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METAMORPHIC AND DEFORMATIONAL HISTORY OF THE STANDING POND AND PUTNEY VOLCANICS IN SOUTHEASTERN VERMONT

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INTRODUCTION

Recent investigations of rocks in eastern Vermont, notably those by Chamberlain et al. (1985), Karabinos (1984), Bothner and Finney (1986), Hepburn et al. (1984) and Laird and Albee (1981), have inspired questions concerning the interpretation of the metamorphic and structural histories recorded by the rocks. The Standing Pond and Putney Volcanics occupy a position near a major boundary separating two metamorphic terranes, the Connecticut Valley-Gaspe synclinorium (CVGS) and the Bronson Hill anticlinorium (BHA; Chamberlain et al., 1985). Because of their stratigraphic position and mafic component, the Standing Pond and Putney Volcanics contain critical evidence relavent to both the structural and metamorphic histories of the area. The purpose of this field trip is to examine the metamorphism and deformation of the Standing Pond and Putney Volcanics in southeastern Vermont.

STRATIGRAPHIC FRAMEWORK

The Standing Pond and Putney Volcanics are included in a northeast trending, steeply dipping homocline (the "Vermont Sequence"; Currier and Jahns, (1941) within the CVGS (Figure 1) in southeastern Vermont. Other papers in this volume address the nature of the western margin of the CVGS (David S. Westerman, Trip A-6) and the stratigraphic order of units within the CVGS (Norman L. Hatch, Jr., Trip B-3). Fisher and Karabinos (1980), Hepburn et al. (1984), Hatch (1986) and Bothner and Finney (1986) present arguments regarding stratigraphic succession within the CVGS. A consensus appears to be emerging that the stratigraphic order of rocks of the Vermont Sequence are (seen on this trip from oldest to youngest): Waits River Fm., Standing Pond Volcanics, Gile Mountain Fm. and Putney Volcanics. Facing directions seen at Stop 6 this trip (Figure 2) support the hypothesis that the Gile Mountain Fm., overlies the Waits River Fm.

The Waits River Formation consists of micaceous schist and calcareous quartzite containing lenses and pods of impure marble. A gradation from micaceous schist to impure quartzite occurs in some areas, but generally, layering is distinct. The schists weather rusty brown to medium to dark gray depending upon the amount of carbonate present; alignment of mica grains define a well developed schistosity in the rocks. The massive impure quartzites weather punky brown, and where the peak of metamorphism attained garnet grade the rock is pocked by garnet knobs.

The Standing Pond Volcanics form a time stratigraphic unit between metasediments of the Waits River and Gile Mountain Fms. (Hepburn et al., 1984) and vary considerably across strike. Mafic to felsic varieties of rock are all included within the Standing Pond Volcanics, but in most areas greenstone or amphibolite predominate. A large pelitic component is present in some rocks and results in a very distinctive fasiculitic layer, examples of which may be seen at Stops 3 and 6. Contacts of the Standing Pond Volcanics with the Waits River and Gile Mountain Fms. are commonly gradational and at low grade (Stop 2) not readily apparent.

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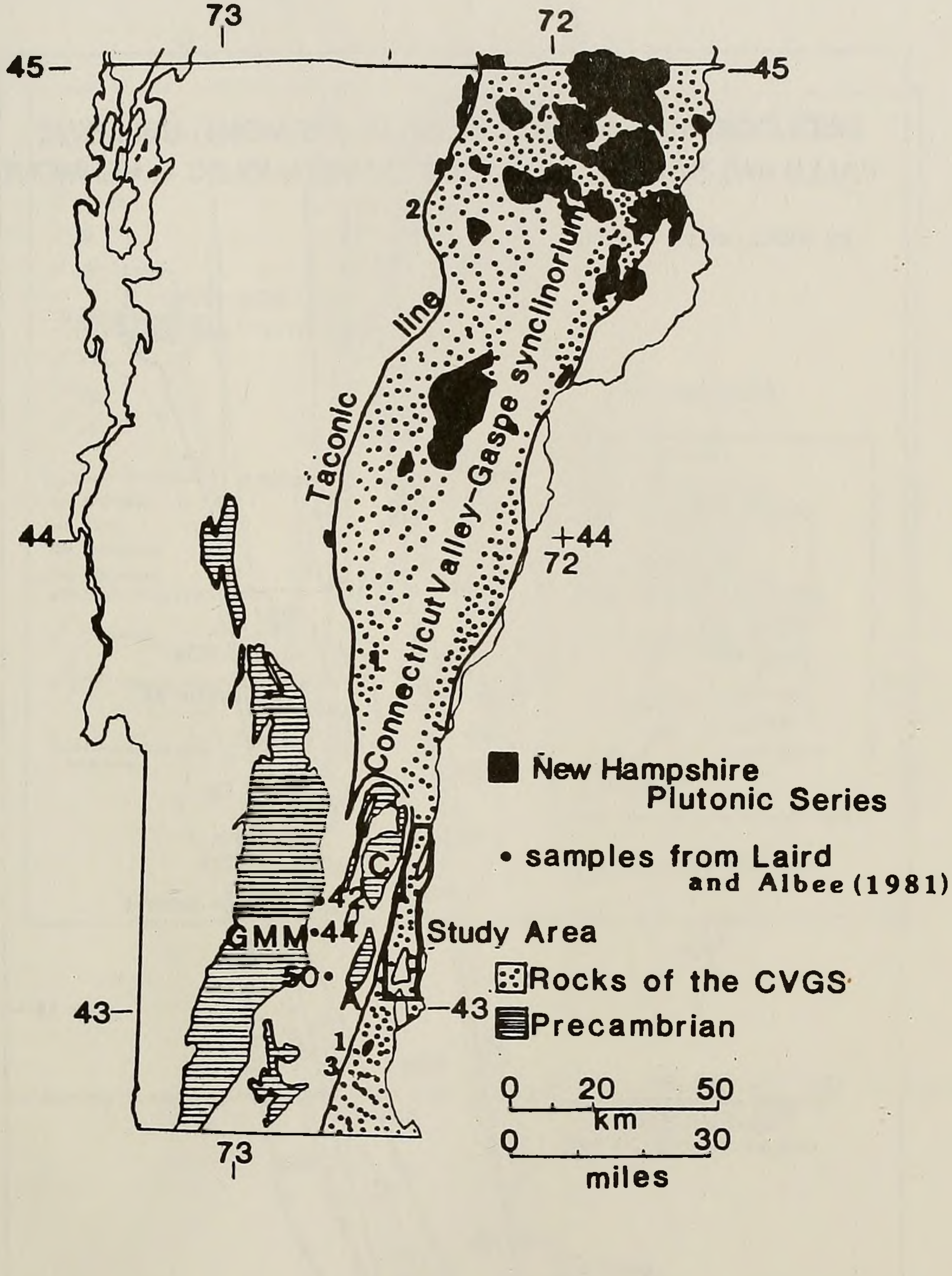
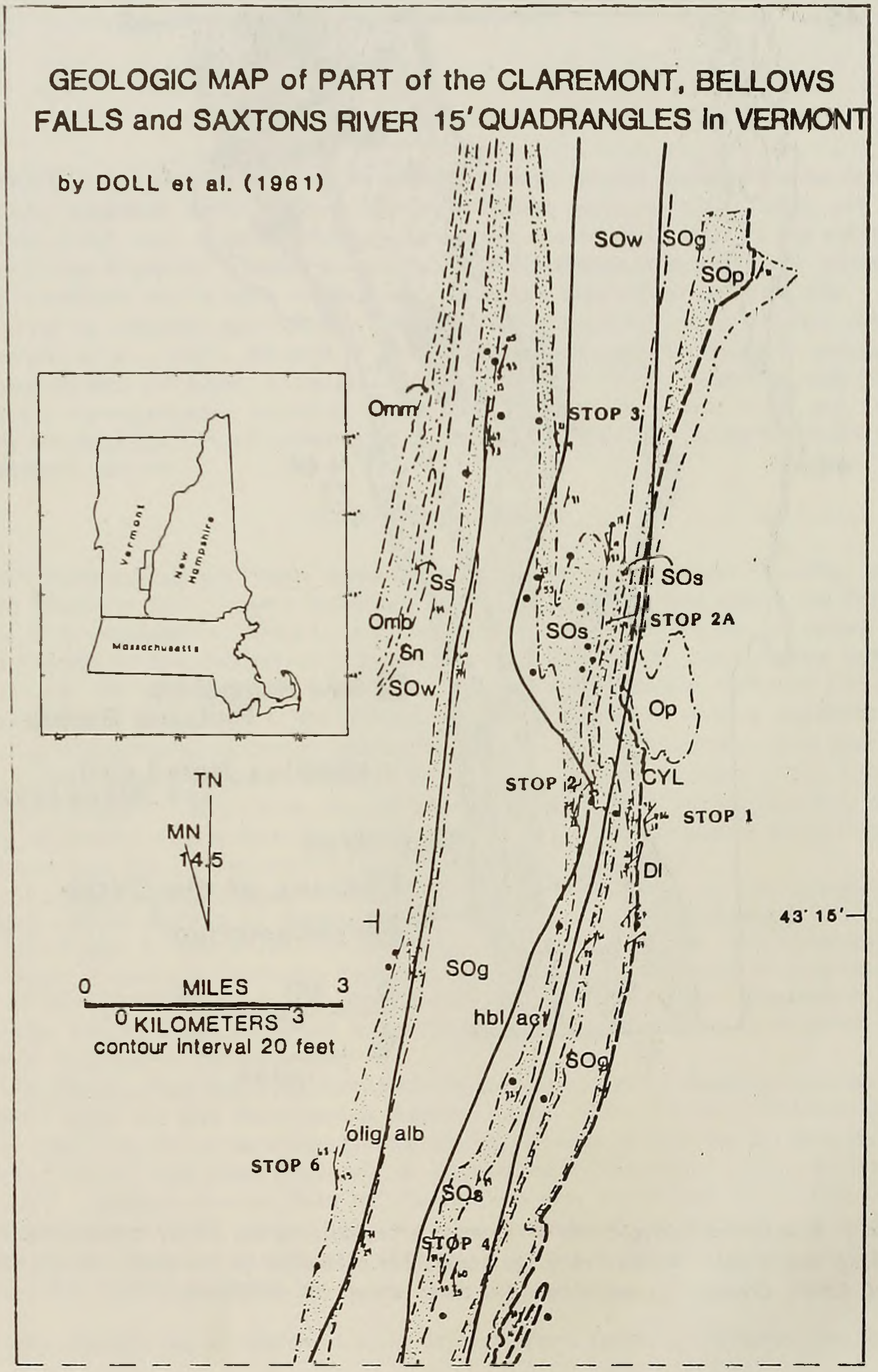


Figure 1. Simplified geologic map of Vermont after Doll et al. (1961) showing the area of this trip (outlined). Numbers refer to localities discussed in the text. Green Mountain massif (GMM), Chester (C) and Athens (A) domes shown for reference.



GEOLOGIC MAP of PART of the CLAREMONT, BELLOWS FALLS and SAXTONS RIVER 15′ QUADRANGLES In VERMONT

by DOLL et al. (1961)

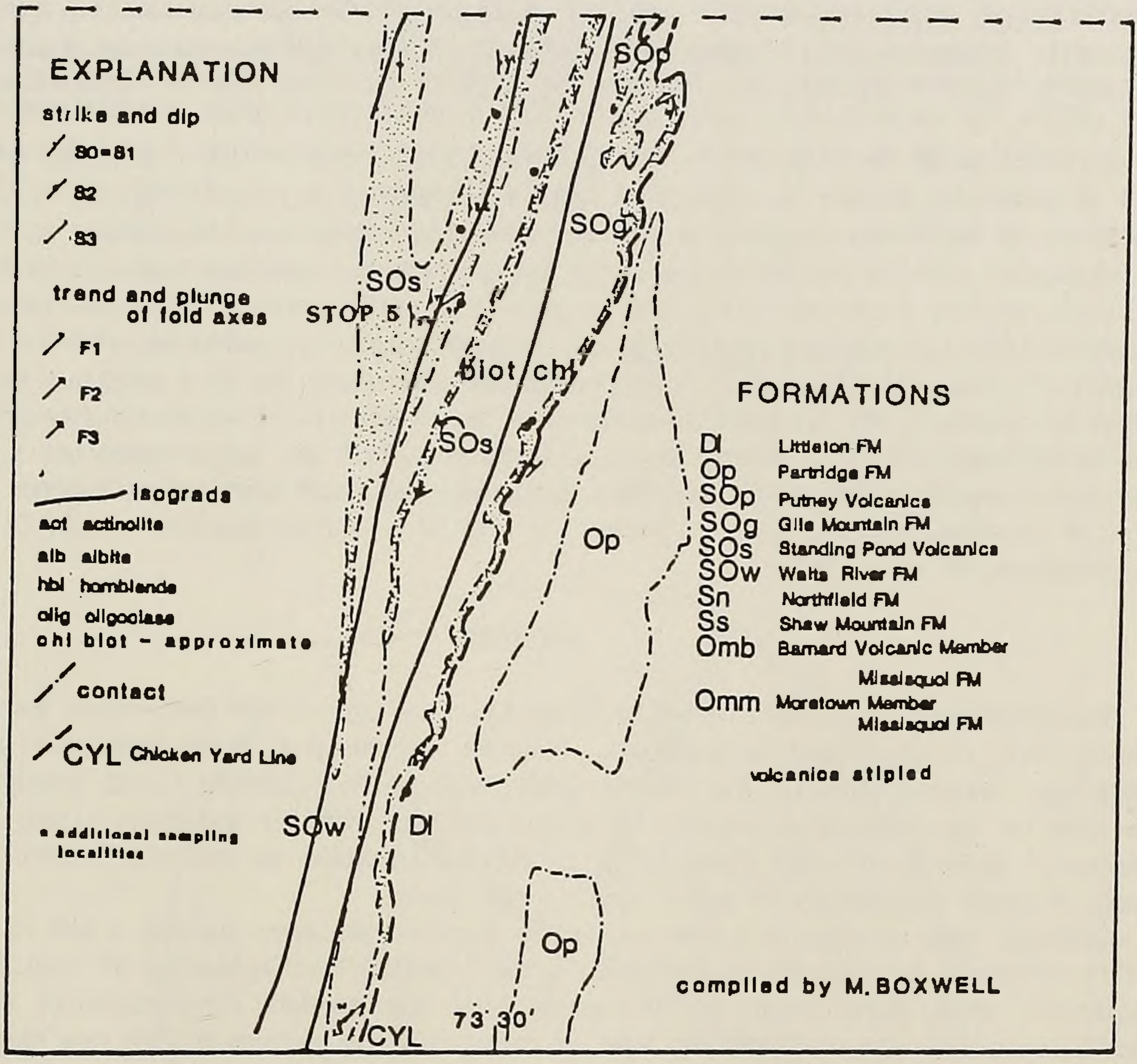


Figure 2. Geologic map of the study area with the stop localities of this trip indicated.

The Gile Mountain Formation in contact with the Standing Pond Volcanics consists of interlayered pelitic schist and quartzite in about equal proportions. Both layers weather medium to dark-gray but are only rarely rusty in contrast to schists and quartzites of the Waits River Fm. Compared with the Waits River Fm., the Gile Mountain Fm. contains a smaller carbonate component and a more monotonous repetition of schist and quartzite. Within the garnet zone, garnet porphyroblasts are abundant in the schistose layers.

The Putney Volcanics are fine-grained, massive greenstones found within the chlorite and biotite zones. At their eastern boundary, the Putney Volcanics are in sharp contact with rocks of the Littleton Fm. The western contact is not nearly as sharp because mafic rocks of the Putney Volcanics grade into chlorite and biotite grade pelitic rocks. Hepburn (1982) distinguishes the Putney Volcanics from the Standing Pond Volcanics on the basis of bulk rock chemistry, and consistent with Hepburn et al., (1984), they are here considered as a formation separate from the Standing Pond Volcanics.

Along the eastern margin of the field area, the Putney Volcanics are separated from the Littleton Fm., included within the Bronson Hill anticlinorium, by a zone of sheared rock (Stop 1). The Littleton Formation consists of dark-gray, massive, micaceous schist and phyllite that contains only a small carbonate component and much less quartz than schists of the Waits River and Gile Mountain Fms. Rocks of the Littleton Fm. generally weather dark-gray or rusty where the sulfide content is high, and are extremely fissile. These rocks are included within the "New Hampshire Sequence" (Currier and Jahns, 1941) which, in southeastern Vermont, is separated from the Vermont Sequence by the Chicken Yard Line (Hepburn et al., 1984).

AGE DATA

The stratigraphic age of the Waits River Fm. as shown on the Centennial Map of Vermont (Doll et al., 1961) is Devonian. However, recent graptolite rediscoveries near Montpelier, Vermont (Bothner and Finney, 1986) support Richardson's (1916) assignment of this unit to the Ordovician (Middle to Upper) period. Bothner and Berry (1985) report the presence of Upper Ordovician graptolites in rocks equivalent to the Gile Mountain Fm. in Quebec, further supporting an older age for the rocks.

Isotopic data constraining the age of the Vermont sequence include a 423 Ma U-Pb age on zircon from a felsic rock mapped within the Standing Pond Volcanics at Stop 2 (Aleinikoff, 1986, pers. comm.) which implies that the Standing Pond Volcanics are early Silurian or older. Crystallization ages of cross-cutting plutons of the New Hampshire Plutonic Series (Figure 1) provide a minimum age. Naylor (1971) obtained a 375 Ma Rb/Sr age on coarse muscovite and whole rock samples from the Black Mountain granite twenty miles south of the field area (Figure 1, location 1). (Data from Naylor (1971 and 1975) and Harper (1968) reported herein are recalculated using standards reported by Steiger and Jäger, 1977.)

Intrusion of the New Hampshire Plutonic Series postdates regional metamorphism and formation of recumbent folds in the CVGS (Naylor, 1975) thereby constraining these "events" to pre-Middle Devonian time if it may be assumed that the deposition of the rocks postdated the Taconic Orogeny. Metamorphic ages, including a K/Ar whole rock age of 369± 8 Ma near the western contact of the Waits River Fm. with the Shaw Mountain Fm. (Harper 1968; Figure 1, herein location 2) and a $^{40}Ar/^{39}Ar$ plateau age of 358.5± 4.3 Ma from hornblende of the Standing Pond Volcanics near Brattleboro, Vermont (Sutter et al., 1985; Figure 1, location 3) indicate that the rocks were metamorphosed during a late Devonian event.

STRUCTURE

At least three fold generations are recognized in rocks examined on this trip. Bedding, S0, is rarely visible, but where present is parallel to an S1 schistosity. S1, inferred to have formed during an F1 fold event, is only rarely preserved, and is crosscut by the main schistosity. Axes of F1 folds trend northerly or southerly with a moderate to shallow plunge, and F1 axial planar surfaces dip steeply to the east.

The dominant folding event, F2, is coaxial with F1. Where present, the foliation axial planar to F2 folds varies from a widely spaced axial plane cleavage to a well developed schistosity, S2. S2 is usually undeformed or only broadly warped or kinked by F3 folds. F2 folds are identified in the field by undeformed to gently deformed S1 surfaces. An "average" S2 dips steeply to the west. The plunge of F2 folds is generally moderate to shallow although some southwest trending folds plunge steeply. The variability in trend and plunge of F2 folds may result from porpoising of shallow plunging F2 axes.

F3 is defined by folds of S0, S1, and S2. The majority of F3 folds likewise trend northeast and southwest but plunge moderately to steeply in several directions. F3 folds appear as rounded folds in competent layers and kink bands in schistose layers. A poorly developed fracture cleavage, defined as S3, is axial planar to F3 folds formed in schistose layers.

F1 folds identified during this study are equated with major recumbent folds described by Hepburn et al. (1984) and Hepburn (1975). These folds may also be equilavent to the nappe-stage folds identified by Thompson and Rosenfeld (1979) which occur directly east of the study area. F2 folds described above are similar in style and orientation to folds formed during back folding associated with dome stage deformation (Rosenfeld, 1968).

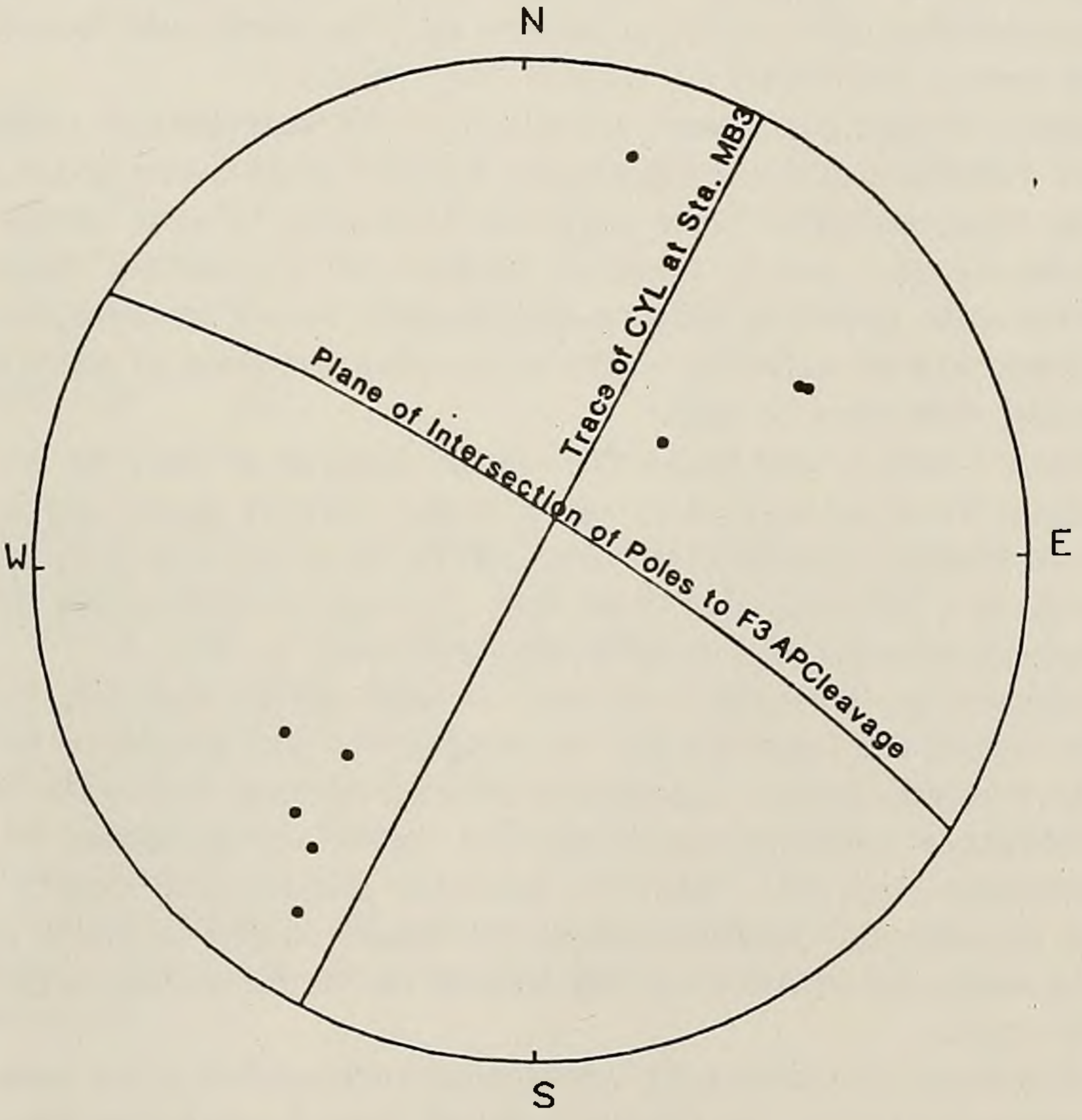


Figure 3. Stereographic projection of poles to F3 kink band axial plane foliation. Arc labelled "Plane of intersection..." is the intersection of contoured F3 axial plane points. Note the orthogonal relationship of this plane to the trace of the Chicken Yard Line measured at Stop 1 (referred to as Sta. MB3 above).

F3 folds cannot be confidently correlated to folds described by previous workers. As Hepburn et al. (1984) state, post-F2 deformation was brittle and affected the same S-surface resulting in a variety of fold styles and orientations which are not easily correlated between outcrops. In addition, F3 folds observed in this study may result from more than one period of folding. Both of these factors may contribute to the apparent random orientation of F3 fold axes observed on this trip.

Separate plots of F3 kink bands, however, suggest an association between the kink bands and faulting coincidence with the Chicken Yard Line. Figure 3 suggests that the kink bands may be conjugate to the trace of some of the faults which occur along this horizon and therefore, may be genetically related. The significance of the horizon mapped as the Chicken Yard Line is a current source of debate. South of the area of this trip the horizon mapped as the Chicken Yard Line is interpreted as an unconformity (Hepburn et al., 1984). However, extensive shearing of rocks along this horizon exemplified at Stop 1 is consistent with the interpretation that one or more faults occur along this contact. Further work is necessary to determine the extent, relative motion and amount of offset along these surfaces.

METAMORPHISM

Three metamorphic events are documented by evidence obtained from rocks of the Standing Pond and Putney Volcanics. The first two "events" appear to represent a continuum in metamorphic conditions, separated by a deformational event. The third event is a retrograde event, the effects of which vary locally.

M2, the second metamorphic event, resulted in the equilibrium assemblages present in the rocks. This event was a medium-pressure facies series event which resulted in the gradual increase in metamorphic grade observed from east to west across the study area. Easternmost rocks, Stops 1 and 2, preserve evidence of greenschist facies metamorphism, while rocks to the west preserve epidote-amphibolite facies metamorphism (Figure 2). Pelitic rocks intercalated with the mafic rocks show evidence of chlorite through garnet grade metamorphism from east to west.

Between Stops 1 and 2, and below the garnet isograd of Doll et al. (1961) amphibole changes composition from actinolite to hornblende. Farther west, and within the garnet zone, plagioclase changes composition from albite to oligoclase (Figure 2). These compositional changes are consistent with changes in rocks metamorphosed in medium-pressure facies series conditions as stated by Miyashiro (1973, p. 250).

As the effects of M2 increase from east to west across the area covered by this trip, the mafic rocks become noticeably more coarse-grained and generally darker in color. Modal changes in the equilibrium assemblage include notable increases in the abundances of amphibole and hematite/ilmenite solid solution laths, and decreases in abundances of chlorite and titanite (Table 1). Biotite, epidote, plagioclase, quartz and carbonate also change in modal abundance; however, changes in modal amounts of these minerals may be a function of bulk composition and/or influences of different metamorphic reactions which occurred in the rocks.

Chemical trends concomitant with increasing metamorphic grade were determined by electron microprobe analysis. In the vicinity of Stop 2 and below the garnet isograd of associated pelitic rocks, amphibole changes composition from actinolite to hornblende (Figures 2, 4 and 5). Specifically, Al^{VI}, Fe^{3+}, A-site occupancy (Na(A) and K contents), Ti and Na (M4) increase while Fe^{2+}, Mn and Mg contents decrease (Boxwell, 1986, Figures 25-31). Farther west and within the garnet zone, plagioclase changes composition from albite ($\leq$An04) to oligoclase (An_{14} - An_{25}). Three samples from the area contained both albite ($\leq$An05) and oligoclase (An_{14} - An_{25}), allowing tight constraint of the oligoclase isograd (Figure 2).

TABLE 1

RANGE OF MODAL PERCENTAGES FROM SAMPLES OF STANDING POND AND PUTNEY VOLCANICS DETERMINED FROM THIN SECTIONS

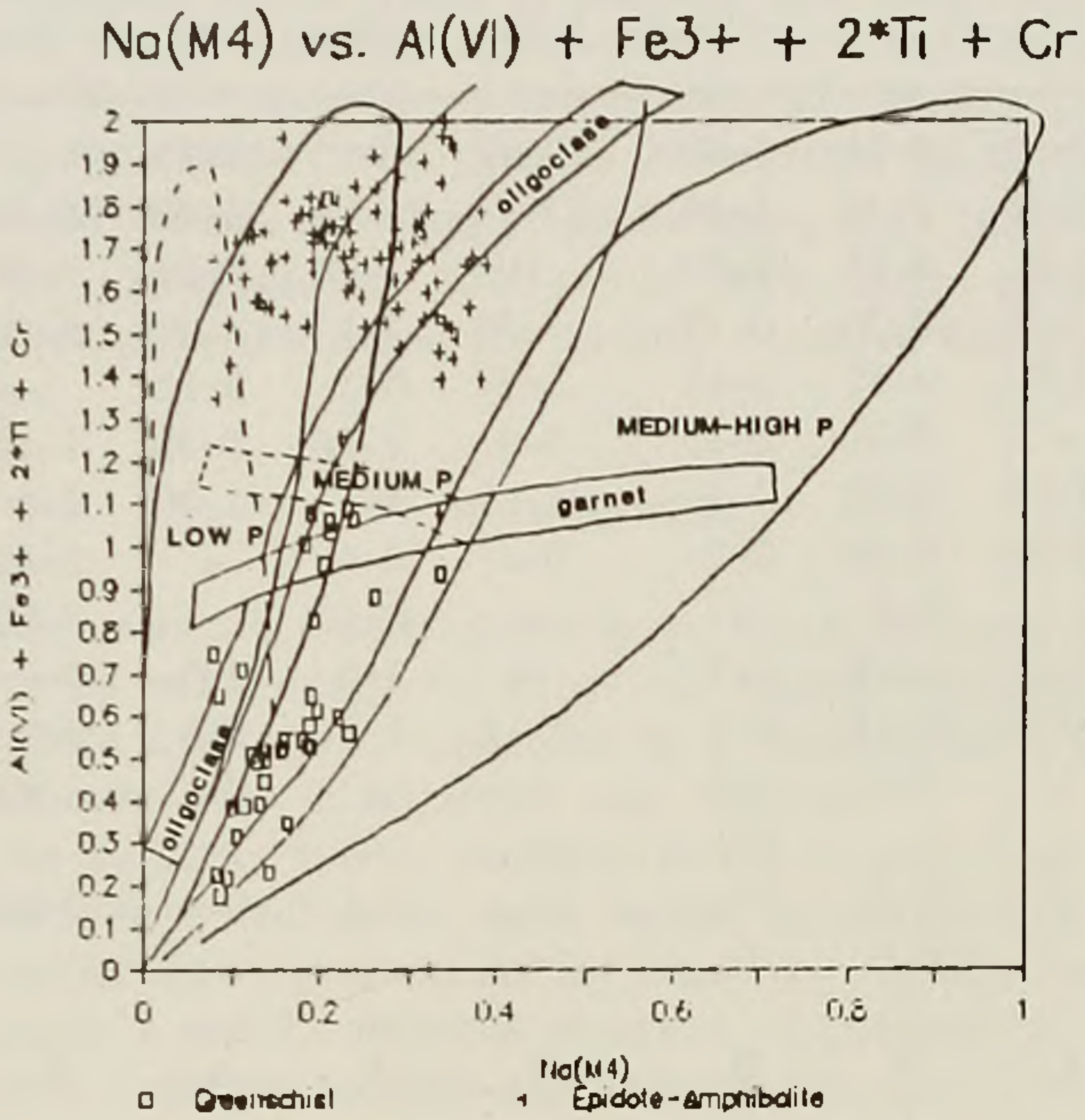
STOP:	1	2	2(int)	2A	3	4	5	5(Al)	6	6(Al)
QUARTZ	10-15	8-24	5-30	10-22	10-15	10-25	4-15	10-13	5-16	10-22
FELDSPAR	20-26	2-36	5-44	23-30	20-25	5-40	12-34	13-23	15-34	13-25
CARBONATE	2-5	5-25	12-32	10	3-20	0-25	5-20	7-20	3-12	2-19
CHLORITE	13-30	10-30	0-19	7-30	2-17	4-25	4-20	5-28	1-8	4-15
WHITE MICA	1-2	0-15	0-40	3-5	0-3	3-15	-	0-5	0-12	0-9
BIOTITE	-	0-18	0-15	0-3	1-16	5-30	1-10	10-15	2-7	5-10
EPIDOTE	7-15	0-20	0-5	2-15	3-6	<1-20	2-8	<1-7	1-8	<1-5
AMPHIBOLE	2-10	0-15	0-5	0-2	0-40	-	5-40	0-24	25-45	14-27
GARNET	-	0-2	-	-	0-10	-	3-10	0-5	0-10	1-10
OPAQUES	1-15	<1-12	1-7	<1	2-5	<1-5	3-7	3-6	2-7	2-5
TITANITE	8-12	0-15	0-5	13-15	2-7	0-8	2-5	2-3	0-10	0-2
ZIRCON	-	0-1	0-1	-	-	0-<1	0-<1	0-2	0-<1	0-1
TOURMALINE	-	-	0-1	-	-	-	-	0-<1	0-<1	-
APATITE	-	0-1	0-1	-	0-1	0-<1	0-<1	0-2	0-2	0-2
OTHERS	ST	P,R	R	-	-	-	-	F	R	-
Number	4	8	9	2	3	4	6	3	9	4
An Content	≤4	≤3			≤6				17-20	

Note: "Number" refers to the number of thin sections from which the range was derived. The symbol "-" is used if the mineral was not identified. Abbreviations used are ST- stilpnomelane, P- pennantite, R- rutile, F- fluorite. The opaque minerals identified were: iron oxide- ubiquitous, sulfide minerals in all samples except rocks from Stop 5, magnetite - Stops 1 and 5, pyrite- Stop 1, chalcopyrite- Stops 1, 3, 6 and hematite/ilmenite laths- all Stops except Stop 1. The letters "Al" refer to aluminous-rich rocks present at Stops 5 and 6. The term "int" refers to rocks at Stop 2 which are gradational between the volcanics and adjacent metasedimentary rocks. The range in An content was determined by electron microprobe analysis.

Other changes in mineral composition with increasing metamorphic grade are summarized as follows: the average Ti and Al (mostly Al^{VI}) contents in biotite increase. Fe^{3+} content in epidote decreases and Al^{VI} component increases. Although the composition of chlorite is variable across the field area, the composition of chlorite in equilibrium assemblages is more restricted and changes regularly with increasing metamorphic grade. In general, Mg, Al^{IV}, Fe^{3+} and Al^{VI} contents increase, whereas Fe^{2+} and Mn contents decrease.

As shown in Figure 4, data from this study plot within the medium- and low-pressure facies fields delimited using data of other mafic schists in Vermont (Laird et al., 1984; the fields and bars are amended as shown in Figure 4 to incorporate data from this study).

The fact that amphibole changes composition from actinolite to hornblende at lower grade than the change in plagioclase from albite to oligoclase occurs indicates that M2 was a medium-pressure facies series event similar to metamorphism preserved in rocks west of the CVGS in southeastern Vermont (Laird, 1980; Laird and Albee, 1981). North of the field area in rocks of the CVGS, low pressure facies series metamorphism is preserved.



Na(M4) vs. Al(VI) + Fe3+ + 2*Ti + Cr

Figure 4. Plot of Al(VI) + Fe3+ + 2*Ti + Cr vs. Na(M4) formula proportion units in amphibole showing that analyses from the study area plot within the medium-pressure facies field delimited by Laird et al. (1984). Analyses plotting to the right of the oligoclase isograd are amphibole which coexist with albite; those plotting to the left of the oligoclase isograd represent amphibole which coexist with albite and/or oligoclase. (Dashed lines represent suggested revisional boundaries for the low-pressure facies field and garnet isograd bar based on data from this study.)

Figure 5 summarizes the compositional changes in the major phases described above. The increase in the Y-component (AF_2O_3 - 3/4CaO - Na_2O) is dominated by an increase in the Tschermak substitution ($Al_2Mg_{-1}Si_{-1}$). As can be seen in Figure 5, the MgO/FMO ratio in chlorite and amphibole spans a range of bulk composition yet the tie line orientations are consistent within samples of the same metamorphic grade. This observation, coupled with the fact that the change in compositions linked by the tie lines is similar to that first observed by Wiseman (1934) and later by Laird (1980, 1982) regardless of bulk composition, supports the idea that the relative increase in Fe2+/Mg ratio in amphibole and the decrease in the same ratio in chlorite is a function of metamorphic grade and not bulk composition.

A sample from Stop 2 (Figure 5b) appears to be intermediate in composition between greenschist facies and epidote-amphibolite facies zone samples. The gradual change in amphibole composition contradicts information supporting a miscibility gap in amphibole compositions between actinolite and hornblende suggested by many workers (e.g. Miyashiro,

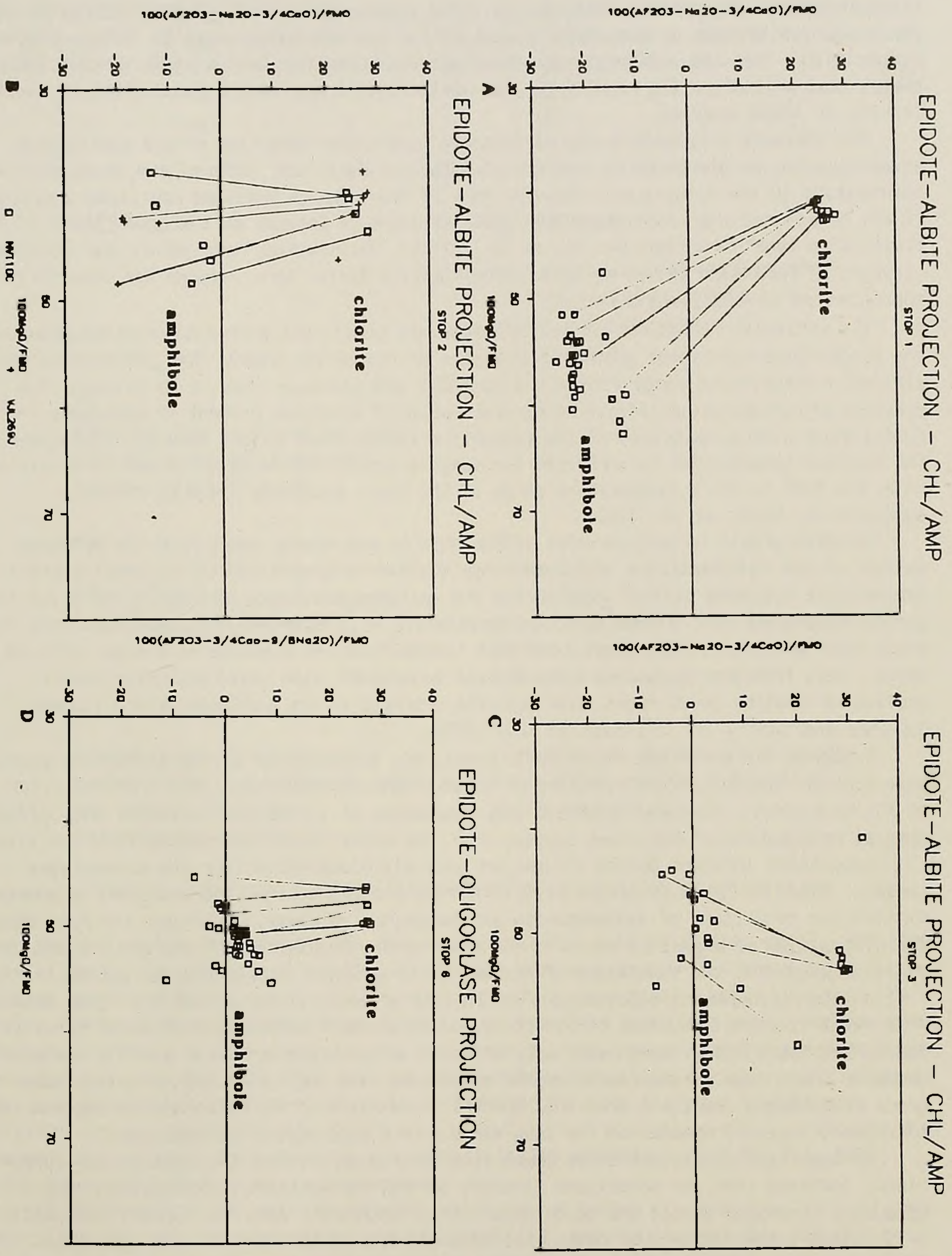


Figure 5. Projection of amphibole and chlorite from epidote and albite (or epidote and oligoclase for sample from Stop 6 where the plagioclase is oligoclase). Lines connect points from the same sample, and are shown for illustrative purposes. Note the change in orientation of the tie lines from greenschist (5a and sample VJL269J - 5b) to epidote-amphibolite facies (sample NVT10C - 5b, 5c and 5d).

1958; Shido and Miyashsiro, 1959; Brady, 1974; Cooper and Lovering, 1970; Doolan et al., 1973). As can be seen by data from sample NVT10C the miscibility gap is "bridged" by this composition. Textural evidence, such as exsolution lamellae, which might support the theory that actinolite and hornblende are immiscible (Grapes and Graham, 1978) is likewise lacking in these samples.

The pressure temperature regime inherent during the formation of the equilibrium assemblage may be discerned by comparing analytical data from rocks of the study area with information in the literature. Because none of the samples analyzed contained andesine, it may be assumed that conditions during M2 were not as intense as the upper limit of the "transition zone" described by Liou et al. (1974). The maximum temperature and minimum pressure of formation of the M2 epidote-amphibolite facies zone samples are therefore approximated at 560^{0}c and 3.4 kbar.

The estimated conditions of metamorphism are consistent with estimates obtained using the plagioclase-hornblende geothermobarometer of Plyusnina (1982). The geothermobarometer yielded a temperature range from 405^{0}c to 540^{0}C and pressure from <2 to >8 kbar. The pressure of metamorphism inferred from the amount of aluminum present in amphibole in equilibrium with plagioclase of the respective composition ranges from <2 to >8 kbars. The maximum temperature is estimated for samples containing no titanite and is consistent with the 500^{0} to 540^{0}c temperature range of the upper stability limit of titanite suggested by Moody et al. (1983).

Mineral growth in samples west of the Chester and Athens domes from the Moretown member of the Missisquoi Fm. and the Pinney Hollow Fm. (Laird and Albee, 1981) yield a temperature estimate of 500^{0} ± 25^{0} c for the garnet-albite zone and 550^{0} ± 50^{0} c for the garnet-oligoclase zone. These data are correlative with M2 mineral assemblages from the study area and empirically consistent with temperature and pressure estimates referred to above. Data from the study area are likewise consistent with solid piezothermometry studies of kyanite grade rocks from Gassetts, Vermont to the northwest which yielded 5.6 kbar and 545^{0} ± 20^{0} c (Adams et al., 1975).

Evidence for the first metamorphic event, M1, is preserved within garnet and amphibole grains. Coarse-grained examples of these phases contain cores which formed prior to an F2 fold event. Textural evidence (e.g. abundance of inclusions in cores) and differing optical orientation of the cores suggest that the cores formed discretely from the rims.

Conditions inherent during M1 are not entirely discernible from the assemblages present. Equilibrium assemblages relict from M1 are incomplete, and therefore attempts to discern the conditions of metamorphism are hampered. However, based upon the fact that the composition of amphibole cores is the same as the composition of amphibole rims, one might suggest that the conditions of metamorphism were the same during M1 and M2.

A late retrograde metamorphism, M3, locally affected rocks within the study area. This event reached a maximum of biotite grade in western samples but affected rocks on a bed-to-bed basis and in some cases only affected microlayers within a specific rock. M3 occurred under less intense metamorphic conditions than M2, as evidenced by the lower grade assemblages resultant from M3. Specific conditions of M3 metamorphism may not be discerned, however, because of the lack of complete equilibrium assemblages.

An important conclusion to be drawn from this study is that the equilibrium assemblages indicate that the conditions inherent during the dominant metamorphism, M2, gradually increased across the study area. This hypothesis does not support the pattern of isograds presented on the Centennial Geologic Map of Vermont (Doll et al., 1961). The isogradic pattern on the state map suggests that metamorphic grade decreases from east to west across the study area, before gradually increasing to the west.

RELATIONSHIP OF METAMORPHISM TO DEFORMATION

The relationship between the timing of metamorphism and deformation within rocks of the field area is summarized in Table 2. Formation of an S1 schistosity is assumed to have accompanied an F1 deformation. This early foliation is preserved by oriented inclusions within mineral grains of the equilibrium assemblage (e.g. amphibole and garnet) suggesting that the F1 fold event preceded the main metamorphism (M2).

Table 2

Deformation		Metamorphism
		M3 post-dates all deformation; sheet silicates aligned parallel to relict cleavage planes in pseudomorphs
F3 Kink folding in schistose rocks, open folds in more competent layers; folds F2 folds		
F2 Formation of dominant schistosity, folds F1; M2 minerals aligned parallel to F2 fold axes		M2 Formation of equilibrium assemblage. Varies from greenschist in the east to epidote-amphibolite facies in the west (chlorite to garnet grade)
F1 Formation of early isoclines preserved in less competent rocks may predate M1 or be contemporaneous with it.	??	M1 Formation of amphibole and garnet cores which contain a foliation which predates F2

Table 2. Summary of the relationship of metamporphism to deformation.

The main metamorphic event, M2, was contemporaneous with an F2 fold event. The long axes of amphibole grains are parallel to F2 fold axes measured in the field (Stop 6). Rotated garnets (Stops 3 and 6) contain concentric inclusion trails indicating that the grains formed during deformation as suggested by Rosenfeld (1968 and 1972). Radial splays of amphibole found in garbenschiefer may have formed in an area of reduced pressure during this deformation. The fact that some of the amphibole splays are curved as well suggests that the grains formed contemporaneously with folding. Also, the main foliation is deformed around porphyroblastic grains of the equilibrium assemblage while other grains of the equilibrium assemblage overgrow the main foliation suggesting that the main metamorphism and deformation were simultaneous.

F3 folds deform the main schistosity which formed during F2; therefore, F3 must post-date F2 and M2. The late regrograde metamorphism, M3, appears to post-date all deformation. The position of sheet silicate grains parallel to relict mineral cleavage planes in pseudomorphs (e.g. chlorite and biotite after amphibole) attests to the interpretation that the M3 retrograde metamorphism occurred after deformation ceased. Sheet silicates which overgrow foliation are interpreted as products of M3 metamorphism.

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Mileage

0.0 STOP 1

The first stop consists of three roadcuts which are located on the north side of Route 11, and extend almost continuously from the driveway into Howard
0.30 Johnson's restaurant westward for approximately .3 miles to Paddock Road. On the east end of the first roadcut are chlorite grade rocks of the Littleton Fm. The fine-grained , gray-green weathering, epidote-carbonate schists display primary layering and a west over east fold sense. F3 generation kink bands are superposed on F2 folds of primary layering and S1. The orientation of primary layering in the Littleton Fm. here is northeast trending, westward dipping.

Approximately 200 feet west of the eastern end of this outcrop is the horizon referred to as the Chicken Yard Line (CYL) which marks the boundary between the Vermont and New Hampshire Sequences in southeastern Vermont. In this roadcut, the CYL occupies a zone less than 6 feet wide and is a light colored, tan to gray, fine-grained, sugary textured rock in which distinct lithons less than four inches in length may be seen. The trace of the CYL here trends northeast and dips nearly vertical and is clearly at a high angle to layering observed in rocks of the Littleton Fm. The nature of the CYL at this locality appears to be a shear zone, and is expected to inspire some debate on this trip.

The Putney Volcanics make up the western end of the first roadcut as well as the entirety of the two western roadcuts of this stop. Here the Putney Volcanics are fine-grained, massive, dull green-gray weathering greenstones. Color and texture vary due to subtle changes in mineralogy and mode (e.g. amount of epidote, presence of carbonate and amount and species of sheet silicates). Sulfide porphyroblasts and epidote knots are abundant in some layers. The amphibole is actinolite and very fine-grained. Layering in the Putney Volcanics is indistinct, similar to Stop 2 and different from Stops 2A to 6, where well defined layering is visible.

Continue west on Route 11 towards Springfield.

0.75 The eastern roadcut of Stop 2 begins on the south side of Route 11.

1.0 Turn right (north) off Route 11 onto road leading over the Black River. Park here on the side of road and cross Route 11 to examine rocks of Stop 2.

STOP 2

Two roadcuts extending 0.25 miles along the southern side of Route 11 comprise Stop 2. Here metasediments of the Waits River and Gile Mountain Fms. are intercalated with the Standing Pond Volcanics. According to Doll et al. (1961) the Waits River Fm. occupies the western end of the eastern roadcut and the Gile Mountain Fm. occupies the western end of the western outcrop. Contacts of both of these formations with the Standing Pond Volcanics, which comprise the remainder of both outcrops, are gradational and therefore not easily pinpointed. The metasedimentary units at this locality are biotite grade. The Standing Pond Volcanics here are similar to the Putney Volcanics seen at Stop 1 with respect to lack of distinctive layering and massive appearance. The Standing Pond Volcanics are weathered light to medium gray-green or brownish and commonly contain rusty pits where carbonate and sulfide grains have weathered out. The fresh surface varies in color due to differences in composition; lighter layers are comparatively felsic, green layers, chlorite- and biotite-rich and punky brown layers are carbonate-rich. Unlike the Putney Volcanics seen at the previous stop these rocks have a smaller mafic component and lack epidote stringers. Amphibole from the eastern roadcut is hornblende which allows classification of the rocks as epidote-amphibolite facies (e.g. after Miyashiro, 1972). The fold style of F2 here is similar to that seen at Stop 1; however, F2 trends southwest instead of northeast. Because the plunge of F2 is shallow ($\leq 30^0$) the change in trend may result from porpoising of F2. F3 folds here appear as large warps of layering with little or no widely spaced crenulation cleavage axial planar to the fold surface. The rock which Aleinikoff (1986, pers. comm.) dated is approximately 100 feet from the western end of the western outcrop.

1.3 Turn left (north) up steep hill, road turns into a dirt road near the top of the hill.

2.7 Turn left (northwest) on Old Crown Point Road just after pavement begins.

3.6 Turn left (west) at intersection onto Old State Route 10.

3.8 Turn right (north) onto Eureka Street.

4.0 Farmhouse on west side of road belongs to Rufus Estes. If you are following this road log after the NEIGC trip, please ask his permission to park off the road and look at the outcrops in the pasture on the east side of the road.

STOP 2A (Optional Stop)

Many different layers of epidote-amphibolite facies zone Standing Pond Volcanics exist in the field which are continuous with those seen at Stop 3 (see below). The purpose of this stop is to examine the nappe-stage fold displayed in cross section in one of the pasture outcrops. The fold can be viewed on the southern face of an outcrop of medium gray-green, massive greenstone near the southeastern edge of the height of land in the pasture. The fold is an isoclinal upright fold with an undeformed axial planar cleavage. It appears to be similar in style to the F1 nappe-stage folds of Rosenfeld (1968 and 1972) yet has an undeformed axial planar cleavage suggesting that it might be an F2 generation fold.

5.5 Turn left (west) on Barlow Road.

6.2 Turn right (north) on Old Crown Point Road.

6.3 Outcrops on the east side of road are biotite-grade metasedimentary rocks.

7.1 Pull off on the east side of the road where a dirt road leads into the pasture. Walk back to farmhouse on west side of road and ask permission of Dick and Helen Moore to enter the pasture to examine the rocks, if you are following this road log after the NEIGC trip.

STOP 3 [PLEASE! NO HAMMERS AT THIS STOP]

Outcrop on the west side of Old Crown Point Road is biotite grade Gile Mountain Fm. The knots on the surface are identified petrographically as chloritized garnet. The chloritization is interpreted as having occurred during M3. The garnets may be M1 or M2 generation. Continuing into the pasture, a wide variety of layers of Standing Pond Volcanics can be seen. Westernmost layers are felsic, light colored, and contain biotite and chlorite but no garnet or amphibole. Farther east in the field are dark-colored, medium-grained amphibolites that may or may not contain garnet. The amphibole is hornblende, and the plagioclase albite. Based on the mafic rocks therefore, the rocks here are classified as epidote-amphibolite facies. One must wonder why the pelitic rocks have been affected by the late retrograde metamorphism, M3, yet the mafic rocks do not appear affected by M3 at all.

The amphibole in most samples is aligned parallel to the foliation. The main schistosity here is F2 and because the amphibole lies in the plane of schistosity one may conclude that the amphibole formed contemporaneously with the formation of the S2 schistosity.

Continue north on Old Crown Point Road.

7.3 Turn left (west) at the T-intersection. At the southwest corner of this intersection is another outcrop of Gile Mountain Fm. which contains garnet replaced by chlorite.

7.9 Turn left (south) at the T-intersection and follow this road into downtown Springfield.

10.4 Turn left (south) on Main Street - Route 11.

10.8 Cross over the Black River and stay to the right (west; do not follow Route 11).

10.85 Go straight (west) at the lights - up the hill.

11.1 At the top of the hill bear left (south).

13.2 Continue south at the intersection at Hardscrabble Corner.

13.3 Bear right at the fork in the road; continue on the paved road.

18.3 Pass under the railroad overpass and pull off the road to the east. The best outcrops are on the east side of the bridge along the river.

STOP 4 Beware of the Poison Ivy.

The rocks along the river bank are primarily mafic schists of the Standing Pond Volcanics. Units vary from dark greenish-gray, weathering, schistose mafic rocks to black and white laminated, massive "amphibolites" with felsic porphyroblasts. In thin section such differences are obscured by the effects of M3 metamorphism. All of the amphibole has been replaced by biotite, chlorite, epidote group minerals, carbonate and felsic minerals. Despite the pervasiveness of the effects of the retrograde metamorphism these rocks may have been subjected to epidote-amphibolite facies metamorphism during M2. The coarse-grained amphibole peudomorphs may indicate that the amphibole was hornblendic in compositon. In the absence of analytical data and because the surrounding rocks are greenschist facies zone rocks, these rocks are included within the greenschist facies zone also.

Downstream from the mafic rock is a fine-grained, massive, calcareous, micaceous quartzite of the Waits River Fm. This biotite grade sample is located near the contact with the Standing Pond Volcanics according to Doll et al. (1961), but unfortunately the contact is not visible.

F2 generation folds are closed folds of layering and S1 which have a cleavage developed that is axial planar to F2. F2 folds plunge moderately to the southwest.

Continue south across the bridge.

12.6 Turn right (west) onto Route 103.

20.2 Turn left (south) onto Pleasant Valley Road.

26.6 Turn left (east) at the T-intersection onto Route 121 towards Saxtons River.

26.9 Continue straight on Route 121 (don't turn right to go over the river).

27.0 Turn right (south) onto side street and head towards the river.

27.05 Turn right (west) and park in the parking area near the river.

STOP 5 (Stop 10 of Rosenfeld, 1972).

The outcrops along the river here are spectacular and afford almost a complete summary of both the structure and metamorphism seen thus far on the trip. The Standing Pond Volcanics at this stop, as mapped, form the southern hinge of a recumbent fold (Doll et al., 1961; Figure 2) and therefore, units should be repeated across the axis of the fold. However, an increase in metamorphic grade within these exposures makes assessment of lithic continuity across the fold difficult to discern.

Beginning in the outcrop southwest of the parking area downsteam from the bridge, three generations of folds are visible. F1 is seen in a carbonate-rich layer folded back upon itself. F2 appears as open to closed folds of layering and S1. F1 and F2 seen here are nearly parallel; F2 plunges moderately to the south. F3 open folds and kinks of S2, S1 and layering are visible in this outcrop also. F3 plunges moderately also, but in a southwesterly direction.

Rocks east of and downstream from the bridge are biotite grade, greenschist facies samples. The metasedimentary rocks are predominantly light-colored, micaceous schists. The contact between the metasedimentary rocks and the Standing Pond Volcanics is gradational. Rocks containing a predominant mafic component are present west of (upstream from) the bridge. West of the bridge the metamorphic grade changes to garnet grade or epidote-amphibolite facies.

The Standing Pond Volcanics, as seen in samples upstream from the bridge, are medium- to coarse-grained, brown-weathering and predominantly massive although some layers appear schistose. Some of the massive rocks appear to contain discrete laminae of mafic and felsic compositions. Others contain garnet, and still others contain approximately 20% carbonate minerals. A question of many workers in this area is whether the layers represent original layering or are a product of metamorphism.

Back track on Pleasant Valley Road to Route 103.
27.10 Turn left (north) back towards the center of Saxtons River.
27.15 Turn left (west) onto Route 121.
27.5 Turn right (north) onto Pleasant Valley Road.
33.9 Turn left (west) on Route 103.
34.0 Turn right (north) towards Brockways Mills.
34.4 Turn right (east) at T-intersection.
34.8 Turn off the road at the clearing, park and cross the railroad tracks into the field. Cross the field and go into the woods at the southernmost corner of the field. Follow the path down to the river.

STOP 6

Streamcuts here are Standing Pond Volcanics in contact with rocks of the Waits River Fm. to the west (upstream) and rocks of the Gile Mountain Fm. to the east (downstream). The contact with garnet grade calcareous schist of the Waits River Fm. is very sharp and well-exposed. The contact between Standing Pond Volcanics and garnet grade, micaceous schist of the Gile Mountain Fm. is not exposed.

Directly east of the contact with the Waits River Fm. is a spectacular example of fasicular schist or "garbenschiefer". Splays of amphibole cover the rock, some of which emanate from two-inch diameter garnet porphyroblasts and radiate in 360^0. Some amphibole grains within individual fasicles appear curved also. Within garnet porphyroblasts concentric and sigmoidal inclusion trails are visible. These patterns have been described by Rosenfeld (1968, 1972) and are used to interpret the rotational directions of the rocks during deformation.

Downstream from the fasicular schists are other well defined layers of Standing Pond Volcanics. Some layers are very micaceous and appear similar to the garbenschiefer yet contain no garnets. Farther downstream massive, laminated, green-gray and white weathering amphibolites, some of which contain rusty pits where carbonate has weathered out, are present. Near the falls, is a layer which weathers orange colored and is very light on the fresh surface. Plagioclase crystals are easily visible and predominate in this felsic rock. This layer appears similar to the felsic layer observed at Stop 3 yet is farther east in the layering sequence at this stop than was the felsic layer seen at Stop 3.

Downstream from the falls is a layer of mafic rock which is laminated black and white. On the eastern side of the pool (downstream) are micaceous schists of the Gile Mountain Fm. Medium-grained garnet knobs are present in this rock.

Microprobe analyses of a sample of laminated, dark green-gray weathering amphibolite that does not contain garnet allowed classification of the amphibole as hornblende and the plagioclase as oligoclase (An_{17} -An_{20}) which is consistent with epidote-amphibolite facies zone classification (Figure 2).

Many of the laminae within layers at this stop appear to be cut by an S2 schistosity. F2 folds plunge moderately to the northeast, and are generally open folds. The long axes of amphibole grains lie parallel to the plane of S2 and in some localities the long axes of amphibole grains are parallel to axes of F2 folds. The curved fasicles of amphibole and rotated garnet grains are interpreted as indicating that F2 and M2 were contemporaneous.

Primary layering is visible in micaceous schists of the Waits River Fm. upstream from the fasicular schist. Graded beds within the layers indicate that rocks to the east stratigraphically overlie those to the west. This is consistent with interpretations of Fisher and Karabinos (1980) in which they conclude that the Gile Mountain Fm. overlies the Waits River Fm.

To get to Northfield, return to Route 103 and turn left (east) on Route 103. Follow Route 103 to Interstate 91 North. Take I-91 North to the Northfield Exit.