BEDROCK GEOLOGY

OF THE

MT. ABRAHAM - LINCOLN GAP AREA

CENTRAL VERMONT

by

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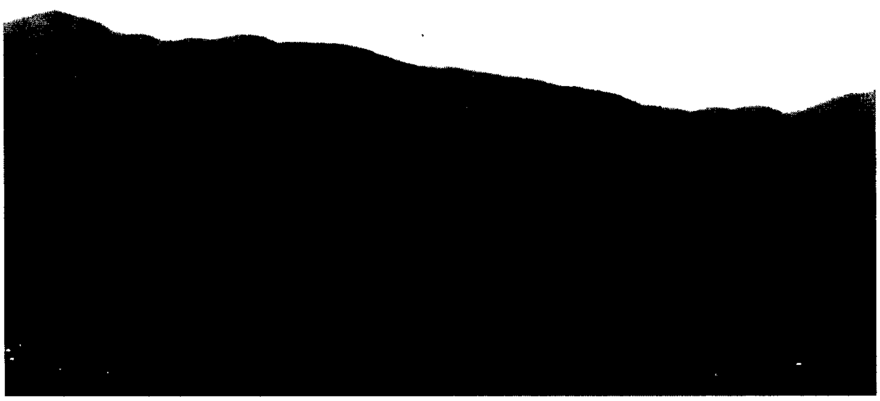

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Cover photograph: View of Mt. Abraham looking toward the northeast. The study area is located on the crest and west slope of the mountain between the peak of Mt. Abraham (high point visible to the left or north, elevation 4006 feet) and Lincoln Gap (the notch to the right).

ABSTRACT

Mapping at the scale of 1:12,000 and detailed petrography have identified complex relationships in the medium grade, late Proterozoic to Cambrian rocks on the west slope of the Green Mountains between Mt. Abraham and Lincoln Gap. The Hoosac, Underhill and Hazens Notch Formations and the Mt. Abraham Schist have been subdivided into 11 mappable lithologies composed of varying proportions of aluminous, albitic, carbonaceous, and mafic schists and metawackes. The aluminous Mt. Abraham Schist and the carbonaceous schist of the Hazens Notch Formation are both distinct from the biotite and albite bearing schists and metawackes of the Underhill Formation and the albitic Hazens Notch schist. The rocks are presently arranged as thrust slices whose boundaries are broadly equivalent to the lithic boundaries mapped by earlier workers (Cady and others 1962). Deformation is most intense to the east and becomes progressively younger to the west.

The current west to east sequence of units is the result of deformation which progressed from east to west in a piggyback manner. The progression is complicated by the emplacement of carbonaceous schist (CZhnc) on a previously assembled and deformed (Fn-1) sequence of albitic Hazens Notch schist (CZhn) and Mt. Abraham Schist (CZa). This emplacement occurred prior to, or synchronously with, the development of the dominant schistosity (Sn) and Fn folds in these units. Fn+1 deformation is superposed on the dominant schistosity (Sn) with mesoscopic and crenulate folds better developed to the east than to the west. Late deformation (Fn+2), is limited to areas in and adjacent to the Prospect Rock belt in the western part of the area. Fn+2 deformation broadly folded Fn+1 axial surfaces.

Peak metamorphism is associated with the development of the dominant schistosity (Sn) and retrograde metamorphism is superimposed upon both Fn and Fn+1 deformation. Fn+2 deformation is associated spatially with the growth of coarse biotite and white mica across both the dominant schistosity (Sn) and Sn+1. Semi-brittle, post-peak metamorphic faults postdate and, in part, reactivate the earlier, ductile, pre- and syn-peak metamorphic faults which are associated with the emplacement of thrust slices.

The albitic Hazens Notch schist and Mt. Abraham Schist in the Lincoln Gap area are lithically similar to the albitic and chloritoid bearing schists of the allochthonous Hoosac Formation and the Greylock slice in western Massachusetts. This relationship suggests that the Lincoln Gap area contains rocks and structures that represent the northern extension of the root zone for the eastern and structurally higher slices of the Taconic allochthons (Group 3 slices of Stanley and Ratcliffe 1985).

INTRODUCTION

The Mt. Abraham - Lincoln Gap area (Pl. 1) is located in central Vermont on the crest and western flank of the Green Mountains in the Lincoln, Vermont 7.5 minute quadrangle. The boundaries of the area approximate the latitudes 44 degrees 5 minutes and 44 degrees 7 minutes 30 seconds north (the quadrangle boundary) and the longitudes 72 degrees 5 minutes and 72 degrees 58 minutes east.

Complex relationships between folds, faults and metamorphism have been recognized as a result of mapping at the scale of 1:12,000 and detailed petrography of 130 thin sections. For more detailed analyses of the relationships presented in this paper, see O'Loughlin (1986).

Previous work in the study area includes mapping by Cady, Albee, and Murphy (1962) in the 15 minute Lincoln Mountain quadrangle and reconnaissance work by Gordon (1927) for the 1925-1926 Report of the State Geologist. Abstracts of preliminary work in the study area include Stanley and others (1985) and Lapp and O'Loughlin (1986).

The units in the study area are Late Proterozoic (Z) to Cambrian (Tauvers 1982, DiPietro 1983, and Stanley and Ratcliffe 1985) and represent remnants of the ancient North American continental margin (rift clastic rocks and slope and rise rocks) which were significantly deformed and shortened during the Taconian orogeny (Stanley and Ratcliffe 1985). Age determination is based upon gross lithic correlations to fossil containing rocks to the west and north. The lithic similarity between the formations in the Lincoln Gap area and the rocks of the Group 3 slices of the Taconic allochthons suggests that this part of the Green Mountains represents the northern extension of the root zone for the Taconic allochthons, as proposed by Stanley and Ratcliffe (1985).

LITHOLOGIES

The four major units present in the Mt. Abraham - Lincoln Gap area are the Hoosac Formation, the Underhill Formation, the Mt. Abraham Schist, and the Hazens Notch Formation. Rock units in the study area are generally lithically gradational into adjacent units and many similarities exist between the micaceous units. Gradational relationships appear as gradual changes in rock composition across a contact but they are not assumed to be indicative of depositional relationships because premetamorphic fault contacts between rocks of similar strengths also result in gradational contacts after metamorphism. Interlayering of lithologies is not observed.

Due to the high degree of structural complexity in the area, the lithologic and petrologic descriptions which follow are presented by thrust slice in a general west to east progression and do not represent a sedimentary stratigraphic sequence.

Hoosac Formation

The Hoosac Formation in the study area is located in the Cota Brook sequence (Pl. 1, location (Loc.) 04) and in scattered outcrops along the western margin of the study area. The Cota Brook section is a well exposed sequence of mafic schist (CZhms), metawacke (CZhg) and other quartz and plagioclase rich rocks in the stream valley of Cota Brook. The nature of the Hoosac Formation in the study area is similar to the Hoosac Formation of Tauvers (1982) and Stanley and Ratcliffe (1985).

<u>Metawacke (CZhg)</u>: The Hoosac metawacke is a light gray to tan, quartz and plagioclase rich (up to 80 percent), massive to schistose metawacke with muscovite, chlorite, and minor biotite and garnet. The texture of the metawacke is relatively coarse. The metawacke is well foliated in outcrop and is found surrounding and between mafic schist (CZhms) of the Cota Brook section (Pl. 1, Loc. 04). The contact of the Hoosac metawacke (CZhg) with the Underhill micaceous schist (CZu) on the eastern side of the Cota Brook sequence is a highly deformed zone of schistose and micaceous rocks. The contact to the west with the Underhill foliated metawacke (CZufg) is laminated and characterized by thin, lineated graphitic and micaceous layers which appear sheared. Both the eastern contact of the metawacke (CZhg) with the Underhill foliated metawacke (CZufg) and the western contact with the Underhill micaceous schist (CZu) are interpreted as syn-metamorphic faults (Pl. 1, Loc. 04).

<u>Mafic schist (CZhms)</u>: The mafic schist is a dark to very dark green, medium to very coarse grained rock consisting of amphibole, chlorite, biotite, plagioclase, and carbonate in varying proportions. Very mafic areas contain coarse amphibole needles in a plagioclase rich matrix. The mafic schist is best exposed in the Cota Brook sequence (Pl. 1, Loc. 04) where numerous layers are in contact with the metawacke (CZhg) and other schistose and quartz rich rocks. Many mafic schist contacts are transitional and gradational across a distance of 10 meters. Other contacts are sharp and undulatory and may represent depositional relationships.

Underhill Formation

The Underhill Formation is located in a linear belt in the western part of the study area. The Underhill Formation consists of three units: highly variable micaceous schist (CZu), foliated metawacke (CZufg), and less abundant mafic schist (CZums). These units are similar in nature to parts of the Underhill Formation previously defined by Cady and others (1962).

<u>Micaceous schist (CZu)</u>: The highly variable Underhill micaceous schist (CZu) is a medium to coarse grained, greenish to brownish schist which is rich in muscovite and chlorite. Biotite, garnet, and albite are abundant at some putcrops. Thin, white to gray, laminated quartzites (1-3 cm thick) are present and are relatively discontinuous. Patches of graphite or graphite seams are present in some areas, especially near fault zones. Coarse garnet porphyroblasts, partially altered to chlorite, are typical of this unit but are relatively small (up to 1 cm) and are commonly scattered across an outcrop. Distinct porphyroblasts of coarse white albite are common.

Individual albite porphyroblasts range in size from 0.5 to 1.5 cm but do not reach the coarseness of albite porphyroblasts in areas of the Hazens Notch Formation (CZhn). The Underhill micaceous schist (CZu) is present in the western parts of the study area.

Adjacent to the Prospect Rock belt of Mt. Abraham lithologies (for description and definition of the Prospect Rock Belt, see the Mt. Abraham Schist), the micaceous schist (CZu) is characterized by coarse garnet porphyroblasts (up to 1.5 cm diameter) and abundant coarse books of biotite (up to 2 cm thick) which randomly cut across the dominant foliation (referred to subsequently as cross biotite). Large grains of muscovite (up to 0.5 cm) are also oriented at random angles across the dominant foliation and impart a distinctive 'spangly' aspect in reflected light. At some outcrops, patches of coarse albite porphyroblasts (1.5 cm diameter) are conspicuous.

Foliated metawacke (CZufg): This unit is a well foliated or laminated quartz and plagioclase metawacke with micas concentrated along the foliation surfaces. Quartz and plagioclase comprise up to 80 percent of the rock. The resistant quartz and plagioclase rich layers are 5-15 cm thick and are separated by thin mica rich layers less than 0.5 cm thick which consist of varying proportions of chlorite, biotite and muscovite. The metawacke is very resistant to erosion, resembles quartzite in polished or smoothed stream bed exposures, and is more blocky in appearance away from the stream exposures. Quartz veins are noticeably rare in this unit. Small garnet porphyroblasts (up to 0.5 cm) may be present and are partly altered to chlorite. Minor opaques, graphite and garnet are present with minor carbonate near mafic schists. The closely spaced, planar, foliation surfaces distinguish this metawacke from the more massive Hoosac metawacke (CZhg).

The Underhill foliated metawacke (CZufg) grades into the micaceous schist (CZu) at a number of locations (Pl. 1, Locs. C5 and E5). This gradation is present as a gradual change in rock composition within 0.5 to 1 m. The foliated metawacke (CZufg) is present in two north-south trending bands in the western part of the study area.

Mafic schist (CZums): Underhill mafic schist (CZums) is medium to very dark green in color, fine to very coarse grained, and contains chlorite, amphibole, epidote, biotite, albite, carbonate, and quartz. In coarse grained areas, the minerals are segregated into dark green, amphibole rich layers and light green, epidote, chlorite and quartz rich areas.

The mafic schist is a resistant rock which forms rounded, long, thin outcrops. A post-peak metamorphic fault contact characterized by semi-brittle fabrics is present between the Underhill mafic schist (CZums) and the magnetite-garnet schist (CZamg) at location C6 (Pl. 1). Sharp contacts are present between the Underhill foliated metawacke (CZufg) and the mafic schist (CZums) at locations D5 and E6 (Pl. 1). Gradational contacts are present between the mafic schist (CZums) and the Underhill micaceous schist (CZu) and are represented by a gradual change in mineral composition across a distance of 30 meters. Amphibole and epidote enrichment of the micaceous schist (CZu) is common near the mafic schist (CZums) at locations D5 and E5 (Pl. 1).

Mt. Abraham Schist

The Mt. Abraham Schist, originally defined by Cady and others (1962) for the rocks at Mt. Abraham (Pl. 1, Loc. C9), underlies most of the northern part of the study area. A linear belt of rocks, lithically related to the Mt. Abraham Schist (CZa), trends from location B5 (Pl. 1) southward to Prospect Rock (Pl. 1, directly south of Loc. Q5). This belt is referred to subsequently as the Prospect Rock belt. Mafic schist is absent from the Mt. Abraham Schist.

The Mt. Abraham Schist, in this report, is elevated in stature only to the level of a formation. We are not attempting to separate the Mt. Abraham Schist from the previously defined hierarchy of lithic names. The Mt. Abraham Schist, however, should not be considered a part of the Underhill Fòrmation. In the study area, the Mt. Abraham Schist is distinct and contains three mappable lithologies.

Chloritoid-white mica schist (CZa): The main body of the Mt. Abraham Schist is characterized by a silvery (pearly) sheen on foliation surfaces that results from the presence of fine to very fine paragonite (Cady and others 1962). The characteristic mineral assemblage is quartz, paragonite, chloritoid, chlorite, and kyanite. Chloritoid and kyanite in association with pearly white mica are very typical of the schist and distinguish it from all other units in the area. Graphite is absent from the Mt. Abraham Schist (CZa).

Scattered, fine grained garnet porphyroblasts, which are partly or totally altered to chlorite, are seen in the main body of the schist. Near the contact with the magnetite garnet schist (CZamg), chloritized garnet is more abundant in the Mt. Abraham Schist (CZa). In most locations, clots of chlorite with long drawn out 'tails' are present on the foliation surface. These features represent chlorite pseudomorphs after garnet in which the garnet has been totally retrograded to chlorite and the pseudomorphs smeared out during deformation.

Rusty to fresh kyanite blades (0.5 - 1 cm long) are locally present in random orientations on the dominant schistosity. In several locations, the kyanite is sufficiently abundant to resemble a mat of intertwined twigs. The blades are commonly altered to white mica and opaques (visible in thin section) and this alteration gives the pseudomorphs a rusty weathered color. Numerous quartz veins of varying thicknesses are abundant throughout the main body of the Mt. Abraham Schist. These veins are parallel to the dominant schistosity and are highly folded by later Fn+1 crenulate folds. Plagioclase is absent from this unit.

At various locations (shown by stippled overprint on CZa, Pl. 1, Locs. C5 through E5 and E6 through F6) the chloritoid-white mica schist is finer grained, has fewer quartz veins and is much more chlorite rich. Coarse porphyroblasts are entirely absent from this fine grained Mt. Abraham Schist (fine CZa) although this unit has the same mineralogy as the main body of Mt. Abraham Schist (CZa).

Dominant schistosity in the fine grained Mt. Abraham Schist (fine CZa) is very well developed in thin section and sheared textures are absent. The fine grained Mt. Abraham Schist grades into the main body of Mt. Abraham Schist (CZa) and into the Mt. Abraham magnetite-garnet schist of the Prospect Rock belt (western CZamg). As the main body of the Mt. Abraham Schist (CZa) is approached, chlorite streaks and the pearly sheen on the dominant schistosity (Sn) are progressively better developed. As the fine grained Mt. Abraham Schist (fine CZa) grades into the magnetite-garnet schist (western CZamg), the contact is marked by the first appearance of magnetite and garnet porphyroblasts which become increasingly more abundant toward the magnetite-garnet schist (western CZamg). The gradational nature of these contacts and the lack of sheared textures suggests that the fine grained Mt. Abraham Schist (fine CZa) does NOT represent a highly sheared part of the Mt. Abraham Schist (CZa).

Magnetite-garnet schist (CZamg): The magnetite-garnet schist is characterized by distinctive porphyroblasts of magnetite (0.5-1.5 cm) scattered throughout a white mica matrix and patches of coarse (up to 2 cm) garnet porphyroblasts, partially altered to chlorite. Individual grains of muscovite are visible in the matrix. The magnetite-garnet schist is characterized by a shine on its foliation surface similar to, but not as uniform as, the sheen on foliation surfaces of the Mt. Abraham Schist (CZa). Much of the quartz in this unit appears to be present in veins. Minor pyrite porphyroblasts were identified at one location (Pl. 1, Loc. L12).

Two separate areas of magnetite-garnet schist (CZamg) are defined within the study area, an eastern and a western facies. These units are lithically similar but are associated with different units.

The eastern magnetite-garnet schist is transitional in mineralogy between the main body of the Mt. Abraham Schist (CZa) and the albitic Hazens Notch schist (CZhn). Both contacts are gradational with the composition of one unit systematically changing into that of the other. Toward the Mt. Abraham Schist, the eastern magnetite-garnet schist is characterized by a higher percentage of white mica in the matrix, minor kyanite, smeared out chlorite patches, a greater percentage of chloritoid, and abundant magnetite and garnet. The sheen on the dominant schistosity is progressively better expressed toward the Mt. Abraham Schist (CZa). Toward the Hazens Notch Formation (CZhn) the magnetite-garnet schist has a higher percentage of chlorite and biotite in the mica matrix, few chlorite clots, increasingly abundant albite porphyroblasts, less magnetite, fewer garnets, and an increasing abundance of laminated quartzites (1-10 cm thick) in the schist.

The eastern magnetite-garnet schist has a greater similarity to the Mt. Abraham Schist (CZa) and related lithologies than it does to the main body of the Hazens Notch (CZhn). Previous workers (Cady and others 1962 and Doll and others 1961), who mapped on a smaller scale (1:62,500), undoubtedly included the majority of this unit within the main body of the Mt. Abraham Schist (CZa).

The western facies of magnetite-garnet schist has been mapped within the Prospect Rock belt (Pl. 1, Locs. D4, F4-G4, J5, M6 and others). The western magnetite-garnet schist is nearly identical to the eastern magnetite-garnet schist lithically and is characterized by the presence of coarse magnetite and garnet porphyroblasts and a white mica sheen on the foliation. Significantly, a much higher percentage of chloritoid is present in the western facies than in the eastern facies. The western body of magnetite-garnet schist grades into both the garnet schist (CZags) and the fine grained Mt. Abraham Schist (fine CZa). The contact of the western magnetite-garnet schist (western CZamg) with the garnet schist (CZags) is defined as the last appearance of magnetite porphyroblasts in the unit as the garnet schist is approached. The contact of the western magnetite-garnet schist (western CZamg) with the fine grained Mt. Abraham Schist (fine CZa) is characterized by the absence of magnetite, the absence of coarse porphyroblasts, and a reduction in grain size toward the fine grained Mt. Abraham Schist (fine CZa).

<u>Garnet schist (CZags)</u>: The garnet schist is characterized by abundant coarse to very coarse (1-3 cm) garnet porphyroblasts which are partially altered to chlorite. The schistose matrix is dominantly white mica with scattered chlorite. Fine grained chloritoid is present in thin section. In general, this unit more closely resembles the chloritoid rich Mt. Abraham Schist (CZa) than it does any of the Underhill lithologies. Coarse cross muscovite which has grown in random orientations with respect to both the dominant foliation and the crenulation foliation is likely the result of a late stage episode of deformation and associated metamorphism. Plagioclase is absent from this unit.

Gordon (1927) noted a coarse garnet porphyroblast schist located in a belt trending southward from east of Elder Hill (Pl. 1, west of Loc. E1; labelled Alder Hill on the topographic map) to Prospect Rock (Pl. 1, south of Loc. Q5). The coarse grained, garnetiferous units which were noted in the Prospect Rock belt of this study include: 1) the Mt. Abraham magnetite-garnet schist (western CZamg), 2) the Mt. Abraham garnet schist (CZags), and 3) the coarse grained, garnetiferous, Underhill micaceous schist (coarse CZu).

Hazens Notch Formation

The main body of Hazens Notch consists of albitic, micaceous schist (CZhn). It is located predominantly in the southeastern part of the study area where it overlies the Mt. Abraham Schist (CZa). The carbonaceous schist (CZhnc) is mainly found in two areas in the southeast part of the study area but it also occurs as slivers along with post-peak metamorphic faults.

<u>Albitic schist (CZhn)</u>: The main body of the Hazens Notch is a chlorite, biotite, muscovite schist with abundant coarse to very coarse (1-3 cm diameter), light gray to white albite porphyroblasts. The porphyroblasts are more resistant than the matrix of the rock and resemble white spots on weathered surfaces. The matrix of the albitic schist (CZhn) contains more chlorite and biotite than muscovite and is darker than the matrix of the Mt. Abraham Schist (CZa). The amount of chlorite commonly varies within a single outcrop. White to gray, laminated quartzites (2 to 30 cm thick) are continuous across a single outcrop, are parallel to the dominant schistosity (Sn), and define an internal layering in the rock which may be related to the development of Sn-1 schistosity and may also represent bedding. Garnet

porphyroblasts, partially altered to chlorite, are commonly visible only in thin section. Abundant quartz veins are parallel to the dominant schistosity and are deformed by crenulation folds.

Small (up to 5 meters long) bodies of albitic, chlorite-rich 'greenstones' with epidote, minor carbonate, and traces of sphene are associated with, and possibly interbedded with, the main body of Hazens Notch rocks (CZhn). Minor carbonate is visible in thin sections from samples of rocks adjacent to these chlorite rich lenses.

Carbonaceous schist (CZhnc and CZhnca): The carbonaceous schist (CZhnc) is very graphitic, gray to black in color, and dull to shiny in luster. The graphite in this rock comes off on the thumb when a moderately fresh foliation surface is rubbed. This unit is not very resistant to erosion and hence it underlies stream valleys and Lincoln Gap. Locally, the carbonaceous schist is rich in fine to medium grained quartz which is disseminated throughout the schist. Minor pyrite cubes are present at a few outcrops (Pl. 1, Loc. L12).

The carbonaceous schist (CZhnc) grades into albitic Hazens Notch schist (CZhn) at one locality in the study area (Pl. 1, Loc. M14). At this locality, the gradation progresses from a white albitic schist (CZhn) into a carbonaceous, black albitic schist (CZhnca), which is characterized by abundant, coarse (0.5-2 cm), black albite porphyroblasts in a carbonaceous matrix, and finally into a dark carbonaceous schist with no porphyroblasts (CZhnc). These gradational relationships are overprinted by tectonic contacts at this location, however, the lithic relationships suggest that the carbonaceous, black albitic schist (CZhnca) is a transitional lithology between the albitic schist (CZhn) and the carbonaceous schist (CZhnc). A similar relationship between the albitic Hazens Notch (CZhn) and the carbonaceous unit at Linclon Gap was proposed by Gordon in 1927 and is noted to the east in the Waitsfield - Warren valley (J. Prewitt, per. comm.).

Mineralogy

Table 1 presents a summary of mineral percentages for each micaceous lithology. These percentages are strongly biased by outcrop and thin section selection. Furthermore, the samples were selected to represent the volume of rock between the numerous quartz veins present in all micaceous units. These mineral percentages therefore represent the volume of rock between quartz dominated areas and do not represent whole rock percentages for each unit. Veins and pods of other minerals, such as albite and chlorite, are present in the units but they are isolated occurrences and are not as volumetrically important as the quartz veins.

Stratigraphic Comparison to Previous Work

A comparison of the map units in this study with the units defined by Cady and others (1962) identifies many similarities and a number of important exceptions. Three important points are discussed below in the order of their importance.

TABLE 1

Estimated Modes for Pelitic Schists and Metawackes of the Underhill Formation, Mt. Abraham Schist, and Hazens Notch Formation, Mt. Abraham - Lincoln Gap Area.

UNIT	CZufg	CZu (coarse)	CZu	CZags	western CZamg	CZa (fine)	CZa	eastern CZamg	CZhn	CZhnc
MINERAL										
Quartz	46	17	17	25	17	24	32	36	28	26
White Mica	22	34	52	32	42	5	34	41	26	16
Chlorite	3	8	9	10	12	8	13	10	17	8
Chloritoid	-	-	-	9	9	14	6	2	-	-
Plagioclase	14	13	10	tr	2	-	-	6	17	21
Garnet	2	13	3	16	10	-	tr	1	3	1
Biotite	4	9	2	-	-	-	-	-	5	4
Kyanite	-	-	-	-	-	-	8	tr	-	-
Graphite	2	4	3	3	1	-	1	tr	tr	23
Opaques	4	5	4	5	7	2	4	4	3	1
Carbonate	3	-	-	-	-	-	tr	-	tr	-
Epidote	-	-	-	-	-	-	-	tr	tr	-
Tourmaline	tr	tr	-	-	-	-	-	-	tr	-
Sphene	-	-	-	-	-	-	-	-	tr	-
Pyrite	-	-	-	-	tr	-	-	-	-	tr
number of samples	11	12	11	2	11	4	12	18	12	13

A dash (-) signifies that the mineral is absent.

Opaques are dominantly magnetite.

For unit abbreviations, see Plate 1.

1. Cady and others (1962) did not map the carbonaceous schist (CZhnc) as a separate unit although it was shown on the Centennial Geologic Map of Vermont (Doll and others 1961) as the Battell member of the Underhill Formation. Our work shows that the carbonaceous schist is lithically related to the albitic schist of the Hazens Notch Formation and that it occurs at a number of locations throughout the Hazens Notch Formation and the Mt. Abraham Schist. O'Loughlin (1986) and Lapp (1986) have shown that the carbonaceous schist is in fault contact with rocks surrounding it. This unit has proved to be one of the most important units in deciphering the tectonic geology in this part of the Green Mountains.

2. The albitic Hazens Notch schist (CZhn) located to the southwest of the Mt. Abraham Schist (CZa) in this study was mapped as part of the Underhill Formation by Cady and others (1962). The rocks in this area are albitic and are traceable to, and similar to, the Hazens Notch schist (CZhn) to the east and south of Lincoln Gap. These rocks have therefore been mapped as the Hazens Notch schist (CZhn) in this report.

3. Cady and others (1962) did not separate the eastern magnetite-garnet schist (CZamg) from the Mt. Abraham Schist (CZa) nor did they separate the garnet schist (CZags) and the western magnetite-garnet schist (western CZamg) of the Prospect Rock belt from the surrounding Underhill Formation. These rocks are lithically more similar to the Mt. Abraham Schist (CZa) than to either the Underhill Formation (CZu) or the Hazens Notch Formation (CZhn) because they contain chloritoid and lack both biotite and plagioclase. A belt of rocks distinguished by very coarse garnet porphyroblasts was, however, noted by Gordon in 1927 (see the description of this belt under the Mt. Abraham garnet schist).

METAMORPHIC ASSEMBLAGES AND RELATIONSHIPS

Metamorphic Assemblages

The assumed peak metamorphic assemblages of the micaceous schists in the study area are listed below. These units include: the Mt. Abraham Schist (CZa), magnetite-garnet schist (CZamg), and garnet schist (CZags), the Underhill micaceous schist (CZu), and the Hazens Notch albitic schist (CZhn) and carbonaceous schist (CZhnc). The assemblages are given in order of relative abundance, from highest to lowest. Muscovite and quartz are additional phases in all assemblages. Opaques and graphite are additional and minor in all assemblages with the exception of the carbonaceous schist (CZhnc) where graphite is a major component.

CZu: albite-chlorite-garnet-biotite
CZhn: albite-chlorite-biotite-garnet
CZhnc: albite-chlorite-biotite
CZa: paragonite-chlorite-kyanite-chloritoid
CZamg: chlorite-garnet-chloritoid-magnetite±albite
CZags: garnet-chlorite-chloritoid

Metamorphic assemblages for units in the study area agree well with pelitic schist assemblages from the Mt. Grant area analyzed in detail by Albee (1965). The Thompson projection (Al_2O_3-FeO-MgO, projected through muscovite) from Albee (1965) (Fig. 1) which illustrates the observed equilibrium assemblages is useful in discussing bulk assemblages of the units defined in this study. Phases which fall on the projection include kyantite, chloritoid, almandite (garnet), chlorite, and biotite. Additional phases for all assemblages include muscovite and quartz and accessory phases may include magnetite, tourmaline, graphite, and pyrite.

Bulk Compositions

The bulk composition of the Mt. Abraham Schist (CZa) with its assemblage of kyanite, chloritoid, and chlorite plots in Area A on the Thompson projection (Fig. 1). Paragonite is commonly observed in the Mt. Abraham Schist (CZa) and is an additional phase in Area A.

Parts of the Mt. Abraham Schist (CZa) are kyanite poor and garnet is present in the Mt. Abraham Schist (CZa) near its contact with the eastern magnetite-garnet schist (CZamg). Additionally, textural evidence suggests that the abundant chlorite streaks in the Mt. Abraham Schist (CZa) are the product of retrograde reactions of garnet. The bulk compositions for kyanite poor and garnet rich areas of the Mt. Abraham Schist (CZa) fall in Area B on the Thompson projection.

Bulk compositions of the Mt. Abraham magnetite-garnet schist (CZamg) and garnet schist (CZags), with chloritoid, chlorite, and garnet, also plot in Area B of Figure 1. Additional phases in this area of the projection are paragonite and ilmenite. Ilmenite was observed in the magnetite-garnet schist (CZamg). Magnetite plots at FeO on this projection but this mineral contains Fe_2O_3 which would bring magnetite off the plane of the projection and allow it to coexist with chloritoid. The bulk composition of the magnetite-garnet schist (CZamg) would thus plot off the plane of the diagram in the volume defined by chloritoid, chlorite, garnet, and magnetite.

The Underhill micaceous schist (CZu) and the albitic Hazens Notch schist (CZhn) both have identical assemblages with garnet, chlorite, and biotite. Bulk compositions for these units plot in Area C of the Thompson projection which includes albite as an additional phase.

The bulk composition of the carbonaceous Hazens Notch schist (CZhnc) with chlorite and biotite plots along the tie line between these two phases. Albite and ilmenite are additional phases in this assemblage. In some areas, garnet is found in the carbonaceous schist (CZhnc). The addition of garnet to the assemblage pulls the bulk composition off the tie line and into Area C.

Discussion

The metamorphic assemblages observed in the units of the study area plot on the Al_2O_3-FeO-MgO Thompson projection through muscovite (Albee 1965) in distinct areas. Crossing tie lines on the projection and disequilibrium assemblages in the rocks are not observed (Albee 1965). Differences in

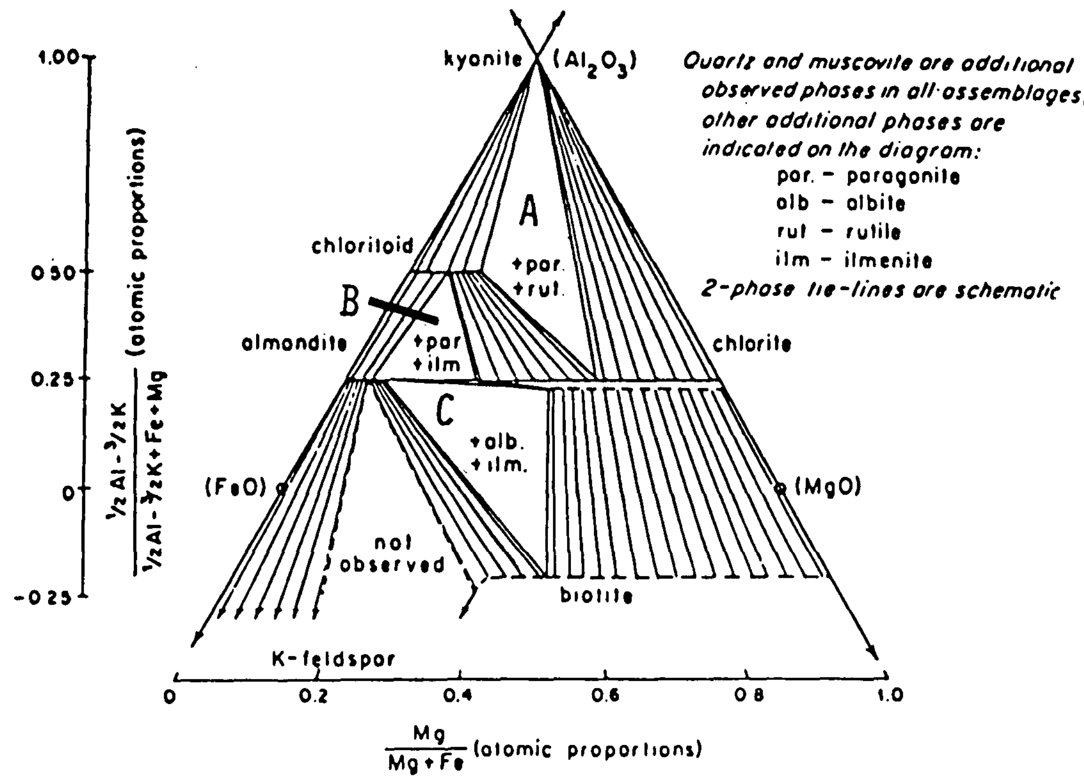

Figure 1. Metamorphic assemblages of the Mt. Grant area from Albee (1965). Thompson projection through muscovite on the Al2O3-FeO-MgO plane. Bulk compositions of Mt. Abraham Schist (CZa) are represented by Areas A and B. Magnetite-garnet schist (CZamg) and garnet schist (CZags) bulk compositions are represented by Area B. Bulk compositions of the Hazens Notch and Underhill Formations are represented by Area C. All assemblages are in metamorphic equilibrium.

metamorphic assemblages, therefore, do not reflect changes in metamorphic grade but are the result of differences in the original bulk compositions of the lithologies. The kyanite bearing Mt. Abraham Schist (CZa) and related chloritoid bearing units (CZamg and CZags) are not higher grade assemblages but reflect a bulk composition which is higher in Al_2O_3 than the albite and biotite bearing Underhill micaceous schist (CZu) and albitic and carbonaceous Hazens Notch schists (CZhn and CZhnc). Peak metamorphic assemblages were formed at depths of 10 to 15 kilometers at approximately 500 degrees Celcius as suggested by Albee (1968).

Retrograde reactions in the study area are important to determining the pressure-temperature paths of the rocks. Sericite and opaques retrograde kyanite in the Mt. Abraham Schist (CZa). Chlorite retrogrades garnet in all units. These retrograde reactions have been interpreted to be either: 1) the result of Acadian metamorphism (Lanphere and Albee 1974) or 2) the result of cooling from peak Taconian metamorphism (Sutter and others 1985). We suggest that some of the retrograde reactions may be the result of late imbrication of thrust slices of contrasting temperatures. Determination of the pressure-temperature paths may provide additional evidence for structural deformations and may suggest deformations which were previously unrecognized. Resolution of the problem awaits further work.

STRUCTURE

Faults and Fault Fabrics

Three categories of faults (pre-peak, syn-peak, and post-peak metamorphic faults) are recognized in the Mt. Abraham - Lincoln Gap area and are distinguished by the criteria listed in Table 2. The peak metamorphic event in the study area is associated with the development of the dominant schistosity (Sn). Post-peak metamorphic faults initiated after the peak of metamorphism commonly reactivate pre- and syn-peak metamorphic faults and are more easily recognized due to the presence of well developed, semi-brittle fault fabrics. Syn-peak metamorphic faults are less easy to recognize due to metamorphism which masks or obliterates older fault fabrics although they are characterized by well developed, anastomosing foliation and strong linear fabrics. Pre-peak metamorphic faults are recognized by the truncation of mappable units along the trace of the fault.

Post-peak metamorphic faults (Table 3) are characterized by limited displacement. They commonly truncate, and are cut by, other post-peak metamorphic faults. Often, displacement along a post-peak metamorphic fault is confined to a single outcrop, although total displacement across zones of post-peak metamorphic faults (up to 300 meters wide) is greater. Pre- to syn-peak metamorphic faults are believed to represent large scale movement along low angle thrusts due to the inferred locations of the formations along the ancient continental margin (Stanley and Ratcliffe 1985).

Schistosities and Fold Generations

At least four distinct schistosities (Sn-1, Sn, Sn+1 and Sn+2) are present in the Mt. Abraham-Lincoln Gap area. The dominant schistosity at the outcrop

Table 2
FEATURES OF PRE-, SYN-, AND POST-PEAK METAMORPHIC FAULTS

<u>PRE-PEAK METAMORPHIC FAULTS</u> Movement occurs before peak metamorphism. Earlier mineral assemblages are absent.

Features:

1. Truncated lithic contacts at map scale or outcrop scale.
2. Exotic rock types (such as mafic schists).
3. Slivers of rock which are out of stratigraphic sequence.
4. Absence of part(s) of known stratigraphic sequence.
5. Fault zone width may be very narrow and represented by a razor sharp (annealed) contact or may be relatively wide as a shear zone.
6. Peak metamorphic zones crosscut fault contacts and peak metamorphic minerals are present across the fault.
7. Paucity or absence of preserved fault zone fabrics.

<u>SYN-PEAK METAMORPHIC FAULTS</u> Peak metamorphism occurs during movement.

Features:

1. Features 1, 2, 3, and 4 from pre-peak metamorphic faults.
2. Sharp lithic contacts which truncate Sn-1 schistosity.
3. Fault zones and shear surfaces parallel the dominant schistosity (Sn).
4. Generally moderate fault zone widths (maximum 1-2 meters).
5. Peak metamorphic assemblages are oriented parallel to the fault and parallel to the movement direction.
6. Sheared out Fn fold limbs.
7. Increasing abundance of graphitic schist patches approaching the fault zone.
8. Anastomosing dominant schistosity (Sn), subparallel to the fault surface.
9. Mineral lineations.
10. Well foliated or laminated zone.
11. Absence of brittle, cataclastic fabrics.

<u>POST-PEAK METAMORPHIC FAULTS</u> Movement occurs after peak and retrograde metamorphism.

Features:

1. Features 1, 2, 3, and 4 from pre-peak metamorphic faults.
2. Sn and Sn+1 schistosity is truncated by the fault.
3. Fault zones may not parallel the dominant schistosity (Sn).
4. Fault zone widths may be great (up to 300-500 meters).
5. Fault zones truncate peak metamorphic assemblages or replace them with retrograde assemblages.
6. Truncated Fn and Fn+1 fold limbs.
7. Sn and Sn+1 schistosity bent into and truncated by the fault surface.
8. Quartz gouge, rods, or grooves.
9. Tectonic mèlange (lack of stratigraphic continuity).
10. Brittle or semi-brittle, cataclastic fabrics.
11. Mylonitic zone (finer grained, weak foliation).
12. Foliation is closely spaced within the fault zone and more widely spaced away from the fault zone.

TABLE 3

SUMMARY OF MEASUREMENTS FROM EQUAL AREA NETS

	DOMAIN	NUMBER OF POINTS	AVERAGE ORIENTATION	PI POLE, HINGE TO FOLDING	GIRDLE
SCHISTOSITIES					
Dominant	1	126	N09E 39E	S44E 33	N46E 57W
Dominant	2	113	N04E 43E		
Dominant	3	50	N03W 56E	S24E 26	N67E 64N
Crenulation	1	55	N09E 48E	S25E 30	N65E 60N
Crenulation	2	75	N61E 21E	S07E 20	N83E 70N
Crenulation	3	20	N85W 24S		

	DOMAIN	NUMBER OF POINTS	AVERAGE ORIENTATION
HINGES			
Hinge to crenulation fold	1	34	S08E 16
Hinge to crenulation fold	2	47	S16E 25
Hinge to crenulation fold	3	13	S08E 34

The dominant schistosity is Sn.
The crenulation schistosity is Sn+1 and consists of crenulate and minor fold data.
See Plate 3 for the boundaries of the domains and a map of Sn+1 and Sn+2 data.

Domain 1 is the Mt. Abraham domain.
Domain 2 is the Battell Trails domain.
Domain 3 is the Prospect Rock Belt domain.

is defined as the Sn surface. The axial surfaces to these crenulate and minor folds represent a younger schistosity (Sn+1) which is the product of Fn+1 deformation. Crenulate and minor folds deform the dominant schistosity (Sn). The axial surfaces, to crenulate and minor folds which deform Sn+1, represent the Sn+2 schistosity and are the product of Fn+2 deformation. Relict hinges of Fn folds preserve remnants of Sn-1 schistosity in the microlithons between layers of the dominant schistosity (Sn). Sn-1 is also preserved as compositional differences in the matrix of micaceous units.

The distribution of structural fabrics is not constant across the study area. Sn and Sn+1 are well developed in all areas, whereas, Sn+2 is poorly developed in most outcrops. Sn+2 is especially well developed, however, in the northern part of the Prospect Rock belt and in adjacent areas of the Underhill micaceous schist (CZu). Relict Fn hinges are best preserved in the eastern parts of the study area. They are also visible as relict fold hinges outlined by white mica in thin sections from many eastern areas.

One excellent example of all four schistosities is found at location K5 (Pl. 1) in the Mt. Abraham magnetite-garnet schist (western CZamg) (Pl. 2, Figs. 2 and 3). Here, Sn-1 is identified as a compositional layering which is defined by lighter and darker areas of micaceous schist and elongated pods and stringers of quartz. The quartz may have originally formed at low angles to the compositional layering but was realigned parallel to Sn-1 during the flattening of that schistosity. Sn-1 surfaces were isoclinally folded during Fn deformation which created the dominant schistosity (Sn). Sn and Sn-1 are, thus, subparallel except in the hinges of Fn folds. Fn+1 deformation then folded the dominant schistosity (Sn) and the isoclinal, Fn fold producing open, crescent shaped folds, pervasive crenulate folds, and crenulation cleavage. These latter features all define Sn+1. Fn+1 axial surfaces were broadly folded during Fn+2 deformation producing shallow, bidirectional dips of the Fn+1 axial surfaces. On one part of the outcrop, Sn+2 crenulate folds and crenulation cleavage, which are parallel to Fn+2 axial surfaces, are developed on a less pervasive scale than the Sn+1 crenulate folds (Pl. 2, Fig. 3).

The four schistosities (Sn-1, Sn, Sn+1, and Sn+2), as defined above, are characterized by distinct expressions in outcrop and can be easily distinguished in the micaceous units. The expression of Sn+1 in the metawackes is localized to a few outcrops, in areas adjacent to micaceous units, where mesoscopic chevron folds of the dominant schistosity (Sn) are present (Pl. 1, Loc. E3). In several locations where Sn+1 is traceable into adjacent areas (Pl. 1, Loc. G4), the orientation of the pervasive schistosity is parallel to the expected orientation of Sn+1. In these areas, the schistosity which is most strongly developed is Sn+1. The older Sn and Sn-1 schistosities (which are subparallel) are marked by laminated quartzite and compositional differences in the schist. The strain level of Fn+1 is strong enough in these areas that Sn+1 dominates the outcrop.

Domain Analysis of Structural Data

The boundaries of the domains for structural analysis were chosen to correspond with lithologic and interpreted fault boundaries and to follow suggested trends in the data as seen on the structural data map (Pl. 3).

The results of the domain analysis for the Mt. Abraham - Lincoln Gap area are presented in Table 3. Fn+1 and Fn+2 data are also presented on Plate 3. The dominant schistosity (Sn) is consistent in both strike and dip across the study area, averaging a north strike and dipping 45 degrees to the east. The dip is shallowest across the crest of the Green Mountains and steepens both to the west toward the Lincoln massif (O'Loughlin 1986 and DelloRusso 1986) and to the east in the Waitsfield-Warren valley (Stanley and others 1985).

The Sn+1 schistosity is slightly steeper than the dominant schistosity (Sn) in the eastern areas but varies in the western areas where the orientation of Sn+1 changes due to the influence of Fn+2 deformation (Pl. 3). Sn+2 crenulate and minor folds and crenulation cleavage are primarily restricted to the Prospect Rock belt and adjacent areas of the Underhill micaceous schist (CZu). The axial trace of Fn+2 deformation is centered on the Prospect Rock belt. Subsequently, the plot of poles to Sn+1 schistosity in this area (Pl. 3) shows that Sn+1 dips predominantly to the south (down the Fn+2 fold axis) and a well developed girdle is not present. Hinges to both Fn+1 and Fn+2 folds are subparallel and plunge moderately to the southeast. Plots of Fn+1 and Fn+2 structural data from the Mt. Grant - South Lincoln area (Lapp 1986), immediately to the south of the Mt Abraham - Lincoln Gap area (Pl. 3), show that the influence of Fn+2 deformation on Sn+1 schistosity continues to be expressed strongly to the west of the ridge of the Green Mountains.

STRUCTURAL AND METAMORPHIC RELATIONSHIPS FROM THIN SECTION

Three generalized stages in the formation of the dominant (Sn) schistosity are defined by the relationships present in thin section. These stages include: 1) the folding of an older schistosity (Sn-1), 2) the growth of new minerals parallel to the new schistosity (Sn), and 3) the flattening of the Sn schistosity (and the wrapping of this schistosity around porphyroblasts) with continued development. No break in the continuity of deformation exists from the creation of the dominant schistosity (Sn) to the flattening of this same surface.

The dominant schistosity (Sn) is recognized in thin section as the elongation and alignment of minerals (commonly, opaques) in a recognizable layering which correlates with the dominant schistosity of the outcrop and hand sample. Relict assemblages and fabrics of the older Sn-1 schistosity may be preserved as inclusions in porphyroblasts and as hinges of white mica and opaques which are truncated by the dominant schistosity (Sn). As the dominant schistosity is flattened during continued development of Sn, the layers of the dominant schistosity wrap around any previously formed porphyroblasts. The initial deformation of the dominant schistosity (Sn) by folds and crenulate folds represents the early stages of Fn+1 deformation. Often, individual porphyroblasts are caught in the hinges of Fn+1 folds and may show undulatory extinction. The minerals which formed during Fn are realigned and new minerals form along the new Sn+1 cleavage which parallels the axial surfaces of the minor folds and crenulate folds (Sn+1) of the dominant schistosity. Sn+1 shear bands wrap around Sn porphyroblasts.

Structural Relationships by Mineral

White mica, graphite, and opaques are present as fine and coarse grains within the matrix of the rock and as inclusions within porphyroblasts. Garnet and plagioclase are commonly present as porphyroblasts with straight to S-shaped inclusion trails. Plagioclase, in all units except the metawackes (CZufg and CZhg), is nearly always zoned and abundant Carlsbad twinning is present. Zonation is represented by changes in extinction and by inclusion density. Chlorite is dominantly a product of retrograde alteration of garnet and is commonly found in pressure shadows on garnet and as grains in the matrix. Chloritoid is present as grains in the matrix and associated with chlorite in pressure shadows on garnet. Kyanite is mostly altered to white mica (sericite) and opaques and is only locally fresh. Two distinct expressions of biotite are present in the study area: fine grained material in the matrix and localized, very coarse, books of cross biotite (Pl. 2, Fig. 4). Quartz is commonly recrystallized and present in veins and layers and throughout the matrix in all units except the metawackes (CZufg and CZhg) where it is present as coarse grains. Table 4 (Pl. 2) summarizes the structural relationships of each unit by mineral as seen in thin section.

Regional Metamorphic Relationships from Thin Section

The relatively consistent relationship of the metamorphic minerals to schistosities across the study area identifies the dominant metamorphism and the development of the dominant schistosity (Sn) as a uniform regional event. This event affected units that had been subjected to various levels of previous metamorphism. The Underhill foliated metawacke (CZufg) was probably previously unmetamorphosed and undeformed since detrital grains of plagioclase and strained quartz are present in this unit. Other units in the area show relict Sn-1 schistosity preserved within garnet and plagioclase porphyroblasts. These units were metamorphosed prior to the highest grade metamorphism, probably by prograde events. The more easterly situated units (CZa, eastern Czamg, CZhn, and CZhnc) may have been subjected to metamorphism earlier than the western units (CZu, CZags, and western CZamg) since a greater amount of strain during Fn-1 deformation is visible in thin sections from the eastern areas.

GEOLOGICAL CONSTRAINTS

The lithic, structural, and metamorphic relations in the Mt. Abraham-Lincoln Gap area indicate the following important constraints which must be considered in any tectonic synthesis of the area. The most recent, and most well understood, relationships are presented first and the more speculative interpretations follow. Since the amount of deformation in the study area increases to the east, the discussion progresses generally from west to east.

Post-Peak Metamorphic Faults

The most recent deformation in the study area is the development of post-peak metamorphic faults which 1) truncate the dominant schistosity (Sn) and Fn+1 minor folds and 2) cut, and in part reactivate, pre- and syn-peak metamorphic faults. The post-peak metamorphic faults represent semi-brittle deformation at relatively shallow crustal levels and the amount of movement associated with individual faults is small. The fault zones do not disrupt the previously developed map pattern to any great extent.

The map scale fold of post-peak metamorphic faults east of Lincoln Gap (Pl. 1, Loc. L12 and adjacent locations) does not significantly rotate hinges of Sn+1 crenulate folds. These faults are either synchronous with Fn+1 deformation in this area or the faults developed along previously folded Sn schistosity. The second alternative seems more likely because the faults contain brittle to semi-brittle fabrics unlike the more ductile Fn+1 fabrics.

Fn+2 Deformation

Crenulate folds and minor deformation associated with Fn+2 deformation are localized in and adjacent to the Prospect Rock belt (Pl. 3). Development of coarse cross biotite (Pl. 2, Fig. 4) and white mica is also confined to the units in this area and may be associated with Fn+2 deformation. It is important to note that coarse white mica, which crosscuts Sn and Sn+1 schistosity, is present in thin sections of the most westerly situated albitic Hazens Notch schist (CZhn) (Pl. 1, Loc. L6). The presence of late white mica in this unit identifies Fn+2 deformation as an event which post dates the emplacement of the albitic Hazens Notch schist (CZhn) in the western area. Fn+2 deformation does not significantly alter the map pattern and the deformation may be due to movement along a thrust fault over a small riser at depth. The relationship of post-peak metamorphic faults to Sn+2 crenulate folds is not clear since both are not developed in the same outcrop. It is assumed that the semi-brittle post-peak metamorphic faults post date the ductile Fn+2 deformation.

Fn+1 Deformation

Fn+1 crenulate and minor folds which deform the dominant schistosity (Sn) are uniform in expression across the study area. The continuity of Sn+1 schistosity and its uniform expression indicates that Sn+1 schistosity is a product of a single generation of deformation (Fn+1). Fn+1 deforms all older structural features including the dominant schistosity (Sn), Sn-1 schistosity, and pre- and syn-peak metamorphic faults.

Fn+1 deformation in the Underhill metawacke (CZufg) is minor and only locally present adjacent to the Underhill micaceous schist (CZu) (Pl. 1, Loc. E3). Well developed Sn+1 schistosity is present only as far west as the Underhill micaceous schist (CZu) and is not developed in the majority of the Underhill metawacke (CZufg). This relationship may result from the strong mechanical contrast between these two units.

The amplitude of Fn+1 crenulate folds (5-6 cm) is greater in the Mt. Abraham Schist (CZa) than in the Underhill micaceous schist (CZu) (1-2 cm). The difference in amplitude is related to the higher abundance of Fn quartz veins present in the Mt. Abraham Schist (CZa) which allowed this unit to behave with greater rigidity than the Underhill micaceous schist (CZu) during ductile Fn+1 deformation. In units other than the Mt. Abraham Schist (CZa), however, Fn+1 folds are tighter and more pervasive to the east. This suggests that Fn+1 deformation is time transgressive and progressed from east to west.

Retrograde Metamorphism

In the study area, chlorite pressure shadows on garnet (associated with the retrograde reaction of garnet to chlorite) are present in different relationships with respect to the development of Sn and Sn+1 schistosities. In the main body of the Mt. Abraham Schist (CZa), nearly all garnet is altered to chlorite during the development of the dominant schistosity (Sn). Later movement during Fn smeared out the chlorite pseudomorphs to form discontinuous mineral lineations which are oriented parallel to the dip direction of the dominant schistosity (Sn). Across most of the study area (in the eastern CZamg, CZhn, and CZu), chlorite pressure shadows on garnet are mainly parallel to the dominant schistosity (Sn). A progressive change in the orientation of chlorite pressure shadows on garnet, however, is seen in the Prospect Rock belt (western CZamg and CZags). In the southern part of this belt, chlorite pressure shadows are parallel to the dominant schistosity (Sn) but to the north, pressure shadows are mainly parallel to Sn+1 schistosity.

Based upon these relationships, the formation of chlorite pressure shadows appears to be initiated earliest in the main body of the Mt. Abraham Schist (CZa) (early in Fn), during Fn across most of the area (eastern CZamg, CZhn, and CZu), and progressively later from south to north in the Prospect Rock belt (western CZamg and CZags) (during Fn to Fn+1).

Although chlorite formation appears to be mainly associated with the development of the dominant schistosity (Sn) in all garnet bearing units, it is also associated with Fn+1 development in these rocks. The presence of pressure shadows parallel to both Sn and Sn+1 in the western areas indicates that chlorite growth lasted through two deformations in the western areas and was superimposed upon the time transgressive development of Sn and Sn+1 schistosity (which become younger toward the west). Chlorite growth in the eastern areas lasted through only Fn deformation.

Fn Deformation and Peak Metamorphism

The dominant schistosity (Sn) is relatively well developed across the study area. The formation of Sn probably becomes younger to the west although definitive proof is lacking in the study area. However, comparison of the descriptions of the dominant schistosity to the west of the study area by DiPietro (1983) and DelloRusso (1986) and the greater evidence for bedding in rocks to the west supports this time transgressive interpretation for the development of Sn. Peak metamorphism was associated with the development of the dominant schistosity in all parts of the study area.

Fn deformation and metamorphism in the Hoosac metawacke (CZhg) and the Underhill foliated metawacke (CZufg) has not totally obliterated the original mineralogy as it has in all other units. Detrital plagioclase and recrystallized quartz grains are partially deformed during the development of Sn. The micaceous layers of the Underhill foliated metawacke (CZufg) may be the location of distributed shear during Fn deformation.

The dominant schistosity (Sn) is relatively constant in orientation across the study area (Pl. 1). Strikes are generally to the north except to the east of Linclon Gap where a map scale Fn+1 fold of the dominant schistosity (Sn) is present (Pl. 1, centered on Loc. L12). Across the study area, dips of the dominant schistosity increase toward the west from 35 to 56 degrees. To the east of the study area, in the Waitsfield-Warren valley, dips are generally steeper than 45 degrees (Stanley and others 1986). The progressive change in dip of Sn across the Green Mountains may be due to the ramp geometry of a deep, regional thrust zone such as the Champlain thrust. Belts of rock where the dominant schistosity (Sn) is relatively steep and Fn+1 and Fn+2 deformation are present may be located over deep ramps (or step-ups) of this thrust zone. Belts of rock where the dominant schistosity (Sn) is less steep than the surrounding areas (for example, the crest of the Green Mountains in this study area) may be located over flats.

The Prospect Rock belt of chloritoid bearing units (CZa, western CZamg, and CZags) contains lithologies similar to the main body of the Mt. Abraham Schist (CZa). The Prospect Rock belt is interpreted to represent the leading edge of a once continuous slice which included the main body of the Mt. Abraham Schist (CZa). The contact of the Prospect Rock belt with the underlying Underhill micaceous schist (CZu) is a pre- or syn-peak metamorphic fault that was isoclinally folded during later Fn deformation and now parallels the dominant schistosity (Sn). Also during late Fn deformation, the eastern units (CZa, eastern CZamg, CZhn, and CZhnc) overrode the fault bounded Prospect Rock belt at locations K6 through O6 (Pl. 1) where the albitic Hazens Notch schist (CZhn) is in contact with the Prospect Rock belt and truncates the eastern fault contact in two locations (Pl. 1, Locs. K6 and O6). This movement occurred along syn-peak metamorphic faults.

The Mt. Abraham Schist (CZa and eastern CZamg) and the Hazens Notch Formation (CZhn and CZhnc) were emplaced on the Underhill micaceous schist (CZu) along pre- to syn-peak metamorphic faults which truncate contacts between the eastern units. Some of these truncations include 1) the Mt. Abraham Schist (CZa and eastern CZamg) - albitic Hazens Notch schist (CZhn) sequence which is truncated against a syn-peak metamorphic fault at locations D6 and I6 (Pl. 1) and 2) the contact between albitic and carbonaceous Hazens Notch schists (CZhn and CZhnc) which is truncated at location N8 (Pl. 1). At location N8 the carbonaceous schist (CZhnc) rests directly on the Underhill micaceous schist (CZu). Importantly, the Mt. Abraham Schist (CZa), the eastern magnetite-garnet schist (eastern CZamg), and the albitic and carbonaceous Hazens Notch schists (CZhn and CZhnc) rest directly on the Underhill micaceous schist (for example, Pl. 1, Locs. C6, H6, J6, and O8) and windows of the Underhill micaceous schist (CZu) are present in the Mt. Abraham Schist and the Hazens Notch Formation to the south of Lincoln Gap (Lapp 1986). The truncation of different contacts along syn-peak metamorphic faults, as discussed above, identifies the eastern units as a previously assembled and folded tectonic sequence which was emplaced on the Underhill Formation (CZu). This sequence of emplacement may also explain why there is a lack of recognizable Fn folds in the Underhill Formation.

Sn schistosity is axial planar to, and synchronous in development with, map scale folds of the Mt. Abraham Schist (CZa and eastern CZamg) - albitic Hazens Notch schist (CZhn) sequence in the eastern areas (hinges of map scale folds, Pl. 1, Locs. M8, G9, and M10). Outcrop scale Fn folds of Sn-1 schistosity are tight to isoclinal and overturned to the west.

Fn folds of the Mt. Abraham Schist (CZa) - eastern magnetite-garnet schist (eastern CZamg) - albitic Hazens Notch schist (CZhn) sequence include carbonaceous Hazens Notch schist (CZhnc) in the center of the synform at Lincoln Gap (Pl. 1, Locs. H9 through L9). Fn folds thus post date, or are synchronous with, the emplacement of the carbonaceous Hazens Notch schist (CZhnc) on the lower units.

The carbonaceous schist (CZhnc) of the Hazens Notch was emplaced on the Mt. Abraham Schist (CZa) and albitic Hazens Notch schist (CZhn) along pre- to syn-peak metamorphic faults which parallel the dominant schistosity (Sn). The continuous carbonaceous schist (CZhnc) body at Lincoln Gap (Pl. 1, Locs. H9 through O9) rests on a sequence of Mt. Abraham Schist (CZa and eastern CZamg) and albitic Hazens Notch schist (CZhn) in the study area and on the reverse sequence of albitic Hazens Notch schist (CZhn) to Mt. Abraham Schist (CZa) to the south where the carbonaceous schist (CZhnc) truncates the CZhn-CZa contact (Lapp 1986). The carbonaceous schist (CZhnc) was thus emplaced on previously deformed sequence of albitic Hazens Notch schist (CZhn) and Mt. Abraham Schist (CZa). The deformation of the albitic Hazens Notch schist (CZhn) and Mt. Abraham Schist (CZa) occurred on a larger scale than, and prior to, Fn deformation and the development of Fn folds in the study area.

The carbonaceous Hazens Notch schist (CZhnc) roots somewhere to the east of the study area. Stanley suggests that the root zone may be as far east as the Ottauquechee Formation. Resolution of this problem must await further field work.

Older deformation

In the study area, Mt. Abraham Schist (CZa) cores southeast plunging Fn anticlines. Here the sequence is Mt. Abraham Schist (CZa) - eastern magnetite-garnet schist (eastern CZamg) - albitic Hazens Notch schist (CZhn). To the south, however, the sequence is reversed with Mt. Abraham Schist (CZa) overlying albitic Hazens Notch schist (CZhn) (Lapp 1986). Farther to the south, albitic Hazens Notch schist (CZhn) appears to overlie Mt. Abraham Schist (CZa) (Doll and others 1961). To the north of the study area, Mt. Abraham Schist (CZa), which is continuous with the Mt. Abraham Schist in the study area, appears to overlie albitic Hazens Notch schist (CZhn) (Doll and others 1961). It is uncertain which sequence may be upright or overturned, although, similar sequences in the allochthonous Hoosac Formation in western Massachusetts and in the Greylock slice of the Taconic allochthons consist of coarsely albitic units overlain by a highly aluminous, chloritoid bearing unit

(Ratcliffe 1979). The aluminous Mt. Abraham Schist (CZa) may thus be stratigraphically higher than the albitic Hazens Notch schist (CZhn).

Two possible interpretations of pre-Fn deformation in the albitic Hazens Notch schist (CZhn) and Mt. Abraham Schist (CZa) are 1) isoclinal folding of albitic Hazens Notch schist (CZhn) and Mt. Abraham Schist (CZa) which creates an overturned limb in the study area and upright sequences to the south and north, and 2) a fault or multiple faults which repeat the sequence of albitic Hazens Notch (CZhn) - Mt. Abraham Schist (CZa) in the Linclon Gap area. Both of these interpretations assume that the Mt. Abraham Schist (CZa) overlies the albitic Hazens Notch schist (CZhn) which is consistent with regional correlations with the Taconic allochthons and across the Berkshire massif (Ratcliffe 1979 and Stanley and Ratcliffe 1985).

An episode of major recumbent fold deformation predates the emplacement of correlative rocks in the Greylock slice of the Taconic allochthons (Ratcliffe 1979). This deformation in the Greylock units may be related to pre-Fn deformation in the Lincoln Gap area.

The eastern magnetite-garnet schist (eastern CZamg), a transitional zone between Mt. Abraham Schist (CZa) and albitic Hazens Notch schist (CZhn), may represent a highly deformed pre-peak metamorphic fault zone. In the Waitsfield - Warren valley to the east, Mt. Abraham Schist (CZa) rests on, and truncates, contacts between the albitic Hazens Notch schist (CZhn) and the carbonaceous Hazens Notch schist (CZhnca) (Stanley and others 1986 and J. Prewitt, per.com.). This relationship suggests that the Mt. Abraham Schist (CZa) was emplaced on the Hazens Notch Formation along pre-peak metamorphic faults. The gradational contact between the Mt. Abraham Schist (CZa) and the albitic Hazens Notch Formation could represent ground up material from both the upper and lower thrust plates which was subsequently metamorphosed into the assemblage of the transitional eastern magnetite-garnet schist (eastern CZamg).

Summary

The current sequence of units from west to east is the result of a tectonic stacking order which superficially resembles a simple east to west piggy back progression (Pl. 2, Fig. 5). The sequence is significantly more complex due to the emplacement of carbonaceous Hazens Notch schist (CZhnc) onto a previously assembled and deformed sequence of albitic Hazens Notch schist (CZhn) and Mt. Abraham Schist (CZa) (Pl. 2, Figs. 5 and 6). Figure 7 represents the sequence and relationships between structural and metamorphic events at the outcrop scale. Outcrops across the study area did not experience the same stage of deformation at any one point in time.

The carbonaceous Hazens Notch schist (CZhnc) was also internally deformed prior to emplacement on the Mt. Abraham Schist (CZa and eastern CZamg) and the albitic Hazens Notch schist (CZhn). Very complex fabrics are present in the carbonaceous schist (CZhnc) between the dominant schistosity (Sn). It is unclear if this deformation occurred prior to, or during, Fn deformation and the emplacement of the carbonaceous schist (CZhnc).

SCHISTOSITY OR AXIAL SURFACE	Sn-1	Sn	Sn+1	Sn+2
METAMORPHISM	PRE-PEAK ⟶	PEAK ⟶	RETROGRADE	LATE
FAULTS	PRE- TO SYN-PEAK METAMORPHIC		POST-PEAK METAMORPHIC	

——— TIME ⟶

Figure 7. Structural and metamorphic relationships in the Mt. Abraham-Lincoln Gap area. Short descriptions of the elements in the figure and abbreviations follow. See text, Figure 1, and Tables 2 and 4 for additional information.

Schistosities:	Sn-1	Relict fold hinges, inclusion trails in garnet and plagioclase porphyroblasts, and compositional layering.
	Sn	Dominant schistosity and alignment of most minerals.
	Sn+1	Axial surfaces to minor and crenulate folds of Sn.
	Sn+2	Axial surfaces to folded Sn+1 axial surfaces and to local crenulate folds.
Metamorphism:	Pre-peak	Assemblages preserved as inclusion trails in garnet and plagioclase porphyroblasts.
	Peak	Garnet to kyanite grade.
	Retrograde	Late peak to post peak retrograde reactions: garnet to chlorite and kyanite to sericite.
	Late	Post Fn+1 (?Fn+2) coarse cross biotite and cross muscovite.
Faults:	Pre- to syn-peak	Multiple generations of movement, cryptic in expression.
	Post-peak	Multiple generations of movement, characterized by well developed fault fabrics.

NOTE:

1. Retrograde reactions are not associated with a single schistosity. These reactions occur during the flattening of the dominant schistosity (Sn), folding of the dominant schistosity (Sn) and the creation of Sn-1.
2. Sn+1 and Sn+2 are strongly developed in the western part of the field area and are not present to the east the of crest of the Green Mountains.
3. Metamorphic and structural events are not synchronous. The overlap suggests that the major deformation in the area is part of a single event and represents a progressive or continuous deformational metamorphic sequence.
4. The syn-peak metamorphic faults were formed at conditions of medium high grade metamorphism.
5. There is not much evidence to support Acadian deformation in the area with the possible exception of the late growth of cross biotite and muscovite.

Deformation began earlier and is more intense eastward in the Mt. Abraham Schist (CZa) and the Hazens Notch Formation (CZhn and CZhnc). These earlier relationships, however, are less well preserved than the fabrics which are due to more recent, less intense deformation to the west. The least amount of deformation occurred in the Underhill metawacke (CZufg) where detrital grains are preserved. Peak metamorphism obscured both fold and fault relationships which existed prior to the formation of the dominant schistosity. Multiple generations of fault movement are common.

Fn and Fn+1 deformation and peak metamorphism are not synchronous across the area but are time transgressive and progress westward, continuously. Fn+2 deformation is confined to the Prospect Rock belt (western CZamg and CZags) and adjacent parts of the Underhill micaceous schist (CZu). Retrograde metamorphism is both time transgressive, itself, and superimposed upon time transgressive deformation. The metamorphic events are superimposed on a complex structural history and do not show a one to one correlation with structural deformations. The metamorphic and structural events in the study area are part of a single orogenic (Taconian) event.

SYNTHESIS

Figure 6 represents a schematic model (looking north) for the structural history of the study area. On this figure, the rectangles represent thrust slices which are separated by pre- to syn-peak metamorphic faults (curved, thick, solid lines with half arrows). Thin solid lines represent lithologic boundaries within the thrust slices which separate the various map units (for unit abbreviations, see Pl. 1). Straight, dashed thick lines with half arrows represent post-peak metamorphic faults which cut the pre- to syn-peak metamorphic faults. The same relationships are shown on the cross sections (Pl. 2, Fig. 5).

From west to east, the thrust slices consist of 1) the Hoosac Formation (CZhg and CZhms), 2) the Underhill Formation (CZufg, CZu, CZums, CZus, and CZugs), 3) the Prospect Rock belt, Mt. Abraham Schist, and Hazens Notch Formation (CZags, CZamg, CZa, CZap, CZhn, and CZhnc), and 4) the carbonaceous Hazens Notch schist (CZhnc). The Underhill sericite schist (CZus), the Underhill garnet schist (CZugs), and the Mt. Abraham plagioclase schist (CZap) are units to the south (Lapp 1986).

Rocks of the Prospect Rock belt (western CZamg and CZags) are lithically related to the main body of Mt. Abraham Schist (CZa) and the Prospect Rock belt represents the leading edge of this slice. A possible pre-peak metamorphic thrust between the main body of the Mt. Abraham Schist (CZa) and the albitic Hazens Notch schist (CZhn) is shown as a curved, solid, thick line between the eastern magnetite-garnet schist (eastern CZamg) and the albitic Hazens Notch schist (CZhn). The eastern magnetite-garnet schist (eastern CZamg) represents a metamorphosed pre-peak fault zone.

Using the schematic relations shown in Figure 6, the structural and metamorphic evolution of the Lincoln Gap area is presented, beginning with the oldest events and ending with the youngest.

1. The Mt. Abraham Schist (CZa) is emplaced upon the Hazens Notch Formation (CZhn and CZhnc) along pre-peak metamorphic faults. Prograde metamorphism is initiated in these units.

2. The Mt. Abraham Schist (CZa) and Hazens Notch Formation (CZhn and CZhnc) are folded (along with the pre-peak metamorphic fault contact between them). This deformation may be represented by Fn-1 deformation with the accompanying development of Sn-1 schistosity in these units. Prograde metamorphism continues in these units and is recorded in the inclusion trails in albite and garnet.

3. The carbonaceous Hazens Notch schist (CZhnc) is emplaced upon the folded Mt. Abraham Schist (CZa) and Hazens Notch Formation (CZhn and CZhnc) along pre- to syn-peak metamorphic faults. Peak metamorphism and the development of the dominant schistosity (Sn) are initiated in the eastern slices (CZa, CZhn, and CZhnc). During this event, the eastern magnetite-garnet schist (eastern CZamg) is developed from the homogenized material possibly along the older fault zone between the Mt. Abraham Schist (CZa) and the albitic Hazens Notch schist (CZhn). Pre-peak metamorphic assemblages are preserved only as relict assemblages in porphyroblasts.

4. Retrograde garnet to chlorite reactions are initiated in the Mt. Abraham Schist (CZa) prior to the flattening of the dominant schistosity (Sn).

5. The carbonaceous Hazens Notch schist (CZhnc), albitic Hazens Notch schist (CZhn), and Mt. Abraham Schist (CZa) are incorporated into tight to isoclinal Fn folds as Fn deformation progresses westward.

6. Retrograde garnet to chlorite reactions are initiated in the eastern slices (eastern CZamg, CZhn, and CZhnc) during the flattening of the dominant schistosity (Sn). This chlorite is seen as pressure shadows on garnet which are parallel to the dominant schistosity (Sn).

7. The assembled eastern slices (CZa, eastern CZamg, CZhn, and CZhnc) and the Prospect Rock belt, (western CZamg and CZags) are emplaced on the Underhill Formation (CZu and CZufg) along syn-peak metamorphic faults. Peak metamorphism and the development of the dominant schistosity (Sn) is initiated in the Underhill micaceous schist (CZu). Fn+1 deformation and the development of Sn+1, including the Fn+1 map scale fold east of Lincoln Gap, is initiated in the eastern slices (CZa, eastern CZamg, CZhn, and CZhnc). Retrograde garnet to chlorite reactions continue in the eastern slices (eastern CZamg and CZhn).

8. Retrograde garnet to chlorite reactions are initiated in the Underhill micaceous schist (CZu) during continued Fn deformation and continue in the eastern slices (eastern CZamg and CZhn) during continued Fn+1 deformation.

9. The eastern slices (CZa, CZamg, CZags, CZhn, and CZhnc) and the Underhill Formation (CZu and CZufg) are emplaced on the Hoosac Formation (CZhg and CZhms) through distributed shear in the Underhill foliated metawacke (CZufg). Metamorphism and the development of the dominant schistosity (Sn) are initiated in the Underhill foliated metawacke (CZufg). Fn+1 deformation

and the development of Sn+1 schistosity is initiated in the Underhill micaceous schist (CZu) and the Prospect Rock belt (western CZamg and CZags). Fn+1 deformation continues in the eastern slices (CZa, eastern CZamg, CZhn, and CZhnc). Retrograde garnet to chlorite reactions are initiated in the northern part of the Prospect Rock belt and continue in the Underhill micaceous schist (CZu).

10. Fn+2 deformation, the development of Sn+2, and the growth of coarse, cross biotite and white mica are initiated in the Prospect Rock belt and the adjacent Underhill micaceous schist (CZu) possibly due to movement over a basement riser at depth.

11. Semi-brittle post-peak metamorphic faults develop at shallow crustal depths, in part, along pre- to syn-peak metamorphic fault zones in all micaceous units (CZa, eastern CZamg, CZhn, CZhnc, western CZamg, CZags, and CZu).

ACKNOWLEDGEMENTS

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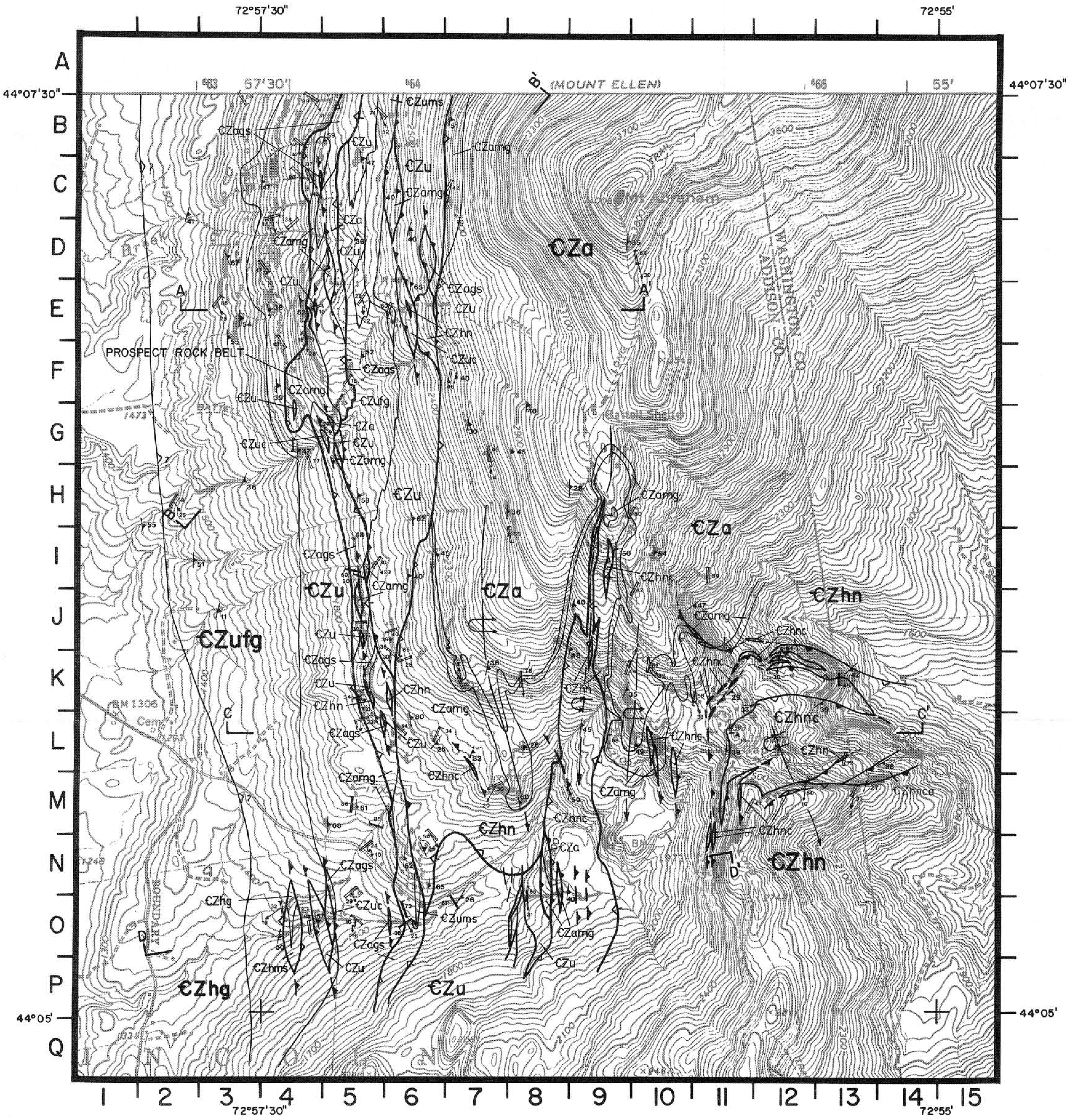
Additional publications: E.T. Lapp and R.S. Stanley (1986) and V. DelloRusso and R.S. Stanley (1986). These publications are in press and are to be published as Special Bulletins of the Vermont Geological Survey.

PLATE 1

Bedrock Geology of the Mt. Abraham - Lincoln Gap Area, Central Vermont

Sharon B. O'Loughlin and Rolfe S. Stanley



EXPLANATION

<u>Contacts</u>

Lithic contact. The accuracy of the contact is indicated by the proximity of outcrop. Some lithic contacts may be annealed, pre-peak metamorphic thrust faults.

Post-peak metamorphic fault. Teeth on the upthrown plate. Subparallel to the dominant schistosity. Dashed where discontinuous.

Pre- to syn-peak metamorphic thrust fault. Teeth on the upper plate. Parallel to the dominant schistosity (Sn).

Overturned pre- to syn-peak metamorphic thrust fault. Teeth on the upper plate. Parallel to the dominant schistosity (Sn).

Pre- to syn-peak metamorphic thrust fault which has been reactivated by post-peak metamorphic fault(s). Teeth on the upthrown plate. Subparallel to the dominant schistosity (Sn).

<u>Planar features</u>

45 Strike and dip of the dominant schistosity (Sn).

50 Strike and dip of the axial surface (Sn+1) of a mesoscopic or crenulate fold which deforms the dominant schistosity (Sn).

89 Strike and dip of the axial surface (Sn+2) of a mesoscopic or crenulate fold which deforms Sn+1.

<u>Linear features</u>

15 Trend and plunge of a fold axis to mesoscopic and crenulate folds (Fn+1).

20 With known clockwise rotation sense.

19 With known counterclockwise rotation sense.

Axial trace of overturned synform. Arrow indicates plunge direction.

Axial trace of overturned antiform. Arrow indicates plunge direction.

A A' Line of cross section.

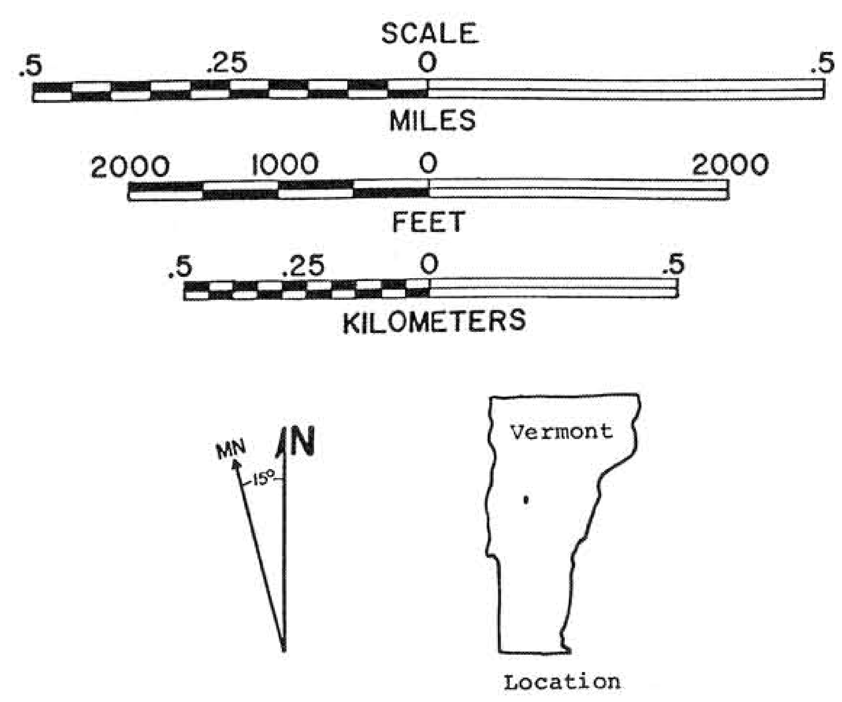
44°07'30" Longitude or latitude value.

Register mark.

A-Q, 1-15 Location coordinates. Given in pairs in the text (for example, E12).

Observed Bedrock Exposure

Contour Interval is 20 feet.



Geology mapped by Sharon B. O'Loughlin June - September 1984 and June - July 1985, assisted by Rebecca J. Dorsey, June 1984.

LITHIC DESCRIPTIONS

BOOSAC FORMATION

CZhg METAWACKE
Light grey to rusty, massive to schistose, fine to medium grained metawacke which is rich in chlorite and muscovite. Minor biotite, garnet, epidote and opaques are present.

CZhms MAFIC SCHIST
Dark to very dark green and black, moderate to very coarse grained, amphibole and chlorite rich schist with varying amounts of plagioclase, biotite, and carbonate. Very mafic rich areas contain coarse amphibole needles in a plagioclase rich matrix. Contacts with CZhg are sheared and appear gradational.

UNDERHILL FORMATION

CZu MICACEOUS SCHIST
A highly variable group of rocks in which chlorite, biotite and muscovite is abundant in the matrix. Zones of moderately coarse (0.5 - 1.5 cm) white albite, coarse garnet (up to 1 cm), and minor graphite are locally conspicuous. Thin, discontinuous grey to white laminated quartzites (1-3 cm thick) are present in some areas. The matrix is richer in chlorite and quartz veins are thicker but less abundant than in CZa. Chloritoid is absent. Local patches or seams of graphite are increasingly abundant toward fault zones. A fault-bounded sliver of carbonaceous schist (CZuc) is present at location E6 on the geologic map.

Adjacent to the Prospect Rock belt, the CZu is very coarse grained (stippled overprint on CZu) and is characterized by abundant coarse biotite books (up to 2 cm thick) and coarse white mica flakes (up to 1 cm) which randomly crosscut the dominant schistosity. The coarse, cross white mica gives the rock a characteristic spangly appearance. Coarse chloritized garnet porphyroblasts (up to 2 cm), and locally abundant, coarse (up to 2 cm) albite patches are also distinctive. Quartz and plagioclase are abundant in the matrix and minor opaques and graphite are present. Some biotite is altered to chlorite.

CZufg FOLIATED METAWACKE
Light to medium grey, well foliated or laminated, quartz and plagioclase metawacke. Abundant muscovite and moderate amounts of biotite and chlorite are present as mica seams (up to 0.5 cm thick) between thicker (5-15 cm), resistant quartz and plagioclase rich layers. Minor opaques, graphite and garnet are present with minor carbonate near mafic schists. Quartz veins are rare. Locally, CZufg grades into CZu by a systematic change in composition within 0.5 to 1 meter.

CZums MAFIC SCHIST
Medium to dark green, fine to coarse grained, amphibole-epidote mafic schists containing chlorite, biotite, albite, carbonate and quartz. In coarse grained schists, mineral segregation is associated with color distinctions. Darker green layers are rich in amphibole whereas the light green areas are rich in epidote, chlorite, albite and quartz.

MT. ABRAHAM SCHIST

CZa CHLORITOID WHITE MICA SCHIST
Fine to very fine grained paragonite-muscovite schist with abundant chloritoid, minor opaques, and a well developed pearly sheen on the silvery colored schistosity. Abundant quartz veins oriented mostly parallel to the dominant schistosity, well oriented clots of chlorite, and randomly oriented, fresh to rusty weathering kyanite blades (0.5-1 cm) are present on the dominant schistosity. Small garnet porphyroblasts, mostly altered to chlorite, are locally abundant near the contact with CZamg. Biotite and plagioclase are absent in the chloritoid bearing schist.

In the Prospect Rock belt and along the western contact of the main body of CZa (stippled overprint on CZa), the schist is uniformly fine grained, with fewer quartz veins. The fine grained CZa is rich in chlorite, chloritoid, white mica, and minor opaques. Garnet, biotite, and plagioclase are absent.

CZamg MAGNETITE-GARNET SCHIST
Shiny, coarse grained muscovite-paragonite schist with distinctive magnetite (0.5-1.5 cm) and chloritized garnet (up to 2 cm) porphyroblasts, minor opaques, trace graphite, and very rare pyrite (location L12). Abundant quartz veins are oriented parallel to the dominant schistosity. Plagioclase is locally abundant near the contact with CZhn. Biotite is absent.

In the eastern areas, CZamg is transitional between CZa and CZhn. Both contacts are gradational with the composition of one unit changing systematically into that of the other. Toward CZa, white mica is more abundant in the matrix, the pearly sheen is better developed, and chlorite clots, chloritoid, magnetite, garnet and minor kyanite are more abundant. Toward CZhn, chlorite, biotite, and porphyroblasts of plagioclase are more abundant and beds of laminated quartzite (1-10 cm thick) are more numerous. Chlorite clots, magnetite, and garnets are less abundant toward CZhn.

In the Prospect Rock belt, CZamg grades into CZags by a systematic change in composition. Coarse magnetite porphyroblasts become scarce toward CZags. Significantly, chloritoid is more abundant in the western CZamg than it is in the eastern CZamg. Only minor plagioclase is present in the western CZamg.

CZags GARNET SCHIST
Muscovite-chlorite schist with abundant coarse to very coarse (1-3 cm) chloritized garnet porphyroblasts. Chloritoid, opaques, graphite, and plagioclase are minor or sparce in abundance. Muscovite is commonly more abundant than chlorite in the matrix. Quartz veins are less abundant in CZags than in CZa and CZhn. Coarse white mica is randomly oriented across the schistosity. Biotite is absent. CZags grades into the western CZamg by a systematic change in composition and more closely resembles CZa and related lithologies than it does CZu lithologies.

HAZENS NOTCH FORMATION

CZhn ALBITIC SCHIST
Silvery white to dark green to black micaceous schist with a chlorite, biotite, and coarse white mica matrix spotted with abundant, coarse to very coarse (1-3 cm) grey to white albite porphyroblasts. Garnet, graphite and other opaques are minor but may be locally abundant. Minor beds of laminated white to grey quartzite (2-30 cm thick) and abundant quartz veins are present. Chlorite and biotite are more common in the matrix of CZhn than in the matrix of CZa. Locally, lenses of albite, chlorite, epidote, and minor carbonate and sphene are present. CZhn locally grades into CZhnc.

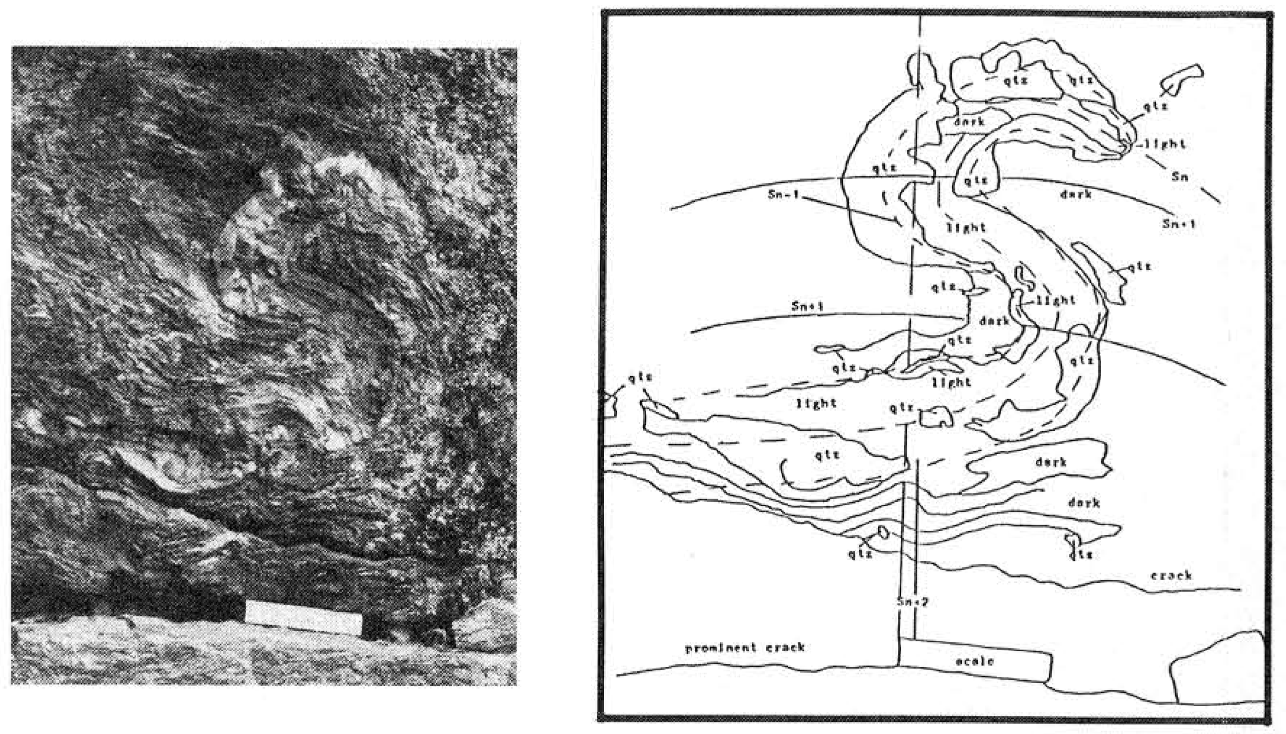
CZhnc CARBONACEOUS SCHIST
Dark grey to black, well laminated, carbonaceous schist with a dull to shiny luster which is locally rusty weathering. The schist is easily eroded and forms topographic lows. Fine grained white mica, chlorite, biotite, quartz and plagioclase and minor garnet and magnetite are present in the matrix. Minor pyrite cubes are present locally. CZhnc grades into carbonaceous black albitic schist (CZhnca) then into CZhn at locations M13 and M14 on the geologic map.

Special Bulletin No. 6 - O'Loughlin and Stanley
Vermont Geological Survey, Charles A. Ratte', State Geologist

PLATE 2

Sharon B. O'Loughlin and Rolfe S. Stanley

Bedrock Geology of the Mt. Abraham - Lincoln Gap Area, Central Vermont



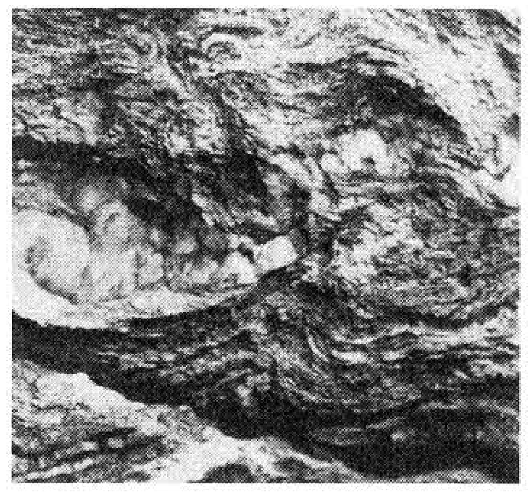


Figure 3
Closeup of Figure 2 showing locally developed Fn+2 crenulate folds.

Figure 2
An example of all schistosities (Sn-1, Sn, Sn+1, and Sn+2) expressed in a single outcrop looking toward the southeast in the magnetite-garnet schist of the Prospect Rock belt (western €Zamg). Sn-1 schistosity is represented by compositional differences in the micaceous matrix (which produce lighter and darker colored areas) and a prominent quartz vein. Sn-1 is isoclinally folded by Fn to produce the dominant schistosity (Sn) which forms the backbone of this S-shaped fold. The dominant schistosity (Sn) is folded by relatively open, crescent shaped Fn+1 folds with axial surfaces (Sn+1) subparallel to crenulate folds in the matrix. Fn+2 broadly warps Fn+1 axial surfaces and is associated with locally developed Fn+2 crenulate folds (Figure 3). Scale is 18 centimeters long. Location L5 (Plate 1).

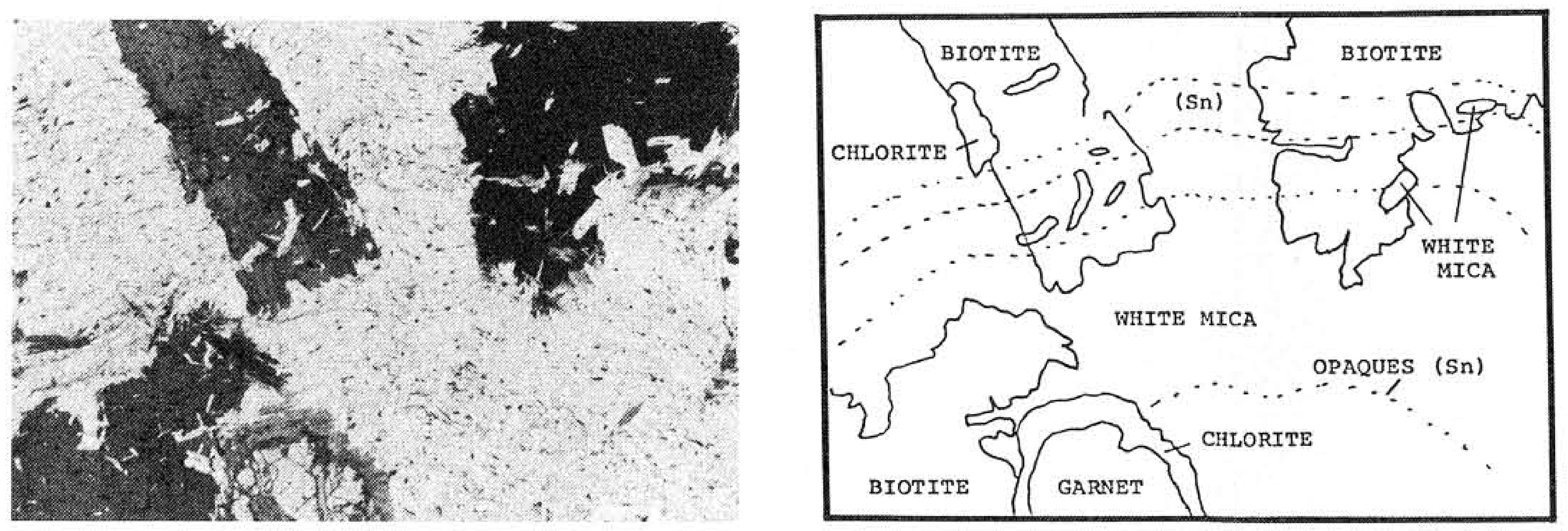


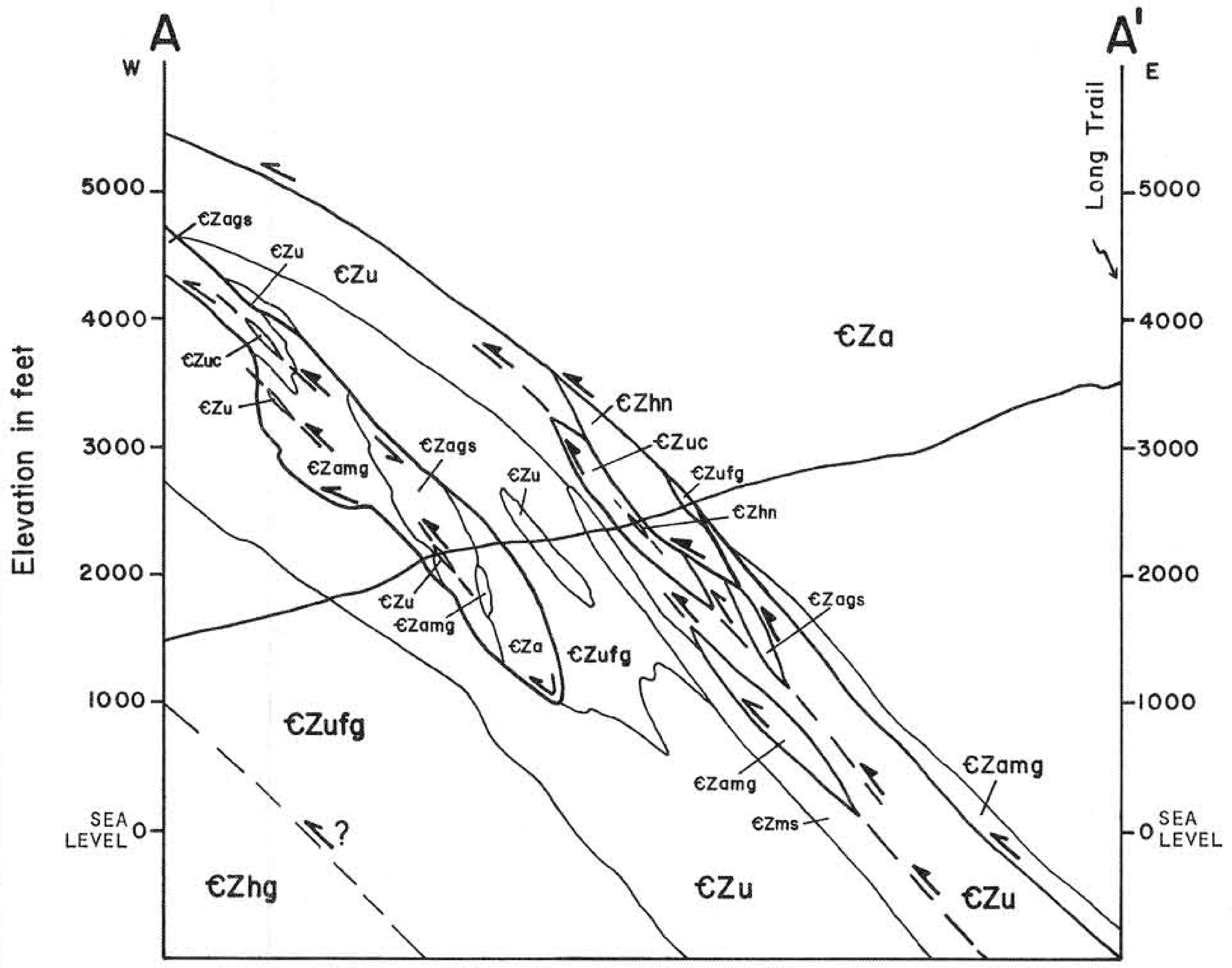
Figure 4
Plane light photomicrograph of coarse grained Underhill micaceous schist (course €Zu). Layers of opaques parallel the dominant schistosity (Sn) and are folded by Fn+1. Coarse, cross biotite grows across and postdates Fn+1 deformation. The biotite is partially altered to chlorite. Field of view is 1.3 by 0.8 centimeters. Location D4 (Plate 1).

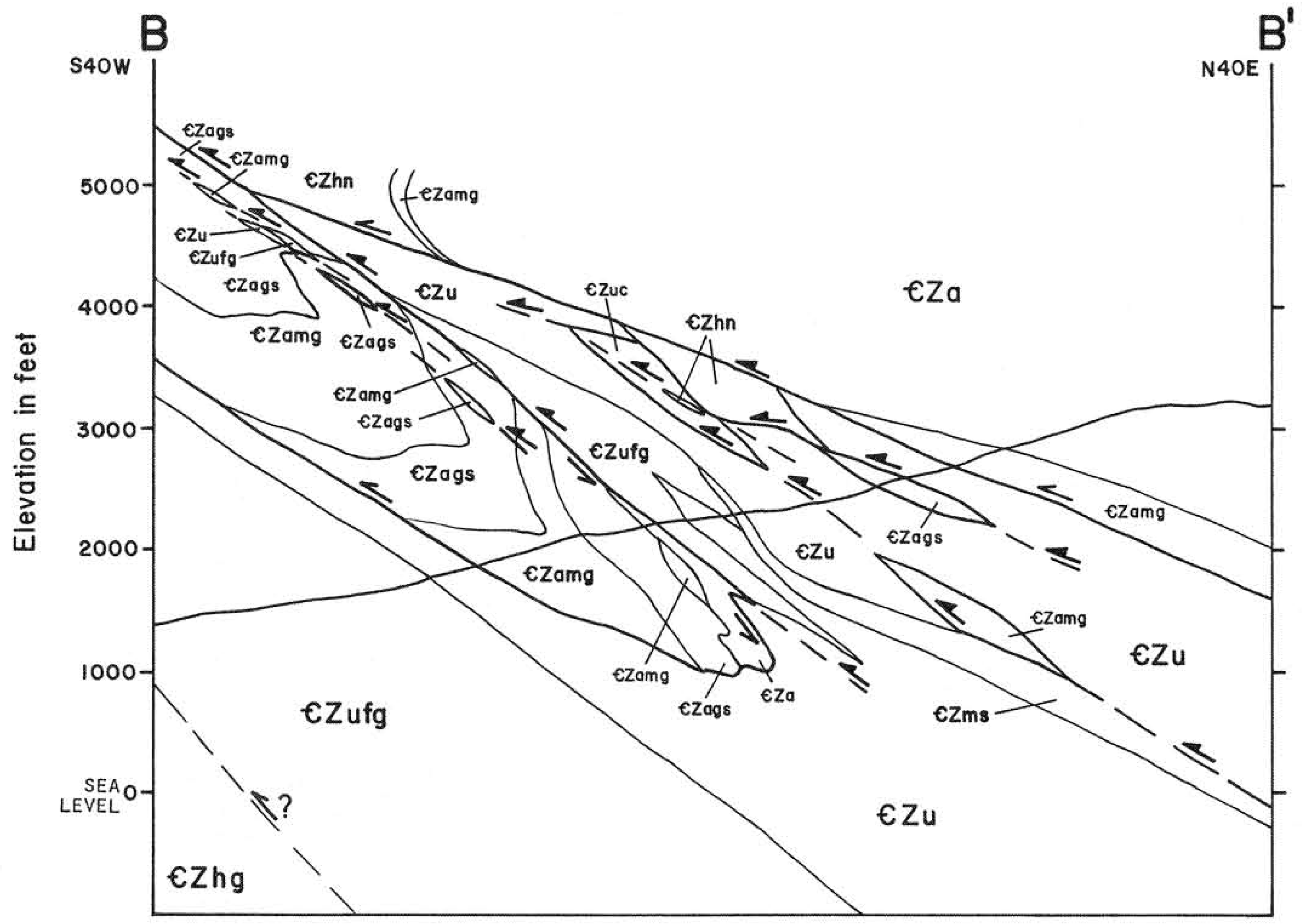
Table 4 Structural Relationships from Thin Section

MINERAL	CREATE Sn-1	FOLD Sn-1	CREATE Sn	FLATTEN Sn	FOLD Sn	CREATE Sn+1	FOLD Sn+1	CREATE Sn+2
WHITE MICA	As inclusions // Sn-1 Relict hinges		// Sn Layers // Sn Fine // Sn	Wraps around plagioclase and garnet	Warped, crenulated, folded, bent and kinked by Fn+1	Coarse // Sn+1 Realigned // Sn+1		Coarse cross
GRAPHITE	As inclusions // Sn-1	Folded and kinked by Fn	// Sn Layers // Sn	Aligned // Fn shear zones	Folded, crenulated, and kinked by Fn+1	Realigned // Sn+1		
OPAQUES	As inclusions // Sn-1		Elongate // Sn Layers // Sn	Sn wraps around Coarse blobs strung out // Sn	Layers bent and folded by Fn+1 Caught in Fn+1 hinges	Realigned // Sn+1 Fn+1 kink bands wrap around		
PLAGIOCLASE (Detrital)		With bent inclusion trails (ZONATION)	With few or straight inclusion trails	Sn wraps around Deformation twins Undulatory extinction Flattened // Sn Alteration	Folded and bent by Fn+1 Caught in Fn+1 hinges Deformation	Sn+1 wraps around or cuts through		
GARNET		With S-shaped and bent inclusion trails	With straight inclusion trails Layers // Sn	Alters to chlorite With chlorite pressure shadows Sn wraps around Fractured	Folded and bent by Fn+1 Fractured	Sn+1 wraps around		Cut by cross white mica
CHLORITE		From alteration of garnet	Fine // Sn From alteration of garnet	Coarse // Sn Sn wraps around As pressure shadows on garnet // Sn	Bent, crenulated, and folded by Fn+1	Coarse // Sn+1 As pressure shadows on garnet // Sn+1 Sn+1 wraps around	Realigned // Sn+1	From alteration of biotite Cut by cross white mica
CHLORITOID			// Sn Layers // Sn	Layers // Sn Sn wraps around Truncates Sn	Bent and folded by Sn+1	// Sn+1 As pressure shadows on garnet // Sn+1		
KYANITE			Elongate // Sn With inclusion trails // Sn	Alters to white mica Sn wraps around				
BIOTITE			Truncates Sn	Coarse // Sn NOT flattened // Sn	At high angles to Sn Undulatory extinction	// Sn+1 Sn+1 wraps around	Truncates Sn+1	Cut by cross white mica
QUARTZ (Detrital)	As inclusions // Sn-1		As veins // Sn Layers // Sn	Deformation Undulatory extinction As pressure shadows on garnet // Sn	Bent, folded, and kinked by Fn+1 Veins folded by Fn+1 Undulatory extinction	As veins // Sn+1 As pressure shadows on garnet // Sn+1 Recrystallization // Sn+1		

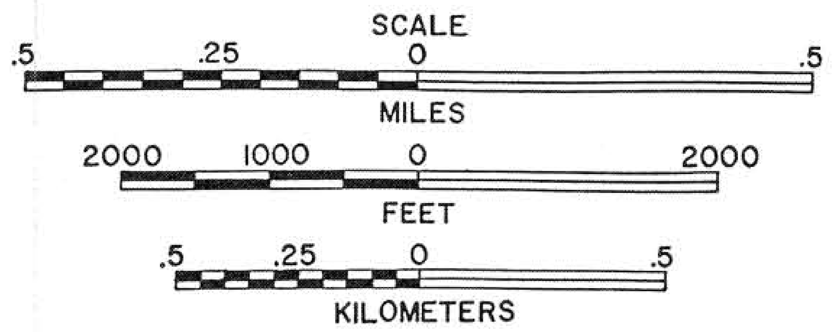
EXPLANATION: Columns represent stages of structural development. Time progresses to the right.
Line patterns symbolize a period of mineral growth in the different units.
For example: the horizontal solid line in the upper left corner box indicates that white mica grew during the creation of Sn-1 schistosity in the Hazens Notch carbonaceous schist (€Zhnc).
Supporting evidence is noted within the boxes.
For abbreviations, see Plate 1.
Based on detailed petrography of 130 thin sections.

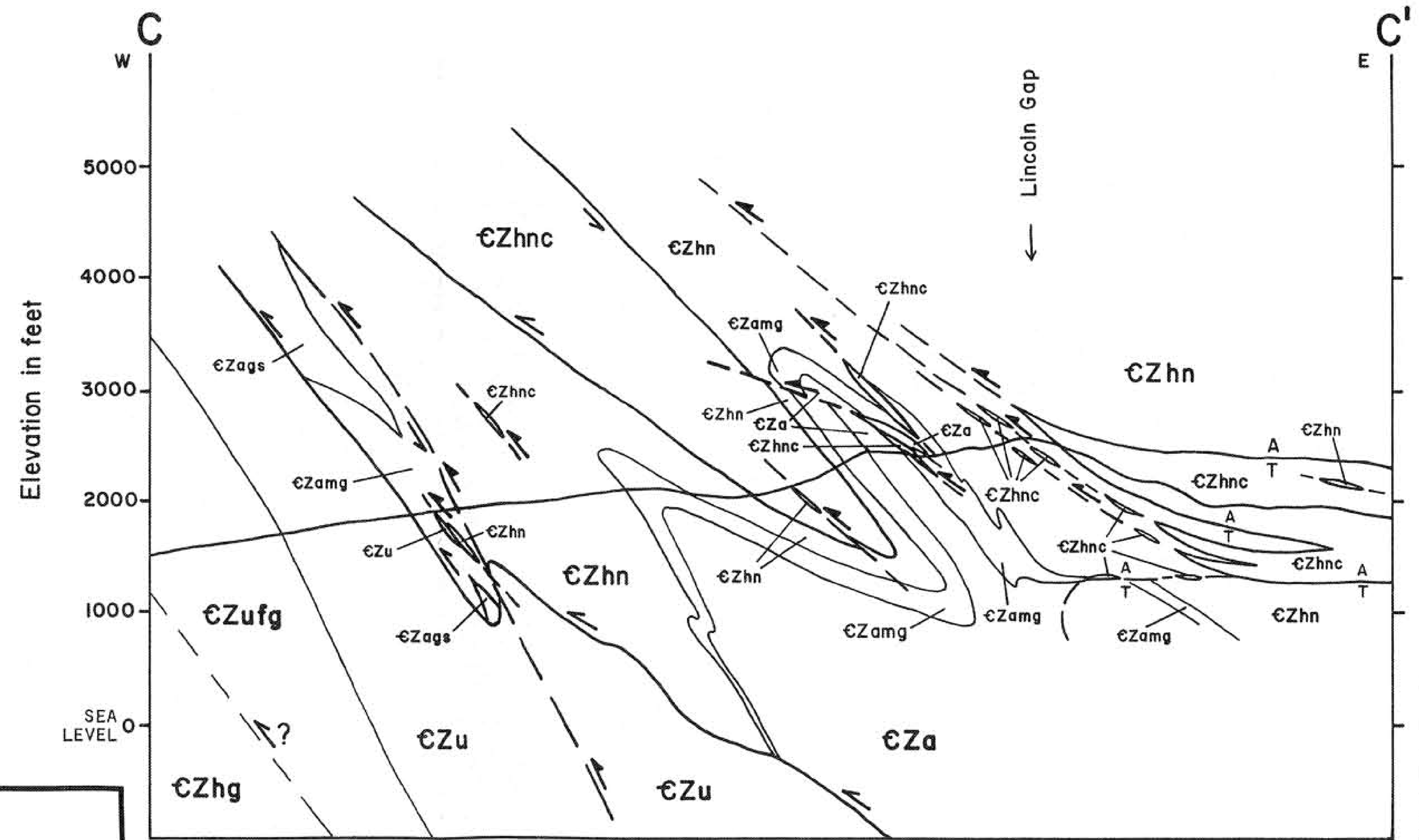
Line Patterns:
- €Zhn Hazens Notch (noncarbonaceous) albitic schist
- €Zhnc Hazens Notch carbonaceous schist
- €Za Mt. Abraham schist
- €Zamg Mt. Abraham magnetite-garnet schist
- €Zags Mt. Abraham garnet schist
- €Zu Underhill micaceous schist
- €Zufg Underhill foliated metawacke





NO VERTICAL EXAGGERATION





EXPLANATION

Lithic contact. Some lithic contacts may be annealed, pre-peak metamorphic thrust faults.

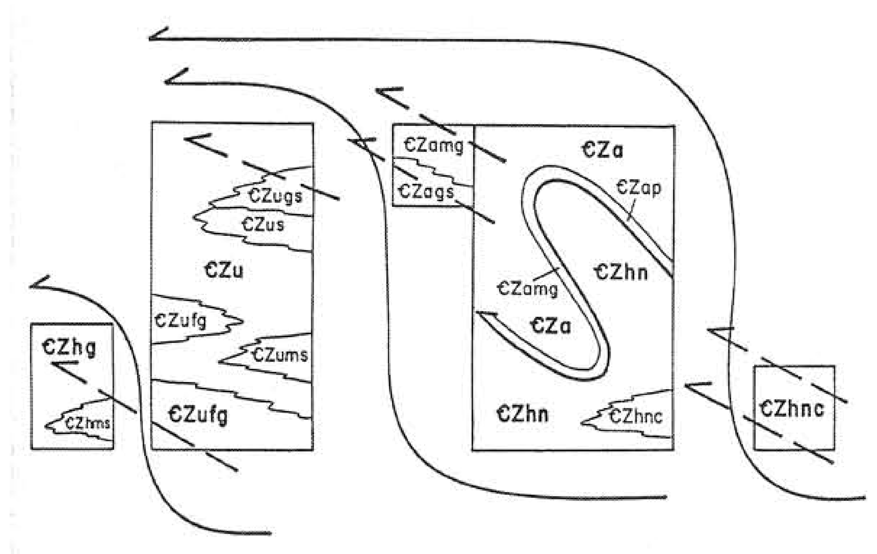
Post-peak metamorphic fault. Subparallel to the dominant schistosity (Sn). Dashed where discontinuous.

Pre- to syn-peak metamorphic thrust fault. Parallel to the dominant schistosity (Sn).

For other symbols and abbreviations, see Plate 1.

Figure 5
Cross sections A-A', B-B', C-C', and D-D'. For location and orientation of section lines, see Plate 1. Note that pre- to syn-peak metamorphic faults are isoclinally folded and are both cut and, in part, reactivated by semi-brittle, post-peak metamorphic faults. Compare with Schematic Model (Figure 6).

SCHEMATIC MODEL



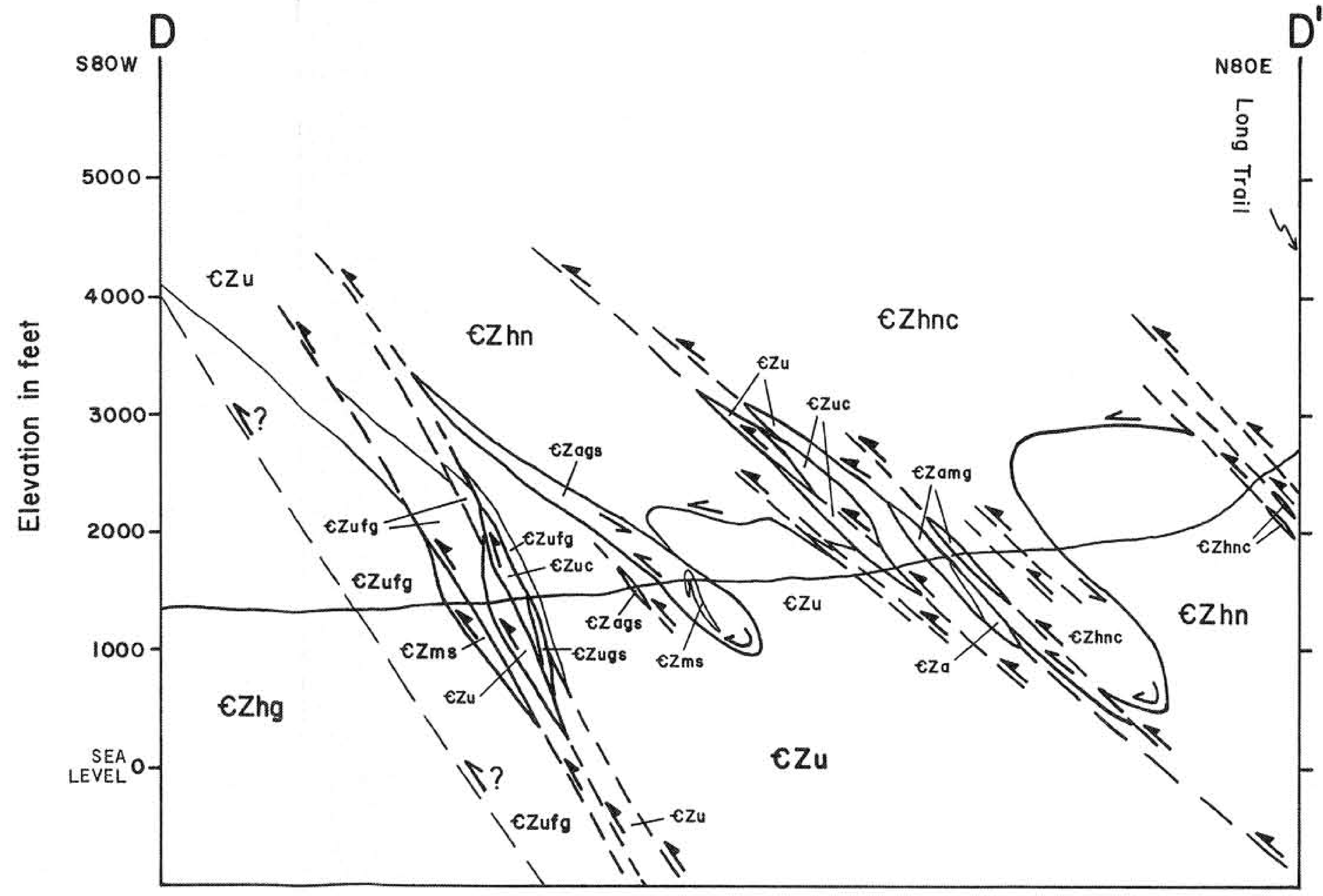


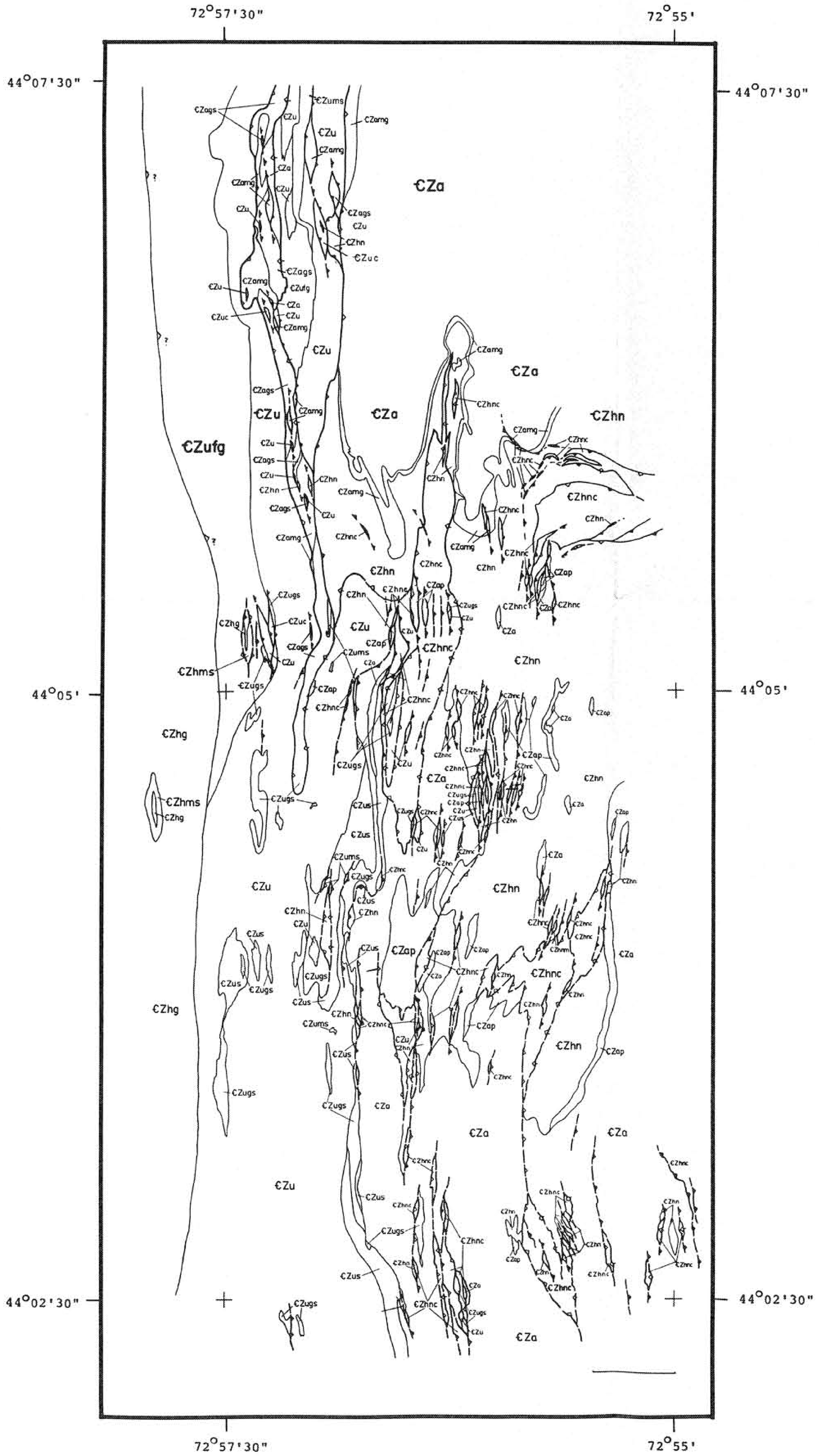
Figure 6
Schematic model of the Mt. Abraham - Lincoln Gap area. Blocks represent thrust slices separated by pre- and syn-peak metamorphic faults (curved, solid lines; half arrows show movement directions). Thin lines within thrust slices represent possible depositional relationships. Semi-brittle, post-peak metamorphic faults (straight, dashed lines; half arrows show movement directions) cut and, in part, reactivate pre- and syn-peak metamorphic faults. Unit abbreviations as on Plate 1. For additional explanation, see text.

PLATE 3

Sharon B. O'Loughlin, Eric T. Lapp, and Rolfe S. Stanley

Crenulate and Mesoscopic Fold Data from the Mt. Abraham - Mt. Grant Area, Central Vermont

Combined Geologic Map



Explanation

COMBINED GEOLOGIC MAP

For symbols, abbreviations, and explanation, refer to Plate 1.

Lithic units which are not explained on Plate 1 are from either Lapp (1986) or O'Loughlin (1986) and include:

ЄZhnm	Marble associated with the Hazens Notch Formation.
ЄZap ЄZamg	Similar units of the Mt. Abraham Schist.
ЄZags ЄZugs	Coarse garnet schist attributed to the Mt. Abraham Schist and the Underhill Formation, respectively.
ЄZus	Sericite schist of the Underhill Formation.
ЄZhg	Metawacke of the Hoosac Formation.

STRUCTURAL DATA MAP

Planar Features

- Strike and dip of axial surface (Sn+1) to crenulate or mesoscopic Fn+1 folds which deform the dominant schistosity (Sn).
- Vertical axial surface (Sn+1) to crenulate or mesoscopic Fn+1 folds which deform the dominant schistosity (Sn).
- Strike and dip of axial surface (Sn+2) to crenulate or mesoscopic Fn+2 folds which deform Fn+1 axial surfaces.

Linear Features

- Trend and plunge of Fn+1 fold axis.
- Trend and plunge of Fn+1 fold axis with known clockwise sense of rotation.
- Trend and plunge of Fn+1 fold axis with known counter-clockwise sense of rotation.
- Trend and plunge of Fn+2 fold axis.
- —— Geologic contact and domain boundary. Most geologic contacts are not represented.
- ---- Lincoln Gap Road and domain boundary.

Other

- + Register mark.

NETS

Lower hemisphere, equal area projections of summary relationships determined from plots of Fn+1 axial surfaces (Sn+1 schistosity). Five domains are represented. These are:

Mt. Abraham Domain - the area including Mt. Abraham, west to the contact and south to the Lincoln Gap Road.

Prospect Rock Belt Domain - the area which comprises the Prospect Rock Belt, south to the Lincoln Gap Road.

Battell Trails Domain - the area west of the Mt. Abraham Domain and north of the Lincoln Gap Road, excluding the Prospect Rock Belt.

Mt. Grant Domain - the area including Mt. Grant, west to the contact and north to the Lincoln Gap Road.

South Lincoln Domain - the area to the east of South Lincoln, east to the contact and north to the Lincoln Gap Road.

On the plots, N denotes the orientation of north and a cross marks the center of the projection. The plane of the projection is horizontal. The number of measurements (poles) represented in each domain is n. A solid half circle represents the statistical plane derived by contouring the poles to Sn+1. The orientation of this plane is labelled. A dashed half circle, where present, corresponds to the orientation of the pi girdle through poles to Sn+1. The pole to the girdle represents the fold axis (solid dot) of Fn+2 deformation in the domain.

Geologic mapping and structural data north of Lincoln Gap Road from O'Loughlin (1986); south of Lincoln Gap Road from Lapp (1986).

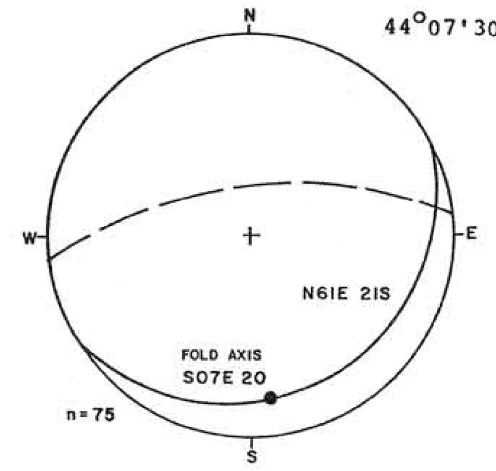
SCALE

.5 0 .5 MILES

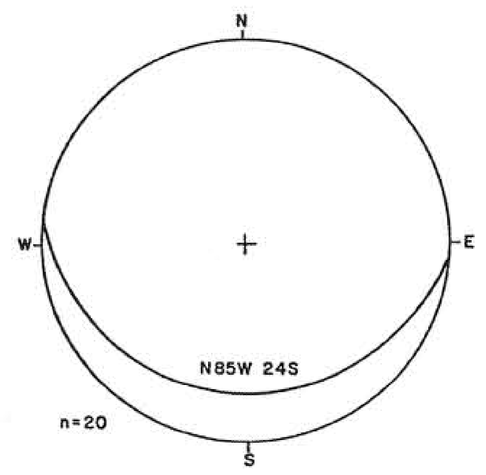
2000 0 2000 FEET

.5 0 .5 KILOMETERS

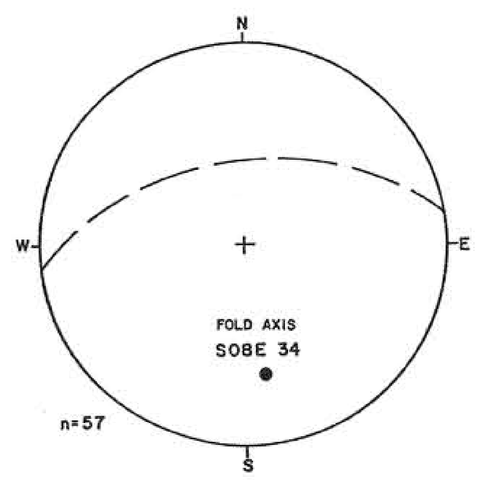
Fn + 1 and Fn + 2
Structural Data Map and Nets



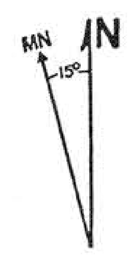
Battell Trails Domain

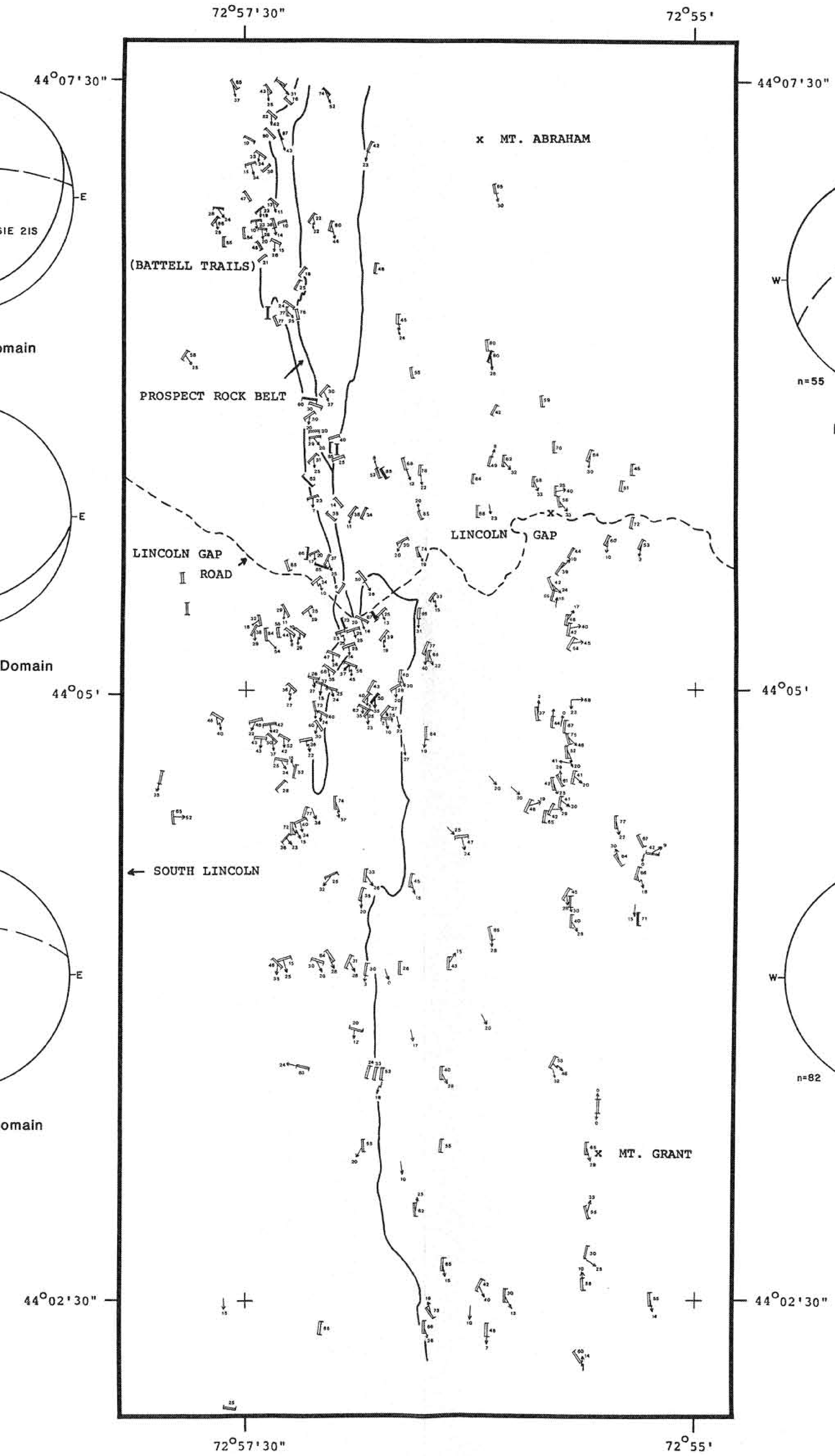


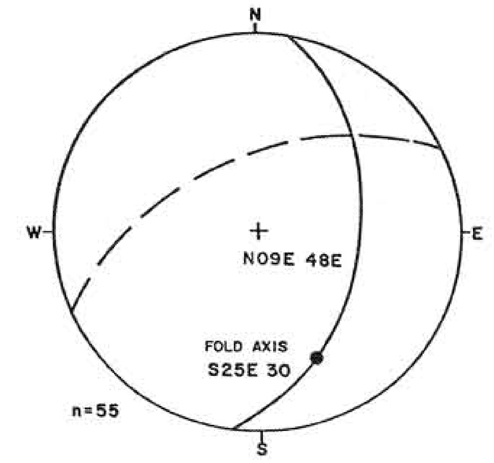
Prospect Rock Belt Domain



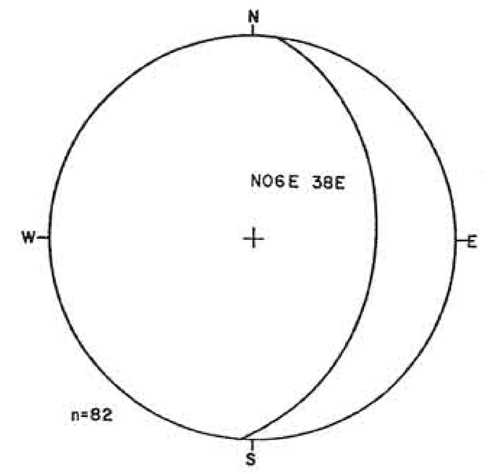
South Lincoln Domain







Mt. Abraham Domain



Mt. Grant Domain