Maine Geological Survey
Studies in Maine Geology: Volume 4
1989

# *$^{40}Ar/^{39}Ar$ Isotopic Dating of the Horserace Quartz Diorite and its Bearing on Age Relationships in the Katahdin Batholith-Traveler Rhyolite System*

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## ABSTRACT

**The Horserace quartz diorite is a small pluton that intrudes the Katahdin granite in north-central Maine. However, some field observations and geochemical data suggest that the Horserace quartz diorite may have been nearly contemporaneous with the Katahdin granite, which is believed to be the intrusive equivalent of the Traveler rhyolite. Stratigraphic control of the Traveler rhyolite is adequate such that reliable age data would provide an Early Devonian time scale correlation point. Thus, it was hoped that by dating the Horserace quartz diorite we could effectively date the Traveler rhyolite and provide an absolute time point for the stratigraphic time scale.**

**Four hornblende samples from the Horserace quartz diorite dated by the $^{40}Ar/^{39}Ar$ incremental heating technique yield plateau age spectra concordant at 2 sigma with a mean of 374.9± 3.2 Ma. Biotite samples from the Horserace quartz diorite do not yield plateau spectra, but total gas ages average 374 Ma, suggesting that the Horserace quartz diorite cooled quickly through the Ar closure temperatures for both hornblende and biotite (about 550°C and 350°C respectively). A single release spectrum for a biotite from the Katahdin granite yields a plateau age of 400.1 ± 1.0 Ma.**

**The new data demonstrate that the Horserace quartz diorite is 375 Ma old and data further suggest that the Katahdin granite is distinctly older, possibly 400 Ma old. These new results for the Horserace quartz diorite probably do not date the time of eruption of the Traveler rhyolite and therefore do not provide an absolute age calibration point for the stratigraphic time scale. The Traveler rhyolite does have great potential for providing such a calibration point and we recommend that future attempts to determine that point concentrate on direct age measurements of the Traveler rhyolite.**

## INTRODUCTION

The Katahdin batholith is a large body of felsic igneous rock in north central Maine. The batholith crops out over an area of approximately 2500 km$^2$ and is roughly elliptical in map pattern, with dimensions of about 65 by 40 km. A sketch map of the state of Maine shows the position and shape of the Katahdin batholith (Fig. 1). The batholith underlies much of Baxter State Park and

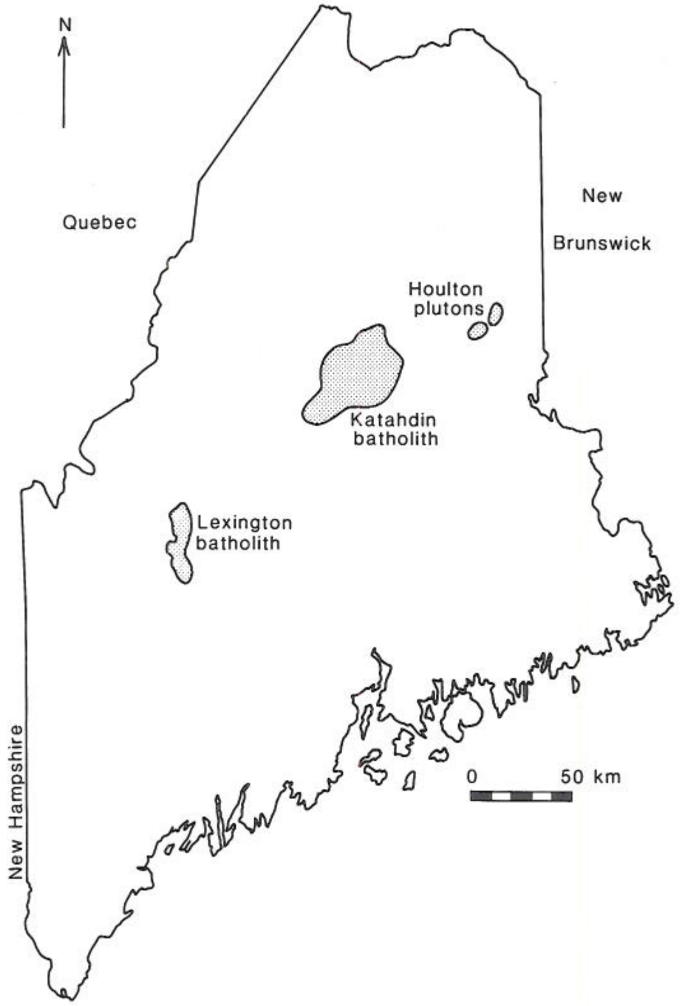

Figure 1. Map of Maine, showing the location of the Katahdin batholith and several other plutons in the dot pattern.

also extends considerably to the south and west of the park. Mapping in the region has been completed by Rankin (1961), Griscom (1976), and Hon (1976).

A geologic sketch map showing the distribution of the major rock types of the Katahdin batholith is presented in Figure 2. The bulk of the batholith is comprised of biotite granite, i.e., the Katahdin granite. Two compositionally different units intrude the granite, namely the Horserace quartz diorite, a small stock about 6 by 2.5 km, and two bodies of the Debsconeag granodiorite. All three of these bodies crop out along the fault system associated with the West Branch of the Penobscot River, suggesting tectonic control for the site of the intrusions (Hon, 1980). There has been much interest in the age of the Katahdin batholith because of the good stratigraphic control on its stratigraphic equivalent, the Traveler rhyolite, and because the Katahdin granite intrudes folded Lower Devonian rocks, yet is itself undeformed.

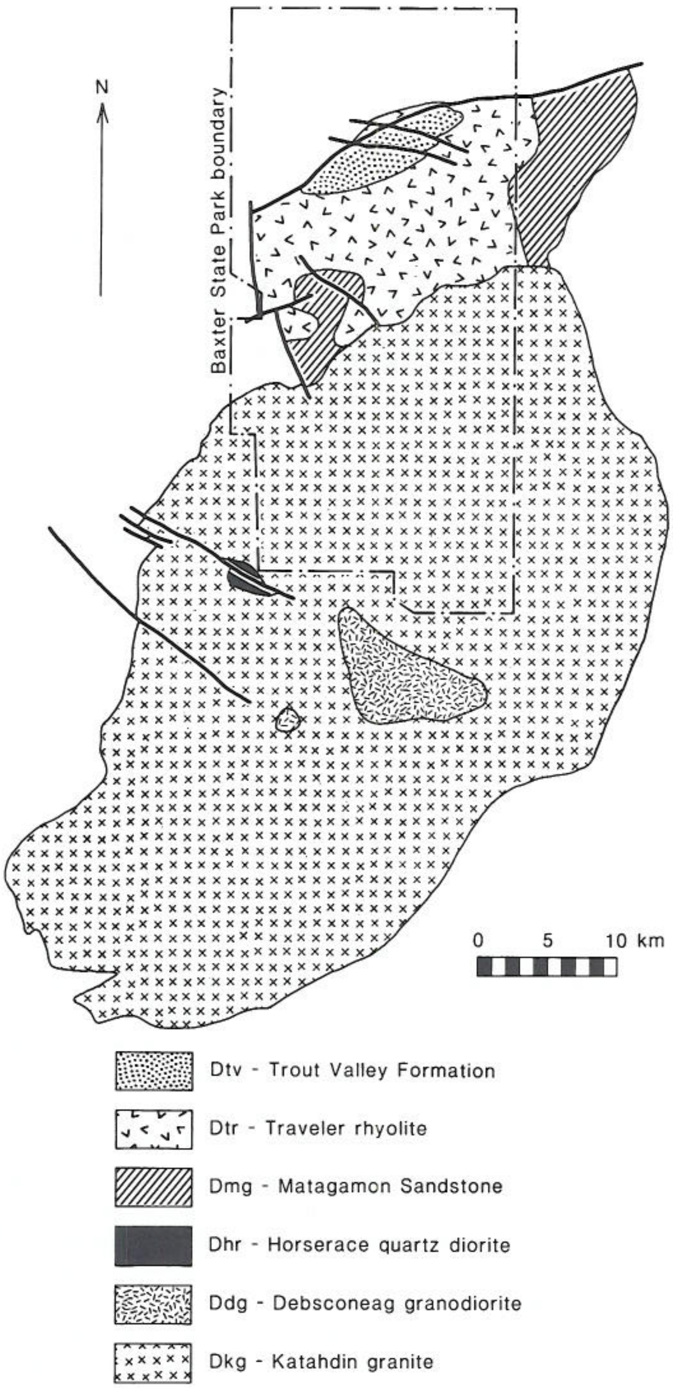

Figure 2. Geologic sketch map of the Katahdin batholith and vicinity showing various of the intrusive phases (after Hon, 1980).

A summary of the stratigraphic relationships of the Lower Devonian units of the area is presented in Figure 3. The base of the section considered here is the Seboomook Formation, of Siegenian age. It is overlain by the Matagamon Sandstone (Siegenian), which is in turn overlain by the Traveler rhyolite. The rhyolite is intruded by the Katahdin granite and is unconformably overlain by the Middle Devonian Trout Valley Formation (Rankin, 1980).

The Seboomook Formation in this area consists of a thick, sparsely fossiliferous sequence of graded beds consisting of fine grained sandstone, siltstone, and slate (turbidites). The Seboomook-Matagamon sequence has been interpreted as a westward-prograding delta (Hall et al., 1976; Pollock et al., 1988). These fossiliferous rocks are conformably overlain by the voluminous Traveler rhyolite volcanic sequence. Scattered pebbles of rhyolite are found in the upper few meters of the deltaic sequence suggesting that very little (if any) time elapsed between the deposition of the top of the sandstone and the ash flow eruptions producing the rhyolite (Rankin, 1961). In addition, Rankin (1961) also reported numerous clastic dikes of sandstone in the rhyolite, which he interpreted to mean that the sandstone was poorly consolidated during the deposition of the lower parts of the rhyolite. This further supports the suggestion of the similarity in age between the Siegenian Matagamon Sandstone and the Traveler rhyolite.

The Traveler rhyolite is unconformably overlain by a basal conglomerate of the Trout Valley Formation. Terrestrial plant fossils from the Trout Valley Formation are believed to be Middle Devonian in age (Rankin and Hon, 1987). The basal conglomerate contains felsite pebbles derived from the Traveler rhyolite. Rankin (1961) observed evidence of deformation in the Traveler rhyolite which is not seen in the Trout Valley Formation, suggesting an indefinite period of time elapsed between the end of the volcanism which produced the felsite and the deposition of the basal conglomerate of the Trout Valley Formation.

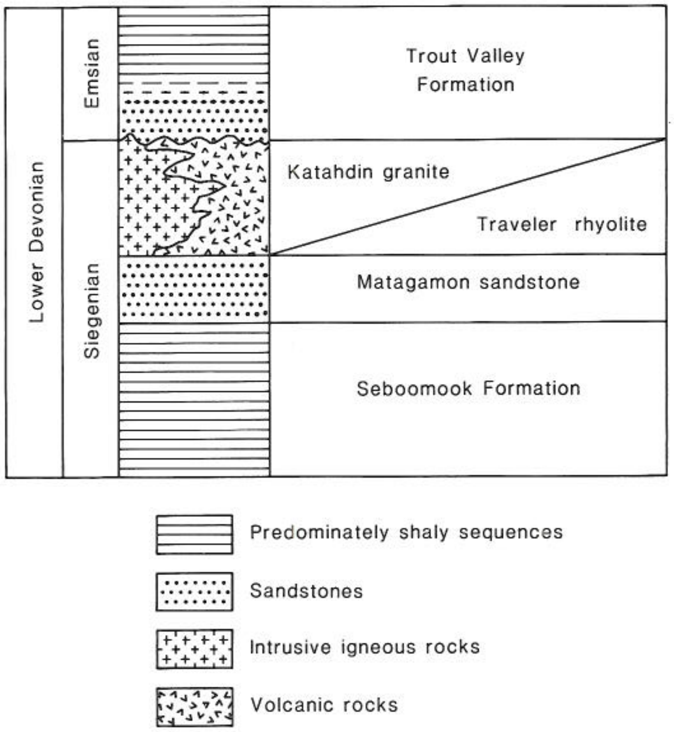

Figure 3. Stratigraphic relationships of Lower Devonian rocks in the study area.

The stratigraphic control on the age of the Traveler rhyolite is fairly good. Unfortunately, obtaining a reliable age of the Traveler rhyolite is complicated by the extensive recrystallization of these rocks in the time since they were extruded. Bottino et al. (1965) reported an Rb-Sr whole rock isochron age of 352 ± 10 Ma (calculated with the decay constants recommended by Steiger and Jager (1977) as are all other ages presented or discussed in this paper). The initial $^{87}Sr/^{86}Sr$ ratio is 0.7105.

The Traveler rhyolite is intruded by the Katahdin granite, but Rankin (1961) suggested that the two were comagmatic with the Traveler rhyolite being the volcanic equivalent of the Katahdin granite. Hon (1980, p. 75) showed by modeling of trace element abundances that "the Katahdin granite can be derived from the Traveler rhyolite magma if 15%-25% phenocrysts are removed by fractionation." Recent efforts to establish the chronology of these rocks have focused on dating the Katahdin granite as an equivalent of the Traveler rhyolite.

Loiselle et al. (1983) suggested that the Katahdin granite could be used as a geological time scale correlation point, making it possible to give an absolute age to rocks of this relative age anywhere in the world. If the granite and felsite are indeed contemporaneous, then it should at least be possible to determine a date for the late Siegenian, as the contact between the Matagamon Sandstone and the Traveler rhyolite is demonstrably conformable.

The age of the Katahdin granite has proved difficult to determine. Boucot (1954) reported an age of 363 Ma that was determined by the K/Ar method. Loiselle et al. (1983) reported two ages for the Katahdin batholith. One is a six point Rb/Sr whole rock isochron age of 388 ± 5 Ma, with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7083. They also reported a $^{207}Pb/^{206}Pb$ age for zircons of 414 ± 4 Ma. These ages are not mutually consistent.

Because the Seboomook Formation contains Siegenian fossils, and the Seboomook-Matagamon sequence is overlain by the Traveler rhyolite, the age of formation of the Katahdin granite must be no older than Siegenian. Current estimates of the age of the Siluro-Devonian boundary include 405 Ma (Boucot, 1975), 408 Ma (Palmer, 1983), and 410 Ma (Spjeldnaes, 1978). Thus, if the zircon age reported by Loiselle et al. (1983) is accurate, estimates of this boundary must be somewhat young.

The present paper attempts to resolve the problem of the age of the Katahdin batholith by using the $^{40}Ar/^{39}Ar$ incremental heating technique. The $^{40}Ar/^{39}Ar$ method may be used for any mineral containing potassium, but is most useful for hornblende because of its relatively high closure temperature and because it is relatively stable during heating in the ultra-high vacuum furnace system during Ar extraction. Unfortunately, the Katahdin granite contains no hornblende. This paper, therefore, focuses on dating hornblende separates from the Horserace quartz diorite which intrudes the Katahdin granite.

The geochemical work of Brown and Hon (1984) has established that the Horserace quartz diorite is derived from a different magmatic source than the Katahdin granite and the Traveler rhyolite, and suggests the Debsconeag granodiorite may be a mixture of the Horserace and Traveler magmas. Nonetheless, they cited field evidence indicating the Katahdin granite was still at least partially molten at the time of intrusion of the Horserace quartz diorite. Contacts between the Katahdin granite and Horserace quartz diorite are observed to be wavy and irregular, and suggest that liquid phases of the two may have mixed. This phenomenon was also noted in the field by the authors. If the Katahdin granite was indeed still molten during intrusion of Horserace quartz diorite magma, then the two units should have been nearly contemporaneous.

If the Katahdin granite and Horserace quartz diorite formed contemporaneously and if both are also the same age as the Traveler rhyolite, then the age determined for the Horserace quartz diorite should be a good estimate of the age of the late Siegenian. Though intrusive into the Kathadin granite, Brown and Hon (1984) indicate that the granite was still partially molten when the quartz diorite was intruded, thereby strongly suggesting a temporal link. However, if the granite cannot be shown to be the same age as the quartz diorite, then the age of the latter still provides a lower limit to the age of the Katahdin granite and the Traveler rhyolite.

## METHODS

Sampling localities are principally a series of well exposed outcrops along a 0.5 km transect on the south side of the West Branch of the Penobscot River between the Golden Road and Big Ambejackmockamus Falls. Samples 83-SD-1 and 83-SD-2 were collected from roadcut outcrops on the Golden Road near Big Eddy just west of the contact of the quartz diorite and the granite. Carrol Brown collected sample HQD-618-3A, but the exact locality was unspecified.

Mineral separates were obtained using standard methods including magnetic and heavy liquid separation techniques. Separates were at least 99% pure. The hornblende separates that were dated weighed 300-1000 mg, and biotite separates weighed about 100 mg.

All samples were irradiated in the U.S. Geological Survey TRIGA reactor in Denver, Colorado. One vial in each irradiation package contained flux monitor minerals of precisely known age. The monitor mineral used was an international standard, MMhb-1, whose age is known to be 519.4 Ma (Alexander et al., 1978).

Samples were heated incrementally in a molybdenum crucible within an ultra-high vacuum extraction furnace and purified using standard gettering techniques. The isotopic composition of the purified Ar was analyzed on a Nuclide 6-60-SGA 1.25 mass spectrometer.

Equations of Dalrymple et al. (1981) were used to calculate ages and estimate uncertainties. Release spectrum plateaus are defined as at least 50% of the gas in consecutive increments with the same age within a 2 sigma confidence interval. The plateau age reported is the unweighted mean of the ages of the increments falling within the limits of the plateau. Uncertainty reported for plateau ages is a 1 sigma confidence interval.

Closure temperatures were calculated by the method of Dodson (1979), using parameters from Harrison (1981) for hornblende and Harrison et al. (1985) for biotite.

## RESULTS AND DISCUSSION

Analytical data from incremental heating and total fusion mass spectrometric analyses of samples from the Horserace quartz diorite and Katahdin granite are presented in Tables 1 and 2. Graphical illustrations of these data are presented in Figures 4 and 5. These age spectra are used to display the data qualitatively. Quantitative comparison of analytical data should be made using the numerical data presented in the Tables 1 and 2.

Five of the release spectra have plateaus as defined above. These are those for hornblendes from the Horserace quartz diorite (83-SD-3, 83-SD-4, 83-SD-6, and HQD-618-3A) and biotite from the Katahdin granite (83-SD-2). All of these plateau spectra show anomalously low ages for the first 5% or so of the gas released. This suggests minor episodic loss of $^{40}Ar_{Rad}$ at some indeterminate time since initial cooling. Because of this Ar loss the total gas age of each of these samples is lower than the plateau age. Plateau ages of the four hornblende samples from the Horserace quartz diorite are concordant within analyti-

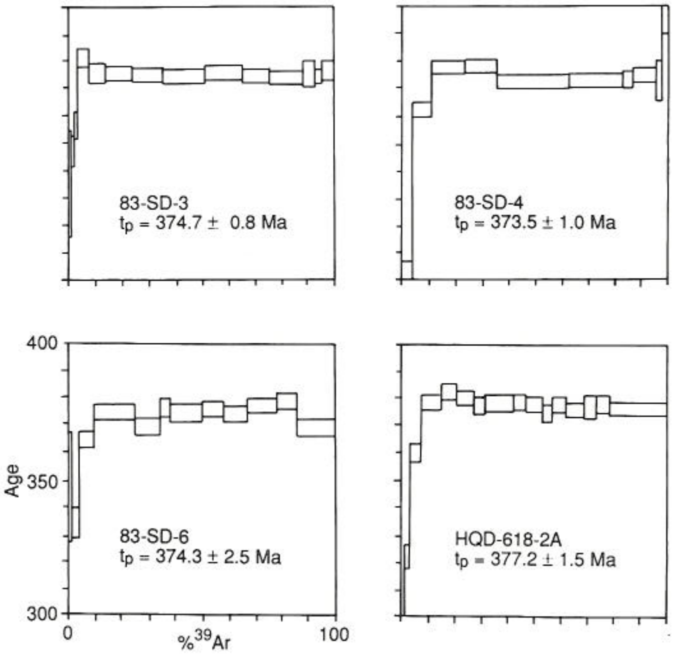

Figure 4. Age spectra of hornblende from samples of the Horserace quartz diorite (see Table 1). The vertical and horizontal scales are all as shown in the lower left. The box height for individual increments represents 2 sigma uncertainties. $t_p$ - plateau age.

TABLE 1. INCREMENTAL RELEASE DATA FOR HORNBLENDE SAMPLES FROM THE HORSERACE QUARTZ DIORITE. MOLES $^{39}$Ar HAS BEEN MULTIPLIED BY $10^{14}$ AND %$^{40}$Ar$_{\mathrm{RAD}}$ REPRESENTS THE PORTION OF $^{40}$Ar DERIVED BY DECAY OF $^{40}$K.

| Temp °C | $\frac{^{40}Ar}{^{39}Ar}$ | $\frac{^{37}Ar}{^{39}Ar}$ | $\frac{^{36}Ar}{^{39}Ar}$ | Moles $^{39}$Ar | $^{39}$Ar %Total | %$^{40}$Ar RAD | $\frac{K}{Ca}$ | Apparent Age Ma |
|---|---|---|---|---|---|---|---|---|
| 83-SD-3 HORNBLENDE | | J = 0.009263 | | | | | | |
| 500 | 153.45 | 2.661 | 0.4602 | 1.50 | 0.3 | 11.4 | 0.18 | 274.0 ± 37.6 |
| 650 | 71.03 | 1.827 | 0.1663 | 3.45 | 0.6 | 30.8 | 0.26 | 335.2 ± 19.4 |
| 750 | 39.45 | 1.895 | 0.0566 | 5.43 | 0.9 | 57.6 | 0.26 | 347.0 ± 5.7 |
| 850 | 38.97 | 4.155 | 0.0534 | 6.94 | 1.2 | 59.5 | 0.12 | 356.4 ± 4.9 |
| 935 | 30.56 | 10.38 | 0.0209 | 25.60 | 4.4 | 79.8 | 0.05 | 380.9 ± 3.3 |
| 965 | 27.89 | 10.43 | 0.0132 | 43.46 | 7.5 | 86.0 | 0.05 | 375.3 ± 3.8 |
| 980 | 27.08 | 10.11 | 0.0104 | 57.47 | 10.0 | 88.6 | 0.05 | 375.1 ± 2.6 |
| 995 | 26.65 | 9.715 | 0.0090 | 66.16 | 11.5 | 90.1 | 0.05 | 374.6 ± 2.6 |
| 1010 | 26.12 | 9.222 | 0.0072 | 90.93 | 15.7 | 91.9 | 0.05 | 374.0 ± 2.5 |
| 1025 | 26.02 | 9.000 | 0.0063 | 83.09 | 14.4 | 92.8 | 0.05 | 375.5 ± 2.8 |
| 1040 | 26.14 | 8.933 | 0.0070 | 56.46 | 9.8 | 92.1 | 0.06 | 374.4 ± 2.5 |
| 1055 | 26.46 | 9.008 | 0.0083 | 39.89 | 6.9 | 90.7 | 0.05 | 373.7 ± 2.5 |
| 1080 | 26.59 | 9.463 | 0.0089 | 33.38 | 5.8 | 90.1 | 0.05 | 373.7 ± 2.5 |
| 1100 | 27.09 | 11.12 | 0.0108 | 26.95 | 4.7 | 88.2 | 0.04 | 375.0 ± 4.9 |
| 1120 | 28.72 | 12.53 | 0.0170 | 14.31 | 2.5 | 82.5 | 0.04 | 374.2 ± 2.8 |
| Fuse | 28.80 | 17.65 | 0.0184 | 22.67 | 3.9 | 81.2 | 0.02 | 376.3 ± 3.5 |
| TOTAL | | | | 577.69 | 100.0 | | | 374.0 |
| PLATEAU AGE | | | | | | | | 374.7 ± 0.8 |
| 83-SD-4 HORNBLENDE | | J = 0.010917 | | | | | | |
| 450 | 52.92 | 1.303 | 0.1231 | 15.06 | 3.3 | 31.3 | 0.38 | 301.6 ± 5.5 |
| 725 | 25.03 | 3.082 | 0.0167 | 33.48 | 7.4 | 80.3 | 0.16 | 362.4 ± 2.8 |
| 920 | 22.90 | 6.101 | 0.0071 | 57.33 | 12.6 | 90.8 | 0.08 | 378.0 ± 2.5 |
| 950 | 22.74 | 6.991 | 0.0069 | 54.08 | 11.9 | 91.1 | 0.07 | 378.0 ± 2.6 |
| 1010 | 22.04 | 9.028 | 0.0063 | 121.5 | 26.8 | 91.6 | 0.05 | 372.6 ± 2.5 |
| 1065 | 22.03 | 9.953 | 0.0064 | 89.97 | 19.8 | 91.4 | 0.05 | 373.3 ± 2.5 |
| 1090 | 23.34 | 9.977 | 0.0108 | 18.27 | 4.0 | 86.4 | 0.05 | 373.7 ± 2.9 |
| 1120 | 22.29 | 10.21 | 0.0070 | 41.54 | 9.2 | 90.8 | 0.05 | 375.1 ± 2.5 |
| 1130 | 26.46 | 10.17 | 0.0215 | 8.01 | 1.8 | 76.0 | 0.05 | 373.1 ± 7.2 |
| 1150 | 25.26 | 10.10 | 0.0125 | 13.62 | 3.0 | 85.4 | 0.05 | 396.3 ± 5.2 |
| 1175 | 124.0 | 9.789 | 0.3549 | 0.46 | 0.1 | 15.5 | 0.05 | 357.0 ± 65.2 |
| Fuse | 420.9 | 9.553 | 1.382 | 0.24 | 0.1 | 3.0 | 0.05 | 246.6 ± 198.1 |
| TOTAL | | | | 453.60 | 100.0 | | | 371.9 |
| PLATEAU AGE | | | | | | | | 373.5 ± 0.9 |
| 83-SD-6 HORNBLENDE | | J = 0.010892 | | | | | | |
| 450 | 79.11 | 3.842 | 0.2030 | 3.68 | 0.9 | 24.2 | 0.13 | 346.9 ± 20.0 |
| 725 | 41.29 | 2.903 | 0.0774 | 10.77 | 2.8 | 44.6 | 0.17 | 334.2 ± 5.6 |
| 920 | 25.89 | 9.350 | 0.0209 | 21.19 | 5.4 | 76.2 | 0.05 | 364.7 ± 3.0 |
| 980 | 23.11 | 10.27 | 0.0097 | 58.77 | 15.0 | 87.6 | 0.05 | 374.5 ± 2.7 |
| 1025 | 23.65 | 10.34 | 0.0127 | 37.02 | 9.5 | 84.1 | 0.05 | 369.2 ± 3.0 |
| 1040 | 24.89 | 10.20 | 0.0154 | 16.40 | 4.2 | 81.7 | 0.05 | 376.0 ± 3.3 |
| 1080 | 22.99 | 10.48 | 0.0094 | 45.85 | 11.7 | 88.0 | 0.05 | 374.6 ± 2.7 |
| 1090 | 23.49 | 10.83 | 0.0110 | 31.67 | 8.1 | 86.2 | 0.05 | 375.4 ± 2.8 |
| 1110 | 23.03 | 11.34 | 0.0099 | 35.98 | 9.2 | 87.3 | 0.04 | 373.8 ± 2.9 |
| 1130 | 22.66 | 11.39 | 0.0081 | 42.28 | 10.8 | 89.5 | 0.04 | 376.6 ± 2.6 |
| 1150 | 23.01 | 11.26 | 0.0089 | 28.79 | 7.3 | 88.6 | 0.04 | 378.4 ± 3.2 |
| Fuse | 22.62 | 9.508 | 0.0091 | 59.55 | 15.2 | 88.2 | 0.05 | 368.6 ± 2.8 |
| TOTAL | | | | 391.96 | 100.0 | | | 371.8 |
| PLATEAU AGE | | | | | | | | 374.3 ± 2.5 |

TABLE 1. CONTINUED.

| Temp °C | $^{40}\text{Ar}/^{39}\text{Ar}$ | $^{37}\text{Ar}/^{39}\text{Ar}$ | $^{36}\text{Ar}/^{39}\text{Ar}$ | Moles $^{39}\text{Ar}$ | $^{39}\text{Ar}$ %Total | $\%^{40}\text{Ar}$ RAD | K/Ca | Apparent Age Ma |
|---|---|---|---|---|---|---|---|---|
| HQD-618-3A HORNBLENDE | | J = 0.005865 | | | | | | |
| 550 | 74.39 | 1.605 | 0.1785 | 2.79 | 0.9 | 29.1 | 0.31 | 216.9 ± 8.0 |
| 850 | 75.93 | 1.223 | 0.1447 | 5.93 | 2.0 | 43.7 | 0.40 | 321.9 ± 4.5 |
| 1020 | 58.78 | 4.168 | 0.0730 | 12.49 | 4.2 | 63.3 | 0.12 | 359.8 ± 3.4 |
| 1065 | 50.91 | 11.82 | 0.0419 | 22.21 | 7.4 | 75.7 | 0.04 | 378.2 ± 2.8 |
| 1090 | 49.39 | 12.58 | 0.0354 | 18.16 | 6.1 | 78.8 | 0.04 | 382.2 ± 2.9 |
| 1100 | 48.80 | 12.38 | 0.0343 | 19.04 | 6.4 | 79.3 | 0.04 | 379.9 ± 2.7 |
| 1110 | 51.64 | 12.04 | 0.0448 | 11.49 | 3.8 | 74.36 | 0.04 | 377.2 ± 3.1 |
| 1120 | 50.86 | 11.67 | 0.0418 | 32.76 | 11.0 | 75.75 | 0.04 | 378.0 ± 3.0 |
| 1130 | 49.87 | 11.34 | 0.0381 | 12.93 | 4.3 | 77.42 | 0.04 | 378.4 ± 2.9 |
| 1140 | 50.11 | 11.22 | 0.0391 | 17.94 | 6.0 | 76.94 | 0.04 | 377.8 ± 2.9 |
| 1150 | 50.44 | 11.00 | 0.0416 | 11.40 | 3.8 | 75.65 | 0.04 | 374.2 ± 3.1 |
| 1170 | 45.83 | 10.77 | 0.0245 | 15.59 | 5.2 | 84.20 | 0.05 | 377.7 ± 2.7 |
| 1180 | 46.40 | 10.72 | 0.0271 | 21.10 | 7.1 | 82.72 | 0.05 | 375.9 ± 2.7 |
| 1200 | 49.34 | 11.11 | 0.0369 | 12.81 | 4.3 | 77.92 | 0.04 | 376.8 ± 4.1 |
| 1220 | 54.38 | 11.37 | 0.0537 | 12.62 | 4.2 | 70.82 | 0.04 | 377.6 ± 3.2 |
| Fuse | 43.83 | 10.91 | 0.0184 | 69.53 | 23.3 | 87.60 | 0.05 | 376.2 ± 2.6 |
| TOTAL | | | | 298.78 | 100.0 | | | 374.2 |
| PLATEAU AGE | | | | | | | | 377.2 ± 1.5 |

TABLE 2. INCREMENTAL RELEASE AND TOTAL FUSION DATA FOR BIOTITES FROM THE HORSERACE QUARTZ DIORITE AND KATAHDIN GRANITE (83-SD-1 AND 83-SD-2). MOLES $^{39}\text{Ar}$ HAS BEEN MULTIPLIED BY $10^{14}$ AND $\%^{40}\text{Ar}_{\text{RAD}}$ REPRESENTS THAT PORTION OF THE $^{40}\text{Ar}$ DERIVED BY DECAY OF $^{40}\text{K}$.

| Temp °C | $^{40}\text{Ar}/^{39}\text{Ar}$ | $^{37}\text{Ar}/^{39}\text{Ar}$ | $^{36}\text{Ar}/^{39}\text{Ar}$ | Moles $^{39}\text{Ar}$ | $^{39}\text{Ar}$ %Total | $\%^{40}\text{Ar}$ RAD | K/Ca | Apparent Age Ma |
|---|---|---|---|---|---|---|---|---|
| 83-SD-1 BIOTITE | | J = 0.009406 | | | | | | |
| 650 | 16.10 | 0.0988 | 0.0118 | 252.2 | 16.1 | 78.3 | 4.96 | 202.2 ± 1.9 |
| 730 | 25.84 | 0.0230 | 0.0028 | 225.6 | 14.4 | 96.8 | 21.3 | 381.1 ± 2.5 |
| 890 | 26.14 | 0.0292 | 0.0013 | 241.9 | 15.5 | 98.5 | 16.8 | 391.2 ± 2.5 |
| 980 | 28.42 | 0.0312 | 0.0008 | 322.2 | 20.6 | 99.2 | 15.7 | 424.3 ± 2.7 |
| 1090 | 25.82 | 0.0471 | 0.0007 | 429.8 | 27.5 | 99.2 | 10.4 | 389.5 ± 2.5 |
| 1130 | 26.64 | 0.2334 | 0.0033 | 56.36 | 3.60 | 96.3 | 2.10 | 390.4 ± 3.3 |
| 1175 | 27.07 | 0.7211 | 0.0111 | 21.64 | 1.38 | 87.9 | 0.68 | 365.0 ± 7.3 |
| Fuse | 35.04 | 0.4531 | 0.0361 | 14.53 | 0.93 | 69.6 | 1.08 | 373.0 ± 6.8 |
| TOTAL | | | | 1564.17 | 100.0 | | | 365.1 |
| 83-SD-1 TF BIOTITE | | J = 0.006017 | | | | | | |
| Fuse | 39.63 | 0.0509 | 0.0046 | 416.0 | 100.0 | 96.6 | 9.63 | 373.9 ± 2.4 |
| 83-SD-1 TF BIOTITE (duplicate) | | J = 0.006017 | | | | | | |
| Fuse | 39.57 | 0.0501 | 0.0046 | 323.4 | 100.0 | 96.6 | 9.78 | 373.2 ± 2.4 |
| 83-SD-2 BIOTITE | | J = 0.009160 | | | | | | |
| 500 | 20.55 | 0.0679 | 0.0109 | 115.0 | 4.59 | 84.3 | 7.22 | 265.7 ± 2.0 |
| 650 | 27.46 | 0.0097 | 0.0032 | 210.9 | 8.42 | 96.6 | 50.6 | 392.2 ± 2.8 |
| 830 | 27.34 | 0.0067 | 0.0012 | 692.0 | 27.6 | 98.8 | 73.6 | 398.6 ± 2.5 |
| 900 | 27.36 | 0.0131 | 0.0007 | 655.3 | 26.2 | 99.2 | 37.3 | 400.6 ± 2.6 |
| 980 | 27.49 | 0.0317 | 0.0017 | 801.5 | 32.0 | 98.8 | 15.5 | 400.7 ± 2.6 |
| 1050 | 28.12 | 0.5837 | 0.0034 | 23.9 | 0.96 | 96.4 | 0.84 | 400.7 ± 11.5 |
| 1100 | 41.03 | 0.6170 | 0.0544 | 4.89 | 0.20 | 60.8 | 0.80 | 372.0 ± 54.8 |
| Fuse | 186.15 | 0.7404 | 0.5511 | 1.25 | 0.05 | 12.5 | 0.66 | 350.0 ± 123.5 |
| TOTAL | | | | 2504.83 | 100.0 | | | 393.1 |
| PLATEAU AGE | | | | | | | | 400.1 ± 1.0 |

TABLE 2. CONTINUED.

| Temp °C | $^{40}Ar/^{39}Ar$ | $^{37}Ar/^{39}Ar$ | $^{36}Ar/^{39}Ar$ | Moles $^{39}Ar$ | $^{39}Ar$ %Total | $\%^{40}Ar$ RAD | K/Ca | Apparent Age Ma |
|---|---|---|---|---|---|---|---|---|
| 83-SD-2 TF BIOTITE | | J = 0.006072 | | | | | | |
| Fuse | 41.07 | 0.0438 | 0.0049 | 448.9 | 100.0 | 96.5 | 11.2 | 388.9 ± 2.5 |
| 83-SD-2 TF BIOTITE (duplicate) | | J = 0.006072 | | | | | | |
| Fuse | 41.28 | 0.0456 | 0.0052 | 298.1 | 100.0 | 96.3 | 10.7 | 389.9 ± 2.5 |
| 83-SD-3 BIOTITE | | J = 0.009419 | | | | | | |
| 600 | 10.03 | 0.2597 | 0.0478 | 0.01 | 0.8 | 41.5 | 1.89 | 162.9 ± 13.4 |
| 750 | 14.94 | 0.1082 | 0.0073 | 0.02 | 3.4 | 87.4 | 4.53 | 237.5 ± 1.7 |
| 840 | 24.16 | 0.0153 | 0.0024 | 0.15 | 23.3 | 97.1 | 32.0 | 369.8 ± 2.4 |
| 920 | 24.83 | 0.0182 | 0.0016 | 0.07 | 10.2 | 98.2 | 26.9 | 379.2 ± 2.5 |
| 1000 | 25.22 | 0.0357 | 0.0013 | 0.17 | 26.2 | 98.5 | 13.7 | 384.5 ± 2.5 |
| 1060 | 24.63 | 0.0358 | 0.0008 | 0.17 | 26.3 | 99.0 | 13.7 | 376.4 ± 2.5 |
| 1100 | 24.54 | 0.0730 | 0.0025 | 0.06 | 9.4 | 97.1 | 6.7 | 375.1 ± 2.6 |
| Fuse | 24.38 | 0.1433 | 0.1693 | 0.00 | 0.5 | 32.8 | 3.42 | 373.0 ± 12.4 |
| TOTAL | | | | 0.66 | 100.00 | | | 370.8 ± 2.6 |
| 83-SD-8 BIOTITE | | J = 0.010850 | | | | | | |
| 375 | 83.51 | 0.3564 | 0.2508 | 1.66 | 0.2 | 11.3 | 1.38 | 175.8 ± 175.7 |
| 475 | 9.58 | 0.3379 | 0.0212 | 10.29 | 1.3 | 34.7 | 1.45 | 64.3 ± 11.6 |
| 625 | 21.70 | 0.0225 | 0.0023 | 170.3 | 20.8 | 96.9 | 21.8 | 370.7 ± 2.4 |
| 870 | 22.58 | 0.0343 | 0.0017 | 145.3 | 17.7 | 97.8 | 14.3 | 387.6 ± 2.6 |
| 970 | 22.59 | 0.0282 | 0.0011 | 125.4 | 15.3 | 98.6 | 17.4 | 390.7 ± 2.7 |
| 1100 | 22.53 | 0.0658 | 0.0021 | 117.1 | 14.3 | 97.2 | 7.45 | 384.6 ± 3.4 |
| Fuse | 22.25 | 0.0615 | 0.0022 | 249.7 | 30.5 | 97.1 | 7.96 | 379.7 ± 2.5 |
| TOTAL | | | | 819.85 | 100.0 | | | 377.2 |
| 83-SD-8 TF BIOTITE | | J = 0.006176 | | | | | | |
| Fuse | 38.49 | 0.0553 | 0.0027 | 497.3 | 100.0 | 97.9 | 8.86 | 377.5 ± 2.5 |

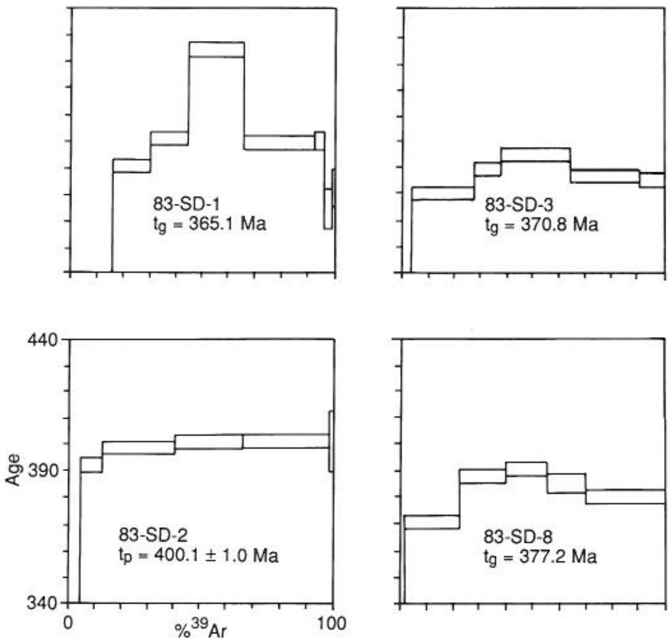

Figure 5. Age spectra of biotite from samples of the Horserace quartz diorite and Katahdin granite (83-SD-1 and 83-SD-2; see Table 2). The vertical and horizontal scales are all as shown in the lower left. The box height for individual increments represents 2 sigma uncertainties. $t_p$ - plateau age, $t_g$ - total gas age.

cal error, with a mean of 374.9 ± 1.6 Ma. This is interpreted as the time since the Horserace quartz diorite cooled through 550°C, the closure temperature calculated for these hornblende samples.

Biotite from the Katahdin granite, sample 83-SD-2 exhibits a well defined plateau, with 87% of the gas having the same calculated age 400.1 ± 1.0 Ma. Like the other plateau spectra, it steps up from very low ages in the first increment, suggesting minor episodic loss of $^{40}Ar_{Rad}$. The effect of this is seen in the fact that the total gas age is only 393.1 Ma. Ages obtained by the total fusion technique were also low, 388.9 Ma and 389.9 Ma. The plateau age of 400.1 ± 1.0 Ma is therefore probably a better estimate of the age of the Katahdin granite than the total fusion or total gas ages.

All other biotite samples analyzed exhibit unexpected "hump-shaped" release spectra. These spectra show anomalously low ages in early, low temperature release increments, as would spectra characteristic of $^{40}Ar_{Rad}$ loss. Ages for intermediate temperature increments are anomalously high, considerably older than the hornblende age of the rocks. Finally, at the higher temperatures and upon fusion of the sample, the ages of the gas released step back down.

Biotite sample 83-SD-1, also from the Katahdin granite, yields a total gas age of only 365.1 Ma, whereas biotite from the same sample analyzed by the total fusion method yields ages of 373.2 and 373.9 Ma. These ages are difficult to reconcile with the total fusion and total gas ages of biotite from 83-SD-2 at 388.9, 389.9, and 393.1 Ma, respectively. One possible explanation could be Ar loss during a later heating event because the sample was collected within five dike widths of a basaltic dike. In light of these difficulties, the age of the Katahdin granite is not well determined by data presented in this paper, but the single plateau age of 400.1 ± 1.0 Ma for 83-SD-2 is the best estimate from the available $^{40}Ar/^{39}Ar$ data. This estimate falls halfway between the previously published Rb/Sr and U/Pb ages for the Katahdin granite.

## CONCLUSIONS

The age of the Katahdin granite is not well determined by the data presented here. The hump-shaped biotite release spectra are problematic and the ages they yield should be used only with great caution. However, in this and other studies (Hubacher and Lux, 1987; Heizler, 1985; Tetley and McDougall, 1978), total gas ages for biotites with "hump-shaped" spectra have ages that are equal to hornblende plateau ages and in that respect appear to be meaningful. A single plateau spectrum (83-SD-2), however, is interpreted as the best estimate of the age of the Katahdin granite, 400.1 ± 1.0 Ma.

Recent age determinations by Hubacher and Lux (1987) for three small plutons southwest of Houlton, Maine, and by Gaudette and Boone (1985) for the Lexington pluton suggest that these may also be about 400 Ma in age. These occur along strike with the Katahdin batholith and the northeast-trending major axis of deformation of the Appalachians and probably represent an early belt of post-Acadian plutons.

The age of the Horserace quartz diorite is much more certain. The plateau ages of the four hornblende samples analyzed clearly indicate the quartz diorite had cooled to the hornblende closure temperature (about 550°C) 375 Ma ago. The two biotites from the Horserace quartz diorite have total gas ages that average 374 Ma and probably date the cooling through the biotite closure temperature, approximately 350°C. The rapid cooling rate implied for the temperature interval between biotite and hornblende closure temperatures can be confidently inferred back to solidus temperatures, and thus the concordant hornblende and biotite ages effectively date the time of intrusion of the Horserace quartz diorite at 375 Ma. This interpretation is also consistent with field relations which demonstrate that the Horserace quartz diorite is intrusive into the Katahdin granite.

The disparity between the ages of the Horserace quartz diorite and the Katahdin granite suggests that the assumption of contemporaneous cooling of the two units is invalid. Furthermore, the concordant biotite total gas ages and hornblende plateau ages for samples from the Horserace quartz diorite and the implied rapid cooling require that the host rocks, i.e. the Katahdin granite, were cool (less than the biotite closure temperature) when the Horserace quartz diorite was emplaced.

This is inconsistent with field observations described above which suggested that the Katahdin granite was still at least partially molten. Solidus temperatures for Katahdin granite magma are considerably lower than liquidus temperatures for Horserace quartz diorite, so it is conceivable that the latter Horserace quartz diorite magma may have locally melted some of the Katahdin granite upon intrusion along the fault it is observed to follow, thus producing the contact relationships.

The age of the Katahdin granite is constrained by the calculated age of the Horserace quartz diorite as at least 375 Ma old, because intrusive relationships clearly indicate the Katahdin granite is older than the Horserace quartz diorite. The assumption that the Katahdin granite and Traveler rhyolite are contemporaneous has not been rigorously tested in this paper. If this assumption is valid, then the age of the late Siegenian is at least as old as 375 Ma, and probably closer to 400 Ma. We recommend that further attempts to fix the absolute age as a geologic time scale calibration should concentrate on a direct determination of the age of the Traveler rhyolite.

## ACKNOWLEDGMENTS

The authors would like to express their sincere appreciation to D. W. Rankin and L. L. Chyi for very helpful reviews of the manuscript. This work was supported by a grant (EAR-82-06549) from the National Science Foundation.

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