Cretaceous and Paleocene potassium-argon mineral ages of the northern Pioneer batholith and nearby igneous rocks in southwest Montana

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CRETACEOUS AND PALEOCENE POTASSIUM-ARGON MINERAL AGES OF THE NORTHERN PIONEER BATHOLITH AND NEARBY IGNEOUS ROCKS IN SOUTHWEST MONTANA

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The Pioneer batholith in the Pioneer Mountains, Beaverhead County, southwestern Montana, is a composite batholith. The plutons of the batholith range in composition from quartz diorite, tonalite, and granodiorite to both biotite-hornblende and biotite-muscovite granite. These plutons have been mapped by Zen (unpublished data), Zen and others (1975, 1980), Snee (1978), and Snee and others (1981). Hammarstrom (1982) studied the detailed mineral chemistry of several plutons, and Snee (1982) studied, using the $^{40}Ar/^{39}Ar$ age spectrum method, the age and cooling history of the entire batholith.

During the past several years, E-an Zen collected samples of plutonic rocks from the northern part of the Pioneer batholith, as well as from other nearby intrusive rocks, as part of an effort to determine the petrogenesis of the batholithic rocks and their relation to the regional tectonic evolution. All the plutons are part of the Pioneer batholith except for plutons to the north, exposed on Lime Kiln Gulch, and on Dodgson Creek in the Wise River 7½-minute quadrangle. The latter pluton has been mapped as a satellite of the Boulder batholith (Tilling, 1973). Mineral separates were dated by the K-Ar method; this article presents the apparent ages obtained for these plutonic rocks and also includes three new determinations of Eocene volcanic rocks from the Pioneer Mountains area. The Eocene dates are addenda to the data already published (Marvin and others, 1982) on the Tertiary volcanic rocks. Sample locations are shown on figure 1.

Some of the dated plutons are large and were emplaced at not more than 3–5 km below the land surface (Snee, 1982). The magma, under such circumstances, does not cool rapidly as contrasted with the cooling rate of magma in a lava flow. Therefore, the apparent K-Ar date given by a hornblende or biotite concentrate from a slowly cooled pluton reflects the time at which the mineral passed through its "closure" temperature. Below this temperature, the crystal quantitatively retains the radiogenic argon—diffusion of argon out of the crystal ceases. For hornblende, this temperature is about 500°C (Dodson, 1973; Harrison, 1981; Snee, 1982). For biotite, the temperature is about 280°C (Dodson, 1973; Harrison and McDougall, 1980; Snee, 1982).

The temperature of emplacement for the various plutons probably ranged from 650° to 850°C, depending on the magma composition. Therefore, approximately 150°–350°C cooling occurred before the hornblende closure temperature was attained. This cooling spanned a significant interval of time. Snee (1982) estimated, based on $^{40}Ar/^{39}Ar$ spectral studies, that the plutons in the southern Pioneer Mountains were emplaced about 1–2 million years earlier than indicated by the K-Ar hornblende dates; for biotite dates, the emplacement age of a pluton probably would be more than 2 million years earlier. A similar time lag would be true for the northern Pioneer batholith. The geochronologic story for some plutons is further complicated by later plutons whose thermal aureoles could raise the temperature of a mineral, say biotite, above its closure temperature and cause loss of radiogenic argon and a lower apparent age.

This investigation dated 13 plutons; K-Ar dates for 18 samples indicate that magmatic activity spanned some 16 m.y.—from 80 m.y. for a quartz diorite pluton to 64 m.y. for a granite pluton. (The 95.9 and 98.8 m.y. hornblende dates for sample 20 are spurious, as excess argon is likely in these hornblendes). However, the small number of dates determined during this geologic investigation of the northern Pioneer batholith is insufficient to determine probable cooling rates and uplift or erosion rates, as was done by Snee (1982) with nearly 130 $^{40}Ar/^{39}Ar$ mineral dates and greater areal coverage. In general, our dates are in agreement with Snee's interpretation as to time of emplacement.

Field relations indicate that the porphyritic granodiorite (sample 9) is intruded by a granite pluton (sample 10). The K-Ar biotite dates for samples 9 and 10 are the same, within the analytical uncertainties, and therefore cannot be distinguished in time. Likewise, granite of sample 12 intrudes the granodiorite of sample 3 according to cross-cutting field relationships, but the K-Ar biotite dates are analytically indistinguishable.

Snee (1982) stated that the hornblende separates that he analyzed by the $^{40}Ar/^{39}Ar$ age spectrum method always gave an older date than the coexisting biotite. The dates given by our biotite-hornblende pairs are much more variable. For sample 1, the hornblende date is significantly older than the biotite date. But for the six other biotite-hornblende pairs—exluding sample 20—the dates are indistinguishable within the limits of analytical uncertainty. Thus, the undertainties involved in the potassium and argon analyses for the K-Ar age method have led to those anomalies.

Despite the uncertainties regarding the geologic significance of the K-Ar dates, it is clear that the plutons were emplaced in Late Cretaceous through earliest Paleocene, an interval of some 10–15 million years. The Pioneer batholith is roughly contemporaneous with the Boulder batholith (Tilling and others, 1968), the Tobacco Root batholith (Giletti, 1966), and the Philipsburg batholith (Hyndman and others, 1972). These are all shallow-level composite intrusions.

The ages given by two samples of Eocene rhyodacite, V1 and V2, are included in this article. These samples came from two outcrops of the same volcanic unit near the community of Divide in the northeast corner of the area of the Vipond Park quadrangle; sample locality for V1 is also marked on figure 1 of Marvin and others (1982). Sample V3 is a 6-meter-wide dike of Eocene quartz basalt that has a wide (about 3 m) contact metamorphic aureole, suggesting passage of considerable magma through the dike at the exposed level, and therefore was probably a feeder to Eocene lava flows found elsewhere in the area.

ANALYTICAL PROCEDURES

Mineral concentrates were obtained by conventional separation techniques using heavy liquids, a magnetic

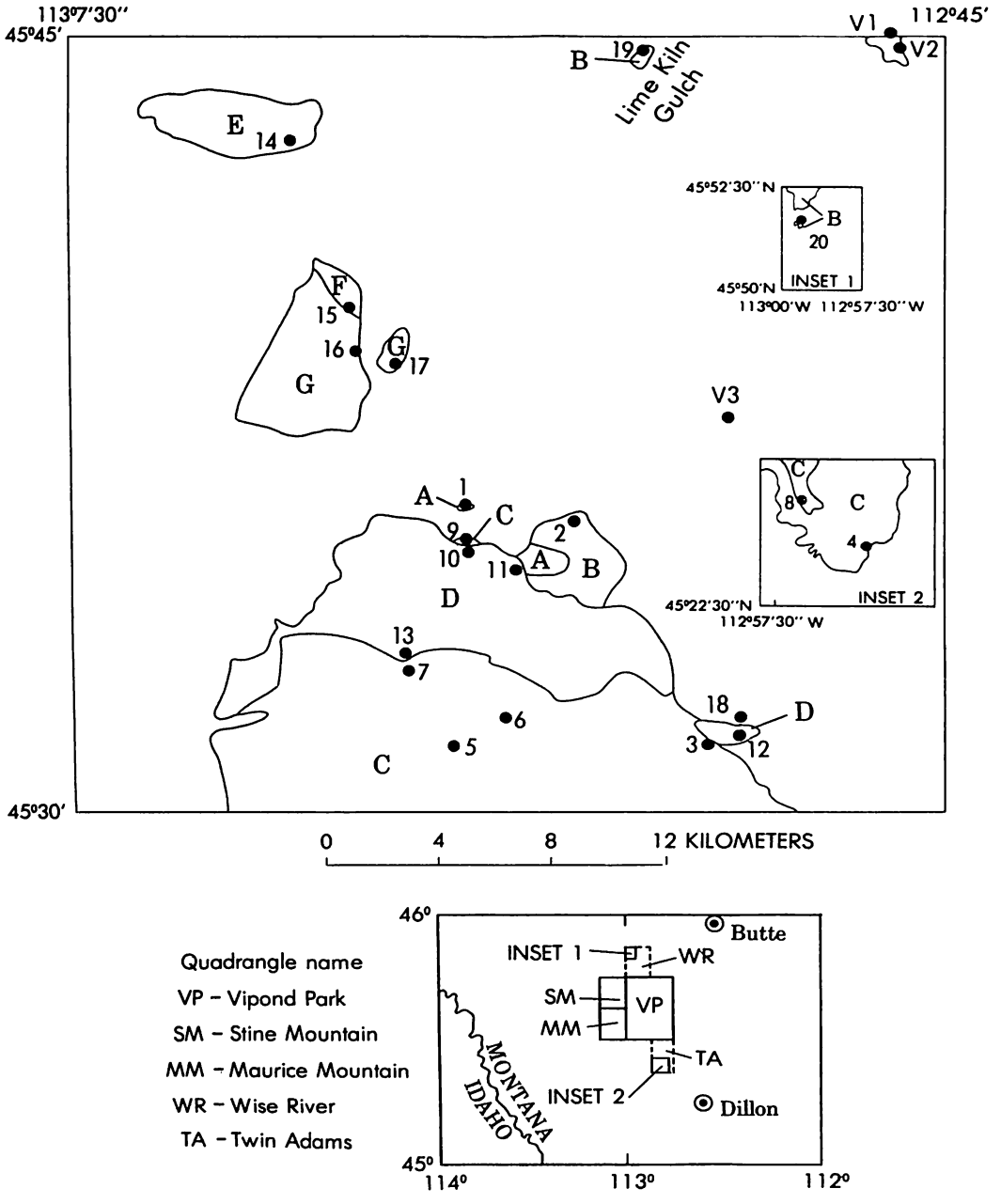

FIGURE 1. Map showing sample localities. Numbers are the samples referred to in the text; relation of the two insets (same map scale) to the main map is shown in the index map, which is the Dillon 1 x 2° quadrangle map. Letter designations of major rock types: A, quartz diorite; B, tonalite; C, granodiorite; D, hornblende-muscovite granite; V, Tertiary volcanic rocks. Geology of the Vipond Park–Stine Mountain–Maurice Mountain area based on unpublished data of Zen. Geology of inset 1 based on Fraser and Waldrop (1972). Geology of inset 2 generalized from Snee (1978).

separator, and a vibration table, with final purification by hand picking. Sample purity was checked by x-ray diffraction and visual inspection and is estimated at 99.5% or better.

The techniques used have been described by Dalrymple and Lanphere (1969); K-Ar dates were calculated using the following decay constants and isotopic abundance: λ_β = 4.962 x 10^{-10}/yr, λ_ϵ = 0.581 x 10^{-10}/yr, and $^{40}K/K$ = 0.01167 atomic percent (Steiger and Jager, 1977). Analytical uncertainty for the K-Ar dates is quoted at 2σ and is obtained from standard deviations (Cox and Dalrymple, 1967).

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SAMPLE DESCRIPTIONS

1. *USGS(D)-M313-1* K-Ar
(Sample DR; Zen and others, 1975)
Quartz diorite (45°35'36"N, 112°57'10"W; prominent ledge at 9540-ft elevation on NW side of Keokirk Mountain; Vipond Park 15' quad., Beaverhead Co., MT). *Comments:* A medium- to fine-grained, dark bluish-gray, biotite-hornblende quartz diorite—52.6% SiO_2 (volatile-free basis). Igneous foliation is very weakly developed. Hornblende laths are as much as 5 mm long; biotite grains have two size modes: 1 mm grains uniformly distributed through the rock and 2–3 mm bronze-colored clusters. Plagioclase is equant, 1–2 mm across; sphene is rare. Published ages have been recalculated in accordance with revised isotopic ratios and decay constants (Steiger and Jager, 1977).
(biotite) 72.6 ± 2.5 m.y.
(hornblende) 79.8 ± 2.2 m.y.
(hornblende) 80.3 ± 2.3 m.y.

2. *USGS(D)-M547-1* K-Ar
Tonalite (45°35'38"N, 112°54'00"W; large loose block at 8200-ft elevation in felsenmeer at base of cliffs south of Trapper Creek; Vipond Park 15' quad., Beaverhead Co., MT). *Analytical data:* (biotite) K_2O = 9.30, 9.33%; $^{*40}Ar$ = 10.18 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 88%; (hornblende) K_2O = 0.91, 0.91%; $^{*40}Ar$ = 0.9618 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 82%. *Comments:* A medium- to coarse-grained, dark-gray, homogeneous-textured, biotite-hornblende tonalite—62.2% SiO_2 (volatile-free basis). Hornblende occurs as 2-mm euhedral grains; biotite is less abundant. Plagioclase grains are 1–3 mm across. Sphene and quartz are sparse. Alignment of mafic minerals causes a faint primary foliation. The felsenmeer is monolithic tonalite and corresponds to the rock of the cliffs. About 700 m SW of the felsenmeer, outcrops on the cliff face show the tonalite in intrusive contact with an earlier quartz diorite body (see sample 1).
(biotite) 74.3 ± 2.7 m.y.
(hornblende) 71.9 ± 4.3 m.y.

3. *USGS(D)-IVP* K-Ar
(Zen and others, 1975)
Granodiorite (easternmost of several blasted outcrops along mine road; NE1/4 S4,T4S,R10W; 45°31'15"N, 112°50'20"W; Vipond Park 15' quad., Beaverhead Co., MT). *Comments:* A medium-grained, uniformly textured, light gray granodiorite—66.3% SiO_2 (volatile-free basis). Conspicuous hornblende and biotite grains are in about equal proportions (1–3 mm); honey-brown euhedral sphene is prominent; plagioclase (3–5 mm) is white. In contrast to samples 5, 6, and 7, all from the same pluton, K-feldspar megacrysts are rare. This rock was tentatively classified as a tonalite by Zen and others (1975) on the basis of a much smaller set of modal data than now exists. Published ages have been recalculated in accordance with revised isotopic ratios and decay constants (Steiger and Jager, 1977).
(biotite) 72.6 ± 2.8 m.y.
(hornblende) 69.5 ± 2.0 m.y.

4. *USGS(D)-FG* K-Ar
Granodiorite (C S15,T5S,R10W; 45°24'02"N, 112°49'57"W; outcrop at 6100-ft elevation on N side of Birch Creek Rd., just W of Farlin Gulch; Twin Adams 7.5' quad., Beaverhead Co., MT). *Analytical data:* (biotite) K_2O = 9.16, 9.17%; $^{*40}Ar$ = 9.491 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 93%; (hornblende) K_2O = 0.50, 0.50%; $^{*40}Ar$ = 0.5186 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 58%. *Comments:* A dark- to light-gray, medium-grained, uniformly textured granodiorite—66.1% SiO_2 (volatile-free basis). Conspicuous hornblende and biotite (1–2 mm), feldspar (3–5 mm), quartz (1–5 mm), as well as euhedral crystals of honey-yellow sphene. A primary foliation, imparted by alignment of mafic minerals, is weakly developed in the rock.
(biotite) 70.5 ± 1.7 m.y.
(hornblende) 70.6 ± 3.2 m.y.

5. *USGS(D)-M121-1* K-Ar
Granodiorite (45°31'14"N, 112°57'27"W; loose block from blasted outcrop at 9100-ft elevation on trail to Tendoy Lake; Vipond Park 15' quad., Beaverhead Co., MT). *Analytical data:* (biotite) K_2O = 8.76, 8.81%; $^{*40}Ar$ = 9.196 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 96%; (hornblende) K_2O = 0.70, 0.71%; $^{*40}Ar$ = 0.7382 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 65%. *Comments:* A medium- to coarse-grained, slightly pinkish-gray, generally uniformly textured granodiorite—66.6% SiO_2 (volatile-free basis). Prominent hornblende and biotite grains (2–5 mm), readily visible honey-brown euhedral sphene, and large K-feldspar megacrysts (10–20 mm) that are anhedral and colorless but contain plagioclase, quartz, and mafic minerals normal for the rock, in slightly smaller than normal (3–5 mm) grain size. Megacrysts have prominent cleavage surfaces. This granodiorite comes from a transition zone between a granite and a granodiorite of the Pioneer batholith where magmatic mixing probably occurred.
(biotite) 71.3 ± 2.4 m.y.
(hornblende) 71.3 ± 4.5 m.y.

6. *USGS(D)-M881-1* K-Ar
Granodiorite (45°31'36"N, 112°56'06"W; loose block at 8700-ft elevation at base of high cliffs, S face of 9330-ft knob; Vipond Park 15' quad., Beaverhead Co., MT). *Analytical data:* K_2O = 8.18, 8.25%;

$^{*40}Ar = 8.687 \times 10^{-10}$ mol/gm; $^{*40}Ar/\Sigma^{40}Ar = 94\%$. *Comments:* A medium- to coarse-grained, slightly pinkish-gray, generally uniformly textured granodiorite—68.0% SiO_2 (volatile-free basis). Prominent hornblende and biotite grains (2–5 mm), readily visible honey-brown euhedral sphene, and large K-feldspar megacrysts (10–20 mm long) that are anhedral and colorless but contain plagioclase, quartz, and mafic minerals normal for the rock, in slightly smaller than normal (3–5 mm) grain size. Megacrysts have prominent cleavage surfaces. A primary foliation due to alignment of mafic minerals is faintly visible. From a transition zone between a granite and a granodiorite of the Pioneer batholith where magmatic mixing probably occurred.

(biotite) 72.0 ± 2.5 m.y.

7. *USGS(D)-M1272-2* K-Ar
Granodiorite (45°32'42"N, 112°58'36"W; large loose block at base of the W face of Tahepia Mountain at 8920-ft elevation; Vipond Park 15' quad., Beaverhead Co., MT). *Analytical data:* (biotite) K_2O = 9.16, 9.10%; $^{*40}Ar = 9.683 \times 10^{-10}$ mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 92%; (hornblende) K_2O = 0.88, 0.87%; $^{*40}Ar = 0.8834 \times 10^{-10}$ mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 79%. *Comments:* A gray, medium-grained, uniform granodiorite—69.3% SiO_2 (volatile-free basis). Conspicuous hornblende and biotite, abundant but small (0.5 mm) sphene, white plagioclase and pale smoky quartz in the 3–5 mm size range, and white K-feldspar megacrysts (10–20 mm) that are visible only by the reflection of light from the cleavage surfaces. Cleavage surfaces contain the other minerals of the rock in slightly smaller than normal size range (1–3 mm). Faint igneous foliation caused by alignment of the mafic minerals. The loose rocks at the base of the west face of Tahepia Mountain and the rocks of the west face of the mountain are, as far as can be determined, petrographically homogeneous.

(biotite) 72.2 ± 2.6 m.y.
(hornblende) 68.8 ± 4.2 m.y.

8. *USGS(D)-BC* K-Ar
(Zen and others, 1975)
Granodiorite (NW1/4 S9,T5S,R10W; 45°25'00"N, 112°51'12"W; roadcut at curve on Willow Creek Road north of Birch Creek Guard Station and BM6420; Twin Adams Mountain 7.5' quad., Beaverhead Co., MT). *Comments:* A fine-grained, light-gray, slightly porphyritic biotite granodiorite—69.6% SiO_2 (volatile-free basis). Plagioclase phenocrysts are as much as 3 mm in size; groundmass is about 1 mm. Biotite is much more abundant than hornblende. The published age has been recalculated in accordance with revised isotopic ratios and decay constants (Steiger and Jager, 1977).

(biotite) 70.4 ± 2.4 m.y.

9. *USGS(D)-BH9850* K-Ar
(Zen and others, 1975)
Granodiorite (45°35'18"N, 112°56'55"W; large loose block at 9850 ft-elevation, immediately E of the northern ridge of Barbour Hill; Vipond Park 15' quad., Beaverhead Co., MT). *Comments:* A medium- to fine-grained, medium-gray, porphyritic granodiorite—65.3% SiO_2 (volatile-free basis). White K-feldspar phenocrysts (1 cm) rest in a groundmass of quartz (1–3 mm), feldspars, biotite, subordinate hornblende, and accessory sphene. A strong primary igneous foliation is caused by alignment of long dimensions of the minerals. Published ages have been recalculated in accordance with revised isotopic ratios and decay constants (Steiger and Jager, 1977).

(biotite) 71.5 ± 2.5 m.y.
(hornblende) 70.0 ± 2.0 m.y.

10. *USGS(D)-BHS* K-Ar
(Zen and others, 1975)
Granite (45°35'14"N, 112°56'55"W; outcrop just E of summit of Barbour Hill; Vipond Park 15' quad., Beaverhead Co., MT). *Comments:* A medium- to coarse-grained, light-gray, uniformly textured granite—73.4% SiO_2 (volatile-free basis). White, subhedral, K-feldspar phenocrysts, as much as 10 cm in size, are present; rare dark specks in the phenocrysts are zonally arranged. Groundmass consists of white plagioclase (2–5 mm); biotite (1–2 mm); quartz; and conspicuous, honey-yellow sphene. A faint primary foliation is caused by alignment of biotite. This granite and sample 11 are from the same large igneous body that intrudes an older porphyritic granodiorite phase exposed on the north slope of Barbour Hill. The published age has been recalculated in accordance with revised isotopic ratios and decay constants (Steiger and Jager, 1977).

(biotite) 72.3 ± 2.5 m.y.

11. *USGS(D)-M1293-1* K-Ar
Granite (45°34'40"N, 112°55'40"W; loose block in large, fresh felsenmeer at 8780-ft elevation at base of high cliffs, NW of Granite Mountain; Vipond Park 15' quad., Beaverhead Co., MT). *Analytical data:* K_2O = 9.01, 8.95%, $^{*40}Ar = 9.777 \times 10^{-10}$ mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 88%. *Comments:* A medium- to coarse-grained, light-pinkish-gray granite—69.0% SiO_2 (volatile-free basis). Biotite is the major mafic mineral, but hornblende is clearly visible in hand specimen, as is fine-grained, euhedral, honey-yellow sphene. White, subhedral to euhedral plagioclase, and anhedral, pale-lilac, smoky quartz constitute the bulk of the rock, in grains 2–3 mm across. The remainder of the rock consists of conspicuous pale-pink, subhedral, K-feldspar phenocrysts 1 cm across; these are nearly inclusion free but the inclusions present are zonally arranged.

(biotite) 74.1 ± 2.7 m.y.

12. *USGS(D)-M744-2* K-Ar
Granite (NE1/4 NE1/4 S3,T4S,R10W; 45°31'32"N, 112°50'09"W; just N of and 100 ft above road at 6800-ft elevation, block from cliff in Rock Creek Gorge; Vipond Park 15' quad., Beaverhead Co., MT). *Analytical data:* K_2O = 8.90, 9.06%; $^{*40}Ar = 9.400 \times 10^{-10}$ mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 91%. *Comments:* A uniform, coarse-grained, pinkish-gray granite—72.2% SiO_2 (volatile-free basis). Large (10 mm across), pink K-feldspar phenocrysts are subhedral to euhedral in shape, containing a few zonally grouped inclusions. The other minerals are subhedral white plagioclase (1–3 mm), light-gray quartz (1–3 mm), biotite (1 mm), subsidiary hornblende, and tiny but conspicuous honey-yellow sphene. This granite cuts the granodiorite represented by sample 3.

(biotite) 71.3 ± 2.4 m.y.

13. *USGS(D)-M1228-1* K-Ar
Granite (45°33'02"N, 112°58'33"W; outcrop at 8980-ft elevation on lower slope of Mount Tahepia, SE of Tahepia Lake; Vipond Park 15' quad., Beaverhead Co., MT). *Analytical data:* K_2O = 8.76, 8.82%; $^{*40}Ar$ = 9.258 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 93%. *Comments:* A medium-grained, light-gray granite—69.2% SiO_2 (volatile-free basis). The mixture of approximately equigranular white plagioclase, salmon-pink K-feldspar, pale-smoky quartz, and dark biotite and hornblende gives the rock a motley appearance. Grain size of the quartz and feldspar is about 2 mm and is 1 mm for the mafic minerals. Igneous foliation is faint to absent.
(biotite) 71.7 ± 2.6 m.y.

14. *USGS(D)-M1162-1* K-Ar
Granite (45°42'57"N, 113°01'31"W; roadcut 300 m N of Bridge 6086 over Wise River; Stine Mountain 7.5' quad., Beaverhead Co., MT). *Analytical data:* K_2O = 9.20, 9.20%; $^{*40}Ar$ = 9.770 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 88%. *Comments:* A light-tannish-gray, medium- to fine-grained (1–2 mm), uniformly textured 2-mica granite—70.9% SiO_2 (volatile-free basis). Biotite is conspicuous but muscovite is visible mainly in thin section as ragged plates; only a few are euhedral intergrowths with biotite, suggesting a magmatic origin. No primary igneous foliation is present. The granite's contact-metamorphic zone is about 100 m wide in the Proterozoic Y sedimentary rocks, just west of Bridge 6086.
(biotite) 72.3 ± 2.6 m.y.

15. *USGS(D)-M516-1* K-Ar
Granite (45°39'52"N, 113°00'00"W; large outcrop N of open valley at 9050-ft elevation, NW of Bob's Lake; Vipond Park 15' quad., Beaverhead Co., MT). *Analytical data:* K_2O = 9.11, 9.15%; $^{*40}Ar$ = 8.946 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 78%. *Comments:* A medium- to coarse-grained, unevenly textured, very pale pinkish-gray, leucocratic granite—71.7% SiO_2 (volatile-free basis). Large (10 mm or less), euhedral, equant quartz phenocrysts are conspicuous and distinctive. The matrix (1 mm or less in size) of the rock consists of felted feldspars, minor biotite, and euhedral, honey-brown sphene. No primary foliation present.
(biotite) 66.8 ± 2.4 m.y.

16. *USGS(D)-M500-1* K-Ar
Granite (45°39'00"N, 112°59'42"W; loose block on cirque floor at 8680-ft elevation, just S of small pond N of Black Lion Mountain; Vipond Park 15' quad., Beaverhead Co., MT). *Analytical data:* K_2O = 9.52, 9.56%; $^{*40}Ar$ = 9.038 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 91%. *Comments:* A mottled-gray, medium- to coarse-grained, homogeneous, 2-mica granite—73.4% SiO_2 (volatile-free basis). The rock contains conspicuous biotite (1–2 mm in size); much rarer, uniformly distributed muscovite; white, euhedral plagioclase (1–3 mm); white, strongly perthitic K-feldspar (≤ 10 mm); and subhedral to euhedral, smoky quartz (3–5 mm). Cirque from which the sample was collected is located within the granite only. Sample 17 is from the same granite pluton.
(biotite) 64.6 ± 2.1 m.y.

17. *USGS(D)-M32-1-4* K-Ar
Granite (45°38'41"N, 112°58'38"W; loose block in felsenmeer at 9460-ft elevation, ENE of the 9578-ft peak; Vipond Park 15' quad., Beaverhead Co., MT). *Analytical data:* K_2O = 8.28, 8.27%; $^{*40}Ar$ = 7.877 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 88%. *Comments:* A light tan-gray, medium-grained, homogeneous, 2-mica granite—75.5% SiO_2 (volatile-free basis). The rock contains biotite, rare muscovite, plagioclase, smoky quartz, and large (1–3 cm) euhedral white K-feldspar phenocrysts scattered throughout. Sample 16 is from the same granite pluton.
(biotite) 64.9 ± 2.2 m.y.

18. *USGS(D)-M741-2* K-Ar
Felsite (SE1/4 SE1/4 S33,T3S,R10W; 45°31'46"N, 112°50'13"W; outcrop at 7900-ft elevation in series of cliffs formed by the Pennsylvanian Quadrant Quartzite; Vipond Park quad., Beaverhead Co., MT). *Analytical data:* K_2O = 5.03, 4.98%; $^{*40}Ar$ = 4.724 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 87%. *Comments:* A light-greenish-gray, fine-grained, resistant felsic dike containing rare 1-mm phenocrysts of white plagioclase (partly saussurite) and 1-mm rusty weathering spots caused by biotite altering to chlorite. White muscovite is sparse.
(whole-rock) 64.4 ± 2.2 m.y.

19. *USGS(D)-M984-2* K-Ar
Tonalite (NW1/4 S20,T1S,R10W; 45°44'34"N, 112°52'18"W; conspicuous outcrop at 6700-ft elevation on W side of gully NW of ridge NW of Lime Kiln gulch; Vipond Park 15' quad., Beaverhead Co., MT). *Analytical data:* K_2O = 8.37, 8.48%; $^{*40}Ar$ = 9.548 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 88%. *Comments:* A very dark, medium-grained (2 mm), uniformly textured, biotite-hornblende tonalite—57.4% SiO_2 (volatile-free basis). Hornblende is more abundant than biotite; sphene is sparse. Igneous foliation is weak to absent.
(biotite) 77.1 ± 2.8 m.y.

20. *USGS(D)-Dodgson Creek* K-Ar, fission-track
Tonalite (SE1/4 S5,T1N,R11W; 45°52'07"N, 112°59'30"W; outcrop at 7100-ft elevation on ridge between Dodgson Creek and a tributary to the east; Wise River 7.5' quad., Silver Bow Co., MT). *Analytical data:* K-Ar: (biotite) K_2O = 9.28, 9.34%; $^{*40}Ar$ = 10.46 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 94%; (hornblende) K_2O = 0.653% by isotope dilution; $^{*40}Ar$ = 0.9258 x 10^{-10}, 0.9547 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 94%, 84%. Fission-track: (5 sphenes) Ps = 1.16 x 10^7 tracks/cm² (2246 tracks counted); Pi = 1.838 x 10^7 tracks/cm² (1787 tracks counted); ϕ = 1.93 x 10^{15} n/cm²; U = 310 ppm; (5 zircons) Ps = 3.11 x 10^6 tracks/cm² (504 tracks counted); Pi = 3.23 x 10^6 tracks/cm² (262 tracks counted); ϕ = 1.08 x 10^{15} n/cm²; U = 100 ppm; decay constant for spontaneous fission of ^{238}U = 7.03 x 10^{-7}/yr. *Comments:* A medium- to fine-grained (1 mm), uniformly textured, dark-bluish-gray tonalite—55.6% SiO_2 (volatile-free basis). Equant and euhedral hornblende and biotite show against a background of plagioclase and quartz; no primary foliation is visible. Sample location is near intrusive contact. The dates given by hornblende separates are spurious; magmatic argon was probably incorporated in the hornblende crystals as they formed. The fission-track date given by the sphene is slightly younger than expected;

the zircon date is much too young. These dates suggest that a younger thermal event occurred in this area, but as yet, no field evidence substantiates such an event.

K-Ar(biotite) 76.4 ± 2.6 m.y.
K-Ar(hornblende) 95.9 ± 2.8 m.y.
K-Ar(hornblende) 98.8 ± 2.8 m.y.
fission-track (sphene) 72.4 ± 4.4 m.y.
fission-track (zircon) 61.8 ± 9.1 m.y.

V1. *USGS(D)-M913-1* K-Ar
Rhyodacite (E1/2 S14,T1S,R10W; 45°45'02"N, 112°46'46"W; Dewey 7.5' quad., Beaverhead Co., MT). *Analytical data:* K_2O = 3.11, 3.12%; $^{*40}Ar$ = 2.176 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 82%. *Comments:* The rhyodacite flow is characterized by phenocrysts of plagioclase and quenched augite in a groundmass of microlites and glass (33%), a few opaque minerals, and a trachytic texture. The flow is part of a series of flows that probably covered a considerable part of the Pioneer Mountains region. The geochronology and some of the petrology of these flows have been described by Zen and others (1979) and Marvin and others (1982).

(whole-rock) 47.8 ± 1.7 m.y.

V2. *USGS(D)-M914-2* K-Ar
Rhyodacite (SE1/4 SE1/4 S18,T1S,R9W; 45°44'48"N, 112°46'09"W; SE flank of small sharp butte of columnar jointed material, about 20 m below the top; Vipond Park 15' quad., Beaverhead Co., MY). *Analytical data:* K_2O = 3.17, 3.17%; $^{*40}Ar$ = 2.202 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 90%. *Comments:* Collection site is located about 0.6 km SE of sample V1; samples V1 and V2 are from the same rhyodacite flow, characterized by phenocrysts of plagioclase and quenched augite in a groundmass of microlites and glass (33%), a few opaque minerals, and a trachytic texture. The flow is part of a series of flows that probably covered a considerable part of the Pioneer Mountains region. The geochronology and some of the petrology of these flows have been described by Zen and others (1979) and Marvin and others (1982).

(whole-rock) 47.6 ± 1.7 m.y.

V3. *USGS(D)-M41-3-1* K-Ar
Basalt (45°37'40"N, 112°50'18"W; Vipond Park 15' quad., Beaverhead Co., MT). *Analytical data:* K_2O = 1.22, 1.21%; $^{*40}Ar$ = 0.8652 x 10^{-10} mol/gm; $^{*40}Ar/\Sigma^{40}Ar$ = 58%. *Comments:* From a plug that is the apparent feeder to one or more Eocene lava flows in the area. The geochronology and some of the petrology of these flows have been described by Zen and others (1979) and Marvin and others (1982).

(whole-rock) 48.8 ± 1.8 m.y.

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