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Duke, Edward F.

Duke, Genet I.

Lyons, John B.

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Edward F. Duke, Genet I. Duke, and John B. Lyons*
South Dakota School of Mines, Rapid City, South Dakota 57701-3995, and
*Department of Earth Sciences, Dartmouth College, Hanover, N. H. 03755

INTRODUCTION

The Peterborough and Concord quadrangles span a geologic terrane from the eastern portion of the Kearsarge-Central Maine synclinorium into the axial region of the Central New Hampshire anticlinorium where, in the southeastern part of each quadrangle, formations and structures are truncated by the Campbell Hill fault. Southeast of the fault is the Precambrian (?) (no younger than Early Ordovician) Massabesic Gneiss. Readers of this quidebook are referred to the accompanying article by Eusden on the Gilmanton quadrangle for a concise synthesis of the stratigraphy and structure of central and southern New Hampshire.

A description of the geology of the Peterborough quadrangle has previously been published by Greene (1970), and of the Concord quadrangle by Vernon (1971). Because both studies were undertaken before correlations had been established between the stratigraphy of western Maine and that of central New Hampshire (Hatch, Moench and Lyons, 1983) all of the metasedimentary rocks in both quadrangles were erroneously identified as members of the Littleton Formation. Remapping of the Peterborough quadrangle was undertaken by E. F. Duke (1984) as part of a Ph. D. study. The portion of the Concord quadrangle east of the Weare pluton of Kinsman Quartz Monzonite was remapped by G. I. Duke (1984) as part of an M.Sc. study. The western part of the Concord quadrangle and the eastern part of the adjacent Hillsboro quadrangle were remapped by Carl Hanson and J. B. Lyons (ms.) with the aid of funds from the Office of the N. H. State Geologist.

The mapping in the Concord quadrangle was greatly facilitated through the help of W. H. Vernon, who generously made his manuscript and outcrop location maps available to us. Greene's (1970) geologic map was also very useful, particularly as a guide to the plutons, which allowed a concentration of the mapping effort on the metasedimentary geology.

STRATIGRAPHIC CORRELATIONS

The Massabesic Gneiss (Figs. 1 and 2) belongs to a widespread terrane characterized by pink orthogneiss and gray migmatitic paragneiss, both with enclaves of calc-silicate , granofelsic, or schistose rocks; all these are cut by a variety of Devonian (?) granitoids. The Berwick Formation, where unmigmatized, is a purplish biotite granofels with discontinuous layers or pods of calc-silicate, and locally, beds of sulfidic schist.

Aside from the plutonic rocks immediately northwest of the Campbell Hill fault, metasedimentary rocks there belong to the Rangeley Formation. The lower Rangeley in this area is a thinly-laminated metapelite, with rare calc-silicate boudins, whereas the upper Rangeley is generally rusty-weathering, with relatively abundant calc-silicate boudins. There are, however, exceptions. In the Gilmanton quadrangle (Eusden, this guidebook) calc-silicate boudins are common in the lower Rangeley, but rare in the upper Rangeley. This is also true in the northeastern part of the Penacook quadrangle (Lyons, this guidebook).

Between the Pinnacle and Campbell Hill faults of the Concord quadrangle, G. I. Duke distinguishes a unit (Grasmere Member of the lower Rangeley) which is more coarsely laminated than the typical Rangeley, carries calc-silicate boudins, and is locally rusty. This corresponds to what, in the Concord quadrangle was mapped as the lowest Littleton (Vernon, 1971) and in the Peterborough quadrangle, the Souhegan Member of the Littleton Formation (Greene, 1970). These rocks are quite similar to Eusden's lower Rangeley. It is conceivable, but certainly not provable, that they could be correlative with the Lower Silurian Greenvale Cove Formation of northwestern Maine, which underlies the Rangeley.

The Perry Mountain Formation is recognizable because it has sharply interbedded metapelitic and quartzite beds (couplets up to 15 or 25 cm. on average), has relatively abundant coticule beds, and is only locally rusty-weathering. Throughout most of central New Hampshire it lacks calc-silicate boudins, but in eastern New Hampshire (Eusden, this volume) boudins are present. Parts of what was mapped by Greene (1970) as the Crotched Mountain Member of the Littleton Formation is partly Perry Mountain and partly Rangeley Formation. Nielson's (1981)

FIGURE 1.

GEOLOGIC MAP OF THE PETERBOROUGH QUADRANGLE, NEW HAMPSHIRE

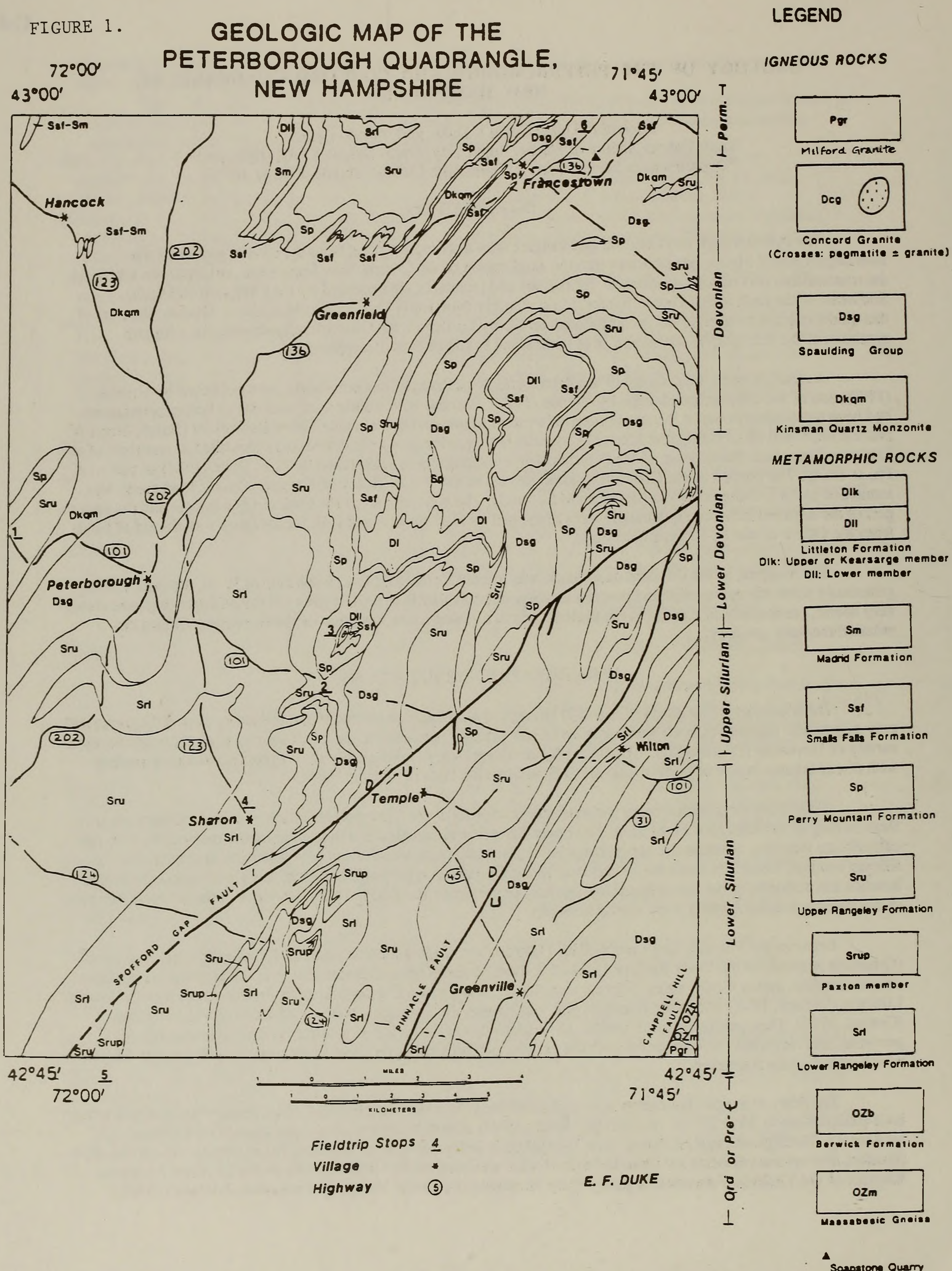
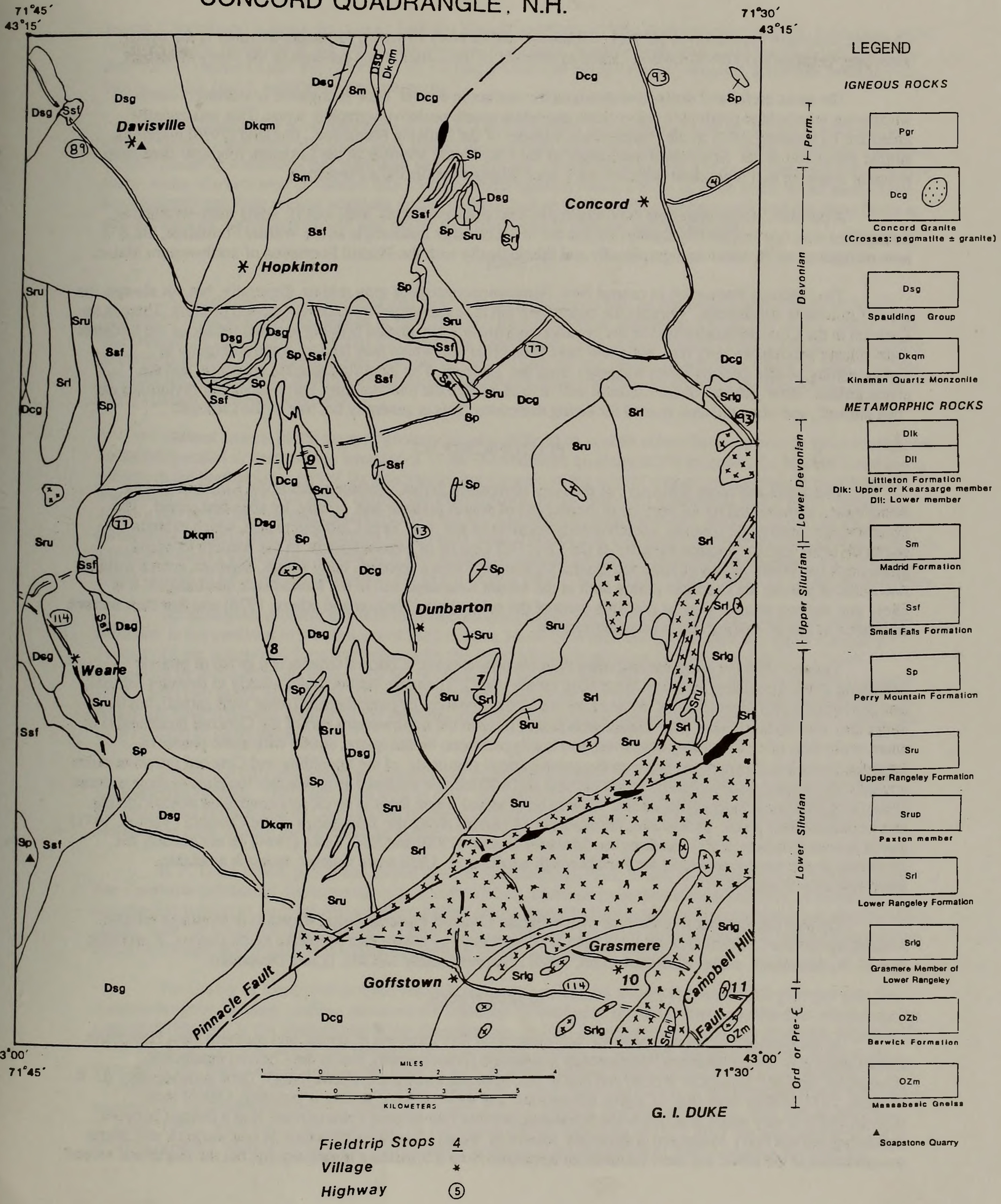


FIGURE 2. GEOLOGIC MAP OF THE CONCORD QUADRANGLE, N.H.



Crotched Mountain Formation is the Perry Mountain, but his rusty Crotched Mountain Member is the upper Rangeley. Englund's (1976) Roundtop Quartzite member of the Littleton is a sub-unit of the Perry Mountain.

The most useful and distinctive stratigraphic marker in central New Hampshire is a strongly rusty-weathering interbedded pyrrhotitic calc-silicate and white quartz-muscovite-graphite schist. This was initially identified by Greene (1970) as the Francestown Member of the Littleton Formation. Englund (1976) mapped a similar formation in the Holderness quadrangle as the Clay Brook Member of the Littleton. It is now clear from regional mapping that both these units are the Upper Silurian Smalls Falls Formation.

A purplish biotite granofels with distinctive calc-silicate boudins and, locally, some rusty-weathering metapelites was first mapped by Lyons (ms.) in the Mt. Kearsarge quadrangle as the Warner Formation, but it is now recognized as identical stratigraphically and lithologically with the Madrid Formation of northwestern Maine.

The Littleton Formation in central New Hampshire consists of gray schists. Generally, but not always, the lower Littleton is nondescript, whereas the upper Littleton is characterized by excellent graded bedding. There is no Littleton in the Concord quadrangle. In the Peterborough quadrangle, graded bedding is characteristic of the Littleton. Calc-silicate boudins are very rare, but a few have been observed, which may lead to some ambiguity in distinguishing boudin-bearing lower Rangeley from the Littleton. The local stratigraphic sequence, and the characteristic "slow grades" of the Littleton will help to resolve the uncertainties. Perry Mountain rhythmites are "fast graded", and often difficult to read for facing directions. This is generally not true of the Littleton.

PLUTONIC ROCKS

The oldest and most distinctive of the New Hampshire Series plutonic rocks is the Kinsman Quartz Monzonite, characterized by its very large megacrysts of potash feldspar and, locally, by abundant garnet. The Peterborough quadrangle contains a southeasterly segment of the very large Cardigan pluton, which extends southerly from here for another 40 miles as the Coys Hill Granite of Massachusetts. In the western Concord quadrangle the Weare pluton of Kinsman Quartz Monzonite forms a separate body which, however, comes within a few miles of joining the Cardigan pluton both in the Mount Kearsarge and in the Monadnock quadrangles. It is likely that the two plutons were at one time parts of the same sheet (Nielson and others, 1976) and that their current separation is due to folding and subsequent erosion.

Younger than the Kinsman and older than the post-tectonic Concord Granite is a group of plutons belonging to the Spaulding Intrusive Suite (Dsg on the maps). These are late-tectonic, weakly to strongly foliated, and petrographically diverse. Most of the rocks are biotite tonalites or granodiorites (some with garnet), but they range into two-mica granites. The Hopkington pluton (Dsg in the northwestern part of the Concord quadrangle) is more mafic than other Spaulding intrusives, and is a hypersthene-biotite quartz diorite with some phases of hornblende gabbro. Distinctions between the peraluminous granitoids of the Spaulding and Concord Intrusive suites are difficult to make, and are based largely on field and microscopic evidence as to whether the plutons show tectonic (Spaulding) or flow (Concord) foliations. As is to be expected where there is no closely controlled isotopic dating, interpretations may differ. This is true, for example, of plutons along the boundaries of the Concord (Vernon, 1971) and Hillsboro (Nielson, 1981) quadrangles. Similarly Greene (1970) and E. F. Duke (1984) do not classify the granitoids in the same way within the Peterborough quadrangle. Until more isotopic dating is available, uncertainties will remain.

Despite the fact that it is the type pluton for the Concord Plutonic Suite, efforts to determine a reliable isotopic age on the Concord Granite stock have been hampered by inheritance problems in the zircons. A probable age (J. N. Aleinikoff, verbal communication, 1986) is approximately 365 Ma. (Later Devonian).

SOAPSTONES

In the nineteenth century soapstone was quarried at four locations in central and southern New Hampshire. One of these is in the northeastern Peterborough quadrangle (Francestown), two in the Concord quadrangle (Davisville, and Mt. Misery in Weare) and one in the Penacook quadrangle (Canterbury). Their geochemistry (D. R. Nielson, 1974) differs from that of alpine ultramafics, and their geologic setting is puzzling. One of them (Davisville) is a very small xenolith in the Spaulding, another (the largest; Francestown) is at a contact between Spaulding and the Perry Mountain, a third (Mt. Misery in Weare) has Perry Mountain as one wallrock and quartz monzodiorite at the other; the latter could be an apophysis from a Spaulding pluton nearby, but the fourth and second largest (Canterbury) is along the contact between Madrid and Smalls Falls. Bulk geochemistry (D. R.Nielson, 1974) implies that the protoliths of the soapstones were mafic gabbros, possibly with ultramafic layers. Mineralogically they consist chiefly of talc and chlorite, with varying amounts of hornblende or pargasite, actinolite, anthophyllite, biotite, olivine (rare), pyrrrhotite and magnetite.

The mechanism of emplacement is occult. The Canterbury occurrence as well as density considerations make it unlikely that the mafic rocks were floated into position during the emplacement of the Spaulding intrusives. A more plausible scenario is that there may be a series of pre- or syn-metamorphic and as-yet-unmapped duplex-type faults, some of which step downward into sheets of mafic igneous rocks. Blocks of these mafic rocks would have been dragged into their present positions during faulting, before the Spaulding plutons exploited the same faults as passageways for emplacement, and also before the completion of regional metamorphism.

FAULTS

Another clue to the hypothesis that there may be unmappped pre- or syn-metamorphic faults in New Hampshire is suggested by the results of the COCORP traverse in New Hampshire (Ando and others, 1984). The line crossed the region of the Concord and Penacook quadrangles close to their mutual contact, and shows a number of strongly defined reflectors at depth, stepping downward easterly in a pattern analogous to those of fault duplexes. Whether the reflectors are all faults, or all intrusive sheets,or some combination thereof (regarded by us as most likely) cannot be proven at present.

Several aspects of the mapped geology are also difficult to explain unless these are pre- or syn-metamorphic faults sub-parallel to stratigraphic boundaries. In the Peterborough quadrangle, for example, the Madrid formation is present in the northwestern part of the quadrangle, but throughout the central area of the quadrangle the Littleton Formation is in contact with a thin strip of the Francestown. In the Hillsboro quadrangle to the north (Nielson, 1981) a belt of the Madrid thins southerly from the Mt. Kearsarge quadrangle over a distance of four miles, is missing for the next five, and is present for the next 10 as it passes into the northwestern Peterborough quadrangle A Littleton-Smalls Falls contact is present in the Gilmanton quadrangle (see Eusden, this guidebook) , but there the lower contact of the Littleton contains clasts of the Smalls Falls ("Wild Goose Grits"), and may be an unconformity.

An analogous problem exists in the Concord quadrangle, but involves different stratigraphic units, so the difficulty is not confined to the contacts of the Littleton. North of Weare, the Smalls Fall and upper Rangeley Formations are juxtaposed for a few miles, with the Perry Mountain missing. North of this, across a break interposed by intrusives, the same units are in contact for another mile, but a wedge of Perry Mountain is present for the next two miles, and then is missing for another mile before this contact is eliminated by an intrusive. We do not yet have sufficient control on the premetamorphic faults to show their distributions accurately on maps, nor to draw them in cross sections.

Faults of a different nature are displayed in a series of silicified zones traversing the Peterborough and Concord quadrangles. These are, from west to east , the Spofford Gap, Pinnacle, and Campbell Hill faults, and an unnamed fault in the northern Concord and southern Penacook quadrangles. The Campbell Hill fault joins the Norumbega fault toward the northeast in Maine.

E. F. Duke (1984, p. 72) has shown that the Spofford Gap fault, which is a splay off the Pinnacle fault, has a probable left-lateral displacement of four miles (6 km), based on palinspastic reconstruction of offset contacts, and the distribution of fault splays and kinks. Offset on the Pinnacle fault is less well constrained, but may be left-lateral, with the west-side-down motion. Juxtaposition of Silurian-Devonian rocks on the west against Precambrian rocks on the east also argues west-side-down motion along the Campbell Hill fault.

The timing of these post-tectonic faults is somewhat uncertain, except that it must be younger than the Acadian orogeny, because Acadian structures are truncated by the faults, and older than a syenite dike which cuts the Campbell Hill fault in the northeastern Milford quadrangle, and has a fission-track zircon age of160 Ma (Aleinikoff, 1978, pp. 116-117). The timing can probably be more closely restricted, however, because there are numerous pegmatites and granites in or close to the trace of the Campbell Hill and Pinnacle faults which are probable "stitching" plutons. One of these, the Barrington pluton or Center Strafford pluton of the Gilmanton and Wolfeboro quadrangles has been interpreted as a stitching pluton, has S-C fabrics, and also a monazite Pb/Uage of 364 Ma. (Eusden, 1988). Very likely, initial motion on the Campbell Hill fault was slightly after the termination of the Acadian orogeny. Motion on the fault was probably active over a long period of time, however, because the

Permian (275 Ma; Aleinikoff, 1978) granite at Milford in southern New Hampshire is another such stitching pluton, strung out along the trace of the Campbell Hill fault. As pointed out by Don Wise (verbal communication, 1988) some of silicified zones along these faults have open-space vugs and evidence of repeated opening and infilling. These features are very unlikely unless the rocks are in the brittle zone (i.e. at a shallow level), so some of the silicification and faulting may be as young as Early Mesozoic age,but prior to 160 Ma age of the syenite dike which cuts the Campbell Hill fault.

METAMORPHISM

Within the Peterborough quadrangle, all the metasediments are in the sillimanite-muscovite subfacies of the amphibolite facies, and lie east of the Al_2SiO_5 isobar. The rocks are retrograded locally and the single observed sample containing staurolite (E. F. Duke, 1984) is from a retrograded metapelite. Calc-silicate rocks contain varying assemblages of the minerals grosssularite- diopside-actinolite-zoisite-biotite or phlogopite- K feldspar- plagioclase-quartz - carbonate.

The Concord quadrangle, by contrast, shows a good example of a regional "hot spot" both mineralogically, and in the biotite-garnet core and rim isotherm pattern (Fig. 3; G. I. Duke, 1984). Pressures as calculated by the garnet-biotite-Al_2SiO_5 -quartz geobarometer range from 3.4 to 4.2 kb.in 6 samples (Duke, op. cit). Their average (3.8 kb) is close to that to be anticipated for an area lying east of the Al_2SiO_5 isobar . The cause of the hot spot cannot be directly related to any known feature of the mapped geology.

REFERENCES CITED

Aleinikoff, J. N., 1978, Structure, petrology, and U-Th-Pb geochronology in the Milford (15') quadrangle, New Hampshire ; Ph. D. thesis,Dartmouth College, 247 p.

Ando, C. J. and 11 others, 1984, Crustal profile of a mountain belt: COCORP deep seismic-reflection profiling in the New England Appalachians, and implications for architecture of convergent mountain chains, Bull. A. A. P. G., v. 68, p. 819-837

Duke, E. F., 1984, Part 1. Stratigraphy, structure, and petrology of the Peterborough quadrangle, New Hampshire and Part 2. Graphite textural and isotopic variations in plutonic rocks, south-central New Hampshire, Ph.D. thesis, Dartmouth College, 168 p.

Duke, G. I., 1984, Structure and petrology of the eastern Concord quadrangle, New Hampshire, M. Sc. thesis, Dartmouth College, 110 p.

Englund, E. J., 1976, The bedrock geology of the Holderness quadrangle, New Hampshire , N.H. Dept. Resources and Economic Development Bull. No. 7, 90 pp.

Eusden, J. D., 1988, The bedrock geology of the Gilmanton 15 minute quadrangle, N. H. , Ph.D. thesis, Dartmouth College, 245 pp.

Greene, R. C., 1970, The geology of the Peterborough quadrangle, New Hampshire, N. H. Dept. Resources and Economic Development Bull. No. 4, 88 pp.

Hatch, N. L., Moench, R. H. and Lyons, J. B., 1983, Silurian-Lower Devonian stratigraphy of eastern and south-central New Hampshire: extensions from Western Maine, Am. Jour. Sci., v. 283, p. 739-761

Moench, R. H., Hafner-Douglass, K., Jahrling, C. E. and Pyke, A. R., 1987, Metamorphic stratigraphy of the classic Littleton area, New Hampshire, in Roy, D. C. ed., Northeastern Section of the Geological Society of America, Centennial Field Guide Volume 5, p. 247-256

Nielson, D. L., 1981, The bedrock geology of the Hillsboro quasdrangle, New Hampshire, N. H. Dept. Resources and Economic Development Bull. No. 8, 76 p.

Nielson, D. L., Clark, R. G., Lyons, J. B. , Englund, E. J. and Borns, D. J., 1976, Gravity models and mode of emplacement of the New Hampshire Plutonic Series, in Lyons, P. C. and Brownlow, A. H., Studies in New England Geology, Geol. Soc. America Memoir 146, p. 301-318

Nielson, D. R., 1974, Metamorphic diffusion in New Hampshire: Soapstone bodies and flecky gneisses, Ph. D. thesis, Dartmouth College, 262 p.

Peterson, V. L., 1984, Structure and stratigraphy in the Ashburnham-Ashby area, north-central Massachusetts, Contribution No. 47, Dept. of Geology and Geography, Univ. of Massachusetts, 182 p.

Vernon, W. W., 1971, Geology of the Concord quadrangle, in Lyons, J. B. and Stewart, G. W., Guidebook for field trips in central New Hampshire and contiguous areas, New Eng. Intercoll. Geol. Conf., p. 118-125

ITINERARY

Field trip commences in Keene, and prodeeds easterly for 12 miles on Rte 101 through Marlborough and Dublin to the intersection of Rte 137 with Rte 101. This is mile 0.

Road Log (in Miles)

0.0 Junction of Rte. 137 and 101. Proceed easterly on 101.

1.6 STOP 1 Excellent exposures of the rusty-weathering upper unit of the Rangeley at the boundary between the Monadnock and Peterborough quadrangles. The unit dips steeply west-northwest and consists of a variety of massive, laminated, bedded, or banded schists and granofelses with abundant calc-silicate beds and pods.

4.5 Junction with Rte. 202. Stay on 101.

8.6 CAUTION. Left turn into Miller State Park at the top of a long hill. Park cars, and walk to highway.

STOP 2. Rocks along the highway are interpreted as representing the uppermost portion of the Rangeley Formation at or near its transition into the overlying Perry Mountain Formation. These strata include a heterogeneous succession of northwesterly-dipping , variably rusty-weathering rocks with locally abundant calc-silicate pods or boudins Dikes and sills of pegmatite-aplite and biotite-muscovite granitoids are common, probably related to the Devonian Spaulding (?) Whitcomb Peak granitic pluton one-half mile to the east. Isoclinal F1(?) of F2(?) folds with west-over-east movement are common here, as are later open F4(?) folds with associated crenulation cleavage. F4 axes plunge north-northwest; F1-F2 axes northwest or southwest.

Not to be seen on this excursion, but of interest from the perspective of the regional geology are some analyzed rhyodacitic metatuffs in the upper Rangeley of the northeastern Peterborough quadrangle (E. F.Duke, 1984, p. 18-19). Moench et al (1987) report similar extensive felsic tuffs in the Rangeley and Perry Mountain Formations of the Piermont allochthon in western New Hampshire.

Walk up the hill to outcrops in the clifs on the west side of the road, which are in the Perry Mountain formation. There are about 120 m. of resistant interstratified quartzite and pelite in "fast-graded" beds 1/2 to 3 inches (1 to 8 cm.) in average thickness, weathering to gray nonrusty outcrops, and facing upward. These are best seen about 1/2 mile from the park entrance at the first switchback, but parking there is difficult. Calc-silicate pods are not conspicuous but occur sporadically throughout this portion of the Perry Mountain. The bedding here dips gently northwesterly, but with many undulations.

Return to cars and drive to the top of Pack Monadnock Mountain.

10.1 Summit parking area. Space is limited

STOP 3 About two-thirds of the way to the summit the Perry Mountain gives way to rusty outcrops of the Smalls Falls. Unlike the Smalls Falls to the west and north these rocks are not calcareous, but do resemble much of the Smalls Falls of the type locality in Maine, as well as similar rocks in Massachusetts which have been mapped as the Smalls Falls. Though somewhat similar to Rangeley lithologies at the base of the mountain, these rocks lack the calc-silicate pods which are typical there, and also on the basis of graded bedding in the Perry Mountain lie stratigraphically above, rather than below that formation. The Smalls Falls is interpreted to have undergone a facies change from metapelites on the southeast to calcareous lithologies on the northwest.

Immediately north of the parking lot and west of the small shelter is what appears to be inverted, thinly-bedded Perry Mountain facing downward toward the rusty Smalls Falls.

Walk north-northwest from the parking lot along the Wapack Trail.The path follows rusty schists for several hundred feet and then crosses into massive non-rusty outcrops across a sharp contact. Along western slopes of this open ridge are good exposures of garnetiferous "coticule" lenses, interpreted to be unis of a highly attenuated infold of Lower Devonian Littleton Formation as exposed on North Pack Monadnock Mountain. The complex outcrop pattern here is believed to be result primarily from interference of north-northwest trending F1 folds by north-northeast-trending F4 folds.

Retrace route to entrance of Miller State Park

11.6 Right turn onto Rte. 101 toward Peterborough

14.3 Left turn on Rte. 123 toward Sharon. DANGEROUS TURN

17.6 Park cars off the highway. Shoulder is very narrow here, so be careful

STOP 4. Several outcrops in the woods east of the road display features typical of the lower Rangeley. The rocks have a laminated or thinly-bedded aspect caused by compositional layering. Although only a few small calc-silicate beds or lenses occur at this location, elsewhere conspicuous calc-silicate pods may measure several meters in plan view. The mineralogy here consists of quartz, plagioclase, biotite and muscovite with subordinate sillimanite, and locally abundant quartz-feldspar streaks and lenses. Intruding the metasediments are sheets of foliated Spaulding (?) intrusives.

The massive to thinly-laminated character of the lower Rangeley distinguishes it from either the more uniformly and somewhat thicker-bedded Perry Mountain, or the even more thickly and variably graded-bedded Littleton. A minimum estimate for the exposed thickness of the lower Rangeley in the Peterborough quadrangle is 400 meters; however, the lower contact has not been exposed.

Proceed southerly on Rte. 123.

17.8 Sharon

19.2 Right on second crossroad.

20.2 Right on Rte. 124.

23.3 Left on Prescott Road, just beyond Millipore Filter factory on left..

25.6 CAUTION. Left at Cathedral of the Pines sign.

27.0 Bear right at T.

27.5 Left on Old Ipswich Road.

28.9 Left on Perry Road.

30. Right on unmarked road. This is North Road, a half-mile north of the hamlet of East Rindge in the Ashburnham (1:24,000) quadrangle.

30.5 Park at large gravel pit on the right.

STOP 5. Small road cut near the base of a utility pole. Despite its inconspicuous nature, this is a significant outcrop for tying some of the Massachusettts formations into those of New Hampshire. The distinctive banded calc-silicate granofels provides the best outcrop of Paxton-type lithologies in the area. Stratigraphically the Paxton apparently lies just above the transition from the lower (non-rusty) into the upper (rusty) member of the Rangeley. Two miles to the east, Peterson (1984) maps a similar Paxton granofels into the Srup unit of Duke's (1984) Peterborough quadrangle. This would establish, as well as any other available evidence, an Early Silurian age for the Paxton.

This member of the Paxton is characterized by non-rusty light-hued outcrops composed of contrasting 1-5 cm. bands of purplish quartz-plagioclase-biotite granofels and light green or pink calc-silicate granofels. The calcareous belt is only 6 meters thick where it is exposed in the Peterborough quadrangle. Despite this apparent tie-in of the Rangeley and Paxton Formations it is only fair to note that Duke's (1984) lower Rangeley east of here is mapped as Littleton by Peterson (1984) in the Ashburnham-Ashby quadrangles.

Turn around and retrace route through Sharon toward Peterborough.

46.7 Dangerous Intersection. Cross Rte 101, continuing on Rte 123

49.2 Junction of Rtes 123, 202, and 136. Sharp right turn on Rte 136

55.2 Greenfield

59.7 Francestown . Right turn on Rte 136

61.3 Left turn on Bible Hill Road

62.3 STOP 6 Type outcrops of the Francestown Member of the Littleton Formation of Greene (1970); (= Smalls Falls Formation). The Smalls Falls Formation in the Peterborough quadrangle is a thin unit that crops out in several structural belts. In the northern portion of the quadrangle it consists chiefly of sulfidic calc-silicate granofels containing varying proportions of quartz, phlogopite, microcline, calcic plagioclase, actinolite, diopside, zoisite, sphene and pyrrhotite. These are interstratified with white graphite-quartz-microcline-muscovite-phlogopite schist. Some of the lithologic members in the Fitch Formation of the Lovewell Mountain quadrangle to the northwest greatly resemble the Smalls Falls, and a correlation is likely. Bedding parallels foliation here and averages N.31 E, 26 NW. The Smalls Falls Formation in the Peterborough quadrangle is very thin, perhaps only 10-50 m. thick in some places. The outcrop width here is misleading, because at these outcrops the Smalls Falls is thought to lie in a structural keel.

Turn around and head toward Rte 136

63.1 STOP 6A (?) Francestown Soapstone Quarry As described by D. R. Nielson (1974) the Francestown soapstone is primarily a tremolite-talc- phlogopite-chlorite rock and thus, unlike the other soapstone bodies of central New Hampshire the protolith may not originally have been a mafic igneous rock but rather, as proposed by Greene (1970, p.58), an argillaceous dolomite. The alternative of a metasomatized mafic rock cannot be ruled out, because portions of the soapstone contain remnant hornblende or actinolite with a lamellar texture, which suggests the uralitization of original augite. The northeast wall of the quarry is the northwesterly-dipping Perry Mountain Formation, and the southeast wall is a biotite-rich blackwall. Further southeast are Spaulding granitoids.

63.5 Left onto Rte. 136.

69.3 Junction with Rte. 77. Continue southerly on Rtes. 136 and 77.

69.6 Left onto Rte 13 in New Boston

76.0 Right on Rtes. 13 and 114 toward Goffstown

76.3 Left on Rte. 13 toward Dunbarton

81.8 Left toward Clough State Park

83.1 Left toward Everett dam

84.7 Everett Dam. Park cars

STOP 7 Perry Mountain Formation, well exposed on the northeast bank of the dam, and particularly in the spillways, showing typical "fast grades" , but also, in the spillways, some unusually rusty outcrops of uncertain affinity (Rangeley(?), Perry Mouintain(?), or Smalls Falls (?)). The structure and lithology in the spillway outcrops is complex, with recumbent folds both in the Perry Mountain and in some of the sheets of Spaulding (?) granitoids intruding it. In the granites a sub-horizontal axial plane cleavage has been developed, indicating that they are partly syntectonic. Interestingly, fold axes directions in the recumbent folds vary by as much as 90 degrees. The Kuncanowet Hills to the east have as many as 10 repetitions of the Rangeley-Perry Mountain contact.

Raymond Cliffs to the west across the dam is the well-exposed eastern basal contact between the Kinsman Quartz Monzonite of the Weare pluton and the Perry Mountain. Here you look under this sheet-like pluton at its semi-concordant floor of Perry Mountain.

Retrace trip toward Rte. 13.

86,7 Right at T.

88.0 Left on Rte. 13.

88.3 Right at Dunbarton common on Robert Rogers Road.

89.2 Right on dirt road (a.k.a. Leg Ache Hill Road).

90.1 Find a spot to park your car off the road, and walk down the hill to the powerline.

STOP 8 Lower and upper Rangeley outcrops. The lower Rangeley outcrops south of the road are characteristically thinly laminated (0.1 to 2 cm. average) gray metapelite with sillimanite, biotite, garnet, plagioclase and quartz. With the exception of the Grasmere member (q.v.) there are no calc-silicates in the lower Rangeley of the Concord quadrangle. As is characteristic of much of the lower Rangeley in central New Hampshire, migmatization appears to be incipient, with the development of anatectic (?) quartz-feldspar pods and veinlets. One sample from this series of outcrops has the assemblage qtz-sill-bio-gar-cord-plag-K-feldspar, which places it in the granulite facies. It lies in the center of a "hot spot" (Fig. 3) with a gar-bio core temperature of 714°-729° C, and a pressure of 3.8 kb (G. I. Duke, 1984).

The upper Rangeley outcrops north of the road are the characteristic rusty-weathering qtz-bio-plag schist with calc-silicate boudins. Muscovite in some of these rocks is likely to be retrogressive.

Return toward Dunbarton.

91.0 Left turn.

92.3 Right on Rte 13.

95.5 Page's Corner. Left (westerly) on Rte. 77.

96.6 Park cars.

STOP 9. Upper Rangeley formation. Lithic types characteristic of the upper Rangeley occur here.The rock is characteristically a qtz-bio-plag-sill schist with lesser amounts of gar-musc-K fs and pyrrhotite. Upper Rangeley is estimated to be a minimum of 700 km. thick in the Concord quadrangle. Sheets of foliated Spaulding (?) granodiorite cut the outcrop, as does a camptonite dike (50% carbonate replacing augite, 40% plagioclase, kaersutite, and accessories).

Reverse direction on Rte. 77.

97.7 Right on Rte. 13.

101.3 Dunbarton

105.5 Left on Page Hill Road

107.9 Left at fork. Locust Hill Road

108.7 Left at fork, and through the hamlet of Grasmere on Goffstown Back Road

109.2 Left at fork.

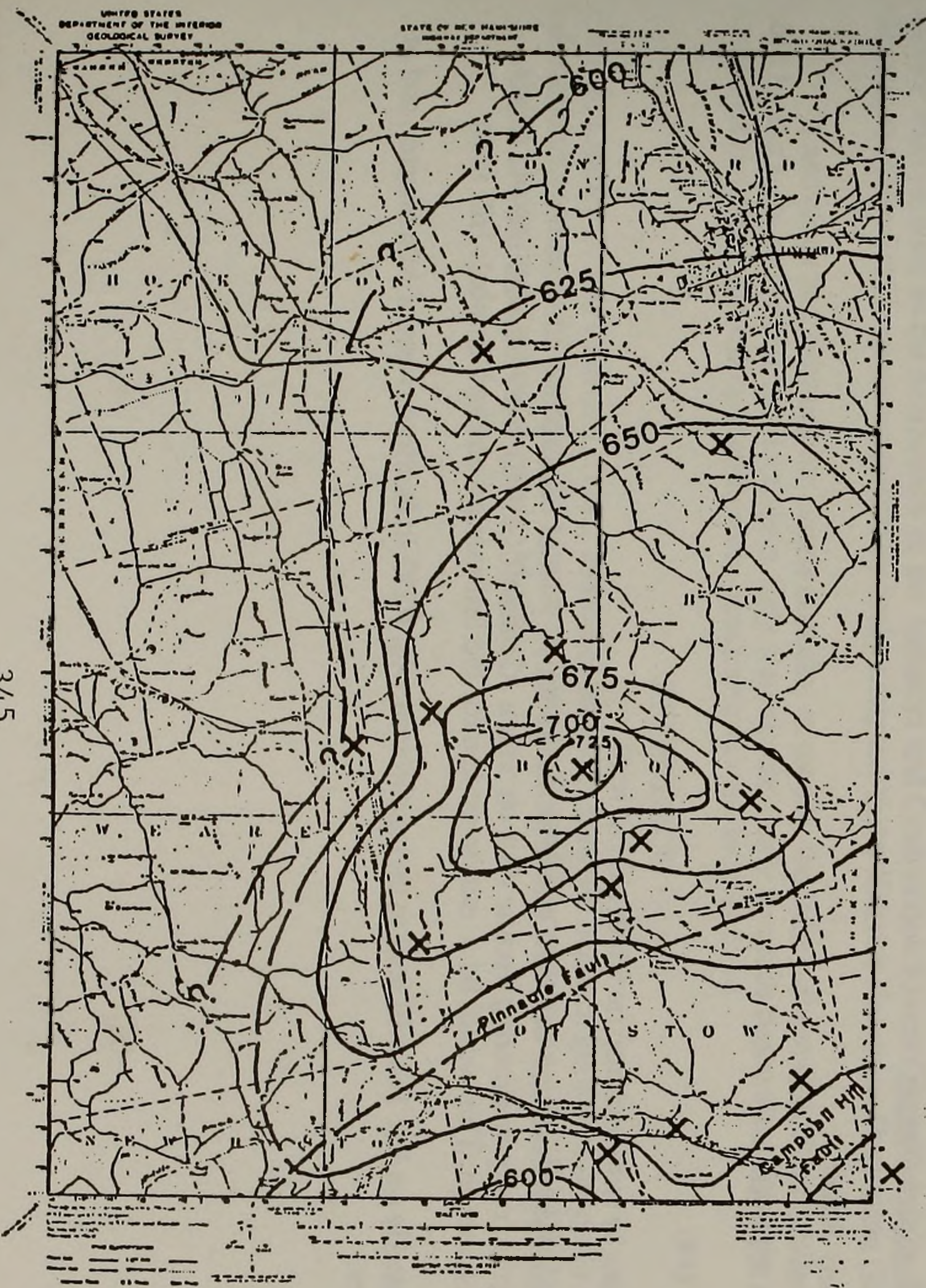
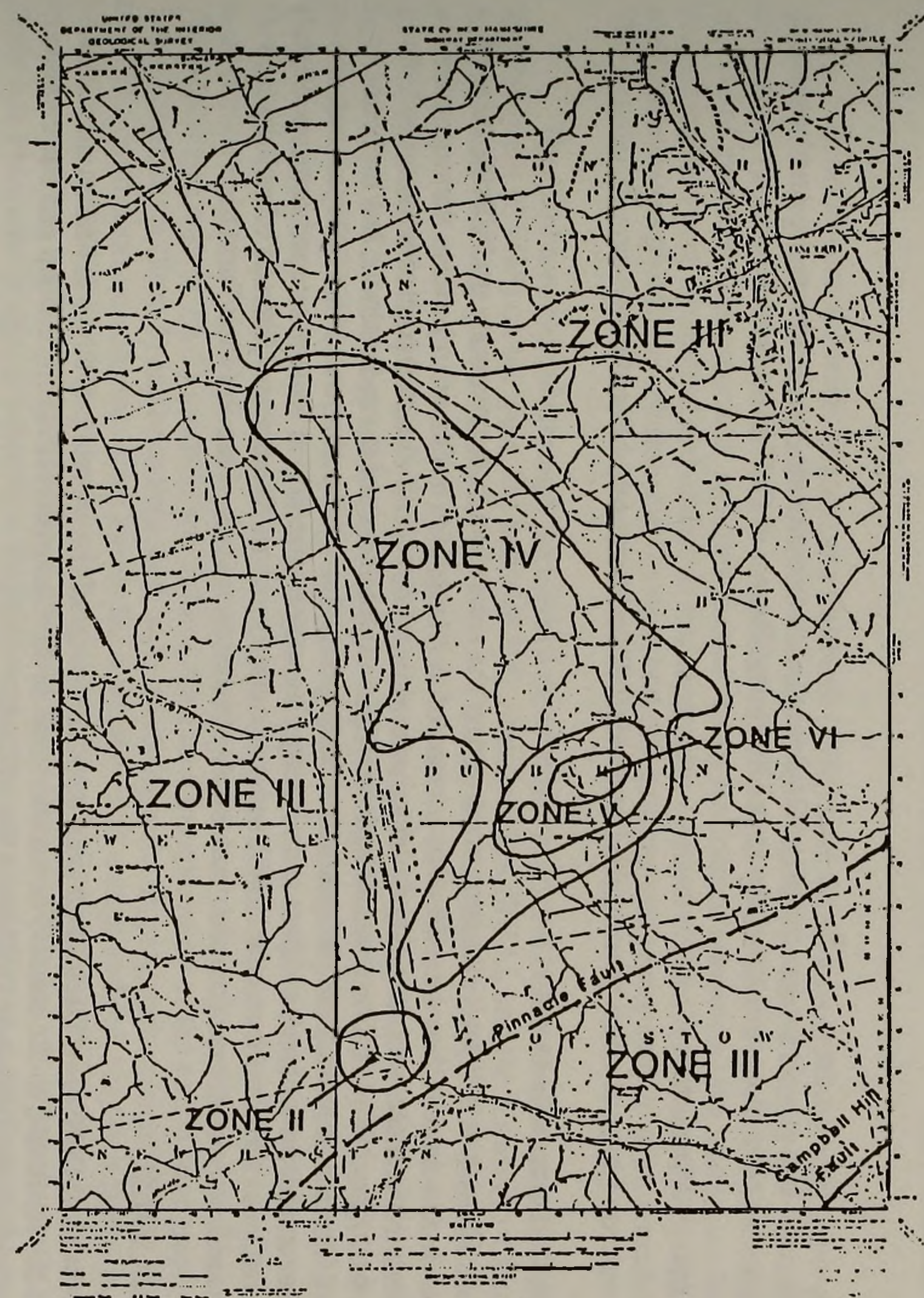


Figure 3: Isotherm map of garnet core temperatures (°C) eastern Concord Quadrangle



Isograd map of the eastern Concord Quadrangle

109.6 Right at Diamond Road, and park cars at powerline. Note thevery rusty outcrop on Goffstown Back Road, just prior to making this turn.

STOP 10 More thickly laminated metapelite than is characteristic of the lower Rangeley. This feature, the interbedding with very rusty metapelite, and the occurrence of calc-silicate boudins in these rocks led G. I. Duke to separate them from the lower Rangeley as the "Grasmere member". Prior to this, Greene (1970) had labelled them "Souhegan Member of the Littleton Formation", but our current consensus if that they are a facies of the lower Rangeley. Outcrops here are warped by F4 (?) folds bearing 210, and plunging 20 SW.

Continue along Diamond Road.

109.9 Right at T

110.2 Tightly folded sill-bio-gar-plag-musc-qtz-plag "Grasmere",with calc-silicate boudins. Note the development of leucosomes, which is characteristic of the lower Rangeley. Return to Goffstown Back Road.

110.9 Right turn toward Manchester

112.9 Pegmatite outcrop (typical when nearing the Campbell Hill fault) recently blasted away

113.1 Park cars in field near radio tower.

STOP 11. Campbell Hill fault outcrops north across the road show quartz veining and silicification of pegmatite. In the woods toward the west are screens of the Rangeley (or Grasmere) within the pegmatite, just as there are in the area undergoing development north of the recently blasted pegmatite outcrop.

Massabesic Gneiss crops out along low ledges slightly north of the radio tower, but far better outcrops of the Massabesic (both paragneiss and orthogneiss) have been uncovered in a field just east of Greatstone condominiums, where there is a recently cleaned-off glacially or stream-scoured outcrop. Slightly further east , near the entrance to the Holy Trinity cemetary north of the road are outcrops of well-layered biotite granofels, calc-silicate granofels and interlayered rusty schists of the Berwick Formation .

END OF FIELD TRIP

Followed toward the east, Goffstown Back Road intersects I-293 west of the Merrimack River in Manchester. I-293 joins I-93 both to the north and to the south. For another look at the Campbell Hill fault, the trip can be continued as follows, by proceeding easterly along Goffstown Back Road.

114.6 Right on Montgomery Street

115.0 Right on Kelley Street

116.2 Right on Rte. 114 A.

118.7 Left on Rte. 114.

119.1 Park car . Cross to rusty outcrop on south side of road.

STOP 11A. Pegmatite and silicified zone, similar to those west of Greatstone condominiums. These are cut by a pyritic rusty-weathering syenite dike on whicn Aleinikoff (1978) determined a 160 Ma fission-track age on zircon. This would be a minimum age for the last motion on the Campbell Hill fault.

Continuing southeasterly on Rte 114 will lead to an intersection with I-293 in Bedford, west of Manchester, and at the Merrimack River.