1-1-1988

Stratigraphy and Structure of the Fall Mountain and Skitchewaug Nappes, Southwestern New Hampshire

Chamberlain, C. Page

Thompson, James B. Jr.

Allen, Tim

STRATIGRAPHY AND STRUCTURE OF THE FALL MOUNTAIN AND SKITCHEWAUG NAPPES, SOUTHWESTERN NEW HAMPSHIRE

C. Page Chamberlain, James B. Thompson Jr.*, and Tim Allen
Department of Earth Sciences, Dartmouth College Hanover, New Hampshire 03755,
*Department of Geological Sciences, Harvard University, Cambridge, MA 02138

INTRODUCTION

On this field trip, we present results of field research on the Skitchewaug and Fall Mountain Nappes. These nappe structures are exposed in two adjacent Acadian structural terranes, the Bronson Hill Anticlinorium and the Merrimack Synclinorium (figure 1). Our research on the nappes was directed towards understanding the tectonic relationships between these two large structural terranes.

Various geological studies have shown that the sedimentalogical, structural, and metamorphic histories of these two terranes are significantly different (Lyons, 1979; Thompson et al., 1968; Robinson and Hall, 1980). Rocks in the Bronson Hill Anticlinorium consist of Ordovician volcanics and sediments, Silurian shallow water marine sediments, and Devonian turbidites folded into a series of domed nappes (Thompson et al., 1968). Whereas, the rocks in the Merrimack Synclinorium consist of Ordovician sediments without volcanics, deep water Silurian sediments, and Devonian turbidites folded into nappes showing several stages of later folding (Lyons, 1979; Hatch et al., 1983). In addition, metamorphism in the Bronson Hill Anticlinorium is generally staurolite grade (ranging from garnet to sillimanite grade) and occured early in the deformation history (Thompson et al., 1968). This metamorphic style contrasts markedly with that observed in the Merrimack Synclinorium, where peak metamorphism is higher grade (sillimanite to sillimanite-potassium feldspar-cordierite grade) and reached peak conditions later in the deformation history (Chamberlain, 1985). Accounting for these sedimentalogical, structural, and metamorphic differences is an important problem facing the geologist interested in the tectonic evolution of the Acadian Appalachians

Toward this aim we have studied the statigraphy, structure, and metamorphism of the Fall Mountain and Skitchewaug Nappes in exposures that are found both on the east and west flank of the Bronson Hill Anticlinorium in southwestern New Hampshire. Our results are consistent with a tectonic history that involves: 1) deposition of sediments in an east-thickening basin during the Silurian; and 2) subsequent emplacement of this east-thickening package of sediments onto the more shallow water shelf sediments during the Devonian as fold and thrust nappes.

FIELD TRIP AREA

Our field trip concerns the metasediments in the Walpole, Bellows Falls, Lovewell Mountain, and Stoddard 7 1/2 minute quadrangles. The metasediments in this region have been the subject of study for over a century, and earlier interpretations are given in a large number of published geologic reports (Kruger, 1946; Moore, 1949; Heald, 1950; Chapman, 1952; Thompson et al., 1968; Dean, 1976).

STRATIGRAPHY

In the most recent published paper on the stratigraphy and structure of this region Thompson et al., (1968) assigned the rocks to the classic Bronson Hill stratigrphy defined by Billings in 1937. According to these authors interpretation the rocks in southwestern New Hampshire consisted of the following sequence, from bottom to top: Ordovician mixed felsic and mafic volcanics (Ammoonosuc Volcanics), Ordovician rusty weathered schists (Partridge Formation), a Silurian conglomerate (Clough Formation), Silurian calc-silicate (Fitch Formation), and a Devonian gray weathered turbidite (Littleton Formation). More recent mapping in northern Maine (Moench and Boudette, 1970; Boone et al., 1970) and New Hampshire (Hatch et al., 1983) have shown that the stratigraphy in both the Bronson Hill Anticlinorium and Merrimack Synclinorium is more complex and different than the stratigraphy originally defined by Billings (1937).

Our remapping of the metasediments exposed in the Skitchewaug and Fall Mountain nappes suggests that the stratigraphic sequence of Billings (1937) cannot be directly applied to these rocks. Our results suggest that rocks in these two nappes show many similarities to some recently defined stratigraphic sequences in Maine (Moench and Boudette, 1970) and central New Hampshire (Hatch et al., 1983). Moreover, the stratigraphy presented here gives direct evidence that the Silurian stratigraphy becomes increasingly complex eastward from the main axis of the Bronson Hill Anticlinorium.

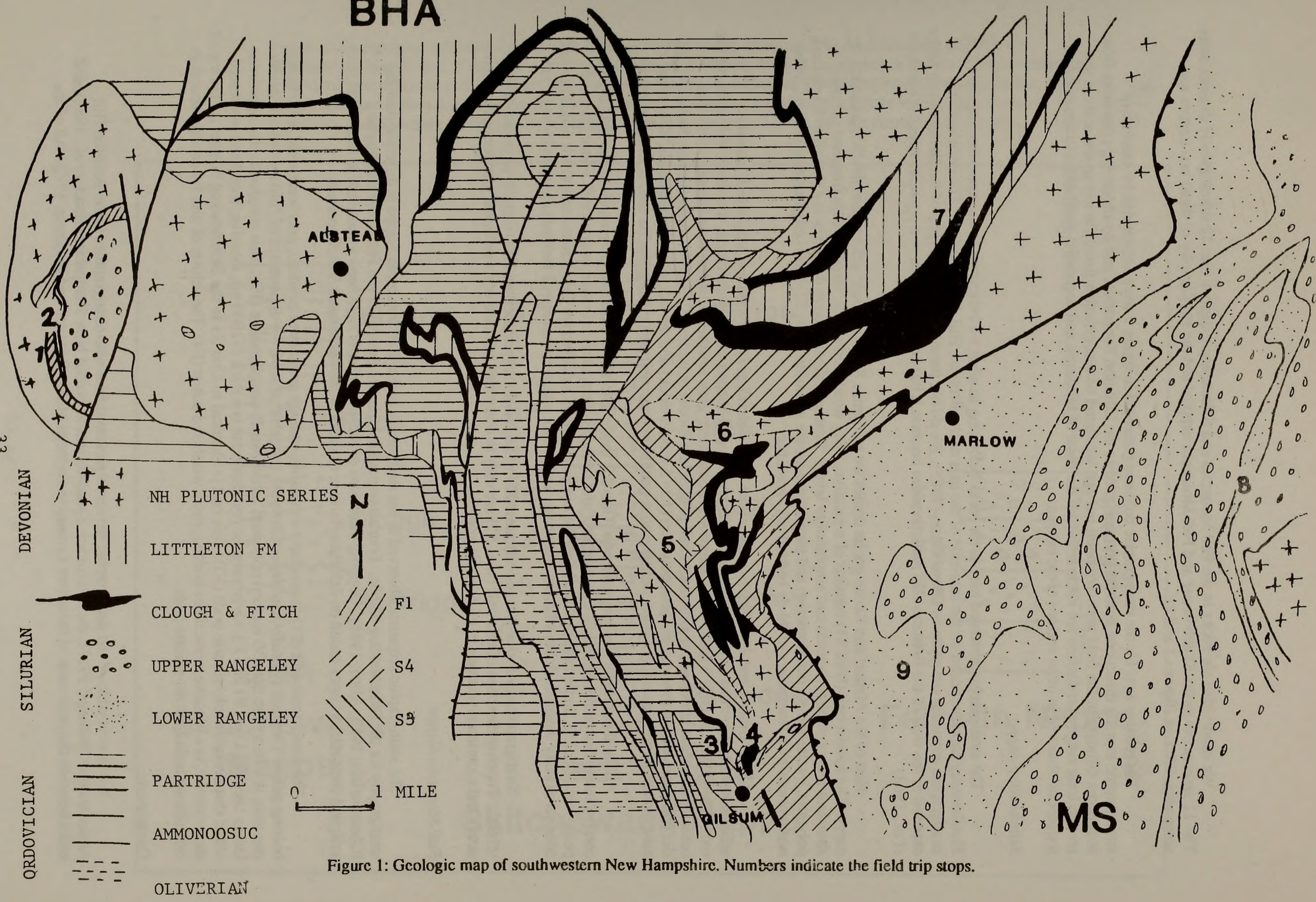


Figure 1: Geologic map of southwestern New Hampshire. Numbers indicate the field trip stops.

We subdivided the rocks in the Fall Mountain and Skitchewaug nappes into 12 lithologically distinct units. The 12 units occur in the Skitchewaug and Fall Mountain nappes, and the stratigraphy of these two nappes are somewhat different (figures 1 and 2).

The relative ages for the stratigraphic columns presented in figure 2 were determined by examining stratigraphic topping directions in rocks here assigned to the Littleton Formation, and by observing consistent lithic sequences throughout the field area. We point out that we found no recognizable fossils in any of the units in this area so long range correlations are made solely on the basis of lithologic and sequential similarities to stratigraphic sequences observed in other regions of the orogen.

Skitchewaug nappe:

The stratigraphy presented here is for rocks belonging to what we believe to be the upper limb of the Skitchewaug nappe exposed on the east-side of the axis of the Bronson Hill Anticlinorium. The details of this stratigraphic sequence are given in Chamberlain (1985). We do not present the stratigraphy of the Skitchewaug nappe exposed to the west of the Bronson Hill Anticlinorium because it has been presented in a previous paper (Thomspon et al., 1968)

East of the Alstead and Keene gneiss domes we recognize 8 stratigraphic units within the Skitchewaug nappe. The lowest unit (Unit S1) consists of a massive, rusty weathered schist. These schists frequently contain abundant lenses of pink coticule and amphibolite layers. Stratigraphicaly above this units is a thin (0 to 50 meters), polymict, quartz-matrix conglomerate and plagioclase-biotite granulite (Unit S2). The conglomerate is overlain in many places by a few meters of thinly bedded calc-granulite.

Above Units 1 and 2 is a thick (greater than 1000 meters), gray to blood-red weathered, massive, sillimanite-bearing schist (Unit S3). These schists contain pod-shaped calc-silicate clasts, which are diagnostic of the unit. The schists of Unit 3 grade into a massive (750 meters), gray weathered, sillimanite-bearing schist that contains abundant lenses of conglomerates and plagioclase-biotite granulites (Unit S4). Both the conglomerates and the granulites within this unit are generally thin (1 to 5 meters thick) and are laterally discontinuous. Two types of conglomerates are present: polymict, schist matrix conglomerates; and polymict, granulite matrix conglomerates.

Above these rocks is a conglomerate (Unit S5) that is laterally continuous over much of the field area. This conglomerate has predominantly a quartz-matrix and contains clasts of mostly vein quartz, with minor clasts of pelite, amphibolite, and quartzite. Overlying the conglomerate is a distinctive calc-silicate unit (Unit S6). This unit consists of rusty weathered calc-silicates at its base, and grades into gray weathered bedded calc-silicates at its top.

Stratigraphically above the calc-silicates of Unit S6 is a thick (greater than 1000 meters) of graded bedded schists. Topping direction of this unit (Unit S7) are easy to determine because compositional gradations between sandy and aluminous portions of each bed is gradual.

Fall Mountain Nappe:

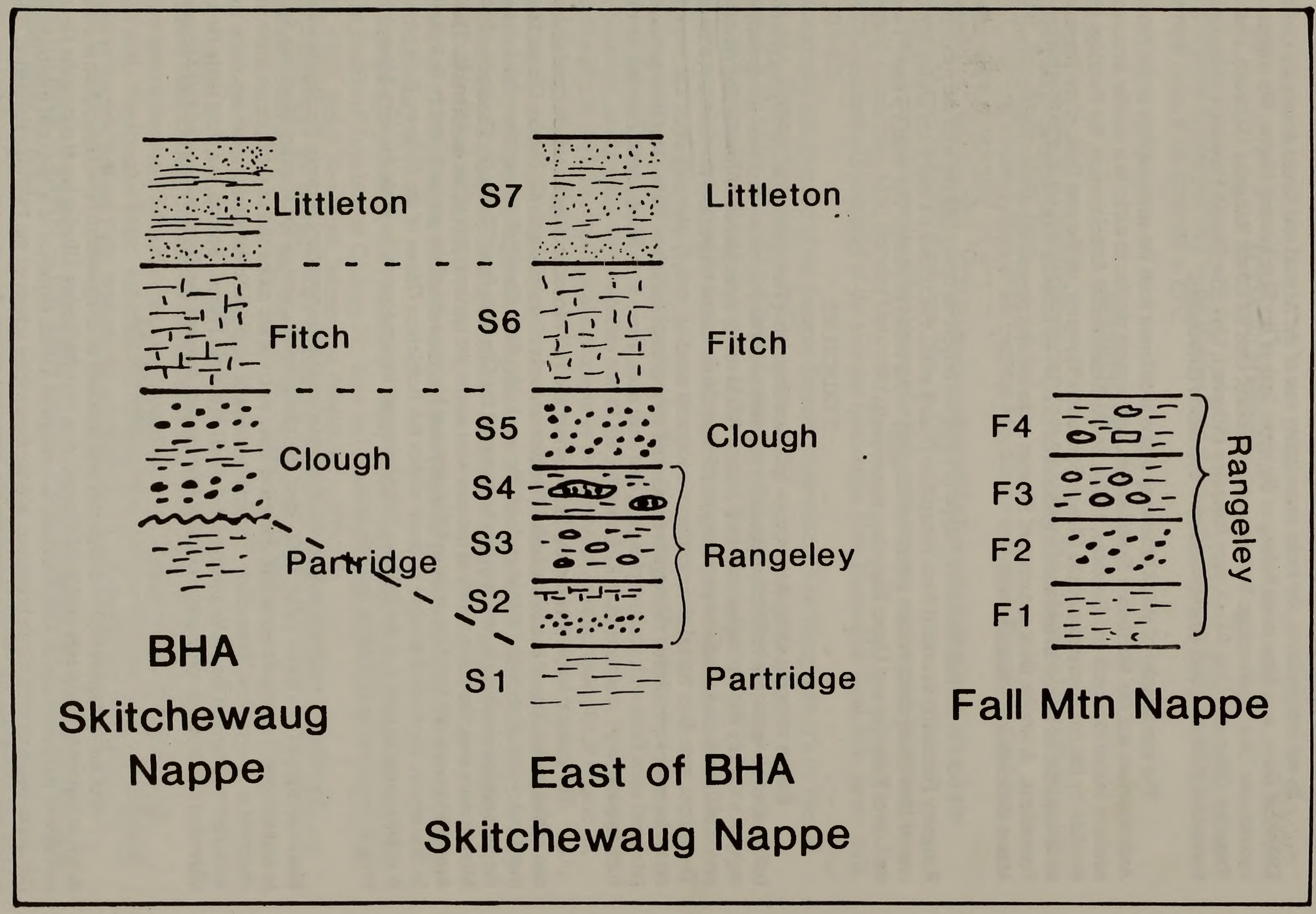
The stratigraphic sequence observed in the structurally higher Fall Mountain Nappe is different than the stratigraphy for the Skitchewaug Nappe. Four stratigraphic units are present in the Fall Mountain Nappe (Chamberlain, 1985, Allen, 1985). Topping directions of these four units have been impossible to determine. We assigned their relative ages based on lithic similarities to rocks in the Merrimack Synclinourium.

The lower most unit (F1) is generally a massive, (though sometimes bedded), gray weathered, sillimanite-bearing pelite. This unit typically has large sillimanite crystals that have the appearance of "turkey tracks". Above this unit, is a thin (less than 30 meters) polymict, schist-matrix conglomerate (F2). This conglomerates appears as lenses between Units F1 and F3. Overlying the conglomerate is a thick (>1000 m), massive, blood-red weathered schist that contains calc-silicate pods (F3). This unit is identical to Unit S3 in the Skitchewaug Nappe. At the top of the sequence, is a massive, sometimes bedded, rusty weathered schist (F4). The schists of unit F4 contain abundant calc-silicate beds and calc-silicate pods.

Correlations:

We have correlated the stratigraphic sequence presented here with stratigraphies in the Bronson Hill Anticlinorium (Billings, 1937), the Merrimack Synclinorium in central New Hampshire (Hatch et al., 1983), and rocks between the main axes of these two terranes in northern Maine (Moench and Boudette, 1970). All of the

Figure 2: Straigraphic columns for the Skitchewaug Nappe on the Bronson Hill Anticlinorium (BHA); the Skitchewaug Nappe east of the BHA; and the Fall Mountain Nappe. Schists are shown as dashes; conglomerates as large dots; calc-silicates and granulites as a brickwork pattern; turbidites as alternating small dots and dashes; open circles enclosed within dashes represent pods within massive schist; lenses of black dots within dashed pattern represents conglomerate lenses in a schist matrix. The abbreviations S1, F1, etc. are described in the text.



correlations that we propose are based on lithic and sequential similarities between the units discussed above and rocks in these three other regions.

In our interpretation, the rocks immediatley east of the Alstead and Keene domes are Ordovician through Devonian strata; and these strata belong to the upper limb of the Skitchewaug Nappe. We suggest the following correlations: Unit S1=Partridge Formation (Ordovician); Unit S2 Lower Rangeley (Silurian), Unit S3= Middle Rangeley (Silurian), Unit S4 = Upper Rangeley (Silurian); Unit S5= Clough Formation (Silurian); Unit S6=Fitch Formation (Silurian); and Unit S7=Littleton Formation (Devonian).

The stratigraphy of the Skitchewaug nappe is different from the stratigraphies of the Bronson Hill Anticlinorium and the Merrimack Synclinorium, and is most similar to rocks in a similar structural setting in northern Maine (Moench and Boudette, 1970). In the Bronson Hill Anticlinorium, the Partridge Formation is overlain by the conglomerates of the Clough Formation. However, on the east flank of the Bronson Hill terrane a thick sequence of mixed schists and conglomerates (S2-S4) lie between rocks assigned to the Partridge and Clough Formations. A similar thick sequence of Silurian rocks are also present above the Ordovician sedimentary rocks in Maine (Moench and Boudette, 1970).

Rocks in the Fall Mountain Nappe (F1-F4) we believe to be correlative with the rocks assigned to the Rangeley Formation in central New Hampshire (Hatch et al., 1983). Our F1 and F2 is unlike any units observed in central New Hampshire, but are similar to Rangeley rocks found in Maine. Our units F3 and F4 we correlate with the Lower Rangeley and Upper Rangeley, respectively.

STRUCTURE

Earlier mapping along the Bronson Hill Anticlinorium (Thompson et al., 1968) suggested that the rocks belonged to several major refolded nappes. Our research confirms this earlier structural interpretation. However, we suggest a slightly more complex structural history that involves three phases of folding and thrusting. The earliest period of deformation produced west-vergent fold and thrust floored nappes and the dominant foliation in this area. The nappes were later folded about northeast-southwest trending, steeply plunging axes. The second stage of folding created a spaced crenulation cleavage and abundant tight to isoclinal minor folds. The latest period of deformation produced open folds with shallow-plunging, east-west axes. There is no recognizable cleavage asociated with the last folding event.

The tectonic break between the Skitchewaug and Fall Mountain Nappes, where these structures are exposed east of the gneiss domes, is a thrust fault. The fault is marked by a stringer of Kinsman Quartz Monzonite (called the Huntley Mountain Spur) that extends off the west side of the Cardigan pluton. The fault contiunues south into the Monadnock quadrangle, where it has been named the Chesham Pond Thrust (P. Thompson, 1984). In the Monadnaock area, the thrust trends to the east-west across the northern part of the quadrangle. The thrust is also exposed between the Fall Mountain and Skitchewaug Nappes west of the gneiss domes in Bellows Falls, Vermont. In this region, the fault is thought to occur within the Bethlehem Gneiss of the Bellows Falls pluton (Allen, 1985). It is interesting to note that the Bellows Fall pluton and the igneous rocks in the Huntley Mountain Spur are similar both in their structural position and lithology.

Two lines of evidence support the interpretation that the boundary between the Skitchewaug and Fall Mountain nappes is a major thrust fault. First, the stratigraphies west of the Huntley Mountain Spur is more similar to rocks exposed on the Bronson Hill Anticlinorium, whereas the rocks east of the Spur are more similar to rocks observed in central New Hampshire. The juxtaposition of vastly different stratigraphic succesion suggests major westward transport of the rocks assigned to the Fall Mountain Nappe. Second, mapping along the tectonic break show that stratagraphic units pinch out along the contact between the Skitchewaug and Fall Mountain Nappes.

SUMMARY

Our interpretation of the stratigraphy and structure of southwestern New Hampshire is consistent with an Acadian history that involves continued closure of an east-thickening Silurian basin during the Devonian. Along the east side of the Bronson Hill Anticlinorium, we recognize a thick sequence of schists and interbedded conglomerates that occur between the Clough Formation and the Ordovician schists of the Partridge Formation. These intervening schists and conglomerates, in our interpretation, represent an east-thickening transitional facies correlative to the Silurian shelf sediments (Clough) of the Bronson Hill and basin sediments (Rangeley) of the Merrimack Synclinorium. Our interpretation is consistent with an earlier hypothesis that during the Silurian an east-thickening basin existed and the Bronson Hill Anticlinorium was a major topographic high (Boone et al., 1970).

During the Acadian the deep water sediments were thrust over the shallow water sediments of the Bronson Hill Anticlinorium. Thus, succesively higher nappes have stratigraphies that contain less conglomerates and more deep water schists. This is best observed when comparing the startigraphic succesions in the Skitchewaug and Fall Mountain Nappes.

ACKNOWLEDGEMENTS

Funds for this research were provided by the Higgins Fund at Harvard University, NSF Grant EAR-81-15686 to JBT, and NSF Grant EAR-8720160 to CPC.

REFERENCES

Allen, T., 1985, A reinterpretation of the Fall Mountain Nappe, as seen from Fall Mountain, North Walpole, NH (abs.): Geol. Soc. Amer. Abstr. Prog., v. 17, p. 2.

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

Boone, G.M., Boudette, E.L., Moench, R.H., 1970, Bedrock geology of the Rangeley Lakes-Dead River basin region, western Maine: in NEIGC 62nd Ann. Mtg., p. 1-24.

Chamberlain, C.P., 1985, Tectonic and metamorphic history of a high-grade terrane, southwestern New Hampshire (Ph.D. Thesis): Cambridge, MA, Harvard University, p. 207.

Chapman, C.A., 1952, Structure and petrology of the Sunapee quadrangle, New Hampshire: Geol. Soc. Amer. Bull., v. 63, p. 381-425.

Dean, C., 1976, Stratigraphy and structure of the Sunapee Septum, southwestern New Hampshire (Ph.D. Thesis): Cambridge, MA, Harvard University, p. 248.

Hatch, N.L.Jr., Moench, R.H., Lyons, J.B., 1983, Silurian-Lower Devonian stratigraphy of eastern and south-central New Hampshire: Extensions from western Maine: Amer. Jour. Sc., v. 283, p. 739-761.

Heald, M.T., 1950, Structure and petrology of the Lovewell Mountain quadrangle, New Hampshire: Geol. Soc. Amer. Bull., v. 61, p. 43-89.

Kruger, F.C., 1946, The geology of the Bellows Falls quadrangle, New Hampshire and Vermont: New Hampshire State Pln. and Devel. Comm., p. 19.

Lyons, J.B., 1979, Structure, stratigraphy, and plutonism east of the Bronson Hill Anticlinorium, New Hampshire: in The Caledonides in the USA, Geological Excursions in the Northeast Appalachians. IGCP Project 27. Skehan and Osberg (eds.). p. 73-92.

Moench, R.H., Boudette, E.L., 1970, Stratigraphy of the northwest limb of the Merrimack Synclinorium in the Kennebago Lake, Rangeley, and Philips quadrangles, western Maine: in NEIGC 62nd Ann. Mtg., p. 1-25.

Moore, G.E., 1949, Structure and metamorphism of the Keene - Brattleboro area, New Hampshire - Vermont: Geol Soc. Amer. Bull., v. 60, p. 1613-1670.

Robinson, Peter, Hall, L.H., 1980, Tectonic synthesis southern New England: in Proceeding on the Caledonides in the USA, Wones (ed.), p. 73-82.

Thompson, J.B.Jr., Robinson, P., Clifford, T.N.,Trask, N.J., 1968, Nappes and gneiss domes in west-central New England, in Studies of Appalachian Geology-Northern and Maritime: Zen,E-An, White,W.S., Hadley,J.B., Thompson, J.B.Jr. (eds.). New York, Interscience Publishers, p. 203-218.

Thompson, P., 1984, Stratigraphy and structure of the Monadnock quadrangle, New Hampshire: refolded folds and associated fault zones (abs.): Geol. Soc. Amer. Abstr. Prog., v. 16, p. 67.

ROAD LOG

Assembly point: Keene State College Commons Parking Lot: 8 am, Friday, Oct. 14:
This trip will involve several strenuous hikes and much travel on steep, narrow gravel roads. The mileage log begins from the first stop. Topographic Maps: either the old Bellows Falls (NH and VT) and Lovewell Mountain (NH) 15' Quadrangles or the new Bellows Falls, Walpole, Lovewell Mountain, and Stoddard 7 1/2' quadrangles.

From Keene take NH Route 12 north to the first stop at the Vilas bridge, connecting North Walpole, NH with Bellows Falls Vermont, about 20 miles.

0.0 **STOP 1:** Park on the east side of the road, just north of the Green Mountain Railroad's yard. Here we will be looking at turkey track sillimanites of unit F1 in contact with the Bellows Falls Pluton.

0.4 North on RT. 12 to Milt's Corner Market, bear right.

0.6 Turn sharp right up hill, past school.

0.7 Turn left, uphill.

1.0 **STOP 2:** Park at end of road to begin hike up Fall Mountain. Keep vehicles close together as parking is limited. This hike will be about 3 miles roundtrip and will involve over 600 feet of elevation gain. We will see all units of the Fall Mountain Nappe stratigraphy on this hike.

1.6 Return to RT 12, travelling south back past Vilas bridge.

3.1 Junction with RT 123, turn left following sign for Alstead.

3.3 Bear left again on Cold River Road.

OPTIONAL STOPS: On the Cold River Road there are several optional stops we can make if time and interest permit, including Partridge Formation underlying the Bellows Falls Pluton, and as xenoliths within the Pluton.

7.1 Intersection of the Cold River Road and RT 123. Continue straight across, now travelling "south" on RT 123.

9.0 Junction with RT 12-A. Turn right then left staying on RTs 123 and 12-A through Alstead village. Stay on RT 123 past junctions with 123-A to Acworth and 12-A to Keene. You will be driving over rocks of the Skitchewauge Nappe and Alstead Dome.

14.5 East Alstead, turn right at blinking light, following sign to Gilsum.

19.4 **STOP 3:** At the top of hill, park on right side as far over as possible. Here we will be looking at the contact between units S1(Partridge) and S2 (Rangeley) in the upper limb of the Skitchewaug Nappe.

20.1 Near bottom of hill,as we are approaching Gilsum village, turn abrupt hard left onto narrow road. Follow paved road until pavement ends.

20.5 **STOP 4:** Park in turn out to the left; avoid blocking the road. From this parking area we will see several different outcrops of units S3, and S4.

20.9 Turn right, downhill, onto paved road.

21.3 Turn right onto RT 10, into Gilsum.

21.6 Turn right into Gilsum Village

21.7 LUNCH STOP: Turn right and park in front of meeting house lawn. We will stop here for lunch, after which we will continue north out of Gilsum village, returning to East Alstead.

25.0 **STOP 5:** park on right side as far over as possible. Here we will see large amphibolite pods within the Rangeley Schists belonging to Unit S3.

26.3 Continue on the right hand fork, straight ahead.

27.4 East Alstead again, turn right on RT 123, towards Marlow.

28.2 Turn right at some mailboxes just past a barn onto Roger's Road

29.2 **STOP 6:** Fork in the road, parking and turn around will be difficult, but park on either side of the road, keeping the road clear. From this parking area we will again disembark to see several outcrops of Unit S5 (Clough-the upper most conglomerate) and S7 (Littleton).

29.5 Ahead on left fork, turn arounds are available in several driveways.

30.6 Turn right on RT 123 again headed toward Marlow.

31.9 OPTIONAL STOP: Schist matrix conglomerate of Unit S4 (Rangeley).

34.1 Entering Marlow village, turn left

34.4 Join RT 10 North

36.6 **STOP 7:** Gee Mill, park on right side as far over as possible, past turn for Sand Pond road. Here we will see graded bedded Littleton Fm (Unit S7), and Fitch Fm (Uniy S6) in the hinge of a large F3 fold.

Turn around, heading south on RT 10, back through Marlow.

40.5 Junction with RT 123 East, turn left following sign for Stoddard.

43.6 **STOP 8:** Turn left into Pitcher Mountain Parking Lot. From here we will take a short hike up Pitcher Mountain. At the summit we will see Units F3 and F4 (assigned to the Rangeley Fm of central NH) that are in the Fall Mountain Nappe.

Turn around, heading west on RT 123, back towards RT 10.

46.6 At sharp bend in road, turn left onto short road that will connect with RT 10.

46.9 Turn left onto RT 10 South.

49.2 **STOP 9:** Park on right side as far over as possible. Spectacular outcrops of high-grade Rangeley Fm. (Unit F3) of the Fall Mountain Nappe.
Continuing south on RT 10 will bring you to Gilsum and then back to Keene, about 10 miles.