

AGES OF THE WHITE MOUNTAIN INTRUSIVES— NEW HAMPSHIRE, VERMONT, AND MAINE, USA

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ABSTRACT. We report K-Ar ages (mostly biotite) for 33 samples from a total of 26 complexes assigned to the White Mountain magma series in northcentral New England. Nearly all White Mountain complexes have now been dated, and the total range of ages is approximately 235 to 100 m.y. Rb-Sr and U-Pb isotopic ages are generally concordant with the K-Ar biotite ages. K-Ar ages of different intrusive members of individual complexes appear to be identical within analytical uncertainty. The small differentiated complexes appear to have been emplaced within a few million years or less.

The ages of the various complexes fall into three groups—near 230, 200 to 156, and 125 to 100 m.y. Magmatic activity was concentrated in the latter two intervals with apparent maxima at 180 and 120 m.y. ago. The distribution of White Mountain rocks in time appears to eliminate the mantle hot-spot hypothesis as an explanation for their origin. The ages are consistent with the hypothesis that the White Mountain and Monteregean Hill intrusions occur along the extension of a transform fault.

INTRODUCTION

After all the major deformational episodes in the Northern Appalachians had ended, about 30 igneous complexes were emplaced in New Hampshire and adjacent portions of Maine and Vermont. In this connection, but not in the sense of position in an orogenic cycle, these intrusions may be termed “post-tectonic”. These rocks are the subject of many papers, among them the classical works by Daly (1903) and Billings (1945) on mechanisms of intrusion. Billings (1956) gives an excellent summary of the details of many of these occurrences. On the basis of chemical, textural, and structural similarities, Billings classified the intrusives from a number of isolated localities as the White Mountain plutonic-volcanic series. Subsequently, other similar units in the same general area have been correlated with the White Mountain series (for example, Hussey, 1968). Here we use the term *White Mountain rocks* to include all the plutonic Mesozoic igneous bodies of the three-state area without implying any comagmatic or coeval relationship. Their distribution is shown in figure 1.

The White Mountain rocks occur as ring dikes and small stocks; the one complex of batholithic size, the White Mountain batholith, is a composite of numerous intrusions. The rocks are of moderate alkaline character and range from basic to acidic with granite (usually termed *Conway granite*) predominating. Some intrusions are composed of a single rock type, others of several intrusive phases. The field relations at any one locality show relative emplacement ages corresponding to a gabbro-to-granite order (Chapman and Williams, 1935), and the petrologic relations among the various units generally have been attributed to magmatic differentiation. The gross similarities of these rocks are perhaps best illustrated by the fact that Billings (1945) postulated that they evolved from a single, albeit very large, magma chamber.

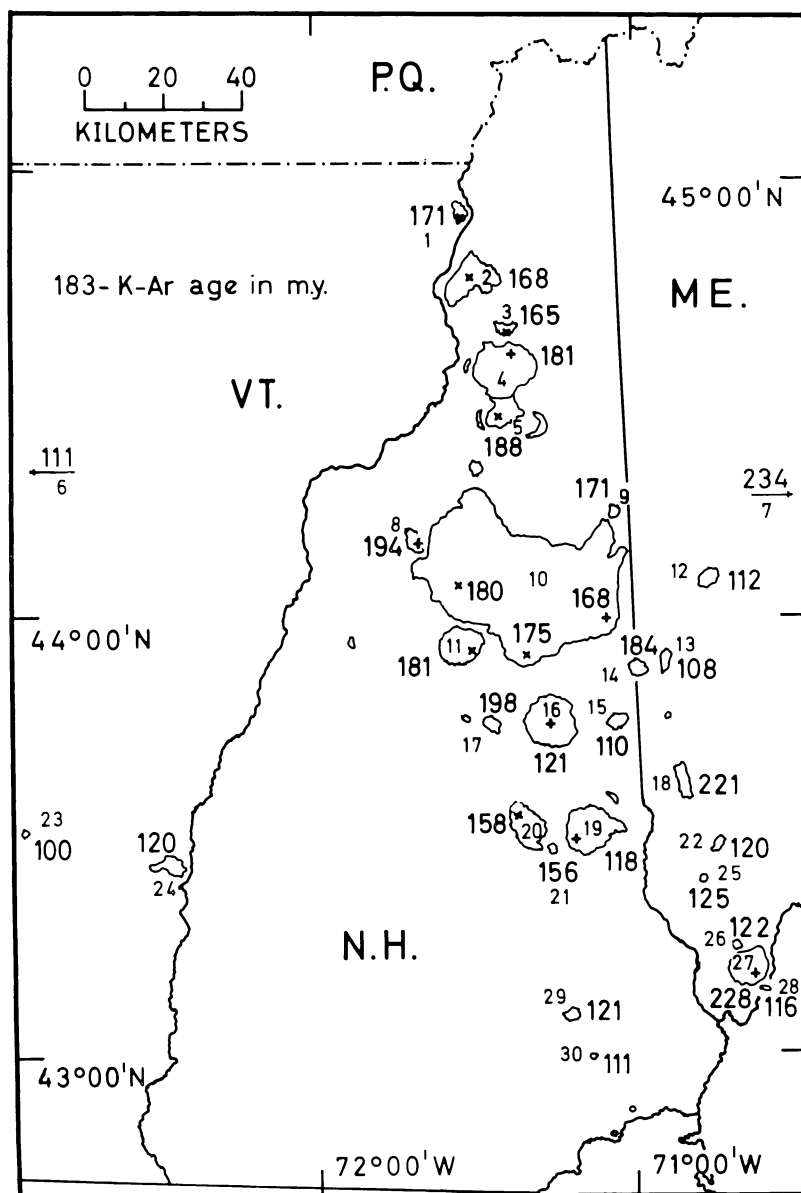


Fig. 1. K-Ar ages of White Mountain rocks, in m.y. (large numbers). The smaller numbers correspond to localities as given in table 1 and app 2. Sample locations are shown only for some larger complexes. Two complexes, Litchfield (7, 69°50' W) and Barber Hill (6, 73°15' W), lie off the map.

The White Mountain intrusions have been placed into the modern framework of plate theories in several ways. Several workers (for example, Morgan, 1971) have suggested that they have a mantle hot-spot or plume origin. Others (for example, Ballard and Uchupi, 1972) suggest emplacement along fracture zones or along the extension of a transform fault (for example, Fletcher, Sbar, and Sykes, 1974).

Previous age determinations.—Lead-alpha determinations by Lyons and others (1957) indicated a Mesozoic age for the White Mountain rocks. Potassium-argon, rubidium-strontium, and isotopic uranium-lead analyses of the Conway granite near Redstone, N.H., produced concordant or nearly concordant results of 170 to 190 m.y. (Tilton and others, 1957; Aldrich and others, 1958; Hurley and others, 1960). Further studies (Faul and others, 1963; Foland, Quinn, and Giletti, 1971; Armstrong and Stump, 1971) showed that White Mountain rocks fall into a wider age bracket, from about 100 to 220 m.y. That made the younger White Mountain rocks roughly contemporaneous with the Monteregian Hills intrusions which stretch southeastward from Montreal (fig. 2) and have ages approximately 100 to 125 m.y. (see Gold, 1967). The older complexes overlap in age with the Newark Group basalts and diabases, which are widespread in the eastern Appalachians, and which have ages clustering around 200 m.y. (see Dalrymple, Grommé, and White, 1975; Armstrong and Besancon, 1970). The ages of 14 White Mountain complexes were not uniformly distributed over the 120 m.y. interval, and at that point it was not clear whether the magmatic activity had been continuous over much of the Mesozoic or whether it had been concentrated within a few, relatively short periods.

Fission track ages for a number of these plutons, as well as a wide variety of rocks in the area, are available (Christopher, 1969; Doherty, ms; Zimmermann and others, 1975), but they do not shed light on this particular question. Apatite fission track ages measured on a wide spectrum of Northern Appalachian units, some Mesozoic and some Paleozoic, are all Cretaceous and indicate time of uplift rather than petrogenesis (Zimmermann and others, 1975). All the apatite fission track determinations fall into a narrow bracket, lower than the youngest K-Ar ages of the White Mountain rocks. Zircon fission track ages (Doherty, ms) for White Mountain localities similar to those of Foland, Quinn, and Giletti (1971) are higher than apatite dates and tend to be concordant with K-Ar biotite determinations. Because of the unresolved uncertainty in the value of the ^{238}U spontaneous fission decay constant, closer comparison between fission track and K-Ar results would have little significance. Using the lower decay constant ($\lambda_f = 6.85 \times 10^{-17} \text{ yr}^{-1}$, Fleischer and Price, 1964), the apatite fission track ages for all the units in northcentral New England would be similar to the K-Ar ages of the youngest White Mountain rocks, but with the higher decay constant ($\lambda_f = 8.46 \times 10^{-17} \text{ yr}^{-1}$, Wagner and others, 1975) they would be 23 percent lower. We interpret the apatite ages in northern New England as cooling ages, re-

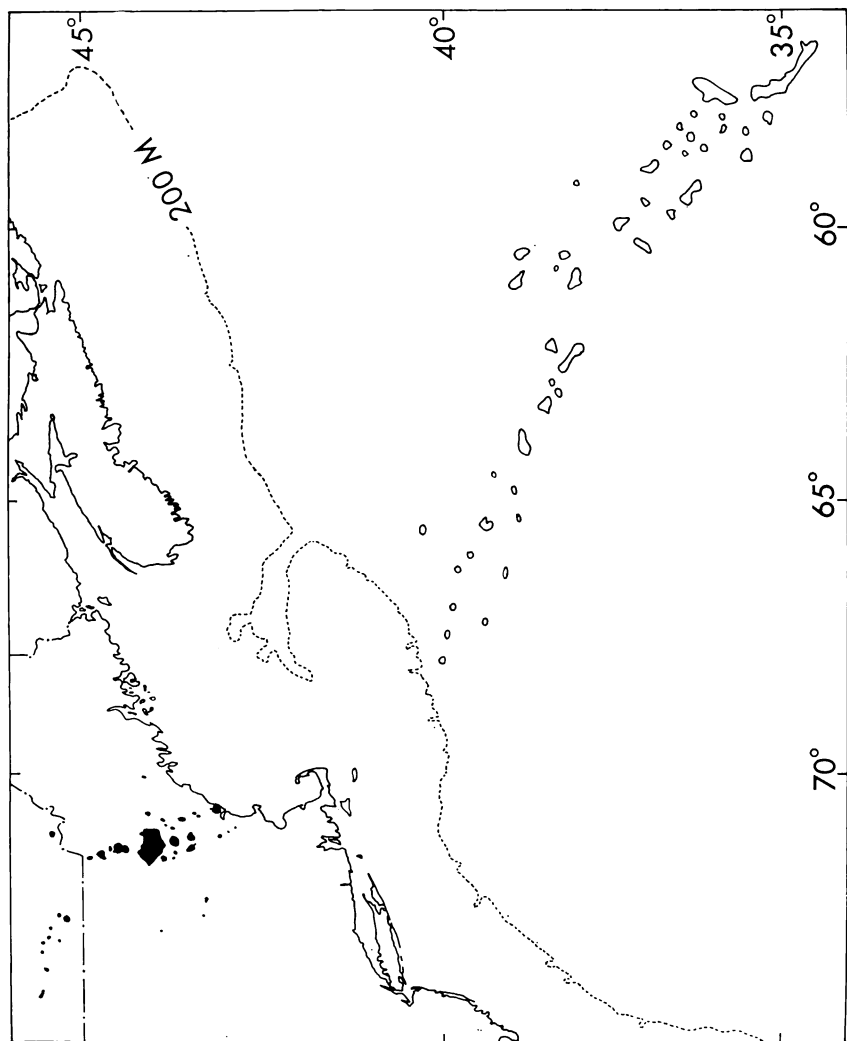


Fig. 2. Sketch map showing the locations of the Montereigian Hills, White Mountain intrusives, and New England seamount chain as interpreted from bathymetry.

flecting regional denudation after the emplacement of the youngest Mesozoic intrusions.

NEW AGE DETERMINATIONS

In this paper we present new age determinations and corrections to previous measurements for a total of 33 samples from 26 igneous complexes. Only a few minor intrusions remain to be dated, either because outcrops of reasonably fresh rock could not be found or because clean mineral separates could not be obtained. The list of dated White Mountain complexes is now essentially complete, and a compilation of all available isotopic age data is given as app 2.

Analytical procedures.—K-Ar analyses were made on separated minerals, typically, but not always >99 percent biotite. Some separates unavoidably contained chlorite as evidenced by low K concentrations. Potassium was determined, in duplicate (or more), by isotope dilution or by flame photometry by the lithium metaborate internal standard technique (Suhr and Ingamells, 1966), calibrated with gravimetric solutions. Sample exchange with the United States Geological Survey laboratory at Menlo Park shows agreement of K values within 0.5 percent. Argon was measured by isotope dilution with an ^{38}Ar spike on a 60°, 15-cm, Nier-type mass spectrometer of our own construction. Our vacuum fusion technique uses induction heating, Ti gettering, CuO purification, and a single-stopcock spike metering system calibrated with reference to a mercury manometer. Five analyses of the LP-6 biotite standard give $1.896 \pm 0.016 \times 10^{-9}$ g-atom radiogenic $^{40}\text{Ar}/\text{g}$. All analyses in table 1 were made with the same spike series.

The data in table 1 include corrections to some values reported by Foland, Quinn, and Giletti (1971) which reflect recalibration on our system of one batch of manifold spikes used in their work. The ^{40}Ar concentrations (and ages) for their sample numbers 1, 2, 3, 5, 7, 9, 12, and 15 (Foland, Quinn, and Giletti, 1971, p. 322-323) are actually approximately 6 percent higher. We have also redetermined the K and ^{40}Ar concentrations on sample Vt-3 from Mount Ascutney (Faul and others, 1963). The new value for K, approximately 2 percent higher than originally reported, is preferred. Comparison of new analyses on the B-3203 (M.I.T.) reference biotite with the early United States Geological Survey results (Faul and others, 1963) suggests that the old (pre-Li standard) K analyses may be systematically low by 2 percent.

To facilitate comparison with New England K-Ar ages reported in the literature, we have used the "old" constants (table 1). Use of the new values proposed by Beckinsale and Gale (1969) would increase all the ages by almost 3 percent. Rb-Sr ages are calculated with a ^{87}Rb decay constant of $1.42 \times 10^{-11} \text{ yr}^{-1}$ (Armstrong, ms) which is nearly halfway between the two values that have been in general use.

Results.—The individual complexes have been assigned ages shown in figure 1 principally on the basis of K-Ar ages in table 1 and app 2. Agreement between the new data and those in the literature is good.

Our corrections of some previously reported data produce a tighter clustering of ages and bring ages of different samples from the same complex into closer agreement.

The new data define the picture more clearly but do not drastically alter it. The K-Ar ages range from about 100 to 230 m.y. but are not evenly distributed within this interval. The data fall into three groups: near 230, 156 to 198, and 100 to 125 m.y. The oldest group consists of three bodies in southernmost Maine: Abbott Mountain, Litchfield (Burke, Otto, and Denison, 1969), and Agamenticus. The group of White Mountain rocks with Jurassic ages includes most of the localities originally termed White Mountain magma series and is found in central and northern New Hampshire. Intrusives of the youngest, Cretaceous group are sprinkled across southern Vermont, southern New Hampshire, and southern Maine. There is no clear geographic line of demarcation between the Jurassic and Cretaceous intrusions. As noted by Armstrong and Stump (1971), there is a central region of older intrusions flanked by younger ones to the north (the Monteregian Hills) and to the south. However, there is clearly no continuous time-transgressive pattern from a central region outward.

DISCUSSION

Most of the White Mountain bodies are small and have been emplaced at shallow crustal levels, so that it is reasonable to assume rapid cooling below temperatures necessary for quantitative ^{40}Ar retention in biotite. The youngest K-Ar ages are found in the southern part of a region where Paleozoic rocks yield Cretaceous fission track ages for apatite. These data cannot be taken to imply a regional Cretaceous thermal event resetting the K-Ar mica ages because the K-Ar ages of other crystalline rocks in the same region are Paleozoic (see Zartman and others, 1970), and some young White Mountain intrusives occur in close proximity to older ones. Furthermore, K-Ar and Rb-Sr (whole-rock and mica) ages of White Mountain rocks are concordant (table 1 and app 2). We take these factors to indicate that K-Ar biotite ages can be taken as emplacement ages. The age differences cannot be attributed to differential uplift or to thermal resetting.

The age variation of different "comagmatic" units within individual complexes is a matter of importance to specific petrologic models. Foland, Quinn, and Giletti (1971) suggested that the time span of emplacement for the various members of a single complex was not more than 10 m.y., but our corrections to their data suggest that this interval is much less. The K-Ar biotite ages for different "comagmatic" members of the five complexes for which data are available (Belknap, Red Hill, Merry-meeting, Cuttingsville, and Mount Ascutney) are not significantly different. The ages of 6 samples from the Ascutney Mountain complex (fig. 3), where there is some areal separation of units, are all within 2 percent of 120 m.y. The order of intrusion is gabbro-diorite, hornblende-biotite syenite, and granite (Chapman and Chapman, 1940), and the results

TABLE I
Analytical data for mineral separates. All results for biotite except Me/N1-67 (amphibole)
and NH-75-45 (amphibole + 20% mica). Sample locations supplied in app I.

Sample no.	Complex/Stock**	Rock type	K (%)	$\frac{\text{g-atom } ^{40}\text{Ar/g} (\times 10^6)}{\text{radiogenic } (\%) \text{ atmospheric}}$	Age (m.y.) [†]
NH-74-30	Mount Monadnock (1)	granite	7.32	2.327 2.336	11.0 171 ± 4
QNH61-1	Gore Mountain (2)	granite	5.73*	1.789*	13.9* 168 ± 3
NH-74-31	Percy Peaks (3)	granite	6.32	1.912 1.930	8.6 7.8 165 ± 4
QNH61-2	Pilot Range (4)	granite	6.26*	2.122*	5.4* 181 ± 4
NH-75-45	Pliny Complex (5)	hastingsite granite	2.58	0.9150 0.9040	16.8 16.4 188 ± 5
QNH61-3	Cannon Mountain (8)	granite	6.80*	2.469*	7.5 194 ± 4
NH-75-41	Baldface (9)	granite	7.74	2.446 2.471	39.7 5.7 171 ± 4
NH-75-40	White Mountain Batholith (10)	granite	6.58	2.205 2.208	7.5 9.8 180 ± 4
NH-74-21	White Mountain Batholith (10)	granite	5.16	1.686	8.9 175 ± 5
QNH61-22	Mad River (11)	granite	5.96*	2.005*	9.2* 180 ± 4
Me/F1-67	Pleasant Mountain (12)	augite syenite	7.37	1.518	10.6 112 ± 3
Me/K2-67	Burnt Meadow (13)	hornblende syenite	6.96	1.387 1.377	12.6 33.4 108 ± 2
NH-74-28	Whales Back (14)	granite	5.24	1.811 1.796	9.0 16.0 184 ± 4
NH-75-2	Green Mountain (15)	granite	4.85	0.974	28.4 110 ± 3
BG-8-68	Ossipee (16)	granite	6.87*	1.532*	13.8* 121 ± 2
NH-74-9†	Red Hill (17)	nepheline syenite	7.80	2.831 2.831	6.3 8.0 194 ± 4
Me/N1-67	Abbott Mountain (18)	fayalite syenite	0.250†	0.105 0.104	25.8 22.4 221 ± 8

QNH61-16	Merymeeting (19)	granite	6.76*	1.438* 1.456* 1.470	27.6* 23.7* 11.3	117 ± 2
QNH61-20††	Belknap (20)	syenite	7.456‡	2.204 2.186	6.6 6.0	158 ± 3
BG-7-68	Belknap (20)	granite	6.47*	1.886*	14.2*	157 ± 3
NH-75-1	Pine Mountain (21)	granite porphyry	4.44	1.282	26.0	156 ± 3
Me 54	Alfred (22)	alkali gabbro	7.13	1.570	17.0	120 ± 2
Vt 33	Mount Ascutney (24)	granite	7.29	1.624 1.600	9.5 12.0	120 ± 2
Vt-75-1	Mount Ascutney (24)	granite	7.68	1.678 1.667	22.7 11.6	118 ± 2
QNH61-25	Mount Ascutney (24)	granite	7.21* 7.25	1.582* 1.594 1.584	9.8* 14.7 11.3	119 ± 2
Vt 32	Mount Ascutney (24)	syenite	5.56	1.238 1.220	21.9 24.8	120 ± 4
Vt 3	Mount Ascutney (24)	diorite	7.44\$ 7.60	1.710\$ 1.701 1.738	19.0\$ 9.2 11.3	122 ± 3
VT-75-8	Mount Ascutney (24)	gabbro	7.55	1.689 1.684	13.2 8.0	121 ± 3
Me-74-4	Lebanon (25)	diorite	6.66	1.537 1.522	40.2 20.7	125 ± 3
Me 55b	Tatic Hills (26)	gabbro	5.094‡	1.134 1.145	11.1 10.5	122 ± 2
BG-10-68	Agamenticus (27)	granite	6.50*	2.793*	16.4*	228 ± 5
CNG-1	Cape Neddick (28)	gabbro	7.145‡	1.517	16.7	116 ± 2
NH-74-2	Little Rattlesnake Hill (30)	gabbro	4.55	0.929	17.8	111 ± 3

+ 1,353 ppm Rb; 6,715 ppm Sr; (⁸⁷Sr/⁸⁶Sr) = 2.337; 197 ± 3 m.y.

†† 458.1 ppm Rb; 10,18 ppm Sr; (⁸⁷Sr/⁸⁶Sr) = 1,009; 164 ± 5 m.y.

\$ Faul and others (1963); * Foland, Quinn, and Giletti (1971), ⁴⁰Ar from new spike calibration; ** number indicates notation on

figure 1.

γ — from: ⁴⁰K = 0.0119 atom %K; λ_β = 4.72 × 10⁻¹⁰ y⁻¹; λ_α = 0.585 × 10⁻¹⁰ y⁻¹; one sigma analytical uncertainty derived from repetitive analyses.

‡ Isotope dilution.

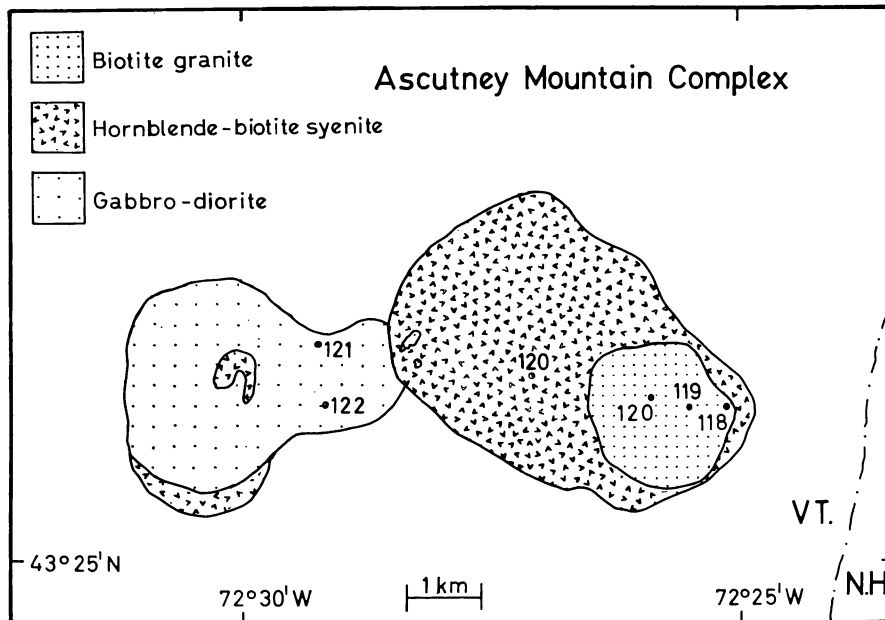


Fig. 3. Simplified geologic map of Ascutney Mountain complex (after Chapman and Chapman, 1940), showing sample locations and K-Ar biotite ages in m.y.

imply that the entire process required 5 m.y. or less. One could argue that the latter intrusions reset ages of the earlier ones, but there is no evidence for this. The new data for Ascutney Mountain and other complexes, coupled with whole-rock Rb-Sr work on the Red Hill complex currently in progress, are consistent with a short time span of evolution. We believe that the small complexes were emplaced within a few million years or less.

The foregoing does not necessarily hold for some larger, composite complexes. The White Mountain batholith and satellitic stocks are composed of many intrusions, and the total range of measured ages is about 25 m.y. In the composite Pilot-Pliny complex, we report 188 m.y. for the Hastingsite granite of the Pliny range, 181 m.y. for Conway granite of the Pilot range, and 165 m.y. for the Conway granite stock at Percy Peaks. The Percy Peaks granite may be more closely related to the Gore Mountain granite (168 m.y.) farther to the north. The ages of the Belknap and Pine Mountain intrusions are identical within analytical uncertainty, and together with their geographic proximity would suggest a close genetic relation.

The similar ages and chemical affinities of the Montereian Hills and the White Mountain rocks suggest that they should be considered together. A frequency diagram of assigned ages (*not* individual age determinations) for these intrusive centers (fig. 4) indicates that the activity was concentrated in two intervals with maxima near 180 and 120 m.y.

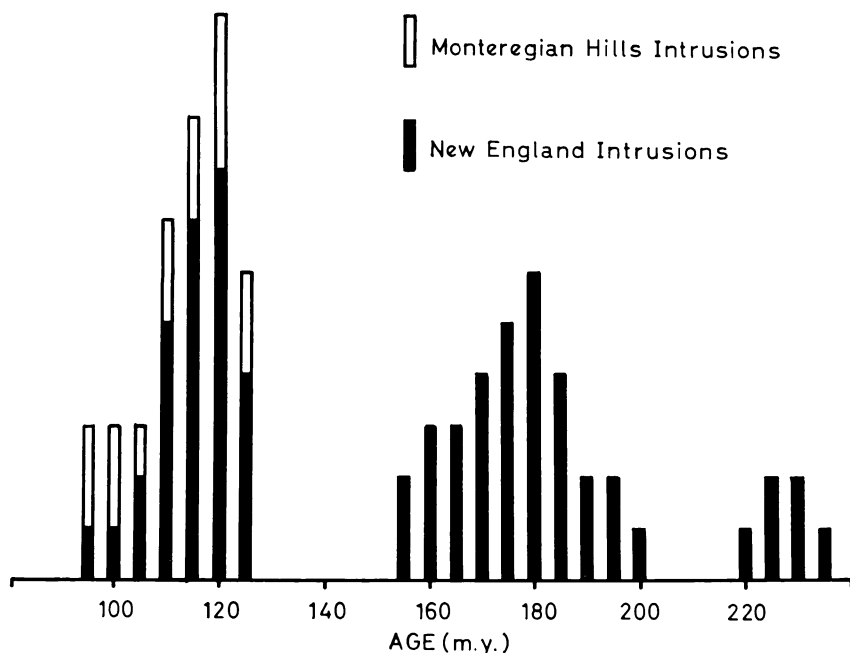


Fig. 4. Histogram of ages of intrusive centers for 40 White Mountain and Montereian Hills intrusions using a 10 m.y. cell size and computed at 5 m.y. intervals. Ages of the White Mountain complexes are given in figure 1 and those for the Montereian Hills as given by Gold (1967), except for Oka (114 m.y.) given in Shafiqullah, Tupper, and Cole (1970). Smallest column represents one intrusion.

ago. The number of complexes in the Jurassic and Cretaceous groups is roughly the same, but the rocks of the older group are far more abundant at the present erosional level. Only a few complexes do not fall into the intervals of 200 to 165 and 120 to 100 m.y. Three complexes in southern Maine are significantly older than the bulk of White Mountain rocks. These dates are suspiciously close to the Permian-reset K-Ar pattern (Faul and others, 1963; Zartman and others, 1970), but the concordant Rb-Sr data for the Agamenticus complex suggest that the K-Ar ages are primary. Consistently, Hussey (1968) observed Triassic (?) dikes crosscutting the Agamenticus but not the younger intrusive complexes in southern Maine.

Clearly, the White Mountain activity was more episodic than continuous. There is a distinct paucity of ages within the two intervals of 220 to 200 and 165 to 125 m.y. It is interesting to note that many of the reported ages of Northern Appalachian dikes (see Armstrong and Besancon, 1970; Reesman, Filbert, and Krueger, 1973; Zartman and others, 1967; Gold, 1967; Dalrymple, Grommé, and White, 1975), which are petrographically distinct from the White Mountain rocks, do fall within the two intervals.

Tectonic hypotheses.—In the light of plate tectonic theories, several hypotheses have been advanced to explain the occurrence of the White

Mountain rocks in the non-orogenic environment. One school has related the origin of the intrusives to motion of the North American lithospheric plate over a stationary mantle "hot-spot" or plume (Morgan, 1971, 1972; Coney, 1971; McGregor and Krause, 1972, Sillitoe, 1974).

The proposal is that the White Mountain rocks and the New England seamount chain (fig. 2) form a lineament which is the trace of the westward motion of the North American plate over a fixed mantle hot-spot. If this were the case, then one might expect decreasing ages proceeding from northwest to southwest along this trend. The ages of the New England seamounts are not known, but a minimum of Upper Cretaceous has been established paleontologically by recent DSDP research (Scientific Staff, 1975). Their ages are further constrained to be less than or equal to the age of the seafloor, which ranges from 180 to 130 m.y. from the western to the eastern end of the chain (Pitman and Talwani, 1972). On the continent, the hypothetical plume "scar" (that is, the area of White Mountain outcrop) stretches for roughly 220 km from southwestern Maine to northern New Hampshire. Assuming appropriate plate velocities, this north-northwestern trend would traverse a fixed mantle plume in about 20 m.y. or less. As noted by Wright (1973), Ballard and Uchupi (1975), and others, the 100 m.y. spread in White Mountain ages tends to make the mantle plume hypothesis rather unlikely.

Within the limitations of previously published data, it was possible to attribute the Jurassic (but not the Cretaceous) White Mountain intrusions and the New England seamounts to a single mantle plume, but the new data almost totally rule out a simple hot-spot model. Zietz and Zen (1973) note that the hot-spot model might be revived, if some White Mountain magmas could be stored in the lithosphere for roughly 70 m.y. Apart from the physical difficulties, we feel that the initial ($^{87}\text{Sr}/^{86}\text{Sr}$) ratios (Foland, Quinn, and Giletti, 1971) and the pattern of magmatism (fig. 4) also eliminate this possibility.

A more complex model would be required to make the plume hypothesis workable. For example, it is necessary to account for roughly synchronous magmatic activity in three different areas—southern Quebec, southern Vermont, New Hampshire, and Maine, and along the New England seamount chain—in the Cretaceous. It is possible to propose much more complicated models, for instance, involving several, non-stationary plumes, which would satisfy the constraints provided by the ages, but these would appear rather unlikely. Such *ad hoc* models then must explain one initial reason for the hot-spot hypothesis, namely, the arrangement of Mesozoic bodies in a >2000 km lineament and would bear little resemblance to that proposed by early workers (for example, Morgan, 1971).

In formulating a tectonic model for the Gulf of Maine, Ballard and Uchupi (1972; 1975) have suggested that the White Mountain intrusions occur along a shear fracture zone formed during translation of crustal blocks prior to seafloor spreading. According to their model the intrusions have formed along a zone of wrench faulting, which formed during

fragmentation of the continental crust. The episode of instability at the continental margin would have ended about 175 m.y. ago, at the onset of the main phase of spreading, and Ballard and Uchupi (1975) suggest that, along major fractures, tectonic and magmatic activity continued into the Cretaceous.

Several lines of evidence (Fletcher, Sbar, and Sykes, 1974) support the hypothesis that the intrusions occur along the extension of an oceanic fracture which was active during the early opening of the Atlantic: there is a seismic zone extending from Boston to Ottawa, roughly along the belt of intrusions; the seismic zone and the pattern of Monteregeian Hills, White Mountain rocks, and New England seamounts lie along a small circle about the center of rotation for early Atlantic opening. The northern part of this belt is also characterized by negative P-wave travel-time residuals. In this case, the New England seamounts could have formed along an oceanic transform fault, and the New England intrusions along its continental expression. The continental fracture zone could have influenced the location of the oceanic transform fault inasmuch as some complexes may have formed prior to extensive seafloor spreading.

It seems likely that the locus of the Northern Appalachian intrusions was controlled by a major lithospheric fracture. This occurrence is probably not an isolated example. Similar behavior would be applicable to alkaline complexes near the Atlantic coastal margins of Africa and South America (Marsh, 1973) and to those bordering the Red Sea in Egypt (Garson and Krs, 1976).

All the White Mountain rocks were not generated during the early stages of Atlantic opening. There is intriguing similarity between their age pattern and that of the South America-Africa lineaments where Marsh (1973) finds that isotopic ages cluster in the intervals of 120 to 135 and 50 to 80 m.y. He correlates the former group with initial separation of Africa-South America and the latter with a major change in spreading shown as a shift in the pole of rotation. The Jurassic White Mountain intrusions would correlate with initial stages of rifting and spreading between North America and Africa at about 180 m.y. (Dalrymple, Grommé, and White, 1975). The clustering of other ages near 120 m.y. may indicate a major shift in the pole of rotation and/or spreading velocity in the North Atlantic during the Early Cretaceous. A similar suggestion has been made by Hallam (1971). The synthesis of North Atlantic spreading by Pitman and Talwani (1972) does not indicate this, but the paleomagnetic model of Phillips and Forsyth (1972) suggests a shift in spreading in early Cretaceous time. The possibility that the New England seamounts were generated by synchronous volcanism has been raised (Scientific Staff, 1975), and present data would lead us to speculate that they may have ages of roughly 120 m.y.

In outlining the concept, Wilson (1965) suggested that transform faults may be initiated along ancient fractures, and this notion is supported in the literature (see Garson and Krs, 1976). It is not clear if an

ancient fracture existed along the New England trend or whether the translation of marginal continental blocks (Ballard and Uchupi, 1972) could have caused the formation of a fracture zone that became a transform once seafloor spreading began in earnest. The "active" portion of the oceanic transform fault, near the Atlantic spreading center, must have been more than 1000 km to the southeast of some sites of alkaline magmatic activity about 120 m.y. ago. If the fracture hypothesis is valid for the White Mountain rocks, then it would appear that such zones are capable of reactivation, at least in the form of intra-plate alkaline magmatism.

CONCLUSIONS

1. The rocks correlated with the White Mountain plutonic-volcanic series were emplaced during three episodes of activity at about 230, 165 to 200, and 100 to 125 m.y. ago. The majority were emplaced during the latter two intervals with apparent maxima in magmatic activity at 180 and 120 m.y.

2. Emplacement of small differentiated complexes, such as Mount Ascutney, required a few million years or less.

3. Emplacement was individual. Close proximity of bodies, small and large, does not necessarily indicate a time relationship.

4. The observed age pattern is not compatible with the hot-spot or plume hypothesis for the origin of the White Mountain rocks. The ages are consistent with the hypothesis that the White Mountain and Montere-gian Hills intrusions formed along the continental extension of a transform fault.

APPENDIX 1

Sample locations for new samples in table 1

Sample no.	Quadrangle	North latitude	West longitude
NH-74-30	Averill (N.H.)	44°52'48"	71°32'22"
NH-74-31	Percy (N.H.)	44°38'09"	71°24'09"
NH-75-45	Mt. Washington (N.H.)	44°25'51"	71°26'08"
NH-75-41	North Conway (N.H.)	44°14'04"	71°03'50"
NH-75-40	Mt. Osceola (N.H.)	44°02'11"	71°30'03"
NH-74-21	Mt. Chocoura (N.H.)	43°54'45"	71°22'30"
Me/F1-67	Fryeburg (Maine)	44°01'30"	70°49'28"
Me/Kf2-67	Kezar Falls (Maine)	43°55'10"	70°53'49"
NH-74-28	Kezar Falls (Maine)	43°53'35"	70°58'45"
NH-75-2	Ossipee Lake (N.H.)	43°45'48"	71°01'50"
NH-74-9	Winnepesaukee (N.H.)	43°44'05"	71°26'17"
Me/N1-67	Newfield (Maine)	43°36'02"	70°50'10"
QNH61-20	Winnepesaukee (N.H.)	43°33'09"	71°22'05"
NH-75-1	Gilmanton (N.H.)	43°28'39"	71°16'07"
Me 54	Kennebunk (Maine)	43°29'21"	70°43'44"
Vt 33	Claremont (Vt.)	43°26'16"	72°25'54"
Vt-75-1	Claremont (Vt.)	43°26'09"	72°25'06"
Vt 32	Claremont (Vt.)	43°26'19"	72°27'10"
Vt-75-8	Claremont (Vt.)	43°26'41"	72°29'22"
Me-74-4	York (Maine)	43°25'07"	70°50'21"
Me 55b	North Berwick (Maine)	43°16'53"	70°42'50"
CNG-1	York Beach (Maine)	43°10'02"	70°35'38"
NH-74-2	Mt. Pawtuckaway (N.H.)	43°00'06"	71°10'49"

5. Magmatic activity along this zone continued into the Cretaceous when the active Atlantic spreading center was more than a thousand kilometers to the southeast.

6. The times of major plutonic magmatic activity could be related to times of significant changes in the opening of the North Atlantic.

APPENDIX 2

Summary of isotopic ages for White Mountain rocks. Reference is to table 1 and to K-Ar biotite ages unless otherwise noted. Locations are shown in figure 1. Successive intrusions within individual complexes are arranged youngest to oldest, as determined by field relations.

(Rb-Sr ages calculated with ^{87}Rb decay constant of $1.42 \times 10^{-11} \text{ y}^{-1}$.)

Complex/Intrusion	Rock type	Age (m.y.)	
Mt. Monadnock (1)	Conway granite	171 ± 4	
Gore Mountain (2)	Conway granite	168 ± 3	
Percy Peaks (3)	Conway granite	165 ± 4	
Pilot Range (4)	Conway granite	181 ± 4	
Pliny Range (5)	hastingsite granite	188 ± 5	amphibole K-Ar
Barber Hill (6)	syenite	111 ± 2	Armstrong and Stump (1971)
Litchfield (7)	nepheline syenite	{ 244 ± 5 234 ± 5	nepheline K-Ar; Burke, Otto, and Denison (1969)
Cannon Mountain (8)	Conway granite	194 ± 4	
Baldface (9)	Conway granite	171 ± 4	
White Mountain batholith near Redstone, N.H. (10)	Conway granite	168 ± 3	Foland, Quinn, and Giletti (1971)
	Conway granite	{ 176 ± 9 178 ± 8	Rb-Sr biotite; Hurley and others (1960)
	green granite	{ 184 168	Rb-Sr biotite; Aldrich and others (1958)
	red granite	{ 184 137	Rb-Sr biotite; Aldrich and others (1958)
	green granite	{ 181 182 187 ± 5 184 ± 4 140 ± 60 190 ± 5	Rb-Sr biotite; Tilton and others (1957) zircon 206/238 zircon 207/235 zircon 207/206 zircon 208/232
east of Lincoln, N.H. near Wanalancet, N.H.	Conway granite	180 ± 4	
Mad River (11)	Conway granite	175 ± 5	
	Conway granite	180 ± 4	
	Conway granite	194 ± 4	Rb-Sr whole rock; Foland, Quinn, and Giletti (1971)
	Conway granite	181 ± 4	
Pleasant Mountain (12)	augite syenite	112 ± 3	
Burnt Meadow (13)	hornblende syenite	108 ± 2	
Whales Back (14)	Conway granite	184 ± 4	
Green Mountain (15)	Conway granite	110 ± 3	
Ossipec (16)	Conway granite	121 ± 2	
Red Hill (17)	nepheline syenite	{ 197 ± 3 194 ± 4	Rb-Sr biotite
	outer syenite	199 ± 4	Armstrong and Stump (1971)
	outer (blue) syenite	197 ± 4	

Complex/Intrusion	Rock type	Age (m.y.)	
Abbott Mountain (18)	fayalite syenite	221 ± 8	K-Ar amphibole
Merrymeeting (19)	Conway granite	117 ± 2	
	Conway granite	114 ± 10	Rb-Sr whole rock; Foland,
	Conway granite	118 ± 2	Quinn, and Giletti (1971)
	granodiorite	113 ± 2	
Belknap (20)	Conway granite	157 ± 3	
	Belknap syenite	{ 158 ± 3	Rb-Sr biotite
		{ 164 ± 5	
	Endicott diorite	158 ± 3	Foland, Quinn, and Giletti (1971)
Pine Mountain (21)	granite porphyry	156 ± 3	
Alfred (22)	alkali gabbro	120 ± 2	
Cuttingsville (23)	biotite syenite	100 ± 2	} Armstrong and Stump (1971)
	essexite	96.4 ± 2	
Mount Ascutney (24)	Conway granite	120 ± 2	
	Conway granite	118 ± 2	
	Conway granite	119 ± 2	
	hb-biotite syenite	120 ± 4	
	diorite	122 ± 3	
	gabbro	121 ± 3	
Lebanon (25)	diorite	125 ± 3	
Tatnic Hills (26)	gabbro	122 ± 2	
Agamenticus (27)	alkali granite	228 ± 5	
Cape Neddick (28)	gabbro	222 ± 3	Rb-Sr whole rock; Hoefs
Mt. Pawtuckaway (29)	monzonite	116 ± 2	(1967)
Little Rattlesnake Hill (30)	gabbro	121 ± 2	Foland, Quinn, and Giletti
		111 ± 3	(1971)

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