Late Cretaceous-Paleocene-Eocene igneous activity in north-central Montana

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LATE CRETACEOUS-PALEOCENE-EOCENE IGNEOUS ACTIVITY IN NORTH-CENTRAL MONTANA

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ABSTRACT

Many of the present-day geographic features of north-central Montana are directly related to igneous activity that occurred, according to the new radiometric ages presented here, during the late Late Cretaceous, Paleocene, and Eocene. Intrusive igneous activity started about 69–68 m.y. ago in the Judith Mountains and spread in time to the Little Rocky Mountains and Moccasin Mountains, with activity continuing until about 60 m.y. ago. Renewed activity, both intrusive and extrusive, occurred 55–50 m.y. ago during the Eocene throughout much of north-central Montana. Widely dispersed activity continued until 46 m.y. ago, followed by an isolated outbreak at 27 m.y. ago.

Ninety-five K-Ar ages for micas, feldspars, hornblendes, and pseudoleucite; 24 fission-track ages for apatites, sphenes, and zircons; 15 U-Th-Pb ages for sphenes; and one Rb-Sr isochron age suggest the following range of ages for igneous activity: Sweetgrass Hills, 54–50 m.y.; Eagle Buttes, 52–50 m.y.; Highwood Mountains, 53–50 m.y.; Bearpaw Mountains, 54–50 m.y.; Little Rocky Mountains, 67–60 m.y.; Moccasin Mountains, 66–53 m.y.; Judith Mountains, 69–47 m.y.; Missouri Breaks diatremes, 52–47 m.y.; and Smoky Butte, 27 m.y. There is no apparent geographic migration of igneous activity suggesting movement relative to a hot spot or hot spots. Radiometric ages suggest that igneous activity within individual igneous centers lasted about 3–4 m.y.

INTRODUCTION

Radiometric ages determined prior to 1962 for igneous rocks of the north-central Montana region suggested that they were probably all of Eocene age (Jaffe and others, 1959; Faul, 1960; Baadsgaard and others, 1961). This idea was strengthened by geochronologic work in the Little Belt Mountains (Marvin and others, 1973), which showed early to middle Eocene igneous activity (56–41 m.y.). The present study indicates that igenous activity in the north-central Montana region ranged from 69 to 27 m.y. In the present study, most samples were collected during 1970 and 1971 from the various igneous centers, and an attempt was made to obtain samples from the oldest and youngest volcanic units and plutons in each igneous center. However, at several centers the oldest and youngest rocks could not be determined, and units of intermediate age were sampled. Published geologic maps and previously established igneous sequences guided the sampling, but field work during sampling revised some sequences. For most samples, igneous rock names are those used by the geologist who mapped the area.

The calculated ages indicate the approximate time span of igneous activity in each igneous center, but in no way give a complete documentation of age of all igneous units in each igneous center. Igneous centers and sample localities are shown on Figure 1. Results for each center are discussed separately; information concerning analyzed samples—rock type, location, analytical data, etc.—follows the short discussion. Paleomagnetic studies in progress by M. E. Beck, Jr., J. F. Diehl, S. Beske-Diehl, and D. Jacobson show potential for resolving some problems of geochronology and structure and will establish Paleocene and Eocene pole positions (Books, 1962; Diehl and others, 1977, 1978, 1980; Jacobson and others, 1980, 1980a).

K-Ar ages were determined by R. F. Marvin, H. H. Mehnert, and V. M. Merritt. Fission-track ages on most samples were determined by C. W. Naeser; fission-track ages on samples 50–56 were determined by D. A. Lindsey and C. W. Naeser. U-Th-Pb ages were determined by R. E. Zartman and Loretta Kwak. Other analysts are acknowledged within the individual sample descriptions.

Some of the K-Ar analytical work is 15 years old; those ages (samples 22, 23, 26–31, and 35) are slightly less reliable than ages determined more recently by more advanced instrumentation. Use of the decay constants recommended by the IUGS Subcommission on Geochronology in 1976 has caused a slight change in calculated ages as compared with those published by Hearn and others (1977). K-Ar ages presented in this report are calculated using the following constants: $K^{40}\lambda_\epsilon = 0.581 \times 10^{-10}$ yr^{-1}, $\lambda_\beta = 4.962 \times 10^{-10}$ yr^{-1}; atomic abundance: $K^{40} = 0.01167$ atomic percent. Potassium content was usually determined by flame photometry except as noted in the analytical data for individual samples; argon content was determined by mass spectrometry. The Rb-Sr isochron age was calculated using $Rb^{87}\lambda_\beta = 1.42 \times 10^{-11}$yr^{-1}; strontium isotopic data normalized to $Sr^{86}/Sr^{88} = 0.1194$. The decay constant for the spontaneous fission of U^{238} used in fission-track ages is 7.03×10^{-17}yr^{-1}. The amount of neutron radiation (n/cm^2) was determined by counting the induced fission tracks present in a piece of muscovite which covered a standard glass during irradiation. The following abbreviations were used: P_s = fossil-track density (tracks/cm^2), number of tracks counted enclosed by parentheses; P_i = induced track density (tracks/cm^2). The quoted uncertainties represent the estimated analytical error at 2 standard deviations (2σ) for K-Ar and fission-track ages.

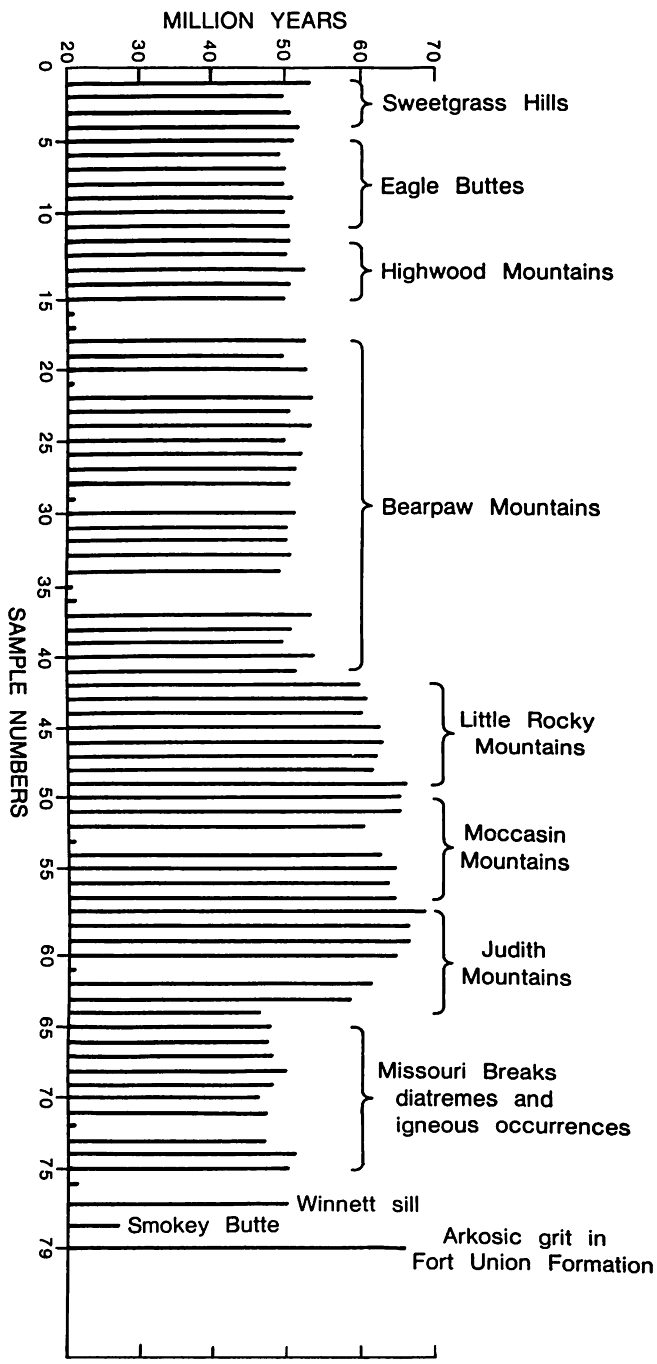

FIGURE 1. Igneous centers and sample localities, alkalic province of north-central Montana.

Most of the samples were collected by B. C. Hearn, Jr.; some were collected by B. C. Hearn, Jr., R. F. Marvin, R. E. Zartman, and D. A. Lindsey. The authors thank R. A. Forrest, Sunshine Mining Co., for providing the roscoelite sample from the Judith Mtns.; R. E. Legg, Niseka Mining Co., for providing drill-core samples from the Little Rocky Mtns.; and Texas Instruments Co. for providing drill-core samples from the Bearpaw Mtns. The contribution of other geologists involved with the work is acknowledged under the description of individual samples. The authors are grateful to P. R. Gucwa, Marathon Oil Co., Littleton, Colorado, for releasing K-Ar analytical data for inclusion in this paper and are indebted to G. T. Cebula and J. W. Groen (Denver), and M. R. Alexander and C. M. Sears (Reston), U.S. Geological Survey, for their excellent mineral-separation work.

SWEETGRASS HILLS

The igneous rocks of the Sweetgrass Hills are intrusive and are mainly concentrated in three prominent topographic features: West, Middle, and East Buttes. Scattered small intrusions are poorly exposed in the surrounding plains, and intrusions also have been encountered in oil and gas exploration holes. The petrology and intrusive sequence in the Sweetgrass Hills have been reported by Kemp and Billingsley (1921) and determined in detail for East Butte by Truscott (1975, 1977). The age range of four samples is 53.6 to 49.8 m.y. The oldest age is from West Butte (sample 1), suggesting that the intrusive sequence of West Butte is older than that of East Butte. Kemp and Billingsley (1921) noted a general change in chemical composition from more mafic rocks in the west to more alkali-rich rocks in the east. The intrusive time span for East Butte is a least 2 m.y.—52.5 to 50.2 m.y. ago. The younger age is an average of two argon determinations for aplite (sample 2). The general age sequence in East Butte, from oldest to youngest, is pyroxene syenite, biotite trachyte porphyry, hornblende vogesite, augite minette I, augite minette II, syenite porphyry, green porphyritic syenite, hybrid rholite, and aplite. Copper-lead mineralization in East Butte is associated with the youngest igneous rocks (Truscott, 1977). Rocks older than augite minette II have not been dated but are probably close to it in age. Baadsgaard and others (1961) gave an age of 49.7 m.y. (recalculated) for biotite from an isolated minette dike at Pinhorn Butte, Canada, 17.5 km north of East Butte.

1. *USGS(D)-H71-17* K-Ar
Hornblende monzonite (hornblende diorite of Kemp and Billingsley, 1921). (Outcrop; SW¼ NW¼ S22, T37N,R1E; 48°57'10"N, 111°35'40"W; West Butte area, West Butte 15' quad. Toole Co., MT). *Analytical data:* K_2O = 0.613, 0.605% (L. B. Schlocker, USGS, Menlo Park–*analyst*); $*Ar^{40}$ = 0.4769 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 87%. *Comments:* Hornblende monzonite cuts pyroxene monzonite elsewhere in West Butte.
(hornblende) 53.6 ± 1.5 m.y.

2. *USGS(D)-H71-14M-1* K-Ar
Aplite. (Outcrop; center of S25,T36N,R4E; 48°51' 00"N, 111°09'15"W; Ribbon Gulch, East Butte area, Haystack Butte 7.5' quad., Liberty Co., MT). *Analytical data:* K_2O = 15.03, 14.98%; $*Ar^{40}$ = 11.10 x 10^{-10}, 10.90 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 81, 82%; *collected by* B. C. Hearn and M. G. Truscott. *Comments:* Aplite dike is youngest igneous phase in Ribbon Gulch area of East Butte.
(K-feldspar) 50.7 ± 1.1 m.y.
49.8 ± 1.1 m.y.

3. *USGS(D)-H71-14A* K-Ar
Augite minette II. (High bench on W side of quarry; NW¼ S32,T36N,R5E; 48°50'20"N, 111°06'57"W; East Butte area, Mt. Lebanon 7.5' quad., Liberty Co., MT). *Analytical data:* K_2O = 8.95, 8.87%; $*Ar^{40}$ = 6.664 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 90%; *collected by* B. C. Hearn and M. G. Truscott. *Comment:* Augite minette II formed near the middle of the intrusive sequence in the quarry area of East Butte.
(biotite) 51.2 ± 1.7 m.y.

4. *USGS(D)-H71-14D* K-Ar
Green porphyritic syenite. (Quarry floor; NW¼ S32, T36N,R5E; 48°50'20"N, 111°06'57"W; East Butte area, Mt. Lebanon 7.5' quad., Liberty Co., MT). *Analytical data:* K_2O = 12.40, 12.36%; $*Ar^{40}$ = 9.488 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 95%; *collected by* B. C. Hearn and M. G. Truscott. *Comments:* Green porphyritic syenite dike is youngest intrusive phase exposed, other than aplite, which is probably younger. K-feldspar grains are slightly sericitized and contain inclusions. The age should be younger than the age obtained for sample 3, but apparently the ages are too close to resolve by K-Ar.
(K-feldspar) 52.5 ± 1.2 m.y.

EAGLE BUTTES

The igneous complex of Eagle Buttes is located midway between the Bearpaw Mountains and the Highwood Mountains. The complex consists of four plug-like or laccolithic intrusions plus numerous dikes, sills, and small plugs. Rock types vary from porphyritic shonkinite and syenite to porphyritic hornblende latite, which are similar to rock types in the Bearpaw Mountains. The complex intrudes Upper Cretaceous marine sedimentary rocks. The geology of the area has been mapped by Lindvall (1962) and Gucwa (1971). The intrusive sequence provisionally determined by Hearn during sampling is, from oldest to youngest, intrusive breccia and diatreme breccia of shonkinite and mafic syenite; massive plugs and laccoliths of shonkinite and mafic syenite; dikes and sills of biotite syenite, of shonkinite and mafic syenite, and of porphyritic latite; breccia and massive plug or laccolith of shonkinite (North Eagle Butte); and mafic syenite dikes.

The igneous activity at Eagle Buttes may have occurred within an interval of 2 m.y. K-Ar ages of biotite concentrates from seven samples range from 51.7 to 49.6 m.y. These ages, however, do not resolve the relative ages of individual intrusions within the igneous complex. A spurious age of 249 m.y. was given by a hornblende concentrate.

5. *USGS(D)-H70-39A* K-Ar
Biotite-olivine-pyroxene shonkinite. (Outcrop; NE¼ SW¼ NE¼ S2,T24N,R13E; 47°51'58"N, 110°01' 45"W; North Eagle Butte, Eagle Buttes 7.5' quad., Chouteau Co., MT). *Analytical data:* K_2O = 8.91, 8.95%; $*Ar^{40}$ = 6.725 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 84%. *Comments:* Shonkinite forms the main igneous core of North Eagle Butte.
(biotite) 51.6 ± 2.0 m.y.

6. *USGS(D)-H70-36B* K-Ar
Biotite syenite. (Outcrop; E½ SE¼ NE¼ S16,T24N, R13E; 47°50'19"N, 110°04'00"W; West Eagle Butte, Eagle Buttes 7.5' quad., Chouteau Co., MT). *Analytical data:* K_2O = 9.33, 9.32%; $*Ar^{40}$ = 6.753 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 89%. *Comments:* Sample is from a 0.3-m-thick syenite dike which cuts the main igneous core of West Eagle Butte and is cut by a younger olivine shonkinite dike.
(biotite) 49.6 ± 1.7 m.y.

7. *USGS(D)-H70-37A* K-Ar
Biotite-hornblende latite. (Outcrop; SE¼ SE¼ SW¼ S12,T24N,R13E; 47°50'42"N, 110°00'50"W; N end of East Egale Butte, Eagle Buttes 7.5' quad., Chouteau Co., MT). *Analytical data:* (biotite) K_2O = 8.67, 8.62%; $*Ar^{40}$ = 6.351 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 88%; (hornblende) K_2O = 1.13, 1.14%; $*Ar^{40}$ = 4.355 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 95%. *Comments:* Sample is from a 0.6-m-thick latite dike cutting the main coarse-grained shonkinite pluton. Biotite age seems to be reliable, but the hornblende age is spurious.
(biotite) 50.3 ± 1.7 m.y.
(hornblende) 249 ± 10 m.y.

8. *X* K-Ar
Shonkinite sill. (Outcrop; SW¼ NE¼ S23,T24N,R13E; 47°49'25"N, 110°02'55"W; Eagle Buttes 7.5' quad., Chouteau Co., MT). *Analytical data:* K_2O = 8.82, 8.91%; $*Ar^{40}$ = 6.416 x 10^{-10}, 6.564 x 10^{-10}, 6.573 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 81, 61, 70%. *Collected by* P. R. Gucwa, while student at Univ. Tex.; *analyst:* F. W. McDowell, Univ. Tex., Austin. *Comments:* Sill is upper of two sills, contains 1 cm olivine and pyroxene and 5 mm biotite, and is cut by younger mafic dikes. Age and analytical data released by Paul R. Gucwa, Marathon Oil Co., Denver Research Center, Littleton, Colo. Age appears in discussion of Bearpaw Mountains gravity slide by Gucwa and Kehle (1978).
(biotite) 50.3 ± 1.2 m.y.

9. *Y* K-Ar
Shonkinite dike. (Outcrop; SW¼ SE¼ NE¼ S28,T24N, R13E; 47°48'30"N, 110°04'10"W; Eagle Buttes 7.5' quad., Chouteau Co., MT). *Analytical data:* K_2O = 9.42, 9.23, 9.20%; $*Ar^{40}$ = 7.059 x 10^{-10}, 6.965 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 83, 87%; *collected by* P. R. Gucwa, while student at Univ. Tex., *analyst:* F. W. McDowell, Univ. Tex., Austin. *Comments:* Contains 2 mm pyroxene, 5 mm biotite; see sample 8.
(biotite) 51.7 ± 1.2 m.y.

10. *Z* K-Ar
Shonkinite dike. (Outcrop; SW¼ SE¼ S12,T24N, R13E; 47°50'43"N, 110°00'30"W; NE side East Eagle Butte, Eagle Buttes 7.5' quad., Chouteau Co., MT). *Analytical data:* K_2O = 9.61, 9.52%; $*Ar^{40}$ = 7.130 x 10^{-10}, 7.054 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 83, 90%; *collected by* P. R. Gucwa, while student at Univ. Tex.; *analyst:* F. W. McDowell, Univ. Tex.; Austin. *Comments:* Contains pyroxene, 2 mm biotite; see sample 8.
(biotite) 50.8 ± 1.2 m.y.

11. *USGS(D)-H68-13J* K-Ar
Biotite-pyroxene shonkinite dike (Outcrop; SE¼ SE¼ S31,T24N,R14E; 47°47'12"N, 109°58'10"W; Pinnacles diatreme area, Dark Butte 7.5' quad., Chouteau Co., MT). *Analytical data:* K_2O = 9.61, 9.56%; $*Ar^{40}$ = 7.177 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 94%. *Comments:* The shonkinitic Pinnacles diatreme is a small circular area (250 mm in diameter) of jumbled Cretaceous rocks and dikes and irregular intrusions of olivine-rich shonkinite that locally contain small inclusions of mantle-derived spinel peridotite. The sampled dike, which lies just outside of the diatreme, cuts dikes of olivine-rich shonkinite similar to olivine-rich shonkinite in the diatreme and thus provides a minimum age of the diatreme.
(biotite) 51.3 ± 1.7 m.y.

HIGHWOOD MOUNTAINS

Only five samples were dated. More samples need to be dated to determine the full chronology of igneous activity. Samples 14 and 15 were collected with the help of M. J. Woods, who has been studying the petrology of the Highwood Mountains (Woods, 1974, 1976, 1977).

The youngest pre-volcanic sedimentary rocks in the Highwood Mountains are probably Wasatch Formation (early Eocene). Field work by Hearn shows that they are preserved in large down-faulted blocks above gravity-slide planes, occurrences which are similar to those in the Bearpaw Mountains. The earliest volcanic activity produced a quartz latite series consisting of flows, breccias, conglomerates, and tuffs. These were eroded and subsequently covered by mafic phonolite flows (Larsen, 1941) that were probably contemporaneous with several types of phonolite dikes. The volcanic rocks and pre-volcanic sedimentary rocks are cut by dikes of amphibole phonolite, pseudoleucite mafic phonolite, augite mafic phonolite, biotite phonolite, and syenite porphyry in order of decreasing age (Buie, 1941), and are also cut by composite stocks composed of shonkinite, monzonite, nepheline syenite, syenite, and biotite pyroxenite (Larson, 1941; Burgess, 1941). The composite Highwood Peak stock is made up, from oldest to youngest, of shonkinite (several varieties), monzonite, gray syenite, white syenite, and syenite pegmatite (Burgess, 1941; Woods, 1974; Hearn, unpublished data, 1972). The syenite phases of the Highwood Peak stock were probably contemporaneous with dikes of syenite porphyry that are the youngest dikes beyond the Highwood Peak stock. The igneous complex of the Highwood Mountains originated in a relatively short period of time during the early to middle Eocene. Volcanic activity had started by 53 m.y. ago (sample 13), and the central syenites of the Highwood Peak stock were emplaced 1 to possibly 5 m.y. later. The composite stock was probably formed within a period of 1 m.y. to possibly 4 m.y., but none of its early intrusions have been dated.

Ore mineralization is sparse in the Highwood Mountains. Woods (1974) reported that abundant calcite in a 1 x 3-km area north of the Highwood Peak stock may be an indication of an underlying carbonatite.

The petrology and geology of the Shonkin Sag intrusion have been described by Barksdale (1937, 1952), Hurlbut and Griggs (1939), and Nash and Wilkinson (1970, 1971). K-Ar ages for biotite and K-feldspar concentrates from sample 12, coarse-grained transition rock (syenite), suggest that the Shonkin Sag intrusion was nearly contemporaneous (about 50 m.y. ago) with the emplacement of the composite Highwood Peak stock and the Square Butte laccolith.

All 39 sites sampled for paleomagnetic studies in the Highwood Mountains are in the younger, phonolitic series of intrusive rocks, and all 39 show normal polarity (Diehl and others, 1980). The prevalence of normal polarities, coupled with the few K/Ar ages, suggests that the phonolitic intrusive activity occurred within a single normal-polarity interval, which would be normal-polarity anomaly 21 (50.31–51.98 m.y.) in the polarity time scale of Mankinen and Dalrymple (1979).

12. *USGS(D)-SS-12A* K-Ar

Syenite pegmatite or transition rock, Shonkin Sag laccolith. (Outcrop; NW¼ NW¼ S26,T21N,R11E; 47°33'10"N, 110°17'20"W; Chouteau Co., MT). *Analytical data:* (biotite) K_2O = 7.30, 7.23, 7.59, 7.60, 7.58, 7.63%; $*Ar^{40}$ = 5.588 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 70%; (K-feldspar) K_2O = 12.44, 12.38%; $*Ar^{40}$ = 8.896 x 0^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 93%. *Comments:* Average age is 50.1 m.y. Mineralogy of the chilled border indicates laccolith was emplaced contemporaneously with the pseudoleucite mafic phonolite dikes. The laccolith is cut by biotite phonolite dikes.

(biotite) 51.1 ± 1.8 m.y.
(K-feldspar) 49.1 ± 1.2 m.y.

12a. *USGS(D)-79MM13* K-Ar

Shonkinite. (Outcrop; S18,T20N,R12E; 47°29'12"N, 110°14'48"W; Square Butte, Powal 7.5' quad., Chouteau Co., MT). *Analytical data:* K_2O = 8.41, 8.44%; $*Ar^{40}$ = 6.203 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 87%; *collected by:* M. E. MacLachlan, U. S. Geological Survey. *Comment:* Sample was collected from the north side of Square Butte, near the Cretaceous contact.

(biotite) 50.4 ± 1.7 m.y.

13. *USGS(D)-H72-H10* K-Ar

Amphibole phonolite dike. (Outcrop; NE¼ S34,T20N, R10E; 47°27'24"N, 110°25'48"W; N side Cottonwood Creek, Chouteau Co., MT). *Analytical data:* K_2O = 2.27, 2.26%; $*Ar^{40}$ = 1.765 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 88%. *Comments:* Sample could indirectly date the quartz latite volcanic series, if the rare amphibole phonolite dikes are petrographically and structurally related to the quartz latite volcanic series as stated by Buie (1941, p. 1758, 1766). However, Woods (1974, p. 17) cited the lack of plagioclase and presence of primary calcite as evidence of affinity with phonolite. Sample from center of a vertical, 3-m-wide dike which intrudes Upper Cretaceous sedimentary rocks.

(hornblende) 53.1 ± 1.8 m.y.

14. *USGS(D)-H72-H1A* K-Ar

Gray syenite. (Outcrop; N½ S6,T19N,R9E; 47°26'36"N, 110°37'48"W; 150-m NNE of summit of Highwood Peak, Chouteau Co., MT). *Analytical data:* K_2O = 7.00, 6.93%; $*Ar^{40}$ = 5.236 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 92%. *Comments:* This coarse-grained gray pyroxene syenite in the Highwood Peak stock is intruded by white syenite (sample 14) according to Larsen (1941) and Burgess (1941).

(sanidine) 51.5 ± 1.8 m.y.

15. *USGS(D)-H72-H1B* K-Ar, Fission-track

White syenite (Outcrop; N½ S6,T19N,R9E; 47°26'36"N, 110°37'48"W; 245-m NNE of summit of Highwood Peak, Chouteau Co., MT). *Analytical data:* (sanidine) K_2O = 6.83, 6.78%; $*Ar^{40}$ = 5.219 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 83%; (sphene, five grains) Ps = 6.04 x 10^6 tracks/cm^2 (1006); Pi = 6.76 x 10^6 tracks/cm^2 (563); ϕ =0.903 x 10^{15} n/cm^2; 220 ppm

U. *Comments:* This coarse-grained white pyroxene syenite and associated pegmatitic syenite are the youngest rocks in Highwood Peak stock (Buie, 1941; Burgess, 1941).

K-Ar (sanidine) 52.5 ± 1.8 m.y.
Fission-track (sphene) 48.1 ± 2.4 m.y.

BEARPAW MOUNTAINS

The Bearpaw Mountains, which contain the largest area and volume of igneous rocks in north-central Montana, consist of a central composite anticlinal uplift—the elongate east-west Bearpaw Mountains arch—and the northern and southern volcanic fields which flank the arch. The central arch contains numerous stocks, laccoliths, bysmaliths, dikes, and sills; intrusions also occur within the volcanic fields, at their distal borders, and beyond in the plains (Pecora and others, 1957a, 1957b; Stewart and others, 1957; Kerr and others, 1957; Bryant and others, 1960; Schmidt and others, 1961, 1964; Hearn and others, 1964, Hearn, 1976). Extensive gravity-sliding (Reeves, 1946; Hearn, 1976) and related collapses have modified the initial structure of the volcanic fields and underlying pre-volcanic rocks.

The main volume of Bearpaw Mountains volcanic rocks consists of mafic phonolite and latite flows and fragmental deposits which are, respectively, similar in composition to the intrusive shonkinite-syenite series and the intrusive porphyritic latite series. Phonolite and latite are interlayered in the southern and northern volcanic fields, whereas most shonkinites and syenites were emplaced earlier than porphyritic latites in the intrusive sequence. The main phonolite and latite volcanics are unconformably overlain in succession by lower volume units of porphyritic analcime trachyte and mafic analcime phonolite which are, respectively, equivalent to the intrusive potassic syenite series and the intrusive mafic analcime phonolite series. In the largest pluton, the Rocky Boy stock, field evidence suggests that biotite pyroxenite was the earliest intrusion, followed by shonkinite (several varieties), monzonite, and potassic syenite (nepheline-aegirite syenite, tinguaite, and porphyritic syenite). Porphyritic syenite in the Big Sandy Creek area was sericitized shortly before or simultaneously with the emplacement of veins and dikes of carbonatite, the youngest igneous unit in the Rocky Boy stock (Pecora, 1962). Biotite pyroxenite may be, in part, a cumulate derivative of shonkinite. The early presence of biotite pyroxenite elsewhere in the Bearpaw Mountains area is indicated by its occurrence as inclusions (sample 22) in basal pyroclastic deposits. Sparse base- and precious-metal mineralization (lead, copper, silver, gold) is associated with the potassic syenite series, and niobium, uranium, and rare-earth elements occur in the carbonatite (Pecora, 1956, 1962; Lindsey and others, 1977). In the eastern Bearpaw Mountains, the general intrusive sequence, from oldest to youngest, is shonkinite and syenite, porphyritic latite, and porphyritic syenite (potassic syenite series). However, porphyritic syenite is locally cut by late porphyritic latite (sample 37) (Hearn and others, 1964). Intrusive mafic analcime phonolites and monzonites are absent in the eastern Bearpaw Mountains.

Twenty-five samples from the Bearpaw Mountains have been dated. However, because the igneous rocks of the Bearpaws occur in a 2500-sq-km area, these samples provide only a partial geographic and petrologic coverage of the total igneous complex (fig. 1).

In general, the radiometric age range of 54–50 m.y. indicates that most of the igneous activity occurred during the early Eocene (55 to 50 m.y.) according to the time scale of Hardenbol and Berggren, 1978; Berggren and others, 1978; and USGS Geologic Names Committee, 1980 edition, Major Geochronologic and Chronostratigraphic Units. If one considers the statistical error of the youngest ages, igenous activity could have extended, possibly, into the middle Eocene. Detailed mapping has shown that the Wasatch Formation (early Eocene), which contains Wasatchian (a provincial land-mammal age) vertebrate fossils, was deposited before the earliest volcanism. The volcanics overlie the Wasatch Formation and older formations on a contact which is partly an erosional unconformity and partly a tectonic fault contact that has resulted from gravity-sliding and related collapse (Hearn, 1976). Volcanism may have started in late Wasatchian time, as flora from one locality near the base of the volcanics is possibly of early Eocene (Wasatchian) age (J. A. Wolfe, written commun., 1965). However, the flora from numerous other localities in the volcanic pile, including several localities close to the base, have been identified as Bridgerian (a provincial land-mammal age) or middle Eocene (J. A. Wolfe, written commun., 1965; H. D. MacGinitie, written commun., 1966; Pecora and others, 1957b).

The radiometric age range of 54 to 50 m.y. for igneous activity raises problems concerning the age of the Paleocene-Eocene boundary and the age of the early Eocene-middle Eocene (Wasatchian-Bridgerian) boundary in recently published radiometric time scales (Berggren and others, 1978; Hardenbol and Berggren, 1978). The 55-m.y. age of the Paleocene-Eocene boundary is within the age range (about 54 ± 2 m.y.) of the oldest igneous rocks of the Bearpaw Mountains. If the 300-m-thick prevolcanic Wasatch Formation actually is early Eocene, the 55-m.y. boundary implies that the Wasatch was deposited in an unreasonably short period of time. However, if the Wasatch Formation is older than 55 m.y., then its vertebrates, identified as Wasatchian, would be of Paleocene age in this area, according to the time scale. The Wasatch Formation, in comparison to the underlying Fort Union Formation, records a marked change in deposition involving a higher energy of transport (conglomerates present) and a change in the character of the source area that is indicated by a major influx of clasts of Belt Supergroup rocks of Precambrian age. Such changes are probably a result of the tectonic emplacement and uplift of the major overthrust sheets of Belt Supergroup rocks in western Montana. An estimated age of slightly greater than 54 m.y. for the Wasatch Formation is close to the youngest reported ages of metamorphism (57.6, 58.3, 58.4 m.y.—recalculated) beneath the overthrust sheets (Hoffman and others, 1976). An attempt was made to obtain a radiometric date on the Wasatch Formation in the Bearpaw Mountains area. However, the analyzed mica separate was from a bentonitic claystone (sample 16) derived by alteration of an originally tuffaceous bed and is a mixture of micas from several sources. The calculated age of 89.1 m.y. on the Wasatch mica is spurious.

Bridgerian time is estimated to have been of relatively short duration, about 2 m.y., between 48 and 50 m.y. ago (McKenna and others, 1973; Berggren and others, 1978; Hardenbol and Berggren, 1978) and is considered to be well bracketed by K-Ar dates from northwestern Wyoming (Berggren and others, 1978). Thus, in the Bearpaw Mountains, the range of radiometric ages (54 to 50 m.y., early Eocene) for volcanic rocks does not agree with the presence of Bridgerian flora (middle Eocene). The disagreement suggests that flora of Bridgerian affinities appeared 4–5 m.y. earlier in north-central Montana than in Wyoming.

Samples 17, 18, and 19, latite blocks in basal pyroclastic deposits, represent early activity in the northern volcanic field. Their ages range from 53.0 to 51.0 m.y. (the 62.8-m.y. age for sample 17 is spurious). In the southern volcanic field, blocks in basal pyroclastic deposits (samples 20, 21, 22) yielded ages of 53.5, 56.0, and 53.9 m.y. The biotite age of 56.0 m.y. (sample 21) is probably too old. The ages show that igneous activity was probably contemporaneous in the northern and southern volcanic fields.

Igneous activity in the Rocky Boy stock (Pecora, 1942, 1962) in the western Bearpaws may have spanned about 3 m.y., 53–50 m.y. ago. Although the ages of some of the 10 samples from this composite stock (samples 23 through 32) do not conform to the geologically established sequence of intrusion, the most recently determined ages for samples 24, 25, and 32, which are from the same intrusion or same locality as previously dated samples 23, 26–27, and 31, respectively, fit the sequence. Four other stock-like plutons have been dated directly or indirectly: Beaver Creek stock, minimum age 49.9 m.y. (sample 34, western Bearpaws), stock near Lloyd, 54.1 m.y. (sample 37, central Bearpaws); Hansen Butte stock, minimum age 51.5 m.y. (sample 41, eastern Bearpaws); bysmalith southeast of Cleveland, 51.5 m.y. (sample 38, eastern Bearpaws). These ages indicate no discernible geographic trend, with time, for stock-like plutons in the Bearpaw Mountains.

Samples of a mafic syenite sill (#39) and two porphyritic latite dikes (#40, #41) in the eastern Bearpaw Mountains gave the following ages, respectively: 50.3 m.y. (biotite), 54.4 m.y. (hornblende), and 51.5 m.y. (sanidine). These ages do not agree with the relative ages as determined by field relations. Mafic syenite (#39) is part of the early shonkinite-syenite group in the eastern Bearpaws; the porphyritic latite dike (#41) represents the youngest igneous phase in the eastern area; and the porphyritic latite dike (#40) is a young intrusion in the porphyritic latite series. The disparity between the radiometric ages and field relations may result from the fact that, in this particular area, igneous activity occurred within the short interval of 1–2 m.y., in which case the intrusive chronology may not be resolved by three K-Ar ages. Moreover, the hornblende age is the oldest of the three ages. Because hornblende ages are noticeably affected by "excess argon", and because several spurious hornblende K-Ar ages have been obtained on samples from elsewhere in north-central Montana, the hornblende age for sample 40 is suspect.

Pseudoleucite from the Beaver Creek tinguaite dike (samples 35 and 36), an intrusive phase late in the Bearpaw Mountains sequence, gave spurious ages of 39 and 31 m.y. The dike was contemporaneous with the tinguaite of sample 30 and probably was slightly older than the carbonatite and syenite of samples 25–29 and the biotite-augite phonolite of sample 33. The sanidine and nepheline which make up these pseudoleucite crystals apparently have lost radiogenic argon.

Structural complexity of the volcanic fields and their borders suggests that gravity-sliding away from the Bearpaw Mountains arch was not a single event. Present evidence indicates that there may have been some movement prior to the earliest volcanism, that major sliding occurred after accumulation of the main volume of latite and phonolite volcanics, and that the youngest volcanic rocks apparently were not affected by sliding. The maximum age of sliding is 51 to 54 m.y., based on the dates of the basal pyroclastic units affected by sliding (samples 17–19 and 20–22), and the minimum age is about 51 m.y., based on the age of a biotite-augite phonolite dike (sample 33) related to the youngest volcanics. Thus, within the limits of K-Ar age resolution, gravity-sliding must have taken place during the igneous activity or shortly thereafter. Distal gravity-slide structures had formed in the Eagle Buttes area by about 51 m.y. (Gucwa, 1971, 1978) and had formed southeast of the Bearpaw Mountains by about 51 to 47 m.y. ago, as indicated by dated diatremes and dikes that cross-cut the distal toe thrusts and tear faults in the Missouri Breaks.

16. *USGS(D)-H71-24* K-Ar

Bentonitic claystone, Wasatch Formation. (Outcrop; SE¼ SW¼ NW¼ S35,T26N,R17E; 47°57′55″N, 109°30′20″W; valley N of Henderson Butte, Blaine Co., MT). *Analytical data:* K_2O = 6.40, 6.46%; $^*Ar^{40}$ = 8.452 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 50%. *Comments:* 0.6-to-1-m-thick claystone layer (altered tuff?) containing biotite flakes; layer is 96-m below top of measured section of Wasatch Formation (early Eocene) and at least 130-m above its base. Mineral concentrate contains brown to red-brown biotite, plus some white mica. Calculated age is too old, probably as a result of a mixture of air-fall mica and detrital or xenocrystic mica in the analyzed concentrate.

(impure biotite) 89.1 ± 3.0 m.y.

17. *USGS(D)-H71-18* K-Ar
Porphyritic biotite latite. (Outcrop; NW¼ NE¼ S33, T32N,R15E; 48°29′45″N, 109°47′15″W; Laredo 15′ quad., Hill Co., MT). *Analytical data:* K_2O = 6.97, 6.97, 6.90, 6.89%; $^*Ar^{40}$ = 6.378 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 92%. *Comments:* Latite block (0.7-m in diameter) in basal pyroclastics, northern Bearpaw Mountains volcanic field. Age is spurious.

(biotite) 62.8 ± 2.1 m.y.

18. *USGS(D)-H71-1A* K-Ar
Biotite latite. (Outcrop; NW¼ NE¼ S33,T23N,R15E; 48°29′45″N, 109°47′15″W; Laredo 15′ quad., Hill Co., MT). *Analytical data:* K_2O = 8.20, 8.10, 8.09%; $^*Ar^{40}$ = 6.289 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 88%. *Comments:* Latite block (0.5-m in diameter) in basal pyroclastics, northern Bearpaw Mountains volcanic field.

(biotite) 53.0 ± 1.8 m.y.

19. *USGS(D)-H71-3* K-Ar
Biotite-hornblende latite. (Outcrop; center NW¼ S34, T32N,R15E; 48°29′35″N, 109°46′20″W; Laredo 15′ quad., Hill Co., MT). *Analytical data:* (biotite) K_2O = 8.54, 8.53%; $^*Ar^{40}$ = 6.360 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 80%; (hornblende) K_2O = 1.253, 1.253% (L. B. Schlocker, USGS, Menlo Park—*analyst*); $^*Ar^{40}$ = 0.9428 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 90%. *Comments:* One-meter latite block in felsic pyroclastics near base of sequence, northern Bearpaw Mountains volcanic field.

(biotite) 51.0 ± 1.7 m.y.
(hornblende) 51.5 ± 1.1 m.y.

20. *USGS(D)-H70-7B* K-Ar
Porphyritic biotite latite. (Outcrop; NW¼ S5,T25N, R18E; 47°47′15″N, 109°26′40″W; West Fork of Black Coulee, Blaine Co., MT). *Analytical data:* K_2O = 8.58, 8.53%; $^*Ar^{40}$ = 6.690 x 10^{-10} mol/gm; $Ar^{40}/\Sigma Ar^{40}$ = 84%. *Comments:* Latite block (0.5-m in diameter) in basal pyroclastics of the southern Bearpaw Mountains volcanic field.

(biotite) 53.5 ± 2.0 m.y.

21. *USGS(D)-H70-7C* K-Ar
Latite. (Outcrop; NW¼ S5,T25N,R18E(?); 47°57′15″N, 109°27′00″W; West Fork of Black Coulee, Blaine Co., MT). *Analytical data:* K_2O = 8.54, 8.57%; $^*Ar^{40}$ = 7.011 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 92%. *Comments:* Latite block (0.3-m in diameter) in basal pyroclastics of the southern Bearpaw Mountains volcanic field. The age seems too old in light of other K-Ar ages and field evidence.

(biotite) 56.0 ± 1.9 m.y.

22. *USGS(W)-294B* K-Ar
Biotite pyroxenite. (Outcrop; NE¼ S11,T26N,R17E; 48°01′30″N, 109°29′20″W; Maddux 15′ quad., Blaine Co., MT). *Analytical data:* K_2O = 8.52%; $^*Ar^{40}$ = 6.705 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 86%; *collected by:* W. T. Pecora, USGS; *analysts:* H. H. Thomas, R. F. Marvin, and P. D. L. Elmore, USGS, Washington, D.C. *Comment:* Biotite pyroxenite inclusion in basal pyroclastics of southern Bearpaw Mountains volcanic field.

(biotite) 53.9 ± 2.7. m.y.

23. *USGS(W)-293B* K-Ar
Biotite pyroxenite, Rocky Boy stock. (Roadcut; S20, T28N,R16E; 48°10′05″N, 109°42′10″W; Warrick 15′ quad., Hill Co., MT). *Analytical data:* K_2O = 9.23%; $^*Ar^{40}$ = 6.880 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 81%; *collected by* W. T. Pecora, USGS; *analysts:* H. H. Thomas, R. F. Marvin, and P. D. L. Elmore, USGS, Washington, D.C. *Comment:* Age appears slightly low; it should be closer to the age given by sample 24.

(biotite) 51.0 ± 2.6 m.y.

24. *USGS(D)-H70-40E* K-Ar
Biotite pyroxenite, Rocky Boy stock. (Roadcut; S20, T28N,R16E; 48°10′05″N, 109°42′10″W; Warrick 15′ quad., Hill Co., MT). *Analytical data:* K_2O = 9.23, 9.16%; $^*Ar^{40}$ = 7.174 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 85%. *Comment:* Same location as sample 23.

(biotite) 53.4 ± 2.0 m.y.

25. *USGS(D)-RZ70-1* K-Ar
Carbonatite, Rocky Boy stock. (Dump from No. 1 dike, vermiculite mine, S of road; SW¼ NE¼ S19, T28N,R16E; 48°10′18″N, 109°42′49″W; Warrick 15′ quad., Hill Co., MT). *Analytical data:* K_2O = 9.61, 9.64%; $^*Ar^{40}$ = 7.030 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 89%. *Comment:* Age determined on a large biotite crystal, about 5-cm in diameter. Carbonatite, No. 1 dike, intrudes sericitized porphyritic syenite plug within Rocky Boy stock.

(biotite) 50.0 ± 1.9 m.y.

26. *USGS(W)-B4-443* K-Ar
Carbonatite. (Drill hole; SW¼ NE¼ S19,T28N,R16E; 48°10′15″N, 109°42′50″W; Warrick 15′ quad., Hill Co., MT). *Analytical data:* (biotite) K_2O = 9.52%; $^*Ar^{40}$ = 7.156 x 10^{-10} mol/gm; $Ar^{40}/\Sigma Ar^{40}$ = 75%; (K-feldspar) K_2O = 14.60%; $^*Ar^{40}$ = 11.51 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 94%; *collected by* W. T. Pecora, USGS; *analysts:* H. H. Thomas, R. F. Marvin, and P. D. L. Elmore, USGS, Washington, D. C. *Comment:* Carbonatite from No. 1 dike which intrudes sericitized porphyritic syenite plug within the Rocky Boy stock.

(biotite) 51.5 ± 2.6 m.y.
(K-feldspar) 53.9 ± 2.7 m.y.

27. *USGS(W)-B11-480* K-Ar
Carbonatite. (Drill hole; SW¼ NE¼ S19,T28N,R16E; 48°10'15"N, 109°42'50"W; Warrick 15' quad., Hill Co., MT). *Analytical data:* (biotite) K_2O = 9.74%; $^*Ar^{40}$ = 7.181 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 72%; (K-feldspar) K_2O = 14.44%; $^*Ar^{40}$ = 11.16 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 91%; *collected by:* W. T. Pecora, USGS; *analysts:* H. H. Thomas, R. F. Marvin, and P. D. L. Elmore, USGS, Washington, D. C. *Comment:* Carbonatite in drill core from No. 1 dike, which intrudes sericitized porphyritic syenite plug within Rocky Boy stock.
(biotite) 50.5 ± 2.5 m.y.
(K-feldspar) 52.9 ± 2.6 m.y.

28. *USGS(W)-296M, 296F (P50-50)* K-Ar
Sericitized porphyritic syenite. (Outcrop; SW¼ NE¼ S19,T28N,R16E; approx. 48°10'15"N, 109°42'15"W; N side of Big Sandy Creek, Warrick 15' quad., Hill Co., MT). *Analytical data:* (sericite) K_2O = 11.47%; $^*Ar^{40}$ = 8.532 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 81%; (K-feldspar) K_2O = 14.02%; $^*Ar^{40}$ = 10.68 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 78%; *collected by* W. T. Pecora, USGS; *analysts:* H. H. Thomas, R. F. Marvin, P. D. L. Elmore, and H. Smith, USGS, Washington, D.C. *Comment:* Altered syenite dike intrudes altered syenite plug within Rocky Boy stock.
(sericite) 50.9 ± 2.5 m.y.
(K-feldspar) 52.2 ± 2.6 m.y.

29. *USGS(W)-B7-515* K-Ar
Sericitized porphyritic syenite. (Drill hole; SW¼ NE¼ S19,T28N,R16E; 48°10'15"N, 109°42'50"W; Warrick 15' quad., Hill Co., MT). *Analytical data:* K_2O = 11.32, 11.31, 11.44%; $^*Ar^{40}$ = 8.031 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 79%; *collected by* W. T. Pecora, USGS; *analysts:* H. H. Thomas, R. F. Marvin, and P. D. L. Elmore, USGS, Washington, D.C. *Comment:* Altered syenite plug in Rocky Boy stock. Age appears too young, as ages given by sample 28 from the same syenite and ages given by carbonatite (samples 25–27) that intrude the syenite are all older.
(sericite) 48.5 ± 2.4 m.y.

30. *USGS(W)-298* K-Ar
Pseudoleucite-sodalite tinguaite, Rocky Boy stock. (Outcrop; SE¼ NE¼ S30,T28N,R15E; 48°09'15"N. 109°42'30"W; head of Black Coulee, Warrick 15' quad., Hill Co., MT). *Analytical data:* K_2O = 13.66, 13.57, 13.42; $^*Ar^{40}$ = 10.26 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 55%; *collected by* W. T. Pecora, USGS; *analysts:* H. H. Thomas, R. F. Marvin, and P. D. L. Elmore, USGS, Washington, D.C. *Comment:* Dike cuts shonkinite in Rocky Boy stock. Samples 35 and 36 from another tinguaite dike of the potassic syenite series, 3 km northeast of the Rocky Boy stock, give ages that are too young.
(pseudoleucite) 51.9 ± 2.6 m.y.

31. *USGS(W)-Q04* K-Ar
Nepheline-aegirite syenite. (Outcrop; SE¼ SW¼ NW¼ S29,T28N,R16E; 48°09'20"N, 109°42'00"W; Elk Peak, Warrick 15' quad., Hill Co., MT). *Analytical data:* (biotite) K_2O = 9.11%; $^*Ar^{40}$ = 6.430 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 80%; (K-feldspar) K_2O = 14.85%; $^*Ar^{40}$ = 11.56 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 93%; *collected by* W. T. Pecora, USGS; *analysts:* H. H. Thomas, R. F. Marvin, P. D. L. Elmore, and H. Smith, USGS, Washington, D.C. *Comment:* Syenite occurs as a lens-shaped mass cutting shonkinite and monzonite in Rocky Boy stock. This syenite is early in the series of potassic syenite intrusions within the Rocky Boy stock. Average age of 50.8 m.y. is in good agreement with the age for sample 32 from the same location.
(biotite) 48.4 ± 2.4 m.y.
(K-feldspar) 53.3 ± 2.7 m.y.

32. *USGS(D)-H70-52A* K-Ar
Nepheline-aegirite syenite. (Outcrop; SE¼ SW¼ NW¼ S29,T28N,R16E; 48°09'20"N, 109°42'00"W; Warrick 15' quad., Hill Co., MT). *Analytical data:* K_2O = 9.19, 9.13%; $^*Ar^{40}$ = 6.799 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 82%. *Comment:* See sample 31 from same locality.
(biotite) 50.8 ± 1.8 m.y.

33. *USGS(D)-H70-22D* K-Ar
Biotite-augite phonolite. (Outcrop; NW¼ S4,T28N, R15E; 48°12'56"N, 109°48'46"W; Centennial Mtn. 15' quad., Chouteau Co., MT). *Analytical data:* K_2O = 9.06, 9.07%; $^*Ar^{40}$ = 6.786 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 85%. *Comment:* Phonolite dike is part of the young mafic analcime phonolite series and is cut by a younger dike in that series.
(biotite) 51.3 ± 2.0 m.y.

34. *USGS(D)-H70-40A* K-Ar
Biotite monzonite, Beaver Creek stock. (Quarry; N½ S10,T28N,R16E; 48°12'15"N, 109°39'05"W; Warrick 15' quad., Hill Co., MT). *Analytical data:* K_2O = 8.94, 8.98%; $^*Ar^{40}$ = 6.527 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 88%. *Comment:* Monzonite dike (Pecora and Fisher, 1946) cuts shonkinite of the Beaver Creek stock and provides a minimum age of that stock.
(biotite) 49.9 ± 1.7 m.y.

35. *USGS(W)-297PL* K-Ar
Pseudoleucite-sodalite tinguaite. (Outcrop; S½ S10, T28N,R16E; 48°10'30"N, 109°39'15"W; Warrick 15' quad., Hill Co., MT). *Analytical data:* K_2O = 14.04, 13.95, 14.02, 13.61%; $^*Ar^{40}$ = 7.981 x 10^{-10}, 8.081 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 71, 74%; *collected*

by W. T. Pecora, USGS; *analysts:* H. H. Thomas, R. F. Marvin, and P. D. L. Elmore, USGS, Washington, D.C. *Comment:* Beaver Creek tinguaite dike. Age is spurious, too young. This tinguaite represents the next-to-youngest group (potassic syenite series) of igneous rocks in the Bearpaw Mountains. Samples 28, 29, and 30 are from the same igneous group.

(pseudoleucite) 39.5 ± 2.0 m.y.
39.9 ± 2.0 m.y.

36. *USGS(D)-H70-40C* K-Ar
Pseudoleucite-sodalite tinguaite. (Outcrop; S½ S10, T28N,R16E; 48°10′30″N, 109°39′15″W; Warrick 15′ quad., Hill Co., MT). *Analytical data:* K_2O = 13.17, 13.12%; $^*Ar^{40}$ = 5.941 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 72%. *Comment:* Age is spurious. Sample is from same dike and same location as sample 35.

(pseudoleucite) 31.1 ± 0.7 m.y.

37. *USGS(D)-H70-5A* K-Ar
Porphyritic feldspar-biotite-hornblende latite. (Quarry; SE¼ NW¼ S11,T29N,R18E; 48°17′10″N, 109°21′35″W; S of Lloyd, Lloyd 15′ quad., Blaine Co., MT). *Analytical data:* (sanidine) K_2O = 10.19, 10.18%; $^*Ar^{40}$ = 8.051 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 88%; (biotite) K_2O = 8.18, 8.18%; $^*Ar^{40}$ = 6.903 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 87%. *Comment:* Stock contains inclusions of crystalline basement rocks of Precambrian age. The difference between ages of coexisting minerals exceeds the analytical error. The biotite age is spurious, and the sanidine age appears slightly too old in the light of other K-Ar ages and field relations.

(sanidine) 54.1 ± 1.2 m.y.
(biotite) 57.7 ± 1.8 m.y.

38. *USGS(D) -P57-1* K-Ar
Porphyritic syenite. (Outcrop; NE¼ NE¼ NW¼ S26, T29N,R20E; 48°14′55″N, 109°05′45″W; Rattlesnake 15′ quad., Blaine Co., MT). *Analytical data:* K_2O = 7.49, 7.49%; $^*Ar^{40}$ = 5.638 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 37%. *Comment:* Porphyritic syenite is from the southern part of a stock or laccolith and is the youngest type of rock in the eastern Bearpaw Mountains except for the latite of sample 41.

(sanidine) 51.5 ± 1.8 m.y.

39. *USGS(D)-P56-120* K-Ar
Mafic syenite. (Outcrop; SE¼ SW¼ NE¼ S32,T29N, R20E; 48°13′50″N, 109°09′20″W; Rattlesnake 15′ quad., Blaine Co., MT). *Analytical data:* K_2O = 6.79, 6.82, 6.84%; $^*Ar^{40}$ = 5.010 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 71%. *Comment:* Mafic syenite sill is representative of the earliest intrusions (shonkinite, mafic syenite, and syenite) in the eastern Bearpaw Mountains.

(biotite) 50.3 ± 1.7 m.y.

40. *USGS(D)-H71-19* K-Ar
Porphyritic hornblende-feldspar latite. (Outcrop; NW¼ SW¼ S10,T28N,R20E; 48°11′48″N, 109°08′30″W; E side of Rieve Creek, Rattlesnake 15′ quad., Blaine Co., MT). *Analytical data:* K_2O = 1.65, 1.65%; $^*Ar^{40}$ = 1.312 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 88%. *Comment:* Five-kilometer-long latite dike cuts other latite dikes that are radial to the nearby Hansen Butte composite stock and cuts other latite laccoliths or stocks. Age appears slightly too old.

(hornblende) 54.4 ± 1.9 m.y.

41. *USGS(D)-H71-18B* K-Ar
Porphyritic hornblende-feldspar latite. (Outcrop; NW¼ NE¼ S16,T28N,R20E; 48°11′20″N, 109°09′15″W; Rattlesnake 15′ quad., Blaine Co., MT). *Analytical data:* (sanidine) K_2O = 5.16, 5.22%; $^*Ar^{40}$ = 3.900 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 79%; (impure plagioclase) K_2O = 2.39, 2.43, 2.37, 2.42%; $^*Ar^{40}$ = 2.030 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 72%. *Comment:* Sample taken from center of a 3-m-wide dike, which is youngest intrusion in Hansen Butte composite stock, 1.6 m south of intersection with an older porphyritic syenite dike. A -80 +150 mesh sanidine concentrate had a specific gravity between 2.60 and 2.625 and thus probably contains barium. The age of sanidine is in agreement with other ages in the Bearpaw Mountains. However, the impure plagioclase concentrate gave an age that is too old, possibly because the concentrate is an inhomogeneous mixture of plagioclase and sanidine, and the mineral split used for argon analysis may have been weighted towards the sanidine fraction.

(sanidine) 51.5 ± 1.8 m.y
(impure plagioclase) 57.8 ± 2.0 m.y.

LITTLE ROCKY MOUNTAINS

The central part of the Little Rocky Mountains contains alkalic plutons that are mostly of Paleocene age. Igneous activity may have started in late Late Cretaceous. Some erosional debris and possibly some eruptive debris from the mountains were deposited into the Fort Union Formation (Paleocene) (see sample 79). Bleached porphyry pebbles, which occur in conglomerate beds within slices of Fort Union Formation in Missouri Breaks diatremes, closely resemble the quartz syenite porphyry of Old Scraggy and the syenite porphyry of Antone in the Little Rocky Mountains.

Geologic maps by Brockunier (1936) and Knechtel (1959) were used to guide our sampling. The sequence of intrusion, as presented by Brockunier (1936) with slight modifications by Bailey (1974) and by us, is, from oldest to youngest, quartz syenite porphyry of Old Scraggy, syenite porphyry of Mission Peak, quartz syenite porphyry of Montana Gulch, syenite porphyries of Antone and Beaver, alaskite porphyry of Silvertip, hornblende syenite porphyries of Indian Peak and Siparyann Butte, and the latest group of three rock types of about the same age—trachyte porphyry, aegirine trachyte porphyry, and syenite porphyry. Mineralization is either contemporaneous with syenite porphyry of Antone or is post-Antone; and locally it is associated with the trachyte porphyries (Corry, 1933; Brockunier, 1936; Bailey, 1974). Mineralogy and chemical compositions show that rocks termed syenite by Brockunier (1936) are actually monzonites. Alnoitic dikes (samples 72–75) of Eocene are locally cut domes that are known to be or are presumed to be intruded by porphyries of the Little Rocky Mountains.

Eight samples were analyzed in an attempt to delineate the span of igneous activity. The last activity occurred about 61 m.y. ago, as indicated by the age given by sample 42, an aegirine trachyte dike. The earliest activity may have been about 67 m.y. ago, the age given by altered porphyry of Antone (sample 49) from the central Antone pluton or plutons. Three samples of hydrothermally altered syenite porphyry of Antone (samples 45, 46, and 47) give an age range of 63.9 to 62.4 m.y. Two young intrussives, the hornblende syenite porphyries of Indian Peak and Siparyann Butte (samples 43 and 44), gave ages of 61.4 and 61.2 m.y., respectively—the average of K-Ar and fission-track ages. The above ages are in agreement with the mapped intrusive sequence. However, the age of 62.5 m.y. determined for quartz syenite porphyry of Old Scraggy (sample 48), the oldest intrusion according to Brockunier (1936), raises some questions. Is the intrusive sequence correct? Is 62.5 m.y. a primary age or is it a reduced age? The thermal regime accompanying the later intrusives or hydrothermal activity could have caused loss of radiogenic argon from the dated sample. From present data, all the intrusions in the Little Rocky Mountains appear to have been emplaced within the period 67 to 60 m.y. ago, but additional geologic mapping and radiometric age determinations are needed to complete our understanding of the intrusive chronology.

Rostad (1978) reported an age range of 58 to 66 m.y. for the Hawkeye breccia pipe, located 4.0 km west of Zortmann in the Little Rocky Mountains, which is a slightly greater age range than we found for the entire igneous sequence. According to Bailey (1974), breccia in the Hawkeye mine consists of fragments of syenite porphyry of Antone in a fine-grained quartz-pyrite matrix. Fragmentation of syenite porphyry of Antone is believed to be a result of nearby intrusion of porphyry of Silvertip.

Paleomagnetic studies show that 24 sites in intrusions in the Little Rocky Mountains are all of normal polarity (Jacobson and others, in press), which could imply that the igneous activity began and ended during a single polarity interval. However, the most reliable K-Ar and fission-track ages are between 63.9 and 61.0 m.y., a 2.9-m.y. age range which, according to the polarity time scale of Mankinen and Dalrymple (1979), contains mainly reversed-polarity intervals and contains only one short, 0.45-m.y.-long normal interval, anomaly 26 (61.51–61.96 m.y.). A period of only 0.45 m.y. seems too short, and thus we conclude that the intrusions probably occurred during two or more normal-polarity intervals and that some ages may have been slightly lowered to the 63.9 to 61.0-m.y. range by hydrothermal alteration.

42. *USGS(D)-H70-45A* K-Ar

Aegirine trachyte. (Outcrop; NW¼ NE¼ S28,T25N, R24E; 47°53′49″N, 108°38′17″W; Landusky Dome, Hays 7.5′ quad., Phillips Co., MT). *Analytical data:* K_2O = 8.12, 8.05%; $*Ar^{40} = 7.219 \times 10^{-10}$ mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 94%. *Comment:* Sample is from a 6-m-wide dike cutting syenite porphyry of Antone and is typical of the youngest dikes in this area. Sample was taken from chilled border zone, 0.5-m from north contact. Dike contains lithic inclusions of probable Precambrian rocks which create contamination possibilities.

(K-feldspar) 61.0 ± 2.1 m.y.

43. *USGS(D)-H70-47* K-Ar, Fission-track

Syenite porphyry of Antone(?). (Hornblende syenite porphyry of Siparyann Butte). (Outcrop; SW¼ NW¼ SE¼ S8,T24N,R24E; 47°51′38″N, 108°40′58″W; Thornhill Butte (Siparyann Butte; Cyprian Butte dome), D-Y Junction 7.5′ quad., Phillips Co., MT). *Analytical data:* K-Ar—(K-feldspar) K_2O = 11.68, 11.83%; $*Ar^{40} = 10.26 \times 10^{-10}$ mol/gm; $*Ar/\Sigma Ar$ = 94%; (hornblende) K_2O = 1.885, 1.888% (isotope dilution determinations, W. T. Henderson, USGS, Denver—*analyst*); $*Ar^{40} = 2.980 \times 10^{-10}$ mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 94%. Fission-track—(apatite) $Ps = 14.8 \times 10^6$ tracks/cm² (370); $Pi = 14.8 \times 10^6$ tracks/cm² (370); $\phi = 1.17 \times 10^{15}$ n/cm²; (zircon) $Ps = 3.13 \times 10^6$ tracks/cm² (217); $Pi = 3.42 \times 10^6$ tracks/cm² (119); $\phi = 1.12 \times 10^{15}$ n/cm²; (sphene) $Ps = 2.40 \times 10^6$ tracks/cm² (700); $Pi = 2.54 \times 10^6$ tracks/cm² (724); $\phi = 2.27 \times 10^{15}$ n/cm². *Comment:* Hornblende syenite porphyry of Siparyann Butte, shown as syenite porphyry of Antone by Brockunier (1936), is one of the few intrusives with fresh mafic minerals. Its similarity to syenite porphyry of Indian Peak suggests that it also could by younger than syenite porphyry of Antone. The K-feldspar, zircon, and sphene ages are in fair agreement and give an average age of 61.4 m.y. The apatite age appears too old, but the large analytical uncertainty allows it to be in analytical agreement with the K-feldspar, zircon, and sphene ages. The hornblende ages is spurious.

K-Ar (K-feldspar) 59.6 ± 1.4 m.y.
(hornblende) 107 ± 2 m.y.
Fission-track (apatite) 69.7 ± 10.2 m.y.
(zircon) 60.8 ± 13.6 m.y.
(sphene) 63.8 ± 3.2 m.y.

44. *USGS(D)-H70-46* K-Ar, Fission-track

Syenite porphyry of Indian Peak. (Outcrop; center S½ NW¼ S21,T25N,R24E; 47°54′33″N, 108°38′47″W;

Indian Peak, Hays 7.5′ quad., Phillips Co., MT). *Analytical data:* K-Ar–(K-feldspar) K_2O = 10.22, 10.28%; $*Ar^{40}$ = 9.280 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 96%; (hornblende) K_2O = 1.648, 1.638% (isotope dilution determinations, W. T. Henderson, USGS, Denver–*analyst*); $*Ar^{40}$ = 2.180 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 95%; Fission-track–(apatite) Ps = 17.3 x 10^6 tracks/cm² (463); Pi = 21.3 x 10^6 tracks/cm² (532); ϕ = 1.17 x 10^{15} n/cm². *Comment:* This porphyry cuts across the flanks of two domes that have cores of syenite porphyry of Antone and thus is thought to be slightly younger than the syenite porphyry of Antone (Brockunier, 1936). The K-feldspar and apatite give an average age of 61.2 m.y.; the hornblende age is spurious.

K-Ar (K-feldspar) 61.8 ± 1.5 m.y.
(hornblende) 89.9 ± 2.0 m.y.
Fission-track (apatite) 60.7 ± 7.7 m.y.

45. *USGS(D)-H70-48* K-Ar
Hydrothermally altered syenite porphyry of Antone. (Drill hole DDH68 at a depth of 140-m, 135° azimith, 50° plunge, Niseka Mining Co. base of mine dump; NE¼ NW¼ SE¼ S15,T25N,R24E; 47°55′17″N, 108° 36′55″W; Zortman 7.5′ quad., Phillips Co., MT). *Analytical data:* K_2O = 12.69, 12.66%; $*Ar^{40}$ = 11.79 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 75%. *Comment:* Apparent age may date the time of hydrothermal activity.

(K-feldspar) 63.5 ± 1.5 m.y.

46. *USGS(D)-H70-49* K-Ar
Hydrothermally altered syenite porphyry of Antone. (Mine adit 90–105 m from portal, Niseka Mining Co. property; SW¼ SW¼ SE¼ S15,T25N,R24E; 47°54′ 55″N, 108°37′07″W; Zortman 7.5′ quad., Phillips Co., MT). *Analytical data:* K_2O = 10.20, 10.25%; $*Ar^{40}$ = 9.58 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 87%. *Comment:* Apparent age may date the time of hydrothermal activity.

(K-feldspar) 63.9 ± 1.5 m.y.

47. *USGS(D)-H70-13* K-Ar
Hydrothermal altered syenite porphyry of Antone(?), fine-grained. (Roadcut; SW¼ NW¼ NE¼ S22,T25N, R24E; 47°54′43″N, 108°37′05″W; 30 m S of adit of Gold Bug Mine, Zortman 7.5′ quad., Phillips Co., MT). *Analytical data:* K_2O = 13.60, 13.57%; $*Ar^{40}$ = 12.42 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 83%. *Comment:* Apparent age may date the time of hydrothermal alteration. Sample location close to edge of plug of trachyte porphyry of Gold Bug, which is younger (Brockunier, 1936).

(K-feldspar) 62.4 ± 1.4 m.y.

48. *USGS(D)-H70-16* K-Ar
Quartz syenite porphyry of Old Scraggy. (Roadcut; NW¼ SW¼ NE¼ S17,T25N,R25E; 47°55′27″N, 108° 31′55″W; Ruby Gulch Road, Zortman 7.5′ quad., Phillips Co., MT). *Analytical data:* K_2O = 11.18, 11.10%; $*Ar^{40}$ = 10.20 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 94%. *Comment:* Coarse K-feldspar phenocrysts weathered out of quartz syenite porphyry of Old Scraggy, supposedly the oldest intrusive (Brockunier, 1936). Quartz syenite porphyry of Old Scraggy is cut by alaskite porphyry of Silvertip 0.25 km to the northwest (Brockunier, 1936) and is cut by a syenite porphyry dike 0.1 km to the east (Knechtel, 1959).

(K-feldspar) 62.5 ± 1.8 m.y.

49. *USGS(D)-H70-18* K-Ar
Syenite porphyry of Antone. (Roadcut; SW¼ SW¼ S8, T25N,R25E; 47°55′44″N, 108°32′25″W; Ruby Gulch Road, Zortman 7.5′ quad., Phillips Co., MT). *Analytical data:* K_2O = 10.74, 10.71%; $*Ar^{40}$ = 10.57 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 91%. *Comment:* Sample location is within 0.25 km of younger alaskite porphyry of Silvertip to the north and east according to the map by Brockunier (1936). Age may be slightly too old.

(K-feldspar) 67.2 ± 1.5 m.y.

MOCCASIN MOUNTAINS

The Moccasin Mountains contain two large intrusive centers, North Moccasin and South Moccasin. Each is an eroded laccolith having apophyses of sills and dikes (Blixt, 1933; Miller, 1959; Lindsey, 1980). Syenite porphyry of identical appearance is the most abundant type of rock in each center. Radiometric dating indicates that the rocks are of Paleocene age.

Four samples from the North Moccasin Mountains indicate that the main laccolith of syenite porphyry was emplaced about 66 m.y. ago—an age determined from an average of seven K-Ar and fission-track ages (samples 50 and 51). A large sill-like apophysis of syenite porphyry, south of the main laccolith, has a fission-track age of 60.5 m.y. (sample 52); this age may be somewhat young because the sill continues into the main laccolith without a mappable contact between the two. The apparent age of hydrothermal alteration and mineralization of a small apophysis of porphyry at the Kendall Mine is 53.5 m.y. (sample 53).

The South Moccasin Mountains contain an intrusive complex of syenite porphyry (oldest unit), alkali syenite porphyry, and quartz monzonite porphyry (youngest unit)—called leucorhyolite by Miller (1959). Samples (54–57) from this intrusive complex indicate that the syenite of Tower Peak (the core of the intrusive complex), the syenite of the South Peak sill, the alkali syenite porphyry, and the quartz monzonite porphyry are 63.7, 64.8, 64.4, and 64.2 m.y. old, respectively. These ages suggest that the entire intrusive complex formed within about 2 m.y. The fission-track zircon age of 75.4 m.y. for the quartz monzonite porphyry is probably too old. New mapping conclusively shows that the quartz monzonite porphyry intruded the syenite porphyry (Lindsey, 1980).

Thus, most igneous activity in the Moccasin Mountains probably occurred within a short interval between 66 and 64 m.y. (Paleocene), but hydrothermal activity and mineralization may have continued as late as 53.5 m.y. ago (Eocene).

50. *USGS(D)-K48* K-Ar, Fission-track
Syenite porphyry, main laccolith, North Moccasin Mountains. (Outcrop; SW¼ SW¼ S30,T18N,R18E; 47°17'18"N, 109°29'14"W; Fergus Co., MT). *Analytical data:* K-Ar–(sanidine) K_2O = 8.38, 8.41%; $^*Ar^{40}$ = 7.890 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 70%. Fission-track–(seven zircons) Ps = 7.45 x 10^6 tracks/cm² (1073); Pi = 7.43 x 10^6 tracks/cm² (535); ϕ = 1.04 x 10^{15} n/cm²; (10 sphenes) Ps = 0.83 x 10^6 tracks/cm² (297); Pi = 3.08 x 10^6 tracks/cm² (555); ϕ = 4.23 x 10^{15} n/cm². *Comment:* Age of emplacement is 66 m.y. (avg. of seven ages); see sample 51.

K-Ar (sanidine) 64.1 ± 1.5 m.y.
Fission-track (zircon) 62.1 ± 6.6 m.y.
(sphene) 67.4 ± 9.6 m.y.

51. *USGS(D)-K51* K-Ar, Fission-track
Syenite porphyry, main laccolith, North Moccasin Mountains. (Outcrop; NE¼ SW¼ S30,T18N,R18E; 47°17'37"N, 109°28'52"W; Fergus Co., MT). *Analytical data:* K-Ar–(sanidine) K_2O = 9.14, 9.17%; Ar^{40} = 8.838 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 90%. Fission-track–(50 apatite grains counted by population method) Ps = 0.60 x 10^6 tracks/cm² (1072); Pi = 0.51 x 10^6 tracks/cm² (923); ϕ = 0.93 x 10^{15} n/cm²; (five zircons) Ps = 7.00 x 10^6 tracks/cm² (1008); Pi = 6.68 x 10^6 tracks/cm² (481); ϕ = 1.05 x 10^{15} n/cm²; (10 sphenes) Ps = 1.06 x 10^6 tracks/cm² (382); Pi = 3.81 x 10^6 tracks/cm² (686); ϕ = 4.28 x 10^{15} n/cm². *Comment:* Age of emplacement is 66 m.y. (avg. of seven ages); see sample 50.

K-Ar (sanidine) 65.8 ± 1.6 m.y.
Fission-track (apatite) 64.3 ± 6.4 m.y.
(zircon) 65.5 ± 7.2 m.y.
(sphene) 70.9 ± 9.0 m.y.

52. *USGS(D)-K16* Fission-track
Syenite porphyry sill-like apophysis of main laccolith, North Moccasin Mountains. (Outcrop; SW¼ SW¼ S31, T18N,R18E; 47°16'35"N, 109°29'05"W; Fergus Co., MT). *Analytical data:* (six zircons) Ps = 7.22 x 10^6 tracks/cm² (1126); Pi = 7.32 x 10^6 tracks/cm² (571); ϕ = 1.03 x 10^{15} n/cm². *Comment:* Syenite porphyry is a large apophysis connected to the main syenite porphyry laccolith. Fission-track age may be slightly young.

(zircon) 60.5 ± 6.2 m.y.

53. *USGS(D)-K2* Fission-track
Hydrothermally altered syenite porphyry, small apophysis of main laccolith at Kendall Mine, North Moccasin Mountains. (Outcrop; SW¼ NE¼ S31,T18N, R18E; 47°16'49"N, 109°28'37"W; Fergus Co., MT). *Analytical data:* (six zircons) Ps = 3.70 x 10^6 tracks/cm² (732); Pi = 4.24 x 10^6 tracks/cm² (420); ϕ = 1.03 x 10^{15} n/cm². *Comment:* Age probably dates the latest time of hydrothermal alteration and mineralization.

(zircon) 53.5 ± 6.6 m.y.

54. *USGS(D)-M111* Fission-track
Syenite porphyry of Tower Peak, South Moccasin Mountains. (Outcrop; NW¼ SE¼ S2,T16N,R17E; 47°10'43"N, 109°32'05"W; Spring Creek Junction 7.5' quad., Fergus Co., MT). *Analytical data:* (50 apatite grains counted by population method) Ps = 0.44 x 10^6 tracks/cm² (789); Pi = 0.37 x 10^6 tracks/cm² (667); ϕ = 0.92 x 10^{15} n/cm²; (six zircons) Ps = 3.62 x 10^6 tracks/cm² (1012); Pi = 4.04 x 10^6 tracks/cm² (565); ϕ = 1.04 x 10^{15} n/cm²; (11 sphenes) Ps = 1.09 x 10^6 tracks/cm² (433); Pi = 4.98 x 10^6 tracks/cm² (986); ϕ = 4.79 x 10^{15} n/cm². *Comment:* This syenite porphyry is at the core of the South Moccasin Mountains intrusive complex. The average of fission-track ages for apatite and sphene gives an apparent emplacement age of 63.7 m.y. Zircon age appears too young.

(apatite) 64.8 ± 6.5 m.y.
(zircon) 55.6 ± 5.8 m.y.
(sphene) 62.6 ± 7.2 m.y.

55. *USGS(D)-S346* K-Ar, Fission-track
Syenites porphyry of South Peak sill, South Moccasin Mountains. (Outcrop; SE¼ SE¼ S10,T16N,R17E; 47° 09'35"N, 109°32'42"W; Spring Creek Junction 7.5' quad., Fergus Co., MT). *Analytical data:* K-Ar (sanidine) K_2O = 11.85, 11.96%; $^*Ar^{40}$ = 11.53 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 85%. Fission-track (10 sphenes) Ps = 1.53 x 10^6 tracks/cm² (551); Pi = 6.91 x 10^6 tracks/cm² (1244); ϕ = 4.83 x 10^{15} n/cm². *Comment:* Age of emplacement is 64.8 m.y. (avg. of two ages).

K-Ar (sanidine) 66.0 ± 1.5 m.y.
Fission-track (sphene) 63.7 ± 6.6 m.y.

56. *USGS(D)-S463* K-Ar, Fission-track
Quartz monzonite porphyry, South Moccasin Mountains. (Outcrop; SE¼ SE¼ S10,T16N,R17E; 47°09' 56"N, 109°30'19"W; Spring Creek Junction 7.5' quad., Fergus Co., MT). *Analytical data:* K-Ar (sanidine) K_2O = 10.41, 10.39%; $^*Ar^{40}$ = 9.787 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 94%. Fission-track (five zircons) Ps = 6.91 x 10^6 tracks/cm² (995); Pi = 6.06 x

10^6 tracks/cm^2 (436); $\phi = 1.11 \times 10^{15}$ n/cm^2. *Comment:* The quartz monzonite porphyry is younger than the syenite porphyry of South Peak sill as shown by intrusive relationships. The K-Ar ages for samples 55 and 56 agree with the field relations. Apparent age of emplacement is 64.2 m.y.; the zircon age appears spurious.

K-Ar (sanidine) 64.2 ± 1.5 m.y.
Fission-track (zircon) 75.4 ± 8.6 m.y.

57. *USGS(D)-S567* K-Ar
Alkali syenite porphyry, South Moccasin Mountains. (Outcrop summit of North Peak (hill 5775); NW¼ SE¼ S34,T17N,R17E; 47°11′27″N, 109°32′17″W; Spring Creek Junction 7.5′ quad., Fergus Co., MT). *Analytical data:* K_2O = 10.32, 10.34%; $^*Ar^{40}$ = 9.749×10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 79%.

(sanidine) 64.4 ± 1.5 m.y.

JUDITH MOUNTAINS

The geology of the Judith Mountains has been mapped by Weed and Pirsson (1898) and by Goddard and Wallace (in Wallace, 1953, 1956). The Giltedge area has been mapped by Forrest (1971), and the Judith Peak–Red Mountain area by Hall (1976). Kinnard (1979) is studying the tinguaites of the Judith Mountains. Radiometric dates indicate that intrusive activity in the Judith Mountains ranges from very Late Cretaceous to Eocene.

The sequence of intrusions as deduced from field relations is generally similar among the several studies, but in detail various conflicts remain. Weed and Pirsson (1898) recognized two groups of intrusions within a single epoch of igneous activity: earlier intrusions of porphyry and related rocks (granite porphyry, syenite, syenite porphyry, diorite porphyry) were followed by sills and dikes of phonolitic rocks (tinguaite porphyry, non-porphyritic tinguaite, aegirite syenite porphyry).

According to Wallace (1953, 1956), the intrusive sequence, from oldest to youngest, is quartz monzonite group (includes quartz monzonite, monzonite, quartz diorite, diorite), intrusive rhyolite, intrusive rhyolite breccia, syenite, alkali syenite, tinguaite group (includes both older gray tinguaite and younger green tinguaite), and alkali granite group. The last group contains the fine-grained, coarse-grained, and breccia facies—in order of decreasing age—occurring in the Judith Peak intrusion and nearby alkali rhyolite dikes and sills. In the Giltedge area, Forrest (1971) recognized the sequence quartz monzonite, rhyolite, and rhyolite breccia, but noted that quartz monzonite locally can have rhyolite, syenite, or diorite as border phases.

Hall (1976) studied a 700-m core from a drill hole between Judith Peak and Red Mountain and concluded that intense potassium metasomatism and late calcite-quartz-fluorite veins indicate that a carbonatite is present at a level below 700 m. His geologic map shows an intrusive sequence similar to that deduced by Wallace (1953, 1956), but adds two petrologic-time units: trachyte (plugs and dikes) followed by late rhyolite (dikes), both of which are later than alkali syenite and earlier than tinguaite. The late rhyolite dikes are mapped separately from the still younger dikes of alkali granite of Judith Peak. The core shows alkali syenite cut by trachyte dikes and fine-grained alkali granite dikes; monzonite in the lowermost 100 m of the core is of uncertain relative age. Late calcite-quartz-fluorite veins cut monzonite, alkali syenite, and trachyte. These late veins are found only in the bottom 400 m of the core, and thus their age relative to alkali granite dikes that occur only at 200–250 m of depth is unknown.

Although eight samples do not constitute complete coverage for all rock types and intrusions in the Judith Mountains, the radiometric ages for these samples agree, in part, with the igneous sequence of Wallace (1953, 1956). Some rock types may be coeval, and some rock types may have been intruded more than once during the total span of igneous activity. Radiometric ages indicate that intrusive activity occurred at various times from late Late Cretaceous to Eocene, a span of about 22 m.y., a much longer time than for any of the other igneous centers covered by this study. As a result of this longer period of activity, the Judith Mountains are geochronologically more complex than the other areas and our understanding of the intrusive sequence is limited.

The earliest intrusive, 69–68 m.y., according to the radiometric ages, appears to be the quartz monzonite (sample 58) at Black Butte, followed by the monzonite (sample 59), diorite (sample 59a), alkali syenite (sample 60), and other intrusives, possibly including the sills and dikes of tinguaite (sample 61). During the Paleocene, the alkali granite of Judith Peak (sample 62) formed and was accompanied or closely followed by mineralization (sample 63). Eocene intrusive activity was sporadic and minor; a rhyolite sill (sample 64) is representative of the Eocene intrusions.

Unfortunately, the radiometric ages are quite discordant for some of the Judith Mountains samples and are thus subject to various interpretations. The most reasonable interpretation is presented under "comments" for each sample.

Recent paleomagnetic data for the dated late Late Cretaceous intrusions indicate that their paleomagnetic pole positions are close to established latest Cretaceous-Paleocene pole positions (Jacobson and others, 1980).

58. *USGS(D)-H71-7* K-Ar, Fission-track, U-Th-Pb
Quartz monzonite. (Outcrop; SE¼ NE¼ S13,T17N, R21E; 47°14′10″N, 108°58′30″W; W side of Black Butte at about 1570-m elev., Judith Peak 15′ quad., Fergus Co., MT). *Analytical data:* K-Ar–(K-feldspar) K_2O = 7.34, 7.48%; $^*Ar^{40}$ = 0.6925×10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 90%; (oligoclase) K_2O = 0.632, 0.628%; $^*Ar^{40}$ = 0.6067×10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 70%; (hornblende) K_2O = 1.35, 1.34%;

$^*Ar^{40}$ = 1.522 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 87%.

(K-feldspar) 63.8 ± 2.2 m.y.
(oligoclase) 65.7 ± 1.8 m.y.
(hornblende) 76.9 ± 2.9 m.y.

Fission-track—(zircon) Ps = 7.45 x 10^6 tracks/cm^2 (1379), Pi = 7.26 x 10^6 tracks/cm^2 (672), ϕ = 1.06 x 10^{15} n/cm^2; 210 ppm U; (sphene) Ps = 2.42 x 10^6 tracks/cm^2 (1044), Pi = 3.45 x 10^6 tracks/cm^2 (742), ϕ = 1.73 x 10^{15} n/cm^2, 60 ppm U.

(zircon) 68.4 ± 3.3 m.y.
(sphene) 76.6 ± 3.3 m.y.

U-Th-Pb—(sphene) U = 40.08 ppm, Th = 12.69 ppm, Pb = 5.053 ppm; isotopic composition of lead (atom percent) is 204:206:207:208 = 1.2695:29.60:20.01: 49.12; initial lead composition Pb^{206}/Pb^{204} = 17.53; Pb^{207}/Pb^{204} = 15.49; Pb^{208}/Pb^{204} = 38.00 as determined on coexisting K-feldspar.

(sphene) Pb^{206}/U^{238} = 68.7 ± 1.3 m.y.
Pb^{207}/U^{235} = 68.0 ± 8.2 m.y.
Pb^{208}/Th^{232} = 79.2 ± 11.3 m.y.

Comment: The primary age for the quartz monzonite is 69–68 m.y. (See the Pb/U ages plus zircon fission-track age.) The K-feldspar and oligoclase K-Ar ages are slightly young; the hornblende age (76.9 m.y.) and sphene age (76.6 m.y.) are anomalously old. The hornblende probably has excess radiogenic argon; the reason for the old sphene age is not known, but similarily old ages were obtained for sphene in samples 59 and 60.

59. *USGS(D)-H71-10* K-Ar, Fission-track, U-Th-Pb
Porphyritic monzonite. (Roadcut; NW¼ NW¼ NE¼ S31,T17N,R20E; 47°11′52″N, 109°13′05″W; SW slope of Big Grassy Peak, Judith Peak 15′ quad., Fergus Co., MT). *Analytical data:* K-Ar—(K-feldspar) K_2O = 10.75, 10.75%; $^*Ar^{40}$ = 9.809 x 10^{-10} mol/gm; $^*Ar^{40}$ /ΣAr^{40} = 87%; (hornblende) K_2O = 0.453, 0.455% (L. B. Schlocker, USGS, Menlo Park—*analyst*); $^*Ar^{40}$ = 0.8767 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 89%.

(K-feldspar) 62.3 ± 1.4 m.y.
(hornblende) 129 ± 4 m.y.

Fission-track—(zircon) Ps = 12.2 x 10^6 tracks/cm^2 (845), Pi = 12.6 x 10^6 tracks/cm^2 (439), ϕ = 1.11 x 10^{15} n/cm^2, 370 ppm U; (sphene) Ps = 2.54 x 10^6 tracks/cm^2 (847), Pi = 3.32 x 10^6 tracks/cm^2 (553), ϕ = 1.80 x 10^{15} n/cm^2, 60 ppm U.

(zircon) 63.6 ± 7.3 m.y.
(sphene) 82.0 ± 4.0 m.y.

U-Th-Pb—(sphene) U = 54.50 ppm, Th = 91.74 ppm, Pb = 3.647 ppm; isotopic composition of lead (atom percent) is 204:206:207:208 = 1.0564:32.72:17.11: 49.12: initial lead isotopic composition Pb^{206}/Pb^{204} = 18.28, Pb^{207}/Pb^{204} = 15.59, Pb^{208}/Pb^{204} = 38.64 as determined on coexisting K-feldspar.

(sphene) Pb^{206}/U^{238} = 66.6 ± 1.2 m.y.
Pb^{207}/U^{235} = 67.3 ± 4.2 m.y.
Pb^{208}/Th^{232} = 74.6 ± 1.8 m.y.

Comment: The porphyritic monzonite has K-feldspar phenocrysts as much as 5 cm long, inclusions of alkali syenite from the adjacent intrusion (sample 60), and inclusions of Precambrian rocks and sulfide clots. The concordant Pb^{206}/U^{238} and Pb^{207}/U^{235} ages indicate a primary age of 67 m.y. The discordancy between the Pb/U ages and the Pb^{208}/Th^{232} age (74.6 m.y.) is not understood. The K-Ar age of 129 m.y. (see hornblende age) and the fission-track age of 82 m.y. (see sphene age) are anomalously old. As mapped by Wallace (1953), this porphyritic monzonite is continuous with the Maiden Peak intrusion; the U-Pb ages given by the sphene from these two intrusions surely indicate a coeval relationship.

59a. *USGS(D)-79-14A* K-Ar, U-Th-Pb
Hornblende diorite (or monzonite). (Outcrop; NW¼ NW¼ SW¼ S31,T17N,R20E; 47°11′23″N, 109°13′ 44″W; base of cliff at 1700-m elev., SE side Maiden Peak, Judith Peak 15′ quad., Fergus Co., MT). *Analytical data:* K-Ar—(orthoclase) K_2O = 6.30, 6.26%; $^*Ar^{40}$ = 5.551 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 81%.

(orthoclase) 60.4 ± 2.1 m.y.

U-Th-Pb—(sphene) U = 67.85 ppm, Th = 69.90 ppm, Pb = 3.860 ppm; isotopic composition of lead (atom percent) is 204:206:207:208 = 1.0701:35.18:17.38: 46.37; initial lead isotopic composition Pb^{206}/Pb^{204} = 18.11, Pb^{207}/Pb^{204} = 15.54, Pb^{208}/Pb^{204} = 38.36 as determined on coexisting K-feldspar.

(sphene) Pb^{206}/U^{238} = 66.7 ± 1.2 m.y.
Pb^{207}/U^{235} = 67.1 ± 3.8 m.y.
Pb^{208}/Th^{232} = 66.5 ± 2.2 m.y.

Comments: The hornblende diorite (or monzonite) contains large orthoclase (as much as 2-cm long) and hornblende (as much as 1-cm long) phenocrysts; medium-sized plagioclase and pyroxene phenocrysts; small sphene, magnetite, and apatite(?) phenocrysts; all in a fine-grained groundmass of orthoclase, quartz, and magnetite(?). This diorite is the same as the diorite porphyry of Weed and Pirsson (1898, p. 565) and is the probable rock source of the porphyritic "hornblende diorite" dated by McDowell (1971, p. 8–9, entry 39). The age of this intrusion, Maiden Peak intrusion, is 67 m.y. The K-Ar age of 60 m.y. is too young. The 50.3-m.y. hornblende age reported by McDowell (1971) appears spurious.

60. *USGS(D)-H71-9* K-Ar, Fission-track, U-Th-Pb
Alkali syenite. (Roadcut; NW¼ NW¼ NE¼ S31,T17N, R20E; 47°11′52″N, 109°13′05″W; SW slope Big Grassy Peak, Judith Peak 15′ quad., Fergus Co., MT). *Analytical data:* K-Ar—(K-feldspar) K_2O = 9.31, 9.27%; $^*Ar^{40}$ = 8.249 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 86%.

(K-feldspar) 60.7 ± 2.0 m.y.

Fission-track—(zircon) Ps = 6.00 x 10^6 tracks/cm^2 (806); Pi = 4.80 x 10^6 tracks/cm^2 (322); ϕ = 1.11 x

10^{15} n/cm^2; 140 ppm U; (sphene) Ps = 1.81 x 10^6 tracks/cm^2 (781); Pi = 2.39 x 10^6 tracks/cm^2 (515); ϕ = 1.81 x 10^{15} n/cm^2; 43 ppm U.

(zircon) 82.6 ± 4.6 m.y.
(sphene) 81.6 ± 4.2 m.y.

U-Th-Pb—(sphene) U = 49.46 ppm, Th = 103.75 ppm, Pb = 9.421 ppm; isotopic composition of lead (atom percent) is 204:206:207:208 = 1.2530:27.65:19.73: 51.36; initial lead isotopic composition Pb^{206}/Pb^{204} = 18.39, Pb^{207}/Pb^{204} = 15.56, Pb^{208}/Pb^{204} = 38.42 as determined on coexisting K-feldspar.

(sphene) Pb^{206}/U^{238} = 65.1 ± 1.6. m.y.
Pb^{207}/U^{235} = 70.5 ± 11.7 m.y.
Pb^{208}/Th^{232} = 66.2 ± 3.3 m.y.

Comment: This alkali syenite contains inclusions of basement rock of Precambrian age and clots of copper-bearing sulfides which may have come from the Precambrian basement or are associated with pre-syenite intrusions in the Judith Mountains. The alkali syenite is intruded by porphyritic monzonite (sample 59) which has an age of about 67 m.y. The analytically most reliable age for the alkali syenite is 65 m.y. (Pb^{206}/U^{238}). This is a slightly younger age than the age of the intruding porphyritic monzonite. It seems likely that the two rock types were emplaced within 1–2 m.y. of each other. The K-Ar age of 60.7 m.y. is obviously too young; the fission-track ages appear anomalously old. There is no geologic evidence to substantiate the fission-track ages, such as eruptive debris in nearby Upper Cretaceous sediments, or local thickening or thinning of formations in the vicinity of the Judith Mountains. As mentioned above, paleomagnetic data also do not indicate an emplacement age of around 82 m.y. (Jacobson and others, 1980).

61. *USGS(D)-H71-6* K-Ar, Fission-track

Green tinguaite. (Outcrop; NE¼ SE¼ S23,T17N, R20E; 47°11′22″N, 109°10′08″W; Collar Gulch, Judith Peak 15′ quad., Fergus Co., MT). *Analytical data:* K-Ar—(K-feldspar) K_2O = 14.60, 14.39%; $^*Ar^{40}$ = 11.37 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 92%. Fission-track—(apatite) Ps = 0.362 x 10^6 tracks/cm^2 (754); Pi = 0.329 x 10^6 tracks/cm^2 (686); ϕ = 1.12 x 10^{15} n/cm^2. *Comment:* A tinguaite sill, 2 km from the nearest exposures of igneous rock other than sills and dikes of tinguatie, was samples 1.6 m above the sill base. At this level, the groundmass is finer and the K-feldspar phenocrysts are clearer and lack the white cloudy rim that is present on K-feldspar phenocrysts elsewhere in the sill. Yellow sphene is prominent, but it could not be used for isotopic dating as it carried insufficient uranium. The age of the tinguaite sill has not been established, although, by the geologic field relationships expressed by the intrusive sequence of Wallace (1953, 1956) and the radiometric ages determined by this study for members of that sequence, an age of around 65 m.y. would be compatible. The K-Ar age appears too young, possibly due to diffusion loss of radiogenic argon, and the apatite age appears too old. Something of the analytical problems encountered in dating the apatite are represented by the large analytical uncertainty.

K-Ar (K-feldspar) 53.7 ± 1.2 m.y.
Fission-track (apatite) 73.3 ± 7.7 m.y.

62. *USGS(D)-H71-5* K-Ar, Rb-Sr

Alkali granite of Judith Peak. (Outcrop; SE¼ S19, T17N,R20E; 47°13′00″N, 109°12′40″W; east ridge of Judith Peak, Judith Peak 15′ quad., Fergus Co., MT). *K-Ar analytical data:* (K-feldspar) K_2O = 10.82, 10.75%; $^*Ar^{40}$ = 5.238 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 85%; (plagioclase) K_2O = 1.237, 1.240% (L. B. Schlocker, USGS, Menlo Park—*analyst*); $^*Ar^{40}$ = 1.059 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 78%. *Rb-Sr analytical data* for three-point isochron with initial Sr^{87}/Sr^{86} = 0.7066: (plagioclase) Rb = 28.7 ppm, Sr = 32.4 ppm, Rb^{87}/Sr^{87} = 2.569, Sr^{87}/Sr^{86} = 0.7088; (whole rock) Rb = 143 ppm, Sr = 47.7 ppm, Rb^{87}/Sr^{87} = 8.661, Sr^{87}/Sr^{86} = 0.7143; (K-feldspar) Rb = 284 ppm, Sr = 39.1 ppm, Rb^{87}/Sr^{87} = 21.01, Sr^{87}/Sr^{86} = 0.7251 (C. E. Hedge, USGS, Denver—*analyst*). *Comment:* Alkali granite of Judith Peak is Paleocene in age (62 m.y. old). Dated sample is from the middle unit in a sequence of three different facies of alkali granite: fine-grained (oldest), coarse-grained, and breccia (youngest). A fourth facies, dikes and sills of alkali rhyolite peripheral to Judith Peak, is not specifically correlated with any one of the three other facies (Wallace, 1956). The plagioclase gave a K-Ar age a bit too young; the K-Ar K-feldspar age is spurious.

K-Ar (K-feldspar) 33.4 ± 0.7 m.y.
(plagioclase) 58.4 ± 1.3 m.y.
Rb-Sr isochron 62.0 ± 1 m.y.

63. *USGS(D)-RAF-D(2)* K-Ar

Roscoelite-fluorite-quartz-carbonate vein. (Spotted Horse Mine; NW¼ SE¼ S5,T16N,R20E; 47°10′30″N, 109°12′40″W; Judith Peak 15′ quad., Fergus Co., MT). *Analytical data:* K_2O = 9.39, 9.36%. $^*Ar^{40}$ = 8.120 x 10^{-10}, 8.065 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 93, 95%; *collected by* R. A. Forrest, Sunshine Mining Co., Kellogg, ID). *Comment:* Veins described by Corry (1933) and Forrest (1971). Age probably dates gold-telluride mineralization associated with these veins. Roscoelite concentrate contained 5–15% chlorite.

(roscoelite) 58.8 ± 2.1 m.y.
59.2 ± 2.1 m.y.

64. *USGS(D)-H71-8* K-Ar

Rhyolite sill. (Outcrop; SW¼ NW¼ S11,T16N,R20E; 47°10′00″N, 109°09′38″W; Judith Peak 15′ quad., Fergus Co., MT). *Analytical data:* K_2O = 4.91, 4.82%; $^*Ar^{40}$ = 3.313 x 10^{-10} mol/gm; $^*Ar^{40}/\Sigma Ar^{40}$ = 87%.

Comment: Float collected close to base of sill.

(K-feldspar) 46.7 ± 1.6 m.y.

MISSOURI BREAKS DIATREMES AND ISOLATED IGNEOUS OCCURRENCES

Eleven samples were collected from dikes, plugs, and breccias of alkalic ultramafic rock and kimberlite associated with a diatreme swarm mapped by Hearn (1968, 1979) in the Missouri River Breaks. In most cases, the ages of mica separates (46.7–52.0 m.y.) confirm the Eocene age inferred from structural and stratigraphic features. Several diatremes have inclusions of pebbles of Bearpaw Mountains volcanic rocks (some of which are mafic analcime phonolite, the youngest rock in the Bearpaw Mountains sequence) derived from erosional debris on the surface at the time of diatreme emplacement. In general, these isolated igneous features mark the waning phase of igneous activity in the north-central Montana alkalic province.

An alnoite sill (sample 77) representative of the Grass-range cluster of breccia pipes, sills, and dikes (Ross, 1926; Johnson and Smith, 1964) southeast of the Missouri Breaks diatremes is also of Eocene age (50.2 m.y.). Mica from Froze-to-Death Butte, a breccia pipe in another area of sparse diatremes and dikes farther southeast, near Porcupine Dome, gave a spurious age (sample 76).

The youngest age determined for any igneous activity in this province is Oligocene (27 m.y.), which was given by mica from a phonolite or lamproite (sample 78) exposed at Smoky Butte.

The K-Ar age given by sanidine crystals (sample 79) in an arkosic grit at the base of the Lebo Member, Fort Union Formation (Paleocene), suggests an origin connected with early igneous activity at the Little Rocky Mountains; texture and alteration of associated pebbles fit a Little Rocky Mountains source area. The age, 67 m.y., appears to be slightly too old in comparison with dates near the Cretaceous-Paleocene boundary at 65 m.y. (Bergren and others, 1978; Obradovich and Cobban, 1975; Folinsbee and others, 1965).

65. *USGS(D)-P66-20-2* K-Ar

Monticellite peridotite. (Outcrop; 47°38N, 110°13'W; Haystack Butte plug, Chouteau Co., MT). *Analytical data:* K_2O = 8.74, 8.71%; $*Ar^{40}$ = 6.148 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 87%. *Comment:* Haystack Butte plug or chonolith (Buie, 1941) is the westernmost intrusion related to the Missouri Breaks diatremes (Hearn, 1968). The plug contains mainly monticellite peridotite and minor later alnoite that contains pegmatitic veins. A partial sheath of breccia contains pelletal autoliths which may be a criterion of surface eruption at higher level.

(phlogopite) 48.2 ± 1.8 m.y.

66. *USGS(D)-P66-15* K-Ar

Pegmatitic vein. (Outcrop; 47°38'N, 110°13'W; Haystack Butte plug, Chouteau Co., MT). *Analytical data:* K_2O = 7.63, 7.67%; $*Ar^{40}$ = 5.404 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 85%. *Comment:* Coarse-grained phlogopite in a late-stage pegmatitic vein cutting alnoite. See sample 65.

(phlogopite) 48.4 ± 1.9 m.y.

67. *USGS(D)-H68-25* K-Ar

Monticellite peridotite. (Outcrop; NE¼ NE¼ S20, T24N,R20E; 47°50'34"N, 109°10'35"W; Black Butte diatreme, central plug, Bird Rapids 7.5' quad., Blaine Co., MT). *Analytical data:* K_2O = 7.70, 7.72%; $*Ar^{40}$ = 5.445 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 85%. *Comment:* Central plug is the youngest mass in the Black Butte diatreme as indicated by field relations.

(phlogopite) 48.4 ± 2.0 m.y.

68. *USGS(D)-H65-11E* K-Ar

Monticellite peridotite. (Outcrop; NE¼ NE¼ SW¼ S35, T25N,R21,E; 47°52'40"N, 108°59'10"W; Burnt Wagon dike, John Coulee 7.5' quad., Blaine Co., MT). *Analytical data:* K_2O = 8.25, 8.17%; $*Ar^{40}$ = 6.059 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 88%. *Comment:* Dike, 3 km long, aligned N58°W between Gilmore and Burnt Wagon diatremes.

(phlogopite) 50.6 ± 2.0 m.y.

69. *USGS(D)-P65-11B* K-Ar

Pegmatitic vein. (Outcrop Burnt Wagon dike 0.32 km S of NE corner S35,T25N,R21E; 47°52'27"N, 108°58'25"W; John Coulee 7.5' quad., Blaine Co., MT). *Analytical data:* K_2O = 9.20, 9.23%; $*Ar^{40}$ = 6.564 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 86%. *Comment:* Coarse-grained phlogopite in late-stage pegmatitic vein cutting monticellite peridotite. See sample 68.

(phlogopite) 48.8 ± 1.8 m.y.

70. *USGS(D)-H70-9AB* K-Ar

Ultramafic inclusion, carbonate-bearing pyroxenite. (E½ S33,T24N,R21E; 47°48'30"N, 109°01'30"W; Bullwhacker diatreme, Bullwhacker Creek, Sturgeon Island 7.5' quad., Blaine Co., MT). *Analytical data:* K_2O = 9.46, 9.43%; $*Ar^{40}$ = 6.426 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 82%. *Comment:* Ultramafic inclusion is composed of phlogopite, carbonate, pyroxene (corroded), and opaques.

(phlogopite) 46.7 ± 1.6 m.y.

71. *USGS(D)-H70-9AA* K-Ar

Loose phlogopite flakes. (E½ S33,T24N,R21E; 47°48'30"N, 109°01'30"W; Bullwhacker diatreme, Bullwhacker Creek, Sturgeon Island 7.5' quad., Blaine Co., MT). *Analytical data:* K_2O = 9.64, 9.68%; $*Ar^{40}$ = 6.757 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 82%. *Comment:* Phlogopite probably derived from disaggregated inclusions like sample 70.

(phlogopite) 47.9 ± 1.6 m.y.

72. *USGS(D)-H67-28F-1* K-Ar
Kimberlite. (S7,T24N,R24E; 47°51'N, 108°42'W; Williams 4 dike, D-Y Junction 7.5' quad., Phillips Co., MT). *Analytical data:* (+28 mesh phlogopite) K_2O = 8.37, 8.40%; $*Ar^{40}$ = 53.89 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 90%; (-100 +150 mesh phlogopite) K_2O = 7.59, 7.57%; $*Ar^{40}$ = 18.92 x 10^{-10} mol/gm; $*Ar^{40}$ = 95%. *Comment:* Ages are spurious; excess argon is probably present.

(+28 mesh phlogopite) 399 ± 14 m.y.
(-100 +150 mesh phlogopite) 166 ± 6 m.y.

73. *USGS(D)-H73-1J-1* K-Ar
Altered monticellite(?) peridotite or alnoite. (Outcrop; S7,T24N,R24E; 47°51'N, 108°42'W; Williams 1 pipe, D-Y Junction 7.5' quad., Blaine Co., MT). *Analytical data:* K_2O = 8.14, 8.15%; $*Ar^{40}$ = 5.644 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 88%. *Comment:* Probable age of Williams 1 pipe and also Williams 4 dike (sample 72).

(phlogopite) 47.5 ± 1.6 m.y.

74. *USGS(D)-H67-40E* K-Ar
Alnoite. (Outcrop; 47°55'N, 108°31'W; Zortman 1 east dike, NE side of Whitcomb Butte (Zortman Butte), Zortman 7.5' quad., Phillips Co., MT). *Analytical data:* K_2O = 8.87, 8.94%; $*Ar^{40}$ = 6.766 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 84%. *Comment:* Zortman 2 west plug, 1 km WSW of Zortman 1 east dike, contains inclusions of syenite porphyry of Antone(?) of Little Rocky Mountains and is probably contemporaneous with Zortman 1 east dike.

(phlogopite) 52.0 ± 1.9 m.y.

75. *USGS(D)-P65-27B* K-Ar
Alnoite. (47°52'55"N, 108°22'30"W; dike on SE side Ricker Butte (West Coburn Butte), Coburn Butte 7.5' quad., Phillips Co., MT). *Analytical data:* K_2O = 8.82, 8.82%; $*Ar^{40}$ = 6.5541 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 88%. *Comment:* Dike is the easternmost occurrence of alkalic ultramafic rocks of the Missouri Breaks diatreme swarm.

(phlogopite) 50.8 ± 1.9 m.y.

76. *USGS(D)-H67-38D* K-Ar
Mica peridotite. (SW¼ SW¼ S24,T8N,R35E; 46°25'35"N, 107°17'55"W; small breccia pipe, N slope of Froze-to-Death Butte, Steie Ranch 7.5' quad., Treasure Co., MT). *Analytical data:* K_2O = 9.35, 9.37%; $*Ar^{40}$ = 10.83 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 91%. *Comment:* Age is spurious. Breccia pipe cuts Bearpaw Shale (Late Cretaceous), but pipe probably formed during the early or middle Eocene. A diatreme northeast of this pipe contains inclusions of Fort Union Formation (Paleocene) and probably Wasatch Formation (early Eocene).

(phlogopite) 78.6 ± 2.7 m.y.

77. *USGS(D)-GR-2E* K-Ar
Alnoite. (Outcrop; NE¼ NE¼ SE¼ S6,T14N,R25E; 47°00'00"N, 108°35'20"W; 18 km W of Winnett, Petroleum Co., MT). *Analytical data:* K_2O = 6.12, 6.13%; $*Ar^{40}$ = 4.494 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 78%. *Comment:* Alnoite sill was studied by Ross (1926) and is part of a group of breccia pipes, plugs, sills, and dikes (Johnson and Smith, 1964) east of the Little Snowy Mountains.

(biotite) 50.2 ± 1.1 m.y.

78. *USGS(W)-GEA-2* K-Ar
Phonolite or lamproite. (Quarry; NW¼ SW¼ S12,T18N, R36E; approx. 47°20'N, 107°04'W; Smoky Butte, Garfield Co., MT). *Analytical data:* K_2O = 8.23%; $*Ar^{40}$ = 3.278 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 62%; *collected by* A. F. Bateman, Jr., USGS; *analysts:* H. H. Thomas, R. F. Marvin, P. L. D. Elmore, and H. Smith, USGS, Washington, D.C. *Comment:* This phonolite, mapped by Matson (1960 and termed armalcolite-Ti-phlogopite-diopside-analcite-bearing lamproite by Velde (1975), is the youngest intrusive known in north-central or eastern Montana. It cuts Fort Union Formation (Paleocene) and may have been emplaced close to the surface as suggested by an occurrence of bedded phonolitic tuff found by one of us (BCH) beneath phonolite in Smoky Butte.

(biotite) 27 ± 3 m.y.

79. *USGS(W)-GEA-1* K-Ar
Arkosic grit. (Outcrop; NW¼ NW¼ S22,T18N,R33E; 47°19'N, 107°29'30"W; Garfield Co., MT). *Analytical data:* K_2O = 12.00%; $*Ar^{40}$ = 11.73 x 10^{-10} mol/gm; $*Ar^{40}/\Sigma Ar^{40}$ = 97%; *collected by* A. F. Bateman, Jr., USGS; *analysts:* H. H. Thomas, R. F. Marvin, P. L. D. Elmore, and H. Smith, USGS, Washington, D.C. *Comment:* Arkosic grit at the base of the Lebo Member, Fort Union Formation—70 m above base of the Fort Union. Sanidine crystals separated from the grit are only slightly rounded; they probably were reworked from coarse tuffs erupted from the Little Rocky Mountains, 115 km to the northwest. Large size of feldspars and lack of fresh mafic minerals in porphyry pebbles in the grit suggest a Little Rocky Mountains source.

(sanidine) 67 ± 3 m.y.

SUMMARY

Igneous activity in the alkalic province of north-central Montana occurred 69 to 27 m.y. ago. There were two main episodes: predominantly intrusive activity during the Late Cretaceous-Paleocene, 69–58 m.y. ago, and intrusive and extrusive activity during the Eocene, 54–47 m.y. ago. Minor intrusive activity occurred 27 m.y. ago (Oligocene) near Jordan. Considerably more geochronologic work needs to be done to fully document the intrusive activity during

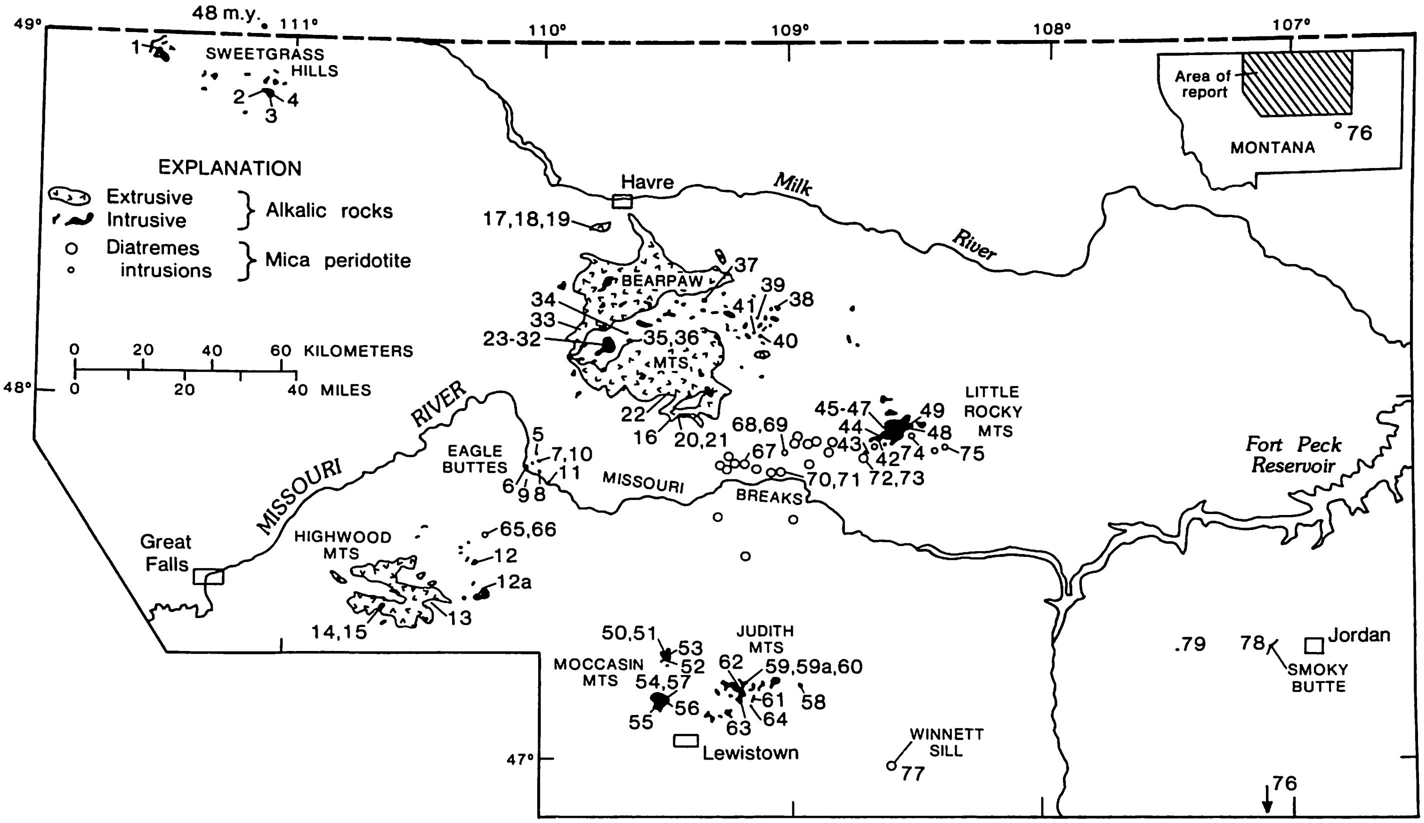

FIGURE 2. A plot of the most reliable age determined for samples in the alkalic province of north-central Montana.

the Late Cretaceous and Paleocene. The age range for individual areas is Little Rocky Mountains, 67–60 m.y.; Moccasin Mountains, 66–53 m.y.; Judith Mountains, 69–47 m.y.; Bearpaw Mountains, 54–50 m.y.; Highwood Mountains, 53–50 m.y.; Sweetgrass Hills, 54–50 m.y.; Eagle Buttes, 52–50 m.y.; and Missouri Breaks diatremes, 52–47 m.y. The ages determining these ranges are shown on Figure 2. Several of these age ranges are similar to the 3- to 5-m.y. life spans of late Tertiary-Quaternary basic-silicic magma systems of the western United States. Biotite ages and potassium-feldspar ages from the same rock show no systematic direction of discordance. Five out of nine hornblende ages are anomalously old by 8 to 197 m.y.

There is no apparent systematic geographic migration of igneous activity suggesting movement relative to a single hot spot or a number of hot spots. The parental magmas are probable mantle-derived, as shown by the occurrences of lherzolite xenoliths in the Bearpaw Mountains, Eagle Buttes, and various diatremes. Although these igneous centers of north-central Montana show a range of ages, many show a sequence of magma types that have progressed toward a late tinguaitic, porphyritic syenite magma, or toward an alkali rhyolite; magma evolution has been repetitive in the region. Similarly, generation of ore deposits, late in several of the sequences, appears to have been repeated in time. Ore deposits are Eocene in the Little Belt Mountains (Marvin and others, 1973), Bearpaw Mountains, and Sweetgrass Hills, and are Paleocene in the Little Rocky, Judith, and Moccasin Mountains. The occurrence of ore deposits in the Little Rocky, Judith, and Little Belt Mountains suggest a correlation with northeast alignment of Precambrian basement structure inferred from aeromagnetic anomalies as well as the possibility of recycling of mineralization in the Precambrian basement. The Little Belt, Judith, and Little Rocky Mountains are within the northeast-trending Idaho–Montana porphyry belt which contains many porphyry-type copper and molybdenum deposits (Rostad, 1978). Uplift associated with emplacement of the Moccasin, Judith, and Little Rocky Mountains should have influenced the migration of hydrocarbon fluids in Late Cretaceous or Paleocene time and may help explain the presence or absence of oil and gas in nearby structures.

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