1967; see Mabey, 1971 for a somewhat different interpretation of the geology). Contemporaneously (35,000-25,000 yrs ago, Bright and others *in* Richmond and others, 1965) basalt flooded the Portneuf River valley. Then Lake Bonneville rose to overflow Red Rock Pass and flow down the Portneuf River valley and onto the Snake River Plain some time before 29,700 yrs ago (Trimble and Carr, 1961). Some of the radiocarbon dates are internally inconsistent.

We have dated the basalts in the Gem Valley as 0.10 ± 0.03 m.y. and the Portneuf River valley basalts near Inkom as 0.14 ± 0.03 m.y. Although these results cannot be independently confirmed they suggest a more leisurely chronology of Bear River events than the radiocarbon dates with which they disagree. Obviously this is a significant problem that might benefit from fission track dates for the basalts, if suitable material can be found.

One other date pertinent to the Bonneville Flood is 0.1 ± 0.2 m.y. for the Cedar Butte Basalt near American Falls. This flow dammed the Snake River, creating the ancestral American Falls Lake into which the Bonneville Flood gushed, depositing the Michaud Gravel (Trimble and Carr, 1961; Carr and Trimble, 1963). This result is compatible with the 29,700 yr date for the flood itself. The flood deposits are not overlain by a volcanic rock that might be analyzed to provide an independent post-flood date for comparison with the radiocarbon result.

DISCUSSION

Our dating documents and quantifies the concept of eastward transgression of Snake River Plain volcanism. Figure 2 illustrates the relations as exposed along the plain across the entire state of Idaho. Data for the northern margin of the plain are lacking for those areas where pre-Snake River Group rocks are exposed. Also, over much of the northern margin of the eastern Snake River Plain basalts of the Snake River Group lap directly on pre-Miocene strata precluding a discussion of earlier stages of Snake River Plain development there.

Throughout the history of the Snake River Plain three facies have been present. The earliest in any local succession, is what might be called the siliceous volcanic facies, consisting of a complex of volcaniclastic sediments, airfall and ash flow rhyolite tuffs, rhyolite flows, and, distinctly subordinate basalt flows and basaltic pyroclastics. This facies is typified today by the Yellowstone-Island Park region, where the siliceous volcanics are clearly associated with large calderas. No calderas are known farther west, but perhaps they are concealed beneath younger deposits. The siliceous volcanic sequence is overlain by a facies composed of basalt with some interbedded sediment and a few rhyolite flows and domes. In contemporary outcrops the area between Mud Lake and Twin Falls represents this subdivision. Isolated features such as East Butte and Big Southern Butte represent the minor siliceous volcanic component of this facies. An ancient analog of these middle facies rhyolite domes is the siliceous volcanic mass that forms Shoshone Falls, and an ancient analog of the basaltic lava flows would be the thick sequences of Banbury Basalt from Twin Falls westward.

Farther west, or uppermost in the local section, sediments predominate over basalt flows. Rhyolite flows are absent, but volcanic ash from farther east in the plain is locally an important component of the sedimentary rocks as for example in the Chalk Hills Formation. Complex stratigraphic relations between basalt flows and sediments are decipherable only where rivers have cut deep canyons. Glenns Ferry and Bruneau Formations are included in this facies. As a general rule sedimentary units thicken and increase in time span as they are traced westward. For example the base of the Glenns Ferry Formation becomes more and more deeply buried toward the west and the exposed part becomes younger. Basalt flows of the sediment-dominated facies come, mainly, from vents located near the central axis of the sedimentary basin.

In detail the eastward transgression may not be smooth but may occur as a series of jumps, the volcanic front moving abruptly eastward 50 to 150 km each time. The volcanic transgression began about 18 m.y. ago with the eruption of Columbia River Basalt and related lavas in far western Idaho, and farther to the west. The first widespread outburst of silicic volcanism occurred between 15 and 16 m.y. ago and included eruption of rhyolites in the Silver City, Wall Creek, and Jarbridge area. Downwarping or faulting of the Snake River Plain probably began at about that time (Malde, 1959; McIntyre, 1972). Idavada silicic volcanism transgressed eastward about 12.5 m.y. ago in western Idaho. By the time Idavada volcanism climaxed in the Cassia Mountains-Goose Creek area 8.5 m.y. ago, silicic volcanic rock had appeared farther to the east. This eastward migration of silicic units reached Blackfoot about 10 m.y. ago. A particularly intense episode of silicic eruptions, spread over an area from near Twin Falls to Idaho Falls, occurred about 6.3 m.y. ago, and this was followed quickly by the eruption of large amounts of basalt. The final eastward steps involving silicic eruptions spanned the last 5 m.y., at last reaching the now-active area of Yellowstone National Park. Because ash flows may travel large distances from their source vents, the eastward jumps we document are only a crude indication of the eastward shift of volcanic centers, which may have progressed smoothly or in a erratic fashion.

Basalt eruptions associated with eastward development of the Snake River Plain and the burial of extinct or dying silicic eruptive centers began slightly before 10 m.y. ago in the west, 5 to 6 m.y. ago near American Falls, and have yet to reach east of the Island Park caldera. Much of the present surface of the eastern plain and scattered areas in the western part are covered by basalt flows erupted within the last several hundred thousand years. Volcanic activity has persisted until recently; the probability of future eruptions anywhere within the Snake River Plain remains high. A real catastrophe is possible east of the Snake River Plain where future ash-flow eruptions are expectable, but on a human time-scale the likelihood of eruption is quite small. Nevertheless, a major ash flow eruption in Yellowstone would devastate much of the eastern plain and cause disruption and inconvenience over an even wider area.

On the average, the eastward shift of volcanic centers and facies has been at the rate of 1° of longitude every 2 m.y., or 3.5 cm per yr. Obviously this region can be described as the trace of an upper mantle melting spot. Our new data are useful for investigations of the motions of crustal plates and possible mantle plumes during the Neogene and the Quaternary (Morgan, 1971; Suppe, Powell, and Berry, 1973). Although the data bear on genesis of the volcanic rocks and the mechanism of downwarp associated with the volcanic eruptions, such discussions are beyond the scope of this paper.

With our K–Ar dates for Snake River Plain volcanic rocks, the confusion, disagreement, and controversy in stratigraphic assignments involved in earlier attempts at correlation of time-transgressive or lithologically similar, but noncorrelative, formations can be placed in improved perspective. Reliance on similarity in lithology or sequence led to Axelrod's (1964) assignment of the Trapper Creek flora to the lower Barstovian (16 m.y. rather than the ~10 m.y. of this report) and to Carr and Trimble's (1963) expression of doubts about Mansfield's (1927) dating of rhyolite near Ammon as Pleistocene. The dates given here indicate that the rhyolite near Ammon is distinctly younger than that near American Falls, rather than being nearly contemporaneous as both Mansfield and Ross (1935) and Carr and Trimble (1963) thought. These examples illustrate the usefulness of applying K–Ar dating to young volcanic rocks. Our study also illustrates some of the pitfalls that may be encountered and recognized only when the interpretation of numerous dates is constrained by detailed stratigraphic studies.

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