Rb-Sr age of the New Hampshire Plutonic Series

JOHN B. LYONS *Department of Earth Sciences, Dartmouth College, Hanover, New Hampshire 03755*
DONALD E. LIVINGSTON *Laboratory of Isotope Geochemistry, Department of Geosciences, University of Arizona, Tucson, Arizona 85721*

ABSTRACT

Rb-Sr whole-rock isochrons for four main representatives of the syntectonic to post-tectonic New Hampshire Plutonic Series yield the following ages: Kinsman Quartz Monzonite, 411 ± 19 m.y.; Bethlehem Gneiss, 405 ± 78 m.y.; Spaulding Quartz Diorite, 402 ± 5 m.y.; and Concord Granite, 359 ± 11 m.y. (or 330 ± 3 m.y.?). The Kinsman and Spaulding ages are consistent with a growing number of Rb-Sr ages determined for northern Appalachian granites, which are of Early Devonian or younger geologic age, and represent a major magmatic pulse of the Acadian orogeny. Comparison of Rb-Sr ages and geology implies that the beginning of the Devonian Period can be no later than approximately 415 m.y. and that the entire Devonian time scale needs revision.

The Concord Granite is at least 40 m.y. (possibly 70 m.y.?), younger than other members of the New Hampshire Plutonic Series, and its time of emplacement is therefore probably Late Devonian(?) or Mississippian(?).

Isochron plots imply that, although the members of the New Hampshire Plutonic Series have been derived by anatexis of lower crustal rocks, there is admixture of and contamination by mantle-derived magmatic material.

INTRODUCTION

The principal members of the syntectonic to posttectonic New Hampshire Plutonic Series, which was assigned a Late Devonian(?) age by Billings (1956), are (1) the Bethlehem Gneiss, (2) the Kinsman Quartz Monzonite, (3) quartz diorites and related rocks here considered to be correlative with the Spaulding Quartz Diorite, and (4) two-mica granites herein equated with the Concord Granite. These plutonic formations have been listed in order of decreasing geologic age as deduced from crosscutting field relationships, but there is uncertainty about Bethlehem-Kinsman age relations. Quinn (1941, p. 8), however, reported inclusions of Meredith porphyritic granite (Kinsman?) in Winnipesaukee Quartz Diorite (Bethlehem?); therefore, the Kinsman is probably the older formation. On the geologic map of New Hampshire (Billings, 1956, Pl. 1), all four plutonic units are shown in contact with the Lower Devonian Littleton Formation. However, on the basis of recent field studies in central and southwestern New Hampshire (Englund, 1976; Nielson, 1974; Dean, 1976), it seems likely that part of what had previously been shown as Littleton Formation in central New Hampshire (Billings, 1956) is of Silurian or older age.

It has been suggested by Thompson and others (1968) that the sheetlike Bethlehem Gneiss was injected concurrently with the development of large-scale nappes during the early stages of the Acadian orogeny. Similar relationships have been suggested for the Kinsman Quartz Monzonite (Nielson and others, 1976). Structural relations imply a late Acadian tectonic age for the Spaulding Quartz Diorite and a post-Acadian tectonic age for the Concord Granite. Thus, the magmatic rocks provide the potential for assigning radiogenic ages to the sequence of events occurring during the Acadian orogeny in this part of the northern Appalachians. Locations of the plutonic rocks isotopically analyzed in this study are shown in Figure 1.

PREVIOUS ISOTOPIC AGE STUDIES

There are no definitive isotopic age determinations for the New Hampshire Plutonic Series within New Hampshire. Faul and others (1963) published several K-Ar (246 to 306 m.y.) and Rb-Sr (241 to 335 m.y.) mineral ages, which were known at the time from geologic field relations to be erroneously young. These determinations throw into question the results of earlier Rb-Sr mineral ages (304 to 318 m.y.) on micas from the Concord Granite determined by Fairbairn and others (1960) and a K-Ar age of 323 m.y. of a pegmatite mica by Damon and Kulp (1957). Zartman and others (1970) published several additional K-Ar ages (221 to 337 m.y.) on New Hampshire plutons with results comparable to those of Faul and others (1963). Faul and others had concluded that the disturbed age pattern in New Hampshire was due to a Permian tectonic overprint. Although this overprint is strong in southern New England, Zartman and others believed that in New Hampshire, Vermont, and Maine the age pattern largely reflected unloading, and not Permian tectonism.

LABORATORY INVESTIGATIONS

Table 1 presents analytical data used to construct whole-rock Rb-Sr isochrons for the Bethlehem, Kinsman, Spaulding, and Concord plutons shown in the area of Figure 1. Rb and Sr were determined by x-ray fluorescence with a precision of approximately 0.3% of the amount reported or 0.3 ppm, whichever was larger. Rb^{87} was calculated using the accepted atomic ratio of Rb^{85}/Rb^{87} of 2.5906. Sr isotopes were measured on a 6-in. radius, 60° sector, triple-rhenium-filament mass spectrometer. All isotope ratios are based on Sr^{88}/Sr^{86} = 8.375 and adjusted to Sr^{87}/Sr^{86} = 0.7080 for Eimer and Amend standard $SrCO_3$. The Sr^{87}/Sr^{86}, Rb^{87}/Sr^{86} isochron age was calculated with $\lambda = 1.39 \times 10^{-11}\ yr^{-1}$ using York's modified program (York, 1966, 1969; Brooks and others, 1972), which takes account of all measurement errors and reports age determinations with a 1σ standard deviation. Computation programs have

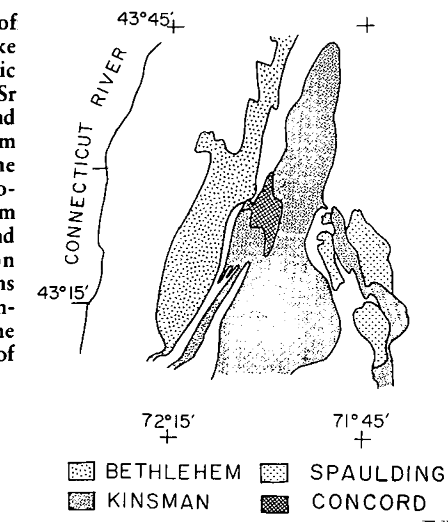

Figure 1. Sketch map of a portion of the sheetlike New Hampshire Plutonic Series. Samples for Rb-Sr isochrons of Concord and Bethlehem rocks come from the plutons shown on the map. The Kinsman isochron was constructed from rocks of the main sheet, and the Spaulding isochron from the three main plutons shown; these plutons are interpreted as parts of the same sheet on the basis of gravity studies.

Geological Society of America Bulletin, v. 88, p. 1808–1812, 5 figs., 2 tables, December 1977, Doc. no. 71212.

TABLE 1. Rb-Sr ANALYTICAL DATA, NEW HAMPSHIRE PLUTONIC SERIES

Formation	Rb (ppm)	Sr (ppm)	Sr^{87}/Sr^{86} (atomic ratio)	Rb^{87}/Sr^{86} (atomic ratio)
Concord Granite				
Mk 4-74	159 ± 0.8	574 ± 1	0.7110 ± 0.0002	0.222 ± 0.004
S1-74	157 ± 0.8	84 ± 0.5	0.7391 ± 0.0001	5.38 ± 0.04
S2-74	217 ± 0.7	50 ± 0.4	0.7735 ± 0.0003	12.7 ± 0.1
Mk107-74	198 ± 0.7	38 ± 0.4	0.7826 ± 0.0001	15.1 ± 0.2
Mk1-74	274 ± 0.8	33 ± 0.4	0.8286 ± 0.0001	24.6 ± 0.3
Mk 108-74	239 ± 0.8	14.8 ± 0.3	0.9321 ± 0.0001	47.6 ± 1.0
Bethlehem Gneiss				
S11-73	67.6 ± 0.5	1,436 ± 2	0.7044 ± 0.0005	0.136 ± 0.001
M19-73	148 ± 0.6	253 ± 0.7	0.7142 ± 0.0001	1.69 ± 0.01
M15-73	81.5 ± 0.6	207 ± 0.7	0.7160 ± 0.0001	1.14 ± 0.01
M16-73	134.6 ± 0.7	131.4 ± 0.6	0.7240 ± 0.0001	2.97 ± 0.02
M9-73	184 ± 0.7	124 ± 0.5	0.7323 ± 0.0002	4.30 ± 0.02
M10-73	285 ± 1	172 ± 0.7	0.7354 ± 0.0003	4.82 ± 0.03
S9-73	243 ± 1	87 ± 0.6	0.7465 ± 0.0002	8.11 ± 0.07
Kinsman Quartz Monzonite				
Mk37-73*	40.9 ± 0.5	1,164 ± 2	0.7042 ± 0.0001	0.102 ± 0.001
Mk35-73	43.6 ± 0.5	144 ± 0.7	0.7157 ± 0.0002	0.880 ± 0.011
S3-67	108 ± 0.8	204 ± 0.7	0.7197 ± 0.0001	1.54 ± 0.01
S37-66	130 ± 0.7	192 ± 0.7	0.7218 ± 0.0004	1.96 ± 0.01
Mk36-73	127.6 ± 0.6	123 ± 0.6	0.7272 ± 0.0001	3.01 ± 0.02
Mk7-74	93.2 ± 0.5	59 ± 0.4	0.7381 ± 0.0002	4.58 ± 0.04
Spaulding Quartz Diorite				
Co29-72*	9.5 ± 0.5	321 ± 1	0.7071 ± 0.0002	0.085 ± 0.004
Mk9-71*	56.5 ± 0.5	283 ± 1	0.7094 ± 0.0001	0.579 ± 0.006
Mk-37-74*	97 ± 0.6	226 ± 0.8	0.7162 ± 0.0002	1.24 ± 0.01
Co2-71*	86.3 ± 0.6	146.5 ± 0.6	0.7170 ± 0.0002	1.71 ± 0.01
Mk3-71	125 ± 0.6	128 ± 0.6	0.7302 ± 0.0001	2.84 ± 0.02
Mk10-71	222 ± 0.7	110 ± 0.5	0.7475 ± 0.0005	5.84 ± 0.03
Hi91-72	225 ± 0.8	74.3 ± 0.5	0.7630 ± 0.0003	8.82 ± 0.06
Hi1-71	229 ± 0.8	64 ± 0.4	0.7734 ± 0.0003	10.46 ± 0.08

Note: All precision estimates are for one standard deviation.
* Not used for isochron calculations of Figures 2 to 5.

been cross-checked against those of Brooks and others (1972), using their data for the Heemskirk Granite.

RESULTS

Isochrons for the data of Table 1 are plotted in Figures 2, 3, 4, and 5. The six points on the Concord Granite isochron yield an age of 359 ± 11 m.y., with an initial Sr^{87}/Sr^{86} ratio of 0.7107 ± 0.0009. The first sample (Mk4-74, Table 1) is a granodiorite that plots below the isochron of the other five Concord rocks. Without this sample there is a much tighter isochron age of 330 ± 3 m.y. (dashed isochron in Fig. 2) and an initial Sr^{87}/Sr^{86} ratio of 0.7144 ± 0.0004. However, we have no geologic nor other geochemical grounds at present for eliminating sample Mk4-74, which originates from the same stock as the other Concord rocks.

The Bethlehem Gneiss (Fig. 3) shows a disturbed pattern. The isochron for all seven points on the plot (405 ± 78 m.y., initial Sr^{87}/Sr^{86} = 0.7065 ± 0.0022) has an unacceptably large range, which only allows a conclusion that the formation is of mid-Paleozoic age.

The Kinsman Quartz Monzonite for all six isochron points also yields an unsatisfactory isochron of 605 ± 83 m.y. The isochron shown in Figure 4, however, has been drawn by eliminating sample Mk37-73 of Table 1; the resulting isochron of 411 ± 19 m.y., with an initial Sr^{87}/Sr^{86} ratio of 0.7107 ± 0.0006, embraces what we take to be an accurate determination of the age of emplacement of the Kinsman. Sample Mk37-73 is a sheared and boudinaged dike of aplitic texture which intrudes the Kinsman Quartz Monzonite and has been deformed along with it. Mineralogically, it is leucocratic biotite tonalite, with an extraordinarily high Sr content (Table 1), extraordinarily low Rb/Sr ratio, and a sufficiently low Sr^{87}/Sr^{86} ratio (0.7042) to imply mantle derivation. Sample S11-73 (Table 1) is a very similar aplitic rock cutting the Bethlehem Gneiss, probably

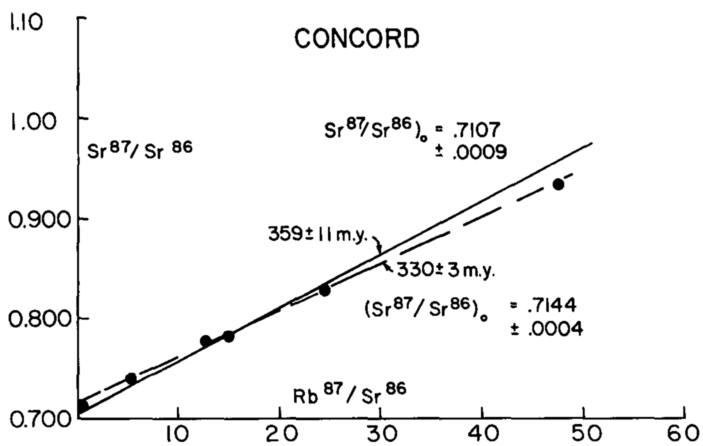

Figure 2. Whole-rock Rb-Sr isochron for the Concord Granite.

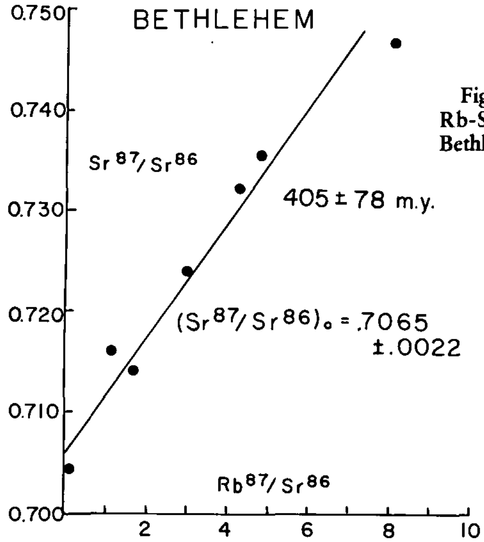

Figure 3. Whole-rock Rb-Sr isochron for the Bethlehem Gneiss.

with a similar petrogenetic history. Geochemically, both these rocks have Rb, Sr, and Sr^{87}/Sr^{86} contents similar to those of basalts (Kistler and Peterman, 1973). These data imply, to us, that the anatexis responsible for the initial development of Kinsman (and Bethlehem) magmas occurred near the crust-mantle interface. Major melting occurred in the lower crust, giving rise to granite magmas with initial Sr^{87}/Sr^{86} ratios of approximately 0.710. Infrequently, however, residual melts of mantle derivation were vented upward along the same conduits that were previously used by Kinsman or Bethlehem magmas — hence the injection of minor amounts of mantle-derived material into rocks of predominantly crustal derivation.

This brief digression into petrogenesis has been necessary to elucidate what we believe to be true of the unusual isochron for the Spaulding Quartz Diorite. Four of the eight samples, those with high Rb^{87}/Sr^{86} and Sr^{87}/Sr^{86} ratios, lie along an excellent isochron of 402 ± 5 m.y., with an initial Sr^{87}/Sr^{86} ratio of 0.7143 ±0.0003 (Fig. 5). The remaining four points, all lying below the isochron, tail off to a Sr^{87}/Sr^{86} ratio of 0.7071. Three of these low-value rocks are garnet-bearing tonalite, and the fourth, with the lowest Sr^{87}/Sr^{86} ratio, is hornblende gabbro-diorite. The simplest and, we believe, the best explanation of the isochron of Figure 5 is to extend the model for the petrogenesis of the Kinsman rocks. The four upper points on the diagram we take to represent an originally homogeneous pocket of magma of crustal derivation; the lower four points represent mantle-contaminated crustal melts, or crustal-contaminated mantle melts. Given the facts that experimental error is low (Table 1) and that processes which would progressively fractionate Sr or Rb isotopes are both difficult to envision and to substantiate, the contamination model appears to us to be the one that is most satisfactory for the data at hand. Alternative interpretations such as heterogeneities in mantle or crustal source rock, gain or loss of Rb and Sr, or the existence of Spaulding magmas of slightly differing age as well as source region are all possible. The problem, however, is basically insoluble with the information available, so that further speculation is pointless. The interpretation we favor for the Spaulding magma is consistent with the data for the Kinsman and Bethlehem series.

DEVONIAN TIME SCALE

If the age results for the Bethlehem Gneiss have an unacceptably large scatter (405 ± 78 m.y.), the ages that we accept for the Kinsman Quartz Monzonite (411 ± 19 m.y.) and the Spaulding Quartz Diorite (402 ± 5 m.y.) also present a problem, because although these ages agree with the observed intrusive sequence, they fall outside the limits commonly accepted (400 to 350 m.y.; Kulp, 1961; Harland and others, 1964) for the duration of the Devonian Period. It is instructive, therefore, to look at the Devonian time scale in light of some recent Rb-Sr data (Table 2) from the northern Appalachians.

The data on the age of the Silurian-Devonian time break (Table 2) are, unfortunately, somewhat inconsistent, with Brookins and others (1973) reporting ages approximately 20 m.y. younger than those by Bottino and Fullagar (1966) for formations that apparently straddle this time boundary. Other data in the table would be consistent with the older age (413 m.y.) and more in line with a suggestion by Lambert (1971, p. 31), based on a world-wide survey of Rb-Sr ages, that the break may be as old as 430 m.y. (for $\lambda = 1.39 \times 10^{-11}$ yr^{-1}).

For the Early to Middle Devonian time interval, the northern Appalachian data of Table 2 are much less complete. The only relevant ages (353 and 365 m.y. for the Traveler and Kineo felsic volcanic rocks) led Fullager and Bottino (1968b) to propose a time span of at least 50 m.y. for the Early Devonian. More data are obviously needed, because these ages are grossly inconsistent with Lambert's (1971, p. 25) proposal that the Devonian-Mississippian break may be as old as 380 m.y., and with the whole-rock Rb-Sr age of 379 ± 15 by Cormier and Kelly (1964) for the Lower Mississippian Fisset Brook Formation of Nova Scotia.

In summary, there is enough doubt concerning the absolute time scale for the Devonian so that our ages of 405 m.y. (Bethlehem), 411 m.y. (Kinsman), 402 m.y. (Spaulding), and 359 m.y. (Concord) cannot yet be assigned with certainty to either the Early, Middle, or Late Devonian, even if we agree, as most evidence now suggests, that the Silurian-Devonian break lies in the range of 413 to 430 m.y.

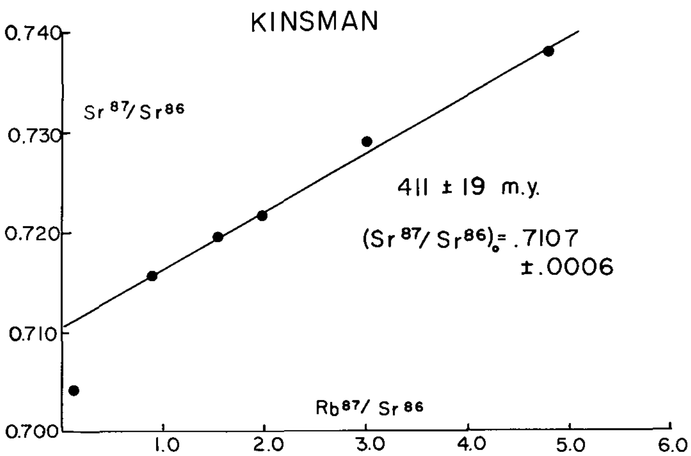

Figure 4. Whole-rock Rb-Sr isochron for the Kinsman Quartz Monzonite.

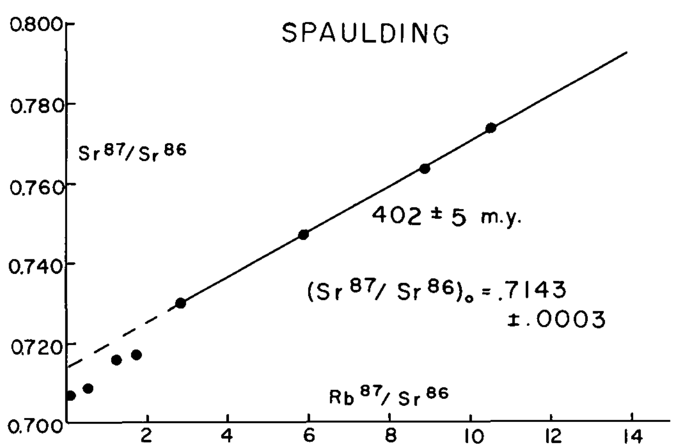

Figure 5. Whole-rock Rb-Sr isochron for the Spaulding Quartz Diorite.

DISCUSSION

The age of the Acadian orogeny in the northern Appalachians has been dated in various ways. Boucot (1968, p. 89–93) preferred a middle Middle Devonian age partly on the basis of the facts that the youngest marine sediments are of Onondaga-Eifelian (early Middle Devonian) age and that in northern Maine there is an angular unconformity beneath terrestrial upper Middle Devonian sediments. Naylor (1971) has argued that the entire cycle of Early Devonian sedimentation, subsequent folding, igneous intrusion, and regional metamorphism is encompassed in the time span between 410 and 380 m.y. As we have seen, however, it is not absolutely certain how these numbers fit into the Devonian time scale. Also, Rb-Sr whole-rock ages in the 360 to 370 m.y. range are common in the northern Appalachians (Fairbairn, 1971; Naylor, 1973; Hatch, 1975; Mose and others, 1976), so a cut-off date of 380 m.y.B.P. for the end of the Acadian orogeny seems unrealistic. Pajari and others (1974), relying in part on the ages of the Eastport volcanic rocks and St. George pluton (Table 2), have argued for an Early Devonian age of Acadian folding, metamorphism, and intrusion in the Maine–New Brunswick border area.

In New Hampshire, the age of the youngest formation intruded by the New Hampshire Plutonic Series is in some doubt, although Billings' (1956, Pl. 1) geologic map of New Hampshire shows the Lower Devonian Littleton Formation as the youngest. The problem stems from the fact that absolute stratigraphic correlation between the low-grade fossiliferous Littleton Formation of western New Hampshire with its presumed high-grade equivalent in central New Hampshire is not yet possible. Moreover, as discussed by Billings and Cleaves (1934, p. 422) and Billings and Fowler-Billings (1976, p. 26), it is possible that the lower part of the fossiliferous Littleton Formation at the type locality could be as old as Middle Silurian.

In the immediate area of central New Hampshire, from which the samples of Table 1 were collected, the youngest metasedimentary formation (Littleton) is a gray metapelite showing graded bedding, at the base of which is an angular unconformity. A similar unit, also youngest in the area and with a probable unconformity at its base (Dean, 1976), is recognized in the high-grade rocks of southwestern New Hampshire. It is not unlikely, as suggested by Dean, that this cyclically bedded unit is correlative with the Lower Devonian Seboomook Formation of western Maine. Two points are now worth noting: (1) despite the lack of fossil evidence, we can be reasonably confident that rocks at least as young as Early Devonian were intruded by the New Hampshire Plutonic Series in central New Hampshire, and (2) the angular unconformity at the base of the Littleton (Seboomook) Formation implies that the rocks beneath may be of Silurian or older age; this also suggests that Boucot's (1962, p. 156) "Salinic disturbance" (Late Silurian) in Maine may be widespread throughout the northern Appalachians and may signal an early phase of Acadian deformation.

Whatever the correct designation of the New Hampshire Plutonic Series (Early? to Late? Devonian), it is clear that it is representative of a widespread cycle of Acadian plutonism first recognized by Spooner and Fairbairn (1970) as commencing approximately 410 m.y. ago. Plutonism continued fairly strongly for at least 30 m.y. and then tapered off during the next 20 m.y. The pronounced maximum of K-Ar ages at 360 m.y. in the northern Appalachians (Lyons and Faul, 1968) is apparently some 20 to 25 m.y. younger than the maximum for Rb-Sr whole-rock ages, the difference presumably reflecting loss of Ar.

The Hillsboro Plutonic Series of southeastern New Hampshire and southwestern Maine also has several intrusive units which, by Rb-Sr whole-rock dating, are approximately 400 m.y. old (Gaudette and others, 1975, and oral commun.); it is therefore coeval with the New Hampshire Plutonic Series.

Our age for the Concord Granite (359 m.y.) is younger than the Rb-Sr minimum age of 380 m.y. determined by Naylor (1971) for the presumably coeval Barre Granite of northeastern Vermont, but

TABLE 2. SOME RECENT WHOLE-ROCK Rb-Sr DEVONIAN AGES FROM THE NORTHERN APPALACHIANS

Geochronologic age (m.y.)	Formation	Paleontologic-geologic age	Reference
412 ± 5	Eastport volcanic rocks, Maine	Latest Silurian or earliest Devonian	Bottino and Fullagar (1966)
413 ± 10	Hedgehog volcanic rocks, Maine	Gedinnian (earliest Devonian)	Bottino and Fullagar (1966)
400	Red Beach Granite, Maine–New Brunswick	Intrudes Eastport volcanic rocks	Spooner and Fairbairn (1970)
394 ± 20	St. George pluton, New Brunswick	Intrudes deformed Eastport volcanic rocks	Pajari and others (1974)
390 ± 5	Castine Volcanics, Maine	Late Silurian (Pridoli)	Brookins and others (1973)
387 ± 9	Cranberry Island volcanic rocks, Maine	Late Silurian to Early Devonian	Brookins and others (1973)
393 ± 6	Vinalhaven Rhyolite, Maine	Early Devonian (Gedinnian)	Brookins and others (1973)
353 ± 7	Traveler quartz latite, Maine	Early Devonian (Esopus = Emsian)	Fullagar and Bottino (1962)
365 ± 15	Kineo rhyolite, Maine	Late Early Devonian or early Middle Devonian (Onondage-Oriskany)	Fullagar and Bottino (1968b)
417 ± 38	Nova Scotia quartz monzonites	Cuts deformed rocks of earliest Devonian age	Cormier and Smith (1973)
379 ± 6	Mooselookmeguntic pluton, Maine	Lower to Middle Devonian; Postmetamorphic	Zartman (1974)
385 ± 20	Prescott complex, Massachusetts	Post-Acadian nappes pre-Acadian doming	Naylor (1970)
379 ± 15	Fisset Brook Formation, Nova Scotia	Earliest Mississippian	Cormier and Kelly (1964)

almost identical to the 360 ± 10 m.y. lead-alpha age of the Concord Granite in the type area at Concord, New Hampshire (W. H. Vernon, 1975, written commun.). Further dating of our Concord Granite stock may conceivably confirm a 330 m.y., rather than the 359 m.y., age. A 330-m.y. age has been reported by Gaudette and others (1975) for two stocks in southwestern Maine, suggesting that a cycle of Mississippian (Variscan) plutonism in New England may be more widespread than heretofore suspected.

ACKNOWLEDGMENTS

We are grateful to Edward Kessler, Gary Johnson, and Robert Dockweiler for their excellent assistance in the Geochronology Laboratory at the University of Arizona, where these Rb-Sr age determinations were made. Financial assistance for the work was provided by National Science Foundation Grants DES72-01535 AO1 (Lyons) and GA-41505 (Livingston). We appreciate constructive criticism of an earlier draft of this paper by M. P. Billings, R. S. Naylor, H. E. Gaudette, D. L. Nielson, and C. S. Dean. Questioning by E. L. Boudette and J. G. Arth of the U.S. Geological Survey led to detection of an error in our original tabulation of the Concord Granite data. We are indebted to them not only for this assistance, but also for several computer recalculations and discussions of the Concord data, as well as cross-check calculations of our other isochrons.

REFERENCES CITED

Billings, M. P., 1956, The geology of New Hampshire: Pt. II, Bedrock geology: Concord, New Hampshire State Planning and Devel. Comm., 203 p.

Billings, M. P., and Cleaves, A. B., 1934, Paleontology of the Littleton area, New Hampshire: Am. Jour. Sci., 5th ser., v. 28, p. 412–438.

Billings, M. P., and Fowler-Billings, K., 1976, Geology of the Gorham quadrangle, New Hampshire–Maine: New Hampshire Dept. Resources and Econ. Devel. Bull. 6, 120 p.

Bottino, M. L., and Fullagar, P. D., 1966, Whole-rock rubidium-strontium age of the Silurian-Devonian boundary in northeastern North America: Geol. Soc. America Bull., v. 77, p. 1167–1176.

Boucot, A. J., 1962, Appalachian Siluro-Devonian, *in* Coe, Kenneth, ed., Some aspects of the Variscan Fold Belt; Internat. Univ. Geol. Cong., 9th: Manchester, England, Manchester Univ. Press, p. 155–163.

——1968, Silurian and Devonian of the northern Appalachians, *in* Zen, E-An, White, W. S., Hadley, J. B., and Thompson, J. B., Jr., eds., Studies of Appalachian geology — Northern and maritime: New York, Interscience Pubs., p. 203–213.

Brookins, D. G., Berdan, J. M., and Stewart, D. B., 1973, Isotopic and paleontologic evidence for correlating three volcanic sequences in the Maine coastal volcanic belt: Geol. Soc. America Bull., v. 84, p. 1619–1628.

Brooks, C., Hart, S. R., and Wendt, L., 1972, Realistic use of two-error regression treatments as applied to rubidium-strontium data: Rev. Geophysics and Space Physics, v. 10, p. 551–577.

Cormier, R. F., and Kelly, A. M., 1964, Absolute age of the Fisset Brook Formation and the Devonian-Mississippian boundary, Cape Breton Island, Nova Scotia: Canadian Jour. Earth Sci., v. 1, p. 159–166.

Cormier, R. F., and Smith, T. E., 1973, Radiometric ages of granitic rocks, southwestern Nova Scotia: Canadian Jour. Earth Sci., v. 10, p. 1201–1210.

Damon, P. E., and Kulp, J. L., 1957, Argon in mica and the age of the Beryl Mt., N.H., pegmatite: Am. Jour. Sci., v. 255, p. 697–704.

Dean, C. A., 1976, Stratigraphy of the Sunapee septum, southwestern New Hampshire: Geol. Soc. America Abs. with Programs, v. 8, p. 160.

Englund, E. J., 1976, The bedrock geology of the Holderness quadrangle, New Hampshire: New Hampshire Dept. Resources and Econ. Devel. Bull. 7, 90p.

Fairbairn, H. W., 1971, Radiometric age of mid-Paleozoic intrusives in the Appalachian-Caledonides mobile belt: Am. Jour. Sci., v. 270, p. 205–217.

Fairbairn, H. W., Pinson, W. H., Hurley, P. M., and Cormier, R. F., 1960, A comparison of the ages of coexisting biotite and muscovite in some Paleozoic granite rocks: Geochim. et Cosmochim. Acta, v. 17, p. 7–9.

Faul, H., Stern, T. W., Thomas, H. R., and Elmore, P.L.D., 1963, Age of intrusion and metamorphism in the northern Appalachians: Am. Jour. Sci., v. 201, p. 1–19.

Fullagar, P. D., and Bottino, M. L., 1968a, Rb-Sr whole-rock ages of Silurian-Devonian volcanics from eastern Maine [abs.]: Am. Geophys. Union Trans., v. 49, p. 346.

——1968b, Geochronology of Silurian and Devonian age volcanic rocks from northeastern North America: Internat. Geol. Cong., 23rd, Prague, v. 6, p. 17–32.

Gaudette, H. E., Fairbairn, A. W., Kovoch, A., and Hussey, A. M., 1975, Preliminary Rb-Sr whole-rock age determinations of granitic rocks in southwestern Maine: Geol. Soc. America Abs. with Programs, v. 7, p. 62–63.

Harland, W. B., Smith, A. G., and Wilcox, B., 1964, The Phanerozoic time scale: Geol. Soc. London Quart. Jour., v. 120 S, p. 206–262.

Hatch, N. L., 1975, Tectonic, metamorphic, and intrusive history of part of the east side of the Berkshire massif in Massachusetts: U.S. Geol. Survey Prof. Paper, 888D, p. 51–68.

Kistler, R. W., and Peterman, Z. E., 1973, Variation in Sr, Rb, K, Na and initial Sr^{87}/Sr^{86} in Mesozoic granitic rocks and intruded wallrocks in central California: Geol. Soc. America Bull., v. 84, p. 3489–3512.

Kulp, J. L., 1961, Geologic time scale: Science, v. 133, p. 1105–1114.

Lambert, R.St.S., 1971, The pre-Pleistocene Phanerozoic time-scale — A review, *in* Harland, W. B., and Francis, E. H., eds., The Phanerozoic time-scale, a supplement. Pt. I, Supplementary papers and items: Geol. Soc. London Spec. Pub. 5, p. 9–31.

Lyons, J. B., and Faul, H., 1968, Isotope geochronology of the northern Appalachians, *in* Zen, E-An, White, W. S., Hadley, J. B., and Thompson, J. B., eds., Studies of Appalachian geology — Northern and maritime: New York, Interscience Pubs., p. 305–318.

Mose, D. G., Ratcliffe, N. M., Odum, A. L., and Hayes, J., 1976, Rb-Sr geochronology and tectonic setting of the Peekskill pluton, southeastern New York: Geol. Soc. America Bull., v. 87, p. 361–365.

Naylor, R. S., 1970, Radiometric dating of Pennine-type nappes in the northern Appalachians: Eclogae Geol. Helvetiae, v. 63, p. 230.

——1971, Acadian orogeny: An abrupt and brief event: Science, v. 172, p. 558–560.

——1973, Age of the Lexington batholith, western Maine: Geol. Soc. America Abs. with Programs, v. 5, p. 200.

Nielson, D. L., 1974, The structure and petrology of the Hillsboro quadrangle, New Hampshire [Ph.D. thesis]: Hanover, N.H., Dartmouth Coll., 254. p.

Nielson, D. L., Clark, R. G., Lyons, J. B., Englund, E. J., and Borns, D. J., 1976, Gravity models and mode of emplacement of the New Hampshire Plutonic Series, *in* Lyons, P. C., and Brownlow, A. H., eds., Studies in New England geology: Geol. Soc. America Mem. 146, p. 301–318.

Pajari, G. E., Trembath, L. T., Cormier, R. F., and Fyffe, L. R., 1974, The age of the Acadian deformation in southwestern New Brunswick: Canadian Jour. Earth Sci., v. 11, p. 1309–1313.

Quinn, A. W., 1941, The geology of the Winnipesaukee quadrangle, New Hampshire: Concord, New Hampshire Planning and Devel. Comm., 20 p.

Spooner, C. M., and Fairbairn, H. W., 1970, Relation of radiometric age of granitic rocks near Calais, Maine, to the time of Acadian orogeny: Geol. Soc. America Bull., v. 81, p. 3663–3670.

Thompson, J. B., Jr., Robinson, P., Clifford T. M., and Trask, N. J., 1968, Nappes and gneiss domes in west-central New England, *in* Zen, E-An, White, W. S., Hadley, J. B., and Thompson, J. B., Jr., eds, Studies of Appalachian geology — Northern and maritime: New York, Interscience Pubs., p. 203–213.

York, D., 1966, Least-squares fitting of a straight line: Canadian Jour. Physics, v. 44, p. 1079–1086.

——1969, Least-squares fitting of a straight line with correlated errors: Earth and Planetary Sci. Letters, v. 5, p. 320–324.

Zartman, R. E., 1974, Dating of metamorphism and tectonic overprinting in western Maine, *in* Geological Survey research, 1974: U.S. Geol. Survey Prof. Paper 900, p. 24.

Zartman, R. E., Hurley, P. M., Krueger, H. W., and Giletti, B. J., 1970, A Permian disturbance of K-Ar radiometric ages in New England: Its occurrence and cause: Geol. Soc. America Bull., v. 81, p. 3359–3374.

Manuscript Received by the Society July 30, 1976
Revised Manuscript Received December 21, 1976
Manuscript Accepted February 5, 1977
Contribution No. 732, University of Arizona Department of Geosciences

Printed in U.S.A.