INTRODUCTION

Mount Monadnock, the centerpiece of the Monadnock quadrangle, is held up by quartzite beds in the Devonian Littleton Formation, which are folded back on themselves to form a thick resistant sequence. The Littleton Formation consists of gray-weathering schists and quartzites, with the proportion of quartzite increasing upwards. Davis (1896) cited Monadnock as the type locality for resistant mountains rising above the general erosion level, thereby coining the term “monadnock” for such isolated peaks worldwide.

The layered rocks of the Monadnock quadrangle, New Hampshire, were remapped by the author (Thompson, 1985) based on a stratigraphic sequence (Fig. 1) that correlates well with the so-called “Rangeley sequence” originally described by Moench and Boudette (1970) in western Maine and extended into central New Hampshire by Lyons and Hatch (Hatch et al., 1983). In this sequence, thick Silurian clastic rocks derived from a sedimentary source to the west are overlain by the Devonian Littleton Formation, distal turbidite flysch apparently derived from the east (Hall et al., 1976). The Littleton Formation lies in the center of an overturned syncline, the Monadnock syncline (Fig. 2), outlined by three distinctive Silurian units, which serve as marker beds. In order from oldest to youngest these are: the Perry Mountain Formation, thinly bedded schist and white quartzite; the Francestown Formation, mainly sulfidic calc-silicate granulite; and the Warner Formation, consisting of a lower clean calc-silicate granulite and an upper feldspathic granulite. Nielson (1981) first described the Francestown and Warner in the Hillsboro quadrangle. The Rangeley Formation lies below the marker beds, and includes sulfidic to gray-weathering gritty schist with calc-silicate pods, granulite beds, quartz-pebble conglomerate lenses near the top, and granulite-matrix conglomerate horizons near the lowest exposed part.

Along the west edge of the Monadnock quadrangle, the Silurian is represented by a much thinner shelf sequence of rocks, part of the classic Bronson Hill anticlinorium stratigraphy (Billings, 1937). Clough Quartzite and locally Fitch Formation, probably correlative with the Silurian units described above, overlie the Ordovician Partridge Formation and Ammonoosuc Volcanics on the Keene dome. Thus the quadrangle straddles a Silurian “tectonic hinge” (Fig. 3), which may have behaved as a zone of weakness during Acadian deformation. Intrusive rocks include the pre- to syn-tectonic Devonian Kinsman Granite, syntectonic Devonian Spaulding Tonalite and related rocks, and post-tectonic Mississippian Fitzwilliam Granite. Microdiorite dikes probably coeval with the Fitzwilliam cut all generations of folds on Mount Monadnock.

STRATIGRAPHY

Fowler-Billings (1949) described most of the layered rocks in the Monadnock quadrangle as members of the Littleton Formation. Her lower and upper schist members are now mapped as Rangeley Formation, and her middle member is retained as Littleton Formation. Her rusty quartzite member is mapped as Francestown and Warner Formations, following Nelson (1975). Topping directions are provided by graded beds in the Rangeley, Perry Mountain and Littleton Formations.

Rangeley Formation

Rocks assigned to the Rangeley Formation in the Monadnock quadrangle include rusty-weathering sulfidic schists, gray-weathering schists, quartz-feldspar-biotite granulites, a variety of conglomerate horizons and lenses, and a variety of calc-silicate granulite horizons and lenses. The mapping of rusty- and gray-weathering rocks within the Rangeley Formation has not shown any clear internal stratigraphy; the situation seems to be more complicated than simply an upper rusty part and lower gray part, as suggested by Hatch et al. (1983) for central New Hampshire. Because of the heterogeneity of the unit, consistent internal stratigraphy would probably not be expected over wide areas.
Figure 1. Stratigraphic column for rocks in the Monadnock syncline.
Figure 2. Simplified geologic map of the Monadnock quadrangle. Summit of Mount Monadnock is shown by a solid triangle. Numbers in parentheses refer to the three structural levels separated by faults discussed in the text. Dotted pattern - - Littleton Fm. Shaded pattern - - plutons.
Figure 3. Stratigraphic diagram showing proposed correlations across southern New Hampshire, modified from Hatch et al. (1983) to include the Monadnock and Peterborough sections. Heavy black arrows show directions of sediment source.
Reddish-rusty, quartz-biotite-muscovite-plagioclase schist, with gritty horizons and calc-silicate pods, is the most common rock type in the Rangeley Formation. The plagioclase ranges from An$_{23}$ to An$_{55}$. Sillimanite, garnet, orthoclase, and retrograde staurolite and Mg-chlorite may be present. Pyrite, pyrrhotite, and marcasite after pyrrhotite account for the rusty weathering. Lenses or pods of calc-silicate granulite are very common, ranging in size from 10 to 100 cm. The discovery of conglomerate lenses at some fifteen localities lends weight to the proposed correlation of this unit with type Rangeley Formation in Maine. Gray-weathering schists in the Rangeley, although quite similar to those of the Littleton Formation, contain somewhat more feldspar and fewer phyllosilicate minerals. Calc-silicate pods similar to those in the rusty schists are also common.

Marker Units

**Perry Mountain Formation.** In the Monadnock quadrangle an interval of thinly bedded (2-5 cm) clean quartzite and gray to slightly rusty schist occurs in most places between the Rangeley and Francestown Formations. Quartzite-schist contacts are sharp, and graded beds are sparse. The rocks consist of quartz, muscovite, biotite, garnet, and opaques, with or without sillimanite, feldspar, and chlorite. Thin garnet-quartz granulite (“coticule”) beds and lenses are locally present. The Clough Quartzite may be in part correlative (Fig. 1), but no fossils have yet been found in the Perry Mountain Formation. We will not see exposures of the Perry Mountain or Rangeley Formations on the hike up Mount Monadnock.

**Francestown Formation.** Extremely rusty-weathering calc-silicate granulite and subordinate rusty-weathering graphic schist make this the most distinctive unit in the Monadnock stratigraphy. Graphite and sulfides together make up to 10% of the rock. The calc-silicates are composed of quartz, plagioclase(An$_{67-73}$), graphite and iron sulfides with or without sphene, actinolite, diopside, zoisite, microcline, minor muscovite, Mg-biotite, and Mg-chlorite. The iron sulfides include pyrite, pyrrhotite and marcasite after pyrrhotite. The rocks are hard and well jointed, breaking into blocky fragments. Schists of the Francestown weather deeply to a rusty brown-orange-yellow rind surrounding white interior flecked with graphite. They contain quartz, muscovite, Mg-biotite, sillimanite, graphite, iron sulfides, and secondary Mg-chlorite. Neither the schists nor the calc-silicates contain black mica, which helps distinguish isolated outcrops from otherwise similar rusty schists in the Rangeley. The correlative Smalls Falls Formation contains a higher proportion of schist to calc-silicate.

**Warner Formation.** The lower part of the Warner consists of thinly bedded (0.5 to 5 cm) green, pink, gray or white calc-silicate granulites. The color variation is due to differences in the relative proportions of actinolite, diopside, garnet, clinozoisite, ferrian zoisite, sphene, biotite and calcite. Quartz is present in all layers. The upper part consists of fine-grained quartz-biotite-plagioclase granulite, with minor muscovite and sphene. Outcrops are thickly bedded, massive, with smooth purplish-gray “salt and pepper” surfaces, much like the correlative Madrid Formation of the Rangeley sequence. Calc-silicate pods much like the layers in the lower part of the Warner are common. The contact with the overlying Littleton Formation is gradational; calc-silicate pods and granulite beds persist into the lower part of the Littleton. For mapping purposes, the uppermost continuous granulite bed is taken as the upper contact of the Warner. Together, the Warner and Francestown probably correlate with the Silurian Fitch Formation of the Bronson Hill sequence.

**Littleton Formation**

The Littleton Formation in the Monadnock quadrangle consists predominantly of gray-weathering pelitic schist and micaceous quartzite. The schists consist of quartz and muscovite with or without biotite, staurolite, garnet, sillimanite, plagioclase (An$_{24-43}$), K-feldspar, graphite and other opaques, and retrograde chlorite, chloritoid and staurolite. Pseudomorphs of sillimanite after andalusite are common in some parts of the quadrangle, depending on the metamorphic history, but no relic andalusite was found in thin section. Some pseudomorphs preserve chialostite cross-shaped inclusion patterns.

The quartzites contain quartz, muscovite, biotite, garnet and opaques. The proportion of quartzite increases in stratigraphically higher parts of the formation, so that two members can be informally distinguished. Quartzite beds are both thicker and more abundant toward the center of the Monadnock
syncline, and where the beds are graded they reveal the pattern of refolded folds on the summit of the mountain. East of the summit, in the youngest exposed part of the formation, thinner quartzite and schist layers alternate rhythmically. Discontinuous coticule layers are found locally throughout the formation. On the basis of both rock type and stratigraphic position, the Littleton Formation of the Monadnock area is correlated to the type Littleton and to the Seboomook Formation of Maine, both of which contain Lower Devonian fossils.

STRUCTURAL GEOLOGY

Introduction

Five phases of Acadian deformation have affected the rocks of the Monadnock quadrangle. The earliest, isoclinal folds, are believed to be related to the huge west-verging nappes proposed by Thompson et al. (1968). West-verging ductile thrust faults then developed and cut across the axial surfaces of the earlier fold nappes. The fold nappes and thrust faults are deformed by two phases of folds and backthrusts related to a complicated “backfolding” episode, and by folds related to the rise of gneiss domes. A summary of the structural history is presented in Table 1. Figure 4 shows the axial traces of the major folds and their relative ages.

The nappes and thrusts transported hot rocks onto relatively cooler rocks, setting up temperature and pressure gradients, which led to peak metamorphic conditions closely following the nappe stage. The dominant foliation is parallel to axial planes of nappe-stage folds. Reactions proposed to explain garnet zoning imply a declining pressure as a result of uplift soon after the peak of metamorphism. However, thermal equilibrium was apparently not attained throughout the pile of nappes, resulting in an inverted metamorphic sequence, with lower grade rocks at the lowest structural level next to the Keene dome.

Fold nappes

The Monadnock syncline is interpreted as a nappe-stage fold. It is separated into two parts by intrusions (Fig. 2). Southwest of the intrusions, the syncline is relatively narrow, with clear symmetry across its axial trace. North of the intrusions it is wider and overturned to the southeast. Although the stratigraphy is grossly symmetrical, the presently upright southeast limb is much thicker than the presently overturned northwest limb. (Prior to backfolding, these topping directions are believed to have been opposite to what they are today.) The southeast limb includes a thick section of the upper part of the Littleton Formation. The thickening is at least in part due to folding.

Nappe-stage folds are abundantly exposed on Mount Monadnock (Fig. 5). They consist of tight isoclinal folds with amplitudes far exceeding their wavelengths, and axial planes parallel to the pervasive foliation. Amplitudes are generally greater than five meters. The best-exposed nappe-stage fold is the “Billings’ fold”, a recumbent syncline on a west-facing cliff 450 feet west of the summit. The cliff provides a view nearly perpendicular to the fold axis. Layers are much thicker in the hinge than on the limbs. Several map-scale folds on Figure 2 are interpreted as nappe-stage folds: Howe Reservoir syncline, Dublin Pond syncline, and Gilson Pond anticline.

Early thrust faults

Three tectonic levels are present in the Monadnock quadrangle, apparently separated by early thrust faults (the Chesham Pond fault and the Brennan Hill fault, Figure 2). These levels consist of:

1. an autochthonous, upright sequence overlying the Keene dome, consisting of Ammonoosuc Volcanics, Partridge Formation, Clough Quartzite, local Fitch Formation, and Littleton Formation,
2. the folded Monadnock sequence consisting of the units shown in the stratigraphic column of Figure 1, intruded by Spaulding Tonalite, and (3) a "gneissified" sequence consisting mainly of Rangeley Formation and Kinsman Granite.

The Brennan Hill thrust fault is interpreted as a fault largely on a stratigraphic basis. The contact is difficult to map. To the west are sillimanite-rich, locally staurolite-bearing, monotonous gray-weathering
<table>
<thead>
<tr>
<th>Age</th>
<th>m.y.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesozoic</td>
<td>245-144</td>
<td>Extensional faulting; silicified zones; diabase dike.</td>
</tr>
<tr>
<td>Late Paleozoic</td>
<td>326-245</td>
<td>Continued local shearing; ?Permian metamorphic disturbance?</td>
</tr>
<tr>
<td>?Mississippian</td>
<td>326</td>
<td>Intrusion of Fitzwilliam Granite plutons and microdiorite dikes.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Late open folds NW-trending, steep AP's; local crenulation cleavage.</td>
</tr>
<tr>
<td>Devonian (Acadian orogeny)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>&lt;380</td>
<td>DOMING Various trends, steep AP's; crenulation cleavage; strong linear fabric swirl</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LATE BACKFOLDING NE-trending fold axes, inclined AP's; linear fabric?</td>
</tr>
<tr>
<td></td>
<td>393</td>
<td>EARLY BACKFOLDING W-over-E verging reclined folds; local mylonitization and mylonitic foliation; some linear fabric; peak of metamorphism?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intrusion of Spaulding Series plutons.</td>
</tr>
<tr>
<td>Ordovician to Devonian</td>
<td>480-415</td>
<td>Deposition of volcanic and sedimentary rocks.</td>
</tr>
</tbody>
</table>
Figure 4. Axial traces of major folds and faults: (1) nappes, (2) thrusts, (3) early backfolds, (4) late backfolds, (5) dome-stage and other late folds, (M) Mesozoic faults. Base of the Littleton (dashed line) is shown locally for reference. Names of structural features are shown on Fig. 2.
Figure 5. Geology of Mount Monadnock summit, showing isoclinal folds marked by the “seven quartzites”. The field trip follows the Smith Summit Trail from Monte Rosa to the summit.
schists of the Littleton Formation. To the east are more feldspathic gray schists of the Rangeley Formation, with abundant quartz-feldspar augen.

The Chesham Pond fault is much better documented than the Brennan Hill fault. The Monadnock syncline is cut by the Chesham Pond fault. North of the Spaulding pluton, Littleton Formation at the top of an upright sequence is overlain by augen schist of the Rangeley Formation. The contact is not exposed, but can be narrowed down to less than ten feet in a few places. To the east, the Chesham Pond thrust is deformed by the Beech Hill anticline, and merges with the Thorndike Pond fault zone, where younger faulting (Mesozoic?) obscures its exact location.

**Backfolding and backthrusting**

A wide range of folds deforms the dominant foliation in the Monadnock quadrangle. In many outcrops younger folds deform nappe-stage isoclinal folds, but there are very few instances of intersecting younger folds, so that little success has been made in sorting out the folds of intermediate age. West-over-east asymmetric folds that deform the dominant foliation are very common on Mount Monadnock, and have the same sense and style as the Thoreau Bog syncline.

The Beech Hill anticline is a major backfold that plunges moderately northwest. At first it appears to be paired with the Monadnock syncline because both are overturned toward the southeast. However, my interpretation is that the Monadnock syncline is an older structure in the southeast limb of the Beech Hill anticline. This overturned limb dips steeply northwest, and continues south across central Massachusetts. It is presumably a short limb in the backfold system.

**Doming**

The Keene dome is one of the many gneiss domes along the Bronson Hill anticlinorium which, due to their relatively low density, rose late in the Acadian orogeny (Thompson et al., 1968). The domes are characteristically separated by tight synclines in the mantling metamorphic rocks. Upright, west-verging minor folds with associated crenulation cleavage are abundant up to three miles east of the Keene dome. North of the latitude of the Troy Quarry pluton minor folds plunge gently north. To the south, most minor folds plunge south. On Mount Monadnock itself, open folds with steep axial planes and associated crenulation cleavage are interpreted as dome stage folds.

**Summary**

Rocks of the Merrimack trough were deformed by fold-nappes and thrust-nappes directed toward the west, followed by backfolds and doming. The Brennan Hill fault transported rocks of the “Monadnock sequence” over the thinner, autochthonous Bronson Hill sequence. The thrust is interpreted here as a ductile thrust near the root zone of the Bernardston nappe. The Chesham Pond thrust carried the Kinsman Granite and Rangeley Formation westward over the Monadnock sequence, cutting across the nappe-stage Monadnock syncline between the Fall Mountain nappe and lower nappes. A major backfold, the Beech Hill anticline, deformed the Chesham Pond thrust, and it is in this anticline that the nappe-stage Monadnock syncline is exposed. A similar interpretation can be extended northward. The “Kearsarge-Central Maine synclinorium” (Lyons et al., 1982), along which the New Hampshire sequence is exposed beneath a sheet of Kinsman Granite, is perhaps the same nappe-stage syncline exposed because of a younger backfold anticline. According to this model, the Fall Mountain nappe and the Kinsman Granite must be rooted east of the Kearsarge-Central Maine synclinorium. Inverted units of the Monadnock sequence appear locally beneath the west edge of the Ashuelot pluton of Kinsman Granite southwest of Keene (Elbert, 1986). The reader is referred to Robinson et al. (1991) for a thorough description of the evolution of geologic models for southwestern New Hampshire and discussion of remaining problems in the region.
METAMORPHISM

In the Monadnock quadrangle regional Acadian metamorphism has affected all the layered rocks and the Kinsman Granite (Fig.6). The peak of metamorphism produced predominantly “upper sillimanite” zone mineral assemblages in the pelitic schists (Zone III, sil-mus-gar-biot, and Zone IV, sil-mus-gar-biot-Ksp, of Tracy, 1975). The Chesham Pond fault coincides approximately with the boundary between Zones III and IV. Rocks containing prograde staurolite (Zone II, sil-mus-st-gar-biot) occur mainly west of the Brennan Hill fault. Cordierite was observed in two thin sections of rocks immediately west of Kinsman Granite in the Cardigan pluton (Zone VI, sil-gar-biot-Ksp-crd). Although zone boundaries roughly follow the nappe-stage thrust faults, there are no sharp discontinuities in grade across the faults. A similar relationship was observed west of the Keene dome between faults and inverted metamorphic isograds below Kinsman Granite in the Ashuelot pluton (Robinson et al., 1991).

Sillimanite pseudomorphs after andalusite are abundant in much of the Monadnock quadrangle. A line on Figure 6 shows the approximate former position of the triple point between the three aluminum silicate polymorphs, kyanite, andalusite, and sillimanite. Kyanite was transformed to sillimanite west of the line, and andalusite was replaced by sillimanite to the east. Neither relict kyanite nor relict andalusite has been found in the quadrangle.

Two garnets from a typical Zone III pelitic schist were studied with the electron microprobe. Pyrope increases toward the rim, except where the garnet touches biotite, and there it decreases abruptly. Almandine is fairly constant except toward rims touching biotite, where it rises. Spessartine follows a pattern inverse to that of pyrope. Grossular shows little variation. One possible explanation for these trends is early prograde garnet growth from staurolite + biotite + quartz. After staurolite was consumed, garnet growth stopped and was later affected by local retrograde cation exchange where garnet touched muscovite and biotite. Two biotite-free garnet rim analyses compared with matrix biotite give temperature estimates of 670° and 635° C, using Thompson’s (1976) calibrations. Spear and Selverstone’s (1984) garnet and biotite isopleth diagram yields an intersection at 650° C and 5.8 kbar for the same data.

FIELD TRIP LOG WITH ELEVATIONS

Assemble in Old Toll Road parking lot. Set altimeter to 460 meters (1509 feet).

480 m, 1575 ft  STOP 1A: Franchestown Formation. Proceed on foot up the road to outcrops dipping toward road along the right side. This tough calc-silicate granulite typically displays blocky and rusty weathering. Fresh surfaces are dark gray, with specks of pyrite and pyrrhotite. The granulite is mainly composed of quartz, calcic plagioclase, actinolite, and iron-sulfides. Biotite, where present, is a very pale phlogopite, all the iron being taken up by the sulfides. The map pattern of the Franchestown, together with the equally distinctive Warner Formation, defines the general shape of the Monadnock syncline. Here the beds dip 44° northwest, on the upright limb of the southeast-facing, overturned syncline.

500 m, 1640 ft  STOP 1B: Warner Formation. Leave the road into the woods toward the west until you reach a trail. Follow trail uphill to outcrops. We will see both parts of the Warner: the lower, well bedded, clean-weathering calc-silicate granulite, and the upper, fine-grained quartz-biotite-plagioclase granulite, with smooth, purplish gray "salt-and-pepper" weathered surfaces. The contact with the overlying Littleton Formation is gradational over tens of meters as the proportion of schist increases. The Littleton continues from here to the summit of Monadnock.

Return as convenient to the road.

546 m, 1790 ft  At steep pitch, ledge of atypical, somewhat rusty Littleton Formation. Parker Trail and spur to right lead 750 feet to excellent exposure of lower Littleton and view southeast (optional stop).

576 m, 1890 ft  Glacially striated outcrop of Littleton along right side of road. Striae and grooves oriented S55E.
Figure 6. Metamorphic zones based on assemblages observed in thin sections (staurolite in hand sample for Zone II). Includes data from Chamberlain (1981). Plutons outlined for comparison to Fig. 2.
STOP 2: Lower Littleton Formation. Trail leaves road near private residence, crossing outcrops of the lower part of Littleton: quartz-biotite-muscovite-garnet-sillimanite schist, typical assemblage in metamorphic zone III. Quartzite layers are thin and widely spaced or absent. At Halfway House clearing (site of hotel from 1860 to 1954), schist is intruded by pegmatite. View of west side of Mt. Monadnock: bedding dips away from us; flat surfaces are joints.

Proceed through clearing on main trail. Where the White Arrow Trail starts up steeply over rocks, take Fairy Spring Trail to left, across brook and past 1855 Fassett's Mountain House site.

707 m, 2320 ft Fairy Spring. Widely spaced, thin quartzite layers.

719 m, 2360 ft Trail goes up over steep ledge: upright graded bed and coticule layer. A garnet in one sample of coticule from near Stop 8B was analyzed by electron microprobe. The core is 72.6% almandine, 14.8% spessartine, and the rim is 75.7% almandine and 12.5% spessartine.

STOP 3: Monte Rosa. Upper Littleton Formation, with good examples of sillimanite pseudomorphs after andalusite. Staurolite within the pseudomorphs may be detected with a hand lens. Beds and schistosity dip gently, near the crest of a dome-stage fold. Monte Rosa provides a 180° view, from Mt. Wachusett in Massachusetts (S25E) to Mt. Ascutney in Vermont (N25W). Low country to the west is underlain by Fitzwilliam Granite and Spaulding Tonalite. The summit of Gap Mt. (S30W) is made of Littleton and Silurian xenoliths (roof pendants?) surrounded by Spaulding. The village of Troy (S65W) lies in the southern extension of the Monadnock syncline, which parallels the ridge of Little Monadnock to the left of Troy. Berkshire-Green Mountains on the western skyline: Greylock at S80W and Stratton Mountain at N70W.

In the next outcrop area toward Monadnock, beyond woods (near big rock named "The Tooth"): large isoclinal folds, tens of feet in amplitude, close both NW and SE. Foliation parallels the axial planes: N39W, 41 NE.

Continue along Smith Summit Trail toward the summit. Quartzite beds, as well as pegmatite and aplite sills, become more abundant. Go past first trail to Black Precipice, which leads to base of cliff.

STOP 4: Upper Littleton Formation. Take second spur trail, which leads to the top of Black Precipice (MK-36, Fig. 5). Seven distinctive quartzite beds 10 to 30 cm thick, separated by schists of comparable thickness, are oriented N63W, 26 NE. We will see these layers again several times as we cross isoclinal folds on our way to the summit (Fig. 7). Here the beds are upright, although the seven quartzites themselves are usually not graded, and one must seek topping directions in the adjacent layers.

Retrace route to the Smith Summit Trail.

STOP 5: Minor Isoclinal Folds. Follow ledges SE to seven quartzites in two tight isoclinal folds (MK-1104) on the upright limb of a larger isoclinal syncline. Beds are attenuated on limbs and thickened in hinges - - classic example of similar folds (Fig. 8).

Return to Smith Summit Trail, where the seven quartzites cross the upper part of a large smooth outcrop area with well developed joint sets. Trail enters spruce woods; note a six-foot wide gap in outcrop oriented N45E up and down the slope. This marks the location of a mafic dike, which crosses the mountain NW of the summit (see Stop 7B). In the next outcrop west of the dike, the trail crosses the seven quartzites, and continues across upright graded beds. Watch for reversal in topping direction of graded beds as we cross a recumbent syncline which opens to the SE.
Figure 7. Comparison of measured sections of a distinctive set of seven quartzite beds in the upper part of the Littleton Formation from four different locations on Mount Monadnock. Station numbers (MK 27, etc.) are shown on Fig. 5.
THOMPSON

887 m, 2910 ft Seven quartzites upside down. Trail follows them up to the north. Look for grading in adjacent beds. Trail leaves the seven quartzites in a muddle of quartz veins and pegmatite.

893 m, 2930 ft Next flattish area has good graded upright beds, coticule lenses, and curious structures, which may be schist boudins between quartzite beds. Adjacent quartzite layers approach each other, often with a quartz knot in the boudin line. A boudin origin suggests unusual ductility contrast conditions between the schist and quartzite.

914 m, 3000 ft **STOP 6A: Large Isoclinal Anticline.** Here the Smith Summit Trail crosses the seven quartzites where they converge in a tight recumbent fold. The two limbs can be seen going off across the mountain to the north. From this vantage point the fold looks synformal, but tops indicate an anticline: the NNW limb is overturned and the NNE limb is upright. (The axial trace may be followed north over to the Dublin Trail near MK 55.)

**STOP 6B: Mafic Dike.** From the same point, leave the trail, descending slightly toward the south, 150 feet to the bottom of a cliff with a sharp cleft. The mafic dike we crossed earlier is exposed in this cleft. The dike is about six feet thick, nearly vertical, and cuts across all folds in the Littleton. It is cut in turn by tourmaline and pegmatite veins. Near the foot of the mountain SW of Monte Rosa, the dike is parallel to unfoliated granite dikes of similar thickness. The mafic dike is chilled against the granite, but the granite also contains mafic inclusions, suggesting a comagmatic relationship.

The dike is a fine-grained, weakly foliated, plagioclase-biotite-hornblende-quartz-ilmenite rock, with clots of biotite that give the weathered rock a spotted appearance. The dominance of biotite and plagioclase in modal analyses suggest microdiorite, or perhaps kersantitic lamprophyre, as an appropriate name for this rock. Some samples contain small corroded garnets (xenocrysts?). The plagioclase is An45. Ilmenite is commonly rimmed by sphene, and hornblende by biotite. The dike is clearly post-Acadian yet seems to have been somewhat metamorphosed. Could this be due to the "Permian disturbance" of southern New England?

Return to the Smith Summit Trail and continue toward the summit.

945 m, 3100 ft **STOP 7A: Dome-Stage Folds.** Nice exposures of open, symmetrical folds in area to left of trail. Late dome-stage folds on Monadnock have steep axial planes that are parallel to crenulation cleavage in schist beds. Fold axes have a wide spread of orientations because the surfaces which were folded had a wide range of orientations prior to dome-stage folding; here they plunge NW.

At this same elevation, cross the Smith Summit Trail and shrubby trace of the mafic dike so as to observe the huge fold exposed on a SW-facing cliff.

**STOP 7B: "Billings' fold".** This fold was pictured in the first edition (1942) of Marland Billings' *Structural Geology*. The fold lies structurally within the uppermost of three southeast-opening isoclinal synclines defined by the seven quartzites (fig, XX). The fold axis (N58E at 32°) is almost perpendicular to the cliff face, and the axial plane is oriented N16W, 36 NE. Note excellent andalusite pseudomorphs on foliation surfaces underfoot, some of which have been partially replaced by muscovite. These weather out as pits in the rock, in contrast to the raised lumps where sillimanite remains.

963 m, 3160 ft Continue to summit of Mt. Monadnock. Views of Dublin Pond (Warner Formation) and Skatutakee Mt. (Kinsman Granite in the Cardigan pluton) to the north. To the northeast, Pumppelly Ridge extends as the east limb of the Thoreau Bog syncline. At the summit, bedding dips NE. On Pumpelly Ridge bedding dips NW, defining an open, N-plunging syncline that deforms the isoclines we've seen so far. Crotched Mt. and Pack Monadnock can be seen in the middle ground to the east. Littleton Formation is exposed on North Pack (Duke, 1984) in what may be the next higher synclinal nappe above the Monadnock syncline. Thorndike Pond can be seen closer to the mountain in the east; layers of Kinsman extend from the Cardigan pluton south past Thorndike Pond toward the Coys Hill Granite in Massachusetts.

Return to vehicles via the White Arrow and Sidefoot Trails to the Halfway House site and thence down the old toll road. Additional stops will be made as time allows. (If time permits, a loop across Bald Rock
Figure 8. Schematic view of Seven Quartzites folded by nappe-stage folds on a surface dipping 30° toward viewer. Fold axes trend nearly perpendicular to this plane. Equal area diagram shows four beds and the axial plane from a smaller nappe-stage fold near MK-1104, with fold axis plunging N87°E at 26°.
and past the old graphite mine on the Cliff Walk Trail is worth the effort. Prior to forest fires in 1820, Bald Rock was the only large area of bare rock on the mountain. Return to Halfway House site via Do Drop or Hedgehog Trails.)

Note: In case of severely inclement weather, the trip will use vans to travel to where we can observe the Gilson Pond anticline, Beech Hill anticline, Chesham Pond fault, Derby Hill window, and other features in the Monadnock quadrangle.

REFERENCES CITED


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