[AMERICAN JOURNAL OF SCIENCE, VOL. 285, MARCH, 1985, P. 267-280]

NEW RADIOMETRIC AGES ON GNEISSES OF THE OLIVERIAN DOMES IN NEW HAMPSHIRE AND MASSACHUSETTS

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ABSTRACT. Gneissic plutons of the Oliverian domes, mantled by Ammonoosuc Volcanics, are located along the axis of the Bronson Hill anticlinorium from New Hampshire to Connecticut. The contacts between the plutonic and volcanic rocks appear to be concordant on a regional scale, but gneiss intrudes the volcanics in several domes. Available radiometric and fossil evidence suggests that the Ammonoosuc Volcanics have a Middle Ordovician age but are somewhat older than the Oliverian gneisses.

New U-Pb zircon data from Oliverian gneisses of six domes plot on a concordia diagram as an almost colinear array that yields an upper intercept age of about 444 m.y. The plotted data vary from nearly concordant to moderately discordant, the degree of discordance correlating with $^{207}Pb/^{206}Pb$ ages that range from 459 to 415 m.y. The pattern of discordance does not relate to the uranium contents of the zircons nor to the geographic distribution of the domes. If $^{207}Pb/^{206}Pb$ ages are considered individually without an assumed consanguinity of the units, however, they do not find particular support in geologic relationships. Thus, we prefer the concordia intercept age of 444 $\pm$ 8 m.y. for the suite as the best estimate for the time of crystallization of the Oliverian gneisses. Possibly, the Whitefield Gneiss in the Jefferson dome represents a 10 to 15 m.y. older unit, although we are cautious about claiming such resolution with the present data.

INTRODUCTION

The so-called Oliverian domes are located along the axis of the Bronson Hill anticlinorium, one of the major structural belts of the New England Appalachians. The domes number about fifteen and have a linear distribution at irregular intervals from northern New Hampshire to Long Island Sound (fig. 1). The rocks exposed in the cores of most of the domes are calc-alkaline granitic gneiss. The gneisses are mantled by Ammonoosuc Volcanics, a dominantly bimodal, potassium-poor suite of metamorphosed tholeiite and quartz keratophyre tuffs and related trondhjemite, now represented by hornblende–plagioclase–biotite amphibolite and quartz–plagioclase granofels, respectively. Locally, as in central Massachusetts and southwestern New Hampshire, the Ammonoosuc section is more varied and includes rhyolitic rocks in its upper part (Schumacher, ms).

The Oliverian domes were described nearly half a century ago (Billings, 1937).[1] Rocks of the Oliverian magma series (hereafter called simply

[1] Billings (1937) introduced the name "Oliverian magma series" to designate the granitic rocks in the interiors of the domes but referred to individual domes by suitable geographic names (for example, Owls Head dome). The term "Oliverian dome" was perhaps first used by Chapman (1939, 1942) followed by Naylor (1968, 1969), and Leo, Zartman, and Brookins (1984), among others. In view of the term's general acceptance, we will continue to use "Oliverian domes" for the structures and will use "Oliverian gneisses" for the granitic rocks in their interiors.

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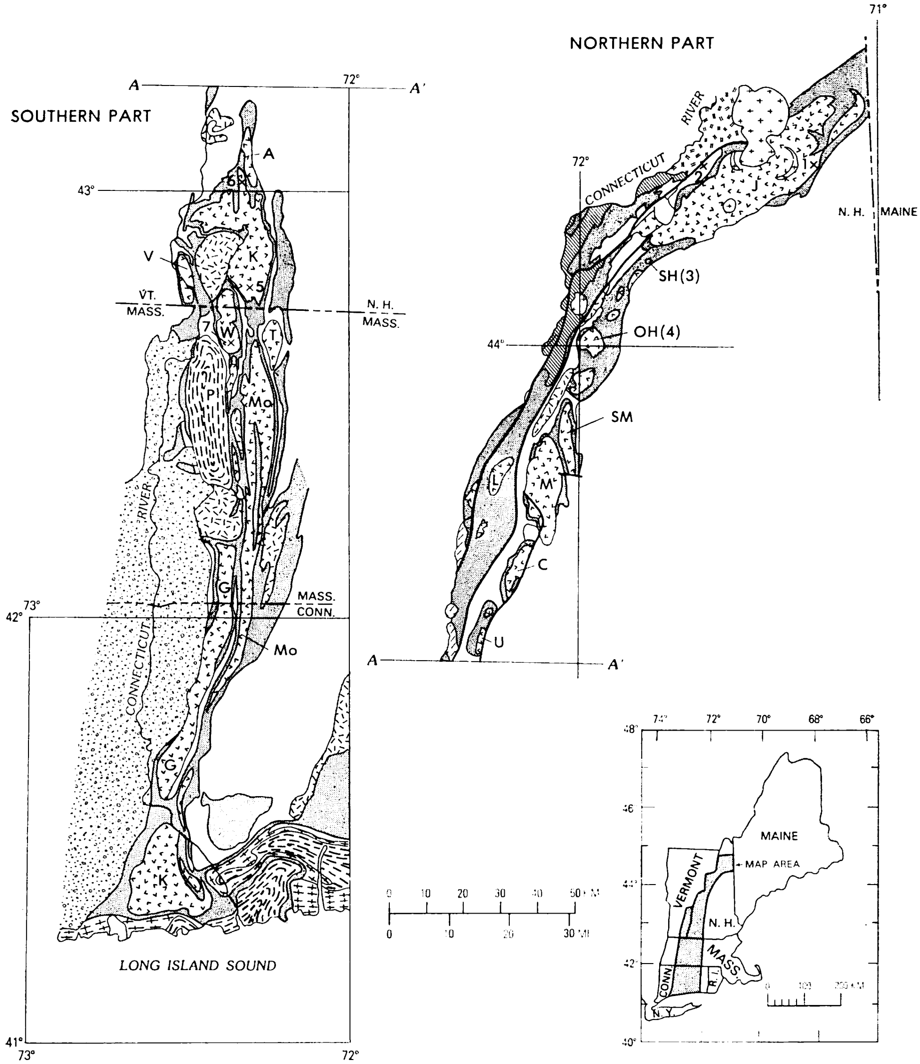

Oliverian gneiss(es) were initially regarded as Devonian on the basis of intrusive contacts with overlying Ammonoosuc Volcanics (Billings, 1937, 1941; Hadley, 1942; Kruger, 1946; Moore, 1949). Eskola (1949) subsequently proposed, by analogy with mantled gneiss domes of Finland, that the cores of Appalachian domes might represent remobilized Precambrian basement. This idea, at least for the Oliverian domes, was effectively disproved by Naylor (1968, 1969) who showed that the core gneisses and mantling volcanics in the Mascoma and Lebanon domes are both Ordovician in age. In these and subsequent studies, Naylor (1968, 1969, 1975) argued from structural and petrologic considerations that other domes

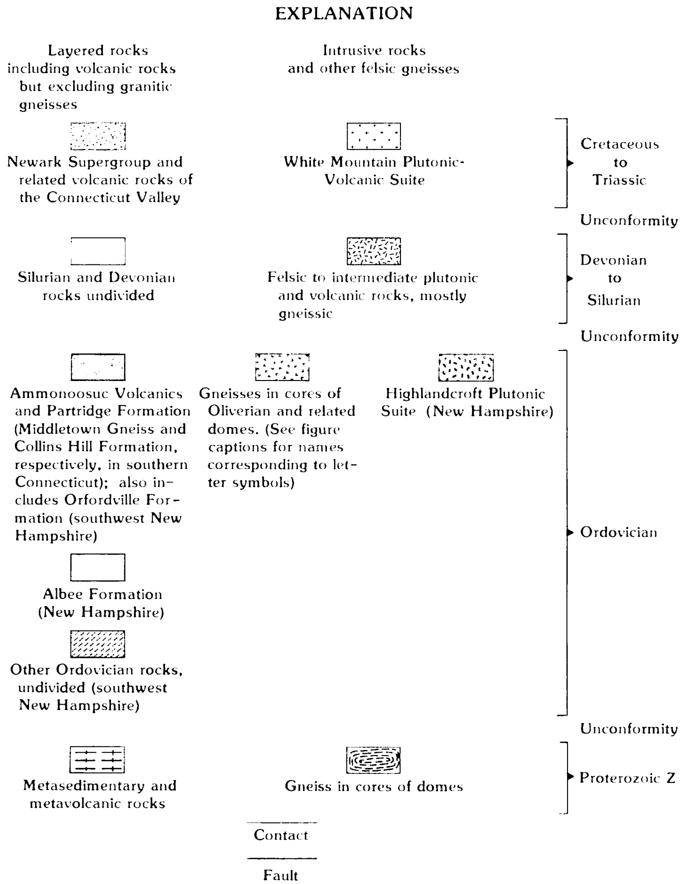

Fig. 1. Geologic setting of the Bronson Hill anticlinorium, emphasizing the Oliverian domes and Ammonoosuc Volcanics. Adapted from Robinson and Hall (1980, fig. 1) and Billings (1955). Letter symbols for Oliverian and other related domes as follows (generally from north to south): J, Jefferson; SH, Sugar Hill; OH, Owls Head; SM, Smarts Mountain; M, Mascoma; L, Lebanon; C, Croydon; U, Unity; A, Alstead; V, Vernon; K, Keene; W, Warwick; T, Tully; P, Pelham; Mo, Monson Gneiss; G, Glastonbury Gneiss; K, Killingworth. Numbered localities correspond to samples described in tables 1 and 2.

along the Bronson Hill anticlinorium were possible coeval analogs of the Mascoma dome. Correlative rocks originating from Ordovician volcanic and plutonic activity were proposed by him to occur in the belt as far south as the Glastonbury dome and as far north as the Jefferson dome.

Foland and Loiselle (1981) determined an Rb-Sr whole-rock isochron age of 441 ± 5 m.y.[2] on syenite in the central Jefferson dome. The dated

[2] Throughout this paper all radiometric ages are given in terms of the decay constants recommended by the International Union of Geological Sciences Subcommission on Geochronology (Steiger and Jager, 1977). This adoption of the new constants has necessitated the conversion of some of the published literature but permits a more straightforward comparison between dating methods.

syenites are weakly foliated and intrude previously foliated, granitic Oliverian gneisses. Thus, the syenite most likely represents the waning stages of Taconic orogeny in the area.

An age of 456 ± 10 m.y., based on U-Pb zircon analyses, was obtained on the Glastonbury Gneiss (Leo, Zartman, and Brookins, 1984). Rb-Sr whole-rock data for this unit scattered considerably on an isochron diagram — in contrast with the lesser scatter on whole-rock Rb-Sr diagrams for the Mascoma and Lebanon gneisses (Naylor, 1969) and virtually no scatter on the whole-rock Rb-Sr diagram for the syenite of the Jefferson dome (Foland and Loiselle, 1981). Such disturbed isotopic systematics probably can best be explained by increasing severity of Acadian, and possibly also Alleghenian, metamorphism southward along the anticlinorium.

The present work was undertaken to provide greater geographic coverage of radiometric dates on the Oliverian gneisses in the context of a petrologic and geochemical study of all the domes (Leo, unpub. data). Primary objectives were to test the possibility that significantly older or younger gneisses might exist among the Oliverian assemblage and to provide an updated summary of the chronostratigraphic relationship between Oliverian gneisses and Ammonoosuc Volcanics.

Our results confirm an Ordovician age (444 ± 8 m.y.) of emplacement for gneiss in six additional Oliverian domes. Also, because the Ammonoosuc Volcanics mantling the New Hampshire domes are intruded by Oliverian gneiss in several places, this age establishes a minimum for the time of volcanism. Regional structural syntheses (Thompson and others, 1968; Robinson and Hall, 1980) suggest that the domes themselves formed in the Middle Devonian (380-370 m.y. ago) as the culmination of intense tectonism, including the formation of giant nappes, during the Acadian orogeny. No evidence exists, however, for melting of Oliverian gneisses on any significant scale at this time.

Ammonoosuc Volcanics.—The age of the Ammonoosuc Volcanics is not precisely established despite several attempts to date the sequence. Published age determinations, all based on whole-rock Rb-Sr isochrons, include the following (Ammonoosuc Volcanics unless otherwise noted; chronological order of publication): 449 ± 15 m.y. (Brookins and Hurley, 1965, samples from Harvard colln.); 431 ± 15 m.y. (Brookins and Hurley, 1965, Middletown Formation [Ammonoosuc equivalent], Connecticut); 421 ± 20 m.y. (Brookins, 1965, central Massachusetts); 448 ± 15 m.y. (Brookins, 1968, central Massachusetts); 431 ± 30 m.y. (Naylor, 1969, Mascoma dome, New Hampshire). No new radiometric data on Ammonoosuc Volcanics are presented in this report.

The Ammonoosuc Volcanics were designated as Upper Ordovician by Billings (1937) on the basis of the unconformably overlying, fossiliferous Silurian Fitch Formation. Subsequently, the Ammonoosuc has been reclassified as Middle Ordovician on the basis of graptolites in black shale (equivalent to Partridge Formation) interpreted to overlie the volcanics in the Cupsuptic quadrangle, west-central Maine (Harwood and Berry, 1967). Reexamination of this critical locality (R. H. Moench, written commun., 1982) now shows the black shale to lie within rather than above the Ammonoosuc. The graptolite assemblage there correlates with zone 12 (Berry, 1960) or, more specifically, with the lower part of that zone (S. C. Finney, oral commun., 1982). Recent evaluation of the Ordovician time scale on the basis of $^{40}Ar/^{39}Ar$ temperature release spectra (Kunk and Sutter, 1984; M. J. Kunk, oral commun., 1982) suggests a corresponding isotopic age with a minimum value of 454 ± 3 m.y. This age, therefore, would seem to be our best estimate for the Ammonoosuc Volcanics, at least for the black shale horizon in the Cupsuptic area. An age in this range is in accord with the implicit age of Ammonoosuc on the Oliverian domes, which is intruded by 444 ± 8 m.y. old plutons.

Recent mapping by R. H. Moench (personal commun., 1984) has demonstrated lithologic correlation between Ammonoosuc Volcanics of the New Hampshire section and that of western Maine (Old Speck Mountain 15-minute quad). In the latter area, rocks very similar to the New Hampshire Ammonoosuc overlie the Lower Ordovician Albee Formation and underlie the Upper Ordovician Quimby Formation. The Ammonoosuc in this area is intruded by gabbro, tonalite, and sheeted diabase, as well as by Oliverian granitic gneiss, and it can be traced west and southwest to the vicinity of Milan and Berlin, N.H.

Along the Bronson Hill anticlinorium in central Massachusetts and south into Connecticut, the Ammonoosuc Volcanics overlie Monson Gneiss, a massively layered quartz–plagioclase gneiss, along an unconformable contact (Robinson and Hall, 1980; Hall and Robinson, 1982). Several samples of the Monson have been dated by U-Pb zircon analysis at 428 to 440 m.y. (Leo, Zartman, and Brookins, 1984; Zartman and Naylor, 1984), suggesting an Ammonoosuc age of less than about 430 m.y. However, in the same region, Glastonbury Gneiss dated at 456 ± 10 m.y. intrudes Ammonoosuc. This incongruity is addressed by Leo, Zartman, and Brookins (1984), who suggest that zircons in the Monson Gneiss may have undergone a disproportionate degree of recrystallization, with attendant loss of lead, during the Acadian (and Alleghanian?) orogenies.

Oliverian gneisses.—The chemistry and petrology of these gneisses are the subject of an ongoing study (Leo, unpub. data). Brief descriptions and contact relationships of dated samples are given in table 1. The gneisses in the interiors of most of the domes are fine- to medium-grained rocks with faint to strong foliation, of which two types of planar fabric have been observed. The first is a foliation trending north-northeast to northeast that is also locally developed in pre-Carboniferous layered rocks outside the domes. The second is a concentric, outward-dipping foliation which wraps around the ends of domes and is evidently related to the doming process itself. Such concentric foliation is not found in all the domes, but it is well expressed in some, notably the north end of the Owls Head (Billings, 1937, map of Moosilauke quad.); the north ends of the Mascoma and Smarts Mountain domes (Hadley, 1942, map); and the northeast end of the Jefferson dome (R. H. Moench, personal commun., 1982). Inasmuch as the doming is regarded as being late Acadian (Robin-

TABLE 1

Locations and petrography of dated Oliverian samples (in approximate order northeast to southwest; see fig. 1) and contact relations between Oliverian gneiss and Ammonoosuc Volcanics, where known, for respective plutons

Location no.	Type and location	Petrography (minerals listed in order of decreasing abundance)	Contact relations
1	Gneiss near Berlin, N.H.*; road-cut west side of N.H. route 16, 3.6 km south of intersection of routes 16 and 110 in Berlin. Northeast part of Jefferson dome. Berlin (N.H.) 7.5-min quad (44°26′12″N., 71°11′31″W.)	Medium-grained, moderately to strongly foliated and partly recrystallized quartz–microcline–oligoclase–biotite–muscovite gneiss.	Gneiss intrudes Ammonoosuc Volcanics at least on a scale of meters in several localities in the Berlin area. Gneiss is cut by amphibolite dikes 1 to 5 m thick. Such dikes may be of late Ammonoosuc age, but they may also be younger (Silurian or Devonian).
2	Whitefield Gneiss; East Whitefield Road, 7.5 km northeast of Whitefield, N.H., 2.2 km south of Prospect Mountain. Northwest margin of Jefferson dome. Whitefield (N.H.-Vt.) 15-min quad (44°25′53″N., 71°34′00″W.)	Strongly foliated, relatively mafic (C.I. ~ 7-20) quartz–plagioclase–microcline–biotite epidote gneiss.	Gneiss constitutes the oldest recognized pluton of Jefferson dome and is cut by at least one younger Oliverian phase (Bray granite of R. H. Arndt, unpub. data). Contact with Ammonoosuc Volcanics not exposed.
3	Sugar Hill quartz monzonite (Billings, 1937); 2.5 km southeast of Sugar Hill village. Sugar Hill (N.H.) 7.5-min quad (44°11′52″N., 71°46′39″W.)	Fine-grained, faintly foliated quartz–microcline–oligoclase–biotite–muscovite granite of hypabyssal aspect, locally porphyritic.	Granite cuts Ammonoosuc amphibolite, notably as a broad lens approx 1 km long on the south flank of Ore Hill; elsewhere cuts Ammonoosuc on outcrop scale.

* Informal designation for the coarse gneissic granite in the Berlin area. Geographic extent and contact relations with other Oliverian phases presently unknown (Leo, unpub. data).

4	Owls Head granite (Billings, 1937); roadcut on N.H. rte. 25, 1.3 km southeast of East Haverhill Village. East Haverhill (N.H.) 7.5-min quad (44°01′19″N., 71°57′26″W.)	Fine- to medium-grained, slightly to moderately foliated quartz–microcline–plagioclase–biotite–muscovite granite.	Intrusive contact with Ammonoosuc Volcanics(?) marked by dikelets and apophyses of granite and by localized contact zones as much as 1200 m wide in which potassic feldspar has been metasomatically introduced. Correlation of metasomatized rocks with Ammonoosuc Volcanics is somewhat controversial.
5	Swanzey Gneiss (Robinson, 1967) of the Keene dome; outcrop north side of N.H. rte. 119, approx 6 km east of Winchester, N.H. (Swanzey I). Keene-Brattleboro (N.H.) 15-min quad (42°45′40″N., 72°18′43″W.)	Medium grained, strongly foliated quartz–plagioclase–biotite–microcline gneiss.	In a roadcut on N.H. rte. 12, approx 8 km Southeast of Keene, N.H., Ammonoosuc Volcanics overlie Swanzey Gneiss along a sharp contact parallel to lithologic layering in Ammonoosuc (Robinson, Thompson, and Rosenfeld, 1979). An unconformity is possible but cannot be proved in this single exposure.
6	Swanzey Gneiss of the Keene dome; roadcut east side of N.H. rte. 12A approx 10 km north of Keene, west edge of Surrey village (Swanzey II). Bellows Falls (N.H.-VT.) 15-min quad (43°00′56″N., 72°19′21″W.)	Medium-grained, moderately foliated, quartz–plagioclase–microcline–biotite gneiss.	Same comments apply as for no. 5.
7	Pauchaug Gneiss (Robinson, 1967) of the Warwick dome; abandoned quarry 4.3 km northeast of Erving, Mass., 1.0 km northeast of Laurel Lake off Quarry Road. Northfield (Mass.) 7.5-min quad (42°37′08″N., 72°21′54″W.)	Slightly foliated quartz–plagioclase–microcline–biotite granite typical of the southern part of the Pauchaug Gneiss.	Contact with Ammonoosuc Volcanics has been studied for many miles and appears to be sharp without intrusive apophyses. Detailed stratigraphy within the Ammonoosuc is not truncated even where the unit is only tens of feet thick. No basal quartzite has been seen. Nature of contact unknown.

son and Hall, 1980), the two foliations must be approximately contemporaneous.

The most common composition of the Oliverian gneisses is granite, which locally grades to granodiorite and biotite tonalite. A sizable mass of syenite occupies the northeast-central part of the large Jefferson dome (Foland and Loiselle, 1981). Trondhjemite, identified in most places as an intrusive equivalent of K-poor, layered felsic Ammonoosuc Volcanics, constitutes all or part of the cores of several domes (Leo and Gromet, 1981; Leo, Zartman, and Brookins, 1984).

ANALYTICAL METHODS

Zircon concentrates were prepared using a Wilfley table, heavy liquids, and magnetic separation from approx 50 kg of fresh, representative samples of the rocks selected for dating. Remaining impurities were hand picked under a binocular microscope from size fractions of the zircon. The zircon crystals were then rinsed in hot 6N HCl and 6N HNO_3 for 20 min each as a final cleansing step prior to chemical dissolution. This rinsing was repeated if coloration of the acids identified the presence of some soluble phase. Because we presently require only about 10 mg of zircon for an analysis, the entire population of grains can be carefully examined and evaluated morphologically. No obvious evidence of multiple growth, metamorphic resorption, or other complicating factors was found in any of the samples, and we interpret the zircon to be a primary crystallizing phase of the rock.

The analytical procedure is a slightly modified version of the Krogh (1973) method, which employs an HF–HNO_3 digestion at 250°C in a Teflon bomb. A combined U and Th tracer is added to the entire sample before bomb digestion, and lead concentration is determined by isotope dilution on an aliquot of the sample removed after digestion. Lead purification is carried out on a bromide-form anion resin column with the isotopic-composition and concentration fractions receiving separate but parallel treatment. Uranium and thorium are extracted together on a nitrate-form anion resin column using the eluate off the lead isotope-composition column. Mass-spectrometric analysis (1) for lead was by surface ionization from a single rhenium filament containing an H_3PO_4-silica gel emitter, and (2) for uranium and thorium was by volatilization off two rhenium side filaments onto a rhenium ionizing filament. Ion currents were measured by means of a vibrating-reed electrometer, and a digital voltmeter was connected to an on-line computer for data reduction.

Uncertainties of ±1 percent (2σ) are assigned to U, Th, and Pb concentrations and ±0.1 percent to the measured $^{207}Pb/^{206}Pb$ ratios. Common lead correction has been made by first subtracting lead equal in amount (1 ng) and isotopic composition to the analytical blank. The remaining ^{204}Pb was then assumed to reflect 450 m.y.-old "model" lead with $^{206}Pb/^{204}Pb = 18.20$, $^{207}Pb/^{204}Pb = 15.60$, and $^{208}Pb/^{204}Pb = 38.10$. All the zircons had quite low common lead abundances, and these corrections do not significantly increase the uncertainty of the age. The U-Th-Pb zircon analytical data and calculated ages are given in table 2 and are plotted on a

TABLE 2

Uranium–thorium–lead isotopic age of zircon from Oliverian gneisses, New Hampshire and Massachusetts

[Numbers in brackets correspond to localities in fig. 1]

Mesh size	Concentration (ppm) U	Th	Pb	Isotopic composition of lead (atom percent) ^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	Age, in millions of years $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{232}Th$
				Gneiss near Berlin, Jefferson Dome [1]							
−150+200	1306.9	450.1	85.1	0.0171	85.16	4.962	9.859	401	405	429	392
−250+325	1144.9	428.1	74.0	0.0102	84.84	4.839	10.31	398	402	424	387
				Whitefield Gneiss, Jefferson Dome [2]							
−150+200	1086.7	353.6	79.3	0.0270	85.25	5.181	9.542	448	450	459	430
−250+325	1531.5	512.7	110.1	0.0151	85.69	5.028	9.267	445	447	457	421
				Sugar Hill Quartz Monzonite [3]							
−150+200	1147.7	535.7	77.2	0.0250	83.04	4.984	11.95	403	408	438	357
−250+325	913.9	469.9	65.7	0.0073	82.37	4.690	12.93	415	419	438	399
				Owls Head Granite [4]							
−150+200	1042.8	597.9	80.2	0.0403	78.83	4.992	16.13	435	437	447	441
−250+325	1020.1	608.2	77.6	0.0220	78.91	4.720	16.35	433	434	442	445
				Swanzey Gneiss, Keene Dome [5]							
−150+200	1428.4	612.8	77.2	0.0218	87.40	5.137	7.438	343	353	418	189
−250+325	1226.4	494.6	69.8	0.0556	85.68	5.526	8.737	351	360	413	212
				Swanzey Gneiss, Keene Dome [6]							
−150+200	2025.8	432.1	136.9	0.0059	88.68	5.044	6.270	434	436	448	431
−250=325	2335.8	488.2	155.0	0.0067	88.77	5.055	6.168	426	430	447	423
				Pauchaug Gneiss, Warwick Dome [7]							
−150+200	2520.2	786.8	168.8	0.0101	85.94	4.917	9.138	417	419	432	423
−250+325	2622.5	731.9	168.6	0.0104	86.63	4.961	8.397	404	408	433	415

Constants: $^{238}U = 1.55125 \times 10^{-10}$ yr^{-1}; $^{235}U = 9.8485 \times 10^{-10}$ yr^{-1}; $^{232}Th = 4.9375 \times 10^{-11}$ yr^{-1}; $^{238}U/^{235}U = 137.88$. Isotopic composition of common lead assumed to be $^{204}Pb:^{206}Pb:^{207}Pb:^{208}Pb = 1:18.20:15.60:38.10$.

concordia diagram in figure 2. Also plotted in figure 2 are five U-Pb zircon analyses of Naylor (1969) for the Mascoma dome.[3]

DISCUSSION

The geochronological data define a composite linear array on the concordia diagram (fig. 2). Such a linear relationship among discordant analyses is often displayed by suites of zircon representing different size or magnetic fractions and different sample localities from individual plutons or groups of cogenetic plutons (see, for example, the discussion of

[3] Two numerical errors were found in the calculated parent-daughter ratios of Naylor (1969), which have been corrected in our plot of his data by recomputing the ratios from the raw data.

this phenomenon in Naylor, 1969). Following conventional interpretation by which discordia lines are projected upward to intersect the concordia curve and give the time of initial crystallization, an age of 444 ± 8 m.y. is derived for the suite of rocks as a whole. In terms of the geologic time scale, the age derived from the pooled discordia line together with its uncertainty would lie within the Middle to Upper Ordovician.

Inasmuch as a major purpose of this study was to question the contemporaneity of the different Oliverian gneiss plutons, one might challenge this approach of treating all samples as a single suite. The minor deviation from perfect alignment and the small degree of discordance shown by the zircon from the various rocks, however, would seem to restrict the time interval for emplacement of the gneisses to, perhaps, 20 m.y. and almost certainly no more than 40 m.y. If our individual dated samples each define their own discordia line rather than belong to a pooled discordia line through all the data, differences in concordia intercepts as large as the range in $^{207}Pb/^{206}Pb$ ages might be entertained. The greatest overall spread in emplacement ages by such reckoning would arise between the Swanzey Gneiss (Robinson, 1967) sample 5, with an average $^{207}Pb/^{206}Pb$ age of 416 m.y. and the Whitefield Gneiss, sample 2, with an average $^{207}Pb/^{206}Pb$ age of 458 m.y. In this respect, the Swanzey Gneiss, sample 5 — and the Mascoma dome assemblage of Naylor (1969) — yield

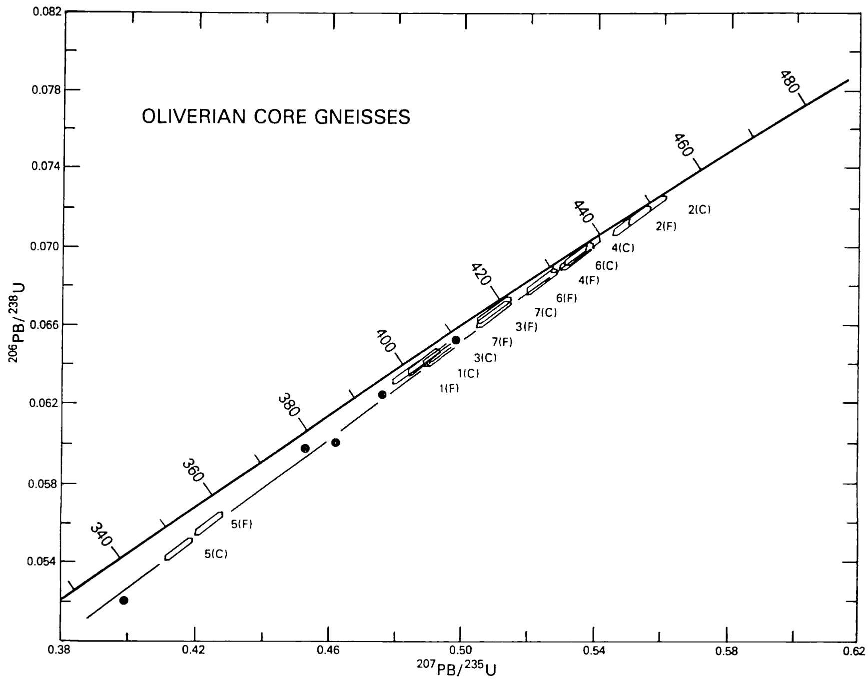

Fig. 2. Concordia diagram of zircon from Oliverian gneisses. Numbered samples analyzed for this study (C, coarser mesh fraction; F, finer mesh fraction); solid circles, Mascoma dome, Naylor (1969).

the most discordant analyses and, therefore, are subject to the greatest uncertainty in establishing a precise age. Our considerably improved success in a second effort to date what we take to be the same Swanzey Gneiss (sample 6) from another locality largely discredits the objective significance of individual ages. The linear array that is defined by the combined four analyses of Swanzey Gneiss project to a concordia intercept virtually identical with the best-fit line to all the samples. Perhaps only in the case of the Whitefield Gneiss, sample 2, where geologic relationships, near-concordancy of the analyses, and greatest deviation from the best-fit line together support an older age for this unit, does it seem reasonable to entertain any real temporal fine-structure to the Oliverian core rocks.

Degree of discordance among zircon fractions of a cogenetic suite is frequently found to correlate with radioactivity (that is, uranium content) or with the intensity of younger, superimposed metamorphism. The pattern of discordance for the Oliverian gneisses seems to relate neither to uranium contents between samples nor to the geographic distribution of the domes relative to regional metamorphic grade. Although the uranium content of zircon fractions from the same sample usually shows positive correlation with the degree of discordance, no convincing trend emerges for the combined suite. In fact, the most radioactive zircon fraction — sample 7 (−250 ± 325) with 2622 ppm U — and the least radioactive zircon fraction — sample MHL-1 of Naylor (1969) with 870 ppm U — encountered for these gneisses plot essentially at the same position on the concordia diagram. Furthermore, sample 2 with the least discordant zircons and sample 5 with the most discordant zircons have similar average uranium contents. Accordingly, a good correlation between uranium content and degree of discordance occurs only within the zircon population of individual samples, which experienced an identical geologic history. Uranium is often sited heterogeneously in the zircon crystal lattice and in a variety of microscopic inclusions contained in the zircon. The same overall concentration of uranium can be distributed very differently — in part uniformly dispersed throughout the zircon lattice and in part strongly enriched in local domains of the zircon or included crystallites — depending on the physicochemical conditions experienced by the crystallizing magma. Subsequent migration of parent and daughter isotopes will be strongly influenced by the accumulating radiation damage. Thus, the distribution pattern rather than the absolute amount of uranium might be the main determining factor to the degree of discordance. We offer this possible explanation of an apparent inconsistency to caution against accepting too simplistic a view of zircon discordance, a view that might be used to argue against a common age for the entire suite.

Let us return to the best-fit line through all of the data on figure 2, which gives upper and lower concordia intercept ages of 444 ± 8 m.y. and 95 ± 55 m.y. If the regression were carried out on a suite of assured coeval rocks, these ages would be conventionally interpreted as the times of primary crystallization and of either episodic lead loss or no significant geologic event (such as in the case of radiation-damage diffusion), respectively. In the present case the plotted data vary from nearly concordant to moderately discordant. The degree of discordance correlates with $^{207}Pb/^{206}Pb$ ages that range from 459 to 415 m.y. Another recent study of U-Pb zircon ages for a wide variety of plutonic rocks from southeastern New England (Zartman and Naylor, 1984) produced linear arrays of data on concordia diagrams for individual rock units that rather consistently gave lower intercept ages of approximately zero m.y. In contrast with the present study, those $^{207}Pb/^{206}Pb$ ages were all very similar and essentially equal to the upper intercept, or primary, age of the unit. Accordingly, recent rock dilation with accompanying access of ground water was thought to be the main cause of discordancy in the U-Pb data in southeastern New England. Possibly some complex response to late Paleozoic or Mesozoic metamorphism in addition to recent rock dilation has produced the 95 ± 55 m.y. lower concordia intercept for the rocks of the Bronson Hill anticlinorium. Certainly this terrain lies along the axis of a Permian "disturbed" belt (Zartman and others, 1970), and plutons of the White Mountain magma series punctuate the geology of New Hampshire.

In conclusion, contact relationships between Oliverian gneisses and Ammonoosuc Volcanics are of two general types (table 1): (1) the gneiss intruded volcanics (gneiss near Berlin; Sugar Hill quartz monzonite; Owls Head granite), or (2) mutual relations are unknown or uncertain. These field relationships, in the light of previous discussion of a probable Ammonoosuc age of 454 ± 3 m.y. in the west-central Maine section, reinforce the concept that the Ammonoosuc is somewhat (10-15 m.y.) older than the Oliverian gneisses. The fact that gneiss is nowhere known to intrude strata *above* the Ammonoosuc seems to put a maximum age of pre-Partridge on Oliverian gneisses, a fact generally compatible with the 444 m.y. age for the pooled discordia line.

ACKNOWLEDGMENTS

We are indebted to Anita G. Harris, Michael J. Kunk, Robert H. Moench, and John F. Sutter for informative discussion, and to Moench and John N. Aleinikoff for careful reviews of the manuscript.

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