1-1-1972

Superposed Folds and Structural Chronology Along the Southeastern Part of the Hinesburg Synclinorium

Gillespie, Richard

Rolfe Stanley

Frank, Terry

Barton, Thelma

Trip B-9

SUPERPOSED FOLDS AND STRUCTURAL CHRONOLOGY ALONG THE SOUTHEASTERN PART OF THE HINESBURG SYNCLINORIUM

by

Richard Gillespie, Rolfe Stanley,
Terry Frank, and Thelma Barton
University of Vermont

INTRODUCTION

The regional geology of the Hinesburg synclinorium has been described by various authors; most notably Cady (1945, 1960, 1969), Welby (1961), Stone and Dennis (1964), and Stanley (1969, and this volume). The Centennial Geologic Map of Vermont (Doll et. al., 1961) is a representation of the state of knowledge of the synclinorium up to the time of its publication. More recent work carried out by various persons at the University of Vermont has greatly added to the knowledge of the structures and deformational history of the area.

It is the intention of this paper to bring together the attainments of the more recent work into an understandable and acceptable revision or alternate interpretation of the state geologic map.

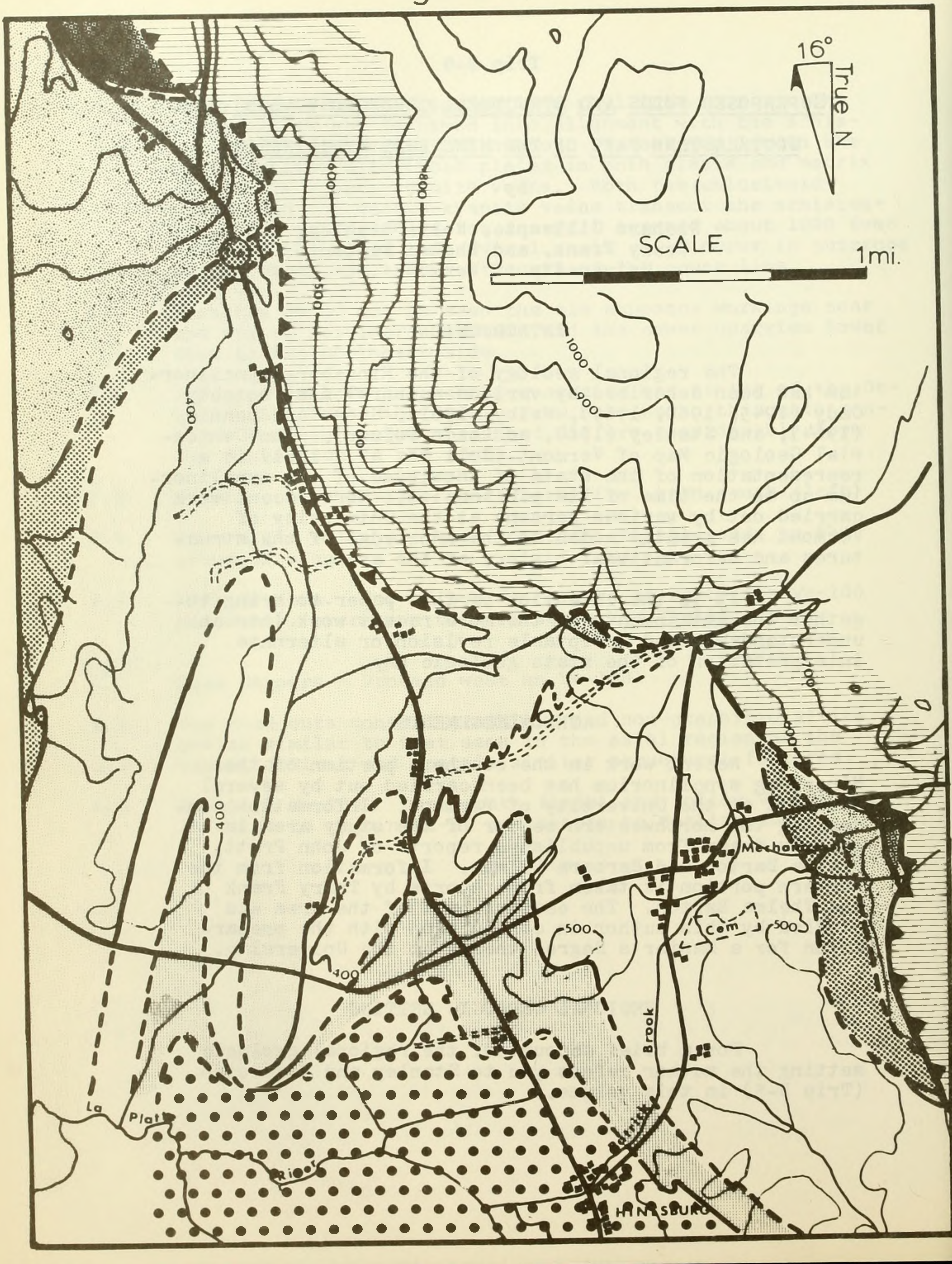
ACKNOWLEDGEMENTS

Recent work in the southern portion of the Hinesburg synclinorium has been carried out by several students at the University of Vermont. Information concerning the northwestern sector of the study area is largely drawn from unpublished reports of John Pratt, Thelma Barton and Barbara Gilman. Information from the western portion is taken from reports by Terry Frank and Thelma Barton. The eastern half of the area was studied by this author in conjunction with the preparation for a Master's Degree thesis at the University.

REGIONAL GEOLOGIC SETTING

For a brief account of the regional geologic setting the author refers you to Stanley and Sarkesian (Trip B-5) in this volume.

Figure 1


16°
True N
SCALE
0
1mi.
400
500
600
700
800
900
1000
Com
Brook
La
Plat
River
HINESBURG

EXPLANATION

ORDOVICIAN	Lower	BROWNELL MTN. PHYLLITE MBR.
		BASCOM FORMATION
		CUTTING DOLOMITE
		SHELBURNE FORMATION
CAMBRIAN	Upper	CLARENDON SPRINGS DOLOMITE
		DANBY FORMATION
	Middle (?)	WINOOSKI DOLOMITE
	Lower	UNDIFFERENTIATED CHESHIRE QUARTZITE AND UNDERHILL PHYLLITE

Thrust fault, sawteeth on upper plate, Hinesburg fault

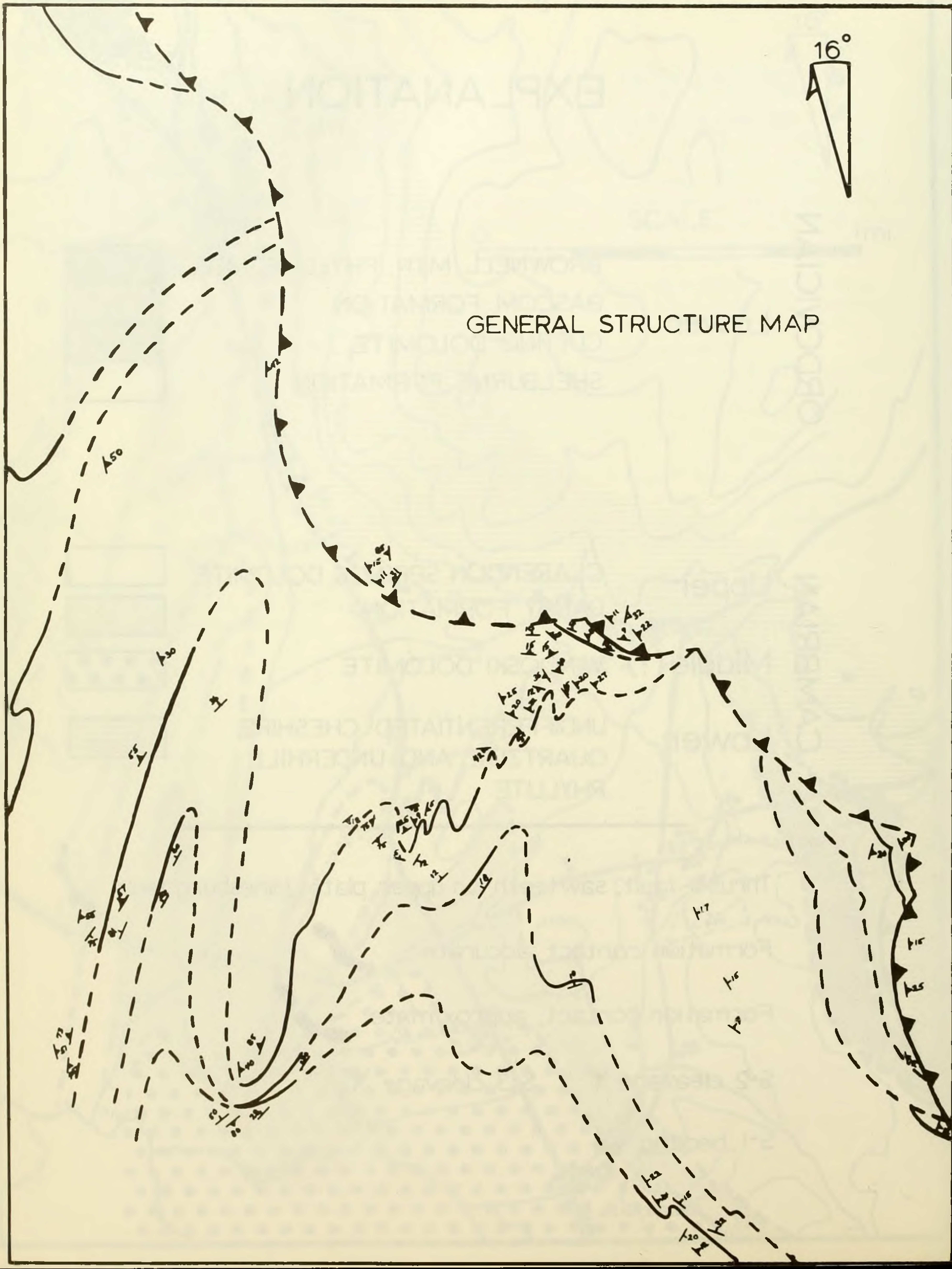
Formation contact, accurate

Formation contact, approximate

S-2 cleavage 20° S-3 cleavage 10°

S-1 bedding 37

Figure 2



STRATIGRAPHY

The stratigraphy of the area is described in Table I and II in the paper by Stanley and Sarkesian in this volume (Trip B-5). Only the Winooski through the Bascom Formation in the Hinesburg area will be discussed here since recent mapping has concentrated on these units.

Lower Cambrian

Cheshire Quartzite - Typical Cheshire is a massive, very thick bedded white quartzite. The lower part is brownish weathering and is quite argillaceous and less massive. East of the Hinesburg thrust, the contact with the Underhill Formation is gradational and placed above the chloritic schists and phyllites and below the mottled gray argillaceous quartzites showing well developed slaty cleavage. The author has not mapped the contact in the Hinesburg area.

Dunham Dolomite - This formation is not present in the area of study but occurs extnsively to the south and west.

Monkton Quartzite - This formation also does not appear in the study area but outcrops extensively to the west in the upper plate of the Champlain thrust.

Middle Cambrian (?)

Winooski Dolomite - The Winooski consists of light gray to buff weathering dolostone, being gray to light pink or buff on the fresh surface. Thin phyllitic or siliceous laminae is sharp and tends to be marked by a distinct physical break. This contact zone, consisting of a thin phyllitic limestone with a closely spaced cleavage parallel to the contact is similar in appearance to a fault contact.

Upper Cambrian

Danby Formation - Beds of gray and brown cross-bedded sandstone interlayered with beds of dolostone 1 to 2 feet thick are characteristic of the Danby Formation. The sandstones may be relatively pure massive white quartzites at some localities. A few thin layers of shale have also been observed near the top of the formation. In one locality (Stop #5), the basal Danby is an unusual boulder conglomerate made up of large blocks of sandstone, dolostone, and quartzite in a sandy matrix. The attitude of bedding is more readily determined in the Danby than in the massive dolomites above and below. The contact with the overlying Clarendon Springs Dolomite appears to be gradational with the sandstones and interbedded dolostones of the Danby gradually giving way to the more dolomitic formation above.

Clarendon Springs Dolomite - The Clarendon Springs is a massive gray weathered dolostone, buff to gray on the fresh surface with a tendency to be coarsely crystalline. The most obvious feature of this unit is the presence of knots and segregations of quartz crystals standing out from the weathered surface. Some of the other dolostones in the section also show quartz knots but they are not as ubiquitous as in the Clarendon Springs. A few beds of calcareous sandstone stand out from weathered surfaces and are generally the only bedding indicator discernable in the monotonous dolostone section. Blue-black chert nodules are common near the top of the formation. The contact with the overlying Shelburne Formation is gradational and marked by a zone of mixture of the two with patches of Shelburne in depressions surrounded by more resistant dolostone.

Lower Ordovician

Shelburne Formation - The Shelburne is a massive dove gray weathered limestone and pink to white marble streaked with buff dolomitic stringers. There are also a few beds of sandy phyllite present. The Shelburne Formation is undoubtedly the most readily identifiable unit found in the Hinesburg area. The variety of rock types near the contact with the surrounding formations provides excellent structural markers of the several generations of folds in the area. The contact with the overlying Cutting Dolomite is usually sharp with sandy dolostone above and white marbles and gray limestones below.

Stone and Dennis (1964, p. 51) state that in the Milton area the Cutting "lies with destinct disconformity on the underlying Shelburne." In the Mechanicsville area, near the thrust contact, the Cutting seems to be absent entirely from the section placing the Bascom Formation on the Shelburne Formation. This could be due to a stratigraphic pinchout of the Cutting which begins in the area of St. George, Vermont. The other explanation would be that the Bascom-Shelburne contact is a thrust contact, the Bascom being dragged up along the Hinesburg thrust.

<u>Cutting Dolomite</u> - The Cutting is a massive whitish to light gray weathering dolostone, dark gray on the fresh surface with a tendency to be fine-grained. Large calcite crystals up to 1" across are common in some areas. The base of the formation is a thinly laminated cross-bedded, calcareous sandstone while the upper part contains black chert nodules. The contact with the overlying Bascom Formation was nowhere observed in the eastern half of the study area but Cady (1945, p. 543) states that there is no "apparent stratigraphic break."

<u>Bascom Formation</u> - This formation contains the widest variety of lithologies of any rocks in the Cambro-Ordovician section (Cady, 1945, p. 42). In the study area the Bascom is a blue-gray limestone with interbeds of buff to orange weathered dolomite and gray calcareous sandstone. Phyllitic laminae can be found in some of the limestone layers. The formation forms the lower plate of the Hinesburg thrust at the Mechanicsville exposure and appears discontinuously to the south.

Cady has more recently divided the Bascom Formation into the Brownell Mountain Phyllite Member and the typical Bascom (see Doll,et. al., 1961 and Cady, 1960, p. 539, footnote #7). According to Cady, the Brownell Mountain Phyllite is a calcareous phyllite in the upper part of the Bascom on the east limb of the Hinesburg synclinorium. During the course of recent field mapping a black calcareous phyllite has been found here and there along the Hinesburg thrust and in lens-shaped bodies on Brownell Mountain. Where the contact can be located within a few feet the change from limestone or dolostone to black phyllite is abrupt. Intermediate rock types between the limestone typical of the Bascom and the black phyllite have not been recognized. Two explanations are suggested for these relationships. First, the black phyllite may be a series of thrust slivers or older shales dragged up along the sole of the thrust plate and intermingled with slivers of allochthonous Bascom carbonates. This interpretation was suggested by Cady (1945, p. 567, 574, and Plate 10) in which the phyllite was correlated with the Skeels Corners Formation of Upper Cambrian age and formed the upper plate of the Muddy Brook thrust. Second, the black phyllite may be equivalent to the Hortonville and Walloomsac Formations of Middle Ordovician age that unconformably overlie older rocks in western New England. Subsequent movement along the Hinesburg thrust has plucked the black phyllites and mixed them with the other carbonate slivers which are found at such places as Mechanicsville near Hinesburg.

POSSIBLE UNCONFORMITIES

Evidence from field mapping seems to indicate that the Winooski Dolomite-Danby Formation contact is an unconformity. The evidence has been previously mentioned in the descriptions of the formations and is discussed under the description of Stop #5.

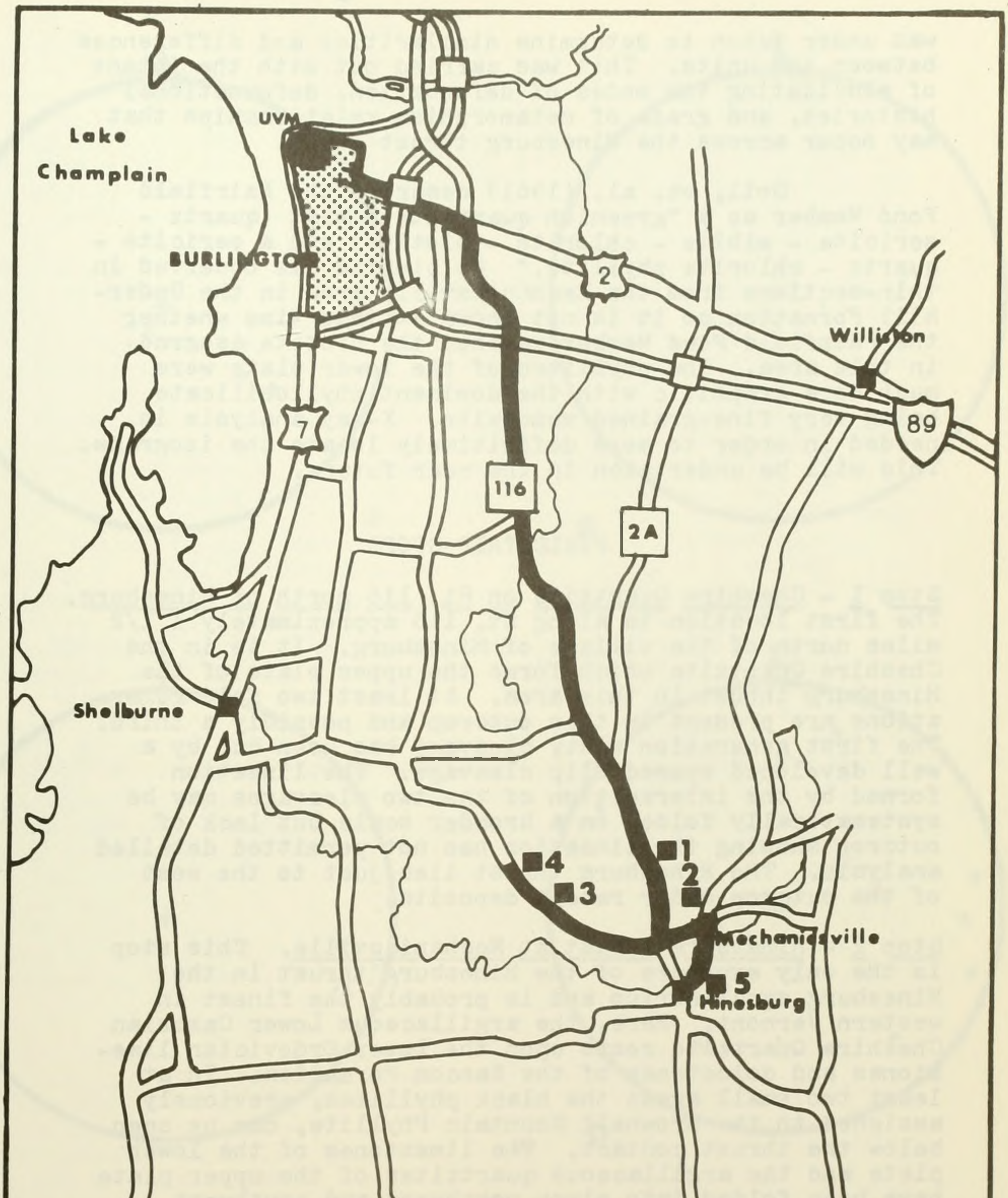
Another area which suggests an unconformity is the area east of the cemetary near Mechanicsville. Here the nondescript dolostones of the Cutting appear to rest on the dolostones of the Clarendon Springs with the Shelburne Formation notably absent, except for a small lens farther to the south. The contact between the two dolostones has not been directly identified but extensive exposure of the two formations makes it likely that the easily identified Shelburne occurs between them. The cause for the unconformity has not been determined. It may be a stratigraphic pinchout or a tectonic result of the nearby Hinesburg thrust; the Shelburne being tectonically squeezed out between the more resistant dolostones or absent due to imbricate thrusting.

The third area which suggests an unconformity is near the Mechanicsville exposure of the Hinesburg thrust. Sandy limestones of the Bascom Formation appear to rest unconformably on the Shelburne Formation with the Cutting absent. The actual contact of the two formations is covered by recent stream deposits. No boulders of dolostone could be found in the stream bed as might be expected if the Cutting were present. The presence of the Cutting is even somewhat doubtful in the area of the anticline depicted on Figure 1 near St. George to the northwest. Outcrops of Bascom and Shelburne occur quite close to each other there with no Cutting evident. Two explanations are possible for this unconformity. First, the Cutting is stratigraphically thinned and disappears to the northwest not reappearing from under the thrust at Mechanicsville. Second, the Bascom-Shelburne contact is a thrust contact at Mechanicsville, the Bascom being a thrust sliver dragged up along the sole of the thrust. However, if this were the case, one would expect a change in the bedding and first generation cleavage across the contact. This does not appear to be the case but does not entirely rule out the thrust hypothesis.

METAMORPHISM

A petrographic study of the Brownell Mountain Phyllite, the Fairfield Pond Member of the Underhill Formation as well as a thin phyllite in the Shelburne Formation

Figure 3



STOP MAP

SCALE

0 5 mi.

ROUTE

STOPS ■ 1

was under taken to determine similarities and differences between the units. This was carried out with the intent of elucidating the modes of deformation, deformational histories, and grade of metamorphism relationships that may occur across the Hinesburg thrust fault.

Doll, et. al. (1961) describe the Fairfield Pond Member as a "greenish quartzite schist (quartz - sericite - albite - chlorite - biotite) and a sericite - quartz - chlorite phyllite." No biotite was observed in thin-sections from the Mechanicsville area in the Underhill Formation so it is not known at this time whether the Fairfield Pond Member reached the biotite isograd in this area. The phyllites of the lower plate were much more graphitic with the dominant phyllosilicate being very fine-grained muscovite. X-ray analysis is needed in order to more definitively locate the isograds. This will be undertaken in the near future.

FIELD TRIP STOPS

Stop 1 - Cheshire Quartzite on Rt. 116 north of Hinesburg. The first location is along Rt. 116 approximately 1 1/2 miles north of the village of Hinesburg. It is in the Cheshire Quartzite which forms the upper plate of the Hinesburg thrust in this area. At least two fold generations are present in this outcrop and possibly a third. The first generation slaty cleavage has been cut by a well developed spaced slip cleavage. The lineation formed by the intersection of the two cleavages may be systematically folded on a broader scale but lack of outcrop showing the lineation has not permitted detailed analysis. The Hinesburg thrust lies just to the west of the outcrop under recent deposits.

Stop 2 - Hinesburg thrust at Mechanicsville. This stop is the only exposure of the Hinesburg thrust in the Hinesburg synclinorium and is probably the finest in western Vermont. Here, the argillaceous Lower Cambrian Cheshire Quartzite rests upon the Lower Ordovician limestones and dolostones of the Bascom Formation. In at least two small areas the black phyllites, previously assigned to the Brownell Mountain Phyllite, can be seen below the thrust contact. The limestones of the lower plate and the argillaceous quartzites of the upper plate have been folded into minor northeast and southwest plunging anticlines and synclines. An exposure of the Brownell Mountain Phyllite just to the west of the thrust shows clear evidence for two generations of deformation with the development of a slip cleavage deforming the original slaty cleavage.

Figure 4

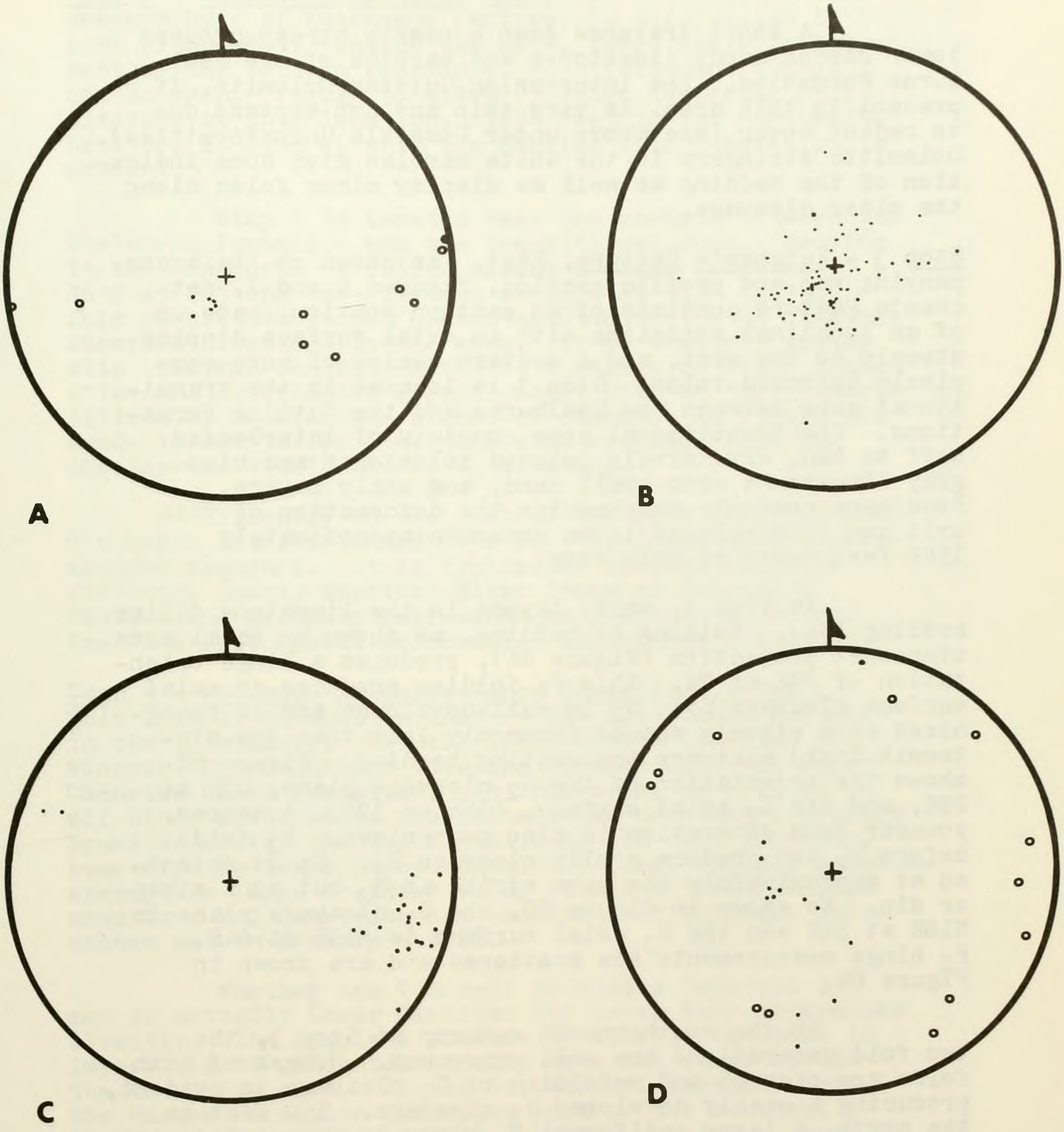


Figure 4 Lower hemisphere equal area projections of structures east of Rt. 116 in the town of Hinesburg, Vermont. A) poles to first generation closely spaced cleavage in Cheshire Quartzite (•) and second generation slip cleavage (∘) at Stop 1. B) 78 poles to first generation closely spaced cleavage in Shelburne, Bascom, and Brownell Mtn. Phyllite Formations (•). C) 22 lineations in Shelburne Formation formed by the intersection of bedding and first generation cleavage (•). D) poles to axial surfaces of folds in the Cheshire, Shelburne, Bascom, and Brownell Mtn. Phyllite Formations at Mechanicsville (•) and hinges of above folds (∘).

A short traverse down a nearby stream crosses lower Bascom sandy limestones and marbles of the Shelburne Formation. The intervening Cutting Dolomite, if present in this area, is very thin and not exposed due to recent cover (see above under Possible Unconformities). Dolomitic stringers in the white marbles give some indication of the bedding as well as display minor folds along the older cleavage.

<u>Stop 3</u> - <u>Ketcham's</u> <u>Pasture</u>, <u>East</u>. As shown on the accompanying map and profile section, Figures 6 and 7, Ketcham's Pasture consists of an eastern portion, made up of an isoclinal anticline with an axial surface dipping steeply to the west, and a western series of more complexly deformed folds. Stop 3 is located in the transitional zone between the Shelburne and the Cutting Formations. The transitional zone consists of interbedded buff to tan, extensively jointed dolostones and blue-gray limestones with small sandy and shaly layers. Boudinage commonly accompanies the deformation of this unit and is displayed in an exposure approximately 1500 feet north of this stop.

At Stop 3, sandy layers in the limestone define bedding (S_1). Folding of bedding, as shown by equal area stereonet projection (Figure 8A), produces a hinge orientation of N9E at 7W. This F_1 folding produces an axial surface cleavage S_2. S_2 is well-developed and is recognized as a closely spaced (commonly less than one-sixteenth inch) cleavage transecting bedding. Figure 8B shows the orientation of the S_2 cleavage plane, N7E at 29E, and the S_2 axial surface, N16W at 32E. A second, younger fold generation is also recognized. F_2 folds deform S_2 and produce a slip cleavage S_3. S_3 is oriented at approximately the same strike as S_2 but at a steeper dip. As shown in Figure 8D, the S_3 cleavage plane is N10E at 80E and the S_3 axial surface is N13E at 64E. F_2 hinge measurements are scattered and are shown in Figure 8E.

At the southernmost outcrop at Stop 3, the two fold generations are well expressed. Hinges of both folds are present and refolding of S_2 cleavage is evident, producing a weakly developed S_3 cleavage. 150 feet to the north, a large antiformal F_2 hinge is associated with folding of the well-developed S_2 cleavage (Figure 5A). Poorly developed S_3 cleavage is oriented N60E at 48S at this outcrop. Further to the north, a series of F_1 folds are observed, again in the sandy layers in the limestone (Figure5B). F_1 hinge measurements from this outcrop are included in Figre 8C and definean axial surface oriented N5E at 15E and suggest a slip line of N80E at 15S.

Stop 4 - Ketcham's Pasture, West. At this stop in the western half of Ketcham's Pasture, F_2 deformation is less pronounced. Inside the gate, immediately to the west of the Ketcham residence, both fold generations can be seen. Figure 5C shows F_2 folds deforming S_2 cleavage at this location. 1000 feet to the northwest, however, at Stop 4, only the earlier fold generation is present.

Stop 4 is located near the contact between the Shelburne Formation and the transitional zone. Bedding in the Shelburne is folded around a hinge oriented N65E at 22S and the cleavage associated with this F_1 fold generation is not characteristic of the S_2 cleavage observed elsewhere in the area. It is a widely spaced slip cleavage resembling the S_3 cleavage at other localities and is oriented approximately N50E at 50S. Quartz filling of S_2 cleavage planes is common. In Figure 5D, sandy layers in the limestone show crinkle folds and display the widely spaced S_2 cleavage.

Slightly to the west of the main cliff at Stop 4 a basic dike, oriented N75W at 74S, intrudes the sedimentary sequence. It is typical of several such E-W striking, nearly vertical dikes found at Ketcham's Pasture and probably represents an event much younger than the most recent deformation at Ketcham's Pasture.

Stop 5 - Winooski Dolomite-Danby Formation Contact. This stop is unusual in that it has never been reported in the literature. We will cross Middle Cambrian (?) Winooski Dolostone and view the contact with the Upper Cambrian Danby Formation. In this area, as well as in all other areas where the contact has been seen, a sharp break separates the two formations. In this locality, however, the lower Danby contains a local boulder conglomerate; the large boulders being blocks of cross-bedded sandstone and quartzite and massive buff to brown dolostones set in a sandy matrix.

Whether the Winooski is Middle Cambrian in age or actually Lower Cambrian has never been determined directly. The complete absence of fossils has made it impossible to paleontologically date the formation in the Hinesburg area. In the St. Albans, Vermont, area, the Parker Formation underlies part of the Winooski there and has yielded Middle Cambrian fossils. Therefore, Stone and Dennis (1964) have assigned a Middle Cambrian age to the Winooski. Cady (1945) has placed the Danby in the Upper Cambrian while Stone and Dennis have correlated the Danby with the Woods Corners Group

Figure 5 Descriptions

A. Large F_2 antiform at Stop 3: The closely-spaced F_1 cleavage has been gently folded by F_2; the poorly developed, more widely-spaced F_2 cleavage is mostly easily seen in the lower left of the photo.

B. Tight F_1 folds at the northern end of Stop 3: A thin dolostone bed in the otherwise massive marble reflects the tight F_1 isoclinal folding.

C. F_1 and F_2 folds by the gate NW of the farm house: The light-colored dolostone bed is gently folded by F_1 which is then refolded by F_2 into tighter folds as seen in the lower left.

D. F_1 folds with quartz-filled cleavage planes at Stop 4: F_1 appears as crinkle folds in the more resistant dolostone beds with widely-spaced, quartz-filled cleavage planes. There is no evidence of F_2 in this area.

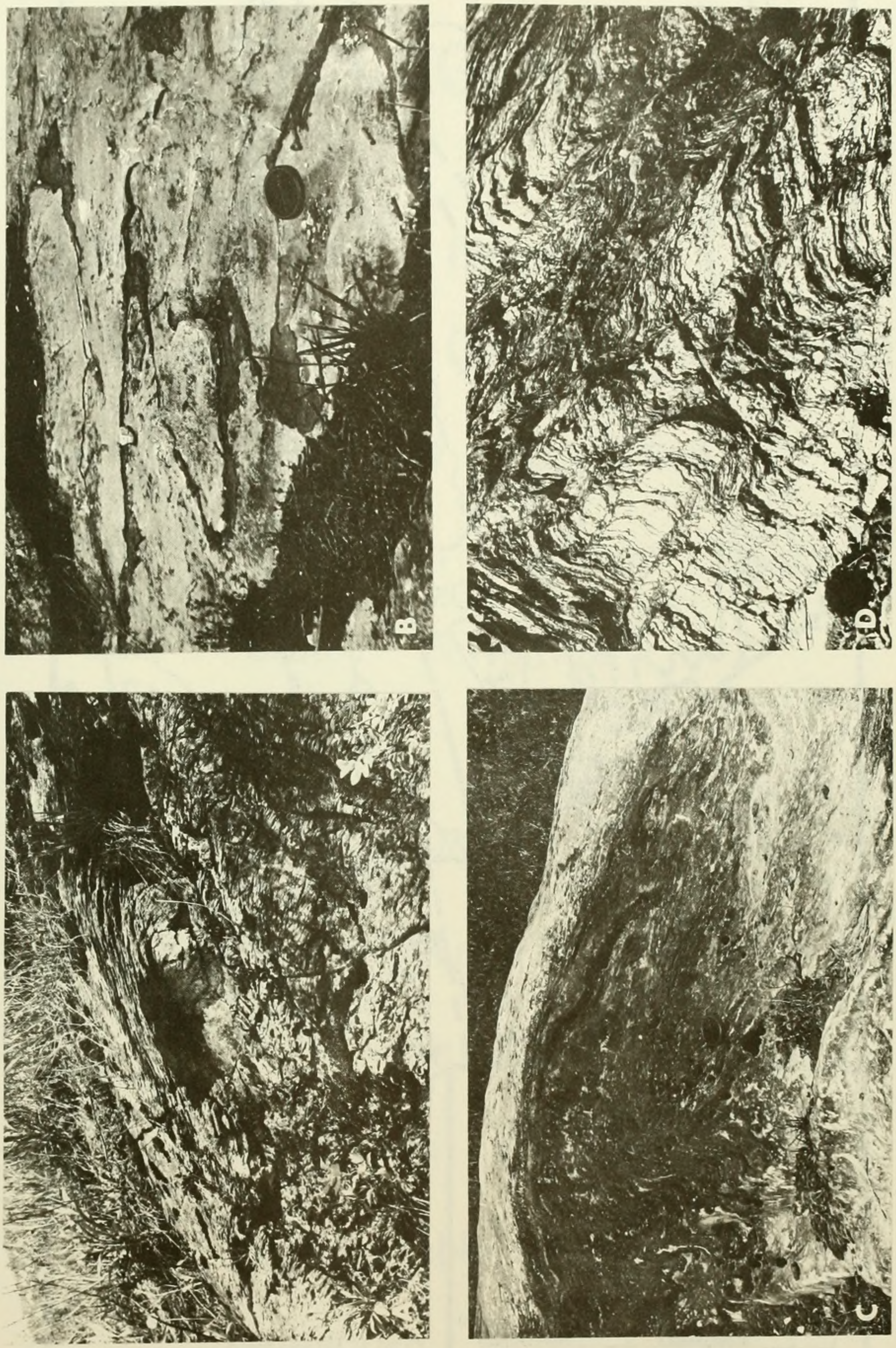


Figure 5

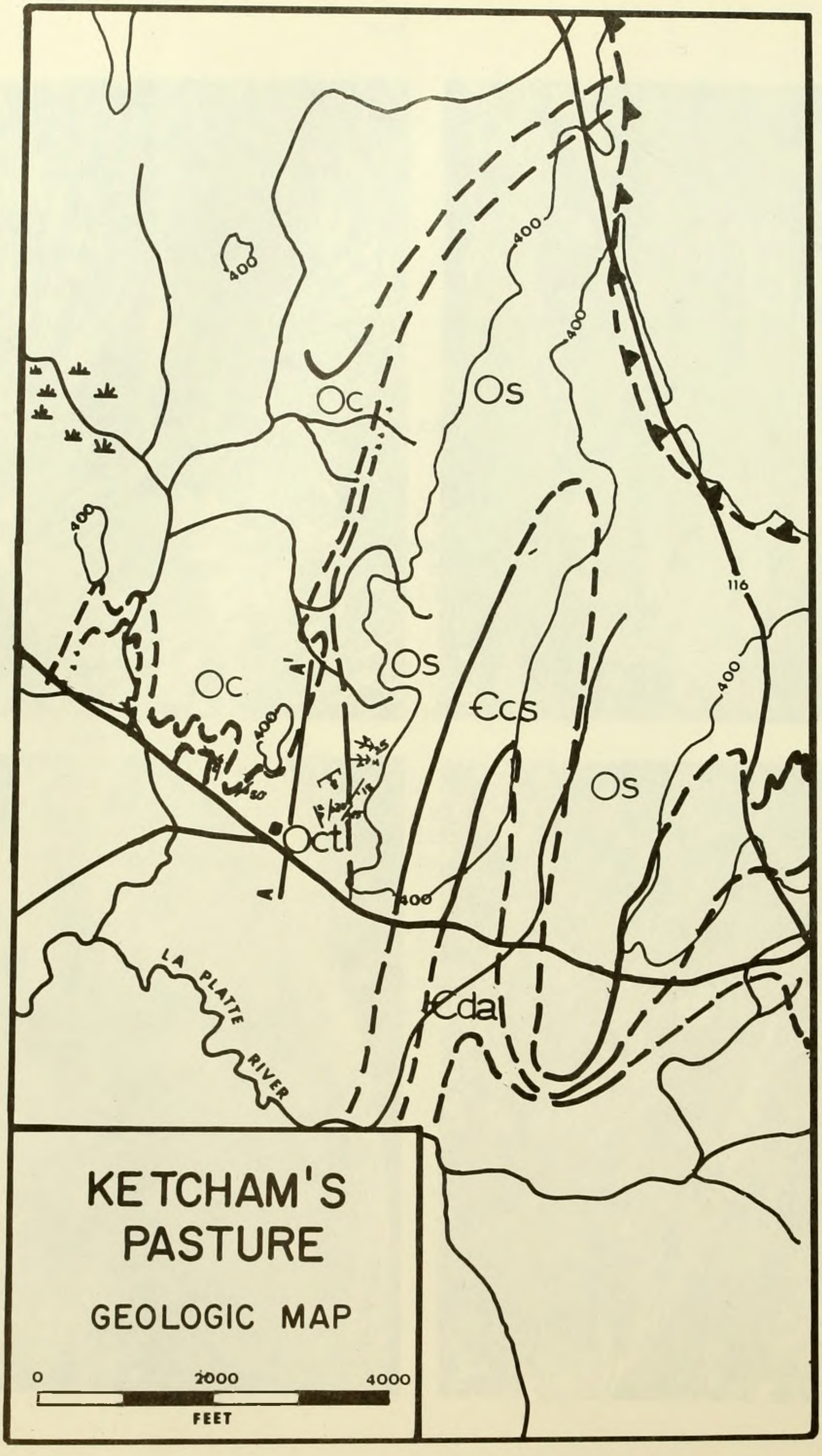
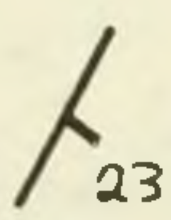
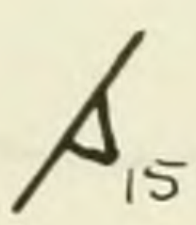
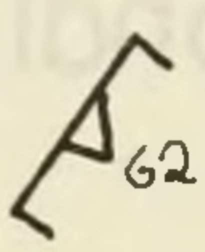
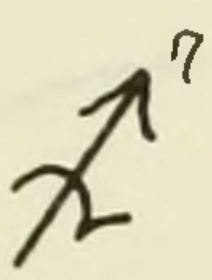
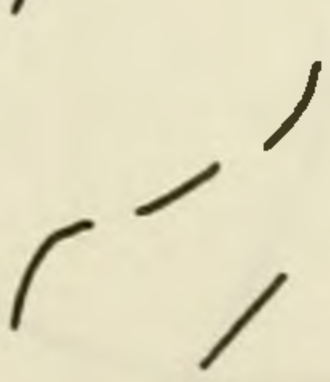
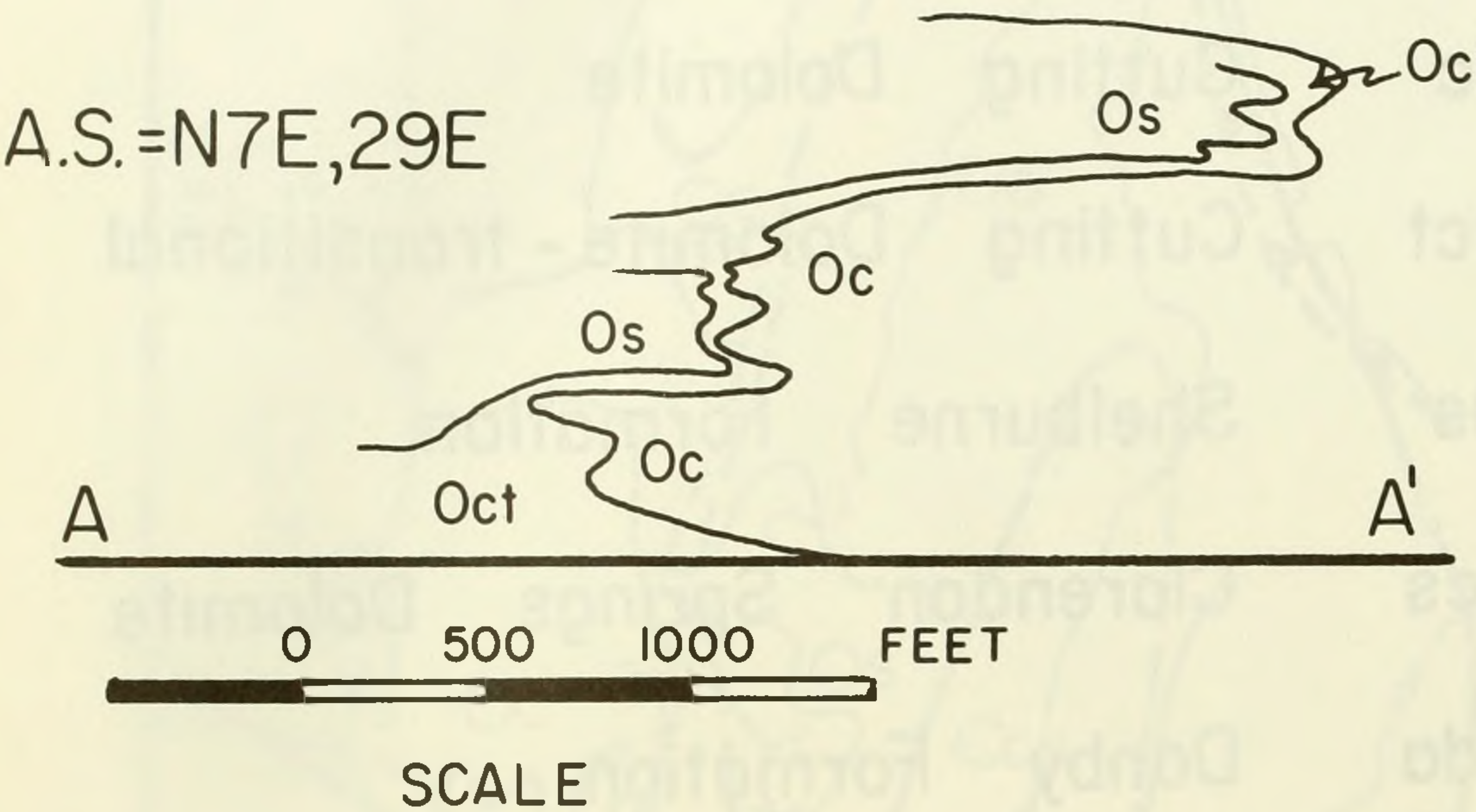

KETCHAM'S
PASTURE
GEOLOGIC MAP
0
2000
4000
FEET
Oc
Os
Oc
Os
Ccs
Os
Oct
Cda
A
A'
400
116
LA PLATTE RIVER

Figure 6

LEGEND

Oc	Cutting Dolomite
Oct	Cutting Dolomite - transitional
Os	Shelburne Formation
€cs	Clarendon Springs Dolomite
€da	Danby Formation
	Bedding
	F_1 Cleavage
	F_2 Cleavage
	F_1 Hinge - C.W. Rotation
	Formation Contact
	Questionable Contact
	Hinesburg Thrust Fault



Oc Cutting Dolomite

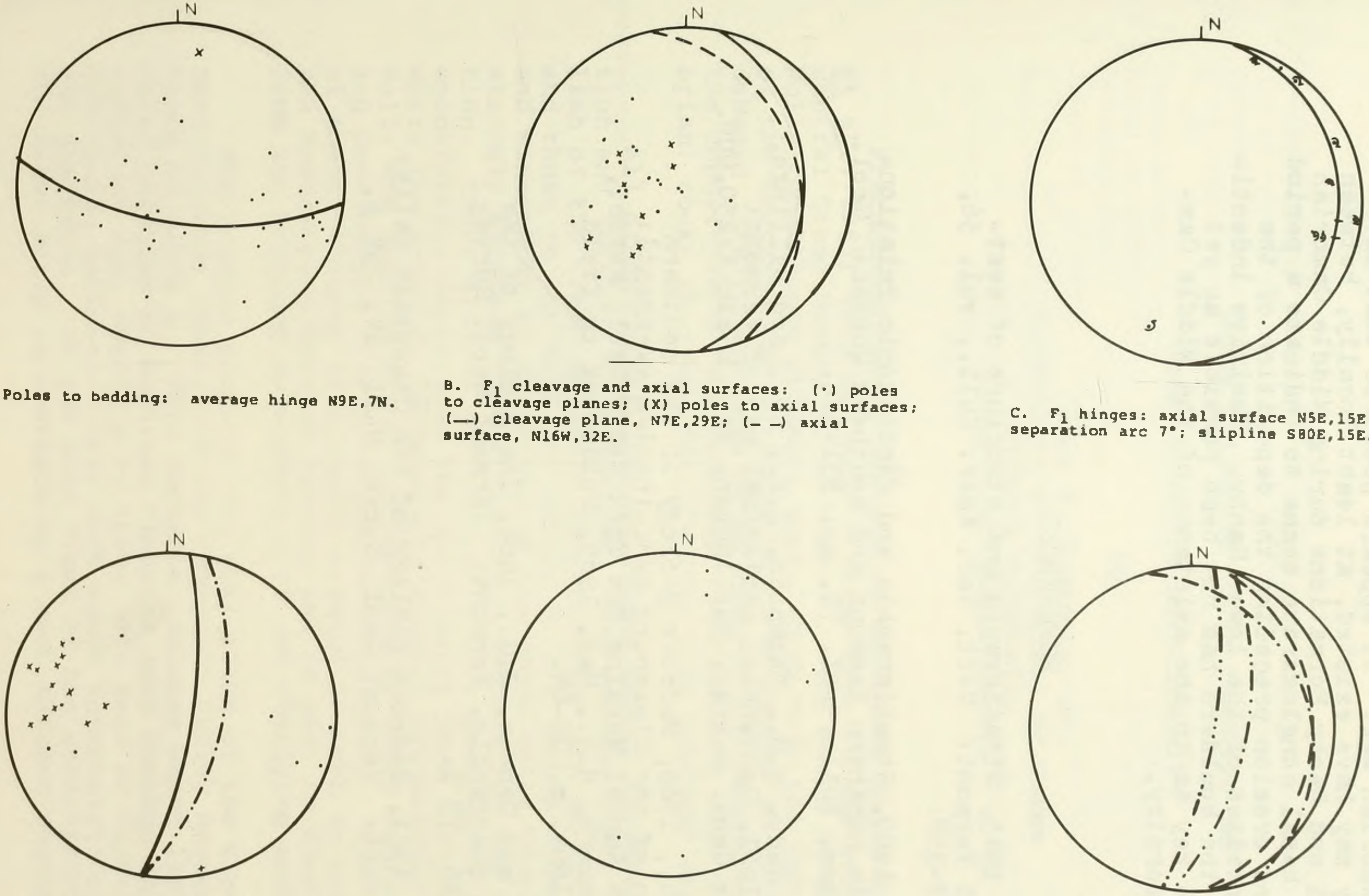
Oct Cutting Dolomite - transitional

Os Shelburne Formation

PROFILE SECTION

along the axial surface of F_1

Figure 7



A. Poles to bedding: average hinge N9E,7N.

B. F_1 cleavage and axial surfaces: (·) poles to cleavage planes; (X) poles to axial surfaces; (—) cleavage plane, N7E,29E; (– –) axial surface, N16W,32E.

C. F_1 hinges: axial surface N5E,15E; separation arc 7°; slipline S80E,15E.

D. F_2 cleavage and axial surfaces: (·) poles to cleavage planes; (X) poles to axial surfaces; (—) cleavage plane N10E,80E; (–·–) axial surface N13E,64E.

E. F_2 hinges.

F. Summary net: (—) axial surface of F_1 hinges N5E,15E; (– –) F_1 cleavage N7E,29E; (–·–) F_1 axial surface N16W,32E; (–··–) F_2 axial surface N13E,64E; (–···–) F_2 cleavage N10E,80E.

Lower Hemisphere Equal Area Projections in the Area of Ketcham's Pasture.

Figure 8

of Middle Cambrian age. It appears possible that an unconformity may have existed, at least locally, between the Winooski and Danby Formations during Middle Cambrian time. This basal conglomerate seems to indicate a period of uplift and erosion preceding the deposition of the massive quartzites of the lower Danby. Positive indentification of the boulders has not been possible as yet but hold the key as to the existence of the Middle Cambrian unconformity.

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