BEDROCK GEOLOGY OF THE EAST FLETCHER-BAKERSFIELD AREA NORTHERN VERMONT

by

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Cover Photograph. View of Fletcher Mountain (Elevation 2,158 feet) and the eastern part of the study area looking to the southeast. Mount Mansfield is in the distant background.

ABSTRACT

Detailed mapping (scale 1:12,000) in the East Fletcher-Bakersfield area shows that a thinned but coherent stratigraphy of rift-stage metavolcanic and clastic rocks and overlying drift-stage rocks are present in the Richford-Cambridge syncline. The rocks within the Richford-Cambridge syncline are part of the Proterozoic Z-Cambrian Camels Hump Group and Cambrian Sweetsburg Formation and are divided into a Western and an Eastern Sequence. The Western Sequence consists of metawackes, metavolcanics, and metapelites of the Pinnacle and Underhill Formations and graphitic phyllites of the Sweetsburg Formation. The Eastern Sequence is primarily made up of the micaceous schists of the Underhill Formation and lesser amounts of metawackes and metavolcanic rocks. The Eastern Sequence is interpreted to be a thrust slice of more easterly deposited rocks similar to those found in the Western Sequence. The Eastern and Western Sequences are separated by the East Fletcher thrust.

The interbedded nature of the metawackes and greenstones and the presence of crossbedding and pillow structures in the greenstones indicates that the rift clastic and metavolcanic rocks were deposited and erupted in a shallow basin. Geochemical analysis of the metavolcanics from both the Pinnacle and Underhill Formations is consistent with their intrusion through thinned continental crust during the opening of the proto-Atlantic Ocean. The Pinnacle Formation represents the coarse clastic detritus resulting from rifting whereas the finer-grained rocks of the Underhill Formation are considered to be both an eastern facies of the Pinnacle Formation and as overlying the Pinnacle Formation on the western side of the Richford-Cambridge syncline. The overlying drift-stage graphitic rocks of the Sweetsburg Formation were deposited in the distal part of a deepening anoxic basin.

Structural and metamorphic analysis shows that the rocks in the Richford-Cambridge syncline have been subjected to three phases of deformation. The earliest deformation (D1) is poorly understood because of overprinting by the later two phases of deformation. D1 is thought to have involved large-scale west verging nappes and concurrent east-over-west faults on the overturned limbs. Evidence for the D1 phase of deformation includes an early schistosity, a complex refolded map pattern, and truncation of map units along the East Fletcher thrust. Metamorphic conditions during D1 reached the garnet grade for rocks east of the East Fletcher thrust.

The second phase of deformation (D2) resulted in the development of the dominant schistosity in the East Fletcher-Bakersfield area. The S2 schistosity shows a fanning from steeply east dipping on the west side of the study area, to steeply west dipping in the Richford-Cambridge syncline; S2 becomes progressively shallower west dipping towards the east and the axis of the Green Mountain anticlinorium. Steep shear zones with west-over-east sense of motion occurred during D2. The Richford-Cambridge syncline formed by refolding of the D1 stage nappes into tight isoclinal folds during D2. Metamorphic mineral assemblages indicate that the rocks in the study area were retrograded to the greenschist facies during D2.

The final phase of deformation (D3) is associated with the development of the Green Mountain anticlinorium east of the study area. This final stage of deformation was the least intense of the three deformations and produced a locally developed crenulation cleavage (S3) and shallow plunging open folds. The D3 stage of deformation does not greatly affect the overall map pattern.

INTRODUCTION

Recent and ongoing geologic mapping in Vermont and southern Quebec has provided additional constraints on the stratigraphic and tectonic history of the northern Appalachian orogenic belt. New tectonic models involving multiple phases of deformation have recently been developed for the hinterland of northwestern New England and southern Quebec (St. Julien and Hubert, 1975; Stanley and Ratcliffe, 1985; Doolan, 1987). These models were developed using modern plate tectonic theory and provide a framework upon which to test the results of new large-scale geologic mapping.

Early workers in northern Vermont recognized the anticlinal structure of the Green Mountains (Keith, 1932). The first comprehensive mapping in the East Fletcher-Bakersfield area was published by Christman (1959) and Dennis (1964) at a scale of 1:62,500 in the Mt. Mansfield and the Enosburg Falls 15 minute quadrangles respectively. These studies confirmed the presence of the Green Mountain anticlinorium and helped define a stratigraphy for the metamorphosed rocks of the Green Mountain hinterland. Cady and others (1962) named the Camels Hump Group for the metamorphosed volcanic and clastic rocks east of the Cambrian-Ordovician shelf strata exposed in the Champlain Valley. The Camels Hump Group as originally proposed, however, required a large number of facies changes along and across strike in order to explain the complex distribution of lithologies on both sides of the Green Mountain anticlinorium.

Studies along strike in central Vermont (Tauvers, 1982; DiPietro, 1983; DelloRusso and Stanley, 1986; O'Loughlin and Stanley, 1986; Lapp and Stanley, 1986) and in southern Quebec (Colpron and others, 1987) have demonstrated that many of the contacts originally thought to be depositional are now considered tectonic. Detailed mapping (scale 1:12,000) in the East Fletcher-Bakersfield area shows that the various lithologies are complexly folded and faulted by three phases of deformation. This report presents the results of bedrock mapping in the East Fletcher-Bakersfield area on the western flank of the Green Mountains and proposes a tectonic synthesis for this part of northern Vermont. The East Fletcher-Bakersfield area provides an important link between the ongoing studies in central Vermont and southern Quebec.

REGIONAL GEOLOGY

The major structural features in northwestern Vermont are the Enosburg Falls anticline to the west of the study area and the larger Green Mountain anticlinorium to the east (Figure 1). The Green Mountain anticlinorium extends for over 300 km from northern Massachusetts into southern Quebec where it dies out as a north-plunging anticline (Osberg, 1965; Marquis and others, 1987). The study area lies between these two northeast trending anticlinoria in what was named by previous workers as the Cambridge syncline (Christman, 1959) and the Richford syncline (Dennis, 1964). For this report, the region between the Enosburg Falls anticline and the Green Mountain anticlinorium is designated as the Richford-Cambridge syncline. The Richford-Cambridge syncline in the East Fletcher-Bakersfield area is one of the few places in northern Vermont where a complete sequence of rift-stage clastic rocks (the Camels Hump Group) and drift-stage cover rocks (the Sweetsburg Formation) are exposed over a relatively narrow zone.

The Camels Hump Group and the equivalent rocks in southern Quebec, the lower part of the Oak Hill Group, form a continuous north-to-northeast trending belt of rift clastic and volcanic rocks in the southern arm of the Quebec reentrant. These rocks represent the debris shed off into a basin formed by rifting of the North American continent during the late Proterozoic (Rankin, 1976). The Richford-Cambridge syncline appears to be a transition zone between the less deformed rift clastic rocks of the Camels Hump Group to the west and the serpentine bearing high-pressure metamorphic rocks of the Hazens Notch Formation to the east (Laird and Albee, 1981). A similar sequence of thinned rift clastic and cover lithologies is present on strike in the Mansville Phase in southern Quebec, 15 km north of the international border (Colpron and others, 1988).

Quartzites and carbonates deposited on the ancient continental shelf of North America are located west of the study area in the Champlain Valley. A number of large-scale north-south trending thrust faults separate the hinterland of the Green Mountains from the foreland and the stable North American craton. The largest of these is the Champlain thrust which has transported part of the platform sequence westward onto the autochthonous carbonate platform. Farther to the east, the Hinesburg thrust formed on the sheared out lower limb of a recumbent fold and transported the rift clastic rocks of the Camels Hump Group westward over the shelf rocks (Dorsey and others, 1983). These thrust faults are related to the closure of the proto-Atlantic Ocean during the latter stages of the Ordovician Taconian orogeny (Stanley and Ratcliffe, 1985).

LOCATION AND PHYSIOGRAPHY

The area described in this report is located in the towns of Fletcher and Bakersfield in the Jeffersonville and Bakersfield 7½ minute quadrangles (Plate 1). The total area covered by this report is approximately 30 km^2. Vermont Route 108 is the major north-south highway in the region and divides the study area into two approximately equal areas. The western part of the study area extends from the eastern flank of Wintergreen Mountain (elevation 495 m) across the valley drained by Black Creek. The eastern boundary is along the northeast trending ridge formed by Fletcher Mountain (elevation 658 m) and Kings Hill Mountain (elevation 606 m). The area is characterized by moderate terrain on the west and steeper slopes to the east. Total relief in the area is approximately 520 m.

STRATIGRAPHY

The rocks within the Richford-Cambridge syncline are part of the Proterozoic Z-Cambrian volcanic and rift clastics of the Camels Hump Group and the overlying cover rocks of the Sweetsburg Formation. No fossils have ever been found in the Camels Hump Group. The only constraint on the lower age of the Camels Hump Group is the discovery that the Pinnacle Formation unconformably overlies the Proterozoic Y Mount Holly Complex near Lincoln, Vermont (Tauvers, 1982; DelloRusso and Stanley, 1986). A lower Proterozoic Z to Cambrian age is assigned to the Camels Hump Group because the Fairfield Pond Formation is unconformably overlain by the Olenellus bearing Cheshire Formation (Dennis, 1964; DiPietro, 1983).

In northern Vermont, the Camels Hump Group consists of six major units. These include the Tibbit Hill volcanic member, the Pinnacle Formation, the White Brook Dolomite, the Underhill Formation, the Fairfield Pond Formation, and the Hazens Notch Formation (Doll and others, 1961). The Sweetsburg Formation overlies the Camels Hump Group in the Richford-Cambridge syncline. The rocks in the East Fletcher-Bakersfield area are composed of the Pinnacle, Underhill, and Sweetsburg Formations west of the rocks of the Hazens Notch Formation. The carbonaceous and rift clastic rocks of the Hazens Notch Formation have recently been reinterpreted as part of an accretionary wedge and no longer as a stratigraphic unit within the Camels Hump Group (Doolan and others, 1982; Stanley and others, 1984). A stratigraphic correlation chart for the rocks found in the East Fletcher-Bakersfield area as mapped by previous workers is shown in Figure 2.

The rocks of the East Fletcher-Bakersfield area can be divided into two stratigraphic

EXPLANATION

10 Devonian New Hampshire Series Plutons

9 Silurian-Devonian Metasedimentary rocks of the Connecticut Valley-Gaspé Synclinorium

8 Early to Mid-Ordovician Volcanic Arc and Related Marine Sedimentary Rocks

7 Allochthonous Rift Clastics and Slope-Rise Cover Rocks
7a-Taconic Allochthons, **7b**-Stanbridge Nappe

6 Taconian Accretionary Wedge
Hazens Notch Formation

5 Cambrian-Ordovician Post-Rift Slope and Rise Cover Rocks
Ottauquechee and Sweetsburg Formations

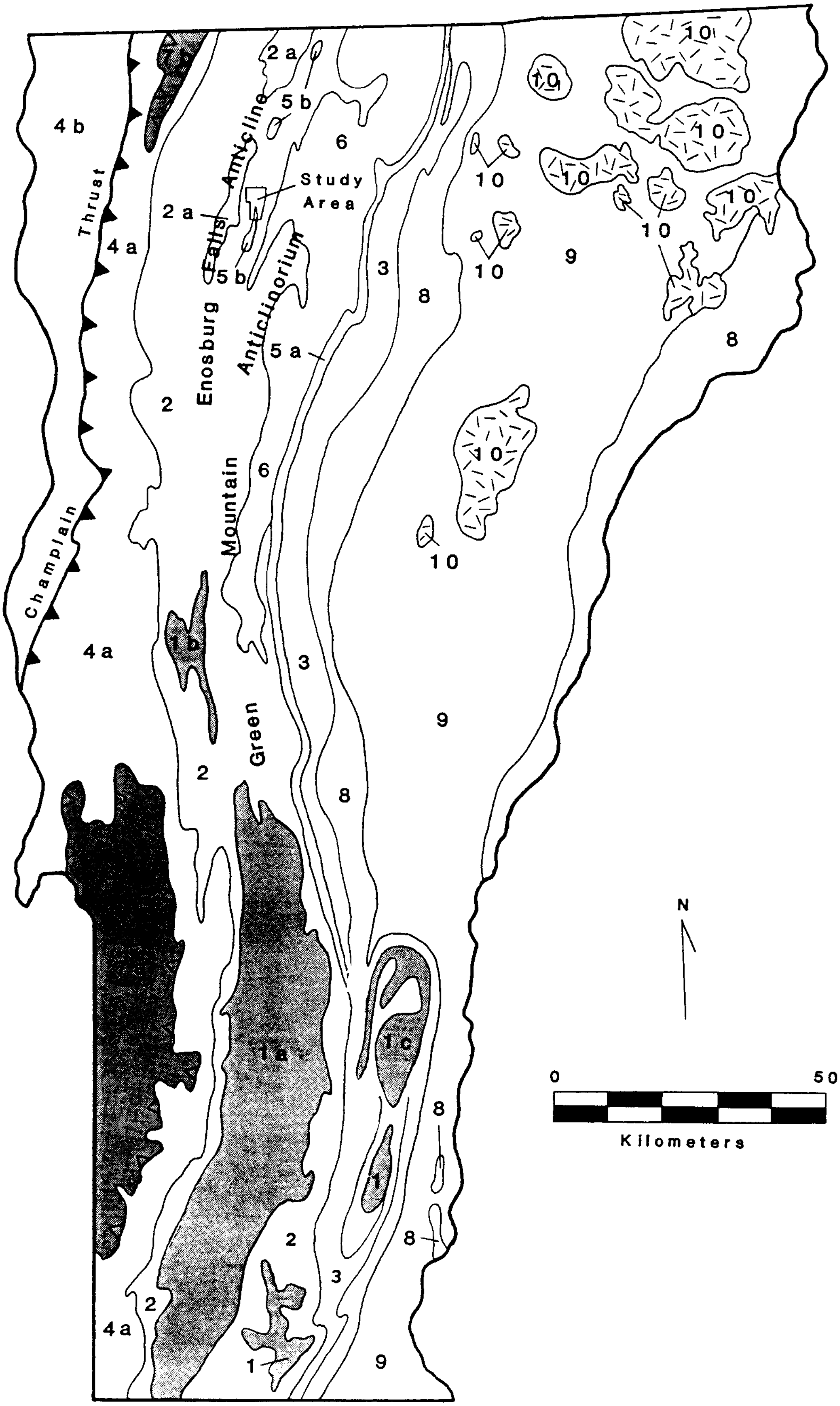
4 Cambrian-Ordovician Shelf-Slope Sequence of North American Craton
4a-Carbonate Platform/Slope Rocks, **4b**-Flysch and Carbonate Rocks

3 Late Proterozoic to Early Cambrian Eastern Rift Clastic Rocks
Stowe Formation (includes the Rowe Formation in southern Vermont)

2 Late Proterozoic to Early Cambrian Rift Clastic Rocks
2-Lower Camels Hump Group, **2a**-Tibbit Hill Metavolcanic Member

1 Middle Proterozoic Basement
1a-Green Mountain Massif, **1b**-Lincoln Massif, and **1c**-Chester Dome

Figure 1. Generalized tectonostratigraphic map of Vermont (modified from Doll and others, 1961; and Williams, 1978). The study area is outlined.



Study Area
Enosburg Falls Anticline
Green Mountain Anticlinorium
Champlain Thrust
1
1a
1b
1c
2
2a
3
4a
4b
5a
5b
6
7b
8
9
10
N
0
50
Kilometers

sequences separated by the East Fletcher thrust. The rocks west of the East Fletcher thrust are designated as the Western Sequence and the rocks east of the thrust as the Eastern Sequence. The major difference between the two sequences is the greater amount of metawacke, phyllite and low grade schists in the Western Sequence and the presence of higher grade schists in the Eastern Sequence. Both the Western and Eastern Sequences contain the graphitic phyllites and carbonates of the Sweetsburg Formation.

The Pinnacle, Underhill, and Sweetsburg Formations are subdivided into 11 members. Each of these members are described below from west to east beginning with the Western Sequence. Topping indicators which show stratigraphic up are rare in the study area because of later metamorphism. The determination of the relative stratigraphic order is based on regional correlation to similar lithologies in western Vermont and southern Quebec where fossils are present and on a limited number of topping indicators in the Western Sequence. A summary of the stratigraphic relationships of the various members is shown on Plate 1.

Western Sequence

The Western Sequence consists of 9 map units of metawackes, metavolcanic rocks, phyllites, and low grade schists in the western part of the study area and in the Richford-Cambridge syncline. These rocks belong to the Pinnacle, Underhill and the Sweetsburg Formations. The eastern boundary of the Western Sequence is the East Fletcher thrust. Graded bedding in the metawackes of the Pinnacle Formation and the quartzites of the Sweetsburg Formation are the basis for determination of the stratigraphic order.

Pinnacle Formation

The Pinnacle Formation is the coarsest lithological unit found within the study area and includes both the fine-grained and coarse-grained metawackes of the Pinnacle Formation and a metavolcanic horizon previously correlated with the Tibbit Hill schists as defined by Clark (1934) in southern Quebec. The Tibbit Hill schists form an approximately 8 km thick volcanic pile underlying the rift clastic rocks in southern Quebec (Kumarapeli and others, 1981). In the East Fletcher-Bakersfield area and farther to the west (Dennis, 1964; Doolan, 1987) the metavolcanic rocks are interbedded with metawacke horizons of the Pinnacle Formation. Therefore, the metavolcanic rocks in the Western Sequence are included as a member within the Pinnacle Formation.

The Pinnacle Formation is confined to the western half of the study area where it generally forms resistant massive outcrops. These exposures are on the eastern limb of the Enosburg Falls anticline which is cored by a wide belt of metavolcanic rocks and metawackes of the Pinnacle Formation (Dennis, 1964). In the East Fletcher-Bakersfield area, the Pinnacle Formation is subdivided into three members: a metavolcanic member (CZpv), a fine-grained metawacke (CZpf), and an coarse-grained metawacke (CZpc). Graded bedding in the coarse-grained metawacke provides stratigraphic control. Modal mineral analyses of these members are given in Table 1.

<u>Metavolcanic member (CZpv):</u> The metavolcanic member is the basal unit within the Western Sequence. It is primarily a calcareous greenstone with lessor amounts of original volcanoclastic sediment. Mineral composition of the greenstone is chlorite-quartz-calcite-epidote-actinolite-albite. The amount of quartz is extremely variable, ranging from less than 15% to greater than 30%. The high quartz content in some of the outcrops indicates that part of the metavolcanic rocks in the study area are volcanoclastic in origin. The chlorite in the metavolcanic member (CZpv) is Mg-rich as determined by their anomalous blue interference color in thin section. A distinctive feature of the greenstones in the Pinnacle Formation is the presence of 4-10 cm round epidote nodules. Calcite stringers are stretched out along the dominant foliation forming a poorly defined compositional layering. The weathered surface is commonly pitted and weathers to a dark green-brown color. The fresh surface is variable

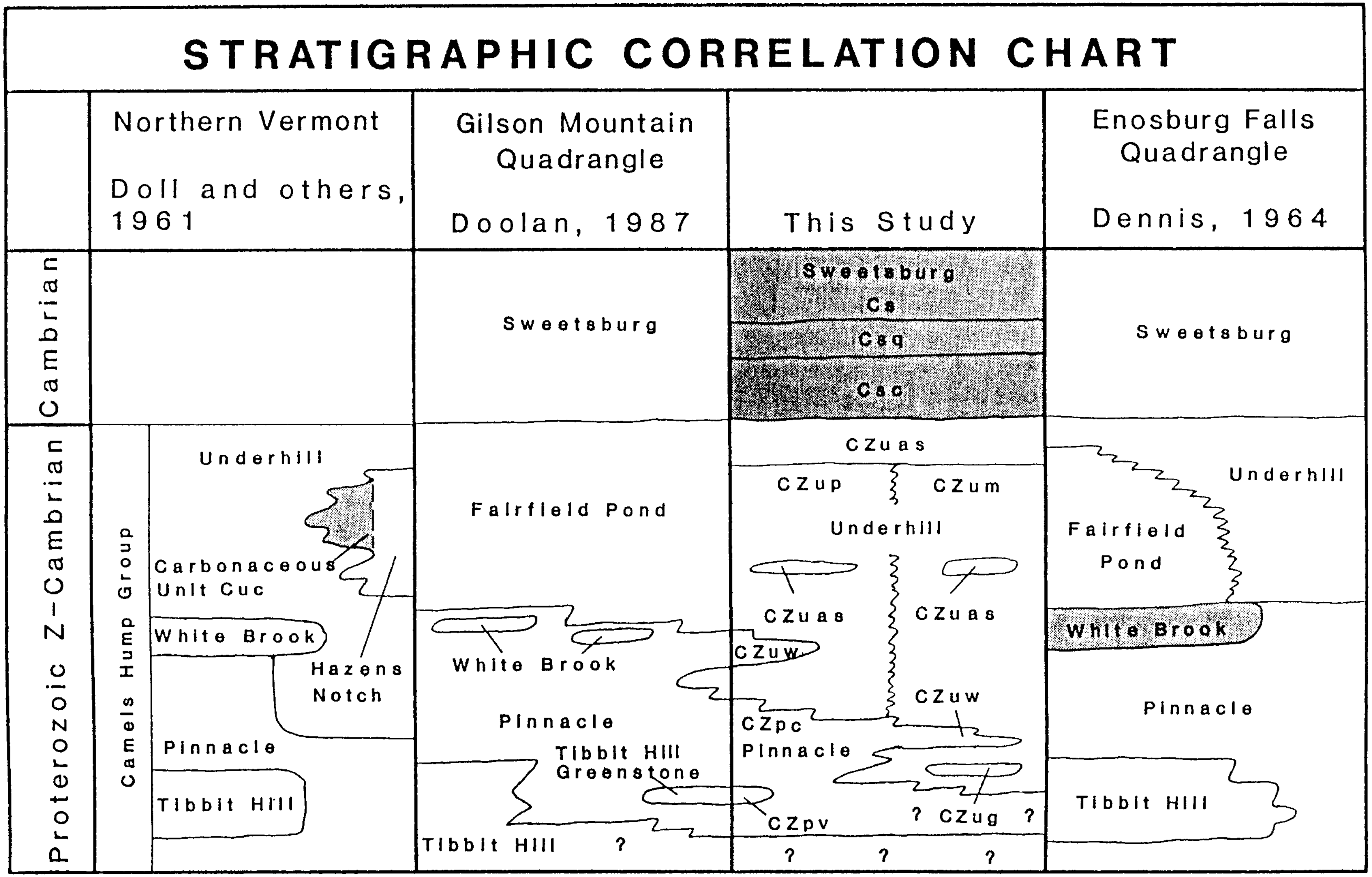


Figure 2. Stratigraphic correlation chart for the Camels Hump Group and cover rocks in northern Vermont. The carbonaceous rocks in the Richford-Cambridge syncline as mapped by various workers are shaded.

in color from dark green in the massive greenstones to a pale green color in the more volcanoclastic outcrops.

The metavolcanic member of the Pinnacle Formation (CZpv) is confined to a single horizon in the extreme northwestern part of the study area. The metavolcanic member is in depositional contact with the fine-grained metawacke (CZpf). The contact with the fine-grained metawacke is gradational and is marked by an increase in quartz and a decrease in chlorite toward the contact. Although no topping indicators were found in the metavolcanic member itself, graded bedding in the coarse-grained metawacke (CZpc), which overlies the fine-grained metawacke (CZpf), indicates that both metawacke members overlie the massive greenstones. Estimated maximum thickness of the metavolcanic member is approximately 50 m. The reference section for the metavolcanic member (CZpv) is at location C2 (Plate 1).

Fine-grained metawacke member (CZpf): This unit is a light gray to green-gray metawacke and grit with phyllitic layers. Mineral composition is quartz-white mica-albite-chlorite-magnetite. The matrix is composed of polygonal quartz, white mica, and chlorite. Blue quartz pebbles are present but are relatively rare in comparison to the coarse-grained metawacke (CZpc).

The fine-grained metawacke (CZpf) is found only in the northwest corner of the study area where it lies between the metavolcanic member (CZpv) and the coarse metawacke (CZpc). Contacts with the greenstone and the coarse-grained metawacke are gradational. Graded bedding in the coarse-grained metawacke indicates that the fine-grained metawacke (CZpf) lies below the coarse-grained metawacke (CZpc). The thickness of the fine-grained metawacke is approximately 70 m. The reference section for the fine-grained metawacke is located at E2 (Plate 1).

Coarse-grained metawacke member (CZpc): The coarse-grained metawacke is the most important of the three members within the Pinnacle Formation in the East Fletcher-Bakersfield area. It is generally a light gray quartz-albite-white mica±biotite metawacke characterized by the presence of distinctive (1-3 mm) blue quartz grains. On weathered surfaces, the coarse grain metawacke is light-to-dark gray and has a rough texture due to the presence of the large rounded quartz grains. Outcrops are generally massive but become strongly foliated in the hinges of late folds.

Iron-rich biotite is commonly present in the coarse-grained metawacke and can be seen partially altered to chlorite in thin section. The upper part of this member commonly contains up to 10 percent recrystallized calcite in the matrix. This calcite-bearing horizon is in the same stratigraphic position as the White Brook Dolomite found to the west of the study area (Dennis, 1964; Doolan, 1987). Therefore, the calcareous upper part of the coarse-grained metawacke (CZpc) may be an eastern facies of the White Brook Dolomite on the east flank of the Enosburg Falls anticline.

The contact with the chloritic phyllite of the Underhill Formation (CZup) is gradational with a decrease in the number of large quartz grains and an increase in chlorite near the upper part of the Pinnacle Formation. The upper contact of the Pinnacle Formation is placed at the last horizon which contains blue quartz grains larger than 1 mm. Thickness of the coarse-grained metawacke (CZpc) is estimated to be 100 m and is considerably thickened by tight isoclinal folds in the north central part of the study area. The reference section for the coarse-grained metawacke is at location G2 (Plate 1).

Underhill Formation

The Underhill Formation in the Western Sequence is primarily a quartz-white mica-chlorite phyllite and low grade schist which is locally abundant in albite and magnetite. Thin horizons of metawacke are also present. The Underhill Formation in the Western Sequence has

TABLE 1. Estimated modal mineralogy of selected lithologies from the Western Sequence in the East Fletcher-Bakersfield area.

Unit	**CZpv**	**CZpf**	**CZpc**	**CZuw**	**CZup**	**CZuas**	**Cs**
Quartz	20	42	44	42	34	12	35
White Mica	--	20	12	12	28	28	--
Sericite	--	--	--	--	--	--	21
Chlorite	28	20	12	14	18	22	8
Biotite	--	--	8	17	--	--	--
Albite	10	6	16	12	18	36	9
Graphite	--	--	--	--	--	--	12
Calcite	20	6	5	--	--	--	10
Epidote	16	4	tr	--	--	--	--
Actinolite	4	--	--	--	--	--	--
Tourmaline	--	--	--	--	--	--	2
Pyrite	--	--	--	--	--	--	3
Leucoxene	--	--	--	--	--	--	tr
Rutile	tr	--	tr	--	--	tr	tr
Opaques	2	2	3	3	2	2	--
Total	100	100	100	100	100	100	100

tr = trace
-- = Not Present

CZpv - Metavolcanic member of the Pinnacle Formation
CZpf - Fine-grained metawacke member of the Pinnacle Formation
CZpc - Coarse-grained metawacke member of the Pinnacle Formation
CZuw - Metawacke member of the Underhill Formation
CZup - Chloritic phyllite member of the Underhill Formation
CZuas - Albitic schist member of the Underhill Formation
Cs - Black phyllite member of the Sweetsburg Formation

been subdivided into three members: a chloritic phyllite (CZup), an albitic schist (CZuas), and a metawacke member (CZuw).

Chloritic phyllite member (CZup): The chloritic phyllite (CZup) is a gray-green to blue-gray phyllite and low grade schist. Modal mineralogy is quartz-white mica-chlorite-albite±magnetite. The chloritic phyllite member has a penetrative schistosity along which the rock is easily fractured.

The chloritic phyllite (CZup) is found on the west side of the Richford-Cambridge syncline and in dome and basin structures within the syncline. Dennis (1964) named these rocks the Bonsecours facies of the Underhill Formation. The chloritic phyllite member occupies the same stratigraphic position and is lithologically similar to the Fairfield Pond Formation found to the west of the study area. The contact with the coarse-grained metawacke (CZpc) is gradational and is marked by the absence of blue quartz pebbles and by an increase in quartz and magnetite in the chloritic phyllite. Thickness of the chloritic phyllite is estimated to be 150-200 m. The reference section for the chloritic phyllite is located at X4 (Plate 1).

Metawacke member (CZuw): The metawacke member is primarily a quartz-albite-white mica-biotite±magnetite metawacke and contains various amounts of chlorite. Color varies from light gray to green-brown in the more chloritic horizons. It is very similar to the coarse-grained metawacke of the Pinnacle Formation (CZpc) except that the metawacke horizons in the Underhill Formation commonly have a more pervasive foliation due to the concentration of micas along the foliation surface.

The metawacke member is found in a number of thin horizons within the Western Sequence at several different stratigraphic positions. The metawacke member is in contact with both the chloritic phyllite (CZup) and the albitic schist (CZuas). Thickness of the metawacke member varies between 2 and 20 m. The reference section for the metawacke member is at location X6 (Plate 1).

Albitic schist member (CZuas): The albitic schist member is an albite-white mica-chlorite-quartz schist and phyllite. It is locally schistose especially in the Richford-Cambridge syncline and but is more phyllitic in the western part of the study area. Color varies from silver-green in the schists to gray-green or blue-gray in the more phyllitic rocks. The albites occur as porphyroblasts approximately 0.5-2 mm in diameter which cut across the dominant schistosity. Many of the albites show simple twinning but the majority are untwinned.

Albite-bearing phyllites and schists are found in both the Western and Eastern Sequences. The grain size of the white micas in the albitic schist member increases from west to east. The albitic schist member is generally found near the contact with the rusty stained graphitic phyllites (Csc and Cs) of the Sweetsburg Formation. This relationship does not always hold, however, because there are discontinuous albitic horizons entirely within the Underhill Formation. The coarsest albite porphyroblasts (1-2 mm) are found at the contact with the Sweetsburg Formation. These rocks commonly have a rusty weathering rind on the outer surface approximately 2 cm thick, whereas the rest of the rock retains its normal silver-green to gray-green color. The location for the reference section of the albitic schist in the Western Sequence is at V5 on Plate 1.

Sweetsburg Formation

The Sweetsburg Formation is found in the core of the Richford-Cambridge syncline. These rocks have been placed at different stratigraphic positions during mapping by previous workers. Christman (1959) mapped the graphitic phyllites as part of the Ottauquechee Formation overlying the Camels Hump Group, at the same stratigraphic level as the Sweetsburg Formation. Dennis (1964), however, considered them to be an eastern facies of the

White Brook Dolomite which placed them much lower in the section between the Pinnacle and Fairfield Pond/Underhill Formations (Figure 2). Detailed mapping shows that the graphitic rocks of the Sweetsburg Formation are the youngest rocks in the East Fletcher-Bakersfield area, in agreement with Christman's interpretation. The graphitic phyllites are generally in contact with the schists and phyllites of the Underhill Formation and not with the metawackes of the Pinnacle Formation. In addition, these graphitic phyllites and carbonates are lithologically very similar to rocks on strike in southern Quebec which have been mapped as part of the Sweetsburg Formation (Marquis, 1987; Colpron and others, 1987). Therefore, these rocks are included within the Sweetsburg Formation, a western equivalent of the Ottauquechee Formation (Doll and others, 1961; Osberg, 1965).

The Sweetsburg Formation has been subdivided into three members based on detailed mapping of an excellent stream exposure at East Fletcher (location W8 to V10, Plate 1). These lithologies include a basal carbonate-bearing graphitic phyllite member (Csc), a middle quartzite member (Csq), and an upper black phyllite member (Cs). A detailed stratigraphic column based on the stream exposure at East Fletcher is shown in Figure 3. The carbonate-bearing graphitic phyllite and the black phyllite are virtually indistinguishable outside of stream exposures because of differential weathering of the carbonate beds. Therefore, all outcrops of graphitic phyllite are designated as Cs on the geologic map (Plate 1) where no carbonate beds are found.

<u>Carbonate-bearing graphitic phyllite member (Csc):</u> The carbonate-bearing graphitic phyllite is the basal member of the Sweetsburg Formation. Three distinct lithologies are included in this member: graphitic phyllite, black marble, and blue-gray dolomite. The most abundant lithology of this member is a quartz-sericite-graphite phyllite with pyrite-rich horizons. Graphite makes up as much as 12% of the rock. The graphitic phyllite is thinly laminated and is very black on both weathered and fresh surfaces but is locally stained a rusty color where pyrite has weathered out.

Marble and dolomite beds are interbedded within the graphitic phyllite. The marble is completely recrystallized and appears black because of the presence of a small amount of graphite ($\approx$10%). Dolomite beds are massive 8-15 cm thick and are blue-gray on fresh surfaces which weather to a light tan color. The blue-gray dolomites are very fine-grained and contain approximately 10% quartz. Fresh pyrite cubes are present in the dolomite beds.

The carbonate-bearing graphitic phyllite member is generally in contact with the albitic schist (CZuas) of the Underhill Formation. The contact is commonly marked by a fine-grained rusty weathering quartz-white mica-pyrite schist and grit. This rusty weathering horizon is too thin to map as a separate unit but is very distinctive in the field and marks the contact between the more resistant albitic schist and the easily eroded carbonate-bearing graphitic phyllite member (Csc). The reference section for the carbonate-bearing graphitic phyllite member is at location W9 (Plate 1).

<u>Quartzite member (Csq):</u> The quartzite member (Csq) is only found in the southern part of the study area where it is well exposed in the East Fletcher stream and on the hill slopes north of the stream (location W9, Plate 1). The quartzite member can be divided into two distinct lithologies: a lower massive quartzite and an overlying cyclically interbedded quartzite sequence. The massive quartzite is a light gray to white thickly bedded quartzite approximately 16 m thick. Thin laminae of graphitic phyllite are present, especially near the top of the massive quartzite. A single 6 cm thick bed of blue-gray dolomite is present within the massive quartzite.

Overlying the massive quartzite is approximately 12 m of thin bedded quartzite interbedded with graphitic phyllite. The quartzites are dark blue-gray in color on fresh surfaces and occur in beds approximately 10 cm thick. Bouma turbidite sequences B-E are present. Graded bedding and crossbedding in the quartzites show that the thin bedded

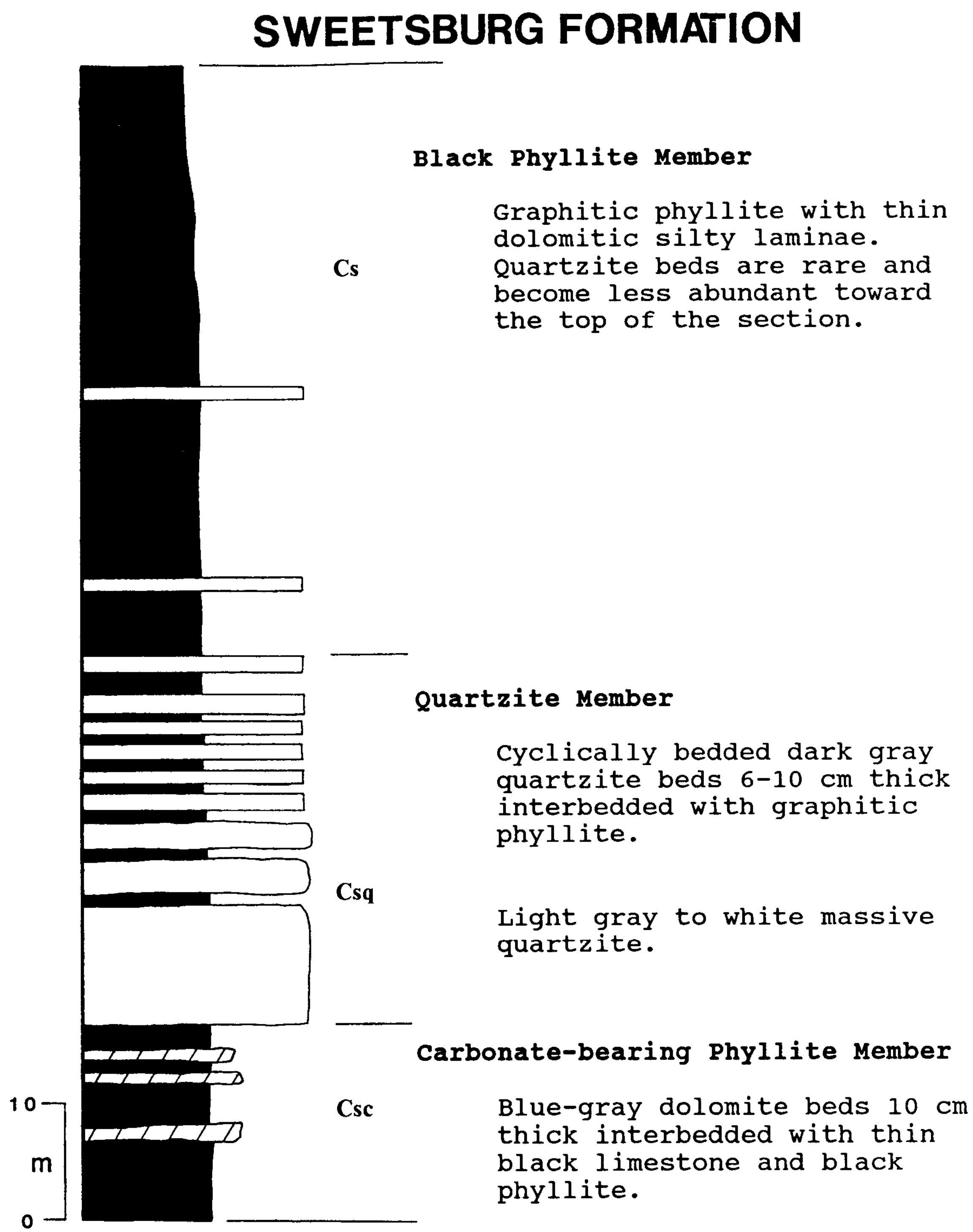


Figure 3. Measured stratigraphic section of the Sweetsburg Formation in a continuous stream exposure at East Fletcher (Location W9-V10). Graphitic phyllite beds are shown in black. The lower contact with the Underhill Formation is not exposed at this location. Graded bedding in the quartzites indicate topping direction.

quartzite sequence overlies the massive quartzite. The contact with the overlying black phyllite member (Cs) is gradational and is marked by a decrease in the number of quartzite beds interbedded within the black phyllite. The reference section for the quartzite member is location W9 on Plate 1.

Black phyllite member (Cs): This unit is primarily a black to dark gray quartz-white mica-graphite-pyrite phyllite. It contains brown weathering, dolomitic silty laminae which gives the rock a striped appearance which is characteristic of the Sweetsburg Formation (Clark, 1934). Minor amounts of brown and green phyllites are also present. Tourmaline needles are locally abundant and cut across all schistosities. The rock is easily broken along the dominant schistosity. Pyrite-rich horizons give the rock a rusty stained weathered surface. Graphite content is somewhat greater in the black phyllite member than in the carbonate-bearing member (Csc) and is approximately 12 percent. The lithological similarity of this member to the carbonate-bearing graphitic phyllite member (Csc) makes distinction between them difficult except in stream beds where the carbonate beds are more likely to be exposed due to continued stream erosion.

Black marble and dolomite beds are present in the black phyllite member but are not nearly as abundant as in the carbonate-bearing graphitic phyllite member (Csc). Contact with the underlying quartzite member (Csq) is gradational and is marked by a gradual decrease in the number of quartzite beds interbedded within the black phyllite. The contact is taken to be where the spacing between quartzite beds is greater than 1 m. No upper contact was observed because these rocks are the youngest rocks in the study area. The minimum thickness of the black phyllite member is 120 m. The reference section for the black phyllite member is at location W9 (Plate 1).

Eastern Sequence

The Eastern Sequence includes all of the rocks east of the East Fletcher thrust. The Eastern Sequence primarily consists of silver-green schists of the Underhill Formation and black phyllite of the Sweetsburg Formation. Coarse-grained metawackes and metavolcanic rocks are present in the Eastern Sequence but are not nearly as abundant as in the Western Sequence. No topping indicators were observed in the Eastern Sequence. Therefore, the five members of the Underhill and Sweetsburg Formations within the Eastern Sequence are described from west-to-east. Modal mineralogy for several of the lithologies in the Eastern Sequence are listed in Table 2.

Underhill Formation

The Underhill Formation is the most extensive formation in the Eastern Sequence and occurs in a 2 km wide belt on the western flank of Fletcher and Kings Hill Mountains. The Underhill Formation in the Eastern Sequence differs from the Western Sequence by the presence of metavolcanics and by the larger grain size of the white micas. Biotite is conspicuously absent from the metapelites of the Underhill Formation. The Underhill Formation in the Eastern Sequence has been subdivided into four members. From west to east, these include a metavolcanic member (CZuv), a metawacke member (CZuw), a micaceous schist member (CZum), and an albitic schist member (CZuas).

Metavolcanic member (CZuv): The mafic rocks in the Underhill Formation in the Eastern Sequence are lithologically heterogeneous. The most important of these lithologies is a calcareous greenstone chiefly composed of chlorite-actinolite-epidote-calcite-quartz. Other metavolcanic horizons within the Underhill Formation include an amphibolitic greenstone, a biotite-rich greenstone, and a biotite-quartz-albite felsic rock. These metavolcanic lithologies form a single horizon and are therefore considered as a single map unit on the geologic map (Plate 1).

TABLE 2. Estimated modal mineralogy of selected lithologies from the Eastern Sequence in the East Fletcher-Bakersfield area.

Unit	**CZuv**	**CZuw**	**CZum**	**CZuas**	**Cs**
Quartz	20	44	38	30	35
White Mica	--	14	26	26	--
Sericite	--	--	--	--	26
Chlorite	24	12	14	20	8
Biotite	4	12	--	--	--
Albite	14	12	18	24	8
Graphite	--	--	--	--	12
Calcite	16	3	--	tr	6
Epidote	10	tr	--	--	--
Actinolite	10	--	--	--	--
Tourmaline	--	--	--	--	tr
Pyrite	--	--	--	--	3
Leucoxene	--	--	--	--	2
Rutile	tr	--	tr	--	tr
Opaques	2	3	4	tr	--
Total	100	100	100	100	100

tr = trace
-- = Not Present

CZuv - Metavolcanic Member of the Underhill Formation
CZuw - Metawacke Member of the Underhill Formation
CZum - Micaceous Schist Member of the Underhill Formation
CZuas - Albitic schist member of the Underhill Formation
Cs - Black phyllite member of the Sweetsburg Formation

The calcareous, amphibolitic, and biotite-rich greenstones are a dark green color. The outcrops of the calcareous greenstones are pitted on the surface where calcite has weathered out. Chlorite is iron-rich and shows anomalous blue-purple interference colors in thin section. Pleochroic scheme of the actinolite is colorless (X), pale green (Y), and green to blue green (Z). The amphibolitic greenstones are locally light green in color and have a mottled appearance due to the presence of feldspars.

A distinctive massive white quartz-albite-biotite-epidote felsic rock is interbedded with the greenstones of the metavolcanic member. Accessory minerals in the felsic rock include rutile and zircon. This lithology may be a felsic tuff because of its high quartz content. Chemical analysis shows that it is rhyolitic in composition. Chemical analysis of the various metavolcanic lithologies is presented in the section on metavolcanic geochemistry.

Metawacke member (CZuw): The metawacke member of the Eastern Sequence is a quartz-albite-white mica-biotite-chlorite metawacke. It is very similar to the metawacke member in the Western Sequence except that the metawacke member in the Eastern Sequence is slightly more foliated. The metawacke member is limited to a single horizon in the western part of the Eastern Sequence where it is in fault contact with the Sweetsburg Formation on the eastern boundary of the Richford-Cambridge syncline. The thickness of the metawacke member is approximately 20 m. The reference section for the metawacke member in the Eastern Sequence is at location P9 (Plate 1).

Micaceous schist member (CZum): The micaceous schist member (CZum) of the Underhill Formation is the most extensive lithology in the East Fletcher-Bakersfield area. It is very heterogeneous but is primarily a quartz-white mica-chlorite-albite±magnetite schist with minor phyllitic horizons. The color is normally silver-green to green but locally weathers to a rusty color in horizons which contain pyrite. Quartz veins are abundant and are stretched out along the dominant schistosity where they preserve minor fold hinges. Primary bedding is rarely observed because it has been transposed parallel to the dominant schistosity during later deformation. In minor fold hinges, a compositional layering of light quartz-rich layers alternating with dark chlorite-rich layers occurs at a high angle to the dominant schistosity.

The micaceous schist member forms a one kilometer wide belt on the eastern side of the study area. Its western border is in fault contact with the graphitic rocks of the Sweetsburg Formation along the East Fletcher thrust. On the eastern side of the study area, the micaceous schist grades into the albitic schist (CZuas) of the Underhill Formation which is in contact with the graphitic rocks of the Sweetsburg Formation. The reference section for the micaceous schist member is at location H13 (Plate 1).

Albitic schist member (CZuas): The albitic schist member in the Eastern Sequence is a silver-green to dark green albite-white mica-chlorite-quartz schist. This member is also present in the Western Sequence where it is more phyllitic. Albite porphyroblasts approximately 0.5-3 mm in diameter have grown across the dominant schistosity. The albitic schist is in contact with the phyllite of the Sweetsburg Formation in the extreme eastern part of the study area. The reference section for the albitic schist member is at location U14 (Plate 1).

Sweetsburg Formation

The Sweetsburg Formation in the Eastern Sequence is found in two separate belts. The narrow northern belt is approximately 50 m wide and contains limited amounts of carbonate beds similar to those found in the Western Sequence. The wider southern belt is on the extreme eastern edge of the study area and was mapped by Thompson (1975) as part of the Hazens Notch Formation. The similarity of the quartzite, dolomite, and graphitic phyllite lithologies with those found in East Fletcher Brook suggests that these rocks are part of the Sweetsburg Formation.

Black phyllite member (Cs): The black phyllite member in the Eastern Sequence is nearly identical to the black phyllite found in the Richford-Cambridge syncline. The mineralogy is quartz-sericite-graphite-pyrite with leucoxene locally present. The grain size of the black phyllite member in the Eastern Sequence is generally larger than the black phyllite found in the Western Sequence.

Carbonate beds of blue-gray dolomite and black marble similar to those found in the carbonate-bearing graphitic phyllite member (Csc) are present in the black phyllite member in stream exposures in Hunt Brook (location U16, Plate 1) and Kings Hill Brook (location H14). The carbonate beds are not continuous enough to map separately from the black phyllite member. The black phyllite member is in contact with the albitic schist member of the Underhill Formation (CZuas). The reference section for the black phyllite member in the Eastern Sequence is at location H14 (Plate 1).

Depositional Environments

Detailed mapping at a scale of 1:12,000 has shown that a coherent stratigraphy is present in the East Fletcher-Bakersfield area even though the rocks have been severely folded and faulted during subsequent deformation. The Western and Eastern Sequences contain a similar stratigraphy of metavolcanics, metawackes, and metapelites. The possible depositional environments of the Eastern and Western Sequences are discussed below.

Western Sequence

The lower part of the Western Sequence contains the interbedded coarse-and fine-grained metawackes and metavolcanic rocks of the Pinnacle Formation. The Pinnacle Formation is interpreted to represent the coarse clastic debris derived from early rifting of the North American continent during the late Proterozoic (Doolan, 1987). Dowling (1988) has shown that the Pinnacle Formation in southern Quebec was deposited in a flat, shallow basin less than 3 m deep based on the presence of sedimentary structures and heavy mineral horizons. In the East Fletcher-Bakersfield area, sedimentary structures are not present. Instead, graded bedding in the coarse-grained metawacke (CZpc) suggests deposition by turbidity currents. The metawacke and metavolcanic rocks of the Pinnacle Formation in the study area are interpreted to be proximal submarine fan deposits.

A change to deeper and/or more distal depositional environments is indicated by the overlying fine-grained sediments of the Underhill and Sweetsburg Formations. The fining upward sequence indicates that basin subsidence occurred faster than the infilling of the basin by sedimentation. The absence of a carbonate-bearing horizon such as the White Brook Dolomite between the Pinnacle and Underhill Formations in the East Fletcher-Bakersfield area may be a result of the greater water depth in this part of the basin. Coarse-grained sediments are limited to thin horizons of metawacke in the chloritic phyllite member (CZup) of the Underhill Formation and show that coarse-grained sediments were periodically able to make it out into the farther reaches of the basin.

The graphitic phyllites of the Sweetsburg Formation are interpreted to be drift-stage sediments deposited after the basin began subsiding because of thermal subsidence. Dolomites and marble beds interbedded with pyritiferous graphitic phyllites indicate that the basin was becoming locally anoxic but that it was periodically still above the calcite-compensation depth. The cyclically interbedded quartzite member (Csq) is interpreted to represent distal turbidite deposits deposited at the base of a distal submarine fan in a deepening basin. A submarine fan would provide the means for bringing quartz-rich sediment farther out into the basin.

Eastern Sequence

The Eastern Sequence is composed of the fine-grained rocks of the Underhill and

Sweetsburg Formations. The lower part of Underhill Formation contains metawacke (CZuw) and metavolcanic horizons (CZuv) which are in the same relative stratigraphic position as the Pinnacle Formation in the Western Sequence. Therefore, the lower part of the micaceous schist (CZum) is interpreted to be an eastern facies of the Pinnacle Formation. The micaceous and albitic schists in the easternmost part of the study area are considered to be in the upper part of the Underhill Formation because of the absence of volcanic rocks and the gradational change from albitic schists to graphitic phyllites of the Sweetsburg Formation on Fletcher Mountain. The eastern non-volcanic rocks of the micaceous schist are therefore an eastern equivalent of the chloritic phyllite (CZup) of the Underhill Formation in the western part of the study area. The micaceous schist (CZum) appears to differ from the chloritic phyllite (CZup) only by the grade of metamorphism.

METAVOLCANIC GEOCHEMISTRY

Whole rock and trace element geochemical analyses of 3 samples from the metavolcanic members of the Pinnacle (CZpv) and Underhill Formations (CZuv) are presented in Table 3. All three samples were greenstones and do not include the felsic unit of the Underhill metavolcanic member (CZuv). The location of the outcrops from which the samples were taken is shown on Plate 3. The whole rock geochemistry indicates that the protolith of the greenstones were basaltic in composition. Primary textural features which give a clue as to their mode of origin are not observed in the horizons from which these samples were taken. However, pillow basalts and cross bedding in other nearby greenstone horizons indicate that the volcanic rocks were erupted in a shallow basin (Dennis, 1964, Figure 5). The greenstones are geochemically very similar to the Group A greenstones of Coish and others (1985) from the Tibbit Hill metavolcanic member of the Pinnacle Formation and from the Underhill Formation.

Trace element geochemistry has been used with some success in determining the original tectonic environment of metamorphosed igneous rocks (Coish and others, 1986; Pintson and others, 1985). In Figure 4, the concentration of selected major and trace elements are plotted on two discrimination diagrams which have been used to differentiate between tectonic settings. The greenstones from the metavolcanic member of the Pinnacle Formation (CZpv) and the Underhill Formation (CZuv) plot in the within plate basalt fields. The geochemistry of the Pinnacle and Underhill metavolcanics indicates that they were intruded through relatively thick continental crust during rifting of the North American continent. The geochemical similarity of the Pinnacle and Underhill greenstones supports the interpretation that the lower part of the Underhill Formation may be an eastern facies of the Pinnacle Formation and that both the Pinnacle and Underhill Formations were deposited on thick continental crust.

STRUCTURAL GEOLOGY

The deformational history of the study area has been developed using field evidence, thin section analysis, and constraints from the geologic map (Plate 1) and cross sections (Plate 2). The results of this analysis shows that the East Fletcher-Bakersfield area has been subjected to at least three phases of deformation. Each phase of deformation resulted in folds and related cleavage development. This agrees with the work of earlier researchers who have worked in the area (Dennis, 1964; Thompson, 1975; Doolan, 1987). Structural data for each phase of deformation are described separately below beginning with the earliest deformation. The structural data are also presented on Plate 3.

D1 Deformation

Evidence for the earliest phase of deformation is not readily apparent in the field. At the outcrop scale, a poorly defined early schistosity (S1) is locally present in microlithons between the dominant S2 schistosity. In most outcrops S1 has been transposed parallel to S2. S1 is best

TABLE 3. Metavolcanic geochemistry of the metavolcanic members of the Pinnacle and Underhill Formations.

Major Elements (Weight %)

Sample	TM 8-28-8 (CZpv)	TM 8-25-3 (CZpv)	TM 6-30-11 (CZuv)
SiO_2	48.01	48.47	48.47
TiO_2	3.03	3.10	3.16
Al_2O_3	14.50	14.41	13.34
Fe_2O_3	13.89	10.52	14.41
MnO	0.17	0.22	0.25
MgO	4.48	3.38	6.82
CaO	8.88	13.52	6.30
Na_2O	3.36	4.91	3.77
K_2O	0.34	0.38	0.78
P_2O_5	0.56	0.54	0.54
Total	97.22	99.45	97.84

Trace Elements (ppm)

Sample	TM 8-28-8 (CZpv)	TM 8-25-3 (CZpv)	TM 6-30-11 (CZuv)
Sc	27	27	28
V	313	299	324
Cr	121	96	87
Co	117	99	104
Ni	83	52	94
Cu	1549	9	15
Sr	351	193	138
Y	34	42	41
Zr	220	220	251
Ba	412	188	123

CZpv - Metavolcanic member of the Pinnacle Formation
CZuv - Metavolcanic member of the Underhill Formation

Location of the samples are shown on Plate 3.

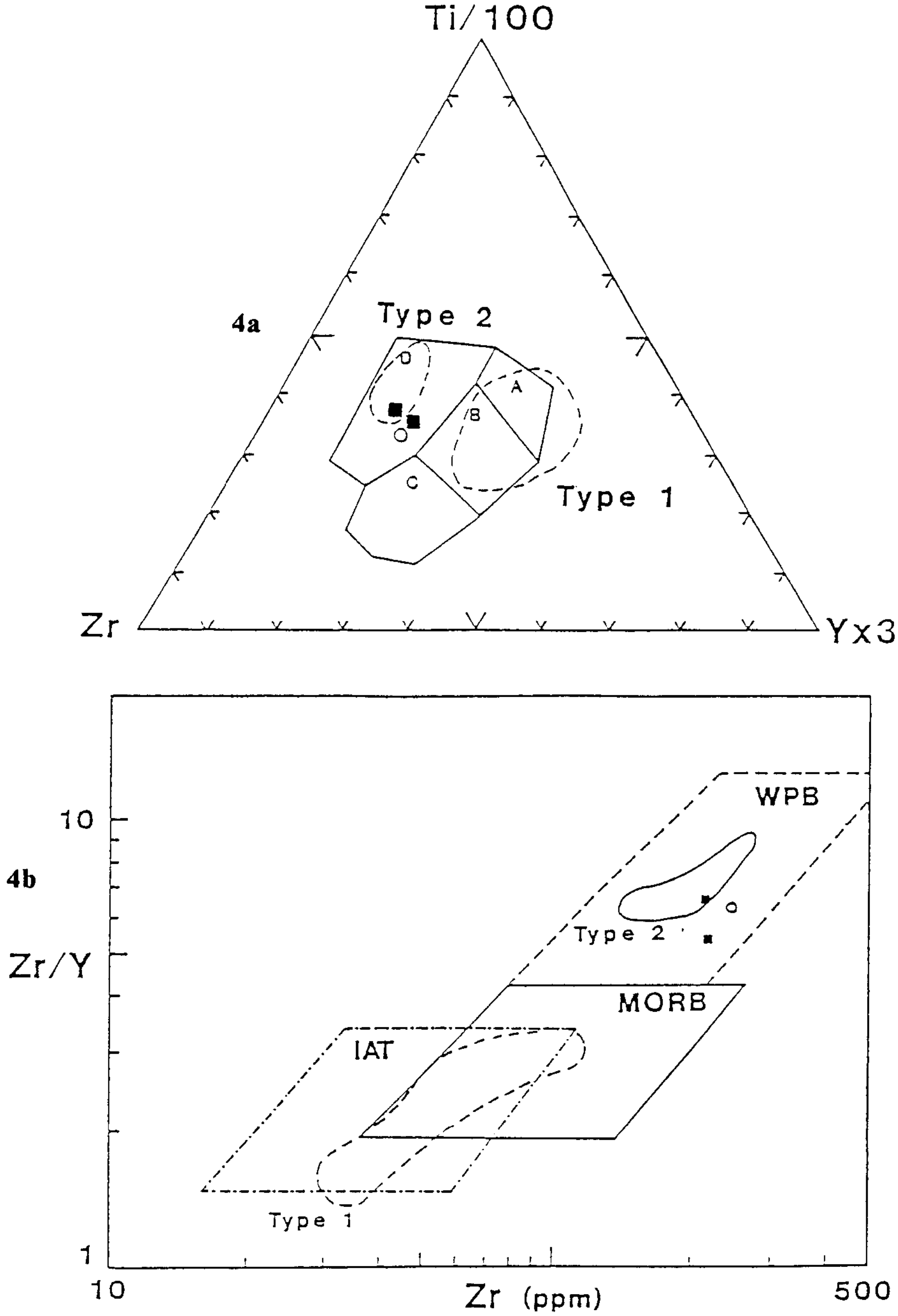


Figure 4. Geochemical tectonic discrimination diagrams for the metavolcanic rocks from the Pinnacle and Underhill Formations. **4a.** Ti-Zr-Y ternary variation diagram with tectonic fields for island arc tholeiites (A), mid-ocean ridge basalts and island arc tholeiites (B), calc-alkali basalts (C), and within plate basalts (D) (from Pearce and Cann, 1973). **4b.** Zr/Y versus Zr variation diagram with tectonic fields outlined for island arc tholeiites (IAT), mid-ocean ridge basalts (MORB), and within plate basalts (WPB) (from Pearce and Norry, 1979). The metavolcanic rocks from the Pinnacle Formation (solid square) and the Underhill Formation (open circle) plot in the within plate basalt fields in both diagrams which indicates that these rocks were erupted through relatively thick continental crust. Type 1 and Type 2 basalt fields are from Coish and others (1986).

preserved in minor F2 fold hinges where it has been folded by F2 folds and is at a high angle to the dominant schistosity. Folded quartz veins which are cut by S2 are also seen in a number of outcrops. These quartz veins define relict Fl fold hinges and are generally oriented more east-west than the more abundant F2 fold hinges which are predominately southwest trending.

In thin section, the presence of the early Sl schistosity is observed as a poorly preserved schistosity of micas between the minerals aligned parallel to the dominant schistosity (S2) and as relict inclusion trails in albite porphyroblasts. Where observed, the Sl schistosity is parallel to a compositional layering which indicates that the Dl phase of deformation may have been intense enough to result in transposition of bedding parallel to Sl during isoclinal folding.

The best evidence, however, for an early phase of folding is the complex refolded map pattern (Plate 1). The overall map pattern is primarily a result of an interference pattern produced by the earliest recognized phase of folding (Dl) and a later phase of folding (D2). A series of domes and basins and hook patterns in the Richford-Cambridge syncline and to the west of the study area in the Gilson Mountain quadrangle (Doolan, 1987) show a complex interference pattern between the two early phases of folding. Minor fold hinges in the same outcrop commonly show different senses of rotation.

West-directed thrust faulting was associated with the Dl phase of deformation. The East Fletcher thrust juxtaposed the lower part of the Underhill Formation in the Eastern Sequence against the younger graphitic rocks of the Sweetsburg Formation in the Western Sequence. The thrust contact is marked by the truncation of greenstones, schists, and metawackes against the graphitic phyllites along the entire eastern margin of the Richford-Cambridge syncline in the study area. The East Fletcher thrust is interpreted to have developed as a sheared out limb of a west facing nappe during the later phases of Dl. No movement indicators that give the direction of transport are present along the East Fletcher thrust contact because of metamorphic overprinting during the later phases of deformation. The direction of movement is inferred from the juxtaposition of the older rocks of the Eastern Sequence to the east of the younger rocks in the Richford-Cambridge syncline and by the cutoff geometry of metavolcanic rocks (CZuv) and metawackes (CZuw) on the upper plate of the East Fletcher thrust (location Q11 to X11 and N11 to P10, Plate 1).

D2 Deformation

The second deformation (D2) was an intense period of folding and produced tight upright to overturned isoclinal folds. Numerous small-scale F2 folds are preserved in quartz veins in the schists and phyllites of the Underhill Formation. The S2 schistosity is a penetrative schistosity and is the dominant schistosity in the study area. S2 is axial planar to the F2 folds which are generally steeply plunging. The average orientation of the F2 fold hinges is approximately S22°W 67° with a predominant sinistral sense of rotation. In the central and southern parts of the study area, the minor F2 folds are steeply plunging to the southwest. In the extreme southern part of the study area and farther to the south, the F2 folds become steeply north plunging (Rose, 1987). This indicates that the belt of graphitic phyllites exposed in the Richford-Cambridge syncline is a doubly plunging F2 synform.

The study area has been divided into three structural domains. The rocks of the Western Sequence are included in Domains 1 and 2 with Domain 2 corresponding to the Richford-Cambridge syncline. Domain 3 includes all the rocks east of the East Fletcher thrust in the Eastern Sequence. The boundaries of the three domains are shown on Plate 3. Table 4 lists the structural data for the entire study area and for each of the three domains.

The modal orientation of S2 changes from steeply east dipping on the western side of the study area (Domain 1) to steeply west dipping in the eastern part of the study area (Domain 3). This fanning of the dominant schistosity is centered on the western part of the Richford-Cambridge syncline where S2 is nearly vertical to steeply west dipping. Farther to the east,

Table 4. Summary of structural data in the East Fletcher-Bakersfield area.

	Study Area	Domain 1	Domain 2	Domain 3
S2	N17°E 80°SW	N14°E 84°SE	N17°E 82°NW	N18°E 74°NW
F2	S22°W 67°	S17°W 46°	S32°W 71°	S22°W 64°
S3	N10°E 81°SE	N07°E 80°SE	N06°E 83°SE	N12°E 80°SE
F3	N12°E 13°	N07°E 10°	N17°E 14°	N14°E 13°

the dominant schistosity becomes progressively flatter until it is nearly horizontal on the crest of the Green Mountain anticlinorium (Christman and Secor, 1961; Dennis, 1964; Thompson, 1975).

Steep shear zones parallel to S2 in the center of the Richford-Cambridge syncline show a west-over-east sense of shear, determined from rotated albite porphyroblasts shear bands in the white mica. The F2 folds become progressively more isoclinal toward the center of the Richford-Cambridge syncline. The Richford-Cambridge syncline is thought to have formed by backfolding of the Fl nappes into tight east-facing isoclinal folds during the D2 phase of deformation.

D3 Deformation

The third, and final, phase of deformation is associated with the formation of the Green Mountain anticlinorium. The anticlinorium axis lies approximately 6 km east of the study area. D3 is characterized in the East Fletcher-Bakersfield area by broad open folds which consistently show west-over-east sense of motion, as minor drag folds climbing toward the axis of the Green Mountain anticlinorium. These F3 fold axes are generally subhorizontal, plunging both to the northeast and southwest, and have an average orientation of approximately N12°E 13° (Table 4).

The F3 folds have an associated axial planar crenulation cleavage (S3). The average orientation of S3 is N10°E 81°SE which is consistent in all three domains of the study area (Table 4). S3 is only locally developed on the western side of the study area (Domains 1 and 2) but becomes more strongly developed to the east (Domain 3). Where present, S3 is spaced approximately 0.5 cm apart. The F3 folds do not greatly affect the map pattern because the D3 phase of deformation was very intense in the East Fletcher-Bakersfield area and because the average axial plane of the F3 folds are nearly coplanar to the F2 folds. The effect of the F3 folds on the overall map pattern is to locally offset the general northeast strike of the map units a few tens of meters.

METAMORPHISM

The rocks within the East Fletcher-Bakersfield area are in the biotite zone of the greenschist facies. This is indicated by the predominant mineral assemblages of quartz-white mica-chlorite-albite in the metapelites of the Underhill Formation (CZum and CZup) and quartz-albite-biotite in the coarse-grained metawackes of the Pinnacle (CZpc) and Underhill (CZuw) Formations. Biotite is not present in the schists and phyllites of the Underhill Formation because of the high aluminum content in the protoliths of the metapelites (Miyashiro, 1973).

As a result of its three phase deformational evolution, the Richford-Cambridge syncline has undergone a complex metamorphic history. Two distinct phases of metamorphism are documented: 1) an early high grade metamorphism (M1) that reached the garnet zone and 2) a lower grade metamorphism (M2) that retrograded the rocks within the Richford-Cambridge syncline to the greenschist mineral assemblages seen today. A later phase of metamorphism (M3) occurred also under greenschist facies conditions.

M1 Metamorphism

Evidence for the early M1 phase of metamorphism is extremely sparse because of overprinting by the later M2 metamorphism. A tightly folded S1 schistosity is locally preserved in microlithons between the penetrative S2 schistosity at the outcrop scale. In thin section, the white mica laths which outline the early S1 schistosity in folds are straight which indicates that the relict S1 schistosity has been recrystallized during a later metamorphic event.

Pseudomorphs of metamorphic mineral assemblages indicate that the M1 metamorphism may have been under higher temperature conditions than subsequent periods of metamorphism. Hexagonal pseudomorphs of magnetite-chlorite-quartz and anhedral chlorite clots are present in the micaceous schist (CZum) of the Underhill Formation. No hexagonal pseudomorphs were found in the Western Sequence. The pseudomorphs are probably after garnet because of their hexagonal shape and the composition of the replacement minerals. The hydration reaction

$$\text{Garnet} + H_2O \rightarrow \text{Magnetite} + \text{Chlorite} + \text{Quartz}$$

occurs under decreasing temperature conditions (Hyndman, 1985).

Thompson (1975) found small garnets preserved in greenstones of the Underhill Formation immediately east of the study area along Shattuck Ridge. The presence of garnets and garnet pseudomorphs in the Eastern Sequence and their absence from the Western Sequence suggests that temperature conditions were higher in the rocks of the Eastern Sequence than in the Western Sequence. Table 5 is a summary of the different stages of mineral growth during the three phases of metamorphism.

M2 Metamorphism

The M2 phase of metamorphism is associated with the development of the regional dominant S2 schistosity. The age relationships of mineral growth are determined from their orientation with respect to S2. Those minerals which are aligned parallel to S2 in thin section are considered to have developed during M2. Equant minerals such as albite, which commonly show a rotation of inclusions with the outer rim merging into parallelism with S2, also developed during M2.

The predominant mineral assemblages of the schists and phyllites of the Underhill Formation is quartz-white mica-chlorite. These minerals indicate that the temperature and pressure conditions during M2 were at the lower greenschist facies. Medium-grained white micas are present in the schists (CZum) of the eastern stratigraphic sequence, whereas sericite is present in the phyllitic rocks of the Western Sequence (CZup). This indicates that the rocks in the Eastern Sequence have undergone a longer period of recrystallization during M2 than have the rocks in the Western Sequence.

The metawackes of the Pinnacle Formation (CZpc) and the Underhill Formation (CZuw) show a weak fabric of aligned chlorite, biotite, and micas parallel to S2. There is a much less strongly developed fabric in the metawackes than in the finer grained schists of the Underhill Formation. The matrix of the metawackes contains many equant grains which appear to be detrital in origin or formed during an early phase of metamorphism. The mica grains which define the dominant schistosity are deflected around these mineral grains.

TABLE 5. Summary of metamorphic mineral growth in the East Fletcher-Bakersfield area.

		WESTERN SEQUENCE			EASTERN SEQUENCE		
	Mineral	M1	M2	M3	M1	M2	M3
Metapelite	Quartz	—	—	—	—	—	—
	White Mica	—	—	—	—	—	—
	Chlorite	?—	—	—	?—	—	—
	Albite		—	—		—	—
	Garnet				—		
	Magnetite	—	—		—	—	
	Tourmaline	?—	—				
	Leucoxene	?—	—		?—	—	
Metawacke	Quartz	—	—	—	—	—	—
	Albite		—	—		—	—
	Biotite	—	—		—	—	
	Chlorite	?—	—	—	?—	—	—
	Magnetite	—	—		—	—	
Metavolcanic	Chlorite	—	—	—	—	—	—
	Actinolite	—	—		—	—	
	Epidote		—			—	
	Calcite		—	—		—	—
	Magnetite		—			—	
	Biotite					—	
	Sphene		—			—	

In the metavolcanic rocks (CZpv and CZuv) the predominant mineral assemblages are chlorite-quartz-epidote-actinolite±calcite and chlorite-epidote-actinolite. No primary igneous textures are preserved in the study area but Rose (1987) notes a diabasic texture in greenstones from the Underhill south of the study area. The greenstones of both the Pinnacle and Underhill Formations generally show a strong alignment of minerals parallel to the dominant schistosity. Chlorite appears to have grown during M2 because the 001 plane is parallel to S2. Actinolite surrounded by a fringe of chlorite is preserved in the cores of what were probably once larger amphiboles. This indicates that the actinolite is involved in the retrograde reaction of amphibole to chlorite under lower temperature conditions during M2. Albite porphyroblasts in the albitic schist (CZuas) from location G10 (Plate 1) have helicitic inclusion trails which show approximately 90 degrees of rotation. The S2 schistosity is cut by the later S3 schistosity. This indicates that the albites grew under the D2 phase of deformation and that there was a component of simple shear with west-over-east sense of motion during D2. All the albite porphyroblasts in the albitic schist (CZuas) grew during M2/D2 because the dominant schistosity does not reflect around the porphyroblasts. The albite porphyroblasts commonly show simple albite twinning indicating that they grew under an oriented stress regime (Mancktelow, 1979).

M3 Metamorphism

The M3 phase of metamorphism was the weakest of the three phases of metamorphism and occurred under lower greenschist facies conditions. The only metamorphic fabric associated with this phase of metamorphism is the spaced S3 cleavage which is only locally present. The S3 schistosity was formed by the growth of mica and chlorite with some rotation of elongate pre-M3 minerals into alignment with the S3 crenulation cleavage as observed in thin section.

In both the coarse-grained metawackes of the Pinnacle Formation (Czpc) in the Western Sequence and the Underhill Formation (CZuw) of the Eastern Sequence biotite is intergrown with chlorite. The biotite appears to have been partially altered to iron-rich chlorite. This suggests that the temperature and pressure conditions in the East Fletcher-Bakersfield area during M3 were at the chlorite grade of the lower greenschist facies conditions and resulted in continued retrogression of the M2 mineral assemblages.

The lack of widespread recrystallization of the M2 metamorphic fabric suggests that the M3 metamorphic event was either a short-lived later phase of the M2 phase of metamorphism or a weakly developed distinct separate event. Isotopic age dating by Laird and others (1984) indicate that the M1 and M2 metamorphic events were due to the Taconian orogeny and the later M3 metamorphism was a result of the Devonian Acadian orogeny. Sutter and others (1985) using K-Ar and $^{40}Ar/^{39}Ar$ age dates from southern New England interpret the younger dates to be a result of cooling during the later stages of the Taconian orogeny.

CONCLUSIONS

The results of large-scale mapping (1:12,000) in the East Fletcher-Bakersfield area has provided additional constraints on the development of the hinterland of northern Vermont. The most significant results and conclusions of this study are outlined below.

1. Detailed mapping shows that a coherent stratigraphy of rift clastic rocks and drift-stage rocks are present in the East Fletcher-Bakersfield area. Petrographic analysis and regional correlations support the interpretation by previous workers (Doolan, 1987; Dowling, 1988) that these rocks were deposited in a rift basin on the southern arm of the Quebec reentrant during the late Proterozoic.

2. The rocks in the East Fletcher-Bakersfield area can be divided into a Western Sequence and an Eastern Sequence. The Western Sequence contains a complete stratigraphy of metavolcanics and metawackes of the Pinnacle Formation, fine-grained phyllites and schists of the Underhill Formation, and graphitic phyllites, quartzites, and carbonates of the Sweetsburg Formation. The Eastern Sequence is composed of a similar stratigraphy but contains a much thinner sequence of metavolcanic rocks and metawackes.

3. Geochemical analysis of the metavolcanic rocks shows that the metavolcanic rocks from the Western Sequence (Pinnacle Formation) are similar to those from the Eastern Sequence (Underhill Formation). The relatively high concentration of TiO_2, P_2O_5, and Zr of the metavolcanic rocks suggests that the volcanic rocks of both the Pinnacle and Underhill Formations were erupted through relatively thick continental crust.

4. The Western and Eastern Sequences are eastward-younging stratigraphic packages juxtaposed along the East Fletcher thrust. The lower part of the Underhill Formation in the Eastern Sequence is an eastern facies of the Pinnacle Formation in the Western Sequence. The transition from rift-stage to drift-stage deposition occurred at the Pinnacle-Underhill contact in the Western Sequence and within the lower part of the Underhill Formation in the Eastern Sequence.

5. The carbonate-bearing graphitic phyllites and quartzites exposed in the Richford-Cambridge syncline are the youngest rocks in the East Fletcher-Bakersfield area and are part of the cover sequence to the Camels Hump Group. These rocks are correlated with the Sweetsburg Formation and are not a member within the Underhill Formation or an eastern

facies of the White Brook Dolomite as shown on the Vermont Geological Map (Doll and others, 1961).

6. The rocks in the East Fletcher-Bakersfield area have been subjected to three phases of deformation. The earliest phase (D1) involved west facing nappes and east-over-west thrust faulting on the overturned limbs. The East Fletcher thrust developed during this time and juxtaposed rift-stage metavolcanics and metawackes of the lower Underhill Formation with the drift-stage graphitic phyllites of the Sweetsburg Formation.

7. The D2 phase of deformation resulted in backfolding of the D1 nappes into upright isoclinal folds. The dominant schistosity was developed during this phase of deformation. Steep shear zones with west-over-east sense of shear developed coplanar to the dominant schistosity. The Richford-Cambridge syncline is a large doubly plunging F2 backfold which exposes the Sweetsburg Formation in the center of the study area.

8. The third phase of deformation (D3) was the least intense of the three deformations and resulted in the local development of a crenulation cleavage axial planar to shallow plunging open folds. This final phase of folding was associated with the arching of the Green Mountain anticlinorium east of the study area.

9. Metamorphic intensity was greatest during D1, possibly reaching garnet grade. During the second phase of deformation, the rocks were retrograded to greenschist facies conditions. The M2 phase of metamorphism resulted in the development of a penetrative schistosity and nearly complete recrystallization of the pre-existing mineralogy and fabric. The metamorphic conditions during D3 were at the lower greenschist facies and involved only the local growth of new minerals.

10. The East Fletcher-Bakersfield area is a transition zone from predominately west facing structures to the west to upright and east facing structures in the Richford-Cambridge syncline. The East Fletcher thrust separates the more highly metamorphosed schists, metawackes, and greenstones of the Eastern Sequence (Underhill Formation) from the lower grade metawackes, phyllites, and low grade schists of the Western Sequence (Pinnacle, Underhill, and Sweetsburg Formations). The East Fletcher thrust was important in crustal shortening during the D1 phase of deformation.

ACKNOWLEDGEMENTS

The assistance of Barry L. Doolan and Rolfe S. Stanley who introduced the author to the problems of mapping in Vermont is gratefully acknowledged. Barry L. Doolan and Rolfe S. Stanley read an early version of the report. Charles A. Ratte and Sharon B. O'Loughlin reviewed the manuscript. Funding was provided by the Vermont Geological Survey under the direction of Charles A. Ratte, State Geologist.

REFERENCES CITED

Cady, W. M., Albee, A. L., and Murphy, J. F., 1962, Bedrock geology of the Lincoln Mountain quadrangle, Vermont: U. S. Geological Survey Geologic Quadrangle Map GQ-164, scale 1:62,500.

Christman, R. A., 1959, Geology of the Mount Mansfield quadrangle, Vermont: Vermont Geological Survey Bulletin No. 12, 75 p.

Christman, R. A., and Secor, D. T., 1961, Geology of the Camels Hump quadrangle, Vermont: Vermont Geological Survey Bulletin No. 15, 70 p.

Clark, T. H., 1934, Structure and stratigraphy of southern Quebec: Geological Society of America Bulletin, v. 45, p. 1-20.

Coish, R. A., Fleming, F. S., Larson, M., Poyner, R., and Siebert, J., 1985, Early rift history of the proto-Atlantic Ocean: Geochemical evidence from metavolcanic rocks in Vermont: American Journal of Science, v. 285, p. 351-378.

Coish, R. A., Perry, D. A., Anderson, C. D., and Bailey, D., 1986, Metavolcanic rocks from the Stowe Formation, Vermont: Remnants of ridge and intraplate volcanism in the Iapetus Ocean: American Journal of Science, v. 286, p. 1-28.

Colpron, Maurice, Dowling, W. M., and Doolan, B. L., 1987, Stratigraphy and structure of the Sutton area, southern Quebec: Construction and destruction of the western margin of the late Precambrian Iapetus: in Westerman, D., ed., NEIGC Guidebook For Fieldtrips In Vermont, Montpelier, Vermont, p. 443-463.

Colpron, Maurice, Mock, T., D., and Doolan, B. L., 1988, The Mansville thrust zone: Implications for correlation across the internal domain of the Quebec-Vermont Appalachian orogen: Geological Society of America Abstracts with Programs, v. 20, No. 1, p. 13.

DelloRusso, Vincent, and Stanley, R. S., 1986, Bedrock geology of the northern part of the Lincoln massif, central Vermont: Vermont Geological Survey Special Bulletin No. 8, 56 p.

Dennis, J. G., 1964, The geology of the Enosburg area, Vermont: Vermont Geological Survey Bulletin No. 23, 56 p.

DiPietro, J. A., 1983, Contact relations in the late Precambrian Pinnacle and Underhill Formations, Starksboro, Vermont: Master of Science Thesis, University of Vermont, Burlington, Vermont, 132 p.

Doll, C. G., Cady, W. M., Thompson, J. B., Jr., and Billings, M. P., 1961, Centennial geologic map of Vermont: Vermont Geological Survey, Montpelier, Vermont, scale 1:250,000.

Doolan, B. L., 1987, Stratigraphy and structure of the Camels Hump Group along the Lamoille River transect, northern Vermont: in Westerman, D., ed., NEIGC Guidebook For Fieldtrips In Vermont, Montpelier, Vermont, p. 152-191.

Doolan, B, L., Gale, M. H., Gale, P. N., and Hoar, R. S., 1982, Geology of the Quebec reentrant: Possible constraints from early rifts and the Vermont-Quebec serpentinite belt: in St. Julien, P., and Beland, J., eds., Geological Association of Canada Special Paper 107, Major structural zones and faults of the northern Appalachians, p. 87-115.

Dorsey, R. J., Agnew, P. C., Carter, C. M., Rosencrantz, E. J., and Stanley, R. S., 1983, Bedrock geology of the Milton quadrangle, northwestern Vermont: Vermont Geological Survey Special Bulletin No. 3, 14 p.

Dowling, W. M., 1988, Depositional environment of the lower Oak Hill Group, southern Quebec: Implications for the late Precambrian breakup of North America in the Quebec reentrant: Master of Science Thesis, University of Vermont, Burlington, Vermont, 182 p.

Hyndman, D. W., 1985, Petrology of igneous and metamorphic rocks: McGraw-Hill, New York, 786 p.

Keith, Arthur, 1932, Stratigraphy and structure of northwestern Vermont: Journal Washington Academy of Science, v. 22, p. 357-379, 393-406.

Kumarapeli, P. S., Goodacre, A. K., and Thomas, M. D., 1981, Gravity and magnetic anomalies of the Sutton Mountains region, Quebec and Vermont: Expressions of rift volcanics related to the opening of Iapetus: Canadian Journal of Earth Science, v. 18, p. 680-692.

Laird, Jo, and Albee, A. L., 1981, High-pressure metamorphism in mafic schist from northern Vermont: American Journal of Science, v. 281, p. 97-126.

Laird, Jo, Lanphere, M. A., and Albee, A. L., 1984, Distribution of Ordovician and Devonian metamorphism in mafic and pelitic schists from northern Vermont: American Journal of Science, v. 284, p. 376-413.

Lapp, E. T., and Stanley, R. S., 1986, Bedrock geology of the Mt. Grant-South Lincoln area, central Vermont: Vermont Geological Survey Special Bulletin No. 7, 27 p.

Mancktelow, N. S.,1979, The development of slaty cleavage, Fleurieu Peninsula, South Australia: Tectonophysics, v. 58, p. 21-34.

Marquis, Robert, 1987, Geologie de la region de Richmond-rapport interimaire: Ministre de L'Energie et des Ressources, MB-87-31,82 p.

Marquis, Robert, Beland, Jacques, Trzcienski, W. E. Jr., 1987, The Oak Hill Group, Richmond, Quebec: Termination of the Green Mountains-Sutton Mountains anticlinorium: in Roy, D. C., ed., Geological Society of America Centennial Field Guide, Vol. 5-Northeastern Section, p. 363-368.

Miyashiro, A., 1973, Metamorphism and metamorphic belts: George Allen and Unwin, London, 492 p.

O'Loughlin, S. B., and Stanley, R. S., 1986, Bedrock geology of the Mt. Abraham-Lincoln Gap area, central Vermont: Vermont Geological Survey Special Bulletin No. 6, 29 p.

Osberg, P., 1965, Structural geology of the Knowlton-Richmond area, Quebec: Geological Society of America Bulletin, v. 76, p. 223-250.

Pearce, J. A., and Cann, J. R., 1973, Tectonic setting of basic volcanic rocks determined using trace element analyses: Earth and Planetary Science Letters, v. 19, p. 290-300.

Pearce, J. A., and Norry, M. J., 1979, Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks: Contributions to Mineralogy and Petrology, v. 69, p. 33-47.

Pintson, H., Kumarapeli, P. S., and Morency, M., 1985, Tectonic significance of the Tibbit Hill volcanics: Geochemical evidence from the Richmond area, Quebec: Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 123-130.

Rankin, D. W., 1976, Appalachian salients and recesses: Late Precambrian continental breakup and the opening of the Iapetus Ocean: Journal of Geophysical Research, v. 81, p. 5605-5619.

Rose, H. S., 1987, Stratigraphy, structure and metamorphism, Fletcher Mountain area, Jeffersonville, Vermont: Undergraduate Thesis, University of Vermont, Burlington, Vermont, 148 p.

St. Julien, P., and Hubert, C., 1975, Evolution of the Taconian orogen in the Quebec Appalachians: American Journal of Science, v. 275-A, p. 337-362.

Stanley, R. S., and Ratcliffe, N. M., 1985, Tectonic synthesis of the Taconian orogeny in western New England: Geological Society of America Bulletin, v. 96, p. 1227-1250, 2 plates.

Stanley, R. S., Roy, D. L., Hatch, N. L., Jr., and Knapp, D. A., 1984, Evidence for tectonic emplacement of ultramafic and associated rocks in the pre-Silurian eugeosynclinal belt of western New England: Vestiges of an ancient accretionary wedge: American Journal of Science, v. 284, p. 559-595.

Sutter, J. F., Ratcliffe, N. M., and Mukasa, S. B., 1985, $^{40}Ar/^{39}Ar$ and K-Ar data bearing on the metamorphic and tectonic history of western New England: Geological Society of America Bulletin, v. 96, p. 123-136.

Tauvers, P. R., 1982, Basement-cover relationships in the Lincoln area, Vermont: Master of Science Thesis, University of Vermont, Burlington, Vermont, 177 p.

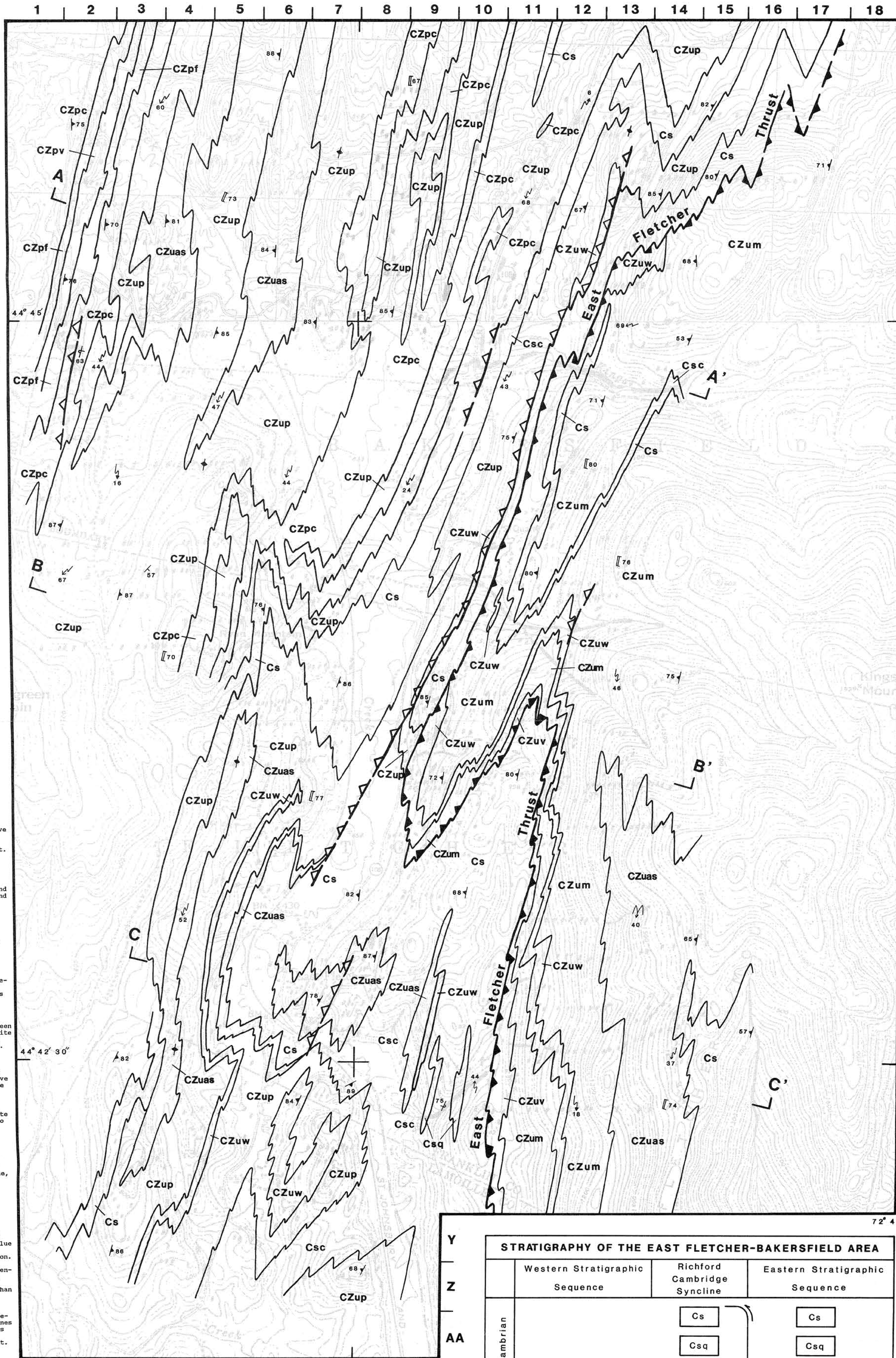
Thompson, P. J., 1975, Stratigraphy and structure of Shattuck Ridge, Bakersfield and Waterville, Vermont: Master of Science Thesis, University of Vermont, Burlington, Vermont, 68 p.

Williams, H., 1978, Tectonic lithofacies map of the Appalachian orogen: Memorial University, St. Johns, Newfoundland, Canada, scale 1:2,000,000.

BEDROCK GEOLOGY OF THE EAST FLETCHER–BAKERSFIELD AREA, NORTHERN VERMONT

PLATE 1

Timothy D. Mock



Explanation

- Observed bedrock exposure. Shown in half tone on topographic base map.
- Lithic contacts. Everywhere solid. Accuracy of location indicated by proximity to bedrock exposures.
- D1 Thrust fault/Shear zone. Teeth on upper plate. Solid where field evidence observed, dashed where inferred. Teeth on upper plate.
- D2 Thrust fault/Shear zone. Teeth on upper plate. Solid where field evidence observed, dashed where inferred.
- 85 Strike and dip of bedding.
- 73 Strike and dip of overturned bedding.
- 82 Strike and dip of penetrative schistosity (S2).
- 80 Strike and dip of crenulation cleavage (S3).
- 62 Trend and plunge of minor F2 fold axes. Arrow indicates plunge direction. Sense of rotation shown for asymmetrical folds as viewed in down plunge direction.
- 44 Trend and plunge of neutral F2 fold axes. Arrow indicates plunge direction.
- 20 Trend and plunge of minor F3 fold axes. Arrow indicates plunge direction. Sense of rotation shown for asymmetrical folds as viewed in down plunge direction.
- C C′ Location of cross section.

Lithic Descriptions

SWEETSBURG FORMATION

Cs — **Black Phyllite Member** Quartz-sericite-graphite-pyrite phyllite. Thin, dolomitic, silt laminae give the rock a striped appearance. The phyllite is generally black to dark gray but is locally brown and green. Tourmaline needles are locally abundant.

Csq — **Quartzite Member** Massive, light-gray to white quartzite overlain by a 12 m thick sequence of cyclically interbedded 6 cm thick quartzite beds and graphitic phyllite. At location W9, graded beds and cross bedding indicate topping direction.

Csc — **Carbonate-bearing Graphitic Phyllite Member** Similar to Cs but contains 8-15 cm thick beds of blue-gray dolomite and black marble within the graphitic phyllite. The contact with the underlying Underhill Formation is marked by a thin zone of rusty weathering schists and grits.

UNDERHILL FORMATION

CZuas — **Albitic Schist Member** Green to blue green albite-quartz-white mica-chlorite±magnetite schists and phyllites. Characterized by albite porphyroblasts 0.5 to 2 mm in diameter.

CZup — **Chloritic Phyllite Member** Gray-green to blue-green quartz-white mica-chlorite-albite±magnetite phyllite and schist. This unit is generally very soft and commonly fractures along the dominant schistosity.

CZum — **Micaceous Schist Member** Heterogeneous, silver-green to green quartz-white mica-chlorite-albite± magnetite schist. Abundant, thin quartz veins give the rock a striped appearance. Euhedral magnetite is common.

CZuw — **Metawacke Member** Light gray to brown quartz-white mica-albite-chlorite-biotite metawacke. Similar to CZpc but is generally more foliated along the dominant schistosity.

CZuv — **Metavolcanic Member** Primarily a heterogeneous, dark green to light green calcareous greenstone. Other lithologies include a feldspathic greenstone, a biotite-rich greenstone, an amphibolitic greenstone, and a massive white quartz-albite-biotite rock.

PINNACLE FORMATION

CZpc — **Coarse-grained Metawacke Member** Massive, light-gray to brown, quartz-white mica-albite-chlorite± biotite±magnetite metawacke. Contains abundant blue quartz grains approximately 1-3 mm in diameter. Locally calcareous in the upper part of the section.

CZpf — **Fine-grained Metawacke Member** Light gray to green-gray, quartz-white mica-albite-chlorite±magnetite metawacke and schist. Locally phyllitic. Blue-quartz grains are present but are less abundant than in CZpc.

CZpv — **Metavolcanic Member** Dark to light green, chlorite-quartz-calcite-epidote-actinolite-albite greenstones and volcanogenic metasediments. Calcite stringers are present parallel to the dominant foliation. Epidote nodules approximately 4-10 cm are abundant.

STRATIGRAPHY OF THE EAST FLETCHER-BAKERSFIELD AREA

	Western Stratigraphic Sequence	Richford Cambridge Syncline	Eastern Stratigraphic Sequence
Cambrian		Cs	Cs
		Csq	Csq
		Csc	Csc
Proterozoic Z-Cambrian	CZuas	CZuas	CZuas
	CZup	CZup	CZum / CZuw
	CZpc	? ?	CZuv
	CZpf / CZpv		

East Fletcher Thrust

Topographic Base Standard USGS 7 1/2 Minute Quadrangle Map (Scale 1:24,000) enlarged to 1:12,000. Sheets used:

Jeffersonville 7 1/2 Minute Quadrangle, 1948
Bakersfield 7 1/2 Minute Quadrangle, 1986

Field geology on Vermont Base Map Orthophotos (Scale 1:5,000), Property Valuation and Review Division, Agency of Administration. Sheets used:

East Fletcher Sheet No. 124244, 1979
Bakersfield-Fletcher Sheet No. 124248, 1979

SCALE

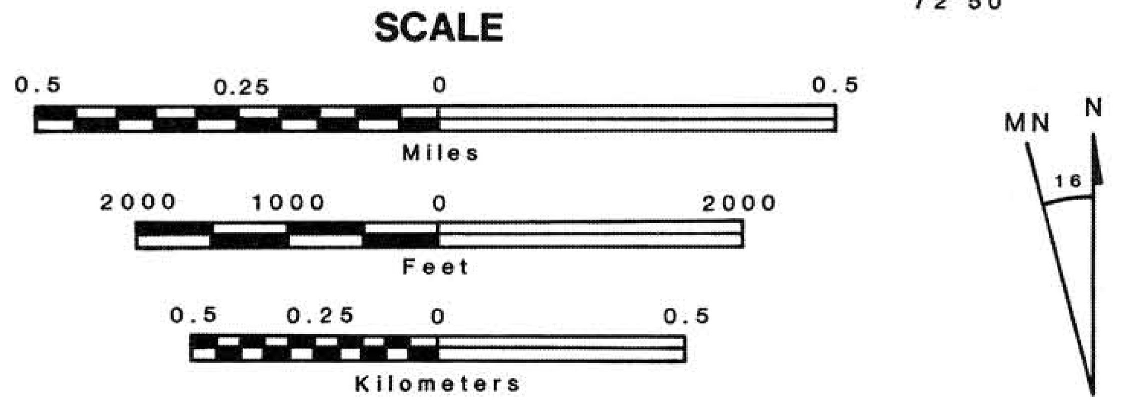


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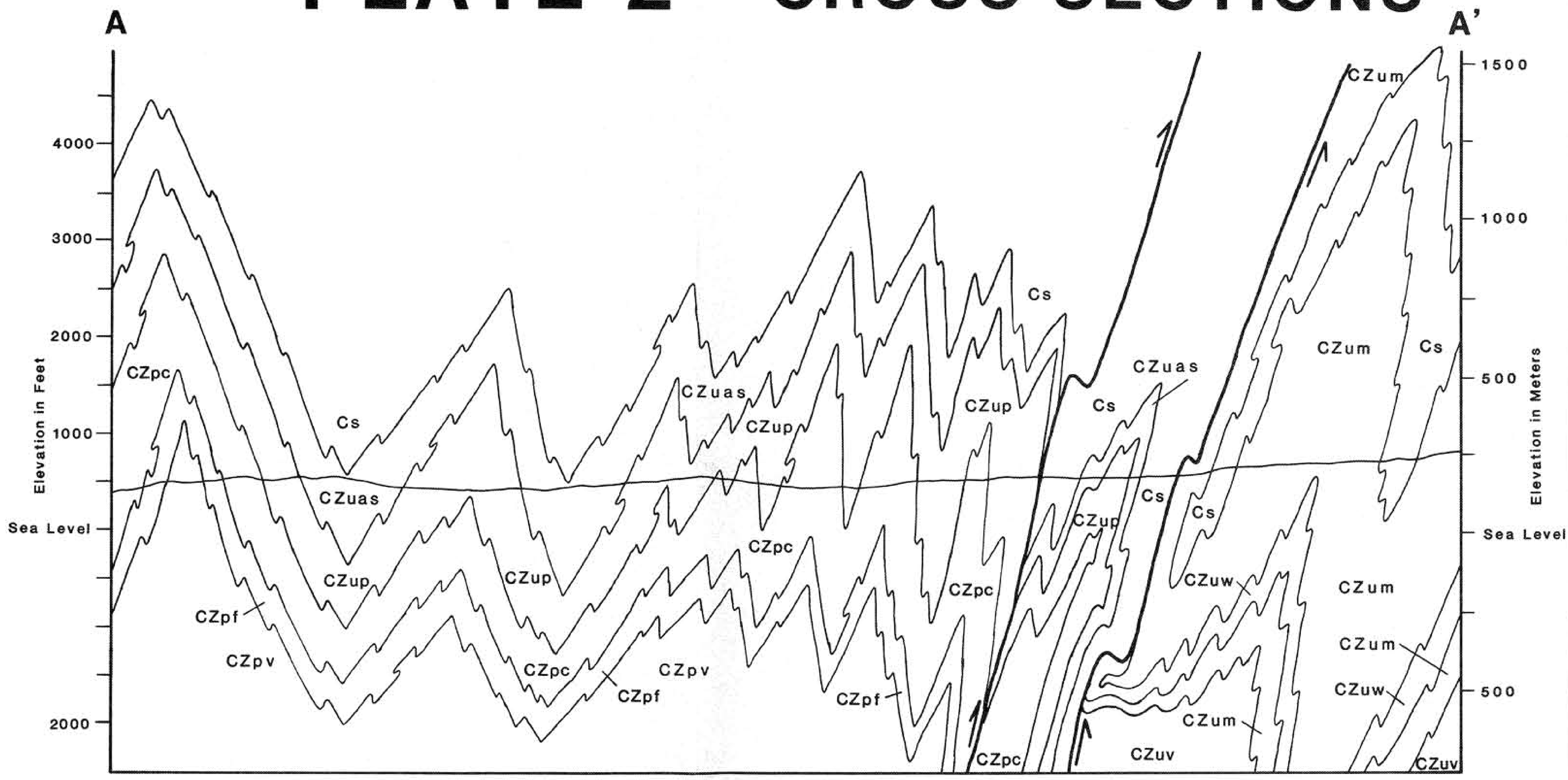
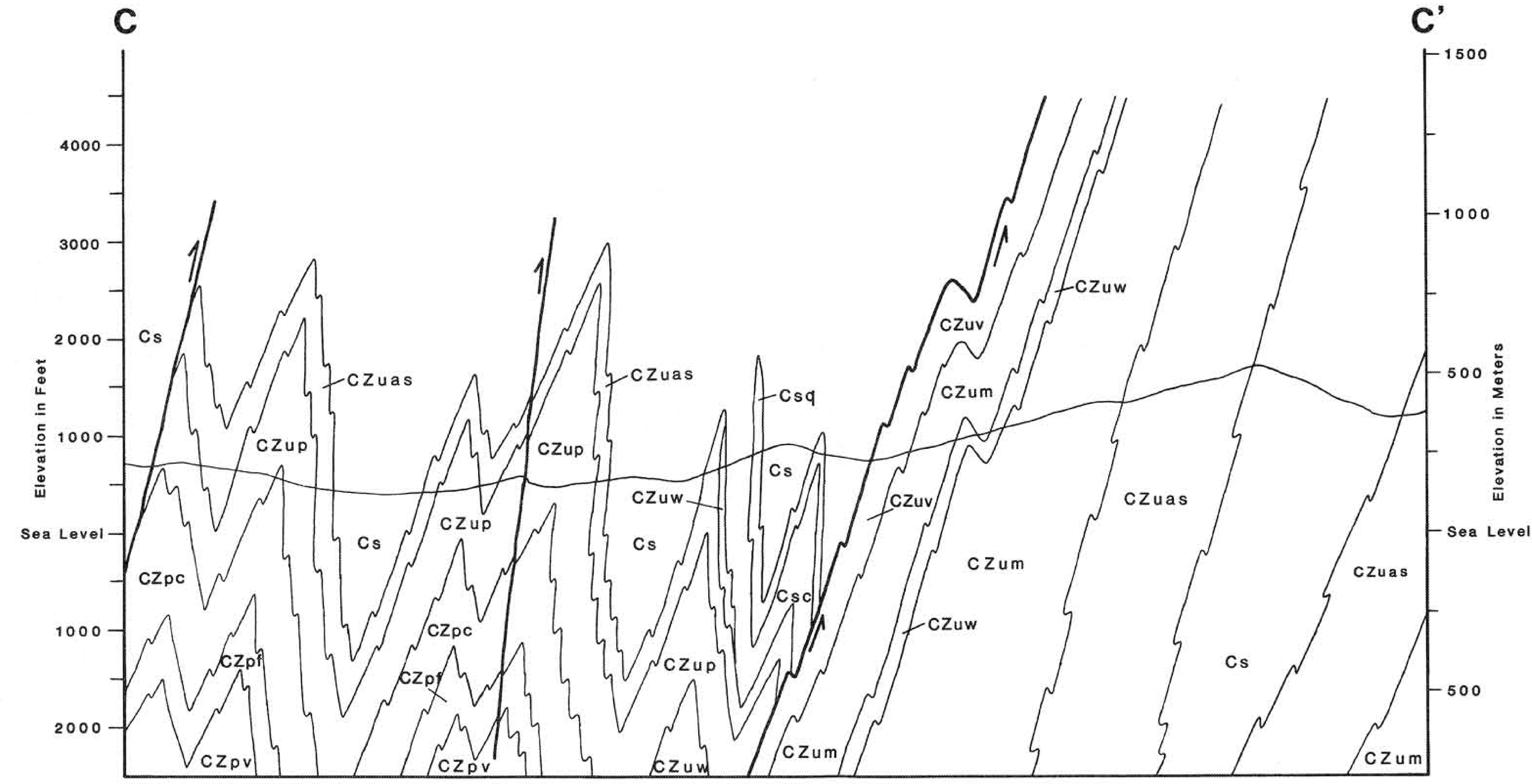
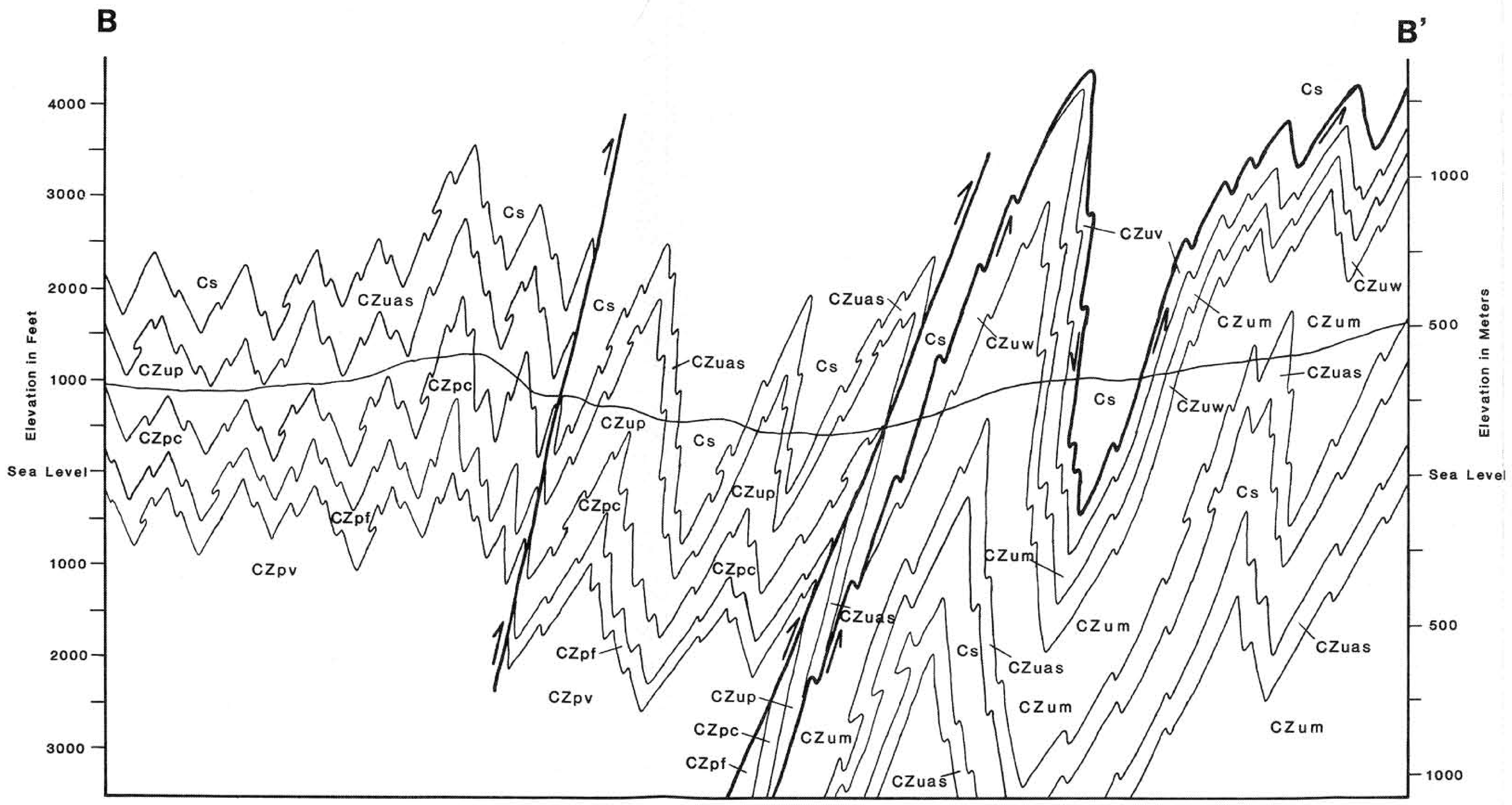
PLATE 2 CROSS SECTIONS







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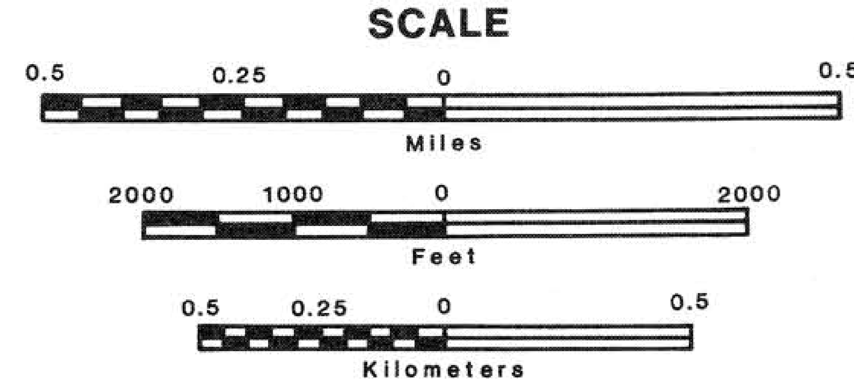

No Vertical Exaggeration

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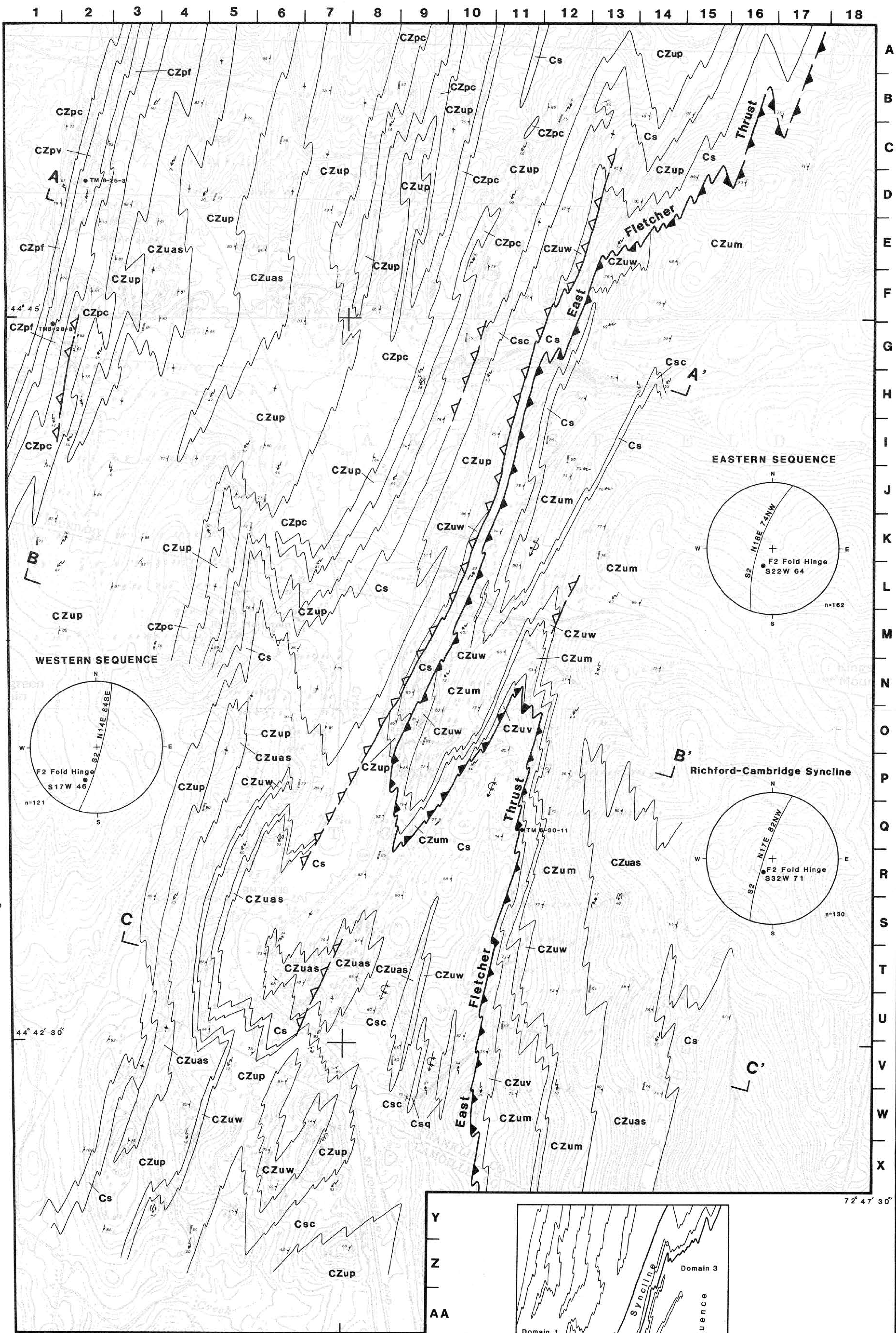
STRUCTURAL DATA

PLATE 3

Timothy D. Mock



Explanation

Lithic contacts.

Axial trace of overturned syncline. Arrow shows direction of plunge.

Axial trace of overturned anticline. Arrow shows direction of plunge.

D1 Thrust fault/Shear zone. Teeth on upper plate. Solid where field evidence observed, dashed where inferred. Teeth on upper plate.

D2 Thrust fault/Shear zone. Teeth on upper plate. Solid where field evidence observed, dashed where inferred.

Strike and dip of bedding.

Strike and dip of overturned bedding.

Strike and dip of penetrative schistosity (S2).

Strike and dip of crenulation cleavage (S3).

Trend and plunge of minor F2 fold axes. Arrow indicates plunge direction. Sense of rotation shown for asymmetrical folds as viewed in down plunge direction.

Trend and plunge of neutral F2 fold axes. Arrow indicates plunge direction.

Trend and plunge of minor F3 fold axes. Arrow indicates plunge direction. Sense of rotation shown for asymmetrical folds as viewed in down plunge direction.

Sample location of metavolcanic rocks.

C C′ Location of cross section.

SWEETSBURG FORMATION

Cs — Black Phyllite Member

Csq — Quartzite Member

Csc — Carbonate-bearing Graphitic Phyllite Member

UNDERHILL FORMATION

CZuas — Albitic Schist Member

CZup — Chloritic Phyllite Member

CZum — Micaceous Schist Member

CZuw — Metawacke Member

CZuv — Metavolcanic Member

PINNACLE FORMATION

CZpc — Coarse-grained Metawacke Member

CZpf — Fine-grained Metawacke Member

CZpv — Metavolcanic Member

Scale

0.5 0.25 0 0.5
Miles

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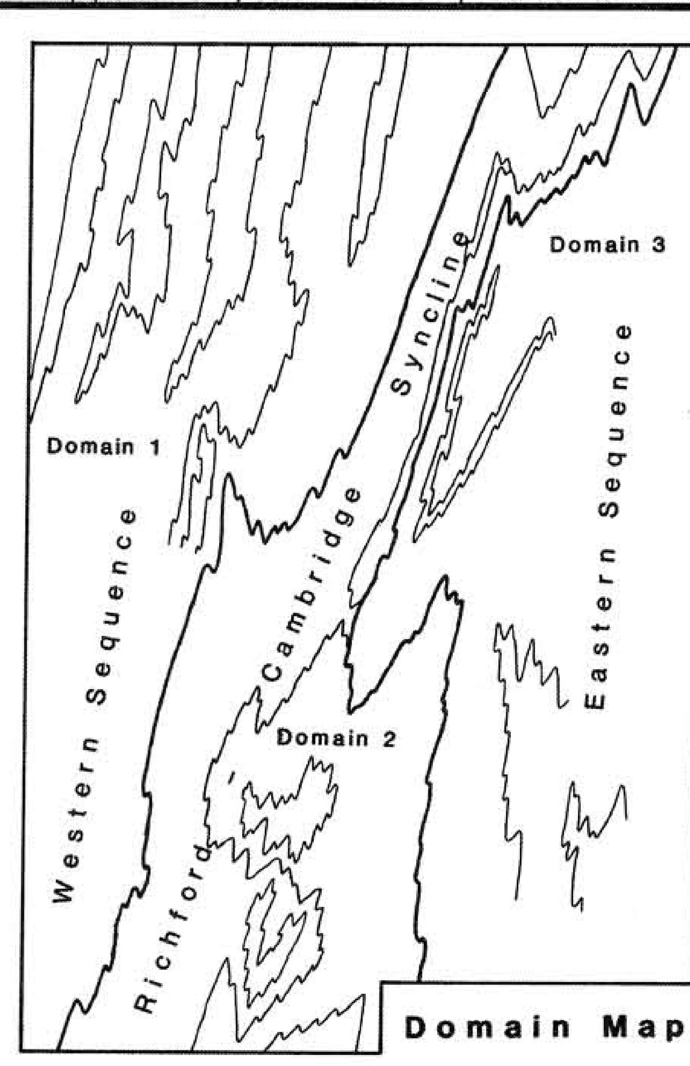
Feet

0.5 0.25 0 0.5
Kilometers

MN N 16°

1986



Domain Map

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