[AMERICAN JOURNAL OF SCIENCE, VOL. 283, SEPTEMBER, 1983, P. 739-761]

SILURIAN-LOWER DEVONIAN STRATIGRAPHY OF EASTERN AND SOUTH-CENTRAL NEW HAMPSHIRE: EXTENSIONS FROM WESTERN MAINE

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ABSTRACT. A sequence of distinctive stratigraphic units has been defined in a succession of sillimanite-grade metasedimentary schists, gneisses, and granulites in eastern and central New Hampshire north of the 44th parallel. These rocks previously had all been mapped as Lower Devonian Littleton Formation. The units are correlated and continuous with the formations of the Rangeley area, Maine, to the northeast. From bottom to top, this sequence includes moderately rusty to nonrusty quartzite, schist, and minor granule and pebbly metaconglomerate correlated with the Rangeley Formation; thinly bedded, nonrusty quartzite and schist correlated with the Perry Mountain Formation; deeply rusty-weathered sulfidic schist, quartzite, and calc-silicate granulite correlated with the Smalls Falls Formation; nonrusty, layered calc-silicate and quartz–plagioclase–biotite granulite correlated with the Madrid Formation; and generally nonrusty, well-graded aluminous schist and granulite correlated with the Carrabassett and Seboomook Formations. In Maine, the Carrabassett and Seboomook are separated by the thin but extensive Hildreths Formation, which is not recognized in New Hampshire.

The same sequence of units has been mapped immediately south of latitude 44° and is firmly correlated southward with a succession of units in south-central New Hampshire previously designated as the Roundtop Quartzite and Crotched Mountain Formation (Rangeley and Perry Mountain), Francestown Formation (Smalls Falls), Warner Formation (Madrid), and Littleton Formation (Carrabassett and Seboomook). Neither the Roundtop nor the Crotched Mountain nor other previously unnamed rocks in central and south-central New Hampshire that we would correlate with the Rangeley Formation are known to contain conglomerate. The age of the Littleton-Seboomook rocks is well established as Early Devonian; all the other rocks are believed to be Silurian. We propose to extend usage of the Maine names Rangeley, Perry Mountain, Smalls Falls, and Madrid southwest into New Hampshire at least as far as latitude 44°. We propose extending the use of the name Littleton northeast to the north end of the Sebago batholith in Maine and using the Maine terms Carrabassett and Seboomook for equivalent rocks northeast of that point.

The extension of the Silurian units into eastern and south-central New Hampshire indicates that the "tectonic hinge" previously described in western Maine and alluded to by M. P. Billings in 1956 between the thin Silurian shelf sequence of the Bronson Hill-Boundary Mountain anticlinorium and the thick Silurian sequence of the

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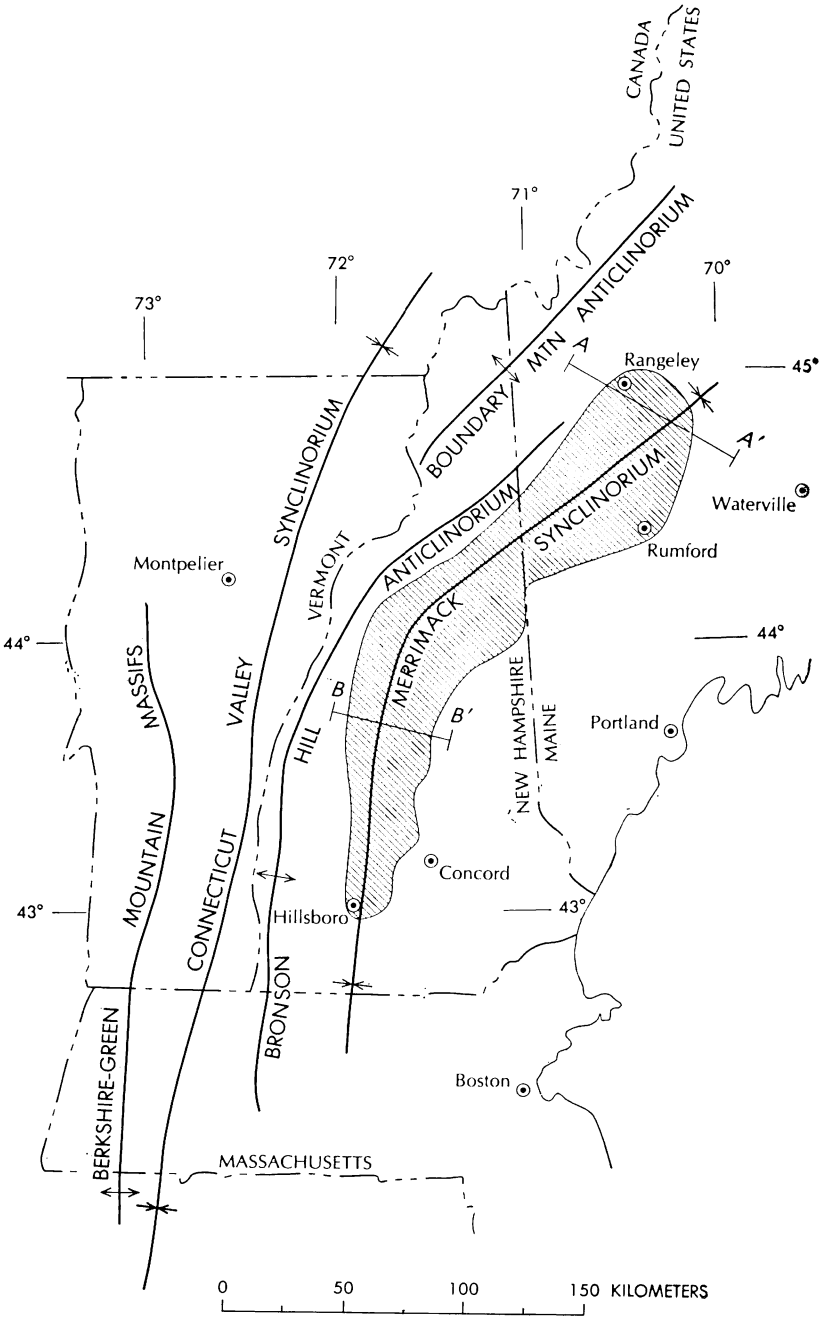


Fig. 1. Tectonic framework of central New England. Area of figure 2 is ruled. A-A′ and B-B′ locate stratigraphic diagrams shown in figure 3.

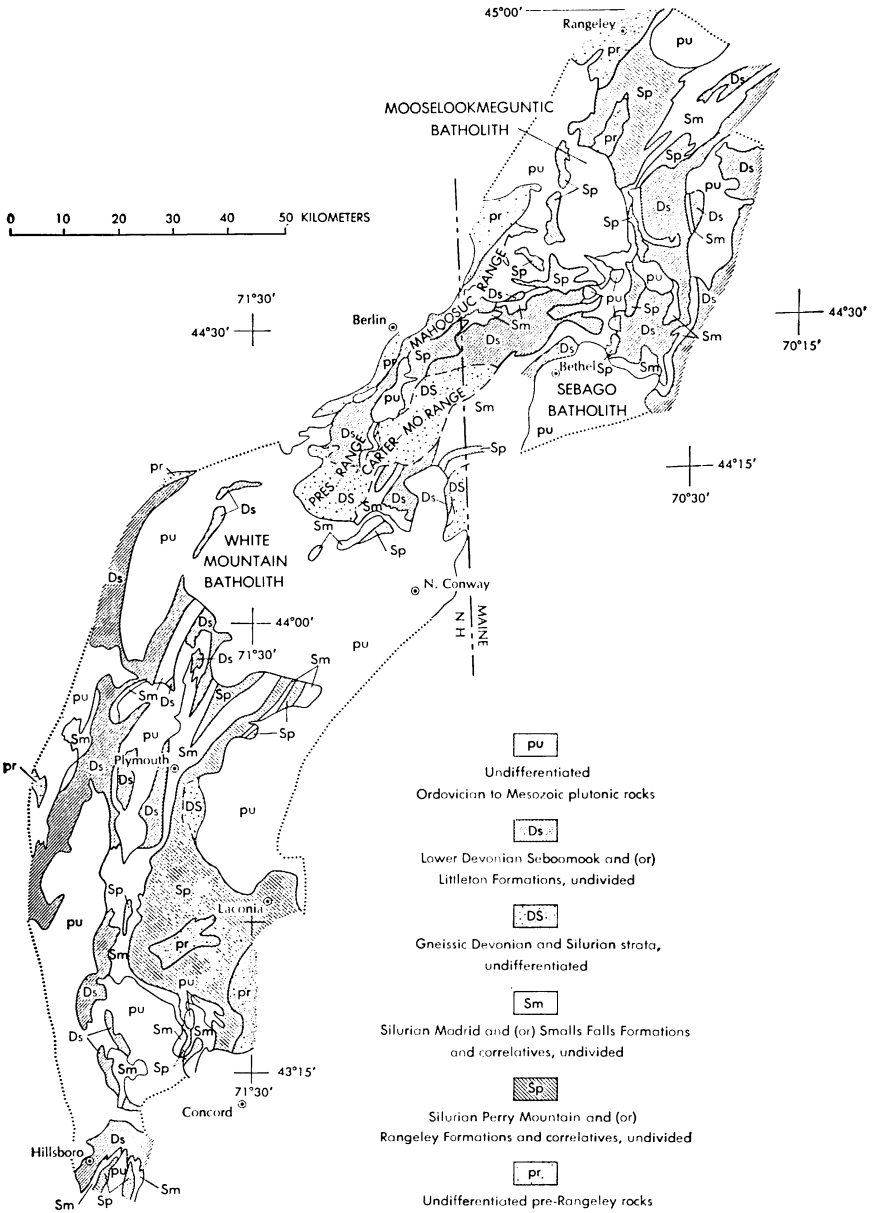


Fig. 2. Map showing distribution of Silurian and Lower Devonian strata in part of the Merrimack synclinorium between Rangeley, Maine, and Hillsboro, New Hampshire.

western Merrimack synclinorium can be traced at least to central Massachusetts.

INTRODUCTION

The Silurian age of a thin conglomerate–quartzite unit, the Clough Quartzite, and a thin marble and calcareous slate unit, the Fitch Formation, in the region of the domes of the Bronson Hill anticlinorium of western New Hampshire (fig. 1), has long been recognized (Hitchcock, 1871, 1874; Billings and Cleaves, 1934; Boucot and Thompson, 1963; see also Harris, Hatch, and Dutro, 1983). In 1971 Moench proposed a Silurian age for a much thicker package of metasedimentary rocks southeast of the Boundary Mountain anticlinorium (approximate en-echelon northeast extension of the Bronson Hill anticlinorium) in the Rangeley area of Maine (fig. 1). Although much quadrangle mapping has been done in westernmost Maine and eastern New Hampshire, and some speculations have been voiced, the Silurian units of the Rangeley area have not heretofore been traced along strike to the southwest into New Hampshire. However, various authors, including Dean (ms), Englund (1976), and Nielson (1981) in southern New Hampshire and Field (1975), Tucker (1977), and Robinson (1979, 1981) in central Massachusetts, have all suggested long-range correlations with the Rangeley units on the basis of lithic similarities.

In the meantime, Osberg (1968, 1979; Osberg, Moench, and Warner, 1968) and Pankiwskyj and others (1976) described another Silurian section in the Merrimack synclinorium in the vicinity of Waterville, Maine, still farther southeast (fig. 1). This section also has yet to be definitively traced southwest along strike into the higher grade, as-yet-unfossiliferous, terrane of southeast New Hampshire and eastern Massachusetts, although once again speculation abounds (for example, Tucker, 1977; Robinson, 1979, 1981; Billings and Lyttle, 1981).

This paper presents the results of some recent mapping, results that pertain to the Silurian stratigraphy of western Maine and eastern and south-central New Hampshire (Hatch, Moench, and Lyons, 1981). In particular, the model summarized here results from mapping (1) by Moench southwest of the Rangeley-Phillips (Moench, 1971) and Rumford (Moench and Hildreth, 1976) areas in Maine and northeastern New Hampshire (Moench and others, 1982); (2) by Hatch between the Carter-Moriah Range and Plymouth, New Hampshire (fig. 2); and (3) by Lyons and others in south-central New Hampshire. All but a few small patches of the area shown in figure 2 have reached the sillimanite grade of regional metamorphism. Despite this fact, the original sedimentary character and composition of the stratified rocks are well preserved in all but those areas labeled DS on the map. Thus, even though no fossils have been found in the area shown in figure 2, we feel that the data upon which we build our thesis are solid.

EASTERN NEW HAMPSHIRE

Billings' 1956 "Geologic Map of New Hampshire" assigned all the stratified rocks of the State between the east flank of the Bronson Hill anticlinorium and Concord (fig. 1) to various members of the Lower

Devonian Littleton Formation. This assignment is compatible with stratigraphic assignments on quadrangle maps published both before and after the State Map by Billings and his associates. It is worthy of note, however, that Billings himself, in a report on the Mount Washington area (Billings, 1941) in the Presidential Range (fig. 2) that predated his quadrangle report on the same area (Billings and others, 1946), assigned some of the rocks to pre-Littleton formations. In particular, a conspicuous calc-silicate unit, which on the 1946 map was mapped as the Boott Member of the Littleton, had earlier (1941) been assigned to the Silurian Fitch Formation, and the schists and gneisses below (east of) the calc-silicate had been assigned to the pre-Fitch Partridge Formation. Since the publication of these two reports, many have pondered over the "true" assignment of the "Boott." Billings and Fowler-Billings (1975), in a report on the Gorham, New Hampshire area immediately east of the Mount Washington area, discussed the possibility that the strata east of (below) the Boott were in part Silurian, although they assigned all the rocks to the Littleton Formation. Moke (ms), in a report on the Plymouth, New Hampshire, area (fig. 2), described occurrences of distinctive calc-silicate rocks and plotted his localities on his text-figure 3, even though he did not distinguish them on his quadrangle map (1946). Our recent restudy of the metamorphic rocks in the Presidential, Carter-Moriah, and Mahoosuc Ranges of northeastern New Hampshire (fig. 2) and in the area north of Plymouth has indicated that these rocks can be separated into distinctive units that form a sequence identical with that earlier defined by Moench (1971) in the Rangeley area of Maine. Figure 2 summarizes the general distribution of these units.

Stratigraphic correlations proposed in this paper imply that a sizable part of the area between the Massabesic Gneiss Complex ("Fitchburg Pluton") of eastern New Hampshire and the Bronson Hill anticlinorium of western New Hampshire is underlain by Silurian and older(?) formations and not solely by the Lower Devonian Littleton Formation, as shown on the Geologic Map of New Hampshire (Billings, 1956). These relations require moving the axis of the Merrimack synclinorium westward from its conventional location locally by as much as 30 km, as has been done in figure 2, to coincide with the belt of Lower Devonian strata within the synclinorium. We retain the name Merrimack synclinorium for the region of Devonian, Silurian, and older(?) formations between the Bronson Hill-Boundary Mountain anticlinorium on the west and a belt of Proterozoic to Ordovician(?) anticlinoria in eastern New Hampshire and eastern Maine. Within this synclinorium, as thus defined, are smaller anticlinoria and synclinoria more sharply outlined on stratigraphic-structural grounds. Lyons, Boudette, and Aleinikoff (1982) have, on this basis, proposed the name Kearsarge-Central Maine synclinorium as an alternative term for the Merrimack synclinorium shown on figure 2.

The nature of the metamorphism in much of the northeastern New Hampshire area is such that large volumes of rock have undergone incipient melting. The result has been that metamorphosed pelitic and

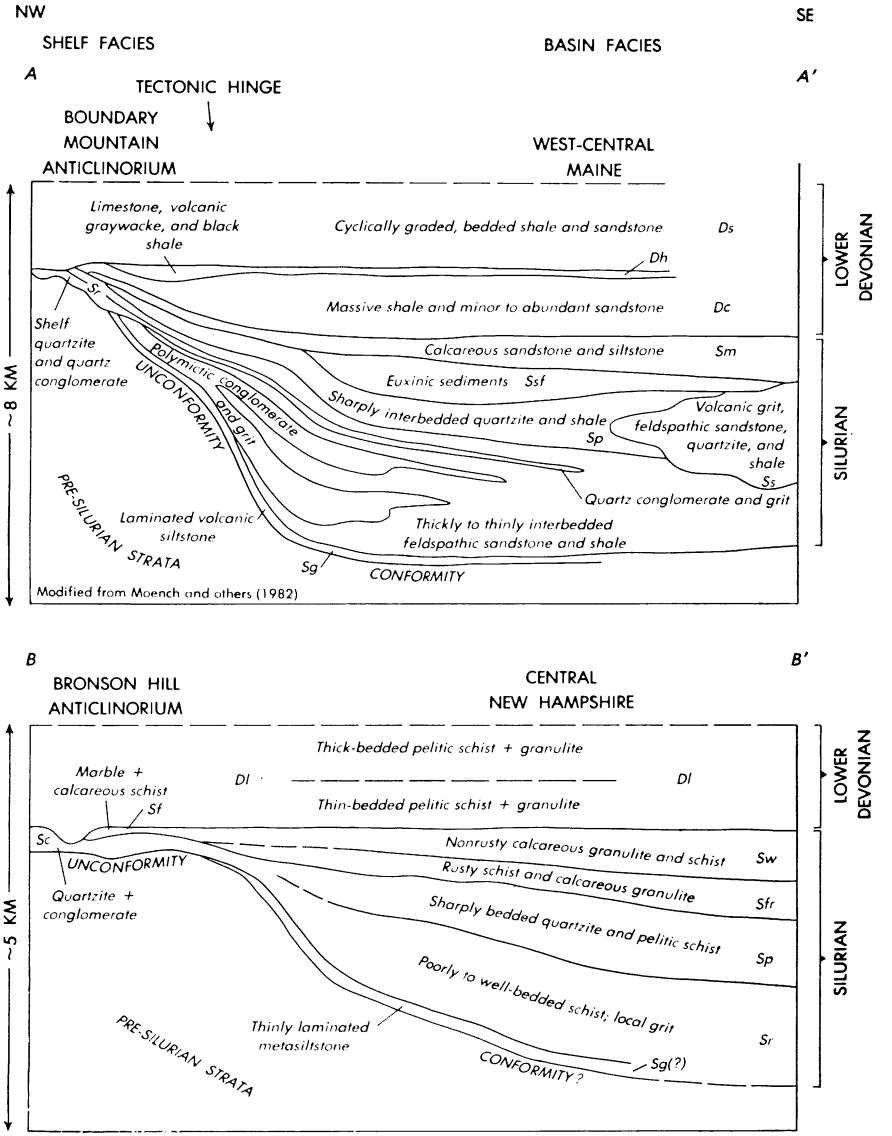


Fig. 3. Stratigraphic diagrams showing tectonic hinge between Silurian shelf and basin facies in western Maine (A-A′) and central New Hampshire (B-B′). Formation symbols: Dl, Littleton; Ds, Seboomook; Dh, Hildreths; Dc, Carrabassett; Sf, Fitch; Sm, Madrid; Ssf, Smalls Falls; Sw, Warner; Sf, Francestown; Ss, Sangerville; Sp, Perry Mountain; Sc, Clough; Sr, Rangeley; Sg, Greenvale Cove. Approximate lines of section are shown on figure 1.

semipelitic rocks with distinctive bedding and compositional features have been largely converted into sillimanitic and quartzo–feldspathic gneiss in which bedding is no longer recognized. Accurate tracing of metapelitic units distinguished largely by character of bedding proved difficult or impossible through these areas. These rocks are designated only as DS on figure 2, although we believe that further study would probably enable assignment of some rocks in this unit to specific stratigraphic formations.

A few kilometers north and west of Pinkham Notch, the pass between the Presidential Range on the west and the Carter-Moriah Range on the east (fig. 2), the rocks are low enough in grade and the exposures are good enough for a local stratigraphic succession to be established and supported by graded beds and a few load casts. Parts or all of this succession were then traced by detailed and reconnaissance mapping into Maine to the northeast and to central New Hampshire south of the White Mountain batholith to the southwest.

The stratigraphically lowermost metasedimentary unit recognized in the Pinkham Notch succession, unit "a" of table 1, consists of well-bedded, commonly graded quartzite and schist, and minor gritty and pebbly metaconglomerate. Billings and Fowler-Billings (1975, p. 17, pl. 1) noted the conglomerate beds and assigned them to the Littleton Formation. Conglomerates having a maximum observed pebble size of 2 to 3 cm are less common than gritty beds and quartzites, which help to distinguish the unit from the well-bedded schists and granulites higher in the section. Small lenses of calc-silicate rock less than 1 m long are present locally. Although the top (west contact) of this unit can be accurately mapped on the hillslopes south and southwest of Dolly Copp Campground (see either the Carter Dome, New Hampshire, 7 1/2 min quad., or the Gorham, New Hampshire-Maine, 15-min quad. of Billings and Fowler-Billings, 1975, pl. 1), the rocks below (east of) the top 500 m of unit "a" in this area have been thoroughly migmatized; thus, no thickness estimate can be made for unit "a" in the Pinkham Notch area.

Although apparently not present in the Pinkham Notch section itself, a few kilometers both to the north and south a few hundred meters (or less) of distinctly bedded, thinly bedded, light-gray- to white-weathering quartzite and mica schist overlie unit "a". These rocks are called unit "b" on table 1. In contrast to the graded beds of unit "a", the transitions from schist to quartzite in unit "b" tend to be sharp, making it difficult or impossible to determine stratigraphic tops in most exposures.

Next above unit "b" in the northeast New Hampshire section are mica schist, flaggy quartz granulite, and calc-silicate granulite, all characterized by abundant streaks and disseminated grains of pyrrhotite, producing a characteristic intense deep rusty weathering that makes this unit (unit "c") readily recognizable in the field. Perhaps because of a more refractory nature and thus greater resistance to the destructive migmatization process discussed above, this unit is locally well preserved and mappable through areas otherwise dominated by gneiss. This rusty sul-

TABLE 1

Correlation of Silurian and Lower Devonian units in part of the Merrimack synclinorium, western Maine, and New Hampshire

	WESTERN NEW HAMPSHIRE	SOUTH-CENTRAL NEW HAMPSHIRE	PINKHAM NOTCH AREA	RANGELEY-PHILLIPS, MAINE	CENTRAL MAINE
	(Bronson Hill anticlinorium)				
	(Billings, 1956)	(Lyons, 1979; Nielson, 1981; Englund, 1976; this paper)	(this paper)	(Moench and others, 1982; modified from Moench, 1971; Moench and Hildreth, 1976; Boone, 1973)	(Moench and others, 1982; modified from Pankiwskyj and others, 1976)
Lower Devonian	Littleton[F]	Kearsarge Member of Littleton	Unit f Thick-bedded schist and granulite	Seboomook[F] Hildreths	Not exposed
Lower Devonian		Littleton	Unit e Thin-bedded schist and granulite	Carrabassett	Carrabassett
Silurian	Fitch[F]	Warner	Unit d Nonrusty calc-silicate	Madrid	Madrid [Fall Brook]
Silurian		Francestown	Unit c Rusty schist and granulite	Smalls Falls	Smalls Falls [Parkman Hill][F]
Silurian	Clough[F]	Crotched Mountain, Roundtop Quartzite, or Perry Mountain	Unit b Sharply bedded quartzite and schist	Perry Mountain	Sangerville[F]
Silurian		Rangeley	Unit a Conglomerate, grit, quartzite, and schist	Rangeley[F]*	
Silurian(?)		Greenvale Cove(?)		Greenvale Cove	

* Fossils are at Blanchard Pond in isolated belt of Rangeley northwest of main belt of Rangeley. [F] indicates presence of fossils. Brackets [ ] indicate formation name in use before revisions by Moench and others (1982). See Billings and Lyttle (1981) for an excellent synthesis of the paleontological control on the age of the stratified rocks of New England.

fidic unit appears to be a few tens to a few hundreds of meters thick in the Pinkham Notch section.

Unit "c" is overlain by a few tens of meters of spectacularly layered *non*rusty calc-silicate granulite, the lower part of unit "d". These rocks are composed of varying proportions of quartz, plagioclase, microcline, tremolite, diopside, garnet, and biotite and form green, white, and purplish layers generally 2 to 15 cm thick. Immediately overlying these layered calc-silicate rocks is a few hundred meters of very light-gray-weathering, massive to thick-bedded, fine-grained quartz–plagioclase–biotite granulite having a distinctive "salt and pepper" appearance and interbedded with semipelitic to pelitic schist. Traces of tremolite, garnet, sphene, and other Ca-rich phases are present locally. About 300 m of the "salt and pepper," upper, part of unit "d" is present just north of Pinkham Notch.

Gradationally above unit "d" is a thick (probably more than 1000 m) succession of gray, locally slightly rusty-weathered, well-bedded, commonly graded pelitic schist and micaceous quartzite (units "e" and "f" of table 1). These rocks hold up Mount Washington and the northern peaks of the Presidential Range. Efforts to subdivide them stratigraphically have been successful only in the Presidential Range. The lower part of the unit ("e") in that area is characterized by beds generally 5 to 25 cm thick in contrast to the upper part of the unit ("f"), in which beds are commonly 25 cm to 2 or 3 m thick. The schist beds throughout the unit are characterized by a great abundance of aggregates of muscovite and/or sillimanite pseudomorphous after andalusite, for which Peter Robinson has suggested the name "andalumps." In the lower, thinned bedded part of the unit these andalusite pseudomorphs are 2 to 3 mm across and 2 to 3 cm long, whereas in the upper, thicker bedded part of the unit, they are about 1 cm across and 10 cm long. This size difference is difficult to explain, but it appears to have been stratigraphically controlled. The thinner bedded part of the unit also contains many lenses a few centimeters thick and a few tens of centimeters long of very distinctive pink garnet–quartz granulite. Many of these lenses are in micaceous quartzite beds, but others are surrounded by schist containing andalusite pseudomorphs. Although they superficially resemble the "coticules" described by Emerson (1898) from metavolcanic-black slate sequences, such as the Hawley Formation of western Massachusetts, they differ from those coticules in two possibly significant ways: (1) The pink granulites in the Mount Washington area occur in a sequence of only locally slightly graphitic and essentially nonsulfidic schists and quartzites containing no recognized intercalated metavolcanic material, whereas the Hawley coticules are invariably associated on outcrop scale with closely intercalated black carbonaceous sulfidic metasediments and metavolcanic rocks. (2) The pink granulites of Mount Washington consist of sand-sized grains of garnet and quartz, forming discrete lenses, whereas the Hawley coticules consist of very fine grained chertlike intergrowths of quartz and garnet in thin (1 mm+) beds commonly intercalated with white, black, gray, or greenish quartzites that can commonly be traced continuously across the outcrop. Although it seems reasonable to

TABLE 2

Characteristic features of Silurian and Devonian stratigraphic units

	Lithology	Bedding features	Fresh color
Littleton, Seboomook, Carrabassett	Aluminous schist and micaceous quartzite	5-30 cm+ beds; cyclically bedded	Gray
Upper Madrid and Warner	Quartz–plagioclase–biotite granulite with pods of calc-silicate; minor aluminous schist. Local rusty schist at top	Massive to thick beds; local grading especially near top	White to light gray; calc pods pale green
Lower Madrid	Calc-silicate granulite	Well layered, 5-20 cm	Green, white
Smalls Falls	Graphitic, sulfidic mica schist, clean quartzite, minor calc-silicate	Local massive schist; locally well bedded in 2-20-cm beds; minor local grading	Black at lower grade; white at higher
Francestown	Graphitic, sulfidic mica schist, calc-silicate	Well-bedded, 3-8-cm beds	White (with graphite spots)
Perry Mountain	Clean quartzite, aluminous schist	Well bedded, 5-15 cm; generally sharp quartzite–schist transitions; local grading and crossbedding	Light gray to white
Rangeley	Mica schist, feldspathic quartzite, local conglomerate in north	Generally well bedded, 5-15 cm+; abrupt grading at tops of massive quartzite beds	Light gray to light brown

conclude that the Hawley and some other similar coticules originated as volcanogenic banded chert, the New Hampshire rocks in question may have originated as clastic rather than chemical sediments. Thus, the lower part of the schist and quartzite unit appears to be distinguished from the upper part of the unit by thinner beds, smaller andalusite pseudomorphs, and the presence of pink quartz–garnet lenses. Unfortunately, the combination of complex structure, poor exposure, and the reconnaissance nature of much of the mapping made it impossible for us to subdivide the unit outside the Presidential Range.

CORRELATIONS TO THE NORTHEAST

Our mapping has traced this Pinkham Notch section to the northeast and to the south and has documented correlations with existing sections in both directions. These correlations are summarized in table 1. In table

in eastern and south-central New Hampshire and western Maine

Weathered color	Distinguishing features	Approximate thickness in meters		
		Rangeley, Maine	Eastern New Hampshire	South-central New Hampshire
Light gray	Aluminous schist; excellent grading widespread, unlike Rangeley	3000	1000+	2500
Light gray to white; locally rusty at top	Massive salt and pepper granulite; calc pods	200	300+	
				450
Green, white, purple	Green-white-purple calc-silicate	100	20-40	
Deeply rusty	Much pyrrhotite; rusty weathering; flaggy quartzite	700	20-300	
Deeply rusty	Much pyrrhotite; rusty weathering; calc-silicate			300
Light gray to white	Relatively clean quartzite; sharp quartzite–schist transition; well bedded	600	200+	500
Gray brown; locally moderate red rusty	Schist less aluminous than Littleton; fair to poor grading in contrast to Littleton; local red rusty weathering	3000	500+	1000

2, we have summarized the characteristic features and thicknesses of the various units.

Unit "a" of the section of northeast New Hampshire is similar to much of the Rangeley Formation of western Maine. In the type area in Maine, the Rangeley has been divided into three members. Member A at the base is predominantly metamorphosed polymict conglomerate and feldspathic metasandstone 1200 m thick. Member B is predominantly graded feldspathic quartzite and schist and minor polymict metaconglomerate, also 1200 m thick. Member C is characterized by quartz pebble metaconglomerate and graded quartzite and schist 1500 m thick. Although the spectacular coarse polymict conglomerates for which the Rangeley is best known have not been recognized in New Hampshire, the well-bedded and locally graded slightly rusty schist and quartzite and local gritty beds

of the New Hampshire unit "a" are characteristic of much of Members B and C of the Rangeley of Maine.

Unit "b" in eastern New Hampshire, which is characterized by sharply bedded light-gray to pale-tan-weathering quartzite and schist, closely resembles the Perry Mountain Formation of western Maine, where it is 600 m thick. Even the fine internal cross-laminations within quartzite beds that are conspicuous at several localities in Maine are equally well preserved at several places in New Hampshire.

The sulfidic, deeply rusty-weathered schists and granulites of unit "c" that overlie the Perry Mountain-like rocks of eastern New Hampshire are identical with the strata of the Smalls Falls Formation of western Maine with which we correlate them. The Smalls Falls in Maine is predominantly pyrrhotite-rich black schist interbedded with pyrrhotitic quartzite and, in the upper part of the formation, some calc-silicate-bearing granulite. Flaggy-weathering sulfidic quartzite and schist characterize most of unit "c" in eastern New Hampshire and sulfidic calc-silicate granulites appear to be most common at the top of the unit. The Smalls Falls is 700 m thick in Maine but thins abruptly to the northwest and gradually toward the southeast.

The spectacularly laminated gray, green, and purple calc-silicate granulite and the overlying thicker bedded "salt and pepper" granulite containing calc-silicate pods of unit "d" are strikingly similar to the lower and upper members, respectively, of the Madrid Formation of Maine, which has a total thickness of 400 m.

Finally, the 3000 m of graded-bedded granulites and schists of units "e" and "f" that overlie the Madrid-like rocks strongly resemble the rocks of the Carrabassett and Seboomook Formations of western Maine. Although minor differences in thicknesses of bedding and the more pelitic composition of the Carrabassett help to distinguish these two formations in Maine, the best distinction between them is stratigraphic position above or below the thin marble, calc-silicate, and granulite beds of the discontinuous Hildreths Formation (table 1), not recognized in New Hampshire. Our distinction between the lower and upper parts of the unit in the Presidential Range may or may not actually correspond to the Carrabassett-Seboomook distinction in Maine, but it appears to be reasonably close. Although we have not been able to identify a consistent calc-silicate unit at the boundary between our upper and lower units, the type locality of Billings' (1956; Billings and others, 1946) Boott Member of the Littleton at Boott Spur, and the exposures of it a few kilometers to the west near the Lakes of the Clouds just southwest of the summit of Mount Washington, *may possibly* represent the Hildreths. The rock of these two localities is predominantly dark-green calc-silicate amphibolite and, although well layered, does not show the spectacular white-green-purple layering of most other exposures of Billings' Boott and of the lower Madrid. We note, however, that Billings' Boott at Boott Spur and Lakes of the Clouds also does not resemble the variegated calc-silicate rock and local marble, dark biotite granulite, and dark sulfidic biotite schist of the

Hildreths. We believe, however, that although these two exposures and others immediately adjacent are slightly ambiguous as to stratigraphic position, other exposures of Billings' Boott in Pinkham Notch and areas to the east are in the lower part of the Madrid Formation. The results of our efforts to trace the Boott Spur "Boott" into the "Boott" that we firmly believe is Madrid a few kilometers to the east in Pinkham Notch are indeterminate because of poor exposures between Boott Spur and Pinkham Notch. At this time, however, we favor Billings' interpretation that the Boott at Boott Spur and his Boott in Pinkham Notch are the same horizon which we consider to be the lower part of the Madrid Formation. The lenses of pink garnet–quartz granulite that are common in the lower part of this sequence in the Pinkham Notch area have not been described from the Carrabassett or Seboomook of western Maine. We are not sure how to interpret this fact. For reasons of scale, none of the divisions of the Carrabassett-Seboomook-equivalent unit can be shown on figure 2. We have attempted in the foregoing paragraphs and in table 2 to describe the distinctions between the well-bedded pelitic schists and granulites of the Littleton (Seboomook-Carrabassett) and Rangeley Formations. The photographs in plate 1 are intended to portray the important, though admittedly subtle, difference in the style of the graded bedding between these two units.

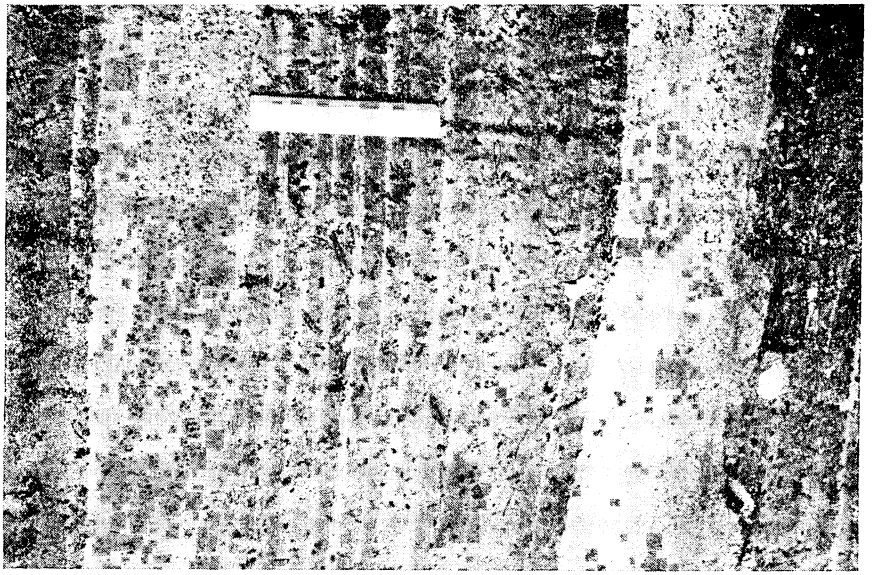
CORRELATIONS TO THE SOUTH

Immediately south of the White Mountain batholith (fig. 2), we have recognized within the previously undifferentiated (Moke, 1946 and ms; Billings, 1956) metamorphic rocks a stratigraphic sequence comparable with that in the Pinkham Notch area. From bottom to top, this sequence includes an unknown thickness of thinly (0.5-1 cm) laminated feldspathic quartzite that resembles the Greenvale Cove Formation of western Maine, about 500 m of moderately red-rusty-weathered, well-bedded schist and granulite that we correlate with the Rangeley Formation, possibly 100 m of light-gray weathering, sharply bedded schist and quartzite identical with rocks of the Perry Mountain of western Maine, as much as a kilometer of deeply rusty, sulfidic Smalls Falls-like schist and thin-bedded calc-silicate, a few tens of meters of nonrusty, spectacularly layered calc-silicate overlain by a few hundred meters of salt and pepper granulite and schist all assigned to the Madrid Formation, and, finally, a thick sequence of well-bedded, graded bedded, nonrusty aluminous schist and granulite identical with the Carrabassett-Seboomook-equivalent rocks to the north. Despite differences in thickness of some units, we are confident that this section is the same as the one described from the Pinkham Notch area. Although the White Mountain batholith separates the two areas, the identity of the two stratigraphic sequences plus the few mapped large inclusions of Smalls Falls- and Madrid-like rocks within the batholith (fig. 2) leave little question as to the pre-batholith continuity of the strata.

South of Plymouth, mapping by Lyons and by his students and others since about 1970 in central and south-central New Hampshire has es-

PLATE 1

Photographs of outcrops of Carrabassett-Seboomook and Rangeley Formations showing the contrast in the style of graded bedding. Ruler is 18 cm long.



A. Well bedded Carrabassett Formation, Orbiton Stream, Phillips Quadrangle, Maine. Note the sharp basal contacts of the lighter colored feldspathic quartzite beds and the continuously gradational upper contacts (to the right) of these beds. Grayer material is pelitic schist with abundant dark crystals of staurolite.

B. Rangeley Formation (middle member), Swift River, Rangeley Quadrangle, Maine. Lighter colored beds are feldspathic quartzite, dark beds are pelitic schist. Note that the upper contacts of the quartzite beds (to the right) are abruptly gradational, in contrast to those in the Carrabassett.

tablished a stratigraphic sequence based entirely upon local succession supported by stratigraphic facing data (Vernon, 1971; Nelson, ms; Englund, 1976; Bullen, ms; Lyons, 1979; Nielson, 1981; Malinconico, ms). This sequence is shown in the second column of table 1.

The oldest metasedimentary rocks thus far mapped in the central and southern New Hampshire area shown in figure 2 consist of units that, on the basis of lithology and stratigraphic position, appear to be correlative with the Silurian Rangeley and Silurian(?) Greenvale Cove Formations of the Rangeley, Maine area. At the base is several hundreds of meters of massive gray sillimanite schist in which calc-silicate boudins are common, and thin calc-silicate beds are locally present. Above this base are at least 400 m of light-colored thinly laminated (1-5 cm) rhythmites of altering arenaceous and pelitic composition. Locally, the laminae thicken to 25 cm, and good grading then develops. This unit resembles parts of the Silurian(?) (Moench and others, 1982) Greenvale Cove Formation at its type locality (Moench, 1969), and we propose this correlation.

Above the Greenvale Cove(?) is gray massive pelitic schist that has few distinguishing characteristics and a thickness of at least 1000 m. It is succeeded by a comparable thickness of a gray to tan, slightly rusty-weathering pelitic schist, in which calc-silicate boudins are locally present. The upper part of this formation has some graded beds. Taken together, the two units just described resemble the rather pelitic facies of the Rangeley Formation south of the type area. We have adopted this correlation on the basis of lithology and stratigraphic position immediately below what is almost surely the Perry Mountain Formation.

Overlying these probable Rangeley rocks is a unit that has a variable but maximum thickness of approx 500 m. It is composed of cyclically interbedded tan quartzite and light-gray pelitic schist, having individual beds that range from 5 to 30 cm in thickness. The transition from quartzite to schist is generally fairly sharp, but graded beds are common enough for facing directions to be decipherable in many outcrops. These rocks are strikingly similar to those of the Perry Mountain Formation to the north.

Greene (1970) identified a stratigraphic unit in south-central New Hampshire that he called the Crotched Mountain and considered to be a member of the Littleton Formation. Nielson (1981), however, concluded that Greene's Crotched Mountain underlies the Francestown Formation (see next paragraph). Because he considered his Francestown to be a separate formational unit, Nielson concluded that Greene's Crotched Mountain could not be a Littleton equivalent. Englund (1976) identified the Roundtop Quartzite (member of the Littleton) in central New Hampshire which also underlies the Francestown. Greene's Crotched Mountain (at least in part) and Englund's Roundtop (plus some additional units) are here considered to be equivalents of the Perry Mountain Formation. Nielson (1981, p. 16) suggested the correlation of the Crotched Mountain with the Perry Mountain. Nielson also noted a thin quartz-pebble conglomerate at one locality; granule conglomerates, though uncommon, have been noted elsewhere in the Perry Mountain (Pankiwskyj and others,

1976). Although Nielson does not give the exact location of his conglomerate locality, it *might* be in the upper part of the Rangeley Formation.

Above the Perry Mountain-like rocks is a unit characterized by deeply rusty-weathered, sulfidic, thinly bedded calc-silicate rocks and mica schists approx 300 m thick. These rocks are continuous with a unit originally described by Greene (1970) as the Francestown Member of the Littleton Formation. Both Lyons (1979) and Nielson (1981) have interpreted the Francestown to be stratigraphically below, rather than within, the Littleton, and have designated it as the Francestown Formation. Although the Francestown is in the stratigraphic position of the Smalls Falls Formation of Maine, and both are deeply rusty weathered sulfidic schists with intercalated granulite, significant differences exist between the two formations. In south-central and central New Hampshire the Francestown consists of calc-silicate granulite and schist. North of the White Mountain batholith the percentage of calc-silicate rocks is significantly less, and quartzites are more abundant than the calc-silicates. Thus, whereas the Francestown is primarily a calc-silicate and schist unit, the Smalls Falls of Maine and north of 44° in New Hampshire is primarily schist and quartzite, and only minor calc-silicate.

Overlying the Francestown is a unit of relatively thick-bedded light-gray-weathering quartz–plagioclase–biotite granulite characterized by calc-silicate pods and interbedded with sillimanite schist and minor calc-silicate granulite. A rusty-weathered interval with some calc-silicate boudins is locally present at the top of this unit south of latitude 44°; the same rusty unit, though less well developed, is present in the Madrid of western Maine. The estimated maximum thickness of this quartz–plagioclase–biotite granulite and overlying thin rusty schist is approx 450 m. Both Lyons (1979) and Nielson (1981) have applied the name Warner Formation to these rocks. Because of the striking lithologic similarity between the Warner and the Madrid Formation of Maine, as well as the similarity of their stratigraphic positions, we regard them as approximate equivalents. We point out, however, that the spectacularly layered green-white-purple calc-silicate granulite that characterizes the lower part of the Madrid of western Maine and of eastern New Hampshire diminishes greatly in abundance a few kilometers south of latitude 44°. Thus the Warner of central and south-central New Hampshire appears to correlate lithically with the upper part of the Madrid to the north, although without fossils the exact stratigraphic equivalencies cannot be determined. It is noteworthy that rocks assigned by Moench and others (1982) to the eastern facies of the Madrid in the Anson-Skowhegan area of central Maine are quite similar to the Warner and likewise lack the lower thinly bedded calc-silicate member.

Overlying the Warner in south-central New Hampshire is a thick sequence of generally gray-weathering, well-bedded sillimanite schist and biotitic quartzite at least 2500 m thick. The lower part of this succession is variably graded, but the upper beds are strikingly well graded, individual units ranging from 5 to 50 cm in thickness. The similarity of the upper part of this unit to the Seboomook Formation of Maine is notable. We adopt this correlation and suggest that the lower part of the unit may

be an approximate equivalent of the Carrabassett Formation of Maine. Nelson (ms), Bullen (ms), Lyons (1979), Nielson (1981), and Malinconico (ms) have assigned these rocks to the Littleton Formation.

Nielson (1981, p. 16) and Dean (ms, p. 215) proposed the following correlations with rocks of the section described by Moench and Boudette (1970) in the Rangeley area of Maine:

	Hillsboro Quadrangle and Sunapee septum (Nielson, 1981; and Dean, ms)	Western Maine (Moench and Boudette, 1970)
	Littleton Formation	Seboomook and Carrabassett Formations
	Warner Formation	Madrid Formation
Fitch	Francestown Formation	Smalls Falls Formation
Fm	Crotched Mountain Formation	Perry Mountain Formation
	Clough Quartzite	Rangeley Formation

We basically agree with these correlations. The only modification that we would make in them is to suggest that the rocks of south-central New Hampshire below the Francestown (including the Crotched Mountain of Nielson) correlate with the Rangeley Formation as well as with the Perry Mountain Formation of the Plymouth area of New Hampshire (fig. 2) and thus with the same formations in the Rangeley area of Maine. We restrict the term Perry Mountain in the Plymouth area (immediately south of the White Mountain batholith) to nonrusty-weathered, sharply bedded, relatively clean quartzite and interbedded schist that form a unit as much as 500 m thick. We correlate the moderately red-rusty-weathered interbedded schist and granulite below the Perry Mountain in the Plymouth area with the Rangeley and suggest the same correlation for south-central New Hampshire.

All but one of the localities of calc-silicate rock discussed by Moke (ms, fig. 3) in the Plymouth area have been mapped by us as either the Small Falls (Francestown) or the lower part of the Madrid (Warner). We have not seen the rock at his locality 7 (Moke, ms, fig. 3). Thus, although Moke did not choose to map the calc-silicates separately, we agree with his identification of them as (a) distinctive unit(s).

AGE OF THE UNITS

As is indicated by table 1, we believe that, with the exception of the Littleton and equivalent units, all the rocks discussed above are Silurian in age. This conclusion is supported by the following relations.

The Rangeley Formation in the Blanchard Ponds belt of that formation in western Maine northwest of Rangeley (Moench and Boudette, 1970) contains late Llandoverian fossils. M. P. Billings (oral commun., October 1980) has pointed out to us that the Blanchard Pond belt of the Rangeley is not continuous on the present ground surface with the main belt of the Rangeley. Despite this fact, we accept the correlation of the two belts of the Rangeley on the basis of lithology and stratigraphic position and thus accept the extrapolation of the age to the main belt of

the formation. The similar late Llandoverian Age of the locally conglomeratic Clough Quartzite in the Bronson Hill anticlinorium is also at least compatible with a late Llandoverian Age for the quartzite and quartz pebble conglomerate in the upper part of the Rangeley.

Although no fossils are known from the Perry Mountain, the apparently correlative (in part) Sangerville Formation (table 1, column 5) does carry graptolites suggestive of a late Llandoverian through middle Wenlockian or early Ludlovian age (Pankiwskyj and others, 1976). Furthermore, if the Silurian age of the Smalls Falls and Rangeley is accepted, the Perry Mountain must also be Silurian. The Sangerville, as mapped by Pankiwskyj and others (1976), contains distinctive rocks that are identical with rocks typical of the Perry Mountain. However, the Sangerville also contains abundant lithic-volcaniclastic sandstones and granule conglomerates that are uncommon in the Perry Mountain and thus are probably indicative of a slightly different provenance.

Although the Smalls Falls of the Rangeley-Phillips-Rumford area does not carry fossils (table 1), Pankiwskyj and others (1976) correlated it with the fossil-bearing Parkman Hill Formation, which they mapped and named in central Maine. Recently, Moench and others (1982) have dropped the names Parkman Hill and Fall Brook Formations, respectively, in favor of the names Smalls Falls and Madrid. These reassignments were based on the mapped equivalence of the Madrid and the Fall Brook and on the lithic similarity and comparable stratigraphic position of the Smalls Falls and the Parkman Hill. Also, at Gee Mill in the Sunapee septum of southwestern New Hampshire, some of the lithologies within the Fitch Formation (as used by Dean, ms) are identical with those of the Francestown Formation (see also discussion by Field, ms, p. 103-105 of the Gee Mill locality and the relations between the Fitch and the Francestown). This implies to us that the two formations are, at least in part, facies equivalents.

The unfossiliferous Madrid Formation of Maine has previously been considered by Moench (1971) to be Silurian(?) but possibly earliest Devonian in age on the grounds that it grades upward into rocks that he then tentatively assigned to the lower Devonian Seboomook. We now favor a strictly Silurian age for the Madrid of both Maine and New Hampshire on the following grounds. Both the Madrid and the Fitch to the west (table 1, column 1) were originally calcareous units directly underlying identical fossiliferous, Lower Devonian graded bedded schists and quartzites. Recent refinement of the age of the Fitch (Harris, Hatch and Dutro, 1983) has set its age as Pridolian and suggests that the overlying Littleton is entirely Early Devonian in age. If this reasoning is valid, and if the correlation of the type Littleton with the Littleton-like rocks above the Madrid to the east is valid, the age of the Madrid is most probably Silurian.

In the Sunapee septum of southwestern New Hampshire, Dean (ms) identified a 750-m thick sequence, which he named the Church Farm Formation lying above the Fitch Formation. His Church Farm was characterized both by its feldspathic composition and the presence of calc-

silicate concretions. Thin polymict conglomerate occurs locally at the top of the formation. A low-angle unconformity separates Dean's Church Farm from the overlying Littleton. Dean (ms) considered the age of his Church Farm to be Late Silurian to Early Devonian. We suggest that the Church Farm is a probable equivalent of the Madrid or Warner Formation.

Although no fossils have been recovered from the Littleton Formation east of the Mount Moosilauke locality of Boucot and Rumble (1980), the similarity of the lithologic and stratigraphic position of the rocks we map as Littleton to rocks of the type area Littleton (Billings, 1937) and to those of the Seboomook of Maine, both of which contain Early Devonian fossils, supports an Early Devonian age for the eastern and south-central New Hampshire Littleton rocks.

NOMENCLATURE FOR NEW HAMPSHIRE

If the correlations of table 1 are accepted, the second-order question of nomenclature can be addressed. Because no formational name other than Littleton has previously been applied to what we here consider to be the pre-Lower Devonian strata of the Plymouth-to-Bethel area, and because the strata are continuous with the rocks of the Rangeley section of Moench (1971), we propose that the names Rangeley, Perry Mountain, Smalls Falls, and Madrid be extended into New Hampshire at least as far southwest as the White Mountain batholith. The batholith provides an interruption in the belts of these rocks tracing southwest from Rangeley and *could* also serve as a breaking point between the western Maine nomenclature and the south-central New Hampshire names Francestown and Warner. We propose that as the break between Smalls Falls-Madrid and Francestown-Warner. Although we recognize the similarities between the Francestown-Warner rocks and the Fitch Formation to the west and support their stratigraphic correlation (table 1), we feel that the much greater thickness of the Francestown-Warner pair (about 750 m versus a few tens of meters), the sulfidic character of the Francestown, and the massive granulite of the Warner all favor the use of separate (from Fitch) stratigraphic names. Although the names of both the Crotched Mountain of Greene (1970; Nielson, 1981) and the Roundtop of Englund (1976) have locally been applied to strata that we now consider equivalent to the Perry Mountain, neither corresponds precisely to the Perry Mountain as we now recognize it in south-central New Hampshire, and neither is a widely recognized term. We therefore recommend extension of the term Perry Mountain at least as far south as the Hillsboro, New Hampshire, area (fig. 2).

No formal or informal stratigraphic names have been applied to the rocks in central or south-central New Hampshire that we here correlate with the Rangeley and the underlying Greenvale Cove. For this reason, and to avoid unnecessary new stratigraphic terms, we also herein tentatively extend the usage of the Rangeley and the Greenvale Cove at least as far south as south-central New Hampshire.

Above the Silurian strata, the names Littleton in New Hampshire and Seboomook in Maine both have long precedence. Although we clearly

consider that only a fraction of the rocks shown as Littleton by Billings (1956) in eastern, central, and south-central New Hampshire are truly correlative with the type area Littleton, we advocate using the name Littleton for those Lower Devonian truly Littleton-correlative rocks in New Hampshire. We suggest extending the name Littleton to the north end of the Sebago batholith in Maine. Here, a narrow belt of Silurian rocks extends between the Sebago and Mooselookmeguntic batholiths (fig. 2) and separates a Devonian succession to the east that has been divided into the Carrabassett, Hildreths, and Seboomook Formations from approximately coeval Lower Devonian rocks all assigned to the Littleton Formation on the west.

DISCUSSION

One of the objectives of this paper is to report the documentation, through our mapping of the intervening area, of the near continuity of the western Maine Silurian-Devonian section of Moench (1971) (table 1, column 4) and the south-central New Hampshire section of Lyons (1979) and Nielson (1981) (table 1, column 2). Although figure 2, because of its necessarily small scale, combines pairs of stratigraphic formations and in places reflects reconnaissance mapping, we feel that it solidly establishes the continuity (interrupted by the White Mountain batholith) and correlation of the two sequences. Most of these correlations have been proposed before, some by many geologists including us, but always on the basis of the long-range look-alike nature of a few key units. Our mapping between the latitude of Plymouth, New Hampshire, and the vicinity of Bethel, Maine, shows the map continuity of the various units and establishes the correlations as firmly as the interruption by the White Mountain batholith will allow.

Boone, Boudette, and Moench (1970, p. 6, fig. 2) and Moench (1973) proposed a "Silurian tectonic hinge" in western Maine along the line where the thin shelf sequence of the Boundary Mountain anticlinorium abruptly thickens to the southeast into thousands of meters of apparently coeval deep-water deposits (fig. 3, A-A′). Whereas the shelf sequence northwest of the hinge line in Maine rests unconformably on more highly deformed pre-Silurian strata, southeast of the line, Ordovician beds appear to pass conformably and without evidence of hiatus upward into the Silurian strata[1]. This uninterrupted Ordovician-Silurian succession in

[1] In western Maine, the conformity is demonstrated by exposed conformable contacts between the Quimby, Greenvale Cove, and Rangeley Formations (Moench, 1969). The Greenvale Cove is a thin but extensive transitional unit of probably volcaniclastic siltstone and fine sandstone that lies between the Upper Ordovician(?) dark sulfidic euxinic metashale, volcaniclastic metagraywacke, and minor metamorphosed felsic volcanic rocks of the Quimby, and the coarsely clastic Silurian deposits of the Rangeley Formation. Moench (1969) assigned a tentative Ordovician(?) age to the Greenvale Cove. In 1982, Moench and others reassigned the Greenvale Cove to the Silurian(?) (lower Llandoverian?) on the basis of lithic and sequential similarity between the Greenvale Cove and the Aroostook River Formation (Roy and Mencher, 1976) of early Llandovery Age exposed in extreme northeastern Maine. Although, as pointed out above, possible correlatives of the Greenvale Cove are present in south-central New Hampshire, no strata stratigraphically below them have been identified. The nature of the lower contact of the Silurian sequence in south-central New Hampshire is thus unknown.

western Maine and central New Hampshire is compatible with the concept of Pavlides, Boucot, and Skidmore (1968) of a narrow belt in northeastern Maine and contiguous Canada, in which Ordovician strata pass conformably upward into Silurian strata. The central New Hampshire Silurian section (fig. 3, B-B′) of about 3000 m is not as thick as its equivalent in Maine, but the sequence of lithic units suggests that it is also southeast, though perhaps not as far southeast, of the hinge line. The nearest Clough Quartzite is 15 to 35 km (depending on the point of measurement) to the northwest. Farther south in southernmost central New Hampshire, the hinge line must lie between the depositional sites of the Clough and the Fitch on the west and the Francestown and Warner Formations, particularly the Warner, on the southeast.

Robinson (1981) reported that "East of the 'hinge line,' in the 'Gardner Zone,' [in central Massachusetts] the base of the Silurian consists of sulfide-rich rutile-bearing schist (=Smalls Falls=Parkman Hill) overlain by a thick and variegated sequence of gray calcareous granulite and interbedded schist of Paxton Fm. (=Madrid=Fall Brook) capped by Littleton (=Carrabassett and Seboomook)." Although ongoing mapping in the Peterborough area of southernmost New Hampshire may or may not bear out these relations, presently available information strongly suggests that much of the Silurian section and the tectonic hinge line from Rangeley, Maine, extend at least as far south as central Massachusetts and perhaps farther (Field, 1975, p. 19, 107-108; Robinson, 1979, p. 132-133, 143-144).

ACKNOWLEDGMENTS

The manuscript was reviewed by Marland P. Billings, Allan Ludman, Dennis Nielson, and Peter Robinson. Their thoughtful comments and suggestions significantly improved the paper, although this does not imply that all reviewers are in complete agreement with our conclusions. Professor Billings was particularly generous of his time in sharing with us his unparalleled experience in and knowledge of the rocks of New Hampshire. The results we present here represent a refinement of his and his colleagues' earlier work and would obviously not have been possible without that excellent work. Discussions with Peter Robinson, who has been working in the same belt of rocks in central Massachusetts, have been extremely helpful and encouraging. Finally, we acknowledge the excellent mapping of Dennis Nielson and Evan Englund in central and south-central New Hampshire. Both men recognized many of the units we discuss here and proposed many of the correlations that this paper attempts to document.

The work reported here has been supported by the U.S. Geological Survey (Hatch and Moench) and by the National Science Foundation (Lyons) through Grants EAR 77-20085, and EAR 80-12690.

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