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SILURIAN AND DEVONIAN ROCKS IN THE ALTON AND BERWICK QUADRANGLES NEW HAMPSHIRE AND MAINE

J.D. Eusden, W.A. Bothner, A.M. Hussey* II and J. Laird
University of New Hampshire, Durham, New Hampshire
*Bowdoin College, Brunswick, Maine

Introduction

This trip will examine stratigraphic, structural and metamorphic relations in staurolite + andalusite to sillimanite + white mica grade, polydeformed metasedimentary rocks on the extreme southeast limb of the Kearsarge-Central Maine Synclinorium (KCMS; Lyons and others, 1982; the former Merrimack Synclinorium of Billings, 1956). We will primarily be examining new outcrops along the Spaulding Turnpike north of Rochester, New Hampshire to establish the stratigraphy and some of the more critical structural and metamorphic relationships between the Maine-New Hampshire border and the southwestern end of the Blue Hills Range (Parker Mountain, Strafford, New Hampshire) (see Figure 1B).

Geologic Setting

The metasedimentary rocks of interest are primarily a mix of rusty, sulfidic and nonrusty pelitic schists and metaquartzites with subordinate calcsilicate schists. This stratigraphic package is intruded by elongate syntectonic (?) diorite bodies. They are similar to the Spaulding quartz diorite, dated by Lyons and Livingston (1977) by Rb-Sr whole rock techniques at 393 ± 5 Ma. (age was recalculated using the presently accepted decay constant, $\lambda = 1.42 \times 10^{-11}\ yr^{-1}$, Steiger and Jager, 1977), and Winnipesaukee quartz diorite, both members of the New Hampshire Plutonic Series. Post-tectonic two-mica granites and quartz monzonites also cross cut the sequence. They resemble lithically the nearby Sebago, Effingham and Lyman plutons dated by Hayward and others (1984) and Gaudette and others (1982) at 322 ± 12 Ma. (Rb-Sr whole rock).

The Nonesuch River/Campbell Hill/Hall Mountain strike slip fault system, with strongly debated relative motion (see Zen 1983, p. 71-73 and Lyons and others, 1982, p. 55-57 for details), forms the southeastern boundary of the KCMS in this area. Juxtaposed along the fault to the southeast are rocks of the Merrimack Trough considered Pre-Silurian (?) by Hussey (1984), Late (?) Ordovician to Precambrian by Lyons and others (1982, p. 54) and Precambrian (?) by Olszewski and others (1984). The Berwick Formation, a calcsilicate bearing, quartz + biotite granofels, crops out southeast of the fault in the trip area and is part of the Merrimack Group.

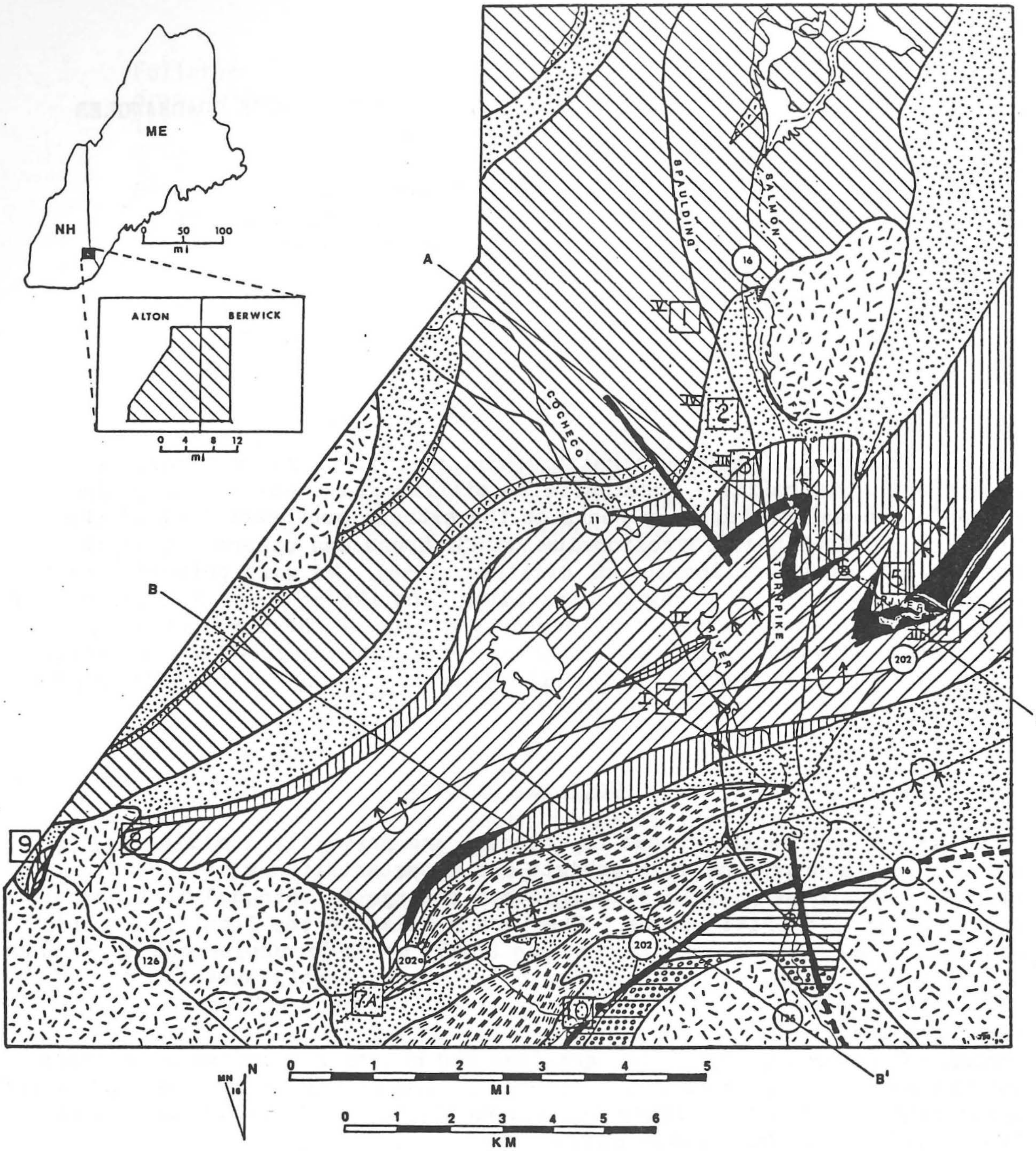
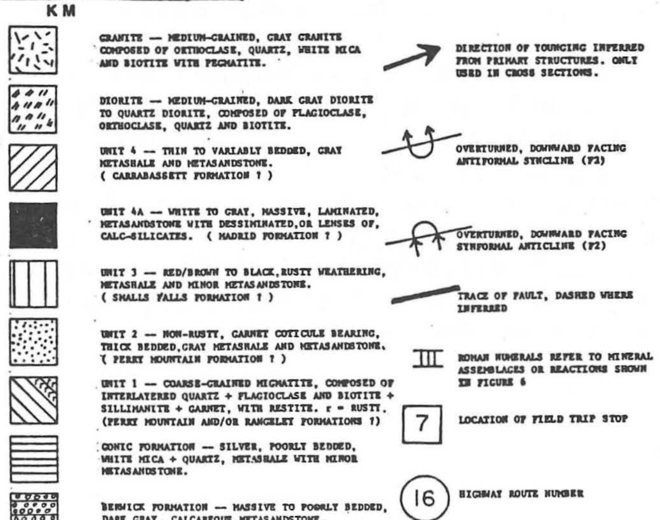
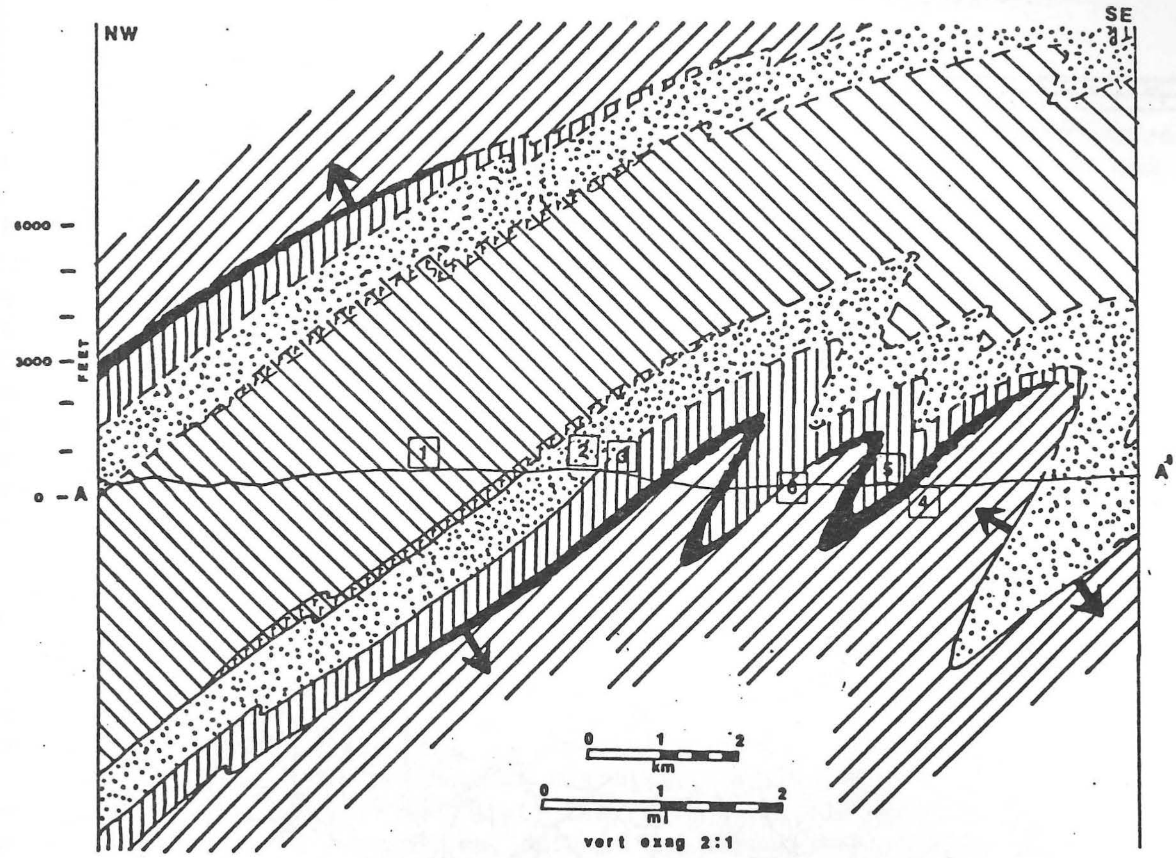


FIGURE 1A Geologic map and cross sections of the field trip area. Field trip stops shown on the cross sections are in places projected to the line of section.

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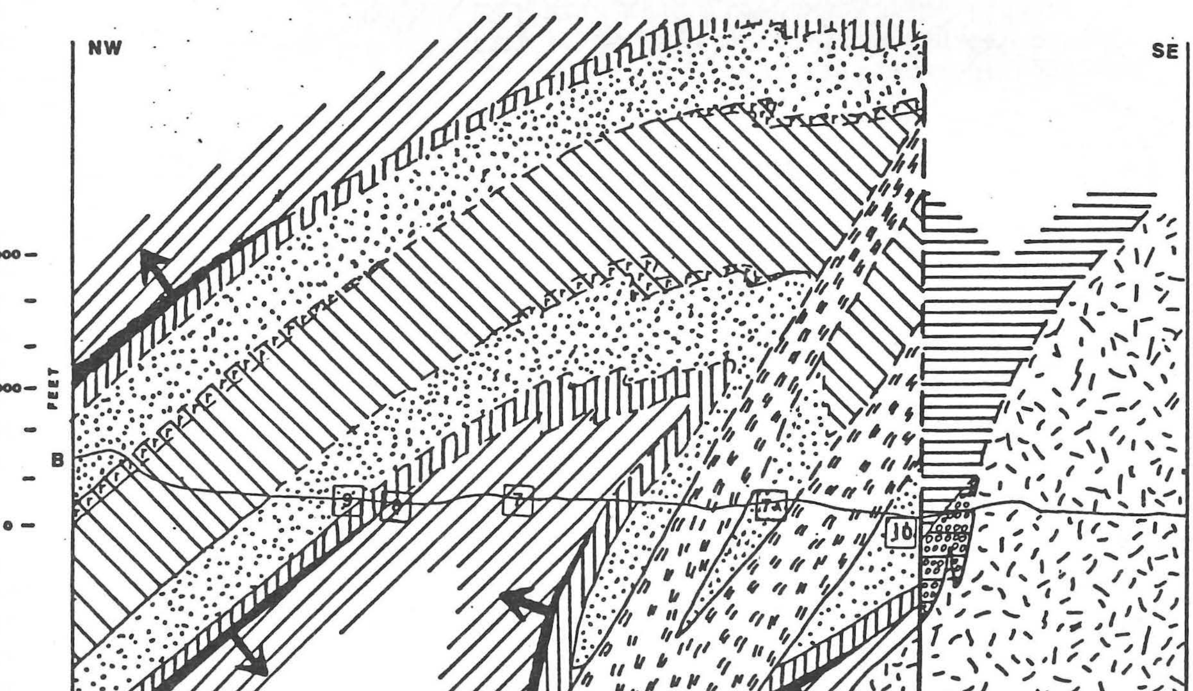
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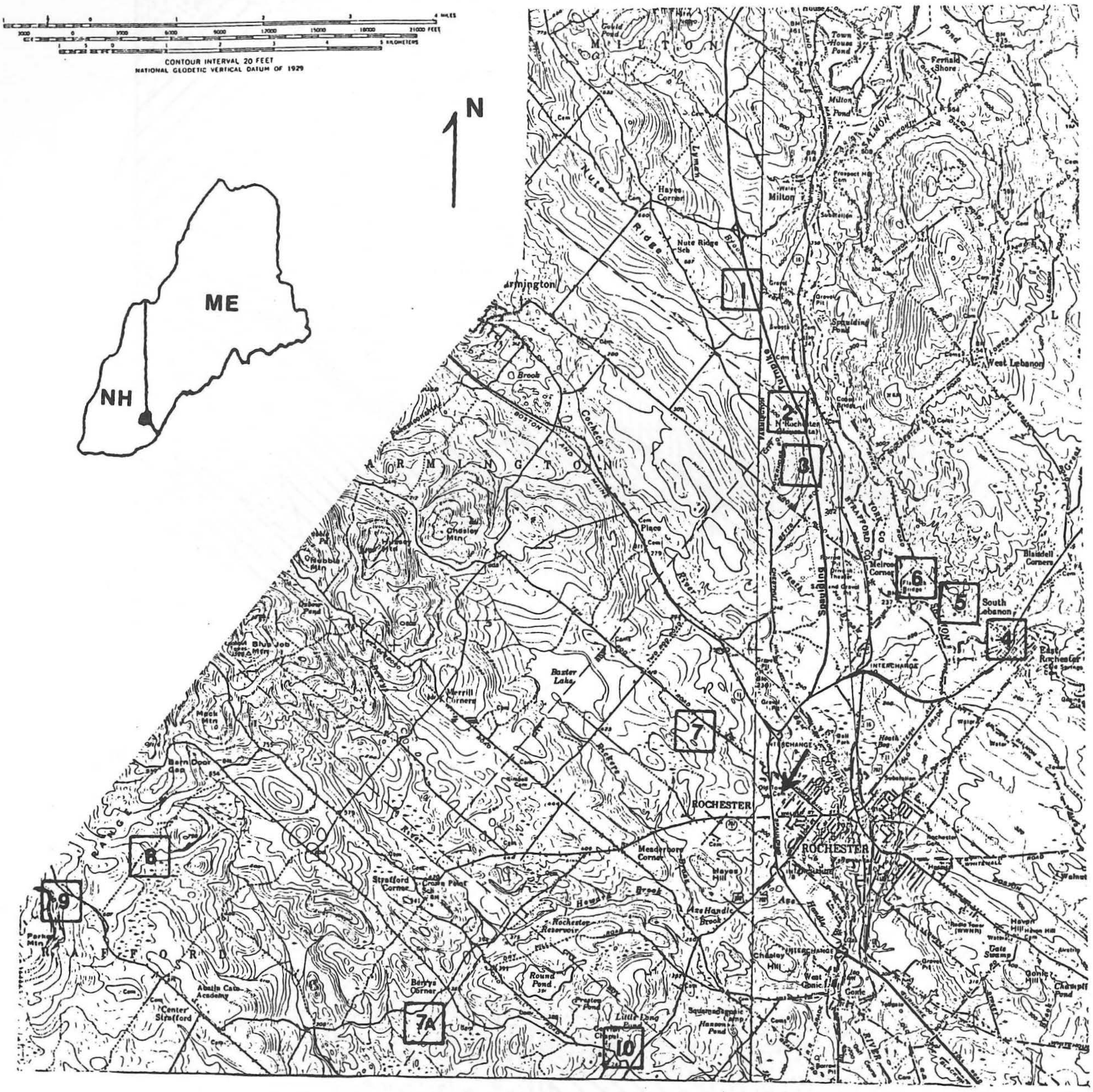

FIGURE 1B Geographic map of the field trip area. Numbers enclosed by square outlines are stop locations reffered to in the text. The thin vertical black line crossing the right center of the figure is the boundary of the Alton, NH (west) and Berwick, ME (east) 15' quadrangles. Tip of arrow east of STOP 7 marks the starting point of the trip.

STRATIGRAPHY

All of the metasedimentary rocks in the trip area were originally shown as the Devonian Littleton Formation by Billings (1956) in New Hampshire and the Rindgmere and Towow Formations by Katz (1917) in Maine. Hussey (1962, 1968) included the Towow and Rindgmere Formations in the Shapleigh Group which he correlated with the Littleton Formation. Gilman (1977, 1978) mapped the Shapleigh Group in the Newfield and Kezar Falls, Maine quadrangles. In New Hamsphire the Littleton Formation was subdivided into a number of distinct lithologic members (Heald, 1955; Stewart, 1961 and Carnein, 1976). All of the metasedimentary rocks were thought to be Devonian in age based on a lithic similarity to the fossiliferous Littleton Formation across the KCMS near Littleton, New Hampshire (Billings and Cleaves, 1934). Figure 2 outlines the stratigraphic correlations prior to this study.

Detailed mapping from this study has redefined what was previously a simple stratigraphy, into a more complex one based on lithic differences and good topping control from primary sedimentary structures, principally graded bedding and to a less extent, cross bedding. The newly recognized stratigraphy is remarkably similar to the Siluro-Devonian section described by Moench and others (1970) in a continuous part of the KCMS near Rangeley, Maine (see Figure 3). We propose to correlate, equivocally the Rangeley Formation, and with greater certainty the Perry Mountain, Smalls Falls, Madrid and Carrabasset Formations, defined by Moench and others (1970) and Boone (1973) to the lithic units of this field trip area. One of us (AMH) considers a correlation of the units of southwestern Maine and adjacent New Hampshire with the Carrabasset-Seboomook sequence of West-central Maine as another alternative (Hussey, 1984) (see Figure 3).

On a small scale map, the units near Rangeley, Maine, do not appear to be on strike with the rocks seen on this field trip. We suggest, however, that indeed the northeast trending, redefined stratigraphic package in southeastern New Hampshire and southwestern Maine, trends north, then northwest through southwestern Maine, recrosses into New Hampshire, where it trends back to the northeast near Conway, New Hampshire, and emerges on the north side of the White Mountains batholith on strike with the Rangeley, Maine, belt (Eusden, 1984). The preliminary compilation map shows the proposed stratigraphic connection between the field trip area and Rangeley, Maine (Figure 4).

The major impact of this correlation is a further extension of an older sequence into southwestern Maine and southeastern New Hampshire. The extension supports ongoing work in central and northeastern New Hampshire that has similarly extended the Rangeley stratigraphy on strike (Hatch and others, 1983; Thompson, 1984). Figure 3 summarizes the proposed correlations.

Because lithic similiarity is the basis of this correlation, the description, bedding character and facies relations of each unit within the southeastern New Hampshire sequence is presented below. Following the reasoning of Moench and Boudette (1970, p. A-1, 1), the usage of the terms metashale, metasandstone, etc. is preferred instead of their metamorphic equivalents. More detailed petrographic descriptions of each unit are

AGE	NH STATE MAP BILLINGS (1956)	SOUTHEASTERN NH HEALD (1955)		SOUTHWESTERN ME HUSSEY (1968)	
LOWER DEVONIAN	LITTLETON FM^F	LITTLETON FM	not recognized	SHAPLEIGH GROUP	Towow Fm
			Jeness Pond Mbr		Upper Rindgmere Fm
			Pittsfield Mbr		Lower Rindgmere Fm
			not recognized		Gonic Fm

FIGURE 2 Stratigraphic correlations of units prior to this study. All units were thought to be Devonian in age

AGE	Southeastern NH THIS STUDY	Rangeley ME Hatch et al (1983)	Central ME Pankiwskyj et al (1976)	Central NH Hatch et al (1983)	Western NH Billings (1956)	AGE	ALTERNATIVE THIS STUDY HUSSEY (1984)
LOWER DEV	not exposed	Seboomook^F Hildreths	not exposed	Kearsarge Mbr of Littleton	Littleton^F	DEVONIAN	Day Mtn Mbr.
	Unit 4	Carrabassett	Carrabassett	Littleton			
UPPER SILURIAN	Unit 4A	Madrid	Fall Brook	Warner	Fitch^F		SEBOOMOOK^F Temple Stream Mbr.
MIDDLE SILURIAN	Unit 3	Smalls Falls	Parkman Hill^F	Francestown			
	Unit 2	Perry Mtn		Crotched Mtn			
			Sangerville^F		Clough^F		
LOWER SILURIAN	Unit 1 (?)	Rangeley^F		Rangeley			Mt. Blue Mbr.
	not exposed	Greenvale Cv	not exposed	Greenvale Cv			
PRE-CAMBRIAN?	Gonic Berwick						Carrabassett

FIGURE 3 Revised stratigraphic correlations of Siluro-Devonian units in the Kearsarge Central Maine Synclinorium. F = fossil control.

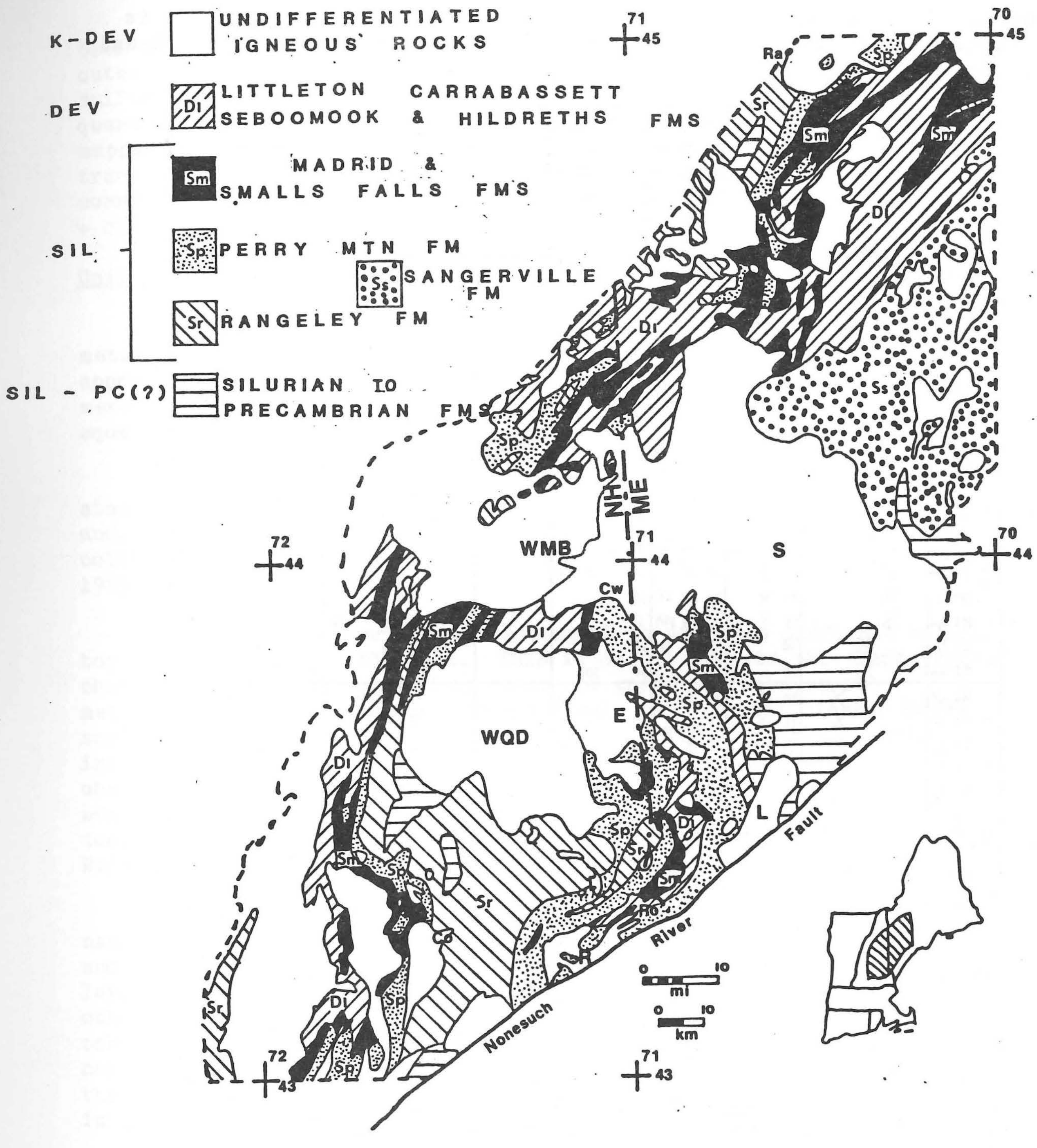

FIGURE 4 Small scale map showing the extent of Siluro-Devonian metasediments in part of the Kearsarge-Central Maine Synclinorium. The distribution of the metasedimentary rocks between the Effingham (E), Sebago (S) and Lyman (L) plutons is preliminary. This map was compiled using data from Hatch and others (1983), Gilman (1978 and 1977), Hussey (1968), Osberg and others (1984) and this study. WMB = White Mtn Batholith, WQD = Winnepesauke quartz diorite, R = diorite exposed around Rochester, NH, Co = Concord, Ro = Rochester, Cw = Conway, Ra = Rangeley.

summarized in Table 1. In brackets next to the subheading of each unit is our proposed correlation to the central-western Maine sequence of Moench and Boudette (1970).

UNIT	SAMPLE #	SH	SS	C	M	CS	Q	PLG	KSP	WM	BIO	CH	GA	ST	AD	SI	AM	EP	CA	SP	AP	OP	TM	ZR	RT	COMMENTS
UNIT 4	93 Oc	X					15			15	10	3F	6	1	50							Tr	Tr			Fresh andalusite
	Mb 54	X					10	5		15	20	1F	10		35	3						1				II Fig. 6
	Mb 63	X					10	3		20	15	10F	10		30					Tr		2		Tr		Sericitized andalusite
	14 Oc		X				55			25	14		5	1	1							2	Tr			Fresh andalusite
	86 Oc		X				70			10	7	5F								1		5	Tr			
UNIT 4A	128 Sm					X	45	20			10	1M	5				10	5	3	1				Tr		Calcsilicate lense within metasandstone
UNIT 3	97 Ssf	X					20	15		30	10	15F	Tr			7					Tr	3				IV Fig. 6
	27^A Ssf	X					17			65	10			3		Tr						5				I→V Fig. 6
	25^A Ssf		X				70	6		2	15	Tr	2	2							Tr	3			Tr	
	25^B Ssf		X				80			2	15		Tr									3				
	26^A Ssf		X				60			23	15	Tr										1	1	Tr		Sericitized andalusite
	26 Ssf		X				50	4		20	15	2F	5									4	Tr			
UNIT 2	Mb 51	X					25	10		20	20	3F	10			10							2			Sericitized andalusite
	30 Spm	X					30			30	25	9F	5			Tr						1				
	109 Spm	X					30	10		20	20	2F	5			10		Tr				2	1			SI from M2
	77 Spm	X					20	7		50	10	Tr	3								2	5	3			
	28 Spm		X				55	5		25	10	Tr	1	1								3	Tr			
	32 Spm		X				55	3		10	15		3		3	Tr						10	Tr	Tr		IV Fig. 6
	104 Spm		X				40	Tr		20	20	5F	10	?								5				
	106 Spm		X				55	3		5	10	15M	5								Tr	5	1		Tr	
	28 Spm			X			40			3	6	Tr	50								Tr	1	Tr		Tr	ZONED GARNETS FIG. 7
	93 Spm			X			20			7	1		60		10?							1	1			
UNIT 1	Mb 63				X		30	15		30	5		3			10						1	3	Tr		All I Fig. 6
	Mb 61				X		17	10		25	20		10			15						3		Tr		↓
	37 Sr				X		50	Tr		15	15		3			15						2				
	38 Sr				X		40	3		10	15		5			15						12				
	40 Sr				X	X	60	10					15				10	Tr		1		3				
	83 Sr				X		25	5	Tr?	35	3		3			20				2		7				SI + KSP ???
GONIC FM		X					25			25	20	5F	10	10								4		Tr	Tr	
BERWICK FORMATION			X				40	25			20	10F						Tr	Tr			4				
						X	40	40			5						10	Tr	1	3		1				

TABLE 1 Table of estimated modes and other petrographic data for the metasedimentary rocks of the field trip area. Roman numerals in comments section are explained in Figure 6. Abbreviations: SH-metashale, SS-metasandstone, C-garnet coticule, M-migmatite, CS-calcsilicate rock, Q-quartz, PLG-plagioclase, KSP-potassium feldspar, WM-white mica, BIO-biotite, CH-chlorite(F-Fe rich, M-Mg rich as determined using the method of Albee,1962), GA-garnet, ST-staurolite, AD-andalusite, SI-sillimanite, AM-amphibole, EP-epidote, CA-carbonate, SP-sphene, AP-apatite, OP-opaques, TM-tourmaline, ZR-zircon, RT-rutile, Tr-trace amount.

Unit 1 (Perry Mountain Formation and part B of The Rangeley Formation?)

Unit 1 is a coarse-grained migmatite composed of intercalated quartzo-feldspathic (plagioclase) and biotite + garnet + sillimanite schistose layers with moderate to abundant secondary white mica. Layering is swirly with a great range in attitude. Sillimanite is locally abundant and has been observed in bundles 8 to 10 cm long and 5 cm in diameter. In places, outcrops have a distinctive yellow stain, probably an alteration product of sulfur-bearing phases. Elongate lenses of zoned calcareous and minor quartzitic concretions are preserved as restite within the migmatite. A mappable, but subordinate rusty weathering migmatite is found close to the transition from migmatite to non-migmatized, well-bedded, Unit 2. This is coarse-grained, dark brown rusty weathering migmatite composed of white mica + sillimanite + quartz + minor tourmaline (see Figure 1A).

Unit 2 (Perry Mountain Formation?)

Unit 2 is a metaturbidite composed of well bedded metasandstone and metashale. Bedding generally thins up section. The thickest beds are approximately 0.5 m and have about four times more metasandstone than metashale. Near the contact with Unit 3, the beds thin to 5-10 cm with equal amounts of metasandstone and metashale.

Bedding is well preserved and is emphasized by the development of abundant, large (≈5 cm) knobby, black weathering, porphyroblasts of andalusite partially or completely pseudomorphed by white mica. These are colloquially referred to as "andalumps" (P. Robinson in Hatch and others 1983).

Despite the well preserved bedding it is at times difficult to tell topping direction in this unit. This is due in part to the "fast graded" character of the beds marked by an abrupt gradation between the metasandstone and metashale within a single bed. In the classic Bouma series, only divisions A and E are observed. Rip up clasts of metashale are infrequently preserved in the metasandstone. These sedimentologic observations suggest that the basal metasandstone represents an environment where all of the turbidity currents during deposition were fast flowing and during quiescence were covered by a relatively thin layer of pelagic mud. Walker (1979) suggests a proximal source for similar turbidities elsewhere.

Distinctive pink colored garnet + quartz coticules occur in the metasandstone as discontinuous stringers and pods that parallel original bedding and often outline folds beautifully. These may represent maganiferous chert layers, but the origin of such a sediment is unclear (Docka, 1984; Hatch and others, 1983) as is also the relation of this peculiar feature to the better constrained paleo-environment previously mentioned. The coticules are in part one of the distinguishing criteria used in separating units 2 and 4, or the Perry Mountain and Carrabasset Formations, two very similar turbidites in this sequence.

The contact between Units 1 and 2 is defined by the first appearance of migmatite. This is an indication of change in metamorphic conditions rather than an exact stratigraphic contact. In fact, recognizable restite, particularly the coticules characteristic of Unit 2 is found in the migmatite near the inferred contact. Elsewhere within the migmatite is a distinctive rusty weathering zone that is stratigraphically below Unit 2, based on facing directions nearest the contact. This rusty migmatite, presumably older than Unit 2, may correlate with part B of the Rangeley Formation as described by Moench and Boudette (1970). Because of these observations we propose to correlate Unit 1, in essence a metamorphic unit, to the lowermost portion of the Perry Mountain Formation and to at least part B of the Rangeley Formation in central-western Maine. All of Unit 2 is correlated to the Perry Mountain Formation.

Unit 3 (Smalls Falls Formation?)

Unit 3 is a distinctive rusty weathering, crumbly, well foliated poorly bedded metashale and metasandstone. At and away from the contact with Unit 2 the bedding character remains generally the same as that described for Unit 2. The abrupt change to a distinctive rusty color marks the contact between the two units. Up section the unit becomes much more shaley with only scattered pods and stringers of metasandstone remaining. Unfortunately, this bedding style change is not systematically well defined.

At STOP 6, unit 3 has lenses of 2-10 m thick, rusty weathering quartz pebble grit with angular to subrounded vitreous quartz clasts and gray lithic fragments up to 0.5 cm in size, often tectonically elongate, within a fine-grained quartz + biotite + minor white mica matrix. Hussey distinguishes between this grit and a grit at the base of the Towow Formation (Unit 3 equivalent) as seen outside the field trip area in the Berwick, Maine quadrangle. An increase in blue, vitreous quartz clasts and the lack of lithic fragments distinguishes the latter from the former for him.

Graded bedding is poorly preserved or absent due to the more homogeneous shaley nature of this unit. Hence stratigraphic position has been determined by careful examination at the contacts with Units 2 and 4 (STOPS 3, 6, 8 and 9) that have well preserved graded bedding and/or cross bedding. The bedding style, rusty weathering, graphite and pyrrhotite suggest that this unit may represent more distal turbidites deposited in an oxygen restricted basin (see also Moench and Boudette, 1970).

The outcrop pattern of unit 3 is quite variable (see Figure 1A). In places it thins sharply to the point that only a few meters of Unit 3 intervene between Units 2 and 4. This is unlikely a function of fold geometry alone but at least partly an expression of the original shape of the euxinic basin which was probably geometrically irregular. Unit 3 is correlated to the Smalls Fall Formation of the central-western Maine section.

Unit 4 A (Madrid Formation?)

Unit 4A is a white to gray, laminated to massive metasandstone with numerous zoned calcsilicate pods or concretions. The lamination is rhythmic in places and is defined by black to dark gray biotite rich layers at about 1-3 cm intervals within the metasandstone. Where massive, the color is much whiter with 10-20 cm long calcsilicate pods intercalated with the metasandstone. The calcareous pods are zoned with biotite rims and amphibole + plagioclase + garnet cores. Fractures and joints in this unit are commonly silica-filled and stand out as resistant mini-ridges on the outcrop surface.

Only four exposures of Unit 4A have been observed in the field trip area and no definitive topping features are known. It is more common to see the contact between units 4 and 3 without any intervening 4A.

This unit is thought to represent an influx of more proximal, higher energy clastics perhaps associated with the waning front of a slightly calcareous sandstone delta similar to the ensimatic carbonate flysch recognized by Roy (1984) in the Maine Slate Belt. Unit 4A and 4 mark a significant change in the depositional regime. Whereas units 2 and 3 may have been deeper water proximal to distal turbidities with variable oxygen supply, Unit 4A may be a more proximal sediment reflecting influx from a new source or a drop in sea level or both. Unfortunately, very few paleocurrent indicators have been found in any of the units to establish a source direction. This is in part due to the high metamorphic grade and deformation observed in this area.

Unit 4 - (Carrabassett Formation?)

Unit 4 is a well bedded turbidite, in places quite similar to Unit 2. This unit is typically rhythmically bedded with thicknesses on the order of 3-5 cm, with slightly more metasandstone than metashale. The metashale is often graphitic and has well developed andalusite (chiastolite) and staurolite that are fresh or only partially pseudomorphed by white mica and chlorite.

When not rhythmic, the bedding style is quite variable. Beds of up to 3 m thick with roughly five to six times more metasandstone than metashale are commonly observed as are thick beds of metashale. This type of bedding character is most typical near the contact with Units 3 and 4A, but can be quite random.

Well preserved graded beds and cross beds give excellent control on topping direction in this unit. Unlike Unit 2 which is "fast graded" Unit 4 is "slow graded" or continuously graded. There is a smooth transition within each bed between metashale and metasandstone. As in Unit 2, the graded bedding is enhanced by large porphyroblasts of andalusite except in areas of low metamorphic grade where normal graded beds still persist. Near East Rochester, New Hampshire, some of the beds in this unit are "fast graded". These have well developed refracted cleavage only in the metashale.

The contact with Unit 4A is marked by the disappearance of calcsilicate rocks and the first appearance of shaley interbeds. When in contact with Unit 3, the transition between the two is marked by the abrupt loss of rusty weathering and appearance of non-rusty, variably bedded turbidite.

Unit 4 is sedimentologically similar to Unit 2. It may, however, represent a more distal turbidite deposited in a lower energy environment as suggested by the "slow grading" of beds. The proximity and depositional energy has decreased significantly in unit 4 with respect to unit 4A.

In summary, the stratigraphy presented here consists of five units, four of which are part of a stratigraphic succession. The fifth and lowermost, Unit 1, is a migmatite. Some changes in the local stratigraphy with respect to the older and better known Shapleigh Group have been made. Unit 1 is approximately equivalent to the Lower Rindgmere Formation. Unit 2 is a part of the Upper Rindgmere Formation. Unit 3 is equivalent to the Towow Formation. The Towow Formation was originally recognized in Maine and not across the state line in southestern New Hampshire (Hussey, 1968).

However, as shown in Figure 1A, we have mapped the Towow Formation or Unit 3 well into southeastern New Hamsphrie. Units 4 and 4A were previously mapped as either the Upper Rindgmere or Towow Formations.

STRUCTURE

The metasedimentary rocks are polydeformed. Three folding events are observed, all possibly Acadian or a combination of both Acadian and Alleghanian in age (Lyons and others, 1982). Table 2 explains the order and timing of both structural and metamorphic events.

TABLE 2

Timing	Deformation	Metamorphism	Comments
Based on Rangeley, ME fossils; Silurian to early Devonian	S_o, soft sediment deformation	Diagenesis	original bedding
Early Devonian?	F1, S1	M1?	fragmented andalusite porphyroblasts, nappe stage folding, inverted sections
Early Devonian based on Spaulding Qtz Diorite Rb/Sr age.	F2, S2	M1? M2	intrusion of diorite near Rochester, foliation, rolled porhyroblasts, NE-SW subhorizontal fold axes.
Middle to Late Devonian? or Carboniferous?	F3?	M3?	no cleavage, small scale bending of metasediments, secondary white mica and chlorite
Carboniferous?	F3? strike slip faulting?	M3?	small scale bending of metasediments, secondary white mica and chlorite, crenulation cleavage near fault trace.

F1 is characterized by large recumbent folds or nappes of uncertain vergence. The main schistosity (S1) is generally parallel to original bedding (So) and consequently is difficult to see. In places though, well developed S1 cleavage is beautifully preserved in what were probably parasitic F1 isoclinal folds on the limbs of the large folds. This cleavage and some of the associated early F1 isoclines are refolded about F2 folds axes.

The most convincing evidence of early recumbent folding is the recognition of extensive inverted sections within the stratigraphic sequence, much of which will be seen on this trip. The inverted limbs are refolded into open, asymmetric, downward facing antiformal synclines and synformal anticlines. This alone is evidence that an early folding event had to have occurred prior to refolding about F2 fold axes.

F2 folds refold large recumbent F1 folds about northeast to southwest gently plunging (up to 20^{o}) axes. These folds are open, asymmetric, and verge to the southeast. Andalusite porphyroblasts are occassionally aligned parallel to F2 axes. Figure 5 is a plot of the F2 fold axes.

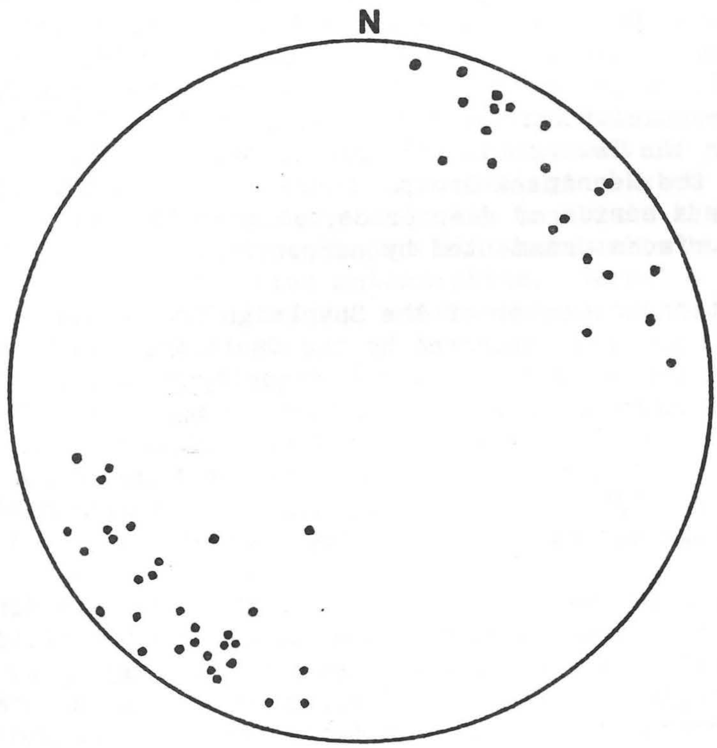

FIGURE 5 Equal area plot of F2 fold axes in the field trip area. Axes trend northeast-southwest with a shallow plunge in either direction

There is a well developed S2 axial plane cleavage. The biotite in the metasandstone of unit 4 is reoriented parallel to S2. Lineations resulting from S2 and S_o intersections are well preserved throughout the area.

The third folding event, F3, is defined by a change in attitude of the metasedimentary map pattern from east-northeast near Parker Mountain, New

Hampshire to north-northeast near West Lebanon, Maine. (see Figure 1A). No observable cleavage associated with F3 is seen in the field trip area.

On a smaller scale map (see compilation map, Figure 4) F3 is more pronounced. The northeast striking metasediments within the field trip area trend north and then northwest between a corridor defined by the Winnepesuake quartz diorite and the Sebago batholith. It is speculated that the change in regional strike may be a result of lateral "shouldering" by the emplacement of these igneous bodies or alternatively as a consequence of major strike slip faulting along the Nonesuch River/Campbell Hill/Hall Mountain fault system.

The Nonesuch River fault defines the southeastern boundary of the KCMS and may be part of a master fault system that includes the Norumbega fault in Maine and the Clinton-Newbury/Wekepeke/Flint Hill/Silver Lake faults in New Hampshire and Massachusetts (see Gaudette and others 1982, p. 1351 and Lyons and others 1982, p. 55-56 for details). A portion of the fault extends through the southeast corner of this area (see Figure 1A). It separates Unit 2 from the Precambrian (?) (Olszewski and others, 1984) Berwick Formation of the Merrimack Group. There is a distinct topographic lineament occupied by a series of deep ponds, abundant silicifed zones and minor slickensided surfaces ornamented by serpentine.

The Gonic Formation, a member of the Shapleigh Group (see correlation chart, Figure 2 and 3) is also separated by the fault from units within the KCMS. Although redefined by this study, the majority of the Shapleigh Group (Upper and Lower Rindgemere and Towow Formations) remain within the KCMS. We support the hypothesis proposed by Hussey (personal communication), that the Gonic Formation should be included within the Merrimack Group and agree with Bothner and others (1984) that it correlates to the Gove member of the Berwick Formation recognized near Raymond, New Hampshire.

The interpretation of the structure as presented above is different from that discussed by previous workers. Hussey (1962) recognized the Lebanon syncline, a major doubly plunging, upward facing syncline in the Berwick, Maine quadrangle. Stewart (1961) proposed a similiar structure for the metasedimentary rocks in adjacent New Hampshire. Gilman (1977) reported that overturned isoclinal folds are refolded into the major structures (Pequawket synform and Hiram antiform) seen in the Kezar Falls, Maine quadrangle.

We elaborate on Gilman's observations and suggest that large, early, F1 recumbent folds or nappes are refolded by open, inclined, F2 folds with west dipping axial surfaces. The inverted limbs of F1 folds are commonly refolded into downward facing F2 folds. Furthermore, we suggest that the Lebanon syncline is in fact better described as a downward facing antiformal syncline with Unit 4 and not Unit 3 or the Towow Formation preserved as the youngest unit in the fold core.

METAMORPHISM

Three events are recognized within the polymetamorphic rocks of the field trip area. (see Table 2). The early event, M1, is a progressive low pressure facies series regional event. In the metashales of all units, M1 reaches sillimanite + white mica grade and is characterized by well developed andalusite and staurolite in Units 4 and 2.

Locally abundant sillimanite and a coarsening of mineral grain size in the metasedimentary rocks near and at the contacts of igneous bodies is thought to represent a contact metamorphic event, herein called M2. It is difficult to distinguish between M1 and M2 in the field trip area. It is possible that these are not separate events, but represent a metamorphic continuum. We have not clearly established the timing of each event at this point. This uncertainty is expressed in Table 2.

The latest event, M3, is characterized by non-foliate decussate white mica and chlorite. The white mica is pseudomorphous after the alumnino-silicates, and chlorite pseudomorphs biotite and garnet. No foliation is associated with M3.

The increase in metamorphic grade to the northwest towards the "sillimanite plateau" of Thompson and Norton (1968), that is associated with M1, is beautifully preserved. The mineral assemblages listed in Table 1 for quartz + white mica bearing rocks rather tightly constrain the pressure-temperature path of M1 metamorphism (Figure 6). Andalusite is common indicating low pressure facies series metamorphism. Garnet + chlorite is not stable whereas staurolite + biotite, andalusite + biotite and sillimanite + biotite are. Therefore, the maximum temperature in all rocks must have been above reaction 1 in Figure 6. Staurolite is most commonly associated with andalusite + garnet + biotite and seldom with sillimanite + garnet + biotite. Consequently, the progressive metamorphic path must have passed close to the intersection of reactions 2 and 3 with the andalusite to sillimanite polymorphic transition (Figure 6). Sillimanite + potassium feldspar assemblages have not been recognized. The maximum observed grade is sillimanite + white mica in areas of abundant migmatites.

The position of the reaction boundaries in Figure 6 will change if X_{H2O} does not equal unity. The occurence of graphite and sulfides in equilibrium with the metashales (pelitic schists) indicate the presence of carbonaceous and sulfide components in the metamorphic fluid phase. Thus the activity of H_2O varied within the study area and may have affected mineral paragenesis (see discussion by Neilson, 1981; French, 1966; Thompson, 1972; Tyler and Ashworth, 1982 on similar rocks). Chamberlain and Lyons (1983) suggest that "graphitic pelites may contain higher-grade assemblages than adjacent non-graphitic pelites" (Chamberlain and Lyons, 1983, p. 536-537). Recent experimental work by Dutrow and Holdaway (1983) supports an extension of the staurolite stability field to lower pressures. These are some of the reasons why in Figure 6 we did not give values for the pressure and temperature axes. We attempt only to show the observed ensemble of mineral assemblages and important reactions and not to quantify the reaction boundaries.

The presence of randomly oriented biotite included in porphyroblastic garnet and andalusite suggest that these phases grew prior or during the development of S1. The prophyroblasts have been subsequently rotated during the development of S2 which is defined by aligned sheet silicates (see Figure 7). Garnet may have continued to grow after the development of S2. As shown in Figure 7, garnet cores contain abundant inclusions of quartz and biotite, followed by a zone of ilmenite. From this textural unconformity to

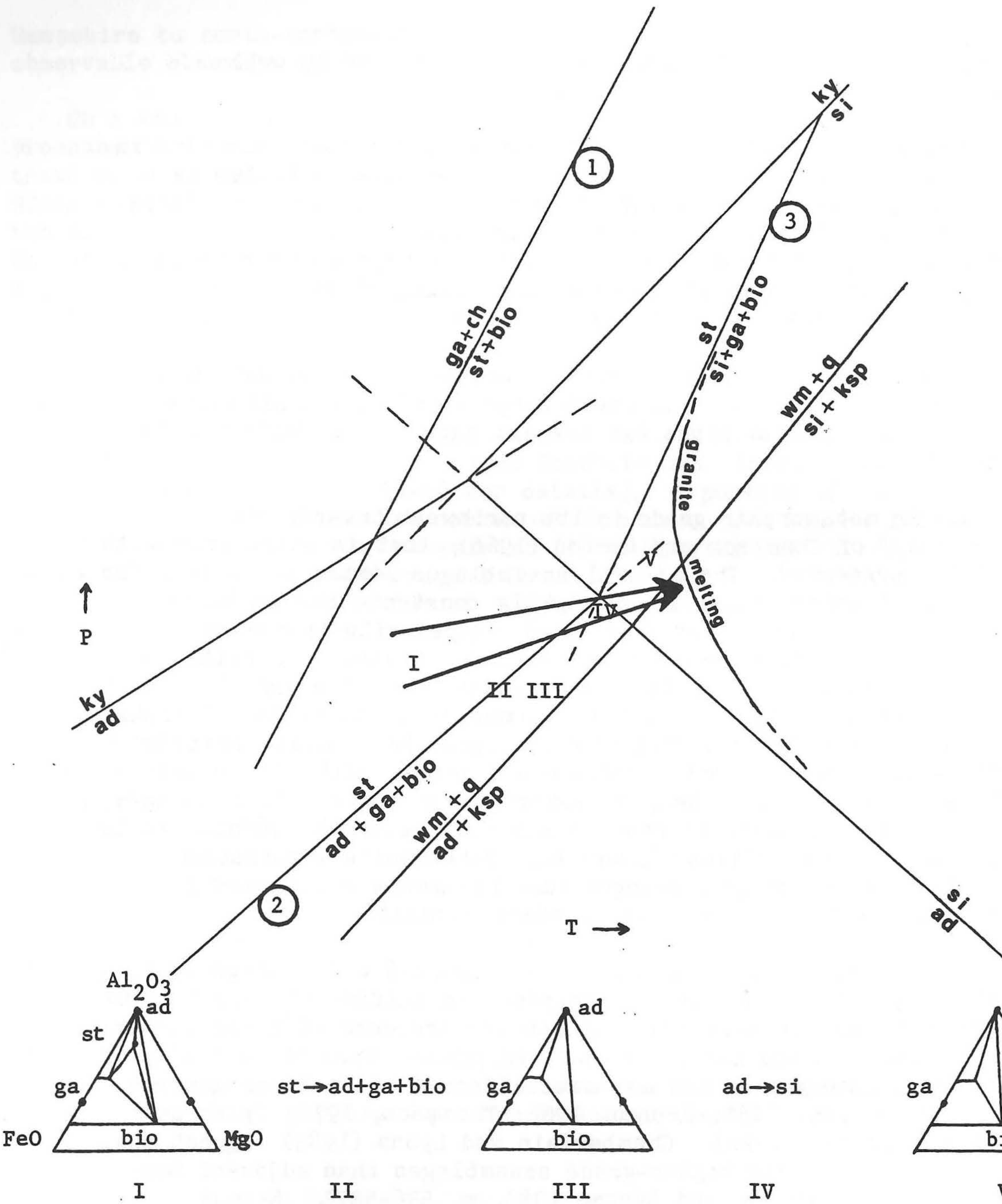

FIGURE 6 Path of low pressure facies series metamorphism associated with Ml. Arrow defines path, Roman numerals refer to pertinent ensembles of assemblages or reactions observed in quartz + white mica metashales (pelitic schists) in the field trip area. Petrogenetic grid after Labotka (1981), granite melting curve (X_{H_2O} = 1) after Kerrick (1972) and Thompson projections showing pelitic assemblages after Thompson (1957). Quartz, white mica and H_2O are involved in the reactions as necessary. Abbreviations the same as in Table 1.

the rim, garnet is idioblastic and has grown over the biotite foliation (S2).

Andalusite is commonly attenuated, fragmented and aligned parallel to F2 fold axes. Elsewhere it is randomly oriented within pelitic layers as radiating clusters.

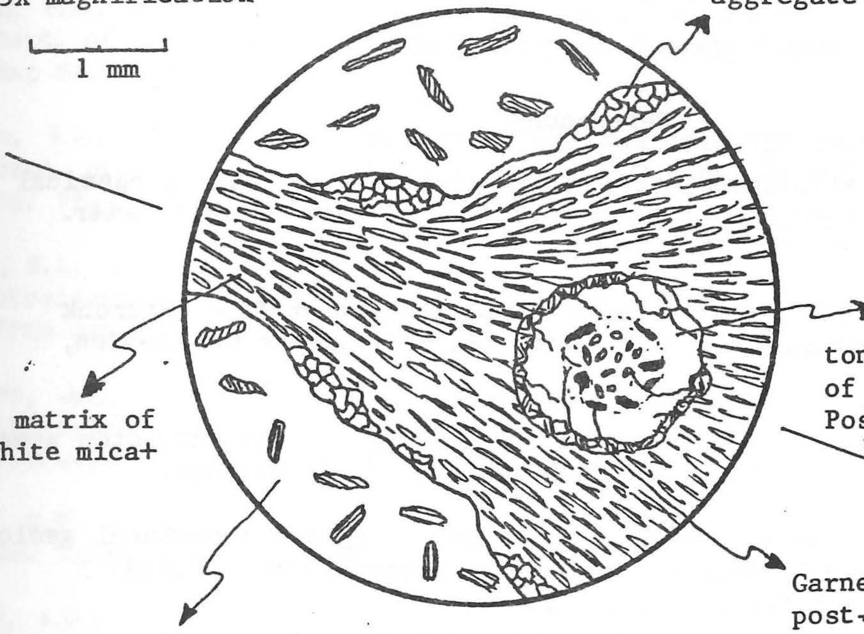

FIGURE 7 Textural sketch of thin section from Unit 4. Sample from East Rochester about .5 mile downstream along the Salmon Falls river from STOP 4.

Conclusions

A revised stratigraphy for the southeastern New Hampshire and southwestern Maine part of the KCMS has been presented. This stratigraphy was developed through detailed mapping of lithologic units with good control on succession from primary sedimentary structures. We have recognized Unit 4 above what was previously considered the top of the exposed section, Unit 3 or the Towow Formation, of the Shapleigh Group.

The remarkable similarity of both the order and lithology of this stratigraphy to the fossiliferous section near Rangeley, Maine suggests that they may be correlative. If so, the age of the metasedimentary rocks in southeastern New Hampshire and adjacent Maine is Siluro-Devonian. The possibility exists, however, that the units in the field trip area correlate to the Devonian Carrabassett and Seboomook Formations of Maine.

The Lebanon syncline, previously described as an upward facing, asymmetric syncline, is better described as a major downward facing, antiformal syncline that has formed by the refolding of large, early recumbent folds.

The staurolite + andalusite to sillimanite + white mica grade metasedimentary rocks of this part of the KCMS are truncated to the southeast by the Nonesuch River Fault. Juxtaposed along the fault trace is an exotic ensemble of metasedimentary rocks, the Merrimack Group, of at least pre-Silurian and probable Precambrian age.

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ROAD LOG FOR TRIP C5

Assembly Point: Rochester Mall parking lot, Ten Rod Road, Exit 14 off the Spaulding Turnpike, Rochester, NH [Berwick, ME 15' Quadrangle]. See Figure 1B for location.

Time: 9:00 a.m.

Mileage

0.0 Proceed N on Spaulding Turnpike

6.7 Take Exit 17, Milton exchange, turn around and proceed S on Spaulding Turnpike to STOP 1.

7.5 STOP 1

Unit 1 (Rangeley and Perry Mtn. Formations?)
Stay on S bound side of turnpike. Park well off breakdown lane on grass shoulder. Watch traffic. This applies to all STOPS on turnpike*

Unit 1, a migmatite, is exposed in a long outcrop. It is composed of swirly, randomly oriented, layers of intercalated quartz + plagioclase and biotite + garnet + sillimanite which are overgrown by secondary white mica. Elongate restite, or mini-mesosomes, are quite common in this outcrop. They are zoned with garnet + amphibole + quartz + plagioclase cores and biotite + quartz + plagioclase rims. The long axes of the restite are oriented NE-SW, approximately parallel to F2 fold axes and lineations.

9.2 STOP 2

Unit 2 (Perry Mtn. Formation?)

A tremendous outcrop of gray, thick bedded, metasandstone and metashale with discontinuous stringers of pink, garnet + quartz, coticules is exposed here. "Fast graded" beds are well preserved and are emphasized by the metshale layer which is entirely made of black weathering porphyroblasts of andalusite (andalumps). Keep an eye out for infrequent crossbeds (or is it early F1 cleavage that has been refolded?) and ripup clasts of metashale. Tops here suggest that the sediments face down. We are within the inverted limb of a F1 recumbent fold and on the NW limb of the major downward facing, F2, antiformal syncline as depicted in section A-A. (see Figure 1A of text).

Pumpellyian F2 folds are sparse here, however, a warp associated with F2 may be seen on the cliff face near the S end of the W outcrop. A beautiful, isoclinally folded, (F1?) garnet coticule can be viewed on top of the cliff face. Minor sillimanite in addition to garnet + biotite + andalusite (fresh to completely sericitized) are observed in the metashale. We are therefore close to Roman numeral IV of Figure 6 in the text.

9.6 STOP 3

Unit 2/Unit 3 contact (Perry Mtn and Small Falls Formations?)

Exposed in this long, but low outcrop is the transition, N to S, from non-rusty, gray, garnet coticule bearing Unit 2, whose bedding thickness has, as it typically does in this area, thinned up section considerably, to rusty weathering metashale and minor metasandstone of Unit 3. The contact is defined by the first appearance of rusty weathering. Because of this, the bedding style of Unit 3 is much the same as Unit 2 near the contact. However, if you walk S down the length of the outcrop a gradual increase in metashale is apparent in Unit 3.

Tops here indicate that the section is inverted. Unit 2, the older unit, structurally overlies Unit 3. We are in the same part of the structure as described for STOP 2. Numerous F2 downward facing minor folds, with fold axes trending SW and plunging about 15°, are seen in both Units. We are also at the same metamorphic grade as described for STOP 2.

Proceed S along turnpike.

10.0 Cross bridge #30.

11.8 Take Exit 16 to Routes 202, 11 and 16, east toward Rochester, NH and Sanford, ME.

12.1 At end of ramp take a left.

12.7 Cross bridge #26.

12.8 Bear right on Rtes. 202 and 11, heading east.

14.9 In E. Rochester center turn left at double flashing red light.

14.95 STOP 4

At end of road, park on right side. Walk down to the edge of the Salmon Falls river. Outcrop is just downstream from an old, rusty, iron beam bridge.

Unit 4A/4 contact (Madrid and Carrabassett Formations?)

Along the riverbank is exposed massive, white to gray weathering, purple on fresh surfaces, quartz + plagioclase + biotite metasandstone with biotite rich partings or laminations spaced about 2-6 cm apart. The calcareous portion of the metasandstone is evenly dessiminated with no observable calcsilicate lenses. Raised ridges, formerly fractures which have annealed , criss-cross the outcrop surface. There are no visible folds in this outcrop.

If the water level is low enough we can walk downstream to the contact with Unit 4 (Carrabasset Formation?). Unit 4 is composed of massive metashale with abundant well developed chiastolitic andalusite pseudomorphed by white mica. The contact is a few tens of yards downstream from the highway bridge. Although no topping information is seen at this STOP, just downstream, behind a factory in E. Rochester, are several outcrops of inverted Unit 4 (see location on cross section A-A' for relative structural position). Thin sections from behind the forementioned factory show pervasive M3 chlorite and white mica alteration of garnet, biotite and andalusite of the metashale in Unit 4.

Lunch Stop. Turn vehicles around.

15.0 Turn left onto 202 east at flashing red lights, proceed across bridge over Salmon Falls river into Maine.

15.1 Turn left on River Road, first left after bridge. Proceed NW along River Road.

15.9 STOP 5

After crest of small hill with outcrop on the right, park on the left in dirt lot.

Unit 3 (Smalls Falls Formation?)

Exposed here in the core of a minor, F2, downward facing synformal anticline (see cross section A-A' for location) is the rusty weathering, crumbly metashale of Unit 3. This is the Towow Formation as mapped by Hussey (1968) (see correlation chart, Figure 2). The major purpose of this STOP is to assess whether this is the same unit as exposed at STOP 3 or a different unit altogether. Based on stratigraphic position and lithology, two of us (JDE and WAB) feel that they are the same, one does not (AMH). In addition to the outcrop along the road, a large cliff outcrop is located about 100 yards due NE from the road, into the woods. Steeply inclined nearly recumbent, F2 folds with subhorizontal NE-SW trending fold axes are seen in both places.

Continue NW on River Road.

16.5 Turn left towards Kings Court Campground and Water Slide.

16.6 Turn left into the Water Slide parking lot. Park.

STOP 6

Unit 4/3 contact (Carrabassett and Smalls Falls Formations?)

In constructing the artificial hill for the water slide, the glacially polished bedrock was stripped of its Quaternary cover and the contact between Units 4 and 3 was exposed. Unit 4A does not appear here. It has presumably "pinched out" as indicated in Figure 1 of the text.

Exposed closest to the parking lot are lenses of grit composed of vitreous and blue quartz and lithic fragments from 1 to 5 mm in size in a quartz + biotite + white mica matrix that is moderately rusty. Proceeding towards the woods to the left of the slide are the rusty metashales more typical of Unit 3. Abruptly the rusty weathering stops and gives way to thick, well bedded metasandstone with cross bedding and minor metashale all completely metamorphosed into "andalumps". This is Unit 4. Subtle graded beds concur with topping information from the crossbeds that these beds are inverted. This outcrop establishes the presence of a non-rusty well bedded unit (Unit 4) above the rusty metashales, (Unit 3 or the Towow Formation of Hussey (1968)) which was not previously recognized within the Shapleigh Group (see correlation charts, figures 2 and 3).

As we have seen elsewhere, the older rock, Unit 3, is structurally on top of the younger one, Unit 4, in this inverted section. (see location on cross section A-A').

Turn left out of Water Slide parking lot and proceed across bridge, back into New Hampshire.

17.1 At intersection, go straight, passing Mike's Auto Body on your left.

17.6 Take a left on Rt. 16 heading S.

17.9 Bear right onto Rtes. 202, 11 and Spaulding Turnpike following sign for Conway and Portsmouth.

18.7 Take a right onto the Spaulding Turnpike, southbound, following sign for Concord and Dover.

19.3 Cross bridge #27.

20.0 Take Exit 14, Ten Rod Road.

Outcrop of Unit 3 on ramp. Go left at end of ramp onto Ten Rod Road. Now in Alton, NH 15' Quad.

21.7 Park in new dirt road that goes up a hill to the left.

STOP 7

Unit 4 (Carrabassett Formation?)

Exposed in low outcrops along the dirt road are inverted, shallow dipping, 4 to 10 cm thick, beds of metasandstone and metashale. Graded beds are well preserved. Andalusite, fresh to partially altered, elongate subparallel to F2 lineations is surrounded by small euhedral staurolite. The pelitic assemblage here is equivalent to that represented by Roman numeral I in Figure 6.

This outcrop is typical of the majority of Unit 4 as mapped in the field trip area. Without such things as the lack of garnet coticules and stratigraphic position with respect to the rusty weathering metashale, Unit 3, it would be difficult to distinguish this rock, Unit 4, from the garnet coticule bearing turbidite, Unit 2, lower in the section.

Continue up Ten Rod Road, heading NW.

21.9 Take a left on Four Rod Road

23.7 Take a left at the "T" intersection.

24.7 Take a right at the four way intersection.

24.9 Bear left on 202 A, heading WSW.

26.1 Outcrop of diorite near Rochester reservoir.

27.1 OPTIONAL STOP 7A (time permitting)

Park under power lines on right side of road. Outcrops are across the road under powerlines.

Unit 2 (Perry Mtn. Formation?)

Under the power lines are several pavement outcrops of thick bedded, 4-20 cm, garnet coticule bearing metasandstones and metashales of Unit 2. The grain size is fairly coarse here reflecting M2 contact metamorphism due to the intrusion of the nearby diorite. Relict andalusite? or staurolite? are overgrown by sillimanite as seen in the thin section here. This is also a result of M2 metamorphism overprinting M1 assemblages.

No definitive topping information has been recognized in this exposure. This is in part due to the high metamorphic grade and the "fast graded" character of each bed. We are still within the inverted limb of the early F1 recumbent fold (nappe, if you will) but are on the upright limb of an inclined, downward facing, F2 synformal anticline (see cross section B-B'). The diorite body probably exploited the weak axial region of this F2 fold. (see cross section B-B'). Minor F2 folds are seen in the outcrops as are probable F1 isoclinal folds in the garnet coticules and refolded S1 cleavage.

Continue W along Rt. 202A

30.0 Junction of Routes 202A and 126 in Center Strafford, NH

30.2 Continue on Route 126. Route 202A leaves to the left.

31.5 Swamp on right, a landmark to check mileage!

31.8 Take a right down a dirt road at a mail box labelled "E. McCarthy, P.O. Box 82".

32.6 STOP 8

Park on continuation of dirt road just beyond where it turns right toward remote residence. Walk about 1/4 mile down same road to brook crossing, follow brook downstream to gorge.

Unit 4/3 contact (Carrabassett and Smalls Falls Formations?)

The contact between the rusty weathering metashale of Unit 3 and the non-rusty thin bedded alternating metasandstone and metashale of Unit 4 is exposed parallel to and in places in the gorge. Specifically the contact is marked by the abrupt loss of rusty weathering color.

At the downstream end of the gorge in some glacial potholes are preserved graded beds and some questionable flames. Topping indicates downward facing sediments. F2 folds are nearly recumbent and also face down.

This STOP confirms the presence of a non-rusty, well bedded, turbidite, Unit 4, above the rusty metashales of Unit 2 as presented at STOP 6. In addition this demonstrates that the stratigraphy as presented earlier in the day along the Spaulding Turnpike and in adjacent Maine extends at least this far into New Hampshire.

Turn around and go back along dirt road to Route 126.

33.4 Take a right onto Route 126 heading NW.

34.2 STOP 9

Just below the top of the hill, park in small dirt parking lot the trailhead for Parker Mountain on the left side of Route 126.

Unit 4/3/2 contact (Carrabassett, Smalls Falls and Perry Mtn. Formations?)

With the exception of Unit 1 (the migmatite) and Unit 4A, the entire stratigraphy is exposed here. About 100 yards down the road from the parking lot is an outcrop of thin bedded Unit 4, quite similiar to that described at STOP 8. Up the road and to the top of the hill are exposed Units 4, 3 and 2 respectively in sequence. Based on graded beds in Unit 4, the sediments here are again inverted. We are very close to a granitic body as evidenced by abundant pegmatite intrusions that are injected throughout the outcrops.

The distinctive rusty weathering metashales of Unit 3 separates, well bedded, garnet coticule bearing Unit 2 from Unit 4 which is well bedded below the parking lot but tends to be a non-rusty massive metashale near the contact.

In the last outcrop of metasedimentary rock along the road on the NE side, at the top of the hill are isoclinally, folded, F1?, coticules. F2 folds are best preserved near and within the rusty metashales of Unit 3.

Depending on desire and time we may walk up the trail from the parking lot to a cliff outcrop of Unit 4 in contact with Unit 3, spotty pavement exposures of which are in the trail. From there we would proceed into the woods above the trail and view outcrops of Unit 2 with some downward facing F2 folds, similar to those seen earlier.

Turn around and retrace route to 202A and Center Strafford, NH.

36.5 Stop sign, go straight ahead.

36.7 Bear left on 202A towards Rochester.

40.2 Take a right on Pond Hill Road.

40.9 Pass Round Pond on left.

42.3 STOP 10 Fault contact between Unit 2 and Berwick Formation

Park at bottom of hill on shoulder.

Unit 2/Berwick Formation/Nonesuch River Fault.

We are right along the extension of the Nonesuch River Fault. This prominent topographic low forms a linear that marks the fault separating the Precambrian (?) Berwick Formation from the metashales and metasandstone of Unit 2 (the Silurian Perry Mtn. Formation?). Silicified zones and minor slickensided surfaces adorned with serpentine have been found about 1/2 mile in the woods to the NE on the NW side of Little Long Pond.

Outcrops of Berwick Formation, are composed of calcsilicate bearing quartz + biotite + plagioclase granofels. Unit 2 is composed of well bedded metashale and metasandstone with partially altered andalusite and staurolite. No garnet coticules have been found in this outcrop.

END OF TRIP

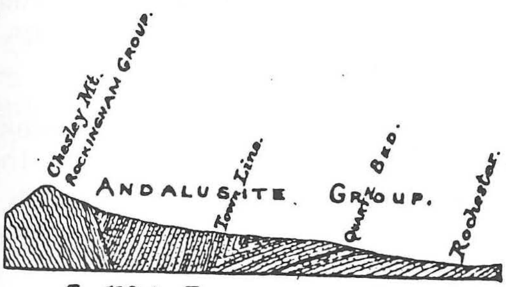

Fig. 110. In Farmington and Rochester.

C.H. Hitchcock, 1877
The Geology of New Hampshire
Volume II, 627

"In Fig. 110 is a section from Chesley mountain, Farmington to Rochester Village, lying partly in the Rockingham and partly in the andalusite group. The strata are much twisted, with a general southeast dip, and the schists contain beds of grainte".