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By John W. M'Gonigle *and* G. Brent Dalrymple

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A summary of ^{40}Ar/^{39}Ar age analyses of eighteen samples of volcanic rocks from the Challis Volcanic Group and a summary of basin stratigraphy in southwestern Montana

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$^{40}Ar/^{39}Ar$ Ages of Some Challis Volcanic Group Rocks and the Initiation of Tertiary Sedimentary Basins in Southwestern Montana

By John W. M'Gonigle[1] *and* G. Brent Dalrymple[2]

ABSTRACT

$^{40}Ar/^{39}Ar$ ages of single sanidine, biotite, and plagioclase crystals from rhyolitic intrusives, tuffs, and ash-flow tuffs within a thick Tertiary volcanic sequence in several topographic basins and in adjacent highlands in southwestern Montana show that these volcanic rocks were emplaced between about 48.76±0.17 Ma and 45.04±0.13 Ma, and they are therefore temporally correlative with the Eocene Challis Volcanic Group of central Idaho. Ages of sanidine crystals from tuff at the base of the overlying Tertiary lacustrine, paludal, and fluvial sedimentary sequence suggest that sedimentation within an ancestral sedimentary basin began in the middle Eocene, predating the development of the modern Horse Prairie and Medicine Lodge topographic basins.

INTRODUCTION

Samples were collected from rhyolitic intrusive bodies, tuffs, and ash-flow tuffs in the Tertiary volcanic sequence at 18 localities in the western Horse Prairie, northern Medicine Lodge, Muddy Creek, and Sage Creek topographic/sedimentary basins and in the adjacent highlands of the Beaverhead and Tendoy Mountains in southwestern Montana (figs. 1 and 2 on plate 1). Single sanidine, biotite, and plagioclase crystals in the samples were analyzed using a continuous laser, $^{40}Ar/^{39}Ar$ dating system. Tuff units at the base of the overlying post-volcanic Tertiary sedimentary sequence of the Medicine Lodge basin area were among those dated. Our objectives were to determine the time represented by the volcanic sequence, to test the temporal correlation of this volcanic sequence with the Eocene Challis Volcanic Group of central Idaho, to check correlations of volcanic units within and between the basins, and to attempt to date the initial lacustrine and fluvial sedimentation in the ancestral Tertiary basin(s) in the absence of paleontologic age control. Preliminary results from 11 sample localities in the Medicine Lodge and western Horse Prairie basin were previously described by M'Gonigle and Dalrymple (1993). This report covers a wider area in southwestern Montana than does M'Gonigle and Dalrymple (1993) and includes seven additional $^{40}Ar/^{39}Ar$ analyses as well as geologic and topographic maps of the sample localities.

SAMPLE LOCALITIES

Figures 5–13 (on plate 1) are geologic maps at a scale of 1:24,000 that show the sample localities. Sample locality 17 (figure 14 on plate 1) is shown on a 1:24,000-scale topographic map, together with a photograph of the volcanic unit that was sampled, because no geologic map at a suitable scale was available. All sample localities are also shown in a schematic time-stratigraphic section (figure 3 on plate 1). Table 1 gives a brief description of the samples, and lists the sample localities by latitude and longitude. More complete descriptions of the geology of the sites and surrounding areas may be found in the references cited in each figure. The geologic maps are arranged geographically from west to east to facilitate comparison with figures 2 and 3 (on plate 1).

For brevity, sample numbers 1–18 were used in the figures and text instead of the field sample numbers; the field numbers are, however, listed in tables 1 and 2. The sample numbers are arranged in order of decreasing age, based on the oldest sample from each site. That is, 1 is the oldest sample analyzed and 18 is the youngest.

GEOLOGIC SETTING

The study area is north of the Snake River Plain near the eastern border of the Cordilleran thrust belt, where it overlaps the Archean craton. The western Horse Prairie and the Medicine Lodge intermontane basins lie between the

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Beaverhead Mountains on the west and south and the Tendoy mountains on the east, and they are separated by the Maiden Peak spur of the Beaverhead Mountains (figs. 1 and 2 on plate 1). These two basins cover an area of about 318 mi^2 (825 km^2) and contain Eocene to Miocene volcanic and sedimentary rocks. The Muddy Creek basin (figs. 1 and 2 on plate 1) is within the Tendoy Mountains and contains Eocene to Oligocene volcanic and sedimentary rocks. The Sage Creek basin is situated between the Blacktail Mountains and the Red Rock Hills, on the eastern side of the study area (fig. 1 on plate 1), and it contains Eocene to Miocene sedimentary rocks, as well as a few exposures of Eocene and Pliocene(?) volcanic rocks.

Pre-Tertiary rocks of the Beaverhead Mountains are predominantly Proterozoic, Paleozoic, and Mesozoic sedimentary rocks, whereas the Maiden Peak spur of the Beaverhead Mountains is composed mainly of Archean granitoid gneiss locally overlain by Proterozoic, Paleozoic, and Cenozoic rocks. The Tendoy Mountains in the study area include Archean gneiss and Paleozoic, Mesozoic, and Cenozoic sedimentary rocks, as do the Blacktail Mountains to the east. The Red Rock Hills are made up of Cretaceous and Paleocene(?), Eocene, and Oligocene sedimentary rocks. The pre-Cenozoic rocks in the region are distributed in several thrust plates, which are broken by younger low-angle and high-angle faults (fig. 2 on plate 1).

GENERAL CHARACTER OF THE TERTIARY VOLCANIC SEQUENCE

Most of the Eocene Tertiary volcanic rocks in the study area are the same age and include similar rock types as the Challis Volcanic Group of central Idaho (M'Gonigle and Dalrymple, 1993). We therefore consider the volcanic rocks to be part of the Challis Volcanic Group, and will so term them in this report.

A large volume of the Challis Volcanic Group rocks in the study area is composed of andesitic to basaltic lava flows, but the Challis also includes intercalated tuff-breccia and rhyolitic flows and tuff, as well as subordinate conglomerate units containing volcanic and Proterozoic quartzite clasts (Staatz, 1972, 1979; M'Gonigle and others, 1986; J.W. M'Gonigle and M.H. Hait, Jr., unpub. mapping, 1991–93). These volcanic rocks were deposited on an erosion surface formed on rocks of the Cordilleran fold and thrust terrain, and the thickness of the volcanic sequence differs from place to place.

Complete sections of the Challis volcanic sequence are present (1) along the east flank of the Beaverhead Mountains, where the east-dipping volcanic rocks overlie Proterozoic rocks along the continental divide and underlie younger Tertiary sediments in the western Horse Prairie basin (figs. 2, 5, and 6 on plate 1), (2) along the northeast flank of the Maiden Peak Spur (figs. 2 and 8 on plate 1), and (3) locally in the Tendoy Mountains, where east-dipping volcanic rocks overlie Archean basement gneiss and are, in turn, overlain by younger Tertiary sedimentary rocks (figs. 2 and 12 on plate 1). An aggregate thickness of at least 2,100 m of Challis volcanic rocks is present in the Beaverhead Mountains (Staatz, 1979) and as much as 1,300 m are present on the northeast flank of the Maiden Peak spur (J.W. M'Gonigle and M.H. Hait, Jr., unpub. mapping, 1991–93). The sequence thins southward in both the Horse Prairie and Medicine Lodge basins and it is very thin or absent across the southern part of the Maiden Peak spur and adjacent areas to the east and west, but it is present further south (fig. 2 on plate 1). The thinning or absence may reflect either nondeposition across a local basement high during volcanism, or subsequent uplift and erosion of the volcanic cover before deposition of the Tertiary basin sediments (M'Gonigle and others, 1991).

Lateral and vertical variations in the volcanic sequence prevent establishing a single reference section, but fairly representative sections were sampled for this study. Six samples were collected from the most complete sections (samples 4–8, 11, 12; figs. 1, 2, 5, 6, 8, and 12 on plate 1). Partial sections of the Challis Volcanic Group in the Horse Prairie, Medicine Lodge, and Muddy Creek basins were also sampled (samples 3, 9, 10, 13; figs. 1, 2, 7, 8, 9, 13, and 14 on plate 1). Samples 14, 15, and 18 are from the youngest Challis tuff units in the Medicine Lodge basin (figs. 2, 9, 10, and 11 on plate 1). Sample 16 is from an isolated welded ash-flow tuff at the western edge of the Medicine Lodge basin (figs.1, 2, and 9 on plate 1). Sample 17 is from the volcanic ash-flow that is intercalated in the Sage Creek basin sedimentary rocks which make up part of the Red Rock Hills (figs. 1, 2, and 14 on plate 1). Samples 1 and 2 were taken from dikes in Archean gneiss of a thrust sheet in the Tendoy Mountains (figs. 1, 2, and 12 on plate 1; DuBois, 1982).

North of the study area, along the Beaverhead Range and in the northern Horse Prairie basin, Challis Volcanic Group rocks are mostly absent or thin (Chadwick, 1981; Ruppel and others, 1993), but the reasons for this absence were not investigated for this study.

GENERAL CHARACTER OF THE TERTIARY SEDIMENTARY SEQUENCE

Tertiary sedimentary beds in the basins were deposited in lacustrine, fan-delta, paludal, and fluvial environments. Paleontologic studies show that they range in age from Eocene to Miocene (Becker, 1969; Cavender, 1977; Dunlap 1982; Fields and others, 1985; Scholten and others 1955; Ralph Nichols, oral commun., 1991; Alan Tabrum, oral commun., 1994.). These lithologic units show marked lateral and vertical variations, and the depictions in figure 2 (on plate 1) are much generalized.

Carbonate beds are locally well developed in the lower parts of the sedimentary section in the Medicine Lodge basin

(M'Gonigle, 1993). Tertiary beds in the western Horse Prairie basin, labeled T in figure 2 (on plate 1), are also known to include a basal limestone (ls in unit T, fig. 3 on plate 1; Flores and M'Gonigle, 1991), but otherwise, as far as we know, the Tertiary beds in the western Horse Prairie basin have not been studied or mapped in detail. Conglomerate beds in units Tml, Tmur, and Thps (fig. 2 on plate 1) contain Proterozoic quartzite, Tertiary volcanic, and some Paleozoic rock clasts, while Archean gneissic clasts are extremely rare (M'Gonigle and others, 1991; Flores and M'Gonigle, 1991; M'Gonigle, 1994; J.W. M'Gonigle and M.H. Hait, Jr., unpub. mapping, 1991–93). In contrast, unit Thp, which unconformably overlies unit Thps in the Horse Prairie basin, the upper parts of the Tertiary beds in the Horse Prairie basin labeled T in figure 2 (on plate 1), and unit Tmc, which interfingers with the top of unit Tmu in the Medicine Lodge basin (fig. 2 on plate 1), locally contain rather large amounts of Archean gneiss clasts (M'Gonigle, 1994; M'Gonigle and others, 1991).

The upper parts of sedimentary units Tml and Tmu in figure 2 (on plate 1) have been paleontologically dated as Oligocene and Miocene in the Medicine Lodge basin on the basis of plant and fish fossils (Becker, 1969; Cavender, 1977), and unit Thps of the southern Horse Prairie basin has been paleontologically dated on the basis of vertebrate fossils as Arikareean or early Miocene (Ralph Nichols, oral commun., 1991). The middle Miocene age of unit Thp has been paleontologically determined by Ralph Nichols (oral communication, 1991). The upper parts of the Tertiary beds in the Horse Prairie basin labeled T on figure 2 (on plate 1) are probably middle Miocene in age, on the basis of their stratigraphic position (J.W. M'Gonigle and M.H. Hait, Jr., unpub. mapping, 1991–93).

The principal source areas for the clasts in the conglomerate beds of units Tml, Tmur, and Thps were apparently to the south or west, where Challis Volcanic Group rocks were laid down over a basement complex of Proterozoic quartzite and Phanerozic sediments rather than over gneiss, as they were across the Maiden Peak spur and in the Tendoy Mountains (fig. 2 on plate 1). It seems likely that Archean gneiss in the study area was not widely exposed to erosion from the time of deposition of the volcanic sequence until the middle Miocene and the deposition of units T, Thp, and Tmc.

These considerations, together with the correlations made during the mapping of units Tc, Tmur, and Tmu across and around the northern half of the Maiden Peak spur from the Medicine Lodge basin into the Horse Prairie basin (M'Gonigle, 1965; J.W. M'Gonigle and M.H. Hait, Jr., unpub. mapping, 1991–93), imply that these two modern topographic basins were derived from the breakup of a larger depositional basin between the early and middle Miocene. The boundaries of this larger ancestral basin are not known. The distribution of Tertiary sedimentary rocks, from the western Horse Prairie basin to the southern Medicine Lodge basin and in down-faulted exposures in the Tendoy Mountains, suggests that the ancestral basin may have covered much of the area of the present Beaverhead Mountains and the northern Tendoy Mountains (fig. 2 on plate 1). The ancestral depositional basin accumulated at least 3,500 m of post volcanic lacustrine, paludal, and fluvial sediments through the early Miocene (Flores and M'Gonigle, 1991; M'Gonigle and others, 1990, 1991). This aggregate thickness was measured on stratigraphic units exposed across the Medicine Lodge basin (map units Tml, Tmur, Tmu, and Tmc; fig. 2 on plate 1). These units are tilted eastward into a west-dipping normal fault east of the basin (M'Gonigle and others, 1991). The depths of the modern Horse Prairie and Medicine Lodge basins, however, are uncertain. The Luff 1–27 Hansen well (fig. 2 on plate 1), which is located about at the midpoint of the Medicine Lodge basin, penetrated 1,538 m of easterly dipping Tertiary sedimentary rocks and 413 m of volcanic rocks before passing into Archean gneiss that was thrust over Paleozoic rocks (M'Gonigle and others, 1991).

ANALYTICAL METHODS

The samples were crushed, disaggregated in water, and wet-sieved. Feldspar and biotite crystals were hand-picked from the dried, sieved fractions of each sample, checked in index oils, cleaned, and washed. The feldspar and biotite crystals were packaged in small aluminum-foil envelopes, which were stacked in a quartz vial and irradiated along with envelopes of a neutron fluence monitor mineral in the core of the U.S. Geological Survey Training Research Isotope General Atomic (TRIGA) reactor for 50 hours, where they received an integrated fast neutron dose of approximately 3.1×10^{18} n/cm^2. Sanidine from the Oligocene Taylor Creek Rhyolite (sample 85G003; 27.92 Ma) was used as the monitor mineral.

The $^{40}Ar/^{39}Ar$ analyses were done using the Great Little Machine (GLM) laser system. This system consists of a continuous Ar-ion laser that has steering and focusing optics. The laser beam was used to melt the crystals, which were positioned within a small, ultra-high vacuum chamber. Zr-Al and Zr-V-Fe getters were used to remove reactive gases, and a rare-gas mass spectrometer, equipped with a Baur-Signer source and electron multiplier, was used to analyze the isotopic composition of the Ar released from the crystals. Details of the irradiation and analytical procedures as well as a description of the GLM continuous laser system are given in Dalrymple and others (1981), Dalrymple and Duffield (1988), and Dalrymple (1989).

Errors given for individual analyses are estimates of the analytical precision at the 67 percent (1 sigma) confidence level. Weighted means and errors of multiple analyses, where weight is by the inverse of the variants, were calculated according to Taylor (1982) and are used here to represent the ages of the dated units.

RESULTS

The analytical data for the 18 samples are given in Table 2. The ages calculated for the individual sanidine crystals from each sample are closely grouped, the highest and lowest values for a single sample differing by no more than 2.1 percent. Three of the sanidine crystals (sanidine 2) analyzed from sample 14 have much lower K/Ca ratios than the other eight crystals (sanidine 1) from this sample. Two of the analyses on these three crystals also have very low contents of radiogenic ^{40}Ar. Based on their K/Ca ratios, we suspect that these may not have been single crystals but instead binary grains consisting of sanidine and plagioclase. Even though the weighted mean ages of sanidine 1 and sanidine 2 are nearly identical, we have elected to use the result from sanidine 1 to represent the age of sample 14.

For samples 6 and 10 we analyzed plagioclase as well as sanidine. In both instances, the apparent ages of the plagioclase crystals have a greater range of values (4 percent for sample 6 and 8 percent for sample 10) and significantly lower weighted means than those of the sanidine crystals. We suspect that this is due to low-temperature alteration (weathering) of the plagioclase crystals and we think that the plagioclase data do not represent the crystallization ages of the units from which they were separated. Biotite crystals were analyzed for samples 1, 2, and 9. The $^{40}Ar/^{39}Ar$ age of the biotite crystals analyzed in sample 9 is younger than the $^{40}Ar/^{39}Ar$ age of the sanidine crystals from the same sample. Samples 1 and 2 did not contain sanidine crystals that could be analyzed for age comparison with their biotite ages. If they had contained sanidine crystals, it seems plausible to us that sanidine ages might likewise have been older than the biotite ages we obtained.

DISCUSSION

The calculated ages for the 18 samples define the interval of time represented by the volcanic sequence and the time of initiation of subsequent sedimentation in the Medicine Lodge basin (fig. 4 on plate 1). The samples from the volcanic sequence show that the duration of the main volcanic activity in the area was approximately 3.7 m.y., from about 48.76 ± 0.17 Ma (sample 3) to about 45.04 ± 0.13 Ma (sample 18). These ages fall within the age range of the Eocene Challis Volcanic Group (Fisher and others, 1992; Marvin and others, 1989; Janecke and Snee, 1993).

Previously, Scholten and others (1955) suggested that volcanic rocks in this area, which they called the Medicine Lodge Volcanics, might be correlative with the Challis Volcanic Group. Staatz (1972) mapped the volcanic rocks on the western flanks of the Horse Prairie basin as part of the Challis Volcanic Group, based on lithologic similarities with Challis volcanic rocks further west and on a potassium-argon age of about 41 Ma for a crystal tuff in the volcanic sequence (Staatz, 1979). In an area of the Beaverhead Mountains adjoining the south border of figure 1 (on plate 1), Skipp (1984) mapped the rocks that had previously been termed the "Medicine Lodge Volcanics" by Scholten and others (1955) as part of the Challis Volcanic Group. Skipp obtained potassium-argon ages on biotite and hornblende crystals in these rocks that ranged from 51.4 ± 3.1 Ma to 47.0 ± 1.3 Ma. Our $^{40}Ar/^{39}Ar$ ages support these earlier interpretations that the volcanic sequence in the Horse Prairie basin and the Medicine Lodge basin are correlative with the Challis Volcanic Group. We do not imply, however, that the volcanic rocks of the Horse Prairie basin and the Medicine Lodge basin necessarily originated in the main Challis volcanic centers, which are 50–70 mi (80–113 km) to the west of the study area shown in figure 1 (on plate 1). Staatz (1979, p. A 12) pointed out that the Challis Volcanic Group can be traced almost continuously from the type locality to the Lemhi Pass area, although flows and ash falls vary in detail from place to place and commonly are local in extent. Our correlation of the Challis Volcanic Group with the volcanic sequences of this study is temporal and not based on specific volcanic lithologies. The new $^{40}Ar/^{39}Ar$ ages have helped confirm the mapped correlations of volcanic rocks in the general area and between the Horse Prairie and the Medicine Lodge basins.

Janecke and Snee (1993) found that there was a hiatus of about 1.5 m.y. during the emplacement of the Challis Volcanic Group in the Lost River and Lemhi Ranges in Idaho. The first phase of deposition, which took place about 49 to 48 Ma, was of thick andesitic and dacitic lava flows and tuff. Later deposition of rhyolitic tuff took place about 46 to 45.5 Ma. Our data show that Challis-type volcanism in the southwestern Montana study area covered a period from about 48.8 Ma (sample 3) to about 45.1 Ma (sample 18), as depicted in figure 4 (on plate 1), so the dates of volcanic activity are nearly the same as in central Idaho. The age distribution of the samples shown in figure 4 (on plate 1) might suggest a hiatus in the volcanism in southwest Montana between samples 8 and 10. However, samples gathered in this study were concentrated at the base and at the top of the Challis volcanic rock sequence and do not show whether or not volcanism was continuous throughout the time period.

MEDICINE LODGE AND HORSE PRAIRIE BASINS

The initiation of lacustrine and fluvial sedimentation in the basin that was ancestral to the Horse Prairie basin and the Medicine Lodge basin probably began during, or shortly after, the deposition of the stratigraphically highest Challis tuff beds. These tuff beds are represented by samples 12, 13, 14, 15, 16, and 18 (figs. 2, 8, 9, 10, and 11 on plate 1), and the beds have an age range of 46.04±0.15 Ma to 45.04±0.13 Ma.

The thin tuff stringer of sample 12 is interbedded with volcanic sandstone at the top of the Challis Volcanic Group on the east side of the Maiden Peak spur. The contact of the volcanic sandstone with overlying sedimentary strata of the Medicine Lodge basin is not well exposed, but the contact is probably an unconformity. In the Horse Prairie basin, the top of the tuff bed of sample 13 as well as any overlying sedimentary strata have been eroded. However, the contact of the Challis tuff beds of unit Tmlt (fig. 2 on plate 1) in the Medicine Lodge basin and the Tendoy Mountains is conformable with unit Tml. A limestone zone (unit Tsll, in M'Gonigle, 1993) at the base of unit Tml locally contains additional fine-grained tuff beds intercalated with carbonate and shale beds (unit Tsll, in M'Gonigle, 1993). This intercalation is interpreted as an interfingering of the uppermost Challis tuff beds of unit Tmlt with the lowermost Tertiary sedimentary rocks of the Medicine Lodge basin. The tuff beds of unit Tmlt are present in the northern and southern Medicine Lodge basin and were deposited on an erosion surface formed on older rocks of the Challis Volcanic Group as well as on pre-Cenozoic rocks from which any previously deposited Challis volcanic rocks had been eroded (figs. 2, 9, 10, and 11 on plate 1). Sample 16 is a welded ash-flow (unit Tr, fig. 9 on plate 1) that was also deposited on this erosion surface. The relatively thin (< 65 m) tuff unit Tmlt (or unit Tslt, in M'Gonigle, 1993) was apparently preserved where it was overlain by lacustrine deposits (for example, units Tsll and Tsl, figs. 9 and 10 on plate 1). We did not find other datable tuffs higher in the Tertiary sedimentary section in either the Medicine Lodge or Horse Prairie basins. Skipp (1984) described a biotite-rich air-fall tuff in similar Tertiary beds to the south of this study area, but this tuff has not been dated.

Paleontologic studies of plant and fish fossils have established an age range of Oligocene to Miocene for most of the lacustrine sediments in the Medicine Lodge basin (Becker, 1969; Cavender, 1977). Our data suggest that the lowermost parts of the sedimentary sequence in the Medicine Lodge basin are as old as middle Eocene in age.

MUDDY CREEK BASIN

Paleontologic studies show that the age of most of the clastic sedimentary rocks in the Muddy Creek basin were early Chadronian (approximately late Eocene to early Oligocene), according to Dunlap (1982), who pointed out that the undated stratigraphically lowest sediments might be slightly older. Sample 9 (fig. 13 on plate 1), is from a tuff (unit Tctb) at the base of the coarse tuff facies unit (Tct) of Dunlap (1982). Sample 9 has a sanidine $^{40}Ar/^{39}Ar$ age of 47.07±0.13 Ma, which is about in the middle of the Challis age ranges in the study area (fig. 4 on plate 1). The coarse tuff unit is made up of interbedded tuffs, clastic sedimentary rocks, and rare limestone and marl units (Dunlap, 1982). The coarse tuff unit overlies a sequence of basaltic to andesitic lava flows and agglomerate, some tuff, and conglomerate containing cobble- to boulder-size, rounded to subrounded clasts of Archean gneiss, Proterozoic quartzite, and basaltic lava (S.U. Janecke, written commun., 1994; W.J. Perry and J.W. M'Gonigle, unpub. reconnaissance mapping, 1994).

We suggest that the tuffs in unit Tct and the underlying sequence of lava, agglomerate, and conglomerate represent the Challis Volcanic Group in this basin, and that most of the stratigraphically higher sedimentary units in the basin (Dunlap, 1982) are probably correlative with unit Tsl of the Medicine Lodge basin (fig. 2 on plate 1).

RED ROCK HILLS

Volcanic rock exposed in the Red Rock Hills consists of a >10-meter-thick basaltic lava ash-flow, ash-flow breccia, and associated tuff, all of which are part of the Sage Creek basin deposits (figs. 2 and 14 on plate 1). The volcanic rocks overlie the Eocene Sage Creek Formation (Scholten and others, 1955) and, locally, the Upper Cretaceous to Eocene Red Butte Conglomerate (Haley and Perry, 1991). The volcanic rocks are overlain by the Oligocene Cook Ranch Formation. Tuff from the unit (sample 17) was dated at 45.54±0.11 Ma. The volcanic unit is thin, is seemingly of local extent, and may not be part of the Challis Volcanic Group.

SOURCE AREAS

The basal Challis tuff units in the Lemhi Pass area of the Beaverhead Mountains (samples 5 and 8, fig. 5 on plate 1), in the Horse Prairie basin (sample 3, fig. 7 on plate 1), and in the Tendoy Mountains (samples 6 and 7, fig. 12 on plate 1), all contain similar micaceous quartzite clasts. The sampled units are similar in age (table 2 and fig. 4 on plate 1), and we speculate that they may have had a common source area. The micaceous clasts are similar to some of the micaceous Proterozoic quartzite units in the region, which likely made up a large part of the country rock in Idaho source area(s).

Janecke and Snee (1993) attributed a second phase of rhyolitic volcanism to eruption of the tuff of Challis Creek from the Twin Peaks caldera, and extended its distribution into the Lemhi Range. Our tuff samples 10–16 and 18 in the Medicine Lodge and Horse Prairie basins have a similar age span to that of the tuff of Challis Creek (about 46–45.5 Ma; Janecke and Snee, 1993), and it is possible that some of these deposits in southwestern Montana represent the tuff of Challis Creek. However, some of the Montana tuff deposits contain plagioclase and mafic minerals (samples 10 and 15, table 1), which the tuff of Challis Creek lacks (Janecke and

Snee, 1993); therefore, the tuff deposits probably came from other eruptive centers.

Source areas for the Challis lava flows in southwestern Montana are not known, but some basic dikes exposed in the Archean gneiss of the Maiden Peak spur may have been feeders to the volcanic sequence (M'Gonigle and others, 1991). Samples 1 and 2 from the two dikes exposed in the Archean gneiss in the Tendoy Mountains (figs. 2 and 12 on plate 1) have biotite ages of about 53 Ma (table 2). We do not know of any volcanic deposits of this age in the study area for which these dikes may have been feeders.

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Table 1.-- Locations and descriptions of samples and sample localities, in and near the Horse Prairie, Medicine Lodge, Muddy Creek, and Sage Creek basins, southwestern Montana

[Sample numbers in parentheses are field notebook numbers used by M'Gonigle; letter symbols in parentheses are map unit designations by Staatz (1972; 1979).]

Sample no.	Latitude and longitude	Description
1 (91-169)	44°53′37″ N 112°56′40″ W	Medium-gray porphyritic rhyolitic dike in Archean gneiss (figs. 2 and 12). Contains quartz and feldspar phenocrysts.
2 (91-168)	44°53′30″ N 112°56′32″W	Medium-gray porphyritic rhyolitic dike in Archean gneiss adjacent to identical dike of sample 1 (fig. 12). In thin section the microcrystalline matrix appears to be divitrified glass. Some feldspar phenocrysts are altered to carbonate and clay, but others are fresh. Quartz crystals are rounded and range from 0.5 to 2.3 mm in diameter; feldspar crystals range from 0.5 to 2 mm. Biotite crystals appear fresh, and x-ray diffraction films indicate no alteration of the biotite from either sample 1 or 2
3 (82-528)	44°57′14.1″ N 113°15′12.5″ W	Pale-yellowish-brown welded crystal-lithic tuff. Glassy matrix contains elongate 1-3 mm feathery pumice fragments, 1-cm-long, medium-dark-gray, fine-grained, micaceous quartzite clasts, and quartz and feldspar crystals as much as 1 mm in length that are commonly broken. Elongate crystals are in parallel alignment. The tuff is at the base of the basaltic-andesitic lava flow sequence of the Challis Volcanic Group (figs. 2 and 7), exposed in the eastern part of the Horse Prairie basin.
4 (82-504)	44°57′14″ N 113°15′13″ W	Medium-gray to pale-yellowish-brown faintly laminated rhyolite or welded ash flow that contains scattered potassium feldspar and quartz crystals as much as 1-2 mm in diameter, and rare small hornblende and magnetite phenocrysts in a glassy matrix that is in part devitrified. The laminations are wavy, 0.1-2 mm wide, within bands that are 2.5-3 cm thick. They probably represent flow banding, which is better developed in an exposure 1,200 m to the north. The rhyolite forms a tabular to dome-shaped mass on the Archean gneiss of the Maiden Peak spur. The rhyolite is at the base of the 1,300-m-thick basaltic-andesitic

Table 1. Locations and descriptions of samples and sample localities in and near the Horse Prairie, Medicine Lodge, Muddy Creek, and Sage Creek basins, southwestern Montana, continued

		lava flow sequence of the Challis Volcanic Group in the northwest part of the Medicine Lodge basin (figs. 2 and 8).
5 (Tcq)	44°58′22″N 113°26′41″ W	(From Staatz, 1972): Pinkish quartzite-bearing rhyolite tuff. The matrix is white to pink ash, consisting of light-brown glass containing a few shards. Contains dark-gray subangular to subrounded quartzite fragments, generally 1.5 -6.3 mm but as much as 38 mm in width, vitric fragments, and crystal fragments of quartz, plagioclase, sanidine, and trace amounts of biotite. Unit Tcq is at the base of the volcanic sequence above Proterozoic rocks (fig. 5).
6 (87-64)	44°52′19″ N 112°59′13″ W	Very light yellowish gray lithic tuff containing 2-5-mm-long, dark-gray, micaceous quartzite clasts and 1-2 mm tuff clasts. Overlies Archean gneiss of a thrust plate (DuBois, 1982) on the west flanks of the Tendoy Mountains (unit Tmc, fig. 2; unit Tcvt, fig. 12).
7 (88-100)	44°51′27″ N 112°59′00″ W	Same unit as that of sample 6; located 1,616 m to the south (fig. 12). The sample is from the tuff at the contact with Archean gneiss of the same thrust plate. The very light yellowish gray lithic tuff contains rounded clasts of dark-gray phyllite and dark-gray, fine-grained quartzite clasts in a micaceous matrix; clasts commonly 2-5 mm long, but ranging to as much as 3 cm long. Pumaceous clasts in the tuff are commonly 1-2 mm in length. Broken quartz and potassium feldspar crystals as large as 0.5 mm are common. The glass matrix is brownish in plain light and is slightly devitrified. Bedding in the tuff is generally about 10-20 cm thick. At this location the tuff unit is 300-400 m thick, but it appears to be considerably thinner near sample locality 6. At both sample localities the tuff is overlain by as much as 500 m of basaltic to andesitic flows and cinder beds, which in turn are overlain by tuff beds of unit Tmlt and lower Tertiary strata of unit Tml (fig. 2). Units Tc, Tmlt, and Tml (fig. 2); units Tcvt. Tcvb, Tslt, and Tsl (fig. 12) are tilted eastward in this area.

Table 1. Locations and descriptions of samples and sample localities in and near the Horse Prairie, Medicine Lodge, Muddy Creek, and Sage Creek basins, southwestern Montana, continued

8 (Tcl)	44°58′21″ N 113°26′31″W	(From Staatz, 1972): White to greenish-white vitric tuff near Lemhi Pass (figs. 2 and 5). Composed of curved glass shards in a matrix of similar-appearing glass. Contains sand-sized crystals, mostly of quartz and plagioclase, with traces of biotite. Locally, the tuff contains some granule-size pieces of dark-gray micaceous quartzite. The unit is stratigraphically higher than the quartzite-bearing tuff of sample 5.
9 (91-171)	44°44′34″ N 112°53′53″ W	Very light gray crystal-lithic tuff. Matrix of shards in glass. The tuff is composed mainly of <1.0-6 mm rounded pumice fragments, but contains 1 mm plagioclase and potassium feldspar crystals, 0.5-1.8 mm quartz crystals, and 1-1.5 mm biotite crystals. Sample is from the base of the coarse tuffaceous facies of Dunlap (1982) in the Muddy Creek basin (figs. 2 and 13).
10 (89-135-3)	44°50′58″ N 113°04′48″W	Light-yellowish-gray, fine-grained, weathered crystal-lithic tuff containing about 40 percent broken crystals of quartz, sanidine, and plagioclase that are as large as 0.5 mm in diameter, as well as a few percent biotite crystals 1-2 mm in width and numerous pumice clasts, some of which are 4 mm long. The glassy matrix shows faint relict shard structure and some clay (?) veinlets and drapes around phenocrysts and rock clasts. The tuff is at the top of a 700-m-thick volcanic sequence of andesite-basalt flows and tuff (units Tcv and Tcvt, fig. 9). Disconformably overlain by similar younger tuff (fig. 9, unit Tslt, sample 15) at the base of the Tertiary lacustrine and fluvial sediments (units Tsll and Tsl, fig. 9) in the western Medicine Lodge basin.
11 (88-59)	44°54′03″ N 113°21′39″ W	Slightly devitrified light-gray rhyolitic welded ash-flow tuff. The ash-flow tuff contains potassium feldspar and quartz crystals 1-5 mm in length. The sample appears to be from the "basalt-rhyodacite sequence" of Staatz (1972) (unit Tcb, fig. 6) and is here overlain by Tertiary lacustrine limestone-chert beds along the western border of the Horse Prairie basin (lower beds of unit T, figs. 2 and 3; unit Tls, fig. 6).

Table 1. Locations and descriptions of samples and sample localities in and near the Horse Prairie, Medicine Lodge, Muddy Creek, and Sage Creek basins, southwestern Montana, continued

12 (81-189)	44°56′03″ N 113°07′31″ W	Very light gray rhyolitic welded ash-flow tuff. Devitrified fine-grained groundmass shows relict shard structure and contains 0.5-2 mm long quartz and potassium feldspar crystals. Intercalated with crossbedded tuffaceous volcanic sandstone beds (unit Tcvs, fig. 8) that are stratigraphically above the main andesitic-basaltic flows of the Challis Volcanic Group (unit Tcv, fig. 8; unit Tc, fig. 2) of the western Medicine Lodge basin. The volcanic sandstone beds are unconformably overlain by the Tertiary sedimentary sequence (units Tsl and Tc, fig. 8).
13 (82-322)	44°55′42″ N 113°10′58″ W	Light-gray rhyolitic ash-flow tuff has a mostly devitrified fine-grained matrix that shows relict shard structure and contains 0.1-1.2 cm tuff clasts. Contains about 5-10 percent quartz and potassium feldspar crystals, some of which are broken. The ash flow is at the top of the Challis Volcanic Group (unit Tmc, fig. 2; unit Tcv, fig. 8) on the east side of the Horse Prairie basin. Top of tuff eroded.
14 (82-551)	44°46′03″ N 112°59′10″ W	Light-gray to very pale orange crystal-lithic tuff containing broken and whole, 1-2-mm-long quartz and potassium feldspar crystals and 1-3 mm pumice fragments in a glass matrix composed primarily of glass shards. The tuff (unit Tmlt, fig. 2; unit Tslt, fig.11) is at the base of the Medicine Lodge basin Tertiary sedimentary sequence (unit Tsl, fig. 11) in a fault block in the Tendoy Mountains (fig. 2).
15 (89-135-4)	44°50′58″ N 113°04′45″ W	Light-yellowish-gray, fine-grained, crystal-lithic tuff. Overlies and is similar to tuff of sample 10, except crystals are generally smaller and make up only about 10 percent of the rock, and the rock appears less weathered. The glass matrix shows some relict shard structure and contains broken crystals of quartz, sanidine, plagioclase, biotite, and pumice fragments 1 mm and larger in diameter. The tuff (unit Tmlt, fig. 2; unit Tslt, fig. 9) is at the base of the Tertiary sediments in the western Medicine Lodge basin (figs. 2 and 9).

Table 1. Locations and descriptions of samples and sample localities in and near the Horse Prairie, Medicine Lodge, Muddy Creek, and Sage Creek basins, southwestern Montana, continued

16 (87-63)	44°49′52″ N 113°05′00″ W	Brownish-light-gray rhyolitic welded ash-flow tuff. The aphanitic glass groundmass shows some faint relict shard structures and contains generally broken 1-2 mm quartz and potassium feldspar crystals, scattered 1-2 mm pumice fragments, and rare 1 cm quartzite clasts. In hand specimen some of the sanidine crystals look bluish to opalescent, and a few 2-10 mm elongate cavities can be seen. The ash-flow tuff (unit Tr, fig. 9) was deposited on Archean gneiss from which any older rocks of the Challis Volcanic Group had been eroded. This exposure is in the western Medicine Lodge basin, just west of the present outcrops of the Challis tuff unit Tmlt (fig. 2; unit Tslt, fig. 9) and the Tertiary sedimentary sequence.
17 (91-170)	44°46′20″ N 112°37′21″ W	Very light gray to yellowish-gray crystal tuff from the volcanic rocks at Hall Creek, in the Sage Creek basin (fig. 14; unit Ths, fig. 2). The tuff contains rounded pumice fragments as large as 2 mm in diameter, and scattered small broken crystals of quartz, feldspar, and biotite. Interstitial spaces are filled with calcite cement, which also appears to have replaced some of the glassy matrix of the tuff.
18 (91-104)	44°45′18″ N 113°05′15″ W	Very light gray to yellowish-gray lithic tuff (unit Tmlt, fig. 2; unit Tslt, fig. 10), which was deposited on Proterozoic rocks. The glass matrix shows some relict shard structures and contains scattered feldspar and quartz crystals that average about 0.1 mm in length, 0.5 mm biotite crystals, and small 0.04-2.3 mm pumice fragments. The tuff unit is conformably overlain by limestone (unit Tsll, fig. 10) at the base of the sedimentary section in the Medicine Lodge basin.

Table 2. Analytical data for single-crystal $^{40}Ar/^{39}Ar$ ages of volcanic dikes and air-fall and ash-flow tuff units in and near the Horse Prairie, Medicine Lodge, Muddy Creek, and Sage Creek Basins, southwest Montana

[^{37}Ar (half-life 35.1 days) and ^{39}Ar (half-life 269 yrs) corrected for decay. $\lambda_\varepsilon = 0.581 \times 10^{-10} yr^{-1}$, $\lambda_\beta = 4.692 \times 10^{-10} yr^{-1}$. Subscript to J indicates irradiation numbers 1-3. Corrections for irradiation 1: $(^{36}Ar/^{37}Ar)_{Ca} = 0.000264 \pm 2$, $(^{39}Ar/^{37}Ar)_{Ca} = 0.000673 \pm 4$, $(^{40}Ar/^{39}Ar)_K = 0.0012 \pm 8$. Corrections for irradiation 2: $(^{36}Ar/^{37}Ar)_{Ca} = 0.000269 \pm 2$, $(^{39}Ar/^{37}Ar)_{Ca} = 0.000670 \pm 5$, $(^{40}Ar/^{39}Ar)_K = 0.0091 \pm 54$. Corrections for irradiation 3: $(^{36}Ar/^{37}Ar)_{Ca} = 0.000269 \pm 2$, $(^{39}Ar/^{37}Ar)_{Ca} = 0.000670 \pm 5$, $(^{40}Ar/^{39}Ar)_K = 0.0051 \pm 4$. Subscripts indicate rediogenic (rad), calcium-derived (Ca) Ar isotopes. σ = one standard deviation. Sample numbers in parentheses are field notebook numbers used by M'Gonigle; letter symbols in parentheses are map unit designations by Staatz (1972, 1979).]

Sample mineral	No. of crystals	K/Ca	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{40}Ar_{rad}$ (10^{-14}mol)	$^{40}Ar_{rad}$ (%)	$^{39}Ar_{Ca}$ (%)	$^{36}Ar_{Ca}$ (%)	Age (Ma)
					Dikes					
1 (91-169)	1	253	4.837	.00194	.000773	23.6	95.2	<.1	0.1	53.52±0.35
biotite	1	90	4.892	.00543	.000720	9.0	95.6	<.1	0.2	54.32±0.54
J_3=0.006540	1	26	4.962	.01898	.001392	43.5	91.6	<.1	0.4	52.86±0.32
	2	17	4.738	.02828	.000607	38.8	96.2	<.1	1.3	52.96±0.32
	2	52	4.850	.00942	.000923	13.8	94.3	<.1	0.3	53.16±0.41
	2	18	4.831	.02764	.000625	24.1	96.1	<.1	1.2	53.97±0.35
							Weighted Mean ± σ_{best} =			53.35±0.15
							Mean ± σ =			53.46±0.58
2 (91-168)	1	11	4.709	.04521	.000643	18.5	95.9	<.1	1.9	52.76±0.34
biotite	1	13	4.901	.03708	.000864	35.8	94.7	<.1	1.2	54.21±0.32
J_3=0.006570	1	27	4.735	.01824	.000844	28.5	94.7	<.1	0.6	52.35±0.32
	1	36	4.979	.01353	.001138	17.5	93.2	<.1	0.3	54.16±0.36
	1	12	4.895	.04035	.001418	54.8	91.4	<.1	0.8	52.27±0.31
	1	31	4.741	.01586	.000836	25.8	94.7	<.1	0.5	52.45±0.32
							Weighted Mean ± σ_{best} =			52.99±0.13
							Mean ± σ =			53.03±0.91
					Samples from the base of the volcanic sequence					
3 (82-528)	1	110	7.320	.00446	.003686	28.1	85.0	<.1	<.1	48.50±0.29
sanidine	1	125	7.400	.00391	.003798	31.9	84.7	<.1	<.1	48.86±0.30
J_2=0.004379	1	108	6.556	.00454	.000908	32.0	95.8	<.1	.1	48.94±0.29
							Weighted Mean ± σ_{best} =			48.76±0.17
							Mean ± σ =			48.77±0.23
4 (82-504)	1	110	2.692	.00447	.000166	35.5	98.2	<.1	.7	48.33±0.28
sanidine	1	92	2.670	.00532	.000115	.8	98.7	<.1	1.2	48.21±1.26
J_1=0.01028	1	115	2.724	.00425	.000149	7.0	98.4	<.1	.8	48.99±0.32
	1	35	2.712	.01401	.000123	3.9	98.7	<.1	3.0	48.93±0.38
							Weighted Mean ± σ_{best} =			48.69±0.18
							Mean ± σ =			48.62±0.40

Table 2. Analytical data for single-crystal $^{40}Ar/^{39}Ar$ ages of volcanic dikes and air-fall and ash- flow tuff units in and near the Horse Prairie, Medicine Lodge, Muddy Creek, and Sage Creek Basins, southwest Montana, continued.

Sample mineral	No. of crystals	K/Ca	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{40}Ar_{rad}$ (10^{-14}mol)	$^{40}Ar_{rad}$ (%)	$^{39}Ar_{Ca}$ (%)	$^{36}Ar_{Ca}$ (%)	Age (Ma)
5 (Tcq)	1	142	4.227	.00345	.000350	59.7	97.4	<.1	0.3	48.64±0.28
sanidine	1	106	4.358	.00464	.000779	33.8	94.6	<.1	0.2	48.69±0.29
J_3=0.006635	1	157	4.196	.00313	.000182	52.5	98.6	<.1	0.5	48.85±0.28
	2	114	4.148	.00431	.000263	64.3	98.0	<.1	0.4	48.02±0.28
	1	105	4.227	.00465	.000240	39.3	98.2	<.1	0.5	49.01±0.29
	2	91	4.345	.00541	.000741	33.6	94.9	<.1	0.2	48.66±0.29
							Weighted Mean $\pm\sigma_{best}$ =			48.64±0.12
							Mean $\pm\sigma$ =			48.64±0.33
6 (87-64)	1	122	2.792	.00402	.000551	18.0	94.1	<.1	.2	48.88±0.30
sanidine	1	113	2.693	.00432	.000234	10.5	97.4	<.1	.5	48.78±0.32
J_1=0.01045	1	101	2.794	.00483	.000692	6.4	92.7	<.1	.2	48.14±0.32
							Weighted Mean $\pm\sigma_{best}$ =			48.61±0.18
							Mean $\pm\sigma$ =			48.60±0.40
6 (87-64)	1	0.4	5.592	1.08180	.0112103.7	42.2	.1	2.5	44.00±0.54	
plagioclase	1	0.4	4.501	1.09600	.007188	3.6	54.7	.1	4.0	45.84±0.54
J_1=0.01045							Weighted Mean $\pm\sigma_{best}$ =			44.92±0.38
							Mean $\pm\sigma$ =			44.92±1.30
7 (88-100)	1	95	3.091	.00515	.001712	7.7	83.6	<.1	.1	47.93±0.35
sanidine	1	100	3.072	.00491	.001570	7.5	84.9	<.1	.1	48.33±0.36
J_1=0.01042	1	117	3.356	.00418	.002486	11.9	78.1	<.1	<.1	48.59±0.33
	1	105	3.105	.00466	.001753	13.4	83.3	<.1	.1	47.95±0.31
							Weighted Mean $\pm\sigma_{best}$ =			48.19±0.17
							Mean $\pm\sigma$ =			48.20±0.32
8 (Tc l)	1	27	4.138	.01813	.000258	21.9	98.1	<.1	1.9	48.14±0.30
sanidine	2	1.3	4.127	.37706	.000131	7.6	99.7	<.1	77.7	48.80±0.46
J_3=0.006665	1	24	4.031	.02060	.000058	21.1	99.5	<.1	9.5	47.59±0.30
	1	13	4.055	.03724	.000119	32.9	99.1	<.1	8.4	47.67±0.28
	1	24	4.098	.02030	.000137	51.1	98.9	<.1	4.0	48.10±0.28
	1	19	4.079	.02532	.000124	38.2	99.0	<.1	5.5	47.93±0.28
							Weighted Mean $\pm\sigma_{best}$ =			47.95±0.12
							Mean $\pm\sigma$ =			48.04±0.43
9 (91-171)	1	57	4.177	.00863	.000051	76.3	99.5	<.1	4.5	47.15±0.27
sanidine	1	59	4.154	.00824	.000045	81.3	99.6	<.1	4.9	46.92±0.27
J_3=0.006370	2	62	4.181	.00789	.000065	30.1	99.4	<.1	3.3	47.15±0.29
							Weighted Mean $\pm\sigma_{best}$ =			47.07±0.13
							Mean $\pm\sigma$ =			47.07±0.16

Table 2. Analytical data for single-crystal $^{40}Ar/^{39}Ar$ ages of volcanic dikes and air-fall and ash- flow tuff units in and near the Horse Prairie, Medicine Lodge, Muddy Creek, and Sage Creek Basins, southwest Montana, continued.

Sample mineral	No. of crystals	K/Ca	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{40}Ar_{rad}$ (10^{-14}mol)	$^{40}Ar_{rad}$ (%)	$^{39}Ar_{Ca}$ (%)	$^{36}Ar_{Ca}$ (%)	Age (Ma)
9 (91-171)	1	13	4.758	.03820	.002780	24.2	82.7	<.1	0.4	45.97±0.30
biotite	1	9	4.170	.05574	.000530	52.8	96.2	<.1	2.8	45.85±0.27
J_3=0.006415	2	18	4.257	.02737	.000937	9.9	93.4	<.1	0.8	45.45±0.43
	1	9	4.312	.05466	.000767	40.4	94.7	<.1	1.9	46.66±0.28
	1	10	4.171	.05093	.000634	65.4	95.5	<.1	2.2	45.51±0.27
	2	10	4.222	04689	.000934	36.7	93.4	<.1	1.4	45.09±0.28
							Weighted Mean ± σ_{best} =			45.61±0.12
							Mean ± σ =			45.59±0.61
				Samples from the upper parts of the volcanic sequence						
10 (89-135-3)	1	61	6.326	.00805	.001591	7.3	92.4	<.1	.1	45.67±0.39
sanidine	1	61	6.420	.00800	.001563	39.2	92.7	<.1	.1	46.46±0.28
J_2=0.004385	1	56	6.141	.00881	.000537	26.1	97.3	<.1	.4	46.65±0.28
							Weighted Mean ± σ_{best} =			46.37±0.18
							Mean ± σ =			46.26±0.52
10 (89-135-3)	1	0.4	10.488	1.23920	.016900	3.1	53.2	.1	2.0	43.68±0.73
plagioclase	1	0.4	7.465	1.39030	.005748	3.8	78.6	.1	6.5	45.87±0.62
J_2=0.004385	1	0.3	6.369	1.82300	.001567	4.1	94.9	.1	31.3	47.23±0.59
	1	0.3	7.222	1.68600	.005288	2.6	80.1	.1	8.6	45.23±0.85
	1	0.2	6.661	2.37800	.003520	1.9	87.1	.2	18.2	45.38±1.14
	1	0.4	7.480	1.21600	.006400	3.5	75.9	.1	5.1	44.39±0.64
							Weighted Mean ± σ_{best} =			45.44±0.29
							Mean ± σ =			45.30±1.23
11 (88-59)	1	24	2.674	.02007	.000722	3.5	92.0	<.1	.7	45.87±0.50
sanidine	1	34	2.604	.01434	.000515	7.6	94.2	<.1	.7	45.70±0.33
J_1=0.01046	1	23	2.796	.02087	.001026	20.5	89.2	<.1	.5	46.45±0.28
							Weighted Mean ± σ_{best} =			46.09±0.20
							Mean ± σ =			46.01±0.39
12 (81-189)	1	30	2.611	.01650	.000370	15.1	95.8	<.1	1.2	45.99±0.27
sanidine	1	40	2.588	.01221	.000284	10.2	96.7	<.1	1.1	46.03±0.28
J_1=0.01032	1	26	2.544	.01909	.000135	15.1	98.4	<.1	3.7	46.04±0.27
	1	26	2.684	.01914	.000583	3.8	93.6	<.1	.9	46.19±0.37
							Weighted Mean ± σ_{best} =			46.04±0.15
							Mean ± σ =			46.06±0.09
13 (82-322)	1	23	2.516	.02094	.000100	8.8	98.9	<.1	5.6	46.15±0.31
sanidine	1	28	2.504	.01755	.000167	7.7	98.0	<.1	2.8	45.54±0.32
J_1=0.01042	1	24	2.509	.02043	.000091	13.9	98.9	<.1	5.9	46.06±0.28
							Weighted Mean ± σ_{best} =			45.93±0.17
							Mean ± σ =			45.92±0.33

Table 2. Analytical data for single-crystal $^{40}Ar/^{39}Ar$ ages of volcanic dikes and air-fall and ash- flow tuff units in and near the Horse Prairie, Medicine Lodge, Muddy Creek, and Sage Creek Basins, southwest Montana, continued.

Sample mineral	No. of crystals	K/Ca	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{40}Ar_{rad}$ (10^{-14}mol)	$^{40}Ar_{rad}$ (%)	$^{39}Ar_{Ca}$ (%)	$^{36}Ar_{Ca}$ (%)	Age (Ma)
				Tuff at the base of the sedimentary sequence, Medicine Lodge Basin						
14 (82-551)	3	52	6.132	.00950	.000838	20.9	95.8	<.1	.3	45.72±0.28
sanidine 1	1	64	7.665	.00768	.007685	9.0	77.3	<.1	<.1	46.07±0.37
J_2=0.04368	1	90	6.186	.00547	.000995	11.9	95.1	<.1	.1	45.78±0.32
	1	100	7.150	.00488	.004417	6.7	81.6	<.1	<.1	45.41±0.42
	1	44	6.210	.01110	.001086	13.6	94.7	<.1	.3	45.75±0.31
	1	96	6.696	.00508	.002535	5.1	88.7	<.1	.1	46.20±0.49
							Weighted Mean $\pm \sigma_{best}$ =			45.79±0.14
							Mean $\pm \sigma$ =			45.82±0.28
14 (82-551)	1	9	41.261	.05550	.120800	.2	13.5	<.1	<.1	43.23±10.60
sanidine 2	1	16	15.191	.03110	.034620	.4	32.6	<.1	<.1	38.60±4.80
J_2=0.004368	1	6	7.175	.07767	.004348	8.3	82.0	<.1	.5	45.80±0.38
							Weighted Mean $\pm \sigma_{best}$ =			45.75±0.38
							Mean $\pm \sigma$ =			42.54±3.65
15 (89-135-4)	3	18	6.388	.02652	.001933	17.6	90.9	<.1	.4	45.44±0.27
sanidine	1	19	5.945	.02580	.000183	25.7	99.0	<.1	3.8	46.02±0.28
J_2=0.004391	1	29	5.991	.01694	.000468	18.0	97.6	<.1	1.0	45.71±0.29
							Weighted Mean $\pm \sigma_{best}$ =			45.72±0.16
							Mean $\pm \sigma$ =			45.72±0.29
				Welded ash flow tuff, west Medicine Lodge Basin						
16 (87-63)	1	44	2.511	.01122	.000062	6.5	99.3	<.1	4.8	45.56±0.30
sanidine	2	33	2.527	.01482	.000082	34.4	99.0	<.1	4.8	45.75±0.26
J_1=0.01026	1	25	2.521	.01964	.000060	9.6	99.3	<.1	8.6	45.77±0.28
	1	23	2.554	.02157	.000186	12.1	97.9	<.1	3.1	45.69±0.27
							Weighted Mean $\pm \sigma_{best}$ =			45.70±0.14
							Mean $\pm \sigma$ =			45.69±0.09
				Tuff from Sage Creek Basin						
17 (91-170)	1	31	3.981	.01579	.000040	69.7	99.6	<.1	10.6	45.66±0.26
sanidine	2	36	3.971	.01366	.000036	65.4	99.6	<.1	10.2	45.56±0.26
J_3=0.006465	1	30	3.960	.01655	.000069	60.2	99.4	<.1	6.4	45.33±0.26
	1	17	4.020	.02838	.000188	9.3	98.5	<.1	4.1	45.62±0.44
	1	20	3.981	.02392	.000107	64.2	99.1	<.1	6.0	45.44±0.26
	1	27	3.994	.01823	.000084	46.2	99.3	<.1	5.9	45.67±0.27
							Weighted Mean $\pm \sigma_{best}$ =			45.54±0.11
							Mean $\pm \sigma$ =			45.55±0.14

Table 2. Analytical data for single-crystal $^{40}Ar/^{39}Ar$ ages of volcanic dikes and air-fall and ash- flow tuff units in and near the Horse Prairie, Medicine Lodge, Muddy Creek, and Sage Creek Basins, southwest Montana, continued.

Sample mineral	No. of crystals	K/Ca	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{40}Ar_{rad}$ (10^{-14}mol)	$^{40}Ar_{rad}$ (%)	$^{39}Ar_{Ca}$ (%)	$^{36}Ar_{Ca}$ (%)	Age (Ma)
				Tuff at the base of the sedimentary sequence, Medicine Lodge Basin						
18 (91-104)	1	9	4.440	.05682	.001919	11.5	87.2	<.1	0.8	45.54±0.39
sanidine	1	22	4.164	.02219	.000990	15.3	92.9	<.1	0.6	45.49±0.34
J_3=0.006602	1	16	4.220	.03125	.001317	20.1	90.7	<.1	0.6	45.03±0.31
	1	12	4.287	.04187	.001718	18.5	88.1	<.1	0.7	44.44±0.31
	2	30	4.176	.01627	.001198	17.7	91.4	<.1	0.4	44.91±0.32
	2	13	4.087	.03780	.000848	38.7	93.8	<.1	1.2	45.10±0.27
							Weighted Mean $\pm \sigma_{best}$ =			45.04±0.13
							Mean $\pm \sigma$ =			45.08±0.41

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