STRATIGRAPHY AND STRUCTURE OF THE GANSON HILL AREA: NORTHERN TACONIC ALLOCHTHON

A thesis presented to the Faculty
of the State University of New York
at Albany
in partial fulfillment of the requirements
for the degree of
Master of Science

College of Science and Mathematics
Department of Geological Sciences

Michelle Aparisi
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ABSTRACT

The Ganson Hill study area is located in the Giddings Brook Slice of the Taconic Allochthon. It contains rocks of Cambrian(?), Cambrian and Ordovician age. The predominant rock type is slate with subordinate lithologies including quartzite, limestone, micrite, arenite and graywacke. The lithostratigraphy identified in the Ganson Hill area extends from the basal Bomoseen wacke to the Poultney slate. A more precisely defined lithostratigraphy is derived from the study area by the occurrence and recognition of the Middle Granville Slate Formation and the documentation of a second Cambrian black/green boundary. Previous workers have included this formation in different places, in two different formations creating much confusion.

Three stages of deformation have been recognized in the Ganson Hill study area. They are: pre-slaty cleavage folding, slaty cleavage development with associated folding and faulting and seen only sporadically, crenulation cleavage development with associated folding and faulting. Documented in this thesis is the Hubbardton Gulf Thrust Fault which places Cambrian green slate (Undifferentiated Bull Fm.) over black and gray slate with interbedded quartzite (Poultney Fm.).

An early Ordovician contourite deposit has been identified in the Poultney unit. The grain size, the composition and the lateral extent of the quartz-rich beds in the Poultney Formation in addition to sharp top and bottom bedding contacts and preserved sedimentary structures are distinguishing characteristics of the contourite

deposit. Paleocurrent directions indicate northerly flowing bottom currents depositing and reworking material fed from the North American Platform adjacent to and south of the present area of the Taconics.

ACKNOWLEDGMENTS

This thesis would not have been completed were it not for the help of two, fine geologists. W.S.F. Kidd, my thesis advisor, who reviewed the manuscript on several occasions and suggested improvements, offered fruitful discussion on specific problems and visited the field area. T.C. Ray, a fellow grad-student, who generously offered free access to his voluminous library, enlightening and helpful conversation on Taconic geology, an enormous amount of encouragement and, also his time in the field. To him, I feel immense indebtedness and a special affection. I also wish to thank Win Means and George Putnam for reviewing the manuscript and for helpful advice, and John Marcell and family for offering the hospitality of their country home during the fall field work. Last, but not least, I wish to thank the entire SUNYA graduate student department for fine friendships and many good memories.

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CHAPTER 1
Introduction

The Taconic Allochthon consists primarily of low-grade metamorphosed (chlorite to biotite grade) pelitic sedimentary rocks associated with lesser quartzite, arenite, limestone, chert, conglomerate and graywacke; of Cambrian (?) and Ordovician age. The Taconic Allochthon crops out in an elongate belt, trending roughly north-south; 200km long and 25-30 k- , from Sudbury, Vermont to Poughkeepsie, New York. It is predominantly contained within the states of New York and Vermont, but also extends into the western-most portions of Massachusetts and Connecticut (Figure 1). The allochthon overlies an autochthonous to parautochthonous sequence of shelf rocks; a coeval sequence of carbonate and shallow water clastic lithologies of the Middlebury Synclinorium. The lithologies of the Taconic Allochthon were on the Cambro-Ordovician, North American continental rise and were thrust upon the continental shelf sequence during the Taconic Orogeny. Presently, the allochthon lies between two crystalline basement, Grenville-age provinces; the Adirondack Mountains, to the west, and the Green Mountains and Berkshire Highlands, to the east (Figure 2).

The allochthon consists of six major thrust slices (Zen, 1967). They are, from lowest to highest; the Sunset Lake Slice, the Giddings Brook Slice, the Bird Mountain Slice, the Chatham Slice, the Rensselaer Plateau Slice, and the Dorset Mountain and Greylock Slices (Figure 3). Zen (1967,1972) proposed a model involving soft-sediment gravity sliding as the mechanism

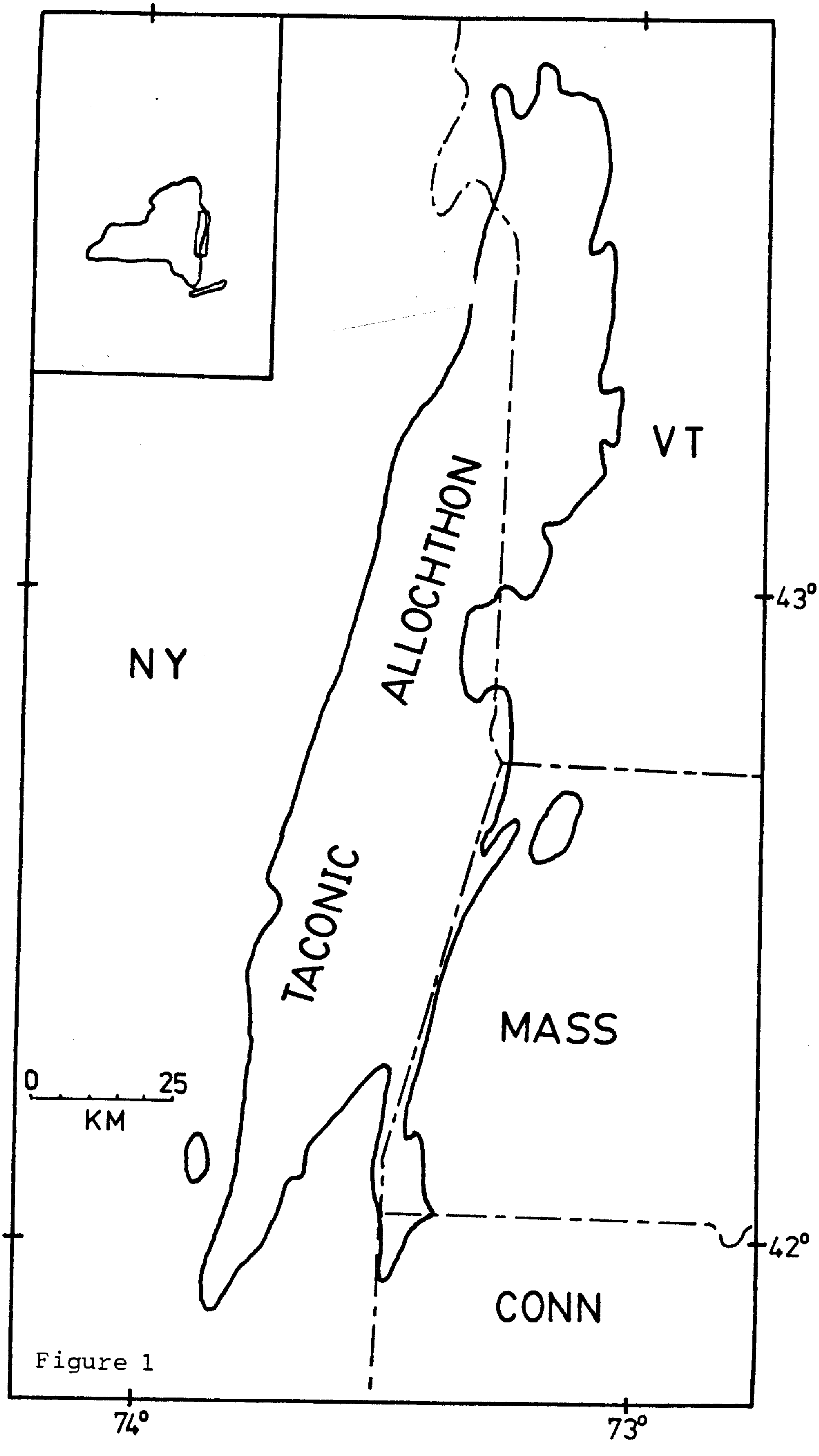


Figure 1

Figure 1.

The Taconic Allochthon outcrops in an elongate belt roughly 200km long and 25-30km wide, extending from Sudbury, Vermont to Poughkeepsie, New York.

Figure 2

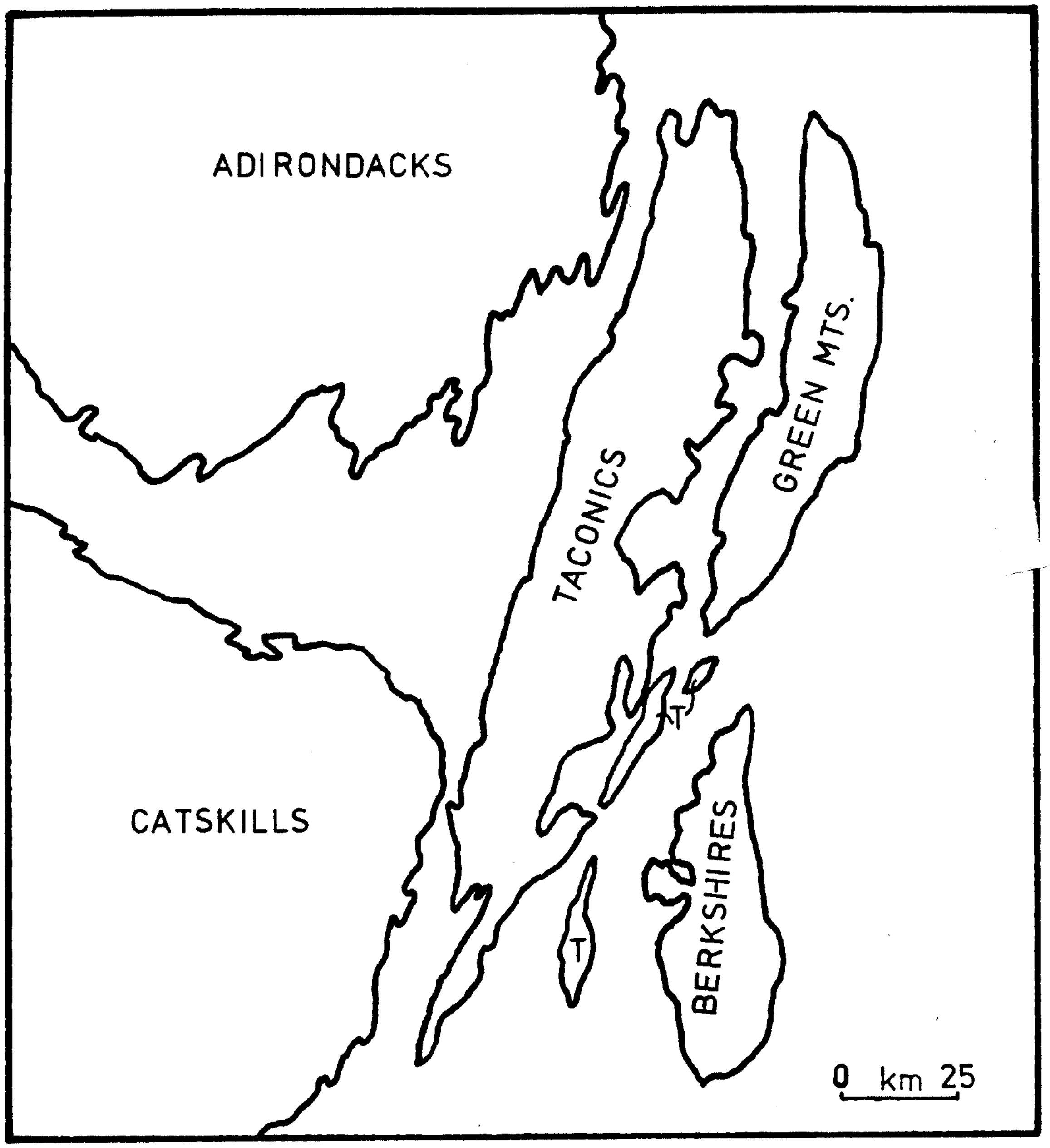
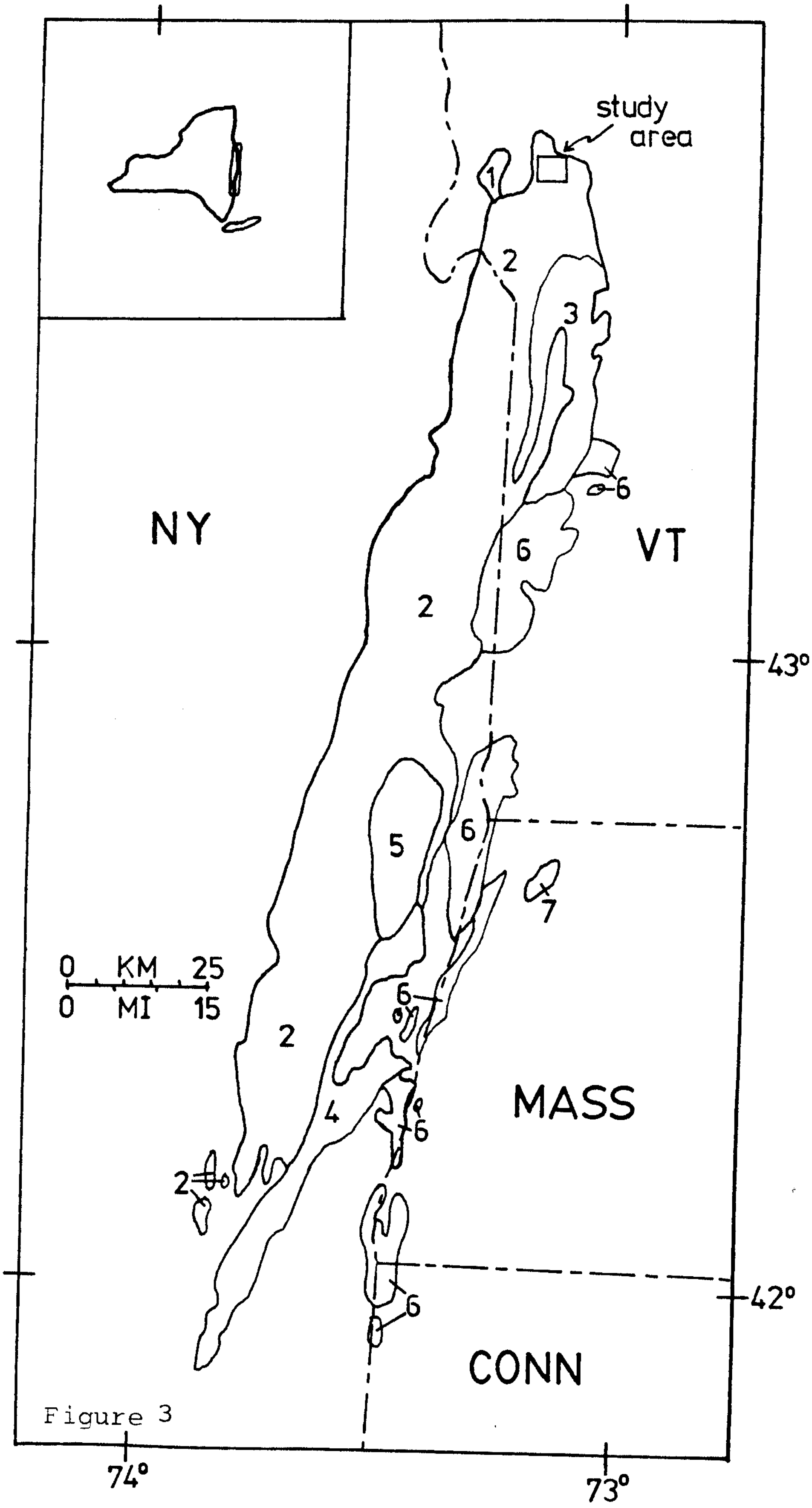

ADIRONDACKS
TACONICS
GREEN MTS.
CATSKILLS
BERKSHIRES
T
T
0 km 25

Figure 2

Location map for the Taconic Allochthon. The Taconic Allochthon lies between Adirondack (Grenville Province crystalline basement) and Catskill (Siluro-Devonian sediments) rocks, to the west; and Green Mountain and Berkshire Highlands (Grenville Province crystalline basement) rocks, to the east.



study area
1
2
3
6
NY
VT
6
2
43°
5
6
7
0 KM 25
0 MI 15
6
2
MASS
4
6
2
42°
6
CONN
74°
73°

Figure 3

Figure 3

Individual slices of the Taconic Allochthon. The Taconic Allochthon consists of six major slices. They are, from structurally lowest to structurally highest:

1 the Sunset Lake Slice
2 the Giddings Brook Slice
3 the Bird Mountain Slice
4 the Chatham Slice
5 the Rensselaer Plateau Slice
6 the Dorset Mountain and Greylock Slices

of emplacement of the lower Taconic slices. Rowley, et al. (1979) argue that structural evidence does not support a gravity slide origin, but instead indicates emplacement by "hard-rock" thrusts of the lower Taconic slices. The initial stacking sequence progressed from east (oldest, structurally highest) to west (youngest, structurally lowest) (Rowley, Kidd and Delano, 1979). Each slice of the Taconic Allochthon, contains a stratigraphy; the Giddings Brook Slice having the most complete, and shows at least two generations of deformation. Generally, the intensity of deformation and the metamorphic grade, increases to the east in the allochthon. Rowley, et al. (1979) have shown that each major slice can be divided into subslices, based on coherent stratigraphies and structural complexities.

The most prominent lithologies of the Taconic Allochthon, are low-grade metamorphosed, variously colored slates. The slates occur in black, green, blue-green, maroon, light gray, dark gray, and purple varieties. They show a range in cleavage development and fissility. Some are soft and silty, others are hard and siliceous. Calcareous, pyritiferous, color-laminated and bioturbated varieties are also common. Numerous other lithologies are associated with the slate. They include graywacke, clean quartz-arenite, dolomitic quartz-arenite, dolomitic calc-arenite, limestone, limestone conglomerate, limestone breccia, micrite, silty quartzite, silicic tuff beds and chert. Fossils which serve to place age constraints on the rocks, as well as younging direction indicators, are present in most of the units. The ages range from beneath lowest Cambrian to middle Ordovician. The fossils include late Early Cambrian Elliptocephala asaphoides fauna and other trilobite faunules, latest Cambrian dendroid graptolites and middle to upper Caradocian graptolites.

The present study is based on approximately 12 weeks (June to August, 1981) and several weekends (during the Fall seasons of 1981 and 1982) of fieldwork. The field area is contained in the Bomoseen 7 1/2 minute quadrangle. It extends from the Keeler Pond Thrust (as mapped by Zen, 1967) to Monument Hill Road, north to south; and from Route 30 to Brandon Mountain Road, west to east (Figure 4). An outcrop map was prepared on a scale of 1;1[illegible],000 using a base map made from topographic maps. The field area is rural, well-vegetated with areas of extensive swamps. The hills generally have steep western slopes and relief varies approximately 800 feet. Cultivated fields and dairy farming are present, but logging is the main resource of the area. Logging roads and streams cut the area providing good access, but not necessarily good outcrop exposure. On steeply sloped hills, the outcrop exposure was adequate, but; gentle slopes and ravines were often covered with thick vegetation or filled in by swamps. Local senior citizens recall when Ganson Hill use to be called "Black Rock", an appropriate name for a hill topped by black Poultney slate.

The field area was chosen with the help of W.S.F. Kidd. Previous workers in the area, indicated at least a portion of the complete stratigraphic section was intact and their structural interpretations served to raise interesting questions and the need for further study in the area. The intentions of the study area are as follows:

1) Make a detailed geologic map of the Ganson Hill area.
2) Compile a detailed lithostratigraphic column to help study variations in stratigraphy and sedimentology of the Giddings Brook Slice.

Figure 4

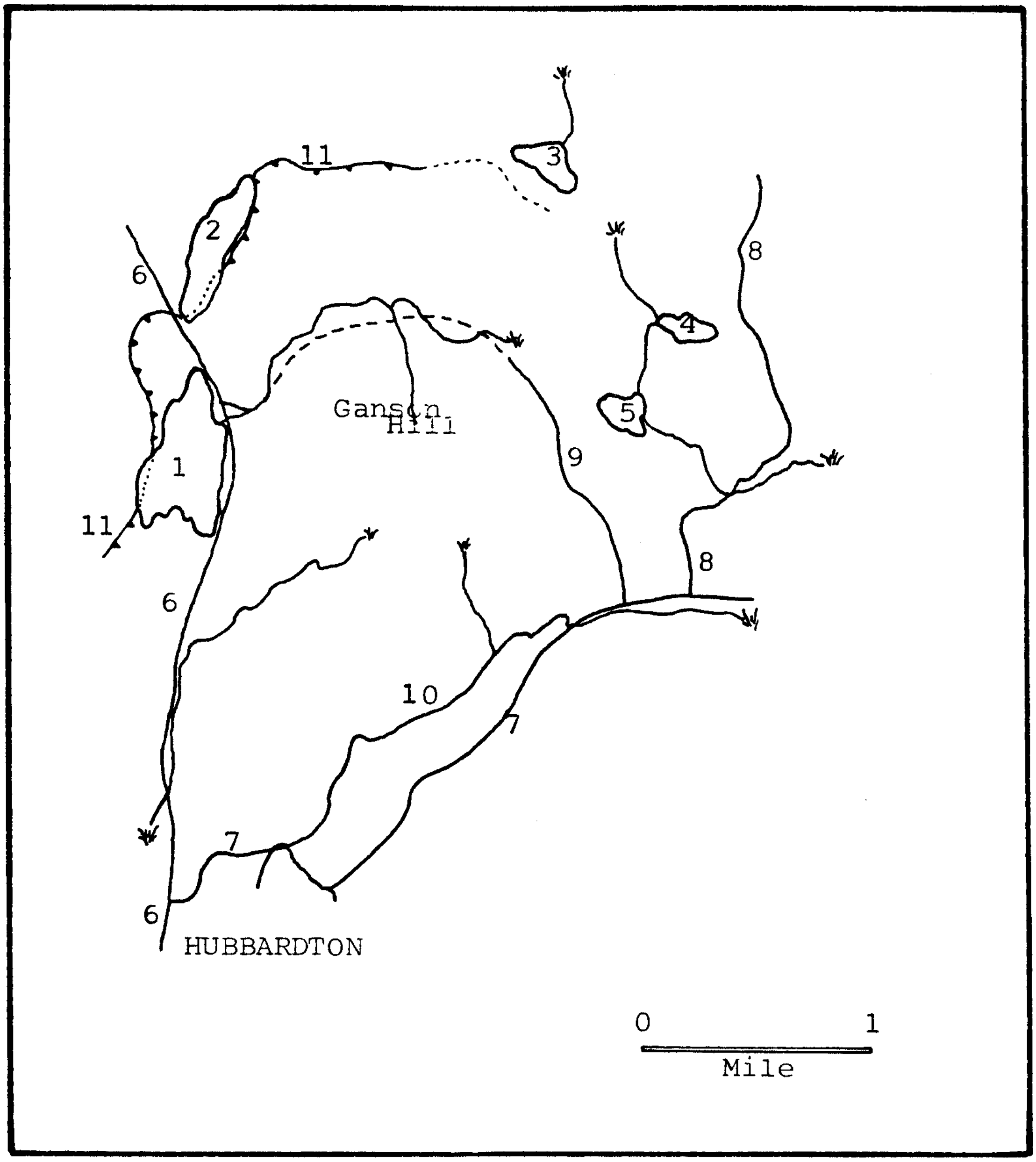


Figure 4

The Ganson Hill field area.
1 Beebe Pond
2 Keeler Pond (Echo Lake)
3 High Pond
4 Walker Pond
5 Mudd Pond
6 Route 30
7 Monument Hill Road
8 Brandon Mountain Road
9 Ganson Hill Road
10 Giddings Brook
11 Keeler Pond Thrust Fault (Zen, 1961)

3) Make a detailed structural analysis of the (alleged) change in orientation of large-scale fold axes from north-south to east-west.

4) In addition to the studies in the local field area, I have also in collaboration with Dr. Kidd collected data on and documented the existence of an Early Ordovician contourite deposit occurring throughout the length of the Taconic Allochthon.

CHAPTER 2
Stratigraphy

2.0 Introduction

During the 19th century, geologists working in eastern New York and western Vermont, grouped both the carbonate and pelitic lithologies together considering them to be a continuous sequence. The idea that the Taconic slate belt was at least partially allochthonous was first thought by Ruedemann in 1909. Until then the entire sequence was termed the Taconic System. The carbonate and pelitic lithologies were shown to be at least partially equivalent sequences of Cambrian and Ordovician age, by the paleontological work of Walcott (1888). By the end of the 19th century, Dale (1899) had provided the first comprehensive description of the slate belt. Using Walcott's (1888) geologic reconnaissance maps and fossil localities, Dale made the first geologic map of the slate belt and further documented the existence of a Precambrian(?) to Ordovician age for the sequence. Dale's work in describing the stratigraphic units of the western Taconics is still an invaluable reference today. His work was detailed, comprehensive and amazingly accurate requiring only moderate modification by subsequent workers, such as the replacement of his cryptic names and letters with formal stratigraphic names.

The 20th century brought to the Taconics many workers, mapping areas geographically distinct from one another and the introduction, definition and revision of many of the stratigraphic units. As a result, much confusion has arisen due to the overwhelming number of names and synomomies. Zen (1964a) compiled an invaluable reference of most of the Taconic stratigraphic units. Rowley (1983) has discussed stratigraphic revisions made since Zen's publication.

The following discussion of the Taconic stratigraphy in the Ganson Hill study area is divided into four sections. The first section of stratigraphic correlations serves as a reference for previously established stratigraphic columns and the presently accepted sequence of stratigraphic units in the Ganson Hill study area. The second section is the bulk of Chapter 2. It gives the lithologic and petrographic descriptions of the stratigraphy preserved in the Ganson Hill study area. In this section, each formation is described as seen in outcrop, members are included and described. Formation thickness, variations in lithologic units and an account of where specific lithologies are well-developed or disappear are also given in this section. Also given in this section is the type locality of each formation and where it can best be seen in the Ganson Hill map area. Petrographic thin sections were made and examined to study the textures of the clastic lithologies. Petrographic descriptions of several lithologies are provided. The textures are described in terms of particle size, sphericity, roundness, orientation and mineral composition. Lithologies were classified using Pettijohn's (1975) classification of sandstones, and the quartz, clay, chert, carbonate tetrahedron for classification of sedimentary rocks (after Krumbein and Sloss, "Stratigraphy and Sedimentation", 1955).

The third section describes the primary sedimentary features preserved in the rocks of the Ganson Hill study area.

Although deformation and metamorphism has altered or in some cases destroyed many of the primary features, several lithologies have retained primary bedding, laminations, burrows, and soft-sediment deformation or slump structures. Other primary features such as graded bedding, channel fills and bottom structures are not discussed in this section, but are included in the lithologic descriptions of specific lithologies (section 2.2).
With the exception of primary bedding, these features do not influence the regional folds or structures in the Ganson Hill map area.

The fourth and last section of this chapter gives a brief discussion of the mechanisms involved in the deposition of specific clastic, as well as nonclastic, lithologies. The depositional mechanisms are inferred based on observed characteristics, such as the grading and sorting of clastic grains and particles, bedding thickness and the nature of bedding contacts with beds above and below, the lateral continuity of beds, the internal structures of beds and the presence or lack of an orderly sequence of structures. A discussion of the sedimentary environments within which these depositional mechanisms operate require further study and are not attempted in this thesis.

In summary, the rocks of the Ganson Hill area show an ordered stratigraphy which spans the interval from early Cambrian to early-medial Ordovician times (see Figure 5). Only a portion of the entire Taconic sequence is recognized here since the uppermost, medial Ordovician section seen elsewhere is not preserved. The stratigraphy extends from the basal Bomoseen wackes up to the Poultney slates, the remaining younger Taconic rocks; the Indian River, Mount Merino,

STRATIGRAPHY
OF THE GANSON HILL AREA

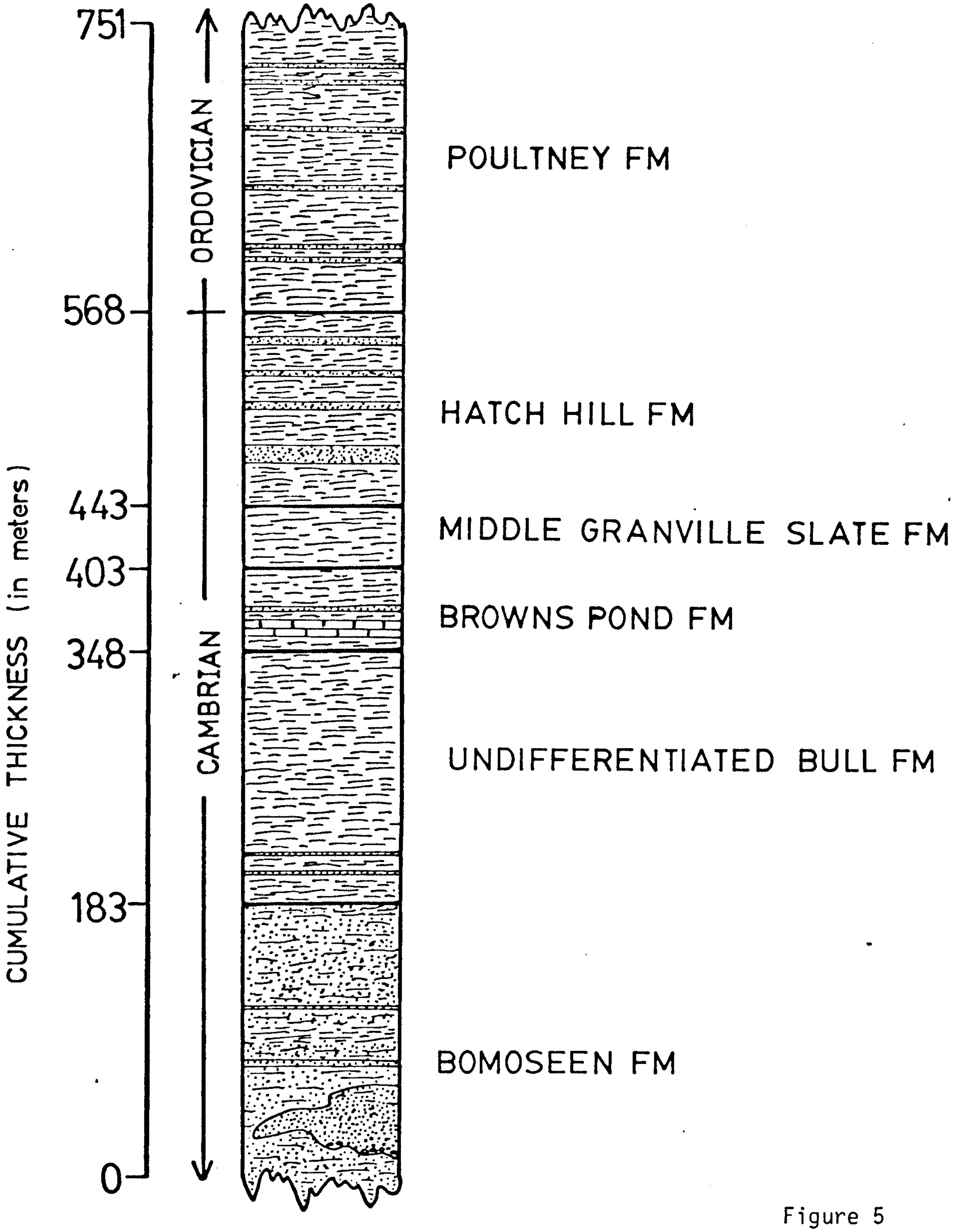


Figure 5

and Pawlet Formations are not found in the study area.

The section is predominantly composed of hemipelagic sediments, originally shales, now slates which exhibit differing degrees of fissility, compositional layering and cleavage development. Interbedded with the slates, and less abundant, are graywackes, arenites, sandstones and limestones, including both calcareous and dolomitic varieties. The section is approximately 750 meters thick as presently constituted.

2.1 Stratigraphic Correlations

Introduction

By the end of the 19th century, a comprehensive account of the rocks comprising the slate belt of western Vermont and eastern New York was documented by Dale (1899). With the help of Walcott's (1888) geologic reconnaissance maps and fossil localities, Dale made the first detailed geologic map of the slate belt. Dale was mainly concerned with the economic value of the various colored slates which were quarried for roofing material. Dale's map shows the areal extent of only two formations, the Lower Cambrian and the Lower Ordovician; but his stratigraphic descriptions are of such high quality that one can easily decipher most of the presently established stratigraphic units, however; Dale's sequence of stratigraphic units is incorrect.

The Giddings Brook Slice And Stratigraphic Correlations Of The Ga[illegible] Hill Study Area.

Individual slices of the Taconic Allochthon are defined not only on the basis of unconformable structural relations, but also by well-defined "packages" of rocks showing an ordered sequence with conformable contacts between units. The Giddings Brook slice, structurally the lowest slice of the Taconic Allochthon, contains the most complete stratigraphy (see Fig.6) covering a time span from Precambrian(?)-Lower Cambrian (Biddie Knob Formation of Zen (1961)) to Middle Ordovician (Pawlet Formation).

FIGURE 6

		YOUNGEST		SEQUENCE OF EVENTS		OLDEST	
		(Mutual Relations Uncertain)		(Mutual Relations Uncertain)			
		Dorset Mtn. and Greylock Slices	Rensselaer Plateau Slice	Chatham Slice	Bird Mountain Slice	Giddings Brook Slice	Sunset Lake Slice
ORDOVICIAN	Middle					Pawlet	Pawlet
	Lower				Indian River	Indian River	?
				?	Poultney	Poultney	Poultney
CAMBRIAN	Upper			?	Hatch Hill?	Hatch Hill	?
	Middle			?	?	rocks mapped as part of W. Castleton	?
	Lower			W. Castleton	W. Castleton	W. Castleton	W. Castleton
		Greylock	Mettawee	Bull	Bull	Bull	Bull
CAMBRIAN(?)		Bellowspipe	Rensselaer	Rensselaer	Biddie Knob	Biddie Knob	
		upper part of Berkshire					

(from Zen, 1967)

The Ganson Hill study area is contained within the Giddings Brook slice of the Taconic Allochthon and subsequent stratigraphic correlations will reflect only this portion of the Giddings Brook slice. The stratigraphy of the Giddings Brook slice is divisible into three groups. They are, from lowest to highest, the Nassau Group, the Mount Hamilton Group and the Willard Mountain Group (Kidd, et.al.; in prep.). The Nassau Group can be subdivided into three units (the Biddie Knob, Rensselaer, and Bull Formations), but the Rensselaer Formation is not represented in the Giddings Brook slice. The Mount Hamilton Group includes all the units from the base of the Browns Pond Formation to the top of the Indian River Formation, and the Willard Mountain Group consists of the Mount Merino and Pawlet Formations.

In the Ganson Hill study area, only portions of the Nassau Group and the Mount Hamilton Group are exposed. Of the Nassau Group, the Bomoseen and Undifferentiated Bull Formations are represented. The Mount Hamilton Group, exclusive of the upper most unit (Indian River Formation), is represented by the Browns Pond, the Middle Granville Slate, the Hatch Hill and the Poultney formations. The Nassau Group consists of all the units below the lowest (oldest) Cambrian black/green slate boundary. A second (youngest) Cambrian black/green slate boundary occurs at the stratigraphic contact between the Middle Granville Slate formation and the overlying Hatch Hill formation. Zen (1961) did not recognize the second Cambrian black/green boundary and therefore included all the green slates within the Bull Formation. What Zen overlooked was the presence of a mappable unit, the Middle Granville Slate (new-Kidd, Delano and Rowley; in Fisher, 1984) of green purple, maroon and lesser gray slates that lie above dark gray to black slates containing limestones, quartz arenites and silty wackes (Browns Pond Formation) and below sooty, black slate containing dolomitic arenites, quartzites and locally limestones. The recognition of a second Cambrian black/green boundary and documentation of the Middle Granville Slate has alleviated much of the confusion created by Zen's stratigraphy.

In the Ganson Hill study area, the Bomoseen Formation is predominantly a silty and shaly graywacke with some interbedded thin quartzites and slates. It is correlative with Dale's (1899) Olive Grit (Unit A). It was formally named by Ruedemann (in Cushing and Ruedemann, 1914) as the Bomoseen Grit, a name used by many subsequent workers (Larrabee,1939; Kaiser,1945; Fowler,1950). Doll et. al. (1961) called the olive drab graywacke the Bomoseen Graywacke Member of the St. Catherine Formation. Zen (1961) introduced it as a member of the Bull Formation. The Bomoseen is given the rank of formation, in the study area, and it includes the Zion Hill quartzite and graywacke as a member. The Zion Hill Quartzite named by Ruedemann (in Cushing andRuedemann, 1914) is equivalent to Zen's Zion Hill Quartzite. It is the Barker Quartzite of Swinnerton (1922) and Keith (1932). The "ferruginous quartzite" of Dale (1899) which others have equated to the Zion Hill are similar to Hatch Hill lithologies and occur higher up in the stratigraphy.

Conformably overlying theBomoseen Formation is a unit of predominantly soft, green, silty slate with interbedded thin, massive, green quartzites comprising a small fraction of the formation. In the Ganson Hill study area, where these slates are conformably overlying Bomoseen lithologies and beneath Browns Pond lithologies, the unit is called the Truthville Slate, following Jacobi (1977); and designated a lithofacies of the Undifferentiated Bull Formation. Where the green slates are not confined between underlying Bomoseen andoverlying Browns Pond lithologies the unit is called the Undifferentiated Bull Formation. The unit is correlative with part of Dale's (1899) Cambrian Roofing Slate (Unit B) and Berkshire Schist (Unit 5b,in part). Ruedemann (in Cushing and Ruedemann, 1914) included it within the Mettawee Slate Formation. Many previous workers have retained the name Mettawee Slate but included portions of the overlying unit within theformation. Zen (1961) included these rocks in a unit he named the Bull Formation. The Truthville Slate lithofacies is lithologically the same as part of Zen's (1961) Mettawee Slate Facies of the Bull Formation. Lithologies included in the Undifferentiated Bull Formation, in the study area, are correlative with part of Potter's (1972) Mettawee Slate of the Nassau Formation. In the Ganson Hill study area, included as a member of this unit is the Mudd Pond Quartzite, a clean, massive, vitreous quartzite. Zen's(1961) Mudd Pond Quartzite member of the Bull Formation included a calcareous quartz wacke because of their close association. A similar calcareous quartz wacke is found interbedded with black and dark gray slate, in the study area, and is therefore included in the overlying Browns Pond Formation. The stratigraphic contact between the Truthville Slate and the overlying Browns Pond marks the lowest Cambrian black/green boundary.

The overlying Browns Pond Formation consists of several lithologies, all in a predominantly black slate matrix. Other lithologies include limestones, micrites, calc-arenites and silty, calcareous, clast-containing wackes. The unit is similar to Jacobi's (1977) Browns Pond Formation and is at the same stratigraphic level. Zen (1961) included this assemblage of lithologies within his West Castleton Formation. In the Ganson Hill study area, the Beebe Limestone is a member of the Browns Pond Formation. Zen (1961) included it as a member of his West Castleton Formation. Keith (1932) gives it the rank of formation and places it above the Bull Slate Formation and below the Hooker Slate Formation.

Conformably overlying the Browns Pond Formation is a unit of green, purple, maroon and lesser gray slate named the Middle Granville Slate Formation (new-Kidd, Delano and Rowley; in Fisher, 1984). It is correlative, in part, with Dale's (1899) Cambrian Roofing Slate, Ruedemann's (in Cushing and Ruedemann, 1914) Mettawee Slate, Keith's (1932) Bull Slate, the Mettawee Slate Facies of the Bull Formation of Zen (1961), theMettawee Slate of the Nassau Formation of Fisher (1970) and possibly the Mettawee-C Member of Potter (1972). Its upper contact with the Hatch Hill Formation marks the second Cambrian black/green boundary.

The overlying Hatch Hill Formation consists of alternating beds of black slate and dolomitic quartz-arenites and quartzites. It was first named by Theokritoff (1959). Elsewhere it has been divided into three members, where the base of the formation also contains limestone and dolostone (West Castleton Member of the Hatch Hill Formation) and the top of the formation contains ribbon limestones and limestone conglomerates (White Creek Member of the Hatch Hill Formation) but; in the Ganson Hill study area, these carbonate lithologies are not exposed. The Hatch Hill Formation is correlative with parts of Dale's (1899) Cambrian Black Slate, some of the Ferruginous Quartzite and Sandstone and the Calciferous; Keith's (1932) Hooker Slate Formation, partially the West Castleton and units 1,3,5 and 6 of the Mount Hamilton Group of Zen (1961) and the West Castleton, Hatch Hill and member A of the Poultney Formation of Theokritoff (1964).

The uppermost unit exposed in the study area is the Poultney Formation, which conformably overlies the Hatch Hill Formation. It is the only unit of Ordovician age exposed in the study area. The Poultney Formation consists of green-gray color-laminated slates inter bedded with thin white, quartz siltstones and quartz arenites. The Poultney Formation was first named by Keith (1932). It is correlative with Dale's (1899) Hudson White Beds and Hudson Thin Quartzites, units 1 through 3 of Zen's (1961) Mount Hamilton Group and members B and C of Theokritoff (1964).

2.2 Lithologic and Petrographic Descriptions

Cambrian

Bomoseen Formation

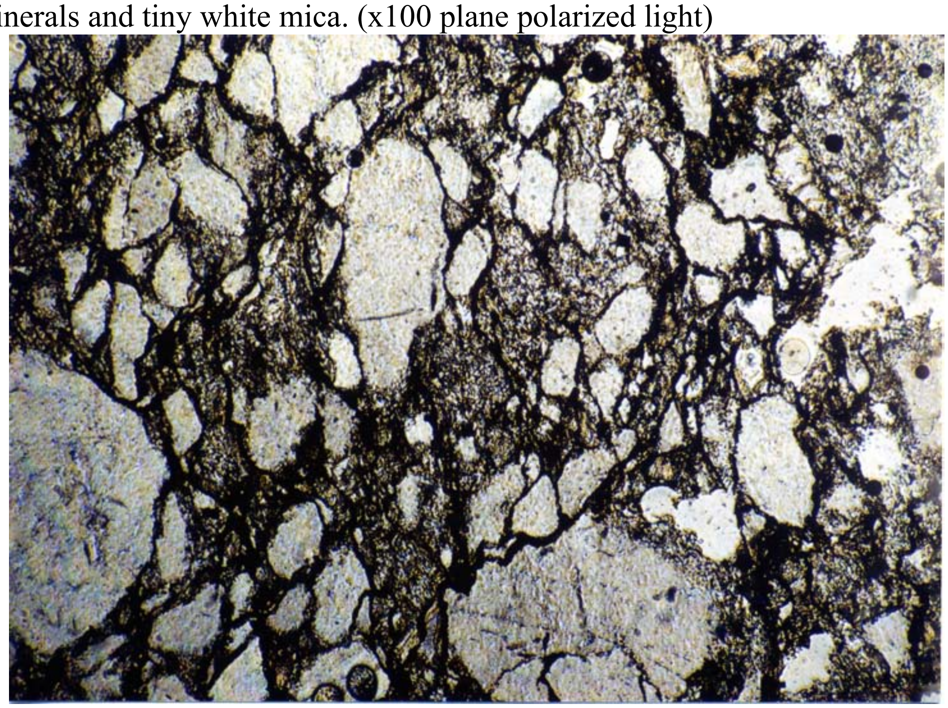
The Bomoseen Formation was first named by Cushing and Ruedemann (1914) as the Bomoseen Grit, following Dale (1899) who described it well but did not name it formally. Its original description is that of a graywacke, hard and poorly-cleaved, olive green and gray on a fresh surface where white mica flakes can typically be seen. Its type locality is on the western shore of Lake Bomoseen near Hydeville, Vermont. In the study area, it can best be seen just north of the stream which roughly parallels Ganson Hill Road (see map).

In the study area, the Bomoseen Formation is predominantly a silty and shaly graywacke, but thin quartzites and slates make up approximately 5% of the formation. The graywacke varies from silty, hard, massive and poorly-cleaved in the easternmost exposures of the map area, near Brandon Mountain Road, to somewhat more shaly and moderately cleaved north of Ganson Hill Road, east-southeast of Echo Lake (see map). Thin beds of slate occur where the more shaly wacke is prominent. Thin, massive beds of silty, green quartzite are interbedded with the graywacke but are widely spaced and discontinuous. The Bomoseen graywacke weathers a light tan to pale orange color and is olive green and gray on a fresh surface. Usually, specks of white mica can be seen in a hand sample. The Formation measures approximately 183 meters thick, but since the base of the formation is not exposed in the study area, a greater thickness is likely. Delano (1977) reports a thickness of 240+ meters in the Granville, New York area. Figure 7 shows a typical outcrop exposure of poorly-cleaved, massive, light-weathering Bomoseen graywacke.

Compositionally, the rock is a quartz wacke (see Figure 8). Poorly sorted subangular clastic quartz grains make up the greatest portion of the rock, with accessory plagioclase, zircon, chlorite and clay minerals and white mica which have a very weak preferred orientation. The interbedded quartzites are fairly clean, light gray and green on a fresh surface, show little or no cleavage and are cut by quartz filled veins. The slates are greenish gray and tend to be more prominent near the top of the formation making the upper contact with the Truthville slates somewhat gradational locally, although generally the contact is marked by a change in lithology, color and cleavage development.

Figure 7
Poorly cleaved, massive, light-weathering Bomoseen graywacke outcrop located on Brandon Mountain Road.

Figure 8
Photomicrograph of Bomoseen graywacke. Subangular, poorly sorted quartz grains constitute the greatest portion of the rock, with accessory plagioclase, zircon, chlorite, clay minerals and tiny white mica. (x100 plane polarized light)



Zion Hill Member of the Bomoseen Formation

The Zion Hill named by Ruedemann (in Cushing and Ruedemann, 1914) corresponds to Dale's (1899) "ferruginous quartzite", however, Dale (1899) reports massive quartzite beds which occur between black slates of Cambrian age and black slates of Ordovician age, in the southern and central parts of the Taconics. These quartzites are not in the correct stratigraphic position to be reported as Zion Hill and are compositionally distinct from the Zion Hill quartzite of the Bomoseen Formation. What Dale described as Zion Hill quartzite and blue calcareous sandstone is correlative with Hatch Hill lithologies. The author follows the usage of Zen (1961) for the Zion Hill quartzite. It is the Barker quartzite of Swinnerton (1922) and Keith(1932).

In the study area, the Zion Hill is a coarse-grained quartzite ranging locally to a pebbly-conglomeratic subgraywacke. It is a discontinuous, lensing unit and so mapping identical rocks on either side of it separately is not feasible. It is found near the base of the formation and locally surrounded entirely by green slate designated as Undifferentiated Bull. It is very hard and massive, pale gray to white on a weathered surface, medium gray and vitreous on a clean surface with a dusting of limonite stain. The grain size varies from medium sand to coarse grit and is locally pebbly. Graded bedding, locally developed, provided younging directions.

In the southern portion of the map area, north of Giddings Brook, the Zion Hill forms prominent, discontinous, north-northwest trending ridges surrounded by monotonous green and greenish gray slate of the Undifferentiated Bull Formation. East of Echo Lake, south-dipping Zion Hill quartzite outcrops near the contact of Bomoseen graywackes and Undifferentiated Bull green slates. A small ridge of Zion Hill quartzite traverses Brandon Mountain Road east of Mudd Pond. It is medium-grained, hard and massive and lies within silty graywackes of the Bomoseen Formation. These may have been mistaken as Mudd Pond quartzite by Zen. Exposures of Mudd Pond quartzite outcrop further south along Brandon Mountain Road.

Undifferentiated Bull Formation

The Bull Formation was first proposed by Swinnerton (1922) for all green and purple slate overlying the Barker quartzite. It is correlative, in part, with Dale's (1899) Cambrian Roofing Slate. The Bull Formation of Zen (1961) includes all the units which occur between the Biddie Knob Formation and the West Castleton Formation. Zen (1961) includes the Mudd Pond quartzite, the Zion Hill quartzite and graywacke, and the Bomoseen graywacke as members of the Bull Formation. In the study area, the Bull Formation includes green and purple slate which outcrops extensively and monotonously in the southern portion of the map area and south of the Keeler Pond Thrust of Zen (1961) in the central portion of the map area (see map). Figures 9 and 10 show the green and purple varities of this formation.

Figure 9
Roadcut exposure on Monument Hill Road, just off Route 30, of Undifferentiated Bull Formation.

Figure 10
Roadcut exposure on Monument Hill Road, near Giddings Brook, of Undifferentiated Bull Formation. Purple and green laminated slate showing well developed slaty cleavage and color lamination parallel with bedding.

Truthville Slate Lithofacies of the Undifferentiated Bull Formation.

The Truthville was first named by Jacobi (1977) for rocks that many previous workers included within the Mettawee Slate. Its type locality is along the Mettawee River near Truthville, New York. It can best be seen in the study area in a roadcut on Route 30 directly east of Beebe Pond.

The Truthville is predominantly a soft, silty slate with lesser quartzites. The quartzites make up a small fraction of the entire formation, perhaps 3%; and are concentrated near the base of the formation. The slates are pale gray and greenish gray on a fresh surface and weather to a light gray, tan or buff color. The slates are fissile and well-cleaved. In hand sample, a granular surface produced by silt-sized particles and white mica specks can be seen. The presence of mica specks and the silty appearence and feel are distinguishing characteristics of the Truthville slate. Rarely, color laminations are evident in weathered outcrops. The laminations are dark green in color and where the relationship can be seen are parallel with bedding. A cut and polished surface shows color laminations to be prominent within the slate, consisting of light gray and dark gray laminations .1cm to .5cm thick, produced by the alternation of quartz-rich and clay-rich laminations. Within an individual clay-rich (dark) layer, a weakly developed non-penetrative foliation can be seen, which is truncated by quartz-rich layers above and below. This is a feature produced by deforming a compositionally-laminated rock so that the foliation only develops in the clay-rich layers (see Figure 11).

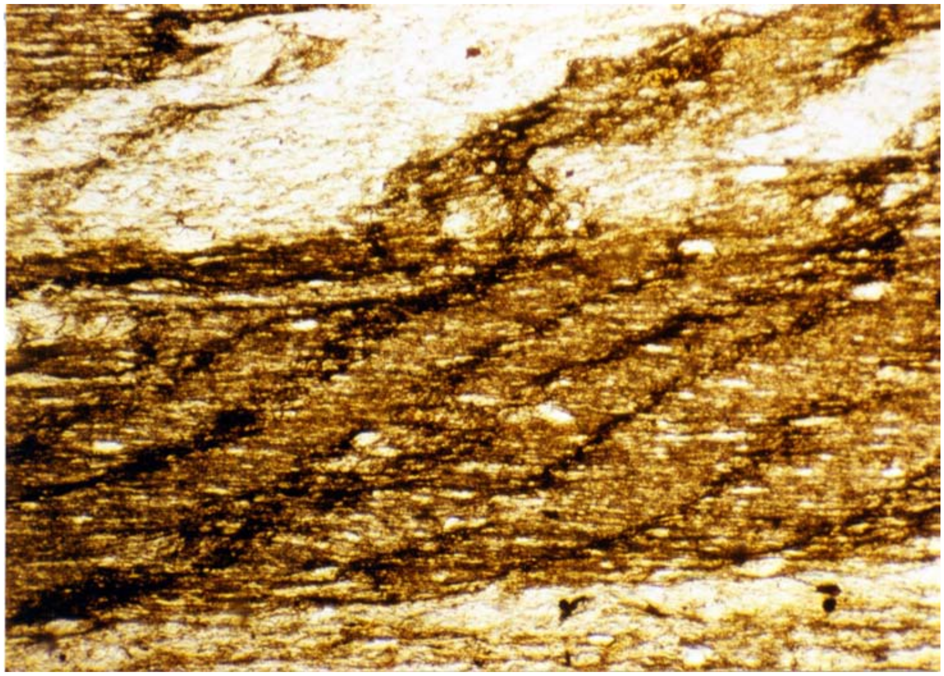


Figure 11
Photomicrograph of the Truthville slate. Individual clay-rich layers exhibit a weakly-developed, non-penetrative foliation which is truncated by the quartz-rich layers above and below. (x40 plane polarized light)

The quartzites are generally thin, ranging from 1cm up to 4cm thick. They are bright green and vitreous on a fresh surface and weather dusty-gray. They are fine to medium grained and recrystallized. They are the only good bedding indicators and are poorly-cleaved.

The measured thickness of the Truthville slate is approximately 165 meters. This measurement was obtained where both the lower contact with the Bomoseen and the upper contact with the Browns Pond is evident. This thickness appears to be maintained where constrained by stratigraphic contacts above and below. The thickness of the Bull Formation could not be obtained, but Zen (1961) reports up to 2000ft. thickness'.

The Truthville slate, as a whole, is fairly resistant forming small cliff outcrops and good roadcut exposures. The lower contact is placed at the top of the last graywacke beds of the Bomoseen Formation and is marked by a change in color, lithology, and cleavage development. The upper contact is placed at the first appearance of dark gray to black slate.

Mudd Pond Quartzite Member of the Undifferentiated Bull Formation.

The Mudd Pond Quartzite is exposed in the map area. It occurs as a member of the Undifferentiated Bull Formation but the lithology is not contained exclusively within this Formation. The Mudd Pond Quartzite is a hard, massive unit which forms small, discontinuous, rounded ridges exposing layers 1 to 3 meters thick (see Figure 12). The rock is vitreous on a fresh surface and the grain size varies from sand to silt. The weathered surface is white to whitish-gray and outcrops are usually cut by numerous, randomly-orientated white quartz veins (see Figure 13). A good exposure of this lithology in the Truthville slate lithofacies of the Undifferentiated Bull Formation can be seen in a roadcut on Rouse 30, east of Beebe Pond.

At one locality, near where the stream which cuts Ganson Hill crosses Ganson Hill Road (see map), graded bedding was observed and samples were taken from the coarsest and finest grained parts of the outcrop for petrographic study. The following observations were made: compositionally, the quartzite does not vary much from fine to coarse grained. Both samples are composed of 99% quartz with 1% accessory minerals, such as plagioclase feldspar, white mica, zircon and opaques. Both samples showed a bimodal distribution of grain size. In the coarser-grained sample, sorting was moderate in the larger-sized mode and well-sorted in the smaller-sized mode, whereas both modes were very well-sorted in the finer-grained sample. The coarser-grained sample shows rounded grains with prismatic to equidimensional sphericity, whereas the finer-grained sample shows subangular grains with the same prismatic sphericity. Both samp

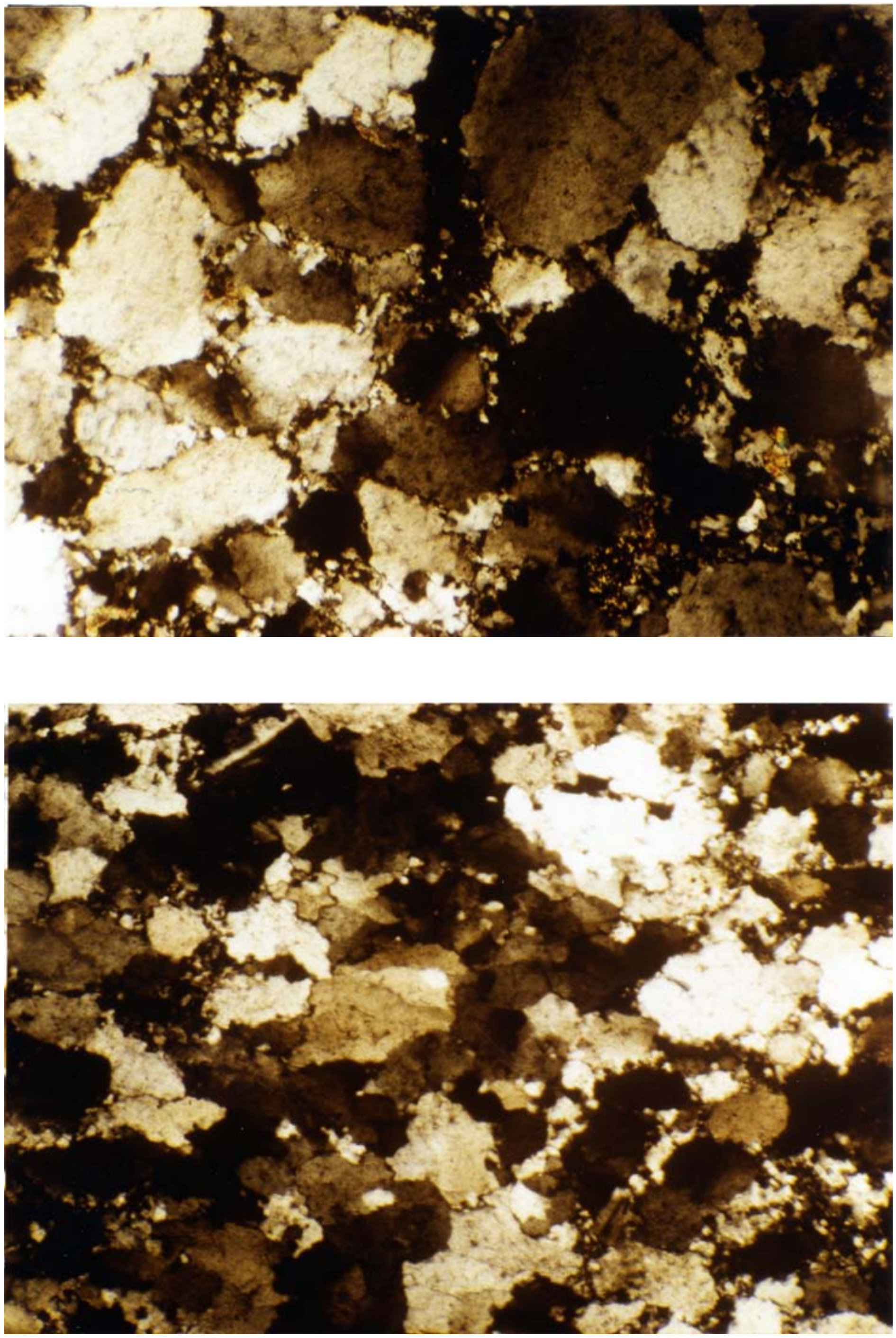
Figure 12
Mudd Pond Quartzite. Outcrops occur as hard, massive, rounded ridges which are discontinuous and lensing. Outcrop crosses Ganson Hill Raod near its west end.

Figure 13
Mudd Pond Quartzite. Fresh surfaces and roadcuts show extensive quartz veining. Roadcut is located on Route 30, just east of Beebe Pond.

show an abundance of strained quartz with undulatose extinction and fractured quartz grains. Subgrain boundaries are evident and the subgrains are often strain-free and form the matrix. The boundaries between the larger clastic grains are sutured and only in the finer-grained sample can a weak preferred orientation of grains be seen (see Figure 14).

The Mudd Pond Quartzite appears at several horizons within the Undifferentiated Bull Formation. It is well-developed within the Truthville slate along Ganson Hill Road just opposite Beebe Pond, and forms a small ridge which cuts Brandon Mountain Road, east of Mudd Pond (see map). It is less prominent and appears only as large boulders in the Undifferentiated Bull Formation along Giddings Brook. The Mudd Pond Quartzite occurs within a black slate unit as well, designated The Browns Pond Formation (see following section).

Figure 14
Photomicrographs of the Mudd Pond Quartzite. Thin sections were made from a single outcrop where graded bedding was preserved. (x40 crossed Nicols)



Browns Pond Formation

The Browns Pond Formation was first named by Jacobi (1977) as a group of several lithologies all in a predominantly black slate matrix. In the Ganson Hill study area, Zen (1961) mapped these rocks as the West Castleton Formation and placed them stratigraphically above a green slate unit which he called the Mettawee slate facies.

Its type locality is near Browns Pond along Holcombville Road at the Granville- Thorn Hill 7 1/2" map quadrangle boundary. In the study area, it can best be seen on Route 30, just south of Beebe Pond in the Hubbardton Gulf.

The Browns Pond Formation consists of several lithologies all in a predominantly black slate matrix. The Browns Pond slates are very dark gray to charcoal black and vary from fissile, pyritic and closely cleaved to cherty, moderately cleaved and whitish-red on a weathered surface (see Figure 15 and 16). The charcoal black, fissile, pyritic variety is more common in the study area, and outcrops are often poorly exposed and crumbly.

Subordinate lithologies include minor occurrences of the Mudd Pond Quartzite, as well as, limestones, micrites, calcarenites and silty graywackes containing slate clasts and large quartz grains. The subordinate lithologies of the Browns Pond Formation constitute approximately 10% of the Formation and are concentrated in the lower half of the Formation. The limestones and micrites are black on a fresh surface and weather to a light, pale gray which stands out against the charcoal black slate.

The type locality of the Beebe Limestone is contained in the study area, just southeast of Beebe Pond on Route 30 (see map). The Beebe Limestone is a black, massive, poorly-cleaved, thickly-

Figure 15
Whitish-weathering Browns Pond slate interbedded with finely laminated limestone. Roadcut exposure on Route 30, near the Hubbardtown Gulf.

Figure 16
A small channel fill in an interbedded calc-arenite bed. The slates are well cleaved and weather to a light color. Roadcut exposure in the Hubbardtown Gulf.

bedded (30cm) limestone cut by abundant calcite veins in random orientation. It is found near the base of the formation and is well developed only in the western portion of the map area in the vicinity of the Hubbardton Gulf. Swinnerton (1922) reports Early Cambrian fossils from the Beebe Limestone found in West Castleton, Vermont, however; no fossils were found in the Beebe Limestone in the study area.

Other interbedded limestones and micrites vary in thickness from very thin (1-3cm) beds to thicker (10cm) beds. Locally, fine laminations can be seen in the thicker limestone beds. Rarely, thin beds of calc-arenite and silty-wacke containing clasts of slate and large quartz grains are observed. The silty, clast-containing wacke may be correlative with Dale's (1899) Black Patch Grit, which is Fowler's (1950) Eddy Hill Grit. Although minimally exposed in the map area, these lithologies can easily be observed at two localities. On Ganson Hill Road, roughly where the 900 foot contour crosses it, and due east of Beebe Pond near the Truthville-Browns Pond formation boundary.

The Browns Pond Formation measures approximately 55 meters thick. It is better developed on the northern and western slopes of Ganson Hill than it is east of Ganson Hill. The lower contact of the formation is placed at the first appearence of dark gray and black slate. In general, distinguishing it from the underlying slates is not difficult. The upper contact is difficult to find, in the field, where the overlying Middle Granville slate is of the medium gray variety. A limestone breccia reported to occur elsewhere at the top of the formation is not found here. The upper contact is marked by a change in color from dark gray and black slate to green slate.

Petrographic analysis of the Browns Pond lithologies show carbonate material to be ubiquitous throughout the unit. The silty-wacke lithology is composed of clastic and matrix material of roughly equal proportions (see Figure 17). The clastic grains are 95% quartz and 5% plagioclase feldspar. They show a wide range in grain size and are poorly to moderately sorted. They are sub-angular to subrounded and prismatic to equidimensional, and mostly supported by matrix material. The matrix is composed of carbonate and clay minerals, quartz, mica and opaques. A weak preferred orientation of the matrix minerals gives a very weak foliation to this lithology.

The carbonate lithologies of the Browns Pond Formation are texturally sparites and calcilutites. Clastic carbonate grains are rare, most show recrystallized rhombs or good crystal cleavage. Minor accessory clastic minerals include quartz, micas, and opaques. The carbonate bearing quartz-arenites have carbonate minerals confined to the small porportion of matrix material.

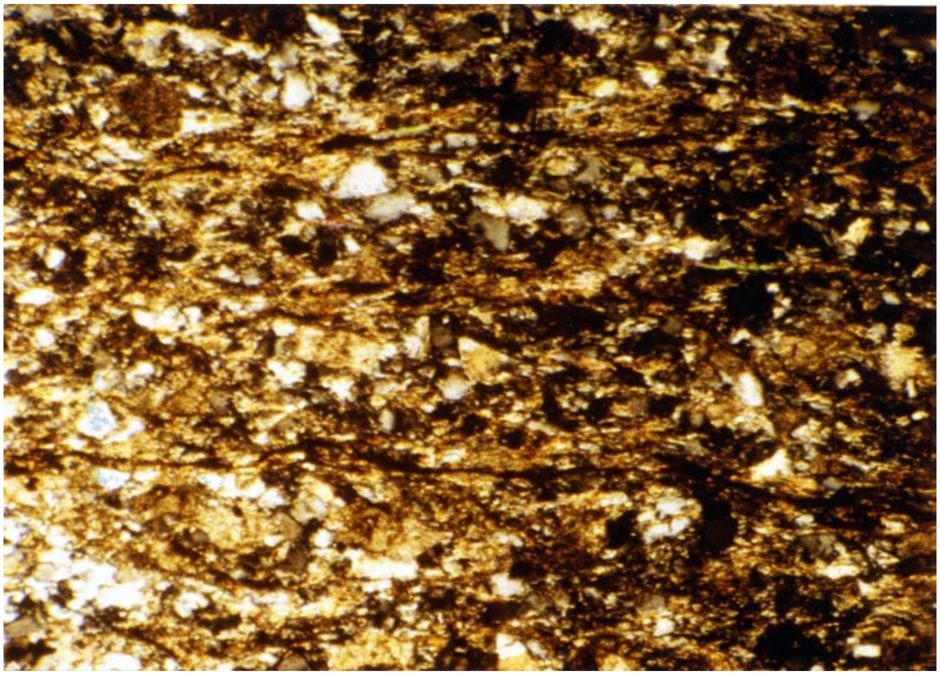


Figure 17
Photomicrograph of a carbonate-rich, silty wacke of the Browns Pond Formation (x10 crossed Nicols).

Middle Granville Slate Formation

The Middle Granville Slate Formation was first named by Kidd, et.al. (in Fisher, 1984). The name was proposed for green, purple, maroon and lesser gray slate that lies above dark gray and black slate containing limestone, and lesser quartz-wackes, and below sooty, black slate containing common domolitic arenites, quartzites and locally, limestones. Its type locality is a series of quarries and adjacent outcrops 300 to 1500 meters north-northwest of the bridge over the Mettawee River at Middle Granville, New York. In the study area, it can best be seen on the north and northwestern slopes of Ganson Hill.

In the Ganson Hill area, the Middle Granville Slate Formation is composed of green and purple slate with lesser ribbon limestones near the base of the Formation. The ribbon limestones make up $\simeq$ 5% of the Formation. The slates are well cleaved, non-fissile and weather to a light gray or tan color. The widely spaced, thin (.5-1 cm) limestones are the only good indicators of bedding. The formation is rather thin, in the study area, measuring 40 meters thick and is poorly exposed. In places, it was mapped by the occurrence of green slate rubble in a position stratigraphically above black and gray Browns Pond slate and below black Hatch Hill slate.

Many previous workers have confused the dark slates and limestones above and below this unit. As a result, this unit has been included in two different formations. By defining and formally naming this unit, the confusion is overcome.

Hatch Hill Formation

The Hatch Hill Formation was first named by Theokritoff (1959), as sooty, black, pyritic, rusty-weathering shales interbedded with rotten-weathering bluish dolomitic sandstones. Its type locality is on the south side of Hatch Hill in the Thorn Hill quadrangle. It can best be seen, in the study area, by traversing due east of Beebe Pond to the 1000 foot contour on Ganson Hill.

The Hatch Hill consists of alternating beds of slate and dolomitic quartzites and quartz arenites. The slates are dark, charcoal gray and black, fissile, well cleaved with an orange rusty-weathering surface on cleavage planes (see Figure 18). The dolomi quartzites and quartz arenites are characterized by their orange rusty-weathering color and numerous quartz veins which traverse the quartz-rich beds. The vein material is bright white in color and stands out against the rusty-weathering color of the bed. The veins vary in width from .5cm to 3cm and locally show a sense of shear or small scale displacements parallel with the bedding planes (see Figure 19a and b).

Slaty cleavage is well developed in the slates and nonexistent in the quartz-rich beds. The dolomitic quartzites and quartz arenites are medium to dark gray on a fresh surface, medium to coarse grained and vary in thickness from thin (1-5cm) to thick (40cm), but thinner beds are more common in the map area. Very fine parallel laminations are present, in places, in the quartz-rich beds. The laminations are defined by a concentration of clay minerals and opaques. Color laminations are common, in the slates, the laminations consisting of alternating bands of dark

Figure 18
Hatch Hill Formation. Interbedded black slate and rusty-weathering dolomitic quartzites and quartz arenites. Outcrop on the western slopes of Ganson Hill.

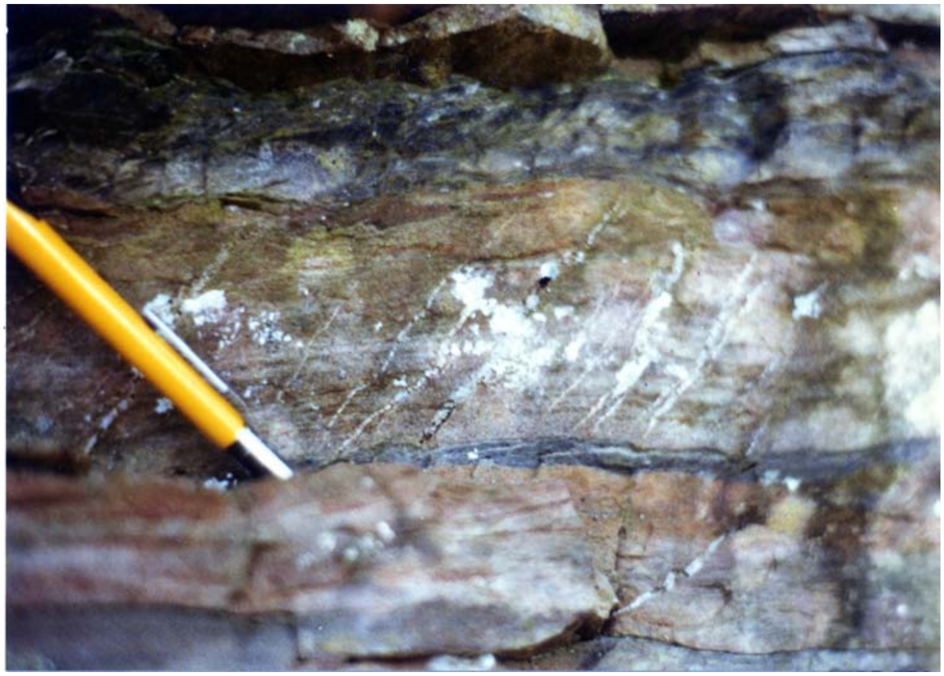


Figure 19a
Interbedded quartz-rich beds and slate of the Hatch Hill Formation. Rusty-weathering beds are cut by numerous quartz veins which show locally a sense of shear. Outcrop on the western slopes of Ganson Hill.

Figure 19b
More massive veins show small scale displacement parallel with the bedding planes. Outcrop located on the northwestern slopes of Ganson Hill.

gray and medium greenish-gray.

The formation thickness is approximately 125 meters. The alternating nature of the slates and the quartz-rich beds is maintained throughout the formation. The Hatch Hill is well exposed in the field area forming large, steep cliff outcrops. It is well developed on the eastern, northern, and western slopes of Ganson Hill.

This formation is easily recognizable, in the field, since even in small outcrops rusty dolomitic quartz-rich beds stand out. The lower contact of the Hatch Hill Formation is marked by the change in color from green and purple slate to black slate; however, this contact is not well exposed in the map area. Previous workers have suggested the presence of a disconformity between the Hatch Hill Formation and the underlying unit based on paleontological evidence (Dale,1899; Berry,1962; Theokritoff, 1964), however; the Hatch Hill-Middle Granville Slate contact in the map area seems to be a conformable contact as structural discordance of bedding attitudes is not apparent. It is likely, as in other areas of the Taconics, that the paleontological evidence is missing. The upper contact of the Hatch Hill Formation is marked by a change in color of slate and loss of fissility and disappearance of dolomitic quartzites and thick quartz arenites.

Petrographically, The Hatch Hill dolomitic quartzites and quartz arenites are simple. The quartzites are fairly pure with a mineral composition of about 90% quartz and the remainder, heavy minerals, which concentrate to form thin lamellae; and a small percentage of carbonate and clay matrix material. Texturally, they show good sorting, well-rounded grains with high sphericity.

The quartz arenites have a slightly greater amount of matrix material composed of predominantly carbonate minerals with accessory opaques, mica and clay. The percentage of matrix is 30%. The clastic grains are mostly matrix supported. The clastic quartz grains are moderately to well-sorted, well-rounded and show moderate sphericity.

Ordovician

Poultney Formation

The Poultney Formation was first named by Keith (1932) as a gray slate which becomes lighter, even white, on exposure. The type locality of the Poultney Formation is along the Poultney River west of Poultney, Vermont. It can best be seen in the map area on the top of Ganson Hill at Eagle Rock.

Jacobi (1977) divided the Poultney Formation into two members. The lower member, called the Dunbar Member, is a thin lenticular unit of fissile, dark gray to black slate with thin, interbedded silty limestone and micrite beds. The upper, Crossroad Member, is described as a variably colored slate which characteristically weathers chalky white, interbedded with clean, white, thin quartzites, quartz arenites and much less common, thicker, coarse-grained quartz arenite beds. In the Ganson Hill area, the distinction of two members is not possible. At one locality on the northwest side of Ganson Hill, rocks were found which fit the Dunbar Member description. The outcrop consists of dark and medium gray color-laminated fissile, well-cleaved slate with a single bed $\approx$20cm thick of hard, light-yellow weathering siliceous micrite. This bed weathers back in relief and can not be traced laterally, even on the scale of the outcrop. It is not known if poor exposure is a function of the limited outcrop of a lenticular unit or a facies change.

Nearly the entirety of the Poultney Formation, in the map area, fits the description of the Crossroad Member. The slates vary in color from green, medium to dark gray, greenish-gray, and black. They are moderately to well-cleaved and nonfissile. Color laminations of alternating dark gray or black bands and greenish-gray bands are common. The slates weather a distintive color which varies from a pale orange, pinkish-white to a chalky white. Interbedded with the slates are very thin (1mm-5cm) white, quartz siltstones or quartz arenites (see Figure 20). A few thic (up to 50cm) quartz arenite beds are present, but rare. The quartz-rich beds show parallel laminations, some show small-scale cross lamination, sedimentary sandy dikes and slump structures. The silty quartzites and quartz arenites constitute 10-20% of the formation.

Petrographic analysis shows the quartz-rich layers to be extremely well sorted, grain size ranging from 3-6 Ø. Compositionally, quartz dominates but minor quantities of feldspar, clay and carbonate matrix and heavy minerals including zircon and opaques are also found.

In this study area, the base of the Poultney Formation is marked by a change in color and fissility in slate. The upper contact is not preserved in the map area. The measured thickness of the Poultney Formation is 183 meters, a thickness comparable with thicknesses obtained for the Poultney from throughout the allochthon where the formation is bounded by the overlying Indian River Formation. Close to the full thickness may therefore be preserved in the Ganson Hill area.

The Poultney Formation throughout the length of the Taconic Allochthon is discussed in detail in the next chapter (Chapter 3). The distinctive sedimentary characteristics of the Poultney are interpreted as having been produced by transport in and deposition from deep, contour-following bottom currents.

Figure 20
Interbedded dark grey slate and thin quartz siltstones of the Poultney Formation.
Outcrop located near the top of Ganson Hill.

2.3 Primary Sedimentary Features

Bedding

Since the greatest portion of Taconic lithologies is essentially fine-grained slate, the recognition of primary bedding is difficult, if not impossible, in many places. In the Ganson Hill area, the difficulty of the task of identifying bedding varies from unit to unit. Outcrops consisting only of slate mostly gave no good bedding indicators. Where slate is interbedded with massive quartzites, quartz arenites or limestones; the distinction of bedding is clear.

Many of the slatesexhibit a fine compositional layering which, when examined under the microscope, is producded by alternating clay and silt-rich layers. Fine alternating lamellae produce the compositional layering. In the Taconic slates, where true bedding is often cryptic, at best, one is often tempted to accept the compositional layering as true bedding or a feature parallel with true bedding. Zen (1961) states that in intensely metamorphosed rocks, what appears as compositional layering may be a metamorphic differentiation which has no semblance of bedding; but that in the slate belt of the Taconics this danger is slight. The author, however, has noted enough, although few, examples of nonparallel bedding and compositional layering to hesitate to use the layering, when seen alone, as representative of true bedding. Figure 21 shows unquestionable bedding in the slates and quartz arenites of the Hatch Hill Formation. With the exception of a few notable members (Mudd Pond Quartzite, Zion Hill Quartzite) the lithologies which display bedding, e.g. quartzites, limestones, arenites, graywackes

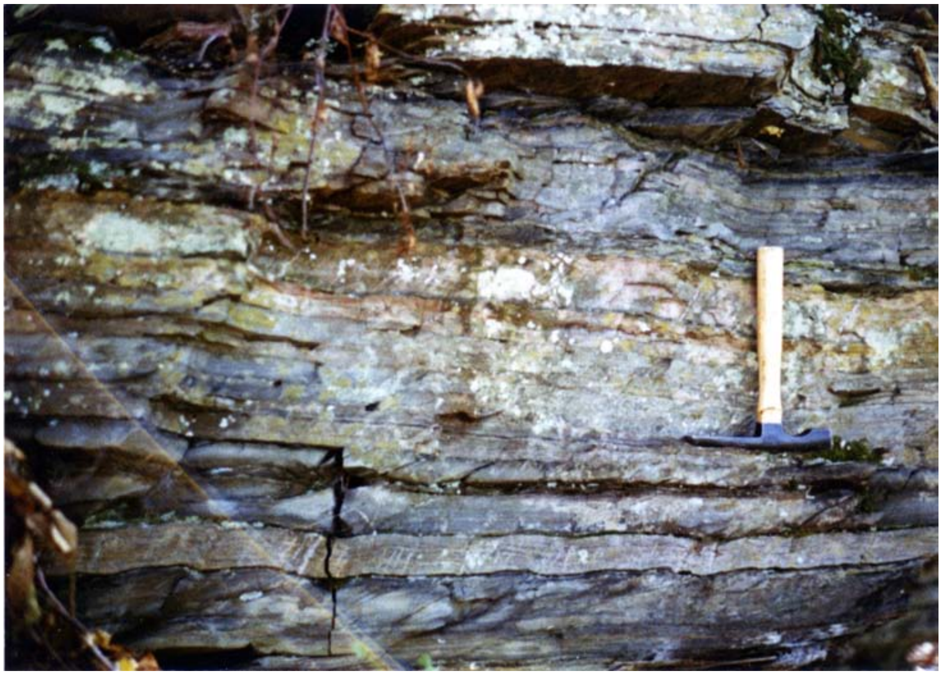


Figure 21
Bedding in the Hatch Hill Formation. Outcrop located on the western slopes of Ganson Hill.

constitute only a small portion of the entire stratigraphic sequence. This coupled with the general lack of good outcrop made the structural interpretation difficult in the Ganson Hill study area.

Laminations

The laminations discussed in this section will not include the color laminations found in the slate lithologies already cited in the previous section. Within the quartz arenites of the Hatch Hill and the quartzites of the Poultney, fine parallel laminations are evident in some beds (see Figure 30). Whe present, the laminations are defined by a concentration of heavy minerals and opaques. Although on a microscopic scale the parallel laminations suggest a weakly developed foliation, in outcrop, the host lithologies are generally massive with no apparent foliation. The slaty cleavage, often well developed in the slate lithologies, is, in places, deflected by the massive, parallel laminated beds.

Cross laminations where found in the clastic beds of the Poultney Formation, serve as younging direction indicators as well as indicators of current transport direction (see Chapter 3). However, data obtained for the Poultney study was collected from numerous localities outside the Ganson Hill area (see Figure 32). Within the study area, the clastic beds of the Poultney did not exhibit well defined cross laminations because the clean, extensive outcrop necessary for these observations is not present.

Slump Structures and Soft Sediment Deformation

Slump structures and evidence of soft sediment deformation are observed on both the microscopic and outcrop scale. This is depicted in Figure 22, in a hand sample of the Poultney Formation. Discontinuous sandy beds appear to be folded and stretched. In the photomicrograph, what appears to be a pinstriping in the darker, clay-rich layers may be the weak development of a cleavage in the soft sediment; it does not produce any structures of significance (see Figure 23).

Figure 22
Folding in the Poultney Formation. (see text above for description).

Burrows

Burrowing is evident in some of the mudrocks, and appears as dark grey dots and smears on the bedding surfaces (see Figure 24) of green slates, particularly in the green variety of Poultney slate.

Figure 23
Photomicrograph of the Poultney Formation. (see text on p60 for description).

Figure 24
Hand sample of the Poultney Formation showing burrow marks on a bedding surface.

2.4 Depositional Mechanisms

Stratigraphic and sedimentologic observations of the lithologies in the Ganson Hill study area, support the established view that the Taconic sequence was deposited in a continental rise environment (Bird and Dewey, 1970). Modern continental rises reveive thick wedge-shaped accumulations of sediment by hemipelagic sedimentation alone, but other depositional mechanisms, such as, debris flows, turbidite flows and related submarine canyon overbank deposits, and contour-following bottom currents influence the sedimentological characteristics of the continental rise. Slates in the Ganson Hill area have not retained diagnostic sedimentary structures. However, the small proportion of less deformed subordinate lithologies interbedded with the slates give evidence for a variety of depositional mechanisms.

Formations containing conglomeratic facies or beds consisting of clasts supported by a silty or mudstone matrix are inferred to be the products of debris flows. The Zion Hill varies from a coarse grained quartzite to a pebbly-conglomeratic subgraywacke. With the exception of only local graded bedding, the Zion Hill shows no internal structures indicative of turbidity current flow. The coarseness of grain size and pebbly clasts suggest a source area relatively nearby. The Zion Hill is locally discontinuous, but has regional lateral extent. The proposed depositional mechanism for such a conglomeratic facies is that of a debris flow. Debris flows can be deposited as sheets or confined to channels of a submarine canyon or fan, the latter often associated with turbidites (Keith and Friedman, 1977). Debris flows deposited as sheets will reflect irregularities in the depositional basin which may therefore, explain the local lensing and discontinuous nature of the deposit.

Within the Browns Pond Formation, a distinctive silty graywacke containing clasts of slate and large quartz grains, is exposed in the field area, and is correlative with lithologies noted by Dale (1899) as the Black Patch Grit and Fowler (1950) as the Eddy Hill Grit. The lithology is inferred to be quite local in origin, with slate clasts similar to the interbedded slate lithologies from which they were derived. An orderly sequence of structures, such as, grading, stratification and lamination is not observed and therefore, a turbidity current is ruled out as the mechanism of deposition. The recognition of a debris flow model for many lithologies having a lack of organized internal structures has become well established (Dott, 1963; Johnson, 1970; Cook et.al., 1972; Hampton, 1972; Middleton and Hampton, 1973; Walker, 1975, 1976).

To a greater degree, the Browns Pond slates are interbedded with locally laminated limestones and thin, structureless micrites. In thin section, the micrites are texturally simple, showing only a recrystallization of the original lime mud. Lime mud is produced only in shallow water environments, but currents can move the lime mud into deeper water where it settles out of suspension. However, hemipelagic deposition is commonly associated with terrigenous sediments transported by turbidity currents dilute in nature once they reach the continental rise. The association of thin micrites and laminated limestones in a predominantly black slate matrix of the Browns

Pond, suggests depositional mechanisms operating in unison, that of hemipelagic deposition on the continental rise of clay and lime mud originally held in suspension and possibly the deposits of dilute turbidity flows carrying terrigenous sediments derived from the carbonate continental shelf lithologies.

The Mudd Pond Quartzite is a thick, massive unit occuring predominantly in green, silty slates of the Truthville, but has been noted also in black slate of the Browns Pond. It occurs as hard, rounded ridges which are discontinous and lensing. The grain size varies from medium to coarse and only locally is grading evident. More commonly, thebeds show no grading or lamination. Channels and load casts are observed at the base of the quartzite where exposed elsewhere, but these feature were not found in the Ganson Hill area. A rather broad interpretive depositional mechanism for this lithology is turbidite flow, where only the "A" division of the classic Bouma model for turbidites is represented. Having only one division represented, however; renders the Bouma model impractical. A more specific mechanism inferred for the deposition of the Mudd Pond Quartzite is fluidized sediment flow. This occurs when water is incorporated into sand deposits by a shock, such as an earthquake, and the sand becomes supported by excess pore pressure. The flow is short lived since the pore fluid can escape rapidly and the sediment comes to rest(Keith and Friedman, 1977). It is interesting to note the occurrence of the Mudd Pond Quartzite at a lower stratigraphic level (Truthville) in the Ganson Hill area than it is elsewhere in the Taconics. Two explanations are proposed for this finding. One is that the Mudd Pond Quartzite in the Ganson Hill area is more proximal to the source of the flow, allowing sediment to cut deeper into older basin sediments or, two; that the Mudd Pond Quartzite occuring throughout the Taconics, is not a time-stratigraphic unit, but the result of numerous episodes of fluidized flow producing similar lithologies introduced at different stratigraphic levels.

CHAPTER 3

Poultney Formation: Early Ordovician Contourite Deposit on the Taconic Continental Rise

3.0 Introduction

The Taconic Allochthon, of eastern New York and western Vermont, consists of Precambrian(?) to medial Ordovician deep water deposits, mostly shales, now metamorphosed to slates with subordinate graywackes, quartzites, limestones, arenites and conglomerates; deposited on the continental rise. During the Taconic Orogeny, the rise sediments were thrust upon a coeval sequence of shallow water continental shelf lithologies, dominantly limestines, dolostones, arenites and orthoquartzites. The shelf sediments unconformablt overlie Grenville Province, Precambrian crystalline basement rocks.

Rocks of the Taconic Allochthon were deposited in a relatively quiet environment of the continental rise. Deposition of mudrocks was occasionally interrupted by debris and turbidity flows carrying quartzose and/or carbonate clastics from the continental shelf. However, the early and early-medial Ordovician unit, the Poultney Formation; shows evidence documented in this chapter of a different depositional facies. The Poultney Formation exhibits distinctive sedimentary characteristics which the author interprets to have been produced by transport in and deposition from deep, contour-following bottom currents.

3.1 Previous Work

The existence of contour-following bottom currents was first made known by Heezen and Hollister, et.al. (1966). Data obtained from piston cores and bottom photography confirmed that the mechanism responsible for shaping the continental rise is the flow of deep bottom currents. The rise is composed of hemipelagic and terrigenous sediments deposited at a relatively high rate, turbidite deposition constitutes only a small precentage of the rise sediments (Heezen, Hollister and Ruddiman, 1966). In 1972, Bouma noticed the distinct similarities between piston cores obtained from the Gulf of Mexico and a section of the Niesenflysch from Switzerland. The Stiegelbach section of the Gresoschisteux Formation of the Frutig Series of the Niesenflysch is a sequence of alternating shale and shale/sandstone beds. Bed thickness is predominantly 4-5 cm thick with sharp upper and lower contacts. Primary structures preserved in the section include parallel laminations and some foreset bedding. The section is overlain by calcareous sandstones and conglomerates interpreted as proximal turbidites, but itself lacks the successive sequence of structures characteristic of turbidites (Bouma, 1972). An alternating contourite/turbidite sequence is what is to be expected from currents which are not continuous over time. It is known that thin layers of mud and plant life establish themselves on the continental rise during the interim time when bottom currents are not operational. However, when sweeping across the rise, the bottom currents have velocities of up to 20cm/sec., strong enough to form ripples and current lineations in fine sand and silt (Zimmerman and Hollister, 1970). Klasik and Pilkey (1975) agreed the rise is affected most by contour-following bottom currents because the turbidites are channellized past the rise by remaining within the confines of a canyon. Their studies included piston coring and bottom photography of the continental rise from Cape Hatteras Canyon to the Blake Outer Ridge. The only primary structures observed were a slight layering, mottling and bioturbation.

Work in the British Isles has yielded the identification of a contourite deposit and a transitional facies of contourite to turbidite. Anketell and Lovell (1976) working in the New Quay area of Central Wales describe a succession of shales and sandstones representative of two distinct environments of deposition. The Grogal Sandstone Formation consists of alternating sandy siltstones and mudstones. The coarser grained siltstones have bedding thickness' of 5cm with sharp upper and lower contacts. The sedimentary structures found within the siltstone beds include cross and parallel laminations. Overlying the Grogal Sandstone Formation is the Aberysywyth Grits Formation. A transitional zone of turbidite and contourite deposition marks the boundary between the two formations, above the transitional zone the Aberystwyth Grits Formation is unquestionably a sequence of turbidite facies rocks (Wood and Smith, 1959). Paleocurrent data obtained from these units show two prominent directions normal to eachother, reflecting the downslope movement direction in turbidity flows and along slope movement direction in the reworking of the turbidites by contour-following currents.

In 1980, Ayers and Cleary studies the terminus of the Wilmington Fan system. They used Hollister's parameters of thickness and abundance of bedded sand/silt to differentiate turbidite from contourite. By studing piston cores, they identified contourite depostis by the number of sand/silt beds present in 10 meters of core. The contourites contained 50 to 500 sand/silt beds per 10 meters of core, whereas the turbidites had much less (less than 50 per 10 meters of core). The contourite cores showed bed thickness' which were extremely thin (1cm), whereas turbidite cores have beds much thicker (20cm). The concluded the turbidites to be the most important factors in the development of the continental rise, but they attribute this to the fact that they examined the fan terminus.

3.2 Occurrence

The Poultney Formation has only been mapped within the lower, western most parts of the allochthon, in particular within the Giddings Brook Slice. Plate I shows the extent of the Poultney Formation within the Taconic Allochthon. The Poultney Formation is now about 200 meters thick. Wood (1973, 1974) estimated 75% shortening perpendicular to slaty cleavage, using deformed reduction spots in purple slates found near the Granville, New York area. The Poultney consists of gray, green and bl ck color laminated slates interbedded with pale gray and tan calcareous quartzites. The author believes the quartzite beds and the enclosing silty mudrocks to be ancient contourites. Laboratory and field studies of the quartzite beds indicate that they were deposited on the continental rise by contour-following bottom currents.

The Poultney Formation are those rocks which overlie the Hatch Hill Formation and underlie the Indian River Formation. The Hatch Hill-Poultney contact is placed at the first appearance of fissile, black slate with or without rotten weathering quartz-rich beds (Rowley et.al., 1979). The Poultney-Indian River contact is more easily distinguishable and is placed at the first appearance of red or sea-green slates (Jacobi, 1977). The name Poultney was first used by Keith (1932) but he may have included some of the underlying Hatch Hill Formation within it. Early workers have divided the Poultney Formation into two Units. Theokritoff (1964) called the units "A" and "B", Platt (1972) called them Lower and Upper and Potter (1972) called the units the White Creek and the Owl Kill Members . Jacobi, mapping in the

Granville, New York area, renamed the units the Dunbar and the Crossroad Members. Dale's (1899) Calciferous unit is equivalent to Jacobi's (1977) Dunbar Member. The Dunbar Member of the Poultney Formation has also been called Unit 6 of the Mount Hamilton Group of Zen (1961). The Crossroad Member has been equated to Dale's (1899) Hudson Slates and Hudson Thin Quartzites.

3.3 Criteria for Identifing Contourites

The effect on sediment deposition by circulation of deep, contour-following bottom currents was first proposed by Heezen and Hollister (1964, 1964). Lovell and Stow (1981) proposed a list of criteria for the identification of ancient sandy contourites (see Table I) and they offer a broad definition as follows:

> Contourite: a bed deposited or significantly reworked by a current that is persistent in time and space, and flows along slope in relatively deep water (certainly below wave base).

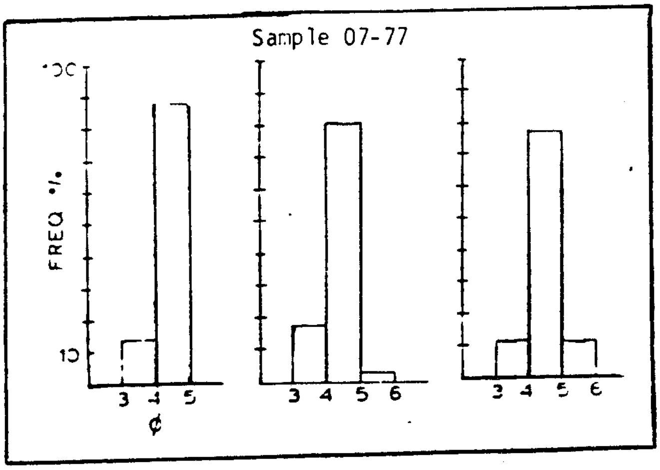
Taken individually, the criteria may be misleading and may be used to correctly identify thin bedded turbidites or portions of a typical Bouma sequence. However, using a combination of characteristics will conclusively identify contourite beds (Lovell and Stow, 1981). For example, divisions "B" and "D" of Bouma's (1962) turbidite facies model show sedimentary structures, such as, parallel laminations common with those found in contourite beds, however; an additional contourite characteristic is the lack of a vertical succession of structural sequences as would be present in turbidites.

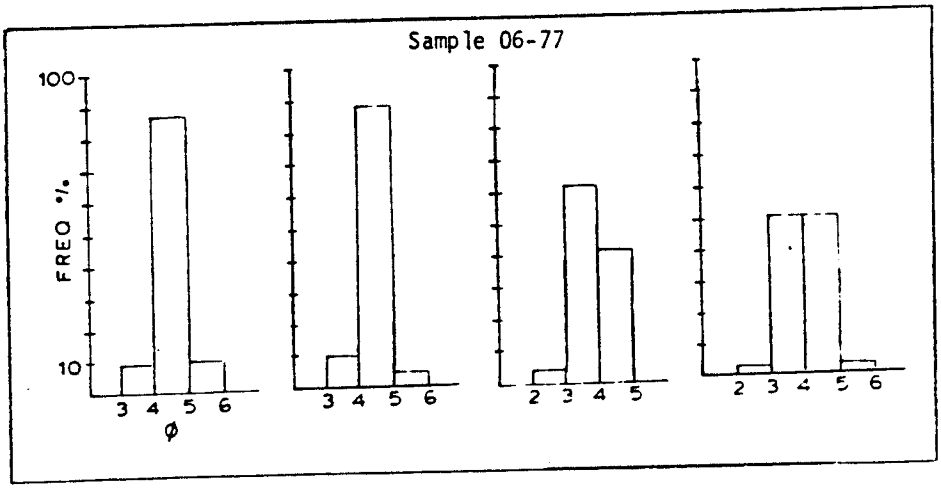
Grain size analysis' of samples taken from Poultney Formation outcrops were preformed by a point-count method and displayed in Figures 25 and 26.Figure 25 shows the range in grain size in individual layers or beds. Data were collected from both light colored, more quartz-rich layers and dark colored, pelitic layers. The grain size ranged from 2 to 6 ϕ, i.e. fine sand to silt, with the greatest frequency precent of 4 to 5 ϕ repeatedly. This narrow range in grain size reflects how well-sorted the clastic grains are in individual beds. Quartz grains

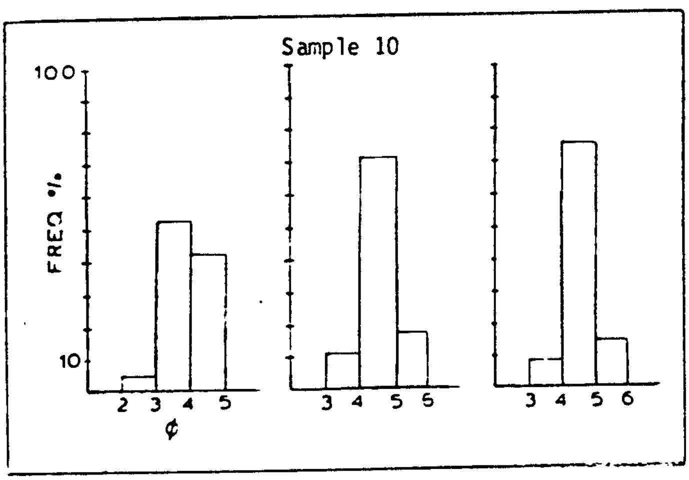
Table

Main criteria		Detailed observations
Occurrence	(a)	Thin beds in thick mudstone sequences that are identified on other grounds as relatively deep water deposits.
	(b)	In turbidite sequences (especially as reworked tops of sandy turbidites).
	(c)	Coarse lag in areas of nondeposition or erosion.
Structure	(a)	In many cases disturbed and bioturbated, irregular coarse layers with little primary structure.
	(b)	In other cases, horizontal and cross lamination resembling that in turbidites, bu with no regular vertical structural sequence such as Bouma divisions of classical turbidites. Orientation of cross lamination is predominantly unimodal, persistent through time and space, and perpendicular to regional downslope paleocurrents, especially turbidite sole marks. Current directions from sole marks and cross laminations in the same turbidite unit are particularly significant.
	(c)	Beds may show reverse grading near their tops and have sharp upper contacts.
Grain size	(a)	Silt or sand, rarely gravel.
	(b)	May contain little mud or be well sorted.
	(c)	Tendency to low or negative skewness.
	(d)	Any regional grain size trends will be along paleoslope as well as downslope.
Fabric	(a)	Grain orientation along paleoslope, perpendicular to associated downslope turbidite grain orientation.
	(b)	Grain orientation may be more polymodal or random than in (a) because of reworking of earlier deposits or postdepositional disturbance.
Composition	(a)	Related to both periodic downslope supply by turbidity currents and other processes and to local supply of material along-slope by persistent regional bottom currents.
	(b)	Grains of higher specfic gravity may be concentrated in laminations.

(Lovell and Stow, 1981)







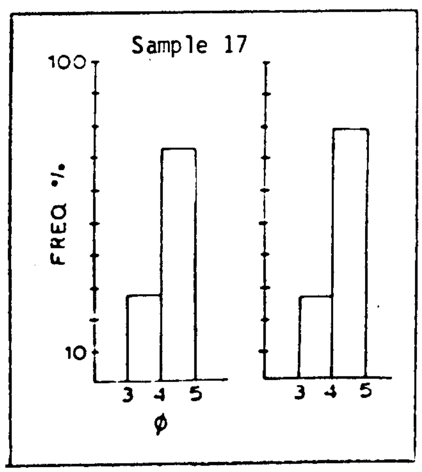


Figure 25

Grain size analysis. Grain size varies from 2-6 Ø, that is; fine sand and silt.

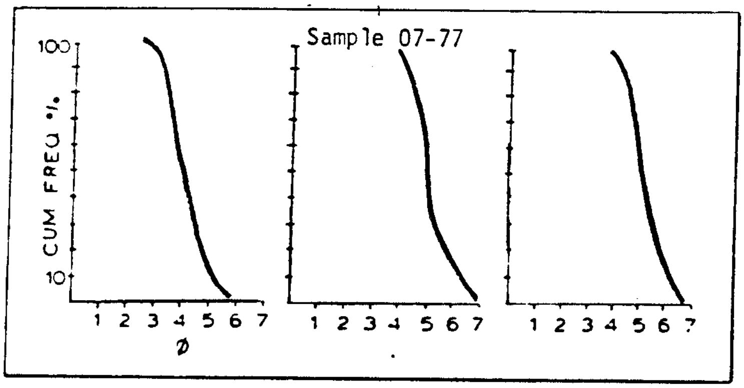
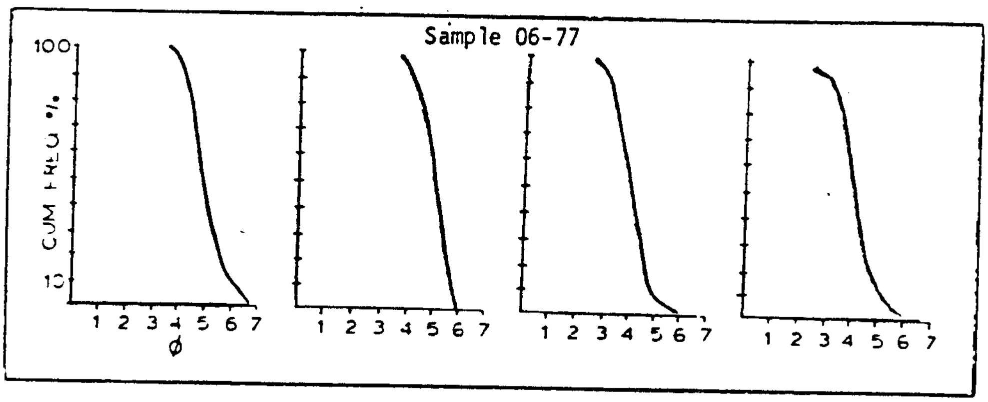
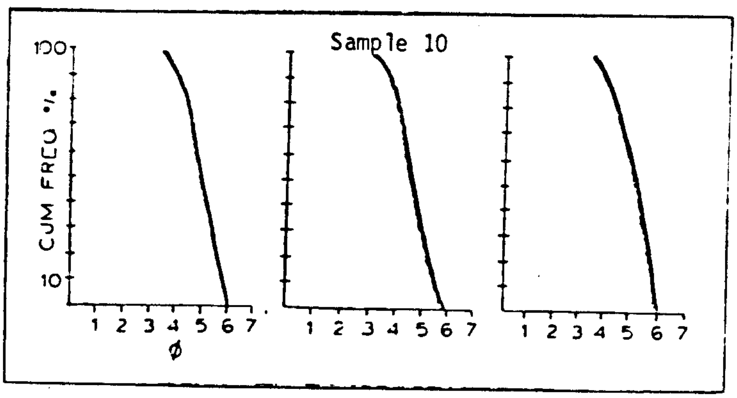
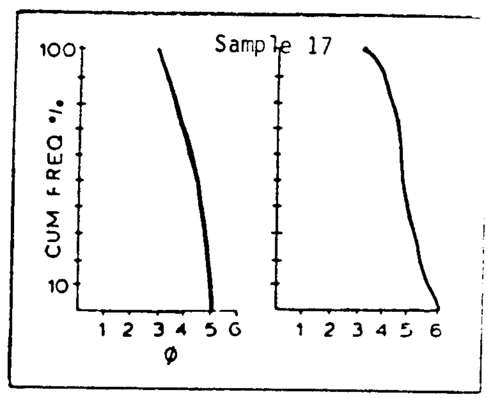


Figure 26

Cumulative frequency curves.
Each curve represents an individual bed.







are well-rounded suggesting a relatively long transport history. The quartz grains also show undulatory extinction and strain which the author attributes to the deformation acquired during emplacement of the allochthon. The range in grain size, degree ofsorting and skewness can be obtained from Figure 26. The cumulative frequency curves of Figure 26 cover a very narrow range of grain size and show a slight negative skewness.

Compositional analysis' were preformed using the point-count method (see Figure 27). Two hundred or more readings per layer were obtained. The histogram represents data from an individual layer or bed. Quartz dominates with lesser amounts of feldspar, mica and carbonate matrix. Heavy minerals, such as, zircon and opaques are present in small amounts and often define the fine parallel laminations. Tiny mica flakes are usually con centrated in cleavage planes and appear to be a product of low grade metamorphism and the alteration of feldspar.

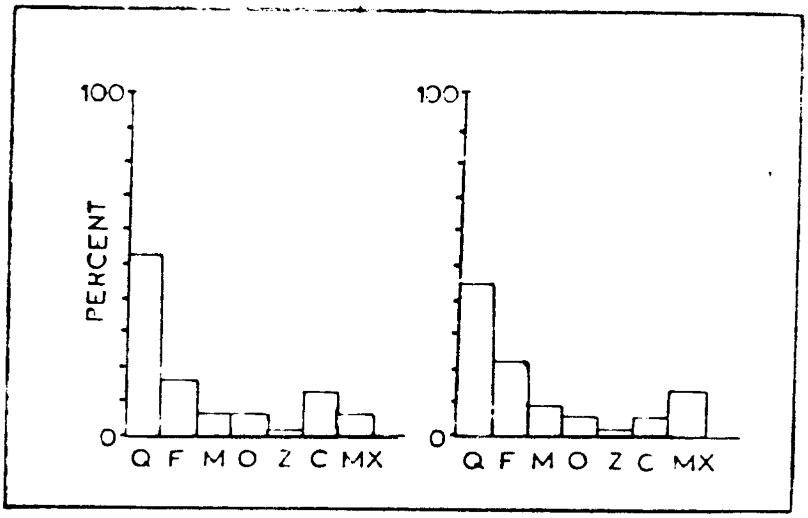


Figure 27

Compositional analysis of quartz-rich beds in the Poultney Formation.
Q = quartz
F = feldspar
M = mica
O = opaques
Z = zircon
C = carbonate
MX= matrix

3.4 Sedimentary Structures and Paleocurrent Data

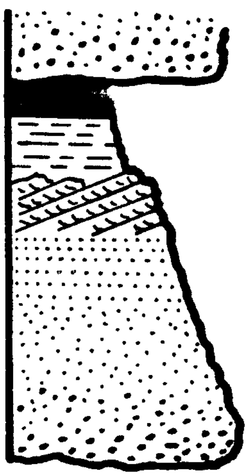
Thinly laminated beds were named "laminites" by Lombard (1963), but the term is no longer used in the literature. Parallel laminated beds of fine sand to silt grain size are characteristic of the "D" division of Bouma's (1962) idealized turbidite sequence (see Figure 28), however; the remaining vertical succession of Bouma's turbidite sequence is not present in the Poultney Formation. The Poultney Formation contains many of the diagnostic characteristics of contourites. The bedding thickness is 5cm or less with consistent lateral extent, at least on the scale of theoutcrop and both upper and lower contacts of the quartz-rich beds are sharp (see Figure 29). Figure 30 shows some of the primary structures observed in outcrop. They include parallel and cross-laminations, ripple marks, small barchan-like structures having crescentric shape in plan view, with the convex side facing the current direction; and small-scale scour marks believed to be tool marks. Also present are post-depositional structures, such as, sedimentary dikes and bioturbation (see Figure 31).

Paleocurrent data was obtained primarily from cross beds, but ripple marks and scour marks were also used as current direction indicators. Figure 32 shows the localities from which data was collected. (The presence of scour marks (shown in circles in Figure 32) indicating a current flow direction at a high angle to cross bed current flow direction should be expected where reworking of turbidity deposits by contour-following currents occurs.)

The rocks have been tectonically deformed, including the pronounced slaty cleavage axial planar to tight folds. Original

Figure 28

BOUMA MODEL FOR TURBIDITES



E Fines in turbidity current.

D Parallel-laminated silt and mud.

C Ripple, cross-laminated fine sandstone.

B Parallel-laminated sandstone.

A Graded or massive sandstone.

Figure 29
Thinly bedded quartz-rich beds with interbedded pelitic beds showing lateral extent and sharp upper and lower bedding contacts.

(a) outcrop located in the Schagticoke Gorge

(b) outcrop located along the Poultney River

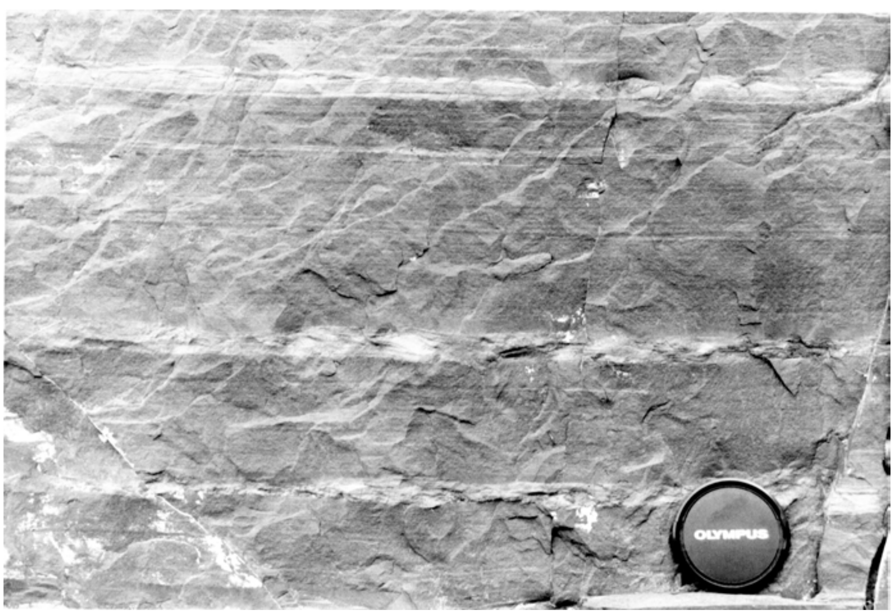


Figure 30
Sedimentary structures preserved in the Poultney Formation, shown in well-exposed roadcuts or in well-polished river outcrops, used to determine current flow direction.

(a) Cross and parallel laminations; Poultney River

(b) Small barchan-like structures; Poultney River

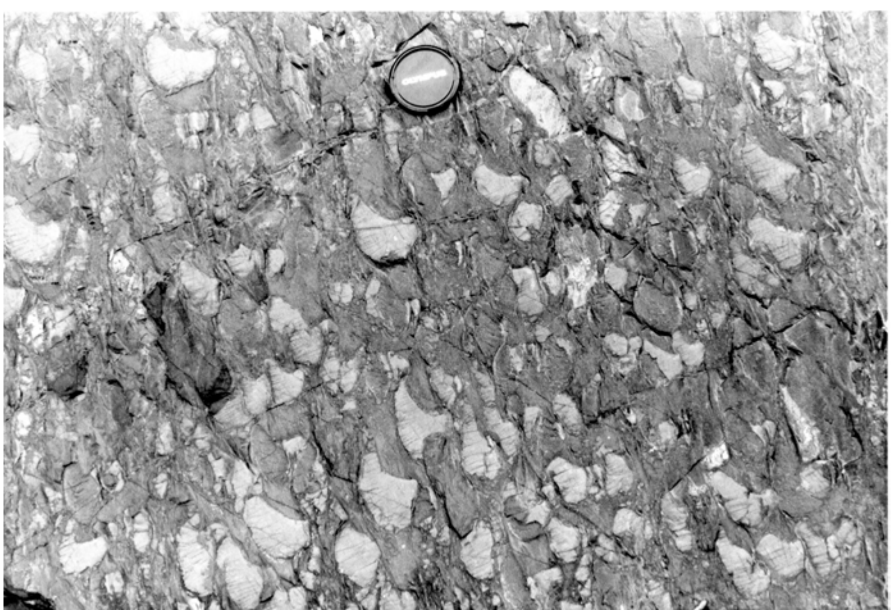
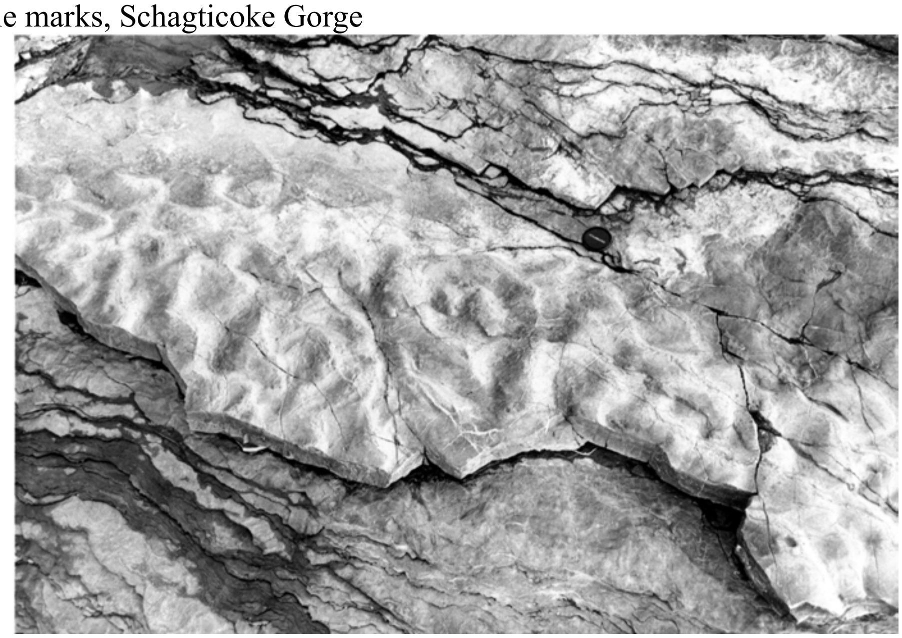


Figure 30 (cont.)
(c) Ripple marks, Schagticoke Gorge

(d) Ripple marks, Schagticoke Gorge



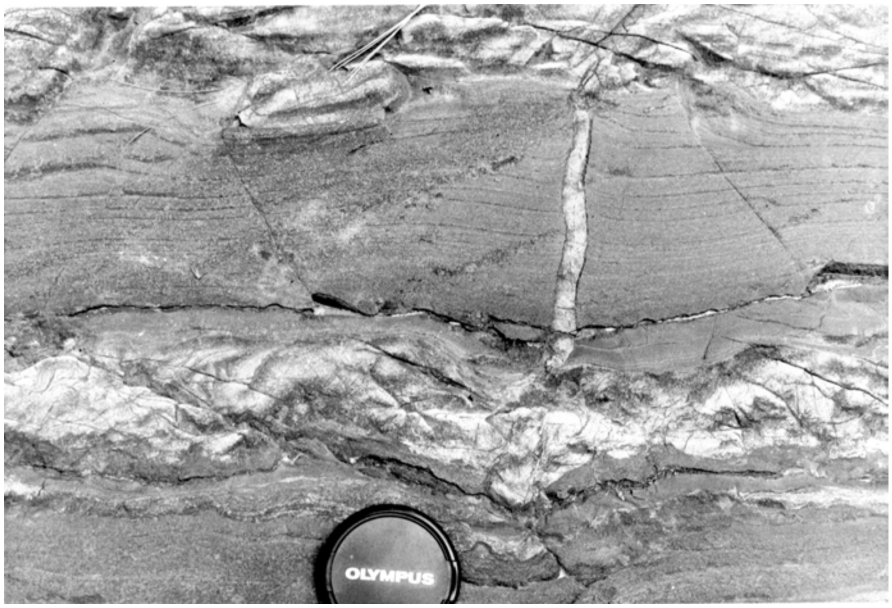


Figure 31
Post-depositional dike in a pelitic-rich bed of the Poultney Formation occurring in a well-polished outcrop along the Poultney River.

Figure 32

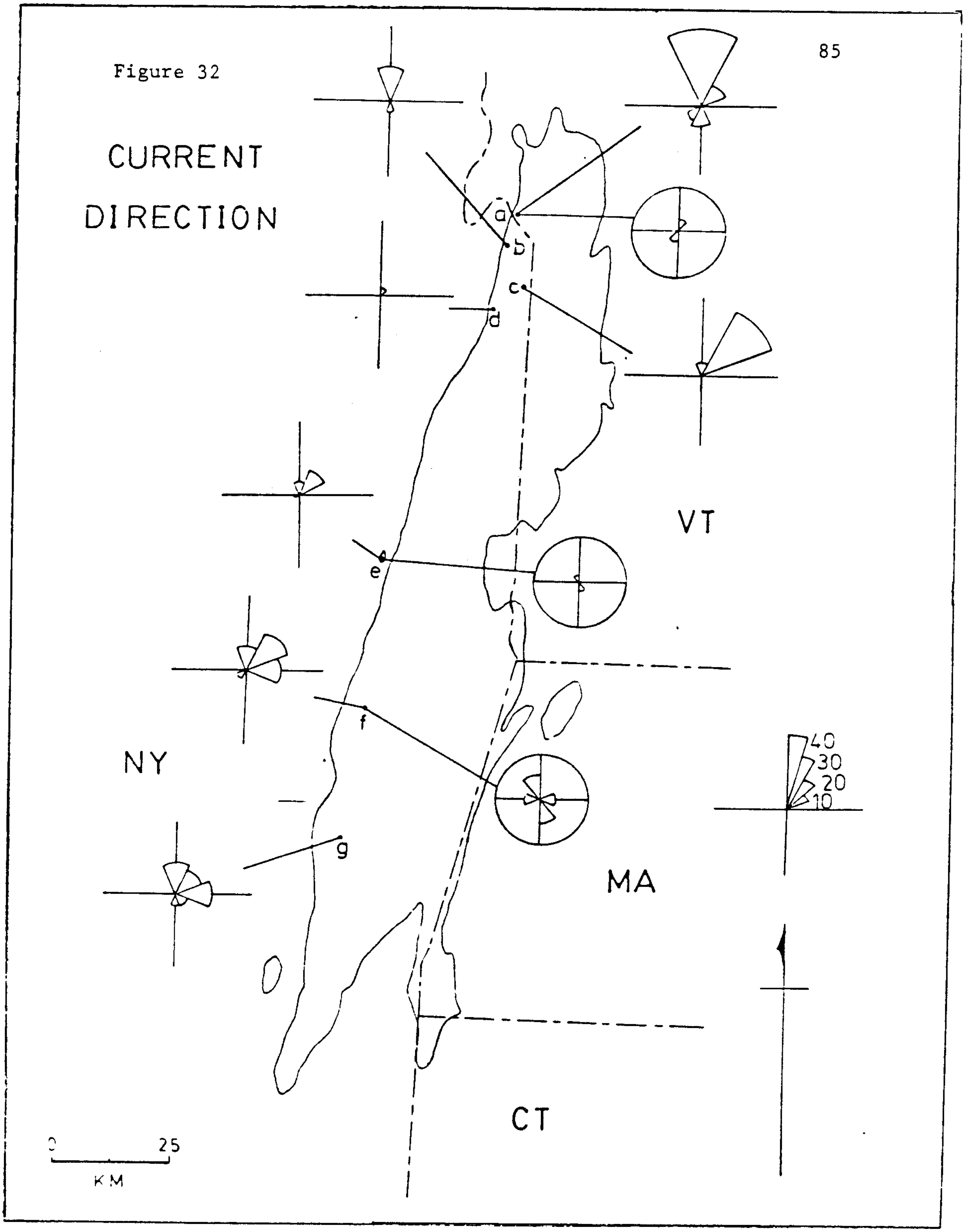


Figure 32

Localities from throughout the Taconic Allochthon where current flow direction data was obtained:
(a) along the Poultney River
(b) slate quarry on Route 4, N.Y.
(c) along Route 22, Granville, N.Y.
(d) along Route 40, Granville, N.Y.
(e) in the Schagticoke Gorge, Schagticoke, N.Y.
(f) along Snyder's Lake Road and Lake Shore Road,

(g) along Route 9, near Styvesant Falls, Kinderhook, N.Y.

orientations of current directions were obtained by the use of stereonets to rotate beds to their unfolded position. Some difficulty was encountered in interpreting ripple marks which were linguoid-shaped in plan-view. Also, thelack of numerous well-polished outcrops or well-exposed roadcuts added to the difficulty of quantitative data, but the author feels the data recovered adequately represents the paleocurrent information recoverable from these rocks.

The paleocurrent data obtained from cross-bedding and ripple marks show consistent north, north-easterly flowing contour following currents. Scour marks, produced by turbidity flow, show current flow direction at a high angle to the contour-following current flow direction.

3.5 Interpretation

The Poultney Formation is characterized by distinct sedimentary features which the author interprets to have been produced by transport in and deposition from deep, contour-following bottom currents. Evidence for a source area is based on the mineral composition of the clastic lithologies. Quartz is the major constituent, approximately 50% of a clastic bed (see Figure 27). The quartz grains are well sorted, well rounded and show some undulatose extinction. Abrasion studies of quartz grains indicate that extremely long distances of transport are neccessary to achieve significant rounding (Kuenen, 1959). Lesser quantities of feldspar, clay, carbonate and heavy minerals, including zircon and opaques; are also found. This suggests that the Poultney detritus is compatible with a cratonic and sedimentary provenance. It is inferred that the detritus was derived by erosion of Cambrian quartz-rich lithologies. These clastic source rocks were originally derived from erosion of crystalline Grenville-type basement rocks (Lajoie et. al., 1974). Erosion of coeval shelf carbonate lithologies, similar to those preserved in the Middlebury Synclinorium, contributed to the carbonate matrix of the clastic lithologies.

A plate tectonic model consistent with source area requirements is needed when considering provenance studies. The well-established plate tectonic model proposed by Chapple (1973, 1979) and Rowley and Delano (1979) is that the emplacement of the Taconic Allochthon was the result of partial subduction of an Atlantic-type North American continental margin in an east dipping subduction zone. Cambrian and early Ordovician (Poultney Formation) lithologies of the Taconic Allochthon, reflect the development of an ocean basin, continental rise environment, eastward of a carbonate shelf deposited on Grenville-type basement rocks. Deposition on the continental rise is dominated by hemipelagic deep water sedimentation and clastic deposition of detritus derived from the craton. Evidence of a volcanic arc to the west is not seen until early N. gracilis time, in the form of tuff bands in the Indian River Formation and volcanogenic chert in the Mount Merino Formation (Rowley et.al., 1979).

Paleocurrent data obtained from sedimentary structures in the Poultney Formation show consistent north, north-easterly flowing currents. Deep ocean currents which flow parallel with the contours of continental margins are well documented (see section 3.1). The author believes the currents which deposited the clastic lithologies of the Poultney Formation followed the contours of the ancient Atlantic-type continental margin, reworking and depositing sediments derived from the North American Platform adjacent to and south of the present area of the Taconics.

CHAPTER 4

Structure

4.0 Introduction

Rocks comprising the Taconic sequence are in thrust contact with the underlying carbonate Valley sequence. Taconic rocks lie structurally above and are nestled in the Middlebury Synclinorium. This allochthonous hypothesis is now well-documented and accepted. However, before the turn of the 20th century, geologists, Dale (1899) being the most notable, interpreted the Cambrian and Ordovician slate belt as a lateral facies of the surrounding carbonate rocks and, therefore, autochthonous. A heated debate arose between workers in the northern Taconics and those in the southern Taconics. In the northern Taconics, evidence for a large thrust fault along the western edge of the Taconic sequence was clear; however, in the southern Taconics arguments persisted for an autochthonous relationship between the Taconic sequence and the coeval carbonate-orthoquartzite suite or rocks. Puedemann (1909) was the first to suggest the two contrasting suites of rocks were in thrust contact. Subsequent workers of the early 20th century (Keith, 1912; Swinnerton, 1922; Prindle and Knopf, 1932) accepted and elaborated on the allochthonous hypothesis.

Presently, the suite of pelitic lithologies which crop out in an elongate belt approximately 200km long, from Sudbury, Vermont to Poughkeepsie, New York, are accepted and well-documented as being in thrust contact with the surrounding rocks and comprise the Taconic Allochthon.

The Taconic Allochthon consists of six major thrust slices (Zen, 1967). Each slice of the series of imbricated and partially nested thrust slices, contain a coherent stratigraphy and complex internal deformation. The Giddings Brook Slice, structurally the lowest large slice of the allochthon, contains the present study area.

The following discussion of the structure of the Ganson Hill area is divided into three sections. The first section reviews the development of structural interpretation in the Ganson Hill area. E-an Zen (1959,1961,1964) was the first to provide a comprehensive discussion of this area. The second section is largely descriptive. Structural elements, such as folds, cleavages, faults and minor structures, are described as seen in outcrop; and how they vary from rock type to rock type is discussed. Generations of structures are mentioned in this section, but a more comprehensive discussion of this is given in the final section. The third and final section of this chapter, discusses the regional structures of the map area including the generations of structures as well as a structural interpretation.

4.1 Previous Workers

Many previous workers have studied structural elements of the Taconic Allochthon, but relatively few have addressed the problems imposed by the complex structure at the north end of the Allochthon. The most notable of previous workers is E-an Zen, but first earlier contributors are discussed.

Kaiser (1945) studied an area of the northern Taconics, bounded to the south by the Castleton Valley from Whitehall, N.Y. east to Rutland, Vt. and to the north approximately 16 miles near Brandon, Vt. The Ganson Hill study area is contained within Kaiser's field area. Kaiser noted structural elements, such as an axial plane foliation striking north - northeast and dipping 20-50 degrees east, and a fracture cleavage striking north - northeast and nearly vertical, yet his cross-sections show essentially flat-lying strata with little or no deformation in the form of folding. He failed to describe the folds associated with the north - northeast trending, east-dipping foliation and attributes the fracture cleavage to a late relaxation of earlier strucutres. Kaiser is mentioned here as a previous worker, but his structural summary is believed to be incorrect and of little value.

Fowler (1950) agreed with Kaiser in that the rocks are essentially flat lying and only slightly crumpled, but recognized that they are overturned to the west and therefore show downward-facing sequences, albeit nearly flat lying. He described an axial plane foliation to long, narrow north - northeast trending folds as a flow cleavage which he equates to the fracture cleavage produced by the folding of the Middlebury

Synclinorium and overthrusting of the Taconics (Fowler, 1950). A later foliation, which he called a slip cleavage or shear cleavage, was postulated to have been produced by a regional thermal metamorphism. The Ganson Hill study area is included in Fowler's map, but his stratigraphic units do not depict the mappable, distinct formations observed in the study area and his map totally lacks structural data in the Ganson Hill area.

Zen (1959,1961,1972) wrote on the structural complexity of the northern Taconics, including the Ganson Hill study area; in some detail. Zen's (1959) first interpretation of the present study area is that of simple structures overturned to the west with nearly horizontal axial planes and north-south trending axes. He envisions the Ganson Hill syncline as the structural complement of the Giddings Brook anticline. Due to the folding of the Middlebury Synclinorium the nearly flat lying axial planes have a slight southern dip, which produces east-west striking map units in the area and the resultant map pattern. Zen (1961) expands on this interpretation by stating that the Ganson Hill syncline is the lateral continuation of the Scotch Hill syncline found west of Lake Bomoseen, and that a later antiformal fold has been superimposed between the two synclines.

He recognized the need for terms which would describe folds whose stratigraphic younging directions do not conform with the fold geometry and, unaware of Shackleton's work (1958) and the introduction of the terms upward and downward-facing folds, Zen introduced topping and bottoming folds. He states (Zen, 1961; pg.313) a topping fold is a fold whose core contains the relatively youngest beds. A bottoming fold is a fold whose core contains the relatively oldest beds. In simply deformed rocks these refer to syncline and anticline, respectively; but in multiply deformed rocks the terms syncline and anticline are used purely as geometric terms while topping and bottoming has stratigraphic connotation. These terms have not won general acceptance or become commonly used; they tend to be extremely confusing and by using terms such as synform and antiform with specific facing direction, one can accomplish a better description of multiply deformed rocks.

Zen (1961) describes the Giddings Brook fold as a major, recumbent, isoclinal upward-facing fold with an axial plane dipping gently south. South of Ganson Hill is where the lower limb of this anticline is younging downward. During the folding of the Middlebury Synclinorium, both limbs of the anticline were, according to Zen, folded into a broad, south-plunging synformal fold. Zen (1961) interprets the upward-facing anticline as closing westward, along a north-south line; except in the Ganson Hill area where the closure swings into a northeast position, and again attributes the east-west trending bedding as insignificant and merely the interference pattern of a south-plunging later fold superimposed on an early fold with flat lying axial plane.

In 1972, Zen revised his interpretation of the Ganson Hill area, to that of a real change in the major fold axes into an east-west position. The explanation he gave for this change in trend of fold axes was the emplacement of a higher Taconic slice and a "push" from the southeast. Zen broadens his interpretation to state that the Giddings Brook fold complex, which includes both the Giddings Brook and the Ganson Hill folds, is the lateral continuation ofthe Great Ledge-Porcupine Ridge fold complex making the Scotch Hill syncline and the Cedar Mountain syncline minor flexures on the normal limb of a large downward-facing fold. A more complete discussion of the regional structure is given in section 4.3.

4.2 Deformational Structures

Cleavage

In the Ganson Hill study area, two generations of cleavage were noted using style and orientation as criteria for their classification. The early cleavage (S_1) is a slaty cleavage found in all the fine-grained, layer silicate containing lithologies (slates). It ranges from poorly-developed in the quartz-rich wackes of the Bomoseen Formation to well-developed in the slates of the Bull and Browns Pond Formations (see Figure 33). In the less abundant, coarser-grained lithologies, such as the arenites and quartzites, the slaty cleavage is generally not developed and often it is seen deflected in the adjacent slates by the more competent beds. Since the rocks have been multiply deformed, the data obtained from bedding/cleavage relationships is used with caution.

Under the microscope, the slaty cleavage in all slate lithologies appears as alternating, differently colored folia. Under crossed-nicols, goldish brown strips rich in chlorite and clay minerals showing a strong preferred orientation alternate with light-colored strips, containing the same minerals, but without a preferred orientation and also including clastic quartz grains carbonate material and opaques. Mica flakes can be found both in preferred orientation parallel with the cleavage planes and in no preferred orientation among the quartz grains.
The folia are planar and do not form anastomosing lenses. In the very fine-grained clay-size particle-rich lithologies, the slaty cleavage is nondomainal at the scale of observation, but this may be a function of the grain size and order of magnification. In the slightly siltier lithologies, the slaty cleavage is defined by alternating domains; quartz-rich and clay-rich.

Figure 33
Ubiquitous slaty cleavage is the early (S_1) cleavage. It ranges from poorly-developed in the quartz-rich beds of (a) the Bomoseen Formation to (b) well-developed in the slate of the Bull Formation.

(a) Photo taken north of Ganson Hill Road

(b) Photo taken along Monument Hill Road

The slaty cleavage (S_1) is axial planar to the regional, large-scale folds (F_1). It is parallel, in most places, with bedding; and may better be called bedding cleavage, except at the hinge regions of F_1 folds. The slaty cleavage is relatively uniform in orientation, striking north - northeast and dipping moderately to the east - southeast. Figure 34 shows a plot of poles to slaty cleavage on an equal area stereo net.

Secondary to the early slaty cleavage is a locally developed crenulation cleavage (S_2). This cleavage grades to a fracture cleavage in the more resistant beds. The development of crenulation cleavage varies from well-developed, finely-spaced, planar partings which visibly crenulate the S_1 foliation (see Figure 35a) to more subtle, finely to closely-spaced, hair-thin stripes which are observed to crenulate the S_1 foliation only on a microscopic scale (see Figure 35b). Under the microscope, the crenulation cleavage is defined by parallel stripes, a fraction of a millimeter wide, rich in chlorite and clay minerals; which fold the slaty cleavage and are axial planar to these microscopic folds. The crenulation cleavage often appears as the extremely attenuated and elongated limb of a fold of the slaty cleavage. Figure 34 shows the crenulation cleavage at a high angle to slaty cleavage, which is parallel with bedding.

Data obtained on the orientation of the crenulation cleavage is sparse (see Figure 34). Generally, the strike of the (S_2) crenulation cleavage parallels that of the (S_1) foliation; but is more steeply-dipping. More abundant are folds which deform

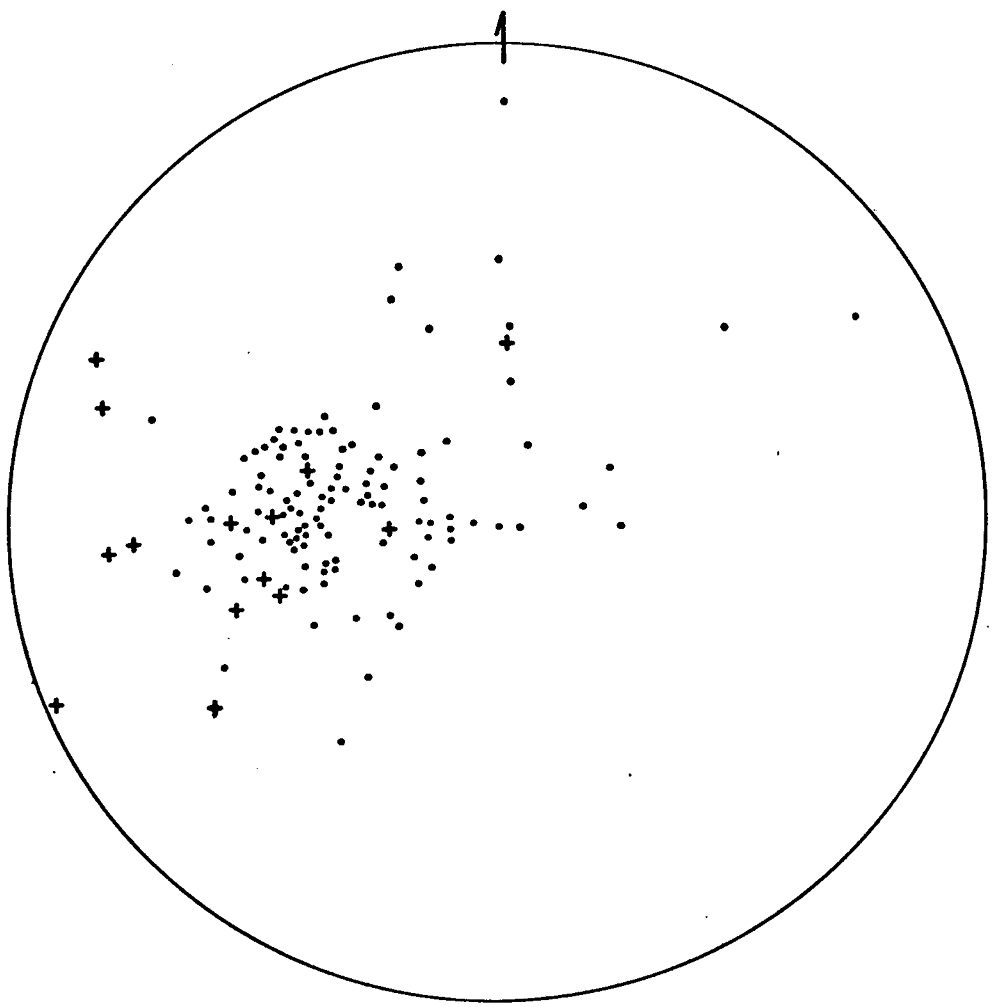


Figure 34

Poles to cleavage

• = slaty cleavage
+ = crenulation cleavage

Figure 35
Secondary (S_2) crenulation cleavage. Crenulation cleavage development varies from finely-spaced partings which visibly crenulate the early (S_1) slaty cleavage, as in (a) the Truthville slate found along Ganson Hill Road, near its west end; to finely-spaced, extremely thin stripes on the S_1 cleavage planes, which are observed to crenulate the slaty cleavage only on a microscopic scale as in (b) the Undifferentiated Bull Formation found along Route 30, near Beebe Pond.

(a)

(b) see next page

Figure 35 (cont.)
Secondary (S_2) crenulation cleavage. Crenulation cleavage development varies from finely-spaced partings which visibly crenulate the early (S_1) slaty cleavage, as in (a) the Truthville slate found along Ganson Hill Road, near its west end; to finely-spaced, extremely thin stripes on the S_1 cleavage planes, which are observed to crenulate the slaty cleavage only on a microscopic scale as in (b) the Undifferentiated Bull Formation found along Route 30, near Beebe Pond.

(b)

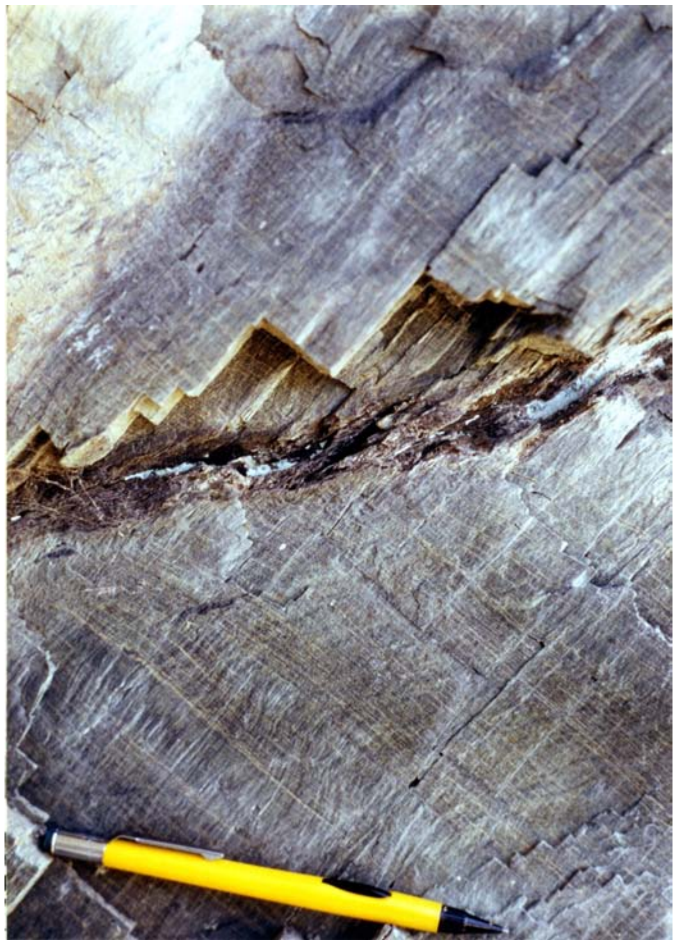
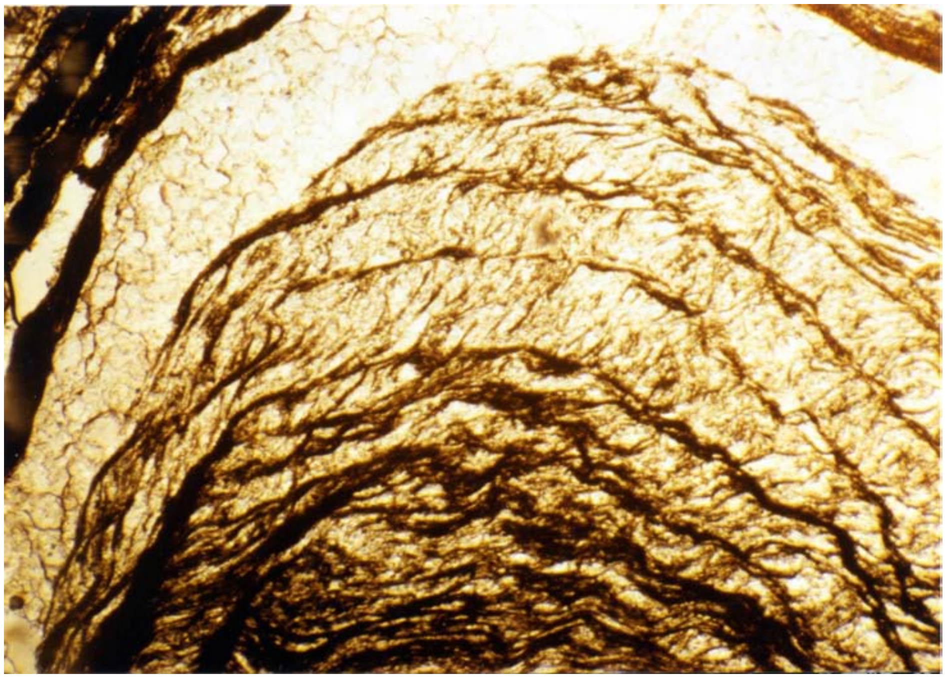


Figure 36
Photomicrograph of two generations of cleavage. The early slaty cleavage, roughly paralleling bedding, is folded by the later crenulation cleavage. (x40 plane polarized light)



bedding and slaty cleavage. Thecrenulation cleavage, although not always observed, is assumed axial planar to these late folds.

Folds

In the Ganson Hill study area, folds of various morphologies, style, wavelength and amplitude were noted. The various types of folds depended largely on the lithology involved. Identifying folds in outcrops of slate alone was virtually impossible, except where the fold is a late fold deforming the early slaty cleavage.

The distinction of early and late folds made at the outcrop depended on the following factors: 1) the type of axial plane foliation. Folds exhibiting an axial plane foliation which cuts slaty cleavage were designated late folds. Folds with axial plane slaty cleavage were designated early folds. 2) The structural elements involved in the folding. Folds consisting of folded bedding and parallel slaty cleavage, with no apparent axial plane foliation were designated late folds. Folds which deform slaty cleavage are considered late folds. Folds of bedding where slaty cleavage is at an oblique angle to bedding are considered early folds.

The folds range from open to tight to isoclinal, in profile. Open folds (see Figure 37) are common in the massive arenites of the Hatch Hill Formation and the graywackes of the Bomoseen Formation. Generally, where bed thicknesses are equal to or less than 1-3cm the folds are tight to isoclinal. Figure 38b shows a thin, (4cm) folded bed of quartzite in purple slate of the Undifferentiated Bull Formation; it is nearly isoclinal with sinistral asymmetry. In places, isoclinal folds have a short limb which is thinned and stretched normal to the compressional direction of

Figure 37
Fold morphology, in profile, varied considerably from unit to unit depending on the lithology involved. In massive arenites as in (a) the Hatch Hill Formation or in the graywackes of (b) the Bomoseen Formation, open folds are common.

(a) Photo taken on the northwest slopes of Ganson Hill

(b) Photo taken north of Ganson Hill Road, near its west end

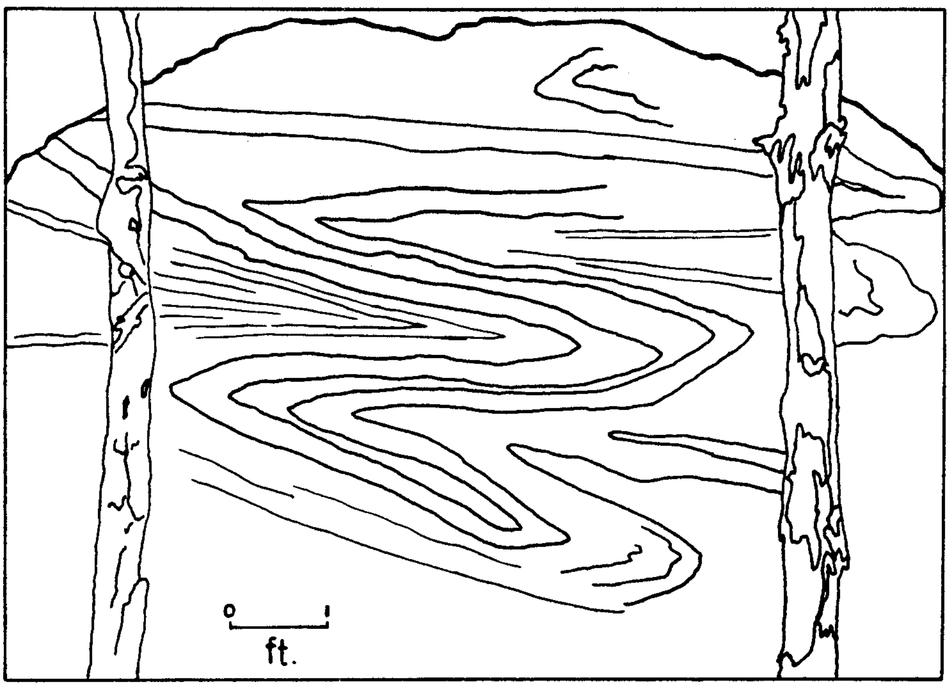
Figure 38
Tight to isoclinal folds. Tight folds as in (a) the Poultney Formation deform thin quartzite beds and the early slaty cleavage. Nearly isoclinal folds as in (b) the Undifferentiated Bull Formation show the slaty cleavage axial planar to the fold.

(a) Photo taken on the top of Ganson Hill

(b) Photo taken along Monument Hill Road

Figure 39

A refolded fold in the Bomoseen graywacke north of Ganson Hill Road, just east of Echo Lake. An early isoclinal fold is refolded tight to isoclinal with sharp fold hinges and no apparent axial plane foliation. (Photo not included due to poor focus.)



the fold (see Figure 33). At one locality, south of Ganson Hill in the Hatch Hill Formation, evidence of a refolded fold was found. The outcrop exposes thin (8-10cm) quartz-rich beds interbedded with a dark gray and black slate, isoclinally folded (see Figure 39). The axial plane of the early fold is bent around sharp fold hinges. The later fold is tight to isoclinal, with no apparent axial plane foliation.

An equal area stereonet projection of fold hinges shows two gener orientations (see Figure 40). One has a northerly trend and shallow to moderate plunge, and the other a southeast trend with shallow plunge. Generally, the early folds are expressed in the map pattern. The mesoscopic folds which mimic the large, regional folds are tight to isoclinal, overturned to the west and nearly recumbent. Late folds are believed to be responsible for the slight flexure in the map pattern. They are upright, open to tight and in some places, isoclinal folds with hinge lines which plunge gently south.

Faults

Along the south side of Ganson Hill (see map), trending roughly east-west, a large thrust fault places Cambrian green slates (Undifferentiated Bull Formation) over black and gray slates and interbedded quartzites (Poultney Formation). The following arguments support the existence of this fault: 1) the truncation of stratigraphic units, with conformable contacts trending roughly north-south on the southwest slopes of Ganson Hill, against a lineament which trends roughly east-west. 2) North of Giddings Brook (see map), westward dipping beds of Zion Hill quartzite

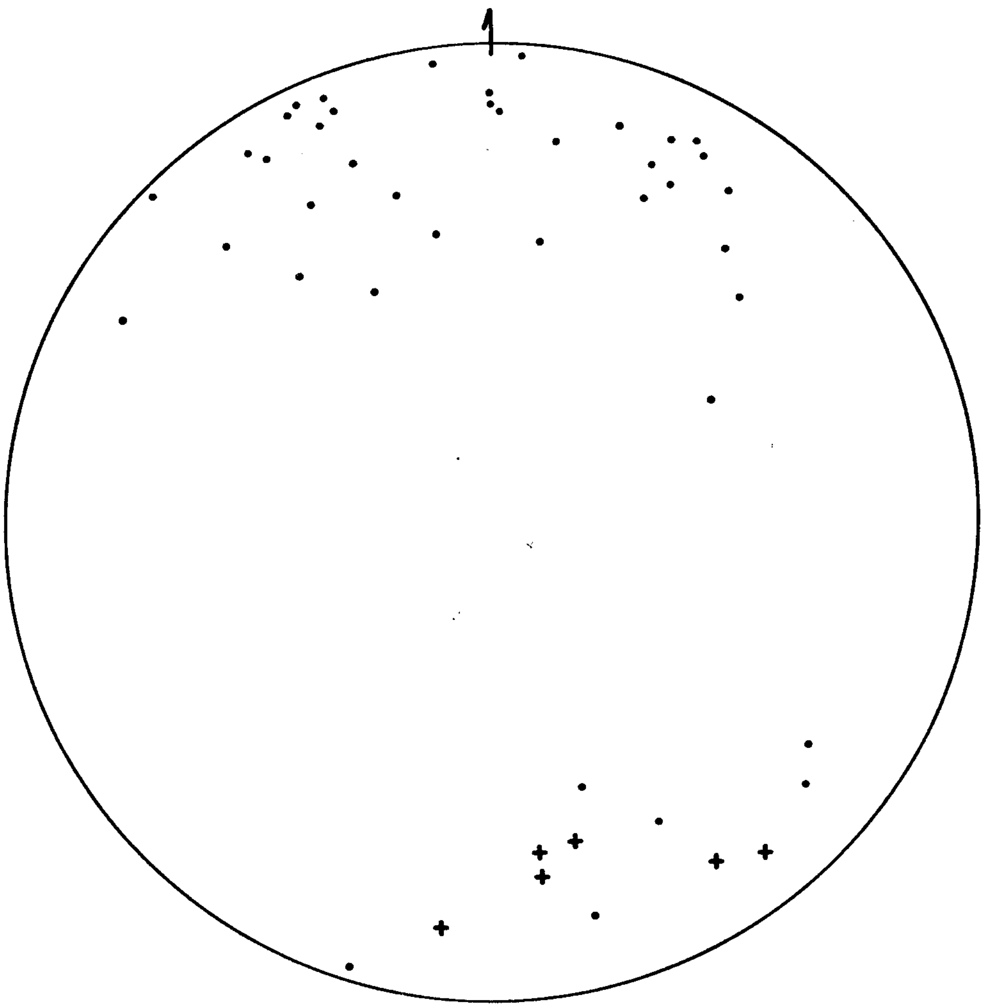


Figure 40

Plot of fold hinges

• = early fold hinges
+ = late fold hinges

which trend northwest, have been traced up to the brook which cuts the base of Ganson Hill. North of this brook, the section is right-side-up. By the lack of stratigraphic section, the map demonstrates this is not the transition zone from an overturned limb of a large fold to the upright limb. It is believed that the Zion Hill quartzite beds are truncated by the east-west trending thrust fault. 3) Ubiquitous north - northeast trending slaty cleavage is disrupted into random orientation along the strike of the thrust fault. 4) The occurrence and high concentration of distinctive, thin layers composed entirely of chlorite cut by massive chlorite veins,in every stratigraphic unit which is cut by the thrust fault (see Figure 41). Associated with the chlorite layers are high concentrations of quartz veins. The occurrence of thin chloritic layers and quartz veins is interpreted as the effect of water introduced along a fault plane. Under conditions of high pressure, and with the presence of water; quartz becomes mobile relative to clay minerals and mica. The quartz can migrate and become concentrated in veins leaving layers rich in clay and mica behind which are then altered to chlorite.

Locally, small-scale faulting of once coherent bedding has been noted (see Figure 42). Thedisplacement is small and not considered to affect the map-scale structures in any way.

Other Minor Structures

Minor structures which are found nearly everywhere Hatch Hill quartz arenites, and to a lesser degree, in silty and sandy beds of the Poultney Formation and the Undifferentiated Bull Formation include: extension gashes found in most cases oriented nor

Figure 41
Presumed evidence of a fault. Thin layers of chlorite cut by more massive chlorite veins as seen in the Browns Pond Formation. Outcrop occurs west of Route 30, approximately 0.5 km south of Beebe Pond.

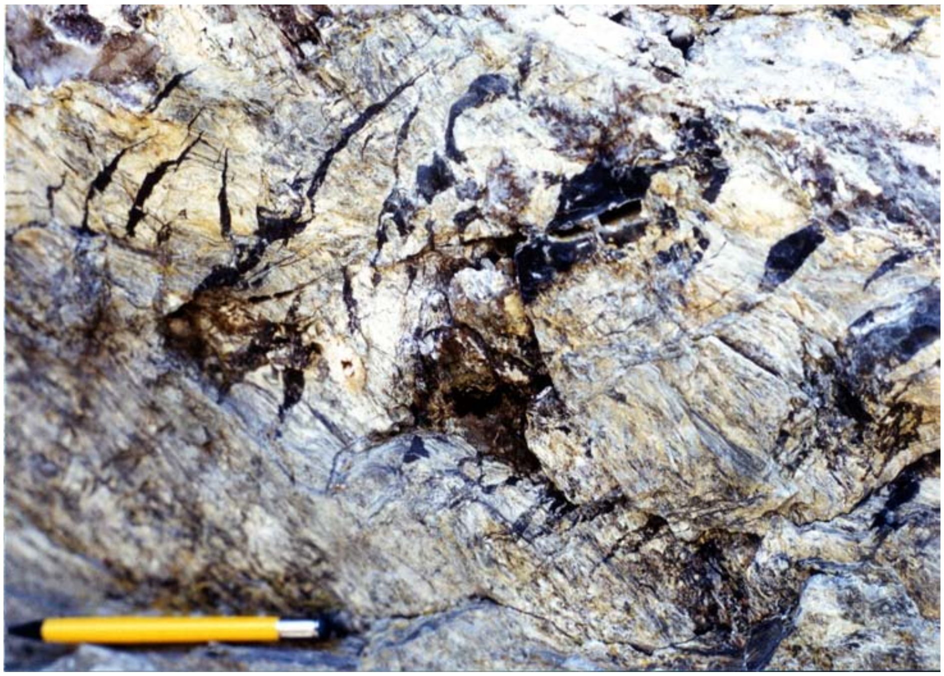


Figure 42
Small-scale faulting of bedding in the Browns Pond Formation showing relatively little displacement. Outcrop occurs west of Route 30, near Beebe Pond.

to bedding planes. In some places they show an echelon orientation (see Figure 43a). Sigmoidal gashes were not noted.

Along Route 30, near Beebe Pond (see map), well-developed kink bands can be seen in the green slate of the Undifferentiated Bull Formation (see Figure 43b). Kink bands have been noted elsewhere in this formation, where the outcrop is exceptionally good forming small, steep cliffs; they are consistently near vertical with north-south strike.

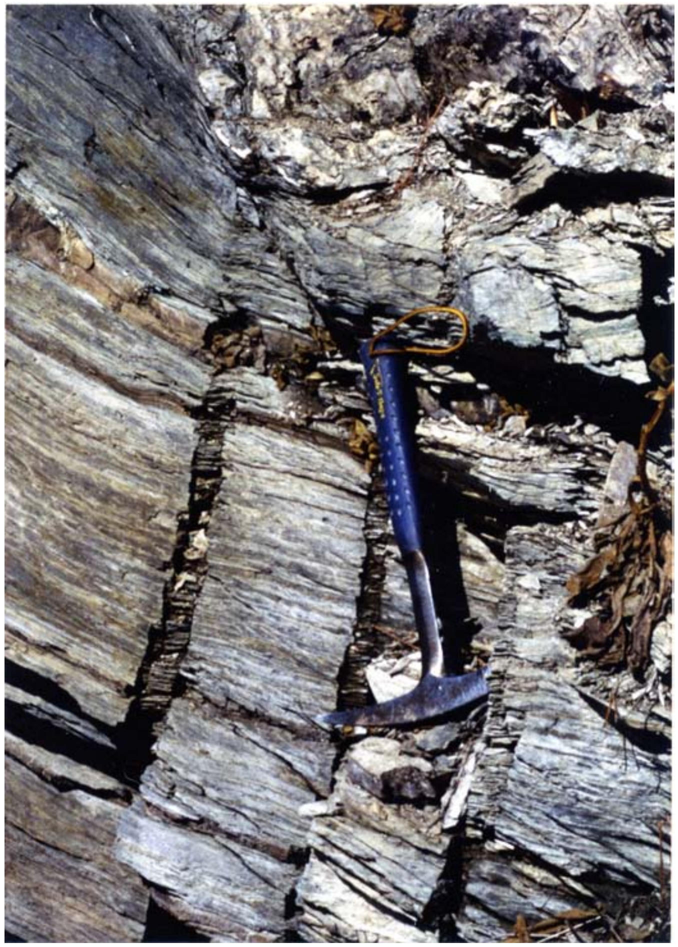
Figure 43
Minor structures. Extension gashes in (a) the Undifferentiated Bull Formation and (b) kink bands in the Undifferentiated Bull Formation, found in roadcut exposures along Route 30, near Beebe Pond.

(a)

(b) see next page

Figure 43 (cont.)
Minor structures. Extension gashes in (a) the Undifferentiated Bull Formation and (b) kink bands in the Undifferentiated Bull Formation, found in roadcut exposures along Route 30, near Beebe Pond.

(b)



4.3 Regional Structures

Map and Cross Sections

A geologic map (Plate II) was prepared for the study area using all stratigraphic and structural data obtained. A base map was prepared from topographic maps at a scale of 1:12,000; topography is shown using 100 foot contours.

The map area can be divided into 3 structural domains. They are, the northern domain; extending from the Keeler Pond Thrust of Zen (1961) to the northern slopes of Ganson Hill, the central domain; that encompassing Ganson Hill, and the southern domain; extending from the Hubbardton Gulf Thrust (Aparisi, this work) to the southernmost extent of the map area. Cross sections were drawn through each domain, normal to the major structural element in each domain (see Plate III).

In the northern domain, the Bomoseen Formation forms the core of an anticline, overturned to the north-northwest, with a moderately south-southeast dipping axial surface. A small parasitic fold separates the anticline from the large-scale Ganson Hill syncline (see x-section A-A'). The Hubbardton Gulf Thrust truncates the overturned limb of the Ganson Hill syncline.

The central domain consists of a large, nearly recumbent syncline (the Ganson Hill syncline), overturned to the west with an axial surface dipping moderately to the east. In x-section B-B', the Ganson Hill syncline and the effect of the locally well-developed late crenulation cleavage, is shown. It is inferred that the more steeply dipping limb of the syncline is folded into late F_2 folds with more steeply-dipping axial surfaces. The folds have smaller wavelength and amplitude than the large-scale syncline, reflected in the broad region which exposes only the Browns Pond Formation, a relatively thin unit.

The southern domain consists of one stratigraphic unit, i.e.; the Undifferentiated Bull Formation. It is an extensive area of monotonous green, greenish-gray and purple slate showing only the regionally developed slaty cleavage. Within the slate, discontinuous ridges of Zion Hill Quartzite are the only good indicators of bedding. The quartzite dips moderately to the west-southwest and shows local graded bedding. The graded bedding indicates upward-younging beds and, hence; upward-facing folds. The slaty cleavage in the encompassing slate dips moderately to the east, therefore the Zion Hill quartzite occupies the hinge region of a fold or folds, which are overturned to the west. In cross-section C-C', only the west-dipping quartzite beds and the east-dipping slaty cleavage are shown. The supplementary cross-sections (of cross-section C-C') are included to demonstrate an alternative possible interpretation. Since the thickness of the Undifferentiated Bull Formation varies to such a great extent, it can not be determined whether the Zion Hill quartzite occupies the core region of a single large fold or several folds.

It is inferred that the trace ofthe Ganson Hill syncline is truncated, to the west, by the Hubbardton Gulf Thrust. There is no evidence in the mapping suggesting the Giddings Brook and the Ganson Hill fold complex is the lateral continuation of the Great Ledge and Porcupine Ridge fold complex as proposed by

Zen (1972). It is not clear if Zen intended the fold hinge of the Giddings Brook "bottoming" fold (an anticline) to be the lateral continuation of the Great Ledge "bottoming" fold and the fold hinge of the Ganson Hill "topping" fold (a syncline) to be the lateral continuation of the Porcupine Ridge fold (an anticline), respectively; but if this is Zen's intent, a twisting of the fold hinge would be required to connect a simple anticline (Porcupine Ridge) with the syncline (Ganson Hill), forming one structure which faces in opposite directions along the trace of the fold hinge. If Zen intended the Ganson Hill syncline to be the lateral continuation of the Mount Hamilton syncline (according to Zen, a secondary fold on the normal limb of a large overturned regional fold) then he has connected a fold of one generation with a fold of a later generation. This, also; is not feasible.

The Hubbardton Gulf Thrust truncates the pre-slaty cleavage folds, placing normal limbs of large overturned folds against normal limbs of the complementary folds. The disruption and reorientation of the early slaty cleavage, along the trace of the thrust, suggests the thrust also post-dates the F_1 folds. Whehter the thrust is folded by the late folds or is synchronous with the F_2 folding cannot be stated conclusively.

The east-west trending bedding, at the north end of the Taconic Allochthon, is an anomaly, in that; the major, regional structures are close to north-south trending. Zen (1972) envisioned a "push from the southeast", caused by the emplacement of the higher Taconic slices, as the mechanism which reoriented structural trends at the north end of the allochthon.

The author offers two other possibilites. First, perhaps shear near the base of the allochthon, during the time of emplacement, reoriented the bedding now exposed at the north end of the allochthon; or alternatively, in a thrust sheet moving from east to west, overriding continental shelf and crystalline basement rocks, perhaps the structures which parallel the tectonic transport direction were produced by irregularities in the thrust surface, such as; ramps and off-set steps in the ramp structures.

CHAPTER V

Summaries and Conclusions

Stratigraphy

In the Ganson Hill study area, only a portion of the complete stratigraphy preserved in the Giddings Brook Slice was observed. The Indian River, Mount Merino and Pawlet Formations are not preserved in the study area. The cumulative stratigraphic thickness of the section from the Ganson Hill area, is slightly less than, but, comparable to those measurements obtained by Jacobi (1977) and Rowley, et. al. (1979) for sequences located south of the present study area.

The poor development or total lack of several key beds noted by Jacobi and Rowley, et.al., may reflect a facies change in a more distal section of rise sediments. For example, Rowley reports some thick quartz arenite interbedded with the Bomoseen wacke from the Granville, N.Y. area. In the Ganson Hill area, only thin beds of quartzite and slate were associated with the Bomoseen wacke and constitute only a small fraction of the formation. Within the Browns Pond Formation of the Ganson Hill area, subordinate lithologies include limestone, micrite, calc-arenite and silty, clast-containing wacke. Combined these lithologies constitute approximately 10% of the entire formation. In the Granville, N.Y. area, similar subordinate lithologies are noted in the Browns Pond Formation, with the addition of distinctive coarse limestone breccia horizons.

The quartzites and arenites interbedded with the dark gray and black slate of the Hatch Hill Formation, in the Ganson

Hill area, are thin (the thickest of these being approx. 40cm)
while to the south, in the Granville, N.Y. area, beds of arenite
up to 400cm thick were noted, as well as beds of arenite breccia
near the top of the unit. Nearly the entirety of the Poultney
Formation, in the present study area, fits the description of
the Crossroad Member of the Poultney Formation of Jacobi (1977).
Jacobi's Dunbar Member, consisting of slate and interbedded
limestone and micrite is not developed in the Poultney Form-
ation of the Ganson Hill area. Also, from the Granville, N.Y.
area, black phosphate pebble conglomerate horizons
is reported near the top of the unit.
These lithologies were not noted in the Ganson Hill area, a
result perhaps due to the top of the formation not being pre-
served.

In general, the Ganson Hill sequence, extending from the
basal Bomoseen wacke to the Poultney slate; is slightly thinner with su
ordinate coarse clastic lithologies either poorly-developed or absent.
These features suggest a more distal facies of correlative seq-
uences found to the south of the study area.

The lithostratigraphy of the Ganson Hill area can be more
precisely defined than was done by Zen (1961) and other previous
workers. Specifically, the occurrence and recognition of the
Middle Granville Slate Formation and documentation of a second
Cambrian black/green boundary, overcomes much of the confusion
created by previous workers who included this formation in diff-
erent places, in two different formations.

Structure

Throughout the Giddings Brook Slice, the style of deformation is generally consistent. Three stages of deformation have been recognized: pre-slaty cleavage folding, folding and slaty cleavage development with associated faulting, and late folding and crenulation cleavage development with associated late faulting. Characteristic of the Giddings Brook Slice are north-trending structures overturned to the west. Three similar stages of deformation have been recognized at the north end of the Giddings Brook Slice, but, in the Ganson Hill area, the pre-slaty cleavage folds are responsible for east-west trending structures and combined with the latter two stages of deformation, are responsible for the overall map pattern.

The trace of the fold axis of the Ganson Hill syncline does not appear to be the lateral continuation of structures west of Lake Bomoseen, as proposed by Zen (1961), and can only be traced to where it is truncated by the Hubbardton Gulf Thrust fault. The Hubbardton Gulf Thrust fault, documented for the first time in this thesis, revises the structural picture in this area, and may be used to study allochthon boundary features by subsequent workers.

Poultney Formation: Early Ordovician contourite deposit on the Taconic continental rise

Early Ordovician sections throughout the length of the Taconic Allochthon all possess a unit (Poultney Formation) with distinctive sedimentary characteristics, which the author interprets to have been produced by transport in and deposition from deep, contour-following bottom currents. The correct identification of a contourite deposit is dependent upon the occurrence of several distinguishing characteristics. In the Poultney unit, the restricted grain size of the quartz-rich beds, the composition of the quartz-rich beds, the lateral extent of beds, the sharp top and bottom bedding contacts and preserved sedimentary structures, in particular cross and parallel laminations, and ripple marks, in association with distinctively thin beds are characteristic of a contourite deposit.

Paleocurrent directions consistently indicate northerly flowing currents. Material fed from the North American Platform adjacent to and south of the present area of the Taconics was reworked by the north flowing currents.

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