Geology of the Penacook and Mount Kearsage Quadrangles, New Hampshire

Lyons, John B.

Follow this and additional works at: https://scholars.unh.edu/neigc_trips

Recommended Citation
https://scholars.unh.edu/neigc_trips/433

This Text is brought to you for free and open access by the New England Intercollegiate Geological Excursion Collection at University of New Hampshire Scholars' Repository. It has been accepted for inclusion in NEIGC Trips by an authorized administrator of University of New Hampshire Scholars' Repository. For more information, please contact nicole.hentz@unh.edu.
REGIONAL GEOLOGIC SETTING

In order to clarify what is now a rather confusing set of tectonic labels in northern New England, Zen (1983, and ms.) has proposed that the geologic terrane lying between the Monroe fault on the west and the Campbell Hill fault on the east be termed the Central Maine Terrane. This suggestion has been followed both in this article, and in the accompanying article by Eusden (this volume) on the Gilmanton quadrangle. The reasons are that a terrane is identifiable chiefly on the basis of the age of its basement, rather than that of its cover, and that it should have well demarked boundaries.

In the Central Maine Terrane the basement, exposed only in the 1.5 Ma Chain Lakes allochthon of northwestern Maine, is different petrographically and older geochronologically than the Grenvillian rocks west of the Connecticut River (Aleinikoff and Moench, 1985; Lyons, Aleinikoff and Zartman, 1986; Harrison, Aleinikoff and Compston, 1987). There are also scattered serpentinite pods along the Connecticut Valley, tracing northerly toward the Boil Mountain ophiolite and the extensive Hurricane Mountain melange in Maine. Just to the east is what is now generally regarded as the leading edge of a paleo-volcanic arc, the Bronson Hill anticlinorium. As proposed by Lyons, Boudette, and Aleinikoff (1982), and Zen (1983), the Connecticut Valley region is at least as likely to have been the site of the closure of Iapetus as the Baie Verte-Brompton Line, which lies entirely within Grenvillian basement.

Toward the southeast, structures of the cover rocks of the Central Maine Terrane are decapitated along the Campbell Hill fault by the pre-Early Ordovician Massabesic-Merrimack-Rye Terrane of Eusden, Bothner, and Hussey (1987), in which there have been several reports of 650 Ma ages (Besancon, Gaudette and Naylor, 1977; Aleinikoff, Zartman and Lyons, 1979; Kelly, Olszewski and Gaudette, 1980).

Within the Central Maine Terrane, from west to east, are the Bronson Hill anticlinorium, the Kearsarge-Central Maine synclinorium, the Central New Hampshire anticlinorium, and the Lebanon antiformal synclinorium. This excursion commences in the Central New Hampshire anticlinorium and progresses southwesterly into the Kearsarge-Central Maine synclinorium. The concurrent trip to the east, by Eusden (this volume) will mirror-image the stratigraphy and structure because vergence is westerly west of the anticlinorium and easterly east of the anticlinorium (Eusden, Bothner and Hussey, 1987).

Eusden (1988) and my current hypothesis concerning the major structural pattern relates, in part, to the Silurian-Early Devonian paleo-geology. During that time this region was a deeply-subsiding trough receiving an accumulation of more than 4 km. of westerly-derived Silurian clastics and volcanics, and at least 1 km. of easterly-derived Early Devonian flysch (Hatch, Moench and Lyons, 1983). The basement was evidently extending during this depositional cycle, but toward the end of the Siegenian Epoch underwent compression (the Acadian orogeny), and the trough was inverted into a "pop-up" structure (Butler, 1982) analogous to those in the Variscan range of western Europe, and the Caledonides of East Greenland and Scandinavia (see also Eusden, this guidebook).

An interesting, but occult, question is why there are such voluminous injections of sheet-like Acadian plutons (408 to 365 Ma) in this terrane. Their tabular forms (Nielsen and others, 1976) are understandable if some of them are synkinematic (Kinsman and Bethlehem suites) or late-kinematic (Spaulding suite), and are involved in nappe or thrust-nappe tectonics, as they are. But their timing is an enigma. Thermal calculations by Chamberlain and England (1985) show that tectonic thickening followed by recovery of the isotherms could produce conditions in the lower crust suitable for the generation of anatectic melts, but only 50 to 100 m.y. subsequent to tectonism. This scenario might possibly apply to the 365 Ma Concord suite, the 325 Ma Sebago and Effingham intrusives of eastern New Hampshire, or possibly the 275 Ma granite at Milford in southern New Hampshire, but surely not to the more abundant earlier intrusives. One is left with the intuitive thought that extension tectonics and crustal thinning may solve the problem, but among the thermal experts who have considered the matter, this theory likewise fails (C. P. Chamberlain, verbal communication), at least for the crustal lithosphere. Nevertheless, mantle-type initial Sr
isotopic ratios in Kinsman and Spaulding suites (Lyons and Livingston, 1977), imply that the upper mantle and/or asthenosphere are implicated in the generation of magmas and the upward advection of heat, possibly even concurrently with the Silurian extensional event. Extension in the mantle may have initiated pressure-release melting. The ascent and ponding of those melts in the lower crust may, in turn, have created the conditions necessary for the generation of the anatectic granitoids which constitute the New Hampshire Plutonic Series. Injection of sheets of these intrusions into the middle crust may then have created the requisite conditions for regional metamorphism.

METAMORPHISM

The same thermal problem exists in explaining the early Acadian advent of regional metamorphism, which has been dated in these environs by Barreiro and Eusden (1988) at 403-386 Ma, using Pb/U isotopic systematics on monazites from the metapelites. These ages overlap, quite closely, the isotopic ages determined on the Kinsman, Bethlehem, and Spaulding Intrusive Suites, suggesting a causal relationship between magmatism and regional metamorphism. That explanation has been advanced, for example, for metamorphism peripheral to the 325 Ma Sebago batholith of Maine and eastern New Hampshire (DeYoreo, Lux and Guidotti, in press). On the other hand, much of central New Hampshire lies within the sillimanite-muscovite zone of regional metamorphism, with rather abrupt gradations upward through sillimanite-muscovite-Kfs, and sillimanite-Kfs zones into granulite-facies sillimanite-garnet-Kfs-cordierite "hot spots" (cf., fig. 3). However, from the mapped geology and what has been inferred about the near-subsurface by gravity measurements, there is no close correlation of the "hot spots" with intrusives in central New Hampshire, so the cause of the overall metamorphic fabric cannot be said to be understood. Chamberlain (1987) has explained the hot spot pattern in southwestern New Hampshire in terms of repeated folding of isotherms during regional metamorphism, but Chamberlain and Rumble (1986) also look favorably on the advection of hot fluids as a possible cause for the "hot spots". The problem remains open.

In the Penacook and Mt. Kearsarge quadrangles the metamorphic pattern (fig. 3) is complex. Although the muscovite-sillimanite zone dominates, there are abrupt and irregular shifts to pockets of lower-grade, staurolite-muscovite rocks, and to higher-grade sillimanite-Kfs and granulite facies assemblages, in unpredictable patterns. The Al\(_2\)SiO\(_5\) isobar crosses both quadrangles in a northeasterly direction, with the higher-pressure (> 3.75kb) rocks to the northwest. The Kinsman Quartz Monzonite an early synkinematic intrusive underlying much of the Mt. Kearsarge quadrangle was subjected to regional metamorphism, but has been shown by Plank (1987) to have a relict mineralogy which even preserves, in its garnet-biotite pairs, relict temperatures in the 750-900°C range. These contrast with the 500-700°C temperatures in the wallrocks.

Chamberlain and Lyons (1983) identify at least three stages of Acadian metamorphism : 1) M1 andalusite metamorphism evidenced by sillimanite pseudomorphs after andalusite, and by flesky gneisses at contacts of intrusives such as the Cardigan pluton of Kinsman Quartz Monzonite; 2) M2 overprinting of M1, generally upgrade, and responsible for the isograd patterns on fig. 3, and 3); M3 local retrogradation. In at least some field situations, the retrogradation is ascribable to fluid circulation peripheral to Concord Granite plutons.

REFERENCES CITED

Barreiro, B. and Eusden, J. D., 1988, Monazite U-Pb age of schists and migmatites in the Kearsarge-Central Maine synclinorium. Geol. Soc. America Abstracts with Programs, v. 20, p. 4
GEOLOGIC MAP OF THE MT. KEARSARGE QUADRANGLE

LEGEND

SURFICIAL DEPOSITS
- Oal
  Swamp and glacial cover

IGNEOUS ROCKS
- Dcg
  Concord Granite
  (Crosses: pegmatite ± granite
- Dlk
  Spaulding Group
- Dkqm
  Kinsman Quartz Monzonite

METAMORPHIC ROCKS
- Dlk
  Littleton Formation
  Dlk: Upper or Kearsarge member
  Dll: Lower member
- Dll
  Madrid Formation
- Sm
  Smollett Falls Formation
- Ssf
  Sperry Mountain Formation
- Sru
  Upper Rangeley Formation
- Sri
  Lower Rangeley Formation

Fieldtrip Stops
- Village
- Highway
FIG. 2

GEOLOGIC MAP OF THE PENACOOK QUADRANGLE

LEGEND

SURFICIAL DEPOSITS

Qat
Swamp and glacial cover

IGNEOUS ROCKS

Dkg
Concord Granite
(Crosses: pegmatite = granite)

Dkgm
Spaulding Group

Dkqm
Kinsman Quartz Monzonite

METAMORPHIC ROCKS

Dlk
Littleton Formation
Dlk: Upper or Kearsarge member
Dll: Lower member

Sm
Madrid Formation

Ssf
Smalls Falls Formation

Sp
Perry Mountain Formation

Sru
Upper Rangeley Formation

Srl
Lower Rangeley Formation

Fieldtrip Stops

4
Village

Highway

°

Soapstone Quarry
Zen, E-An (ms) Tectonostratigraphic terranes in the Northern Appalachians: Their distribution, origin, and age : Evidence for their existence in Int. Geol. Congress Guidebook T-359

ITINERARY

ASSEMBLY POINT: Junction of Rte 3A and Rte 11 north of Franklin, on the west side of the Pemigewasset River.
Proceed westerly on Rte 11.

0.4 Left just beyond cemetery
0.8 Left again
1.3 Right up hill
1.8 STOP 1, on powerline

Nearer the road are outcrops of rusty-weathering gar-sill-bio-musc schists with some calc-silicate boudins, typical of the upper Rangeley Formation. Further along the schists become "lumpy", and then less rusty, well-bedded, and cotite-bearing. Numerous leucosomes, whether from anatectic melting or metamorphic segregation, become conspicuous. We have crossed into lower Rangeley Formation through a typical transition zone. In dealing with structural features of the bedrock, the long-established convention of calling
bedding S0, first foliation S1, second-generation foliation S2, folds of the first generation F1 etc. will be followed. Structures in these outcrops are chiefly S1, striking approximately N 60° E. There is also superposed folding, F3, deforming S1, and plunging easterly. Looking toward the northeast, across the Pemigewasset Valley are Sanbornton and Hersey Mountains in the Holderness quadrangle. These are held up by a lens of well-bedded and graded-bedded lower Rangeley deformed by well-developed westerly-plunging F3 folds. The trace of the Central New Hampshire anticlinorium coincides with the outcrop of the lower Rangeley. To the east, F1 structures verge easterly; to the west, westerly.

Turn around and return to Rte 11.

3.2 Left turn on Rte 11
3.3 Right on Lake Ave.
4.0 Right at T
4.5 STOP 2. Park on left side of road and walk back to outcrop.

Sharply, but thinly interbedded quartzite and metapelite typical of much of the lower Rangeley. It is beds such as these, but thicker, which underlie Sanbornton and Hersey Mountains to the northeast. Bedding strikes N 45° E, dips 64° SE, and is upward-facing toward the projected trace of the upper-lower Rangeley contact to the southeast.

Return to cars

4.6 Right turn
4.9 STOP 3 on powerline

"Lumpy" coticule-bearing outcrops, resembling some of those at Stop 1, but here graded bedding is also evident. Rocks such as those at Stop 2 are exposed to the northwest along the powerline. Grades nearest the road face southeasterly toward mapped upper Rangeley, but a little further along they face northwesterly, indicating, to no one's surprise, that the formation here, as elsewhere, is isoclinally folded and has S0 and S1 fabrics. Almost everywhere in this region the earlier fabrics are deformed by westerly to southwesterly-plunging F3 folds. The origin of the lumps is not totally understood. Mineralogically they consist of concentrations of gar+bio+sill+stau+plag+qtz, and may be pseudomorphs of staurolite porphyroblasts which have been destroyed by an upgrade stau+musc reaction.

5.1 Right turn on Rte 3A
5.3 Outcrops in road cut are somewhat rusty metapelite with abundant calc-silicate boudins, and are mapped as upper Rangeley. They would lie on the southeastern flank of the Central New Hampshire anticlinorium.

Proceed southerly past Franklin, where the Merrimack River begins at the confluence of the Pemigewasset and Winnipesaukee Rivers.

7.9 Right on Rte 127
12.6 Left on dirt road
14.3 STOP 4. Proceed northerly uphill for approximately 600 feet through a completely inverted sequence of Small Falls at the base of the hill, and Perry Mountain toward the top. Smalls Falls is extremely rusty-weathering, and consists of essentially two lithologies, one of these a fine-grained highly pyrrhotitic calc-silicate, the other a porous white qtz-plag-musc-phlog rock, with conspicuous graphite. Perry Mountain consists of sharply interbedded quartzite and metapelite in which (unlike the Littleton Formation) it is difficult to decipher facing directions. Formation boundaries striking approximately N 50° W trace from the Penacook into the Mount Kearsarge quadrangle over a distance of seven miles, and here verge strongly toward the southwest. At either end of this belt they resume a northeasterly trend, and westerly dips.
Throughout much of western New Hampshire, on both map and outcrop scale, there is late-stage sinistral 
deformation, of which this belt is apparently one manifestation. In eastern New Hampshire, however, the 
map pattern implies late-stage dextral deformation. We relate these deformations to the F3 or F4 folds. One 
of the Perry Mountain outcrops shows a minor F1 fold, trending N 50° W, with a sense-of-shear implying a 
downward facing (i.e., toward the Smalls Falls). Much more obvious is the fact that the S0-S1 structures, 
which were originally sub-horizontal, have been deformed by open northeasterly-trending F4 folds.

Turn cars around, and return to Rte 127

16.0 Left on Rte 127
17.0 Right (west) on Rte 4. Poorly exposed outcrops along Rte 4 for a few miles are Smalls Falls.
19.0 Left on West Salisbury Road, just past settlement of Salisbury Heights. DANGEROUS TURN.
21.0 Left at foot of hill
21.4 STOP 5 Park at bridge across Blackwater River.

Outcrops in the bed of the river are in the contact zone of the areally extensive, but thin (< 1 km) 
Blackwater pluton. The predominant rock type is a spotted weakly to moderately foliated biotite granodiorite 
or tonalite, with gradations to granite (Duke, 1978). Garnet is present in many of the biotite clots, and two-
mica granite is common, but some rocks contain hypersthene or pargasite, so the pluton is both 
peraluminous and metaluminous. To the south in Webster, this pluton crosscuts the Cardigan pluton, 
engulfing large xenoliths of Kinsman Quartz Monzonite. It is considered to be a part of the Spaulding 
Intrusive Suite (+ 392 Ma). The numerous xenoliths are chiefly calc-silicates which are refractory, whereas 
their original enclosing metapelitic host has been assimilated by the pluton. The host formation is an 
unusually rusty and calc-silicate rich facies ("Andover Member") of the Madrid Formation.

Retrace route

21.8 Left at fork in road
23.6 Left onto Rte 4. DANGEROUS INTERSECTION
25.5 Junction of Rtes 4 and 11. Outcrops here strongly resemble upper Rangeley, but Madrid outcrops occur to 
the west and Smalls Falls to the east. If the outcrops are Rangeley, there would have to be a folded thrust, 
with this a fenster exposing the lower plate. This is not an impossibility, but there is no field evidence to 
support this interpretation.

28.4 STOP 6 Well bedded and well-graded metaturbidite of the Littleton Formation, characteristic (but not 
absolutely diagnostic) of its upper member. A series of fairly tight upward-facing F4 folds can be deduced 
by walking across the top of the outcrop. Quartz vein at eastern end of outcrop is liberally laced with 
tourmaline, the boron for which may have been freed from the pelites themselves during progressive 
regional metamorphism.

29.1 Junction of Rte 11 and Rte 4A. Stay on 11
30.2 STOP 7 Garnetiferous phase of Kinsman Quartz Monzonite (408 ± 5 Ma) toward the eastern edge of 
Cardigan pluton. As is typical, there are large megacrysts of partly sericitized K-feldspar mantled by 
myrmekite, the garnet is rimmed or replaced by biotite, xenoliths foliation. Clark and Lyons (1986) have 
shown that Kinsman compositions range from tonalite to granite, that the K-feldspars cannot have 
crystallized from an initially homogeneous melt, that the garnet is igneous, that the plagioclase also has 
igneous characteristics, and that geochemically Kinsman compositions can be accounted for on the basis of 
varying mixtures of leucogranite, assimilated pelite (as displayed, for example, at Stop 5), and restite. Plank 
(1987) found that the 750-900° C garnet-biotite temperatures in the Cardigan Pluton are higher toward the 
 margins, just as Clark and Lyons (1986) report that the K-feldspars within the pluton are annealed to 
maximum microcline, whereas those in the wallrocks are orthoclase. The xenoliths here are probably of the
FIGURE 3. GEOLGY OF SUMMIT AREA, MT. KEARSARGE

POLES TO BEDDING
EQUAL AREA

FOLD AXES
EQUAL AREA

Bearing and Plunge
- F2
- F3
- F4

TRAIL

BEDDING
Strike and Dip
- Upright
- Overturned

SCALE IN FEET

67
Madrid Formation, buttressing the idea that Mount Kearsarge is essentially a folded recumbent syncline, opening westerly.

Proceed on Rte 11

31.2 Left off Rte 11
35.8 Right at T intersection
36.3 Left toward I-89
36.4 Left onto I-89 South
36.9 Public Rest Stop
43.7 Offramp from I-89. At end of ramp turn left to Warner on Rte 103
44.6 Right turn on Mill Street
44.8 **STOP 8** Park cars and walk to outcrops on south side of I-89.

Bio-plag-qtz granofels with zoned calc-silicate boudins in the Madrid Formation (originally, but unofficially, dubbed the Warner Formation). Note the distinctly rustier outcrops to the east, several apophyses from a granodioritic (Spaulding ?) pluton which underlies much of the area between Warner and the summit of Mt. Kearsarge, and the spheroidally-weathered, columnar-jointed diabase dikes. At least two generations of folds are present. Earlier F1 folds can be seen in these outcrops, but are best displayed on the flat I-89 median strip, which we cannot visit. Here the F1 folds have a bearing of 240°, and plunge 53 SW, in approximate conformity with steeply plunging folds on the north side of this outcrop, and with lineations visible on the underpass cuts. Later open folds F4(?) plunge gently toward N 20 W.

Turn cars around, and return up Mill Street.

45.0 Right turn
45.1 Left turn toward Rollins State Park
49.3 Kame on right at approximately 900-feet elevation. More extensive gravelly kames occur on both the east and west slopes of Mount Kearsarge at elevations of up to 1200 feet.
50.1 Entrance to Rollins State Park. Narrow climbing curvy road.
53.6 **STOP 9** Parking lot. Proceed up trail toward summit.

The summit area affords a superb display of graded-bedded Littleton Formation along and on either side of the trail, and unequivocal examples of several reversals in facing directions. This is the axial zone of the Kearsarge-Central Maine synclinorium. The Littleton Formation here is lithologically indistinguishable from the Seboomook Formation of western Maine Bedding and foliations dip steeply outward on both the eastern and western flanks of the mountain, and flatten toward the summit, giving the impression is of a northerly-plunging antiform. Mapping on a 1:50 foot scale reveals a more complex pattern. A series of east-northeasterly trending axial planes of early recumbent folds (S0 = S1) have fold hinges (F1 or F2) plunging northeasterly. Deforming these structures are a series of northwesterly-plunging (F3?) and northeasterly-plunging (F4) folds. Many of the folds are downward-facing. The major structure on Mt Kearsarge is related areally to the geology at Stop 4, and at the summit is apparently chiefly on the inverted limb of a westerly-verging refolded F1 nappe. The Cardigan and Weare plutons very nearly join north of Mount Kearsarge. They were probably originally part of the same plutonic sheet which has now been folded and eroded.

Return to Warner
62.3 Right turn in Warner onto Rte 103 toward Bradford.

63.7 Just beyond the I-89 underpass is an elegant outcrop of Kinsman displaying a folded aplite with axial planar cleavage, as well as garnet replacement by biotite as one approaches the aplite.

70.2 Intersection with Rte 114. Outcrop on right just before the stoplight is Lake Massasecum tonalite, a part of the post-tectonic Concord Intrusive Suite. On the lake shore, the tonalite has excellent flow banding.

71.3 **STOP 10** Roadcut west of the stoplight in Bradford village.

Garnetite pod and layer within the Kinsman. Relations on both sides of road show that the garnetite (garn-cord-bio-plag-qtz) is a restite from a slab of Littleton which is undergoing anatexis. The anatectic melt is diffusing into the pluton. Gravity studies indicate that the Cardigan pluton here is at its maximum preserved thickness of 2.5 km.

**END OF FIELD TRIP**

Best route to Keene from here is to return through Bradford to Rte 114. Turn right (southeast) on Rte 114, which, after 9 miles, intersects Rte 9. Turn right (southwest) on Rte 9, and stay on it to Keene.