(200)
T67r

Copy 1

IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

AEC-53/6

August 29, 1955

Dr. T. H. Johnson, Director
Division of Research
U. S. Atomic Energy Commission
16th Street and Constitution Avenue, N. W.
Washington 25, D. C.

Dear Dr. Johnson:

Transmitted herewith is one copy of TEI-523, "Age determinations on New Hampshire granites," by J. B. Lyons, D. Gottfried, W. L. Smith, H. W. Jaffe, and C. L. Waring, July 1955.

We plan to submit this report for publication in the American Journal of Science.

Sincerely yours,

George N. Pipiringos
for W. H. Bradley
Chief Geologist

Geology and Mineralogy

This document consists of 23 pages.
Series A.

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

AGE DETERMINATIONS ON NEW HAMPSHIRE GRANITES*

By

J. B. Lyons, D. Gottfried, W. L. Smith,

H. W. Jaffe, and C. L. Waring

July 1955

Trace Elements Investigations Report 523

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

*This report concerns work done on behalf of the Division of Research of the U. S. Atomic Energy Commission.

USGS - TEI-523

GEOLOGY AND MINERALOGY

Distribution (Series A)	No. of copies
Argonne National Laboratory	1
Atomic Energy Commission, Washington	2
Division of Raw Materials, Albuquerque	1
Division of Raw Materials, Butte	1
Division of Raw Materials, Casper	1
Division of Raw Materials, Denver	1
Division of Raw Materials, Hot Springs	1
Division of Raw Materials, Ishpeming	1
Division of Raw Materials, Phoenix	1
Division of Raw Materials, Salt Lake City	1
Division of Raw Materials, St. George	1
Division of Raw Materials, Washington	3
Division of Research, Washington	1
Exploration Division, Grand Junction Operations Office	1
Grand Junction Operations Office	1
Technical Information Service, Oak Ridge	6
Tennessee Valley Authority, Wilson Dam	1
U. S. Geological Survey:	
Fuels Branch, Washington	1
Geochemistry and Petrology Branch, Washington	20
Geophysics Branch, Washington	1
Mineral Deposits Branch, Washington	1
E. H. Bailey, Menlo Park	1
A. L. Brokaw, Grand Junction	1
N. M. Denson, Denver	1
A. H. Koschmann, Denver	1
R. A. Laurence, Knoxville	1
L. R. Page, Washington	1
Q. D. Singewald, Beltsville	1
A. E. Weissenborn, Spokane	1
TEPCO, Denver	2
TEPCO, RPS, Washington, (including master)	2
	60

CONTENTS

ILLUSTRATION

TABLES

AGE DETERMINATIONS ON NEW HAMPSHIRE GRANITES

By J. B. Lyons, D. Gottfried, W. L. Smith,

H. W. Jaffe, and C. L. Waring

ABSTRACT

Age determinations by the Larsen method are reported for the four Paleozoic plutonic series of New Hampshire. Mean values for the measured ages are: Highlandcroft (Upper Ordivician?) 388 ± 33 million years; Oliverian (Middle or Upper Devonian?) 317 ± 22 million years; New Hampshire (Upper Devonian?) 319 ± 34 million years; and White Mountain (Mississippian?) 233 ± 18 million years. These ages are compared with other reported ages for rocks of the northern Appalachian region.

INTRODUCTION

The Larsen method (1952) for determining ages of plutonic rocks is based upon the measurement of alpha activity and total lead content of selected accessory minerals concentrated from fresh igneous rocks. This paper reports the results of the application of the Larsen method to the four Paleozoic plutonic series of New Hampshire (Billings, 1937, p. 499-511). This study is an outgrowth of an investigation of the radioactivity of the four plutonic series that is currently being conducted by the U. S. Geological Survey on behalf of the Division of Research of the U. S. Atomic Energy Commission. It seemed appropriate to make these age determinations as a check on the general utility of the Larsen method, inasmuch as the plutonic rocks are fairly well dated geologically and are known to belong to certain of the Paleozoic systems.

Several sources of systematic error are possible with the Larsen age method. In using the formula for calculating age,

$$T = \frac{c\ Pb}{\alpha} \quad \text{(Larsen et al., 1952, p. 1049),}$$

T is the age in millions of years, Pb is lead in parts per million, α is alphas per milligram per hour, the constant c has a value of 2680 if uranium alone is the radioactive element in a mineral, and 1980 if thorium alone is the radioactive element. Calculations of zircon ages in this paper are based on the assumption that the Th:U atomic ratio in the zircon samples is 1:1 (that is, c = 2400), which is the approximate average for analyzed zircon (Larsen, E. S., Jr., oral communication). Monazite is assumed to contain thorium alone (c = 1980) and xenotime chiefly uranium (c = 2500). Variations in the Th:U ratio may effect an individual determination by as much as 17 percent (Larsen et al., 1952, p. 1049).

Other errors may be introduced by incorrect measurements of the alpha activity or lead content. Duplicate measurements of alpha activity on the same sample are reproducible to within 5 percent of the measured value. Waring and Worthing (1953, p. 830-831) have demonstrated a high degree of reproducibility for spectrographic lead determinations where a series of tests are run on the same sample, but some single determinations may deviate as much as 10 percent from the average.

Another assumption, that there is no original lead in the minerals used for the age determinations, may also cause slight errors. Larsen and others (1952), and Tilton (1951, 1954) have both demonstrated that zircon from plutonic rocks has virtually no original lead. A cyrtolite from Bedford, N. Y., however, is reported as containing 6.2 percent of its lead as nonradiogenic lead (Nier, 1939, p. 158), which is an unusually high amount. A few percent of original lead may be present in many monazite samples (Jaffe, H. W., in press; Report of the Committee on the Measurement of Geologic Time, 1948-49, p. 27) but not in sufficient amounts to affect seriously an age determination. The assumption of no original lead in xenotime is made largely on a crystal-chemical basis. In the Larsen method age determinations reported in this and other papers, the maximum deviation from the mean age of a plutonic series may be approximately 20 percent. Mean deviation for values reported here is less than 8 percent; standard deviation less than 11 percent. There is, thus, a reasonable probability that possible errors, as discussed above, cancel one another, and that the mean age of a plutonic series, as determined by the Larsen method, is close to its true age.

Mineralogic separations and alpha counts on the Highlandcroft, Oliverian, and New Hampshire plutonic series were made by Lyons; those on the White Mountain plutonic-volcanic series by Gottfried, Smith, and Jaffe. Spectroscopic lead determinations were made by Waring. The ages for the various geologic periods, in millions of years, are those published by the Committee on the Measurement of Geologic Time (1950, p. 18). These differ slightly, but not significantly, from those adopted by Holmes (1946). In the following tables where more than one age determination is listed for a mineral, a split sample has been measured rather than a different separate from another rock.

HIGHLANDCROFT PLUTONIC SERIES

There are four localities where rocks of the Highlandcroft plutonic series have been mapped (fig. 1). West of Littleton, N. H., granodiorite of the Highlandcroft series intrudes the Upper Ordovician(?) Ammonoosuc volcanics and appears to be unconformably overlain by the Silurian (Niagaran) Fitch formation (Billings, 1937, p. 500). The evidence, therefore, favors an Upper Ordovician age for this series, although it cannot be more precisely dated than post-Upper Ordovician(?) and pre-Middle Silurian.

Table 1 lists age determinations for three of the four known stocks of Highlandcroft rocks. Their average age, 388 ± 33 million years, is in good agreement with the geologic age.

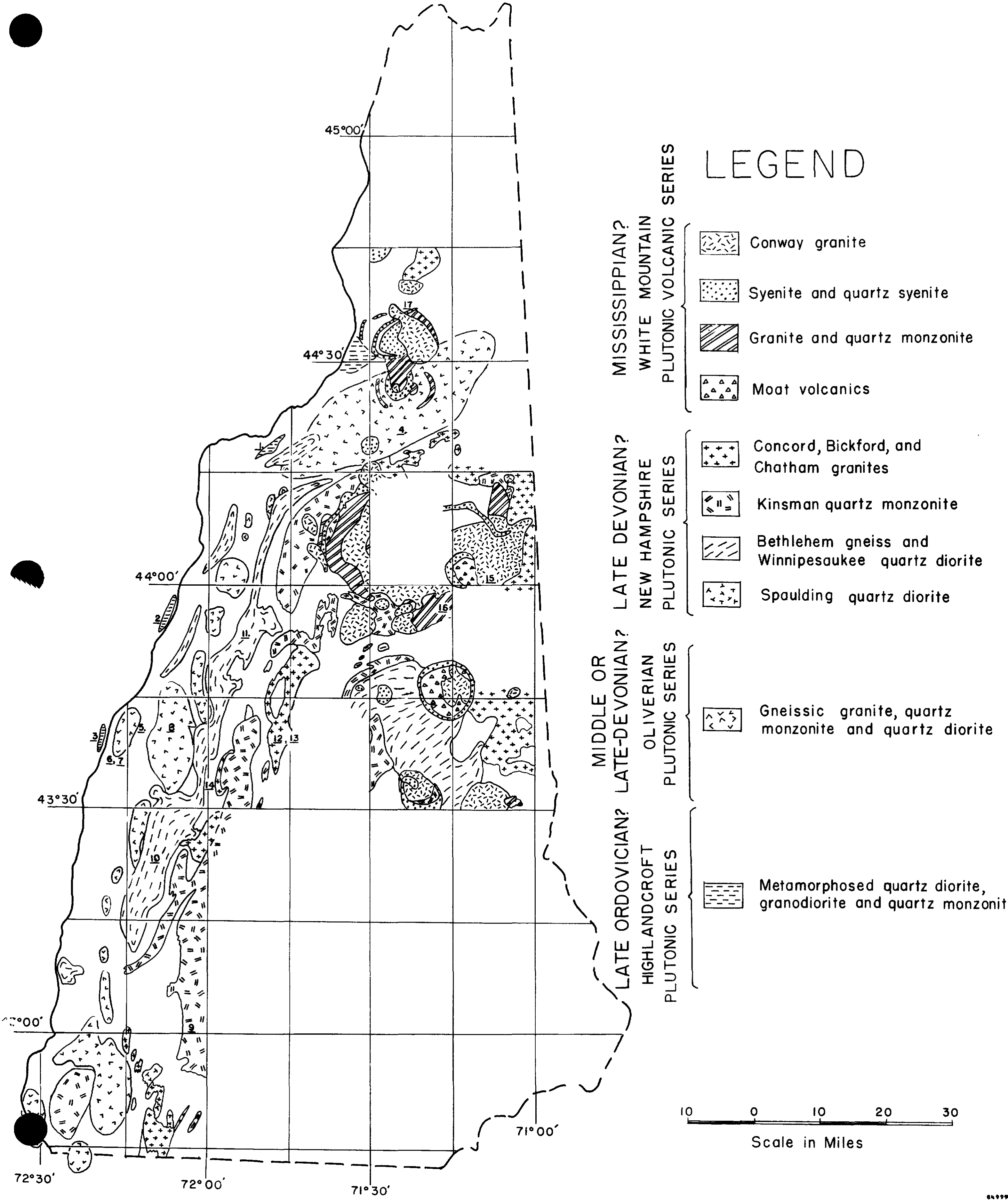
Table 1.--Age determinations on zircon from Highlandcroft plutonic series.

Formation	Location	Mineral	α/mg/hr	Pb (ppm)	Age (million years)
Granodiorite, Highlandcroft plutonic series	Littleton quadrangle	Zircon	171 162	25 27	351 400
Fairlee quartz monzonite	Mt. Cube quadrangle	Zircon	164	25	366
Sodaclase tonalite	Hanover quadrangle	Zircon 1/	882	156	424
Mean age for series					388
Standard deviation					33
Ordovician					440-360 ± 10

1/ Partly metamict.

Figure 1. Index map of New Hampshire showing the locations of specimens used for age determinations.

1. Highlandcroft granodiorite; Littleton quadrangle
2. Fairlee quartz monzonite; Mt. Cube quadrangle
3. Sodaclase tonalite; Hanover quadrangle
4. Oliverian granite; Mt. Washington quadrangle
5. Lebanon border gneiss; Hanover quadrangle
6. Lebanon granite; Hanover quadrangle
7. Aplite in Lebanon granite; Hanover quadrangle
8. Mascoma granite; Mascoma quadrangle
9. Kinsman quartz monzonite; Lovewell Mountain quadrangle
10. Bethlehem gneiss; Sunapee quadrangle
11. Bethlehem gneiss; Rumney quadrangle
12. Concord granite; Cardigan quadrangle
13. Pegmatite in Concord granite; Cardigan quadrangle
14. Ruggles pegmatite; Cardigan quadrangle
15. Conway granite; North Conway quadrangle
16. Mt. Osceola granite; Mt. Chocorua quadrangle
17. Devil's Slide syenite; Percy quadrangle


LEGEND
MISSISSIPPIAN?
WHITE MOUNTAIN
PLUTONIC VOLCANIC SERIES
Conway granite
Syenite and quartz syenite
Granite and quartz monzonite
Moat volcanics
LATE DEVONIAN?
NEW HAMPSHIRE
PLUTONIC SERIES
Concord, Bickford, and Chatham granites
Kinsman quartz monzonite
Bethlehem gneiss and Winnipesaukee quartz diorite
Spaulding quartz diorite
MIDDLE OR LATE-DEVONIAN?
OLIVERIAN
PLUTONIC SERIES
Gneissic granite, quartz monzonite and quartz diorite
LATE ORDOVICIAN?
HIGHLANDCROFT
PLUTONIC SERIES
Metamorphosed quartz diorite, granodiorite and quartz monzonit
10 0 10 20 30
Scale in Miles
45°00′
44°30′
44°00′
43°30′
72°30′
72°00′
71°30′
71°00′

It is of considerable importance to note that all three of the rocks in table 1 have been regionally metamorphosed to the greenschist facies. Despite this, the zircon was evidently not recrystallized, and its age dates the time of formation of the plutonic rock, rather than the time of its metamorphism. Whether zircon will recrystallize under higher intensity metamorphic conditions is unknown.

The best-dated northern Appalachian rocks that may be compared with the Highlandcroft plutonic series are pegmatites at Bedford, N. Y., and Branchville, Conn. According to Rodgers, (1952, p. 419-420) the pegmatites are pre-Triassic, related to the Thomaston granite, and lie east of the Precambrian core of the Hudson Highlands in schists of uncertain age. Chemical and mass spectrometric analyses of the Bedford zircon (cyrtolite) yield an age of approximately 340 to 350 million years (Rodgers, 1952, p. 420; Kulp et al., 1954, p. 354). Uraninites from the Branchville pegmatite range in age from 340 to 370 million years (gravimetric analyses).

OLIVERIAN PLUTONIC SERIES

Rocks of the Oliverian plutonic series crop out in a group of en echelon domes east of and parallel to the Connecticut River (fig. 1). Some of the plutonic rocks intrude the Clough quartzite of Silurian age, and the effects of the emplacement of the domes are apparent in the Lower Devonian (Oriskany) Littleton formation. Billings (1937, p. 536) considers that the intrusion of the Oliverian domes predates the Acadian(?) regional folding and metamorphism and that the series is of Middle Devonian age.

Age determinations for the Oliverian plutonic series are listed in table 2. Their average age (317 ± 22 million years) is higher than that set

Table 2.--Age determinations on zircon from the Oliverian plutonic series.

Formation	Location	Mineral	α/mg/hr	Pb (ppm)	Age (million years)
Granite of Oliverian plutonic series	Mt. Washington quadrangle	Zircon	498	61	318
Border gneiss of Lebanon granite	Hanover quadrangle	Zircon	217	27	321
Lebanon granite	Hanover quadrangle	Zircon	574	79	330
Aplite in Lebanon granite	Hanover quadrangle	Zircon 1/	980	130	328
Mascoma granite	Mascoma quadrangle	Zircon	527 502	60 63	273 301
Mean age					317
Standard deviation					22
Devonian					320-265 ± 10

1/ Partly metamict

by the Committee on the Measurement of Geologic Time (1949-50) for the Middle Devonian (*ca*. 300 million years). The discrepancy between the inferred geologic age and the measured age will be discussed in a later section.

There are no well-dated localities in the Northern Appalachians which may be directly compared with the Oliverian plutonic series. The Monson granodiorite gneiss of Massachusetts is, in part, the same plutonic unit (Hadley, 1949), but in this area it is less well-dated geologically than in New Hampshire. Marble (1950) has published an age of 390 million years for allanite (gravimetric analysis) from a pegmatite lens in the Monson granodiorite at Greenwich, Mass. Inasmuch as this analysis is uncorrected for original lead, which is probably present in the allanite, the discrepancy between this date and that for the Oliverian (317 ± 22 million years) is not unexpected. Whether the Greenwich locality should be correlated with the Oliverian plutonic rocks or with the Bethlehem gneiss of the New Hampshire plutonic series is somewhat uncertain (Rodgers, 1952, p. 420).

NEW HAMPSHIRE PLUTONIC SERIES

Stocks and batholiths of the New Hampshire plutonic series intrude the Lower Devonian Littleton formation. None of these plutons cuts through an Oliverian dome, but on the basis of their internal structures they are regarded by Billings (1937, Pl. 12) as geologically younger than the Oliverian rocks and contemporaneous with or slightly younger than the Acadian(?) folding and metamorphism. A Middle or Late Devonian age, therefore, is favored (Billings, 1937, p. 506). From the data of table 3, the average age of the New Hampshire plutonic series is 319 ± 34 million years.

The determinations on the Bethlehem gneiss of the Sunapee quadrangle are noteworthy. There is good age agreement here for three different minerals from the same rock (319 ± 21 million years) each with its own alpha activity and lead content. This agreement strongly supports the general validity of the Larsen method.

The well-known Ruggles pegmatite at Grafton, N. H., is considered to be comagmatic with the New Hampshire plutonic series. A chemical analysis of uraninite from the pegmatite (Shaub, 1938, p. 338) yielded an age of 305 million years (corrected by Rodgers, 1952, p. 415, to 310 million years). Mass spectrometric determination of the Pb^{207}/Pb^{206} ratio of uraninite from

Table 3.--Age determinations on minerals from the New Hampshire plutonic series.

Formation	Location	Mineral 1/	α/mg/hr	Pb (ppm)	Age (million years)
Kinsman quartz monzonite	Lovewell Mt. quadrangle	Zircon	246 250	26 30	253 288
		Monazite	4260 4198	640 800	300 381
Bethlehem gneiss	Sunapee quadrangle	Zircon	242	30	298
		Monazite	2840	470	331
		Xenotime	4053	530	327
Bethlehem gneiss	Rumney quadrangle	Zircon	246	28	312
Concord granite	Cardigan quadrangle	Monazite	2706	450	333
Pegmatite in Concord granite	Cardigan quadrangle	Monazite	5137	700	327
Mean age					319
Standard deviation					34
Devonian					320-265 ± 10

1/ None of these minerals is metamict.

the same pegmatite by Collins et al., (1954, p. 10) yields an age of 455 ± 160 million years. The first analysis has no correction for original lead; in the second analysis a large correction was made for original lead, but the isotopic composition of this lead was not accurately known. Both analyses would be consistent with the interpretation that the uraninite is at least 295 million years old.

With the objective of cross-checking the Larsen method against these two analyses, four determinations of alpha activity and lead content were made on portions of one large parallel growth of zoned and metamict zircon collected at the pegmatite. Results are listed in table 4.

Table 4.--Age determinations on zoned metamict zircon from Ruggles mine, Grafton, N. H.

α/mg/hr	Pb (ppm)	Age (million years)
4851	630	312
6221	1000	386
5028	950	453
5970	785	316
Mean age		367
Standard deviation		67
Uraninite age by chemical Pb/U ratio		310 (Shaub, 1938)
Uraninite age by Pb^{207}/Pb^{206} ratio		455 ± 160 (Collins, 1954)

Two of the determinations in table 4 agree extremely well with the mean age of the New Hampshire plutonic series (319 million years), but two do not. Aside from the fact that the two fractions which showed good agreement were less magnetic than those which did not, there is no apparent explanation for the anomalous ages. Nier (1939, p. 158) has shown that in a metamict zircon from Bedford, N. Y., 6 percent of the total lead is original lead. Correction of the Ruggles zircon for 6 percent of original lead would reduce the mean age to 343 million years. An improbable figure of 18 percent original lead would be required to reduce the age to 300 million years. L. R. Stieff and

T. W. Stern of the Geological Survey are currently engaged in mass spectrometric work on the minerals of the Ruggles pegmatite, including both uraninite and the zircon of table 4. Their work should provide a cross-check on the Larsen method and may explain the anomalous data in this table.

The plutonic rocks and pegmatites of the New Hampshire series are correlated with some uncertainty with an area east of Middletown, Conn., where a group of pegmatites, possibly of the same age as the Ruggles pegmatite, have yielded several uraninites. Fifteen chemical analyses of the uraninites (uncorrected for original lead) yield ages ranging from 270 to 300 million years (Rodgers, 1952, p. 414-415). The accepted best age determination from this area is on samarskite from the Spinelli quarry at Glastonbury, Conn. Rodgers' calculations (1952, p. 413) show this samarskite to have an age of 260 million years. This determination is important for two reasons: (1) it has been taken by Holmes (1946) as representing the close of the Devonian, on the basis of the uncertain correlation with the New Hampshire pegmatite belts, and (2) it has been assumed that the Middletown pegmatite belt is related to the Glastonbury gneiss, which has been correlated with some uncertainty with some units of the Monson gneiss of Massachusetts (Marble, 1950, p. 846; Rodgers, 1952, p. 425) and with the Bethlehem gneiss of New Hampshire (Herz, N., oral communication). It is not, however, certain that the Middletown pegmatite belt is not related to the nearby Carboniferous Sterling granite gneiss and Westerly granite of Rhode Island (Emerson, 1917, p. 229-230). It is also not certain that the Acadian deformation in New Hampshire occurred at the close of the Devonian.

Summarizing the discussion of the Middletown, Conn. pegmatites, it seems clear that at present they are not well correlated with their supposed equivalents in New Hampshire. Their age, based on geologic evidence, is undoubtedly pre-Triassic and very probably post lower Paleozoic. The assignment of a date of 260 million years to the close of the Devonian on the basis of the Spinelli samarskite is not well supported by concrete field evidence.

The extensive Fitchburg granite of central Massachusetts is the equivalent of the New Hampshire plutonic series (Billings et al., 1952, p. 45). A microanalysis on uraninite from the granite by Hecht and Kroupa, quoted and corrected with new constants by Rodgers (1952, p. 419), yields an age of 340 million years. Ignorance of the original lead content of the uraninite largely vitiates the value of this age determination, which is considerably higher than the average for the New Hampshire plutonic series.

The Katahdin granite of north-central Maine, which is structurally on-strike with the plutonic rocks of New Hampshire, has been dated geologically by Boucot (1954) as post Early Devonian, and probably post-Acadian orogeny. It is a nonfoliated granite somewhat similar to the Concord granite of the New Hampshire plutonic series. An age determination on the Katahdin granite is given in table 5.

Table 5.--Age determination on zircon from the Katahdin granite.1/

Formation	Location	Mineral	α/mg/hr	Pb (ppm)	Age (million years)
Katahdin granite	Ripogenus Dam, Maine	Zircon	212	28	310
		Zircon	230	30	307
Mean age					308
Devonian					320-265 ± 10

1/ Determination by H. W. Jaffe.

Both the geologic evidence and the age determination strongly favor the correlation of the Katahdin granite with the New Hampshire plutonic series.

WHITE MOUNTAIN PLUTONIC-VOLCANIC SERIES

Stocks and ring dikes of the alkalic White Mountain plutonic-volcanic series postdate the Acadian folding and regional metamorphism and crosscut rocks of the older plutonic series. They have been tentatively assigned to the Mississippian(?) (Billings, 1945, p. 43), but there is no field evidence conclusively proving this. The White Mountain plutonic-volcanic series may be contemporaneous with the pre-Pennsylvanian Carboniferous(?) alkalic rocks of eastern Massachusetts (Emerson, 1917, p. 186-187). Data listed in table 6 lend considerable support to the geologic inferences as to their age.

Zircon is so plentiful in the Conway and Mt. Osceola granites that the zircon concentrates were divided magnetically into several splits. In table 6 the more radioactive and more metamict zircon fractions are also the more magnetic fractions. The reason for concomitant increase in magnetism with radioactivity and degree of metamictization of the zircon is not understood.

In addition to the alkalic rocks of southeastern New England, the White Mountain plutonic-volcanic series may be correlative with intrusives and pegmatites in western Maine, which are considered by Fisher (1941) to be Carboniferous. The several age determinations reported from this area and summarized by Rodgers (1952, p. 415) are highly erratic and range from 200 to 540 million years. If the Maine pegmatite belts of the Paris-Rumford

Table 6.--Age determinations on zircon from the White Mountain plutonic-volcanic series.

Formation	Location	Mineral	α/mg/hr	Pb (ppm)	Age (million years)
Conway granite 1/	North Conway quadrangle	Zircon	1417	150	255
			1050	105	240
			1010	85	201
			836	86	247
Mt. Osceola granite 1/	Mt. Chocorua quadrangle	Zircon	843	80	227
			723	68	225
			470	50	255
Devil's Slide syenite 2/	Percy quadrangle	Zircon	465	44	227
Mean age					233
Standard deviation					18
Carboniferous					265-210 ± 10

1/ Age determination by D. Gottfried and W. L. Smith.
2/ Age determination by H. W. Jaffe.

and Topsham districts are Carboniferous, they are younger than the pegmatite belts of New Hampshire and Connecticut.

DISCUSSION OF RESULTS

Larsen-method age determinations on the four plutonic series of New Hampshire have yielded the following data in millions of years: Highlandcroft 388 ± 33, Oliverian 317 ± 22, New Hampshire 319 ± 34, and White Mountain 233 ± 18. All the standard deviations from the mean are within 11 percent of the average age and are believed due chiefly to inaccuracies in the measurement of lead content or alpha activity, or to sample impurity. These average ages, according to F. E. Senftle (oral communication), may be some 5 to 10 million years too high, on the basis of recalculations he has recently made of the constant c used in the age calculations.

Inasmuch as a series of age determinations for any plutonic series will show variability, it is of some importance to examine the data statistically. One method is to apply the t test. The usual formula for the t test (Dixon and Massey, 1951, p. 97) may be rearranged as follows:

$$\mu = \frac{\bar{X}\sqrt{N} \pm ts}{\sqrt{N}}$$

$\bar{X}$ = mean value of sample
μ = population mean, the mean of an infinite number of observations
s = standard deviation of the sample
N = number of observations in the sample

The statistic t may be read from tables and is dependent upon the sample size. The value in the table is determined by the degrees of freedom (N-1) and the chosen confidence interval. To consider the median 90 percent of a series of values and discard the upper 5 and lower 5 percentages is spoken of as the 90 percent confidence interval. The t value at the lower 5 percent limit of our sample is indicated by $t_{0.05}$; that at the upper 95 percent limit by $t_{0.95}$. If t values are read from statistical tables for a given sample, it is then possible to calculate corresponding limits within which μ must lie. Results of such a calculation for the age determinations of this paper are listed in table 7. The μ values in table 7 are ages which, at the 90 percent confidence level, represent maximum and minimum age values between which the true mean values of our samples must lie. We can assign no precise values for μ within these intervals, but we can reject the possibility that the true mean ages of each of our samples lie beyond their respective limits.

Although there is, as has been indicated, some reason for questioning some of the dates currently accepted by the Committee on the Measurement of Geologic Time (1950, p. 18) for the close of some of the Paleozoic periods, these dates nevertheless furnish a convenient framework of reference with which

Table 7.--Geologic ages derived from confidence limits of observed mean ages.

Plutonic series	$\bar{X}$	s	N	$t_{0.05}$	$t_{0.95}$	μ (max.-min.)	Age range
Highlandcroft	388	33	4	-2.35	2.35	427-349	Upper Ordovician-Lower Silurian
Oliverian	317	22	6	-2.01	2.01	335-299	Middle Silurian-Middle Devonian
New Hampshire	319	34	10	-1.83	1.83	339-299	Middle Silurian-Middle Devonian
Ruggles zircon	367	67	4	-2.35	2.35	446-288	Upper Cambrian-Middle Devonian
Katahdin granite	312	7	2	-2.92	2.92	324-300	Upper Silurian-Middle Devonian
White Mountain	233	18	8	-1.89	1.89	245-221	Middle Carboniferous

to compare the data of table 7 and the geologic facts.

The evidence that the Highlandcroft plutonic series is of Late Ordovician age is good, and a date of 388 ± 33 million years would be consistent with the interpretation that this series was emplaced during the Taconic orogeny.

Overlap in the ages of the Oliverian plutonic series (317 ± 22 million years), the New Hampshire plutonic series (319 ± 34 million years), and the Katahdin granite (312 ± 7 million years) indicates the essential contemporaneity of all these rocks. The geologic evidence indicates that they must be of post-Lower Devonian age. The μ values of table 7 demonstrate that they can be no younger than approximately 300 million years and do not fall within the age range currently assigned to the Upper Devonian. There are several possible reasons why these ages may fail to correspond better with the date now assigned to the close of the Devonian and to the close of the Acadian orogeny (260 ± 10 million years). Aside from the possibility of an unknown but systematic error in the Larsen method, it is evident that the choice of the age of the Spinelli samarskite (260 million years) for the close of the Devonian is on very weak ground and may well be erroneous. Another excellent possibility, mentioned by Boucot (1954, p. 148), is that the Acadian folding in northern New England is of Middle rather than Late Devonian age. As matters now stand there is no good reason for discarding any of these possibilities; some of the uncertainties will be narrowed down when more precise dates for the Ruggles pegmatite are established by the mass spectrometric work now being undertaken at the Geological Survey by L. R. Stieff and T. W. Stern.

The age of the White Mountain plutonic-volcanic series (233 ± 18 million years) is in good agreement with what is known of its areal geologic relations (post-Acadian orogeny). Unlike the Highlandcroft series, which reflects the Taconic orogeny, and the Oliverian and New Hampshire series, which reflect the Acadian orogeny, the White Mountain series is apparently unrelated to a major deformation episode.

ACKNOWLEDGMENTS

The authors wish to express appreciation for discussion and advice on technical problems to the following: Dr. E. S. Larsen, Jr., T. W. Stern, F. J. Flanagan, and L. R. Stieff, of the U. S. Geological Survey; and Dr. R. E. Stoiber of the Geology Department, Dartmouth College. The statistical analysis in the paper has been discussed with Dr. J. L. Snell of the Mathematics Department, Dartmouth College.

LITERATURE CITED

Billings, M. P., 1937, Regional metamorphism of the Littleton-Moosilauke area, New Hampshire: Geol. Soc. America Bull., v. 48, p. 463-566.

__________, 1945, Mechanics of igneous intrusion in New Hampshire: Am. Jour. Sci., v. 243-A, Daly volume, p. 40-68.

Billings, M. P., Thompson, J. B., and Rodgers, J., 1952, Guidebook for field trips in New England, Trip 1: Geol. Soc. America, 65th Annual Meeting, 142 p.

Boucot, A. J., 1954, Age of the Katahdin granite: Am. Jour. Sci., v. 252, p. 144-148.

Collins, C. B., Farquhar, R. M., and Russell, R. D., 1954, Isotopic constitution of radiogenic leads and the measurement of geologic time: Geol. Soc. America Bull., v. 65, p. 1-21.

Dixon, W. J., and Massey, F. J., 1951, Introduction to statistical analysis, New York, McGraw-Hill Book Co., Inc., 370 p.

Emerson, B. K., 1917, Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597, 289 p.

Fisher, L. W., 1941, Structure and metamorphism of Lewiston, Maine, region: Geol. Soc. America Bull., v. 52, p. 107-159.

Hadley, J. B., 1949, Bedrock geology, Mount Grace quadrangle, Mass.-N. H.: U. S. Geol. Survey, Geol. Quad. Map Series.

Holmes, Arthur, 1946, The construction of a geological time scale: Geol. Soc. Glasgow Trans., v. 21, p. 117-152.

Jaffe, H. W., in press, Pre-Cambrian monazite and zircon from the Mountain Pass rare earth district, San Bernardino County, California: Geol. Soc. America Bull.

Kulp, J. L., Bate, G. L., and Broecker, W. S., 1954, Present status of the lead method of age determination: Am. Jour. Sci., v. 252, p. 345-365.

Larsen, E. S., Jr., Keevil, N. B., and Harrison, H. C., 1952, Method for determining the age of igneous rocks using the accessory minerals: Geol. Soc. America Bull., v. 63, p. 1045-1052.

Marble, J. P., 1950, Lead-uranium ratio and possible geologic age of allanite from Greenwich, Massachusetts: Am. Mineralogist, v. 35, p. 845-852.

Nier, A. O., 1939, The isotopic constitution of radiogenic leads and the measurement of geologic time: Phys. Rev., v. 55, p. 153-163.

Report of the Committee on the Measurement of Geologic Time (1948-1949): National Research Council, 139 p.

Report of the Committee on the Measurement of Geologic Time (1949-1950): National Research Council, 118 p.

Rodgers, John, 1952, Absolute ages of radioactive minerals from the Appalachian region: Am. Jour. Sci., v. 250, p. 411-427.

Shaub, B. M., 1938, The occurrence, crystal habit and composition of the uraninite from the Ruggles mine near Grafton Center, New Hampshire: Am. Mineralogist, v. 23, p. 334-341.

Tilton, G. R., 1951, The distribution of trace quantities of uranium in nature: Univ. of Chicago, Ph. D. Dissertation, 51 p.; unpublished.

Tilton, G. R., et al., 1954, The isotopic composition and distribution of lead, uranium, and thorium in a pre-Cambrian granite: U. S. Atomic Energy Comm., AECU-2840, 27 p.

Waring, C. L., and Worthing, Helen, 1953, A spectrographic method for determining trace amounts of lead in zircon and other minerals: Am. Mineralogist, v. 38, p. 827-833.