New Potassium-Argon Ages, Geochemistry, and Tectonic Setting of Upper Cenozoic Volcanic Rocks Near Blackfoot, Idaho

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By KARL S. KELLOGG and RICHARD F. MARVIN

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CONTENTS

FIGURES

TABLES

New Potassium-Argon Ages, Geochemistry, and Tectonic Setting of Upper Cenozoic Volcanic Rocks Near Blackfoot, Idaho

By KARL S. KELLOGG *and* RICHARD F. MARVIN

Abstract

The geochronology and geochemistry of volcanic units along the southeastern margin of the Snake River Plain south of Blackfoot, Idaho, document predominantly rhyolitic volcanism between about 10 and 4 million years ago followed by basaltic volcanism (flows of olivine tholeiite) between about 4 and 2 million years ago. Eight new potassium-argon ages from units collected on and near Stevens Peak help to define ages of depositional and tectonic events in the region.

The oldest volcanic units—below the 6.7-million-year-old tuff of Blacktail and overlying deformed, mostly Proterozoic and Paleozoic rocks of the thrust belt—are placed in the Starlight Formation. The lower member of the Starlight Formation is poorly exposed and composed of conglomerate, fanglomerate, gravels, tuffaceous sandstones, ash-flow tuffs, rhyolitic flows, and freshwater limestone. Two rhyolitic flows in the lower member—the rhyolite of Two-and-a-Half-Mile Creek and the rhyolite of Stevens Peak—have potassium-argon ages of 9.1 and 9.8 million years, respectively.

The middle member of the Starlight Formation in the Stevens Peak area is the tuff of Arbon Valley, dated at approximately 7.9 million years. The upper member is poorly exposed and contains gravel, air-fall ash, and one olivine basalt flow dated at 7.0 million years.

The top of the Starlight Formation was highly dissected, and a coarse boulder conglomerate containing conspicuous clasts of Triassic(?) and Jurassic(?) Nugget Sandstone and large boulders of the tuff of Arbon Valley was deposited by steep-gradient, west-flowing streams. The boulder conglomerate is locally overlain by the 6.7-million-year-old tuff of Blacktail, which constrains the age of the boulder conglomerate between 7.0 and 6.7 million years.

The boulder conglomerate was deposited during significant uplift to the east and documents a period of major Basin and Range faulting in the area. This period of active tectonism, between about 7.0 and 6.7 million years ago, is consistent with a model of younging of major Basin and Range faulting to the east. Some Basin and Range faults in the study area were active after 6.7 million years ago, and vertical offset across some faults of at least 50 meters has occurred since about 2.2 million years ago.

The tuff of Kilgore overlies the tuff of Blacktail and is about 4.3 million years old. Between about 4.3 and 3.7 million years ago, the volcanic activity changed markedly from predominantly rhyolitic ash-flow eruptions to olivine tholeiitic basalt flows (the basalt of Buckskin Basin), which are similar in composition to many of the olivine tholeiites of the Snake River Plain. Three potassium-argon ages from the basalt of Buckskin Basin are between 3.7 and 2.2 million years.

All rhyolitic rocks analyzed in the study area are peraluminous. Zirconium-strontium-rubidium ternary diagrams clearly discriminate between the rhyolite of Stevens Peak and the rhyolite of Two-and-a-Half-Mile Creek and between the tuff of Arbon Valley and the tuffs of Kilgore and Blacktail. Although major-element analyses (in addition to petrography) suggest that the tuff of Blacktail may be slightly more silicic than the tuff of Kilgore, neither major-element analyses nor zirconium-strontium-rubidium diagrams clearly discriminate between these two units.

The Buckskin dome, a prominent domical uplift 7 kilometers in diameter with an apparently sagged and faulted center, is entirely composed of the basalt of Buckskin Basin at the surface. The uplift, which began as early as 2.5 million years ago, may be the result of injection of rhyolitic magma, although gravity data are somewhat ambiguous.

INTRODUCTION

Understanding of the timing of eruption and the distribution of rhyolitic and basaltic rocks of the eastern SRP (Snake River Plain) has been refined in recent years by detailed stratigraphic, geochemical, and radiometric studies (for example, Armstrong and others, 1975, 1980; McBroome and others, 1981; Embree and others, 1982; Morgan and others, 1984; Kuntz, 1978). Rhyolitic rocks and their interbedded sediments, although generally older than the basalts which characterize the SRP, are commonly elevated relative to the basalts in hills marginal to the plain so that the stratigraphy of the rhyolitic rocks and interbedded sediments is locally well exposed. This study describes the geologic and tectonic setting and the geochemistry of volcanic and sedimentary rocks in an area along the southeastern margin of the SRP. The timing of major Basin and Range uplift in the area is determined by dating volcanic rocks that bracket the age of a syntectonic boulder conglomerate. Information is also presented regarding the age and geologic history of a basaltic domical uplift that is similar in form to several well-known, larger domical uplifts which occur on the eastern SRP.

The study area is located less than 12 km south of the town of Blackfoot and east of Fort Hall, Idaho, on the Fort Hall Indian Reservation (fig. 1). Stevens Peak is a prominent landmark in the northern part of the study area, and Buckskin Basin occupies the southern part of the area (figs. 1 and 2). The Buckskin Basin and parts of the Fort Hall, Moreland, and Blackfoot 7½-minute quadrangles cover the area. The topography is gently rolling. The maximum elevation, found east of Stevens Peak near the eastern margin of the study area, is 1734 m (5686 ft); the minimum elevation, found along Ross Fork Creek, is 1372 m (4500 ft). Bedrock, which is composed predominantly of a bimodal assemblage of late Tertiary rhyolite flows, ash-flow tuffs, and olivine basalts, is mostly mantled by Quaternary loess deposits, so that outcrops are sparse.

The area was first mapped by Mansfield (1920), who described the rhyolites and basalts on the Fort Hall Indian Reservation. Trimble (1976) mapped the Pocatello 15-minute quadrangle, just to the south of the study area, and described a succession of upper Tertiary and Quaternary basaltic and rhyolitic volcanic rocks and coarse, clastic sedimentary rocks that overlie tectonically complex Precambrian and lower Paleozoic strata of the Idaho-Wyoming fold and thrust belt. Trimble (1982) mapped similar rocks just to the east of the study area in the Yandell Springs 15-minute quadrangle.

Regionally, the volcanic evolution of the SRP in southeastern Idaho has been discussed by numerous authors. Most recently, McBroome and others (1981), Embree and others (1982), Leeman (1982a), and Morgan and others (1984) have discussed the Pliocene and Miocene rhyolite flows and ignimbrites, and Leeman (1982a, b), Greeley (1982), and Kuntz and others (1982) have discussed some of the Quaternary basalts. Armstrong and others (1975, 1980) have discussed the K-Ar (potsssium-argon) geochronology of many volcanic rocks of the eastern SRP. Allmendinger (1982) has inferred the probable timing of Basin and Range faulting in the Blackfoot Mountains, to the northeast of the study area, from a detailed geochronologic and stratigraphic study of ignimbrites. The present study has evolved from detailed mapping of the Stevens Peak and Buckskin Basin areas (Kellogg and Embree, 1986).

ACKNOWLEDGMENTS

Many of the problems described here were first addressed by D.E. Trimble, D.J. Doherty, G.F. Embree, L.A. Morgan, and H.J. Prostka, and discussions with most of these people have helped to orient the focus of this paper. In particular, the discussions and support of G.A. Desborough, in both the office and field, were crucial to the study. Field excursions and discussions with L.A. Morgan were an important factor in establishing much of the basic stratigraphy of the area. Special thanks are extended to Steven S. Oriel who introduced the first author to the geology of the area. The manuscript was improved immensely by reviews from L.A. Morgan and R.A. Thompson.

GEOLOGIC SETTING

The eastern Snake River Plain is largely characterized by voluminous olivine tholeiitic basalt as young as Holocene in age (Leeman, 1982b; Kuntz and others, 1982). Despite this widespread veneer of basalt, it has long been recognized that mostly older rhyolitic flows, ash-flow tuffs, pumice- and ash-fall deposits, and intercalated volcanogenic sedimentary rocks underlie the surface exposures on the SRP and are, in fact, volumetrically dominant, as indicated by deep drilling (Doherty and others, 1979; McBroome, 1981). The buried rhyolitic ash-flow tuffs, lava flows, and interbedded sediments are probably all derived from numerous overlapping calderas located beneath the basalts of the SRP (Prostka, 1979; Prostka and others, 1979; Doherty and others, 1979; McBroome and others, 1981; Morgan and others, 1984). The locus of rhyolitic volcanism has shifted northeastward along the axis of the SRP at a rate of approximately 3.5 cm per year (Armstrong and others, 1975); ignimbrites in the vicinity of Twin Falls, Idaho, are about 9–10 Ma (Williams and others, 1982) and those of the Yellowstone Plateau at the northeastern end of the SRP are as young as 0.6 Ma (Christiansen and Blank, 1972). At any one place along the plain, the cessation of rhyolitic volcanism was followed by basaltic outpourings, producing the striking bimodal assemblage of rocks.

Most of the exposed rhyolitic rocks are topographically elevated relative to the younger basalts, cropping out in hills along the southeastern and northwestern margins of the eastern SRP (Mansfield, 1920; Mansfield and Ross, 1935; Skipp and others, 1979; McBroome, 1981; Trimble, 1982; Allmendinger, 1982). Relative uplift of the hills marginal to the SRP occurred during Neogene and Quaternary Basin and Range faulting, although it should be noted that hills marginal to the plain were probably not uplifted in an absolute sense. A seismic-refraction study of the eastern SRP and its margin indicates that the SRP is a large downwarped feature (Sparlin and others, 1982). Along the southeastern margin of the plain, rocks of the Cordilleran thrust belt might extend locally for several tens of kilometers under the volcanics of the plain. In contrast, the seismic-refraction study suggests that volcanic rocks along the northern margin of the plain might be in fault contact with the rocks of the Cordilleran thrust belt and might not be underlain by pre-Tertiary rocks (Sparlin and others, 1982; Pankratz and Ackermann, 1982).

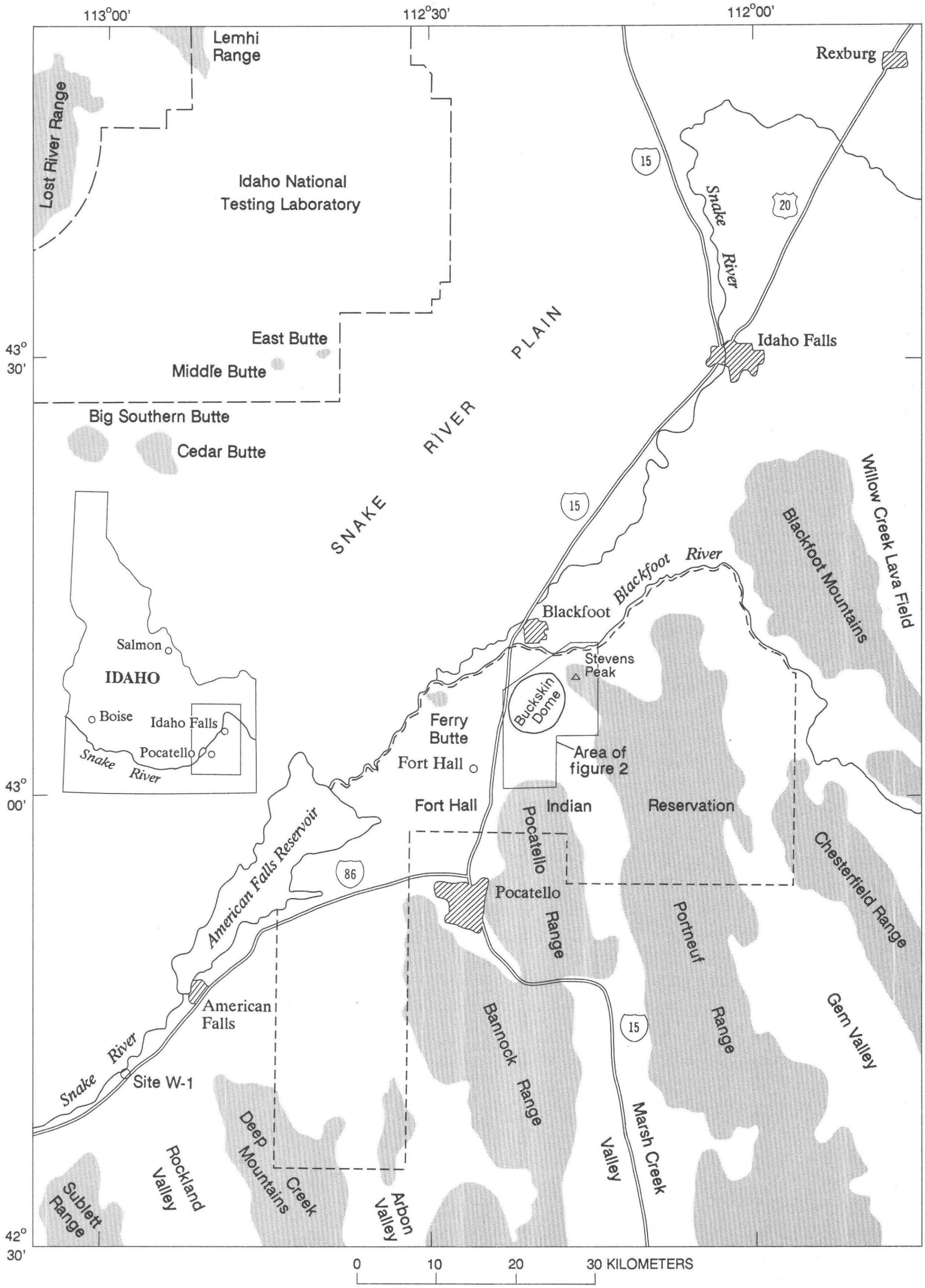

Figure 1. Index map of a part of southeastern Idaho showing major physiographic features adjacent to study area, which is enlarged in figure 2. Site W-1 is locality at which Walcott Tuff was sampled.

In the Blackfoot Mountains about 25 km northeast of Stevens Peak, downwarping has occurred along a complex network of high-angle normal faults, the oldest of which are north and east trending; younger faults of smaller displacement are northwest and northeast trending (Allmendinger, 1982). Allmendinger inferred that Basin and Range faulting in the Blackfoot Mountains occurred primarily between about 5.9 and 4.7 Ma and that Basin and Range faulting has shifted eastward in time since its initiation in north-central Nevada about 17 Ma.

The stratigraphy of the various upper Tertiary, largely rhyolitic volcanic and sedimentary units along the southeastern margin of the SRP is complicated by the active tectonism of the region; major changes in both facies and thickness over small distances are common. A diverse assemblage of rhyolitic ash-flow tuffs, rhyolitic flows, basaltic flows, volcanogenic sandstone, conglomerate, sedimentary breccia of probable mudflow origin, and freshwater limestone were originally defined by Mansfield (1927) as the Salt Lake Formation.

Attempts have been made in the last few years to subdivide the heterogeneous and widespread Salt Lake Formation into localized and stratigraphically distinct units. Carr and Trimble (1963) reassigned the lower part of the Salt Lake Formation in the vicinity of American Falls Reservoir to their Starlight Formation and did not use the term Salt Lake Formation in this area, although they recognize that Salt Lake Formation might be a useful term in other, less volcanogenic areas (D.E. Trimble, written commun., 1986). On the basis of fossil evidence, Trimble and Carr (1976) reported the Starlight Formation is early to middle Pliocene in age, although Late Miocene ages (to be discussed) for both the overlying Walcott Tuff and the tuff of Arbon Valley, the middle member of the Starlight Formation, necessitate that the Starlight Formation be upper Miocene.

The chronology of major ash flows along both margins of the SRP has been discussed by McBroome and others (1981), Embree and others (1982), and Morgan and others (1984). Morgan and others (1984) simplified the stratigraphic terminology that contained many local unit names (their terminology will be used in this paper). Four major ash-flow tuffs recognized in the general study area are, from oldest to youngest, as follows:

1. Tuff of Arbon Valley: This unit was first described by Carr and Trimble (1963) as the middle member of the Starlight Formation, and in most places it makes up the entire middle member. This compound cooling unit has been mapped as far southwest as the Rockland quadrangle (Trimble and Carr, 1976) and is exposed as far northeast as the Blackfoot River in the Blackfoot Mountains (Embree and others, 1982). A K–Ar age of 7.9 ± 0.1 Ma (recalculated using the decay constants of Steiger and Jäger, 1977) was determined for the tuff of Arbon Valley by Armstrong and others (1975).
2. Tuff of Blacktail as described by Morgan and others (1984); also called the tuff of Spring Creek by Embree and others (1982): This major ash-flow deposit of the eastern SRP has been associated with a caldera with eruptive vents on both sides of the plain (Morgan and others, 1984). This unit crops out at least as far southwest as Stevens Peak. Zircon fission-track ages of 6.5 ± 0.3 and 6.6 ± 0.7 Ma have been determined for the tuff of Blacktail (Morgan and others, 1984).
3. Walcott Tuff: This unit crops out prominently in the northern part of the Rockland quadrangle (Trimble and Carr, 1976), almost 50 km southwest of the study area. Trimble (1982) reported an isolated outcrop of Walcott Tuff in the Yandell Springs quadrangle, immediately east of the study area, although paleomagnetic evidence suggests that this rock is the tuff of Kilgore (L.A. Morgan, written commun., 1986). K–Ar ages for the Walcott Tuff (corrected for new decay constants of Steiger and Jäger, 1977) range from 6.3 ± 0.3 Ma (Marvin and others, 1970) to 6.9 ± 0.4 Ma (Trimble and Carr, 1976). Armstrong and others (1975) reported an age (also corrected) of 6.5 ± 0.3 Ma for the Walcott Tuff.
4. Tuff of Kilgore: This name was applied first to the area along the northern margin of the plain by McBroome and others (1981), who correlated the tuff of Kilgore with the tuff of Heise (Prostka and Embree, 1978) along the southeastern margin of the plain. Morgan and others (1984) later renamed the tuff of Heise the tuff of Kilgore. This widespread unit is prominently exposed in hills along the northeastern and southeastern margins of the SRP and has been recognized as far southwest as Stevens Peak. Armstrong and others (1975) reported a whole-rock K–Ar age of 4.2 ± 0.1 Ma (age recalculated with decay constants of Steiger and Jäger, 1977), and Morgan and others (1984) listed two feldspar K–Ar ages of 4.3 ± 0.3 and 4.8 ± 0.3 Ma and four zircon fission-track ages of 4.1–4.4 Ma (maximum uncertainty of 0.6 Ma). From these ages, an average age of about 4.3 Ma can be established for the tuff of Kilgore.

Basalts of the SRP–Yellowstone Plateau province are predominantly olivine tholeiite (Leeman, 1982b). These basalts are as young as Holocene in age in the vicinity of Craters of the Moon National Monument

(Kuntz and others, 1982), about 90 km west-northwest of the study area, and Pleistocene in age along the Blackfoot River (Armstrong and others, 1975), 10 km northeast of the study area. In the Buckskin Basin area, the basalts are late Pliocene in age (this study).

Several domical or piston-shaped uplifts of basalt, cored by Quaternary rhyolitic intrusive bodies, occur along the axis of the SRP. The most prominent of these uplifts is Big Southern Butte (Spear and King, 1982), which is about 50 km west of Blackfoot (fig. 1) and is cored by 0.3-Ma rhyolite (Armstrong and others, 1975). Rhyolite in the core of East Butte, northeast of Big Southern Butte, has a K–Ar age of 0.6 Ma (Armstrong and others, 1975). Middle Butte, another prominent basalt-mantled dome located between Big Southern Butte and East Butte, does not have an exposed rhyolitic core, but aeromagnetic and gravity data indicate that it is also cored by rhyolite (Kuntz, 1978). A prominent but smaller uplifted circular feature in the study area, named Buckskin dome (fig. 2), shares many physical characteristics with these dome-shaped features of the SRP.

Large regions of the SRP and the adjacent hills, including the study area, are mantled by thick loess and dune deposits mostly of Pleistocene age (Lewis and Fosberg, 1982).

UPPER TERTIARY UNITS

Starlight Formation

In the study area, the Starlight Formation overlies pre-Tertiary rocks of the fold and thrust belt and everywhere underlies either the Walcott Tuff or the tuff of Blacktail. Eocene hornblende andesite, which underlies the Starlight Formation about 12 km east of the study area (Trimble, 1982), has not been observed. In most places, the top of the Starlight Formation is not clearly defined largely because of the extensive mantle of eolian deposits.

The Starlight Formation is divided into lower, middle, and upper members (fig. 3). The lower member is very poorly exposed in the study area and includes several outcrops of vuggy, black-stained travertine as thick as 3 m in the eastern part of the area; travertine as thick as about 50 m crops out several kilometers east of the study area (Trimble, 1982). Two rhyolite flows—the rhyolite of Two-and-a-Half-Mile Creek and the rhyolite of Stevens Peak—are placed in the lower part of the lower member. Other lithologies noted by Trimble (1976, 1982) in adjacent areas in the lower member, such as greenish-gray to light-tan rhyolitic tuff, tuffaceous sandstone and marl, and basalt and basaltic tuff, are not exposed in the study area. The total thickness of the lower member is unknown, although Trimble (1982) stated that it is greater than 244 m just east of the study area.

Several small outcrops of diamictite, composed of moderately rounded clasts of Precambrian and Paleozoic quartzite as long as 2 m, crop out in the southeastern part of the study area and are tentatively placed in the lower member. No matrix material is exposed; the boulders are loosely embedded in loess. These rocks occur stratigraphically a few meters above Paleozoic rocks (Ordovician Swan Peak Quartzite), although they could be part of the boulder conglomerate that overlies the Starlight Formation in other areas.

The rhyolites of Two-and-a-Half-Mile Creek and Stevens Peak are added to the lower member of the Starlight Formation in this report and are the oldest dated rocks in the study area. The rhyolite of Two-and-a-Half-Mile Creek in the southern part of the area, named for a creek just south of the area of figure 2 (Kellogg and Embree, 1986), was originally thought by Trimble (1976), who did not give it a formal name, to be younger than the Starlight Formation. A biotite K–Ar age of 9.1 ± 0.3 Ma (table 1) indicates that the rhyolite of Two-and-a-Half-Mile Creek predates the tuff of Arbon Valley, the middle member of the Starlight Formation. The other flow, the rhyolite of Stevens Peak, has a reported K–Ar age of 9.8 ± 0.9 Ma (Karlo and Jorgenson, 1979; mineral separate unspecified).

The two rhyolite flows are petrographically distinct from each other; small, reddish-brown biotite phenocrysts and as much as 10 percent quartz phenocrysts (as long as 2 mm) characterize the rhyolite of Two-and-a-Half-Mile Creek, whereas biotite and quartz were not observed in the rhyolite of Stevens Peak. In both units, the attitude of flow foliation is highly variable, reflecting the highly viscous nature of the magma. High viscosity is also suggested by the approximately 250 m of relief for each unit, although erosion and thick loess largely obscure the original morphology.

The rhyolite of Stevens Peak is almost entirely devitrified, whereas numerous brown glass stringers, typically 1 cm thick but as thick as several meters, define flow foliation in the rhyolite of Two-and-a-Half-Mile Creek. Small folds in flow foliation in the rhyolite of Two-and-a-Half-Mile Creek plunge 5–30° to the west.

The middle member of the Starlight Formation is represented by the tuff of Arbon Valley, which Trimble and Carr (1976) designated as the lower unit of the middle member, although in the study area, the tuff makes up the entire middle member. The tuff of Arbon Valley is a white to tan, pumiceous, crystal-rich (as much as about 30 percent total phenocrysts), rhyolite ash-flow tuff. The phenocrysts are as long as 3 mm and consist of quartz (15 percent), plagioclase (10 percent), sanidine (5 percent), and about 1 percent each clinopyroxene and conspicuous biotite. Pumiceous or densely welded tuff clasts as long as 3 cm are common. As much as 25 m of the lower part of the tuff is white, poorly welded, and

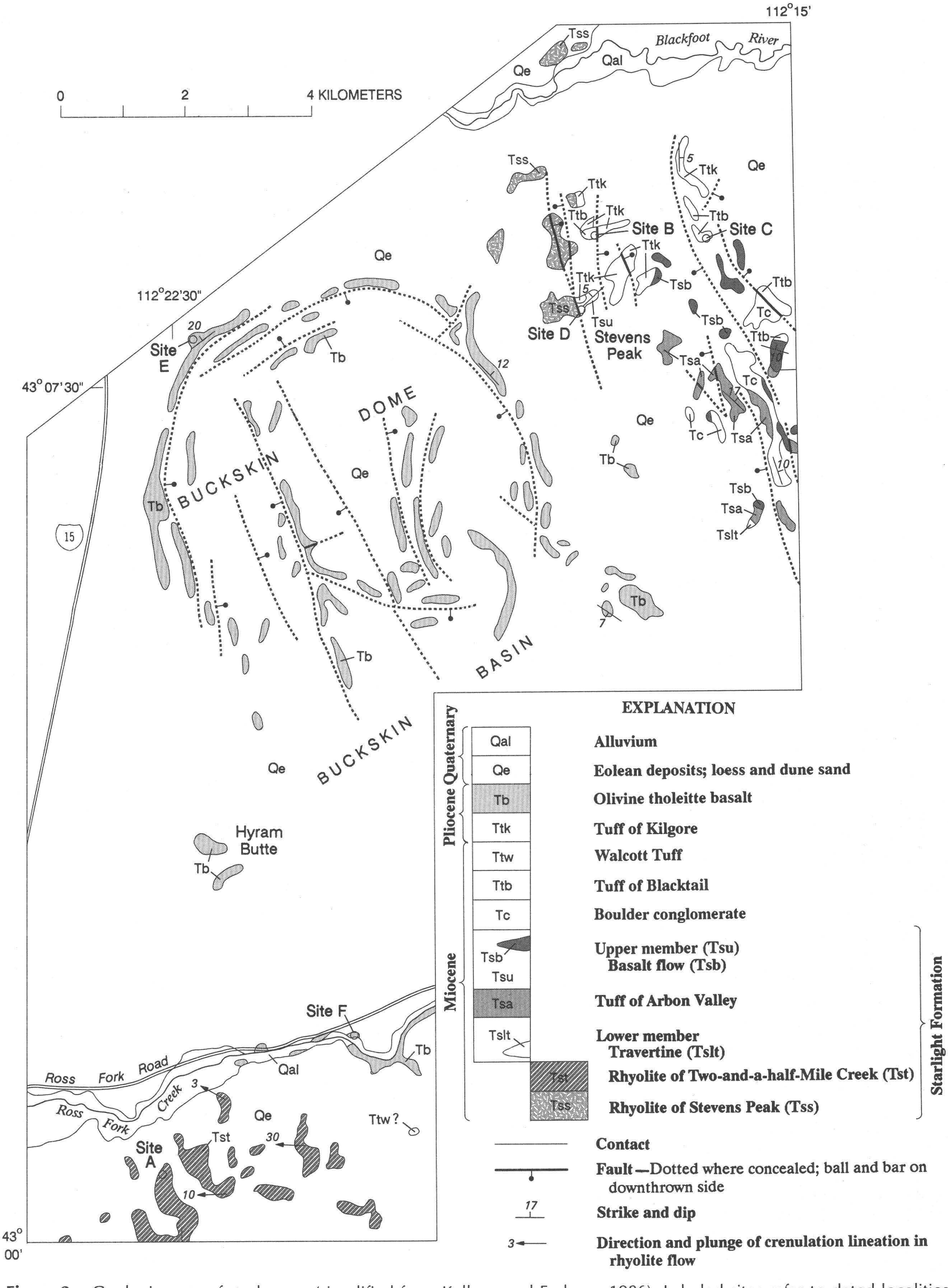

Figure 2. Geologic map of study area (simplified from Kellogg and Embree, 1986). Labeled sites refer to dated localities (table 1).

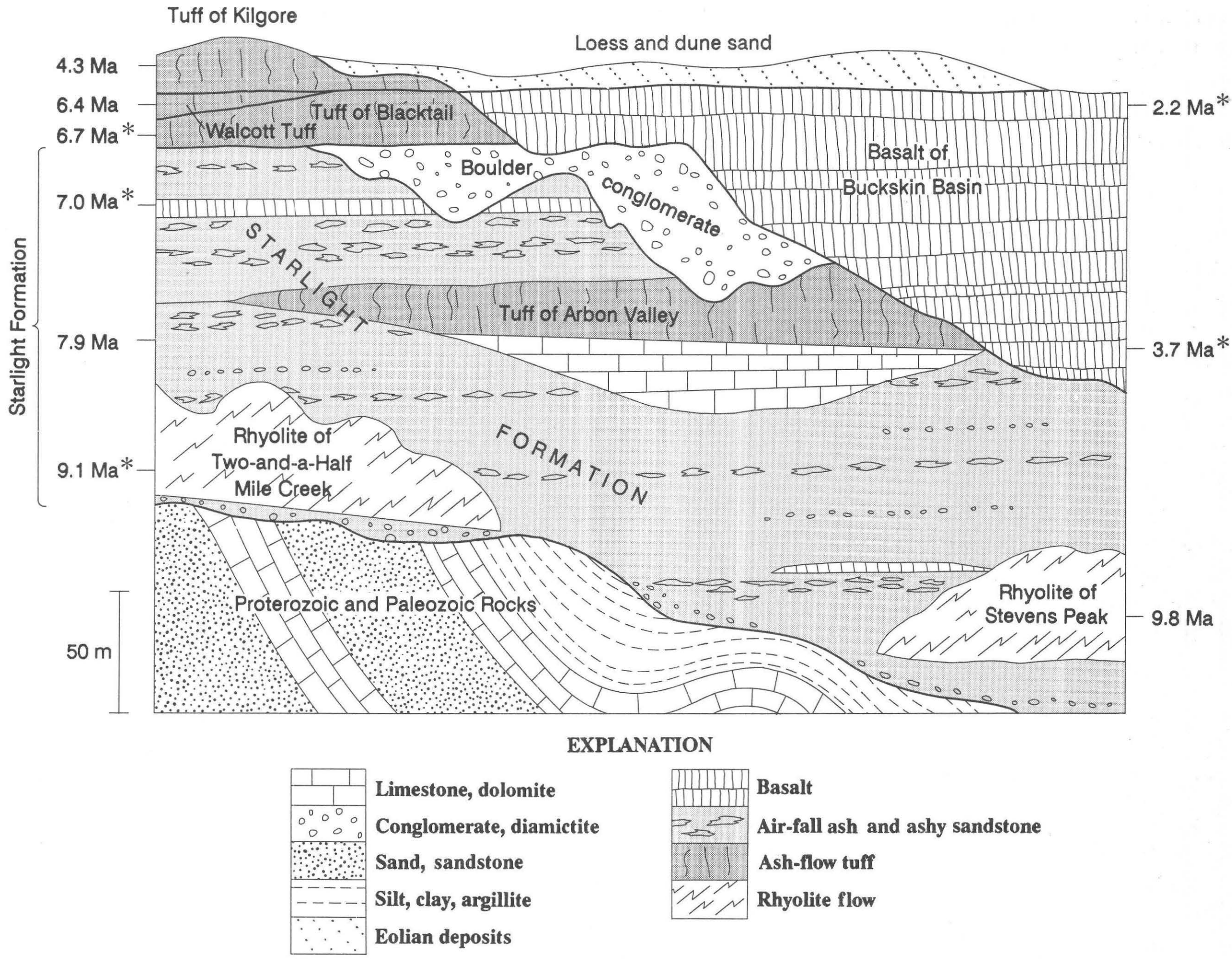

Figure 3. Diagrammatic cross section of units in, and adjacent to, study area. Thicknesses are approximate and are based on this study and Trimble (1982). New ages followed by asterisk.

pumiceous and locally contains tree casts. The total thickness of the tuff of Arbon Valley is as much as 60 m. Magnetic polarity, as determined using a portable fluxgate magnetometer, is normal. Armstrong and others (1975) reported a K–Ar age of 7.9 Ma (recalculated using the decay constants of Steiger and Jäger, 1977) for the tuff of Arbon Valley from a locality southwest of Pocatello.

The upper member of the Starlight Formation consists of gravel and ash- and pumice-fall deposits and, about 20 m below the base of the tuff of Blacktail, a 5-m-thick, fine-grained olivine basalt flow. The uniform thickness of the flow over an area of at least 3 km² suggests that the topography was relatively low at the time of eruption, a situation which prevailed during deposition of most of the Starlight Formation (D.E. Trimble, oral commun., 1986). A K–Ar whole-rock age of 7.0 ± 0.3 Ma was obtained from the basalt (table 1).

Over large areas, the upper member is entirely eroded, and the resistant top of the welded section of the tuff of Arbon Valley is the uppermost exposed unit of the Starlight Formation.

Units Younger Than the Starlight Formation

A coarse boulder conglomerate locally overlies the Starlight Formation in the eastern part of the study area and in places is directly on the eroded top of the tuff of Arbon Valley. The conglomerate resembles the diamictite that is placed tentatively in the lower member of the Starlight Formation, although it contains locally large (as much as 5 m in diameter) boulders of the tuff of Arbon Valley and well-sorted clasts (as much as 1.2 m in length) of white Ordovician Swan Peak Quartzite and tan Triassic(?) and Jurassic(?) Nugget Sandstone. Kellogg and Embree (1986) placed this unit in the upper member of the Starlight Formation, although reexamination of outcrops in the Yandell Springs quadrangle established, as Trimble (1982) originally maintained, that the boulder conglomerate was deposited on a highly eroded and irregular surface cut into the Starlight Formation and is, therefore, a separate unit.

At least two major ash-flow tuffs of the eastern SRP are exposed on or near Stevens Peak. The tuff of Blacktail and the tuff of Kilgore are both mapped in this area, although paleomagnetic evidence suggests that some outcrops near Stevens Peak mapped as tuff of Blacktail might be the Walcott Tuff (L.A. Morgan, oral commun., 1986). Both the tuff of Blacktail and the tuff of Kilgore overlie the boulder conglomerate. The tuff of Blacktail, which overlies the Starlight Formation on Stevens Peak, is a light-gray, dense to glassy ash-flow tuff containing about 5 percent phenocrysts (as long as 2 mm) of plagioclase and quartz and sparse sanidine, clinopyroxene, and opaque minerals. Where observed, the basal vitrophyre is about 50 cm thick. Plagioclase and sanidine separates yielded K–Ar ages of 6.6±0.3 and 6.7±0.2 Ma, respectively (table 1), in agreement with zircon fission-track ages of 6.5–6.6 Ma (Morgan and others, 1984). The magnetic polarity of the tuff of Blacktail is normal, as determined using a portable fluxgate magnetometer.

A small outcrop of tuff questionably correlated with the Walcott Tuff crops out in the southern part of the study area. The tuff is purplish gray, densely welded, and devitrified and contains approximately equal amounts of plagioclase phenocrysts as long as 1.5 mm and smaller sanidine phenocrysts; trace amounts of quartz, clinopyroxene, and magnetite are also present. A whole-rock K–Ar age of 6.4±0.2 Ma was determined for this unit in the study (table 1), an age that falls within the range of corrected published ages of 6.3±0.3 Ma and 6.9±0.4 Ma (Marvin and others, 1970; Trimble and Carr, 1976) for the Walcott Tuff.

The tuff of Kilgore immediately overlies the tuff of Blacktail on and near Stevens Peak and is mostly a gray, pinkish-gray, and tan, dense, very fine grained to glassy ash-flow tuff containing about 2 percent plagioclase (An_{20} by microscopic analysis) phenocrysts (as long as 2 mm) and trace amounts of sanidine, augite, and opaque minerals. On the pointed summit of Stevens Peak, a well-exposed section of flat-lying tuff of Kilgore consists of a basal brown ash greater than 3 m thick that grades upward into a 0.5-m-thick black vitrophyre in turn overlain by a prominent gray to mottled-gray and orange 3-m-thick spherulitic zone capped by a 6-m-thick lithophysal zone. The tuff of Kilgore is undated in the study area but has been dated elsewhere by both the K–Ar whole-rock and fission-track methods at about 4.3 Ma (Armstrong and others, 1975; Morgan and others, 1984).

The youngest volcanic rocks in the study area are a sequence of olivine-augite basalt flows, which are similar to most basalts of the SRP (Leeman, 1982b) (figs. 4 and 5), and here are informally called the basalt of Buckskin Basin. These basalts define a circular pattern of low hills to the west of Stevens Peak and also crop out along Ross Fork Creek. Cuttings from numerous water wells indicate that the basalt also underlies several tens of meters of loess and water-lain sediment within Buckskin Basin (Norman Bird, U.S. Bureau of Indian Affairs, Fort Hall, Idaho, written commun., 1984). The basalt of Buckskin Basin ranges in age from 2.2 to 3.7 Ma (table 1).

The basalt of Buckskin Basin is gray to black, fine to medium grained, and diktytaxitic to subophitic. Flow tops are highly vesicular, and basal zones are typically rubbly and oxidized. Individual flows are between 1 and 10 m thick. The matrix of subophitic basalt is composed of about 70 percent plagioclase (approximately An_{70} by microscopic analysis) laths, about 20 percent olivine, and typically 5 percent but as much as 30 percent augite. The rock contains sparse phenocrysts of plagioclase as long as 3 mm and olivine.

Light-tan, massive, silty loess and light-tan, fine-grained, stabilized dune sand deposits mantle most pre-Quaternary rocks in the area. Quaternary alluvium underlies the flood plains of the Blackfoot River and Ross Fork Creek.

GEOCHRONOLOGY

K–Ar age determinations were made in the U.S. Geological Survey laboratories in Denver, Colo. Potassium analyses were performed by E.H. Brandt using a lithium metaborate flux fusion-flame photometry method (Ingamells, 1970). Argon-extraction and -purification techniques were similar to those described by Dalrymple and Lanphere (1969). Argon composition was determined by H.H. Mehnert using standard isotope-dilution procedures with a 60°-sector, 15.2-cm-radius Nier-type mass spectrometer operating in the dynamic mode. The estimated analytic uncertainty for a calculated K-Ar age is reported as 2σ. K–Ar ages and analytic data for samples collected at seven sites (A through G, fig. 2) are given in table 1.

Three isotopic ages were obtained at site A for the rhyolite of Two-and-a-Half-Mile Creek (table 1): 9.1±0.3 Ma (biotite), 8.1±0.2 Ma (potassium feldspar), and 12.5±2.3 Ma (plagioclase). In view of our experience with discordant ages, we think that the 9.1–Ma age from biotite is the most reliable. It has frequently been observed that potassium feldspars do not quantitatively retain radiogenic argon and, therefore, commonly have ages which are too young; thus, we feel that the 8.1–Ma potassium-feldspar age is too young. The 12.5–Ma age from plagioclase is the least reliable of the three ages because of the very low potassium content; the uncertainty arising from the potassium content is indicated by the large analytic error attached to the isotopic age.

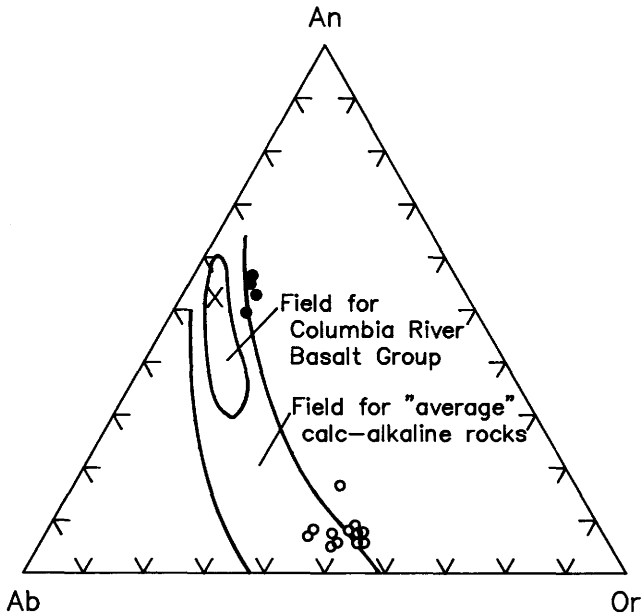

Figure 4. Ab-An-Or diagram for analyzed volcanic rocks shown in table 2. Ab, normative albite+5/3 (normative nephaline); An, normative anorthite; and Or, normative orthoclase. Open circles, rhyolites; closed circles, basalts. X represents average value for 78 samples of olivine tholeiitic basalt from Snake River Plain (Leeman, 1982a). Fields for Columbia River Basalt Group and "average" calc-alkaline volcanic rocks are from Irvine and Baragar (1971).

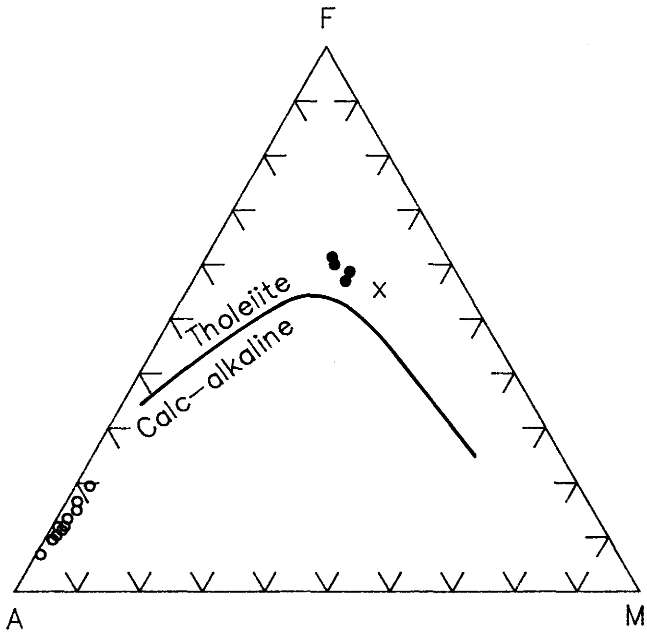

Figure 5. AFM diagram for analyzed volcanic rocks shown in table 2. A, K_2O+Na_2O; F, total Fe as Fe_2O_3; and M, MgO (all values in weight percent). Open circles, rhyolites; closed circles, basalts. X represents average value of 78 samples of olivine tholeiitic basalt from the Snake River Plain (Leeman, 1982b).

Two samples of the tuff of Blacktail were collected (sites B and C) for isotopic dating. Plagioclase from a sample of basal vitrophyre from site B has an age of 6.6±0.3 Ma. Both the potassium feldspar and plagioclase from the devitrified upper third of the tuff at site C have ages of 6.7 Ma (uncertainties are ±0.2 and ±0.3 Ma, respectively). These K-Ar mineral ages are in agreement with fission-track zircon ages of 6.5±0.3 and 6.6±0.7 Ma from samples collected elsewhere from the tuff of Blacktail (Morgan and others, 1984). The age of the tuff of Blacktail is therefore well constrained at 6.6–6.7 Ma.

A specimen of an ash-flow tuff at site G has a K-Ar whole-rock age of 6.4±0.2 Ma. This tuff is tentatively correlated with the Walcott Tuff. The tuff of Kilgore was not collected for dating purposes because its age is already well established at 4.3 Ma (Armstrong and others, 1975; Morgan and others, 1984).

A basalt specimen from the basalt flow in the upper member of the Starlight Formation at site D has a K-Ar whole-rock age of 7.0 Ma, an age consistent with the 7.7-Ma age of the underlying tuff of Arbon Valley (middle member of the Starlight Formation). The age of the basalt flow is also consistent with the age of 6.6–6.7 Ma for the overlying tuff of Blacktail.

Two of the dated samples of basalt of Buckskin Basin were collected in a gully on the northwestern side of the Buckskin dome (site E) where six basalt flows dip gently to the northwest. Sample BB704A, from the top flow, has a K-Ar plagioclase age of 2.5 Ma; sample BB699A, from the bottom flow, has a K-Ar whole-rock age of 2.2 Ma. These ages are not in accord with the relative stratigraphic order of the flows, although the uncertainty in the ages is large. However, the ages do indicate that these flows are Late Pliocene in age.

A third olivine basalt (sample BB608A) was collected in a quarry adjacent to Ross Fork Creek in the southwestern part of the study area (site F in fig. 2). The flow is greater than 3 m thick and has a horizontal attitude. A plagioclase concentrate has an age of 3.7 Ma, significantly older than the basalts on the northwestern side of Buckskin dome. Basaltic volcanism in Buckskin Basin thus encompassed a time span of more than a million years.

GEOCHEMISTRY

Whole-rock major-element analyses were performed at the U.S. Geological Survey's Branch of Analytical Chemistry on 16 rocks that are believed to represent the compositional variation of the volcanic rocks in the study area (table 2 and figs. 4, 5, and 6). These rocks include 12 samples of the rhyolitic rocks and 4 samples of the basalts. Selected trace elements on 67 rhyolite samples and 28 basalt samples were determined

Table 1. Potassium-argon dates for volcanic rocks from Buckskin Basin and Stevens Peak areas, Idaho

[B, biotite; KF, potassium feldspar; Pl, plagioslase; WR, whole rock. Constants used: $\lambda_\epsilon = 0.581 \times 10^{-10}$/yr; $\lambda_\beta = 4.962 \times 10^{-10}$/yr; atomic abundance of $^{40}K/K = 1.167 \times 10^{-4}$ mole/mole]

Description of unit sampled	Sample number (site from fig. 2)	Latitude Longitude	Material dated	K_2O%	^{40}Ar (10^{10} mole/gram)	^{40}Ar%	Age (Ma) ±2σ
Basalt of Buckskin Basin							
Uppermost of six.......... exposed flows.	BB704A (E)	43°07'52"N. 112°22'10"W.	Pl	0.20	0.007183	6	2.5±0.5
Lowermost of six.......... exposed flows.	BB699A (E)	43°07'52"N. 112°22'10"W.	WR	0.39	0.01224	4	2.2±0.2
From quarry adjacent...... to railroad.	BB608A (F)	43°01'57"N. 112°20'25"W.	Pl	0.19	0.009918	6	3.7±0.7
Tuff of Blacktail							
From porphyritic.......... vitrophyre.	BF748A (B)	43°08'44"N. 112°17'27"W.	Pl	0.885	0.08410	36	6.6±0.3
0.5 m above vitrophyre....	BF752A (C)	43°08'38"N. 112°16'07"W.	KF	7.11	0.6834	82	6.7±0.2
0.5 m above vitrophyre....	BF752A (C)	43°08'38"N. 112°16'07"W.	Pl	0.68	0.06531	12	6.7±0.3
Wolcott(?) Tuff.............	BB712A (G)	43°00'57"N. 112°19'40"W.	WR	5.065	0.4681	71	6.4±0.2
Basalt of upper part of..... Starlight Formation.	BF694A (D)	43°08'07"N. 112°17'36"W.	WR	0.625	0.06319	26	7.0±0.3
Rhyolite of Two-and-a-...... Half-Mile Creek	BB731A (A)	43°00'19"N. 112°N.'22"W.	B	8.22	1.074	46	9.1±0.3
(from porphyritic, spherulitic vitrophyre).	BB731A (A)	43°00'19"N. 112°22'22"W	KF	10.68	1.243	86	8.1±0.2
	BB731A (A)	43°00'19"N. 112°22'22"W.	Pl	0.17	0.03058	37	12.5±2.3

Table 2. Major-element analyses and weight-percent norms for selected samples of rhyolite and basalt from Buckskin Basin and Stevens Peak areas, Idaho

	Rhyolite of Stevens Peak		Rhyolite of Two-and-a-Half-Mile Creek		Tuff of Arbon Valley			Tuff of Blacktail	
Sample No.	BF691B	BF624B	BB731B[1]	BB718B	BB671B	BB667B	BB670B	BF707B	BF752B[1]
Latitude	43°08'10"N.	43°08'34"N.	43°00'19"N.	43°00'47"N.	43°07'10"N.	43°07'23"N.	43°07'08"N.	43°08'08"N.	43°08'38"N.
Longitude	112°18'00"W.	112°17'42"W.	112°22'22"W.	112°20'42"W.	112°15'47"W.	112°16'10"W.	112°15'49"W.	112°15'20"W.	112°16'07"W.
Major elements									
SiO_2	74.5	73.6	74.0	74.6	72.8	72.0	72.0	75.6	75.5
Al_2O_3	12.4	12.8	12.3	12.4	13.0	13.1	13.0	12.8	12.4
FeO	0.23	0.43	0.36	0.28	0.21	0.99	0.16	0.25	0.17
Fe_2O_3	1.55	1.35	0.78	0.86	1.00	0.82	0.86	0.38	0.82
MgO	0.42	0.29	0.16	0.16	0.24	0.33	0.27	0.17	0.14
CaO	1.22	0.82	0.74	1.73	0.95	1.76	0.53	0.79	0.54
Na_2O	3.50	3.56	2.67	2.89	2.79	2.64	2.75	3.31	3.19
K_2O	4.74	4.60	5.21	5.07	5.13	4.24	5.18	5.13	5.15
TiO_2	0.48	0.48	0.13	0.13	0.13	0.30	0.05	0.29	0.23
P_2O_5	0.05	0.10	0.03	0.03	0.03	0.08	0.03	0.03	0.03
MnO	0.07	0.07	0.01	0.01	0.01	0.03	0.05	0.01	0.01
H_2O^+	0.19	0.03	2.60	0.19	1.30	1.54	2.34	0.25	0.39
H_2O^-	0.26	0.17	0.08	0.21	0.61	0.32	0.69	0.23	0.36
CO_2	0.27	0.02	<0.01	0.70	<0.01	<0.01	<0.01	<0.01	<0.01
Total	99.88	98.32	99.07	99.26	98.20	98.15	97.92	99.24	98.93
Normative Minerals (volatile free).									
Q	33.44	34.02	38.17	35.47	35.96	37.58	36.60	35.29	36.62
C	0.00	0.73	1.03	0.00	1.25	1.28	2.08	0.44	0.68
OR	28.17	27.70	31.94	30.30	31.48	26.02	32.26	30.69	30.99
AB	29.78	30.70	23.43	24.73	24.51	23.02	24.52	28.36	27.49
AN	4.15	3.48	3.60	5.96	4.69	8.53	2.56	3.77	2.53
DI	0.86	0.00	0.00	0.87	0.00	0.00	0.00	0.00	0.00
WO	0.65	0.00	0.00	0.59	0.00	0.00	0.00	0.00	0.00
HY	0.64	0.74	0.41	0.00	0.62	1.58	0.71	0.43	0.36
OL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	0.00	0.23	0.85	0.56	0.35	1.23	0.56	0.00	0.00
IL	0.64	0.93	0.26	0.25	0.26	0.59	0.10	0.56	0.39
TN	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
AP	0.12	0.24	0.07	0.07	0.07	0.20	0.07	0.07	0.07
Al/(Na+K+Ca)[2]	0.946	1.039	1.081	0.926	1.095	1.083	1.172	1.030	1.051

[1]Potassium-argon age given in table 1.

[2]Molar ratio.

[3]Fe_2O_3 in excess of TiO_2+1.5 is converted to FeO for normative calculations, following Irvine and Baragar (1971).

Table 2. Major-element analyses and weight-percent norms for selected samples of rhyolite and basalt from Buckskin Basin and Stevens Peak areas, Idaho—Continued

	Tuff of Kilgore		Walcott(?) Tuff	Walcott Tuff from site W-1 in figure 1	Basalt of upper part, Starlight Formation	Basalt of Buckskin Basin		
Sample No.	BF750B	BF641B	BB712B[1]	BK753B	BF694B[1]	BB608B[1]	BF699B[1]	BF704B[1]
Latitude	43°08'48"N.	43°08'11"N.	43°00'57"N.	42°41'29"N.	43°08'07"N.	43°01'47"N.	43°07'52"N.	43°07'52"N.
Longitude	112°17'28"W.	112°17'37"W.	112°19'40"W.	112°57'37"W.	112°17'36"W.	112°20'25"W.	112°22'10"W.	112°22'10"W.
Major elements								
SiO_2...........	71.3	72.1	75.9	73.6	48.5	46.2	45.9	46.2
Al_2O_3..........	11.9	12.3	12.2	11.8	13.8	14.7	15.0	14.7
FeO............	0.62	0.72	0.46	0.49	[3]9.28	12.1	10.7	12.5
Fe_2O_3..........	0.74	0.54	0.96	0.77	[3]5.09	3.00	3.31	2.21
MgO............	0.23	0.26	0.17	0.22	6.13	5.75	7.52	7.72
CaO............	2.15	0.68	0.46	0.54	9.92	9.98	10.5	9.95
Na_2O...........	2.78	2.78	3.30	2.89	2.58	2.52	2.46	2.44
K_2O............	5.20	5.29	5.13	5.46	0.65	0.66	0.42	0.41
TiO_2...........	0.23	0.22	0.25	0.21	2.40	3.26	2.73	3.13
P_2O_5...........	0.03	0.10	0.03	0.03	0.31	1.04	0.50	0.55
MnO............	0.03	0.02	0.01	0.03	0.20	0.21	0.21	0.22
H_2O^+...........	2.82	2.72	0.30	2.89	0.37	0.36	0.25	0.25
H_2O^-...........	0.39	0.41	0.13	0.17	0.36	0.18	0.14	0.09
CO_2............	1.15	0.05	<0.01	<0.01	<0.01	0.04	0.17	0.01
Total..........	99.57	98.19	99.30	99.10	99.59	100.00	99.81	100.38
Normative Minerals (volatile free).								
Q..............	32.73	35.64	36.33	35.92	0.97	0.00	0.00	0.00
C..............	0.00	1.06	0.46	0.24	0.00	0.00	0.00	0.00
OR.............	31.89	32.88	30.66	33.59	3.89	3.92	2.50	2.42
AB.............	24.41	24.74	28.24	25.46	22.12	21.44	20.94	20.64
AN.............	4.81	2.86	2.11	2.58	24.47	26.99	28.81	27.94
DI.............	1.68	0.00	0.00	0.00	19.16	13.21	16.58	14.66
WO.............	1.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HY.............	0.00	1.26	0.43	0.57	18.31	17.74	9.53	11.70
OL.............	0.00	0.00	0.00	0.00	0.00	3.64	10.27	12.22
MT.............	1.11	0.82	0.80	1.11	5.73	4.37	4.83	3.20
IL.............	0.45	0.44	0.00	0.42	4.62	6.23	5.22	5.94
TN.............	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RU.............	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AP.............	0.07	0.25	0.07	0.07	0.74	2.48	1.19	1.34
Al/(Na+K+Ca)[2]...	0.844	1.066	1.033	1.013	0.601	0.639	0.636	0.652

by X-ray fluorescence analysis. The trace elements deemed most useful in differentiating the various units are Zr (zirconium), Sr (strontium), and Rb (rubidium) (fig. 7).

Rhyolitic Rocks

The rhyolitic rocks are similar in major-element composition as shown on the normative feldspar ternary diagram (fig. 4) and the AFM diagram (fig. 5). They are average to mildly potassic calc-alkaline rhyolites, as defined by Irvine and Baragar (1971), and most contain normative corundum (table 2), indicating that they generally are mildly peraluminous (that is, the molar ratio Al/(Na+K+Ca)>1), which is common for intracratonic rhyolitic rocks. The rhyolitic rocks are also strongly subalkaline (fig. 6).

Because the rhyolitic rocks erupted from several widespread sources along the Snake River Plain over about a 5–Ma period, the major-element chemical analyses do not define a consistent differentiation trend (fig. 6), although rocks from the same unit are generally grouped together. Both the tuff of Kilgore and the tuff of Arbon Valley have silica contents of less than 73 percent, but the tuff of Blacktail has a silica content greater than 75 percent. The tuff in the southern part of the study area (fig. 2) is similar in its major-element chemistry to the samples of the tuff of Blacktail but for reasons (discussed earlier) other than geochemistry is correlated with the Walcott Tuff. The rhyolites of Two-and-a-Half-Mile Creek and Stevens Peak have similar silica contents of about 74 percent.

Some scatter in both the major- and trace-element composition of the tuffs might be due to (1) vertical chemical zonation, for which samples were not specifically collected (with one exception noted later) and (2) some small, exotic component incorporated during transport. Despite this scatter, the geochemical data suggest that a discrimination of most units can be made.

Sample BB670B (table 2) is from the basal ash of the tuff of Arbon Valley and has a slightly higher content of normative corundum and a smaller normative anorthite content than the two samples (BB671B and BB667B) from the overlying densely welded section. These content differences imply that the early eruptive phases of the tuff of Arbon Valley are more evolved (more peraluminous and contain more sodic feldspars) than the later phases, a fact in agreement with Hildreth's (1979) model for zoned magma chambers underlying calderas (that is, early eruptions tap the higher, more evolved portions of the magma chamber).

The Zr-Sr-Rb geochemistry of the rhyolitic rocks (fig. 7) demonstrates that some units can be discriminated on the basis of trace elements. The groupings are tightest for the two rhyolite flows (fig. 7*A*) rather than for the

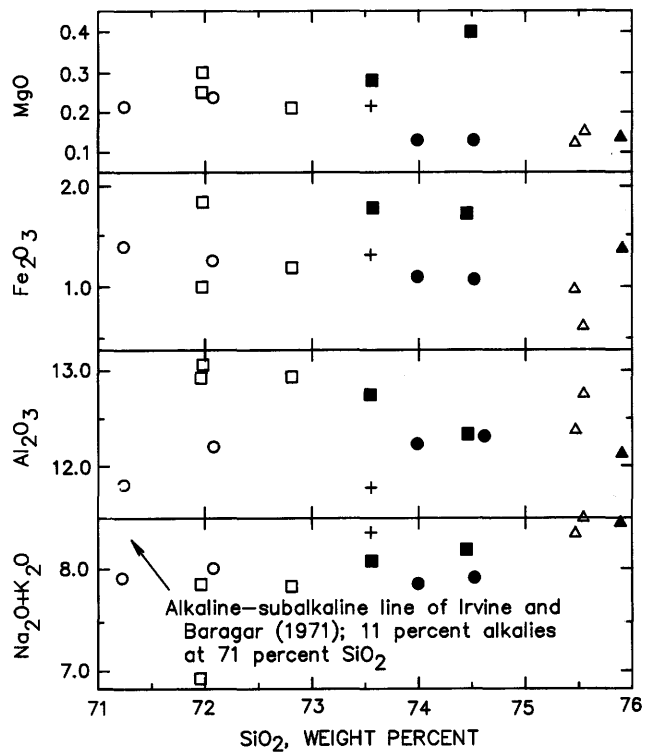

Figure 6. SiO_2-oxide variation diagram for rhyolitic rocks. Fe_2O_3 is total iron calculated as Fe_2O_3. Open circles, tuff of Kilgore; open triangles, tuff of Blacktail; closed triangles, suspected Walcott Tuff collected at site G (fig. 2); crosses, Walcott Tuff collected at site W-1 (fig. 1); open squares, tuff of Arbon Valley; closed circles, rhyolite of Two-and-a-Half-Mile Creek; and closed squares, rhyolite of Stevens Peak. Values are taken from table 2.

ash-flow tuffs (fig. 7*B*), a situation that is most probably the result of some contamination of the ash-flow tuffs by exotic material during transport. The rhyolite of Stevens Peak is enriched in Zr relative to Rb and Sr as compared to the rhyolite of Two-and-a-Half-Mile Creek. The tuff of Arbon Valley is enriched in Sr relative to Zr and Rb as compared to the tuffs of Kilgore and Blacktail. The fields for the Kilgore and Blacktail tuffs overlap, although the field for the tuff of Kilgore extends farther toward the Zr corner. Although differences in silica content (fig. 6) appear to be more useful in discriminating these two tuffs than differences in Zr, Sr, and Rb, chemical data from elsewhere along the margin of the SRP show that the silica content of these two units has considerable overlap (L.A. Morgan, written commun., 1986).

Basaltic Rocks

All analyzed samples of basalt of Buckskin Basin are olivine tholeiites (fig. 5) and are slightly depleted in magnesium and enriched in potassium and iron relative

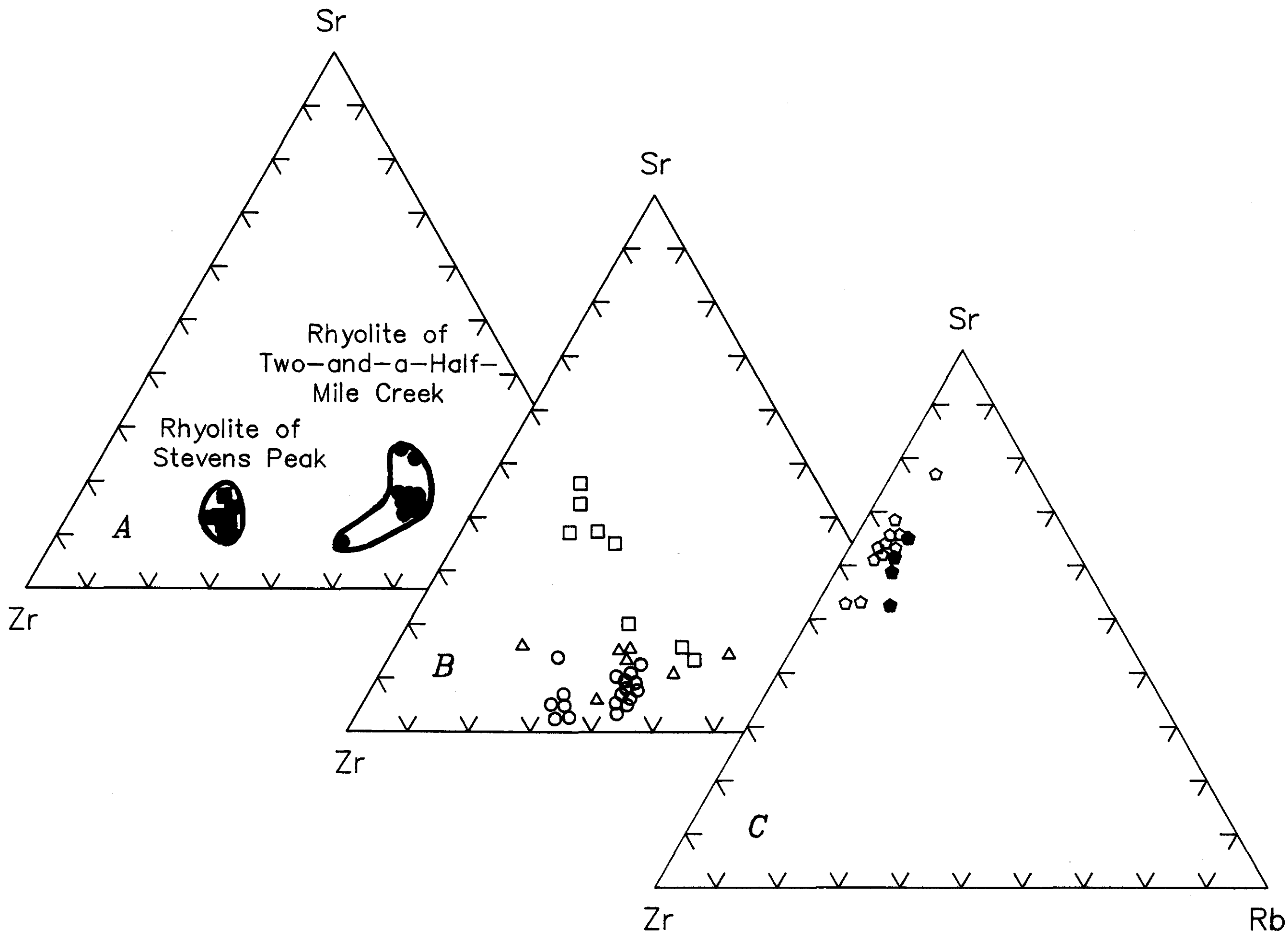

Figure 7. Zirconium-strontium-rubidium ternary diagrams for (*A*) closed circles, rhyolite of Two-and-a-Half-Mile Creek; and closed squares, rhyolite of Stevens Peak; (*B*) open squares, tuff of Arbon Valley; open triangles, tuff of Blacktail; and open circles, tuff of Kilgore; and (*C*) open pentagons, the basalt of Buckskin Basin; and closed pentagons, basalt of upper member of Starlight Formation.

to average SRP basalt (Leeman, 1982b) (figs. 4 and 5). Figures 4 and 5 do not show significant differences between the basalt of Buckskin Basin and the one sample of basalt in the upper member of the Starlight Formation, although the latter basalt is depleted in alumina relative to the basalt of Buckskin Basin and contains no normative olivine (table 2); however, olivine is an observed modal phase.

TIMING OF BASIN AND RANGE FAULTING

North-northwest-trending high-angle faults related to Basin and Range extension are well developed in the study area and outline fault blocks in which strata dip as much as 30°, generally east-northeast. The largest apparent throws of about 120 m occur on faults cutting the tuff of Arbon Valley in the northeastern part of the map area.

The timing of maximum Basin and Range activity in the Stevens Peak area can be determined by bracketing the age of the boulder conglomerate that overlies the Starlight Formation. The boulder conglomerate contains large clasts of Triassic(?) and Jurassic(?) Nugget Sandstone, among other lithologies, which must have come from at least 10 km to the east (Trimble, 1982). Currently, several drainage divides separate outcrops of Nugget Sandstone and deposits of the boulder conglomerate. Displacements across prominent Basin and Range faults cutting Paleozoic and Mesozoic strata at least 5 km to the east of the study area are of the order of 1,000 m or more (Hladky, 1986; Kellogg and others, 1986; Trimble, 1982), and it seems reasonable that erosion of the Starlight Formation and deposition of the boulder conglomerate were controlled by high-energy, west-flowing streams or possibly debris flows during periods of relatively large movements along these Basin and Range faults.

The age of the boulder conglomerate is constrained by the dated volcanic rocks in the study area. Trimble (1982) recognized that the boulder conglomerate, which he called "quartzite gravel," overlies eroded Starlight Formation and is overlain by welded ash-flow tuffs, now known to be the tuff of Blacktail. The basalt in the upper member of the Starlight Formation is 7.0±0.3 Ma, but the tuff of Blacktail is 6.7±0.2 Ma. Therefore, a very large component of Basin and Range faulting occurred between about 7.0 and 6.7 Ma. This age is in agreement with Allmendinger's (1982) evidence that Basin and Range faulting is shifting eastward in time (fig. 8) and supports the contention that the rate of easterly migration is slowing. Initial easterly migration of the eastern edge of Basin and Range deformation, starting 17 Ma in northern Nevada, was about 6.5 cm/yr. Over the past 7.0-6.7 Ma, however, this easterly migration east of Stevens Peak has slowed to about 1.7 cm/yr. Allmendinger (1982) suggested that this slowing might be due to the migration of Basin and Range extension eastward from crust which was initially thinned during Late Proterozoic rifting into increasingly thickened crust to the east.

Evidence exists that at least some Basin and Range faulting occurred in the area during the deposition of the Starlight Formation. Pebble, cobble, and minor boulder conglomerates occur in the lower member of the Starlight Formation in the Yandell Springs quadrangle, immediately east of the study area (Hladky, 1986; Trimble, 1982), indicating that some uplift associated with early phases of Basin and Range movement occurred as long ago as about 9 Ma. The Starlight Formation was probably deposited in north-trending, fault-bounded valleys, although the predominantly fine-grained nature of the Starlight deposits and the continuity and constant thickness of beds over distances of at least several kilometers support the contention that mostly low topography existed during Starlight deposition.

Trimble (1976) also mapped a boulder diamictite in the lower member of the Starlight Formation, within 10 km south of the study area, although the tuff of Arbon Valley does not occur in the same area to mark the top of the lower member of the Starlight Formation. The diamictite lies directly over Proterozoic rocks of the thrust belt and predominantly contains blocks of Proterozoic and Paleozoic quartzites as large as 3 m in diameter as well as minor and smaller basaltic to andesitic clasts. The diamictite contains a tuffaceous matrix and is locally cemented by calcite. Some of these deposits resemble the boulder conglomerate of the study area (K.S. Kellogg, unpub. data, 1984). Although it cannot be proven at this time, we believe that the diamictite south of the study area is equivalent to the boulder conglomerate of the study area, which overlies the Starlight Formation.

Maximum displacement of the 4.3-Ma tuff of Kilgore, 1 km north of Stevens Peak, is 60 m, down to the northeast. Maximum displacement of the 7.7-Ma tuff of Arbon Valley, near the eastern border of the study area, is 120 m, down to the southwest. The difference in the amount of displacement on faults cutting these two tuffs is probably due to movement during the period of major Basin and Range faulting 6.7-7.0 Ma.

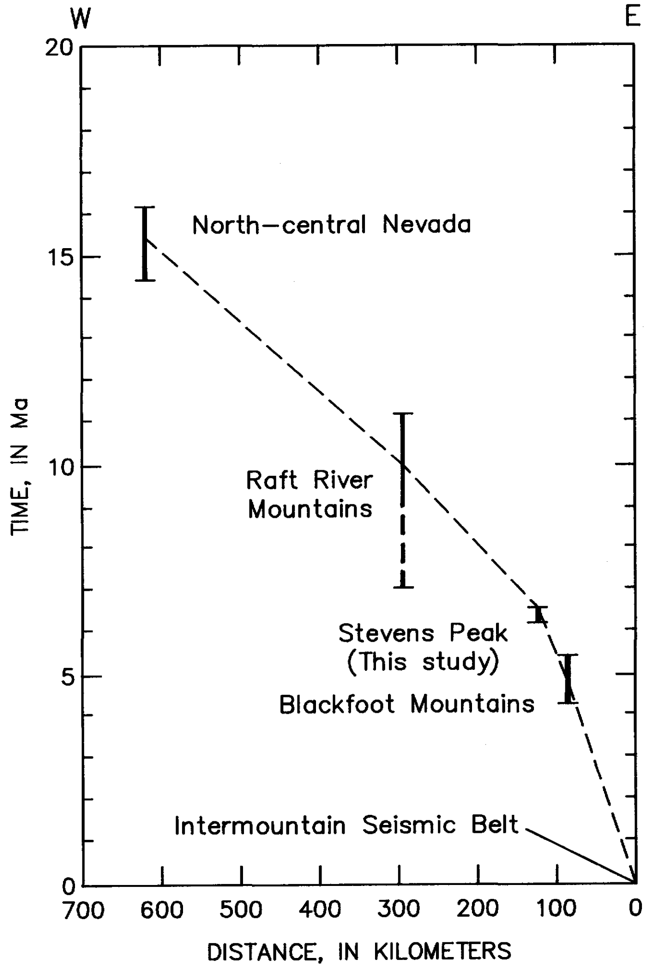

Figure 8. Graph showing the possible eastward migration of eastern boundary of Basin and Range province. Positions are measured west of intermountain seismic belt (Smith and Sbar, 1974), and ages are those of initial uplifts of current mountain ranges. Position and age of inferred major Basin and Range faulting in study area (Stevens Peak) is shown. Adapted from Allmendinger (1982).

Some Basin and Range faults with less than 50 m of throw cut the basalt of Buckskin Basin, indicating that relatively minor Basin and Range faulting has occurred in the area since 2.2 Ma. The exact amount of throw is difficult to determine because of the extensive loess cover that obscures both the faults and the attitude of the flows.

BUCKSKIN DOME

The most prominent feature in the study area is the Buckskin dome, which is a circular feature 7 km in diameter (fig. 2). The rocks underlying the Buckskin dome are composed entirely of the basalt of Buckskin Basin. Kellogg and Embree (1986) described the structure of the Buckskin dome as follows:

> The basalt flows in the outermost arcuate hills of the Buckskin dome dip away from the center of the dome at 5° to 20°. Blocks of faulted basalt inside the Buckskin dome contain flows that generally are nearly horizontal. These orientations suggest either that the interior of the original dome flattened by sagging after uplift or that uplift was piston-like, and the strata on the periphery of the structure was tilted at greater angles than that in the center.

Karlo and Jorgenson (1979) speculated that the Buckskin dome had been uplifted by rhyolitic magma, similar to that observed at Big Southern Butte and East Butte. According to their model, pulses of magma injection resulted in doming of the overlying basalts. Subsequent removal after uplift caused the sagging and faulting in the central part of the dome. We find no evidence to contradict this hypothesis.

At site E (fig. 2), the attitudes on the dated basalt flows give a constraint on the timing of uplift of the Buckskin dome. An angular unconformity of about 8° separates the upper two flows from the lower four flows; the upper two flows dip 12° to the northwest and the lower four flows dip 20° to the northwest. Because the flows were extruded during a short time interval about 2.3 Ma, the significant difference in the dips of the two upper flows compared to the lower flows strongly suggests that some rotation (and presumably uplift of the dome) was occurring contemporaneously with basaltic volcanism but that a substantial if not predominant part of the rotation (and uplift) occurred after about 2.3 Ma.

Geophysical data are somewhat ambiguous regarding the existence of a buried rhyolitic body under the Buckskin dome. The available gravity data (fig. 9) (Bankey and others, 1985) suggest that rhyolitic magma might have intruded to the southeast and possibly under Buckskin dome. No gravity stations were placed on Buckskin dome itself, and the surrounding stations define a north-northwest-trending, 5- by 10-km gravity low of 15 milligals immediately to the southeast of the dome, largely outside the study area. Exposures in the immediate area of this gravity low are of Quaternary loess and alluvium. The trend of the gravity anomaly and several other nearby anomalies is parallel to the prevalent Basin and Range faults in the area and could be at least partially due to these features.

The available aeromagnetic data (Zietz and others, 1978) indicate a northwest-trending, low-amplitude (about 60 gammas), magnetic high zone approximately coincident with the gravity low zone on the southeastern side of Buckskin dome. This anomaly could be due to either Tertiary Basin and Range valley fill (the contained volcanic rocks and debris would be relatively magnetic) or a buried rhyolitic magma body.

Ferry Butte—a 115-m-high, 3-km-in-diameter hill about 5 km west of the study area (fig. 1)—might also be a dome-shaped uplift similar to Buckskin dome. Ferry Butte is almost entirely mantled by loess, although a few, small rubbly outcrops of basalt, similar to the basalt of Buckskin Basin, occur on the eastern side.

SUMMARY AND CONCLUSIONS

The Tertiary rocks of the Buckskin Basin and Stevens Peak areas document a 10-Ma period of volcanic activity that began with deposition of the Starlight Formation, a sequence of variable thickness consisting of early rhyolite flows overlain by ash falls, ash-flow tuffs, genetically related intercalated sediments, freshwater limestone, and basalt flows. The Starlight Formation blanketed much of the eastern SRP until about 7.0 Ma. During deposition of the Starlight Formation, before the onset of major Basin and Range faulting, the topography along the eastern margin of the plain was relatively moderate compared to that which existed after 7.0 Ma.

Two rhyolite flows placed in the lower member of the Starlight Formation—the rhyolite of Two-and-a-Half-Mile Creek (9.1 Ma) and the rhyolite of Stevens Peak (9.8 Ma)—are chemically and petrographically distinct. The 7.9-Ma tuff of Arbon Valley makes up the middle member of the Starlight Formation and is the most prominently exposed unit in the study area.

Major Basin and Range faulting, mostly to the east of the study area, produced west-flowing, high-gradient streams that deeply incised the Starlight Formation and deposited a coarse boulder conglomerate. The timing of the onset of major Basin and Range faulting is constrained by a 7.0-Ma basalt in the upper member of the Starlight Formation and by the 6.7-Ma tuff of Blacktail, which overlies the boulder conglomerate. These ages are consistent with a model for easterly younging of the onset of Basin and Range faulting (Allmendinger, 1982). Although major faulting occurred between 7.0 and 6.7 Ma, some Basin and Range faults have undergone much younger activity; vertical movement of at least 50 m has occurred across north-northwest-trending faults, cutting 2.2-Ma basalt of Buckskin Basin in the area studied.

Both the 6.7-Ma tuff of Blacktail and the overlying 4.3-Ma tuff of Kilgore crop out prominently in the study area and had their sources on both the north and south margins of the eastern SRP (Morgan and others, 1984). Additional work is needed to determine if the 6.5-Ma Walcott Tuff crops out in the study area.

Sometime between 4.3 and 3.7 Ma, the composition of volcanic rocks in the Stevens Peak and Buckskin Basin area changed abruptly and markedly from predominantly rhyolitic to predominantly basaltic. This change reflects the cessation of explosive rhyolitic volcanism after

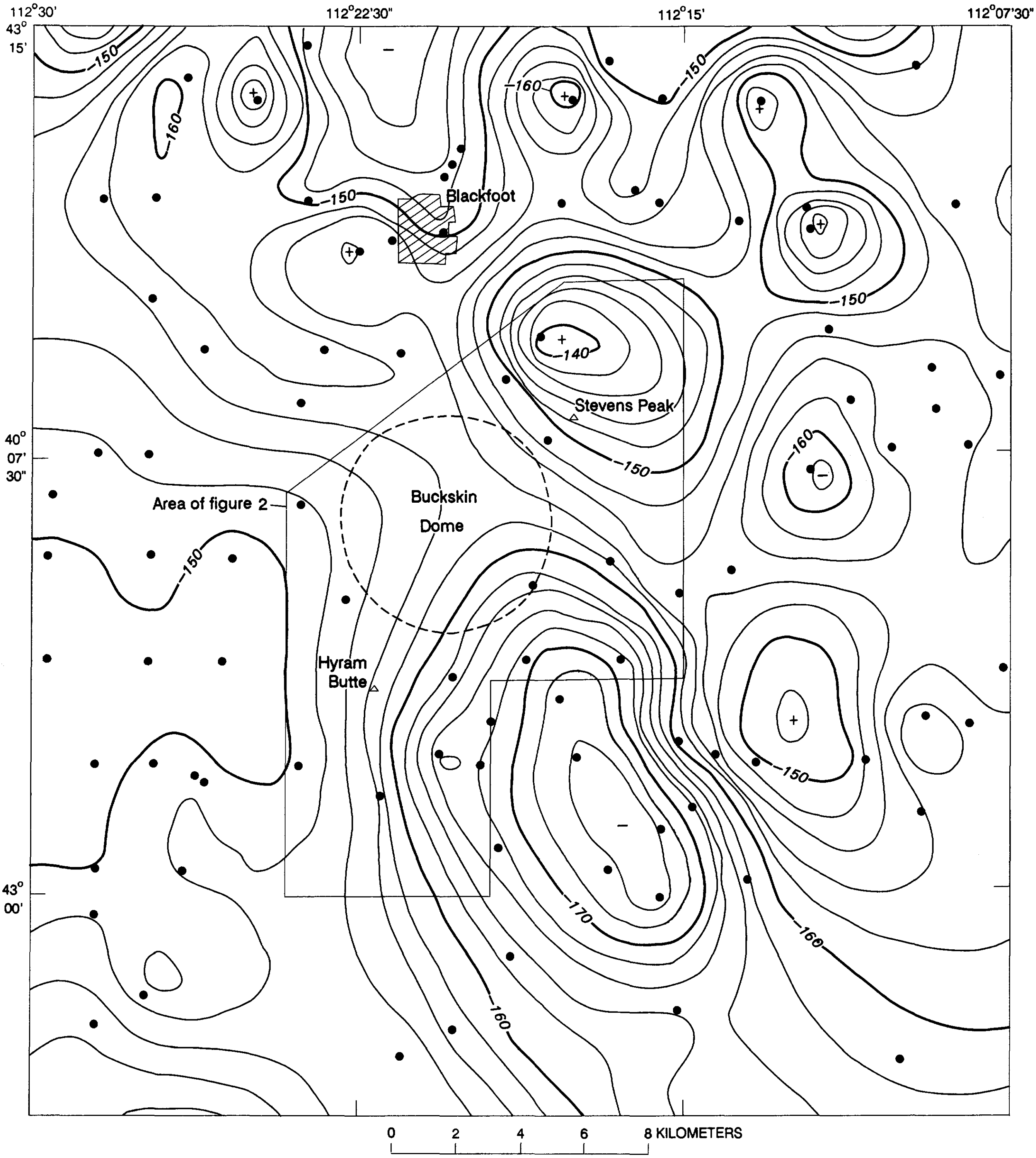

Figure 9. Bouguer gravity map of study area and surrounding region. Contours are in milligals, with 2-milligal contour interval. Dots represent gravity stations. Modified from Bankey and others (1985).

4.3 Ma along the main part of the eastern SRP and the onset of local basaltic fissure eruptions. The 2-Ma-and-younger ash-flow tuffs from the Island Park and Yellowstone Plateau areas (Christiansen and Blank, 1972) at the northeastern end of the SRP have not been observed in the study area.

The Buckskin dome is a circular domical feature 7 km in diameter that formed after about 2.5 Ma and is entirely composed at the surface of basalt of Buckskin Basin, an olivine tholeiite similar to much of the basalt of the SRP. The Buckskin dome has the shape of a sagged domical uplift and is cut both by north-northwest-trending Basin and Range faults and by ring faults probably caused by the uplift and (or) subsequent sagging of the center. Gravity and magnetic data are ambiguous about the nature of the rocks underlying the Buckskin dome. The gravity data suggest that a relatively low-density rock might occur within 10 km to the southeast of the Buckskin dome and might extend under the structure itself. It is suggested that the dome was produced by injection and subsequent withdrawal of rhyolitic magma. Ferry Butte, a prominent hill about 5 km east of the study area composed entirely of olivine basalt, might have formed in the same manner.

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