Stratigraphy, Depositional Environment and Structure of the Taconic Allochthon, Central Washington County, New York

Abstract of

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in partial fulfillment of the requirements

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Master of Science

School of Arts & Sciences

Department of Geological Sciences

Louise D. Jacobi

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ABSTRACT

The Taconic Allochthon contains rocks of Cambrian (?), Cambrian and Ordovician age. It measures approximately 200 kilometers by 25 kilometers and is located in contiguous sections of New York, Vermont, Massachusetts, and Connecticut. The rocks are predominantly slates with lesser amounts of arenites, wackes, limestone, chert, and conglomerates. All have been subjected to chlorite or biotite grade metamorphism and two tectonic deformations. The study area in central Washington County, New York, contains most of the Taconic sequence, and because of both natural and man-made exposure it is more accessible than most other locations.

A lithostratigraphic column has been identified which has more detail than any single previous version. Because of the already excessive Taconic nomenclature pre-existing boundaries and names have been retained wherever appropriate. However, two new formations and four new members have been described and formally introduced. Extensive literature research suggests this column can be applied throughout the Giddings Brook Slice of the Allochthon as a reference section.

Analyses of horizontal and vertical rock type distribution, sedimentary structures, and coarse clastic sedimentary petrography indicate a depositional environment which varies both laterally and with time. The overall picture suggests intermediate depths, moderate distance from shore, and a slope between source and deposition site which is sufficiently steep to permit turbidity, debris, and channel flows. Comparisons with segments of a modern stable rifted margin indicates that only the upper and lower continental rise can accommodate this sedimentological variety on a comparable scale.

Map pattern scale structural observations were consistent with previous work and showed that the major folds have an approximate north strike and are overturned to the west. Regional slaty cleavage is axial planar to these folds. Evidence of a second tectonic deformation, seen only sporadically, consisted of fracture or crenulation cleavage and associated folds. Even more infrequent were examples of soft sediment deformation.

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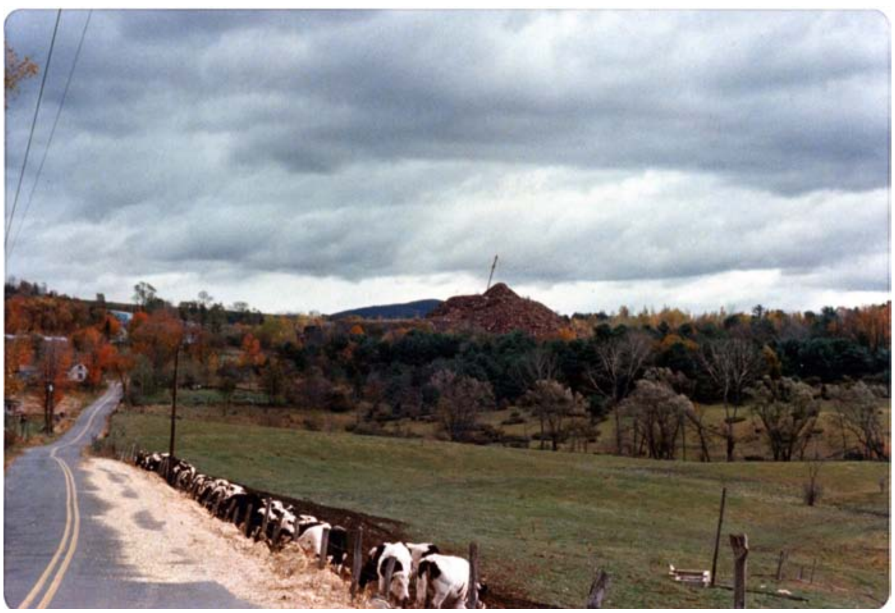
"The Taconic question, I fear, is one never to be settled. This unhappy business of identifying formations many miles away, and bringing into it all sorts of heterogeneous materials must always leave room for doubt and dissension."

James Hall to James Dana (1888)



Frontispiece; The primary industries of the present and of the past, Middle Granville, New York.

ACKNOWLEDGEMENTS

The author is grateful to William Kidd for introducing her to the problems of the Taconic Allochthon and to the field area where some of the solutions have been found. His help and the help of Winthrop Means and Paul J. Fox with the researching and writing of this thesis are appreciated. S.U.N.Y.A. mapping classes of 1975 and 1976 assisted by doing some of the legwork. Sometimes argumentative, but always interesting and beneficial discussions were held with William Kidd, Jerry Sullivan, and others.

My thanks go particularly to the people of the Granville, New York area who were invariably interested, helpful and friendly.

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CHAPTER I

INTRODUCTION

The Taconic Allochthon is an elongate sequence of Cambrian (?), and Ordovician rocks extending from east of Lake Champlain, Vermont, to southern Dutchess County, New York, and measuring approximately 200 km, north to south, by 25-30 km, west to east, (Figure 1). It is comprised primarily of pelitic sedimentary rocks which have undergone low grade metamorphism (chlorite to biotite zone) and varying intensities of deformation. Fossils and sedimentary structures are abundantly preserved, and original bedding is often indisputably recognizable, particularly in the lower, western slices.

The allochthonous Taconic sequence consists structurally of five slices (Zen, 1967). From lowest to highest they are the Sunset Lake Slice, the Giddings Brook Slice, the Bird Mt. Slice, the Chatham Slice, and the Rensselaer Plateau Slice (Figure 2). The lowest two slices have the most complete stratigraphy with fewer of the younger units present as one goes up in the sequence (Figure 3). All of the slices show complex internal deformation, usually of two generations. However, the intensity decreases to the west so that limited evidence of a second deformation is visible in the lowest slices. In general, the first tectonic deformation determines the large scale rock geometry although it suffers increasing modification to the east. The present study was located near the north end of the Giddings Brook Slice whose western boundary is the western boundary of the allochthon.

The rocks are primarily low grade metamorphosed pelites. Variously colored slate predominates; it is present in all the units and has been

Figure 1. The geographic setting of the Taconic Allochthon. The relevant states and counties are outlined and labeled, and the quadrangles are numbered. An identifying list follows:

1 Sudbury
2 Benson
3 Bomoseen
4 Proctor
5 Thorn Hill
6 Poultney
7 West Rutland
8 Granville
9 Wells
10 Middletown Springs
11 Hartford
12 West Pawlet
13 Pawlet
14 Dorset
15 Cossayuna
16 Salem
17 Equinox, N.W.
18 Equinox, N.E.
19 Schuylerville
20 Cambridge
21 Shushan
22 Equinox, S.W.
23 Schaghticoke
24 Eagle Bridge
25 Hoosick Falls
26 Tomhannock
27 Grafton
28 North Pownall
29 Troy South
30 Averill Park
31 Taborton
32 Berlin
33 Williamstown
34 East Greenbush
35 Nassau
36 Stephentown Center
37 Hancock
38 Kinderhook
39 East Chatham
40 Caanan
41 Stottville
42 Chatham
43 State Line
44 Hudson South
45 Claverack
46 Egremont
47 Clermont
48 Ancram
49 Bashbish Falls
50 Rock City

(modified from Zen, 1967)

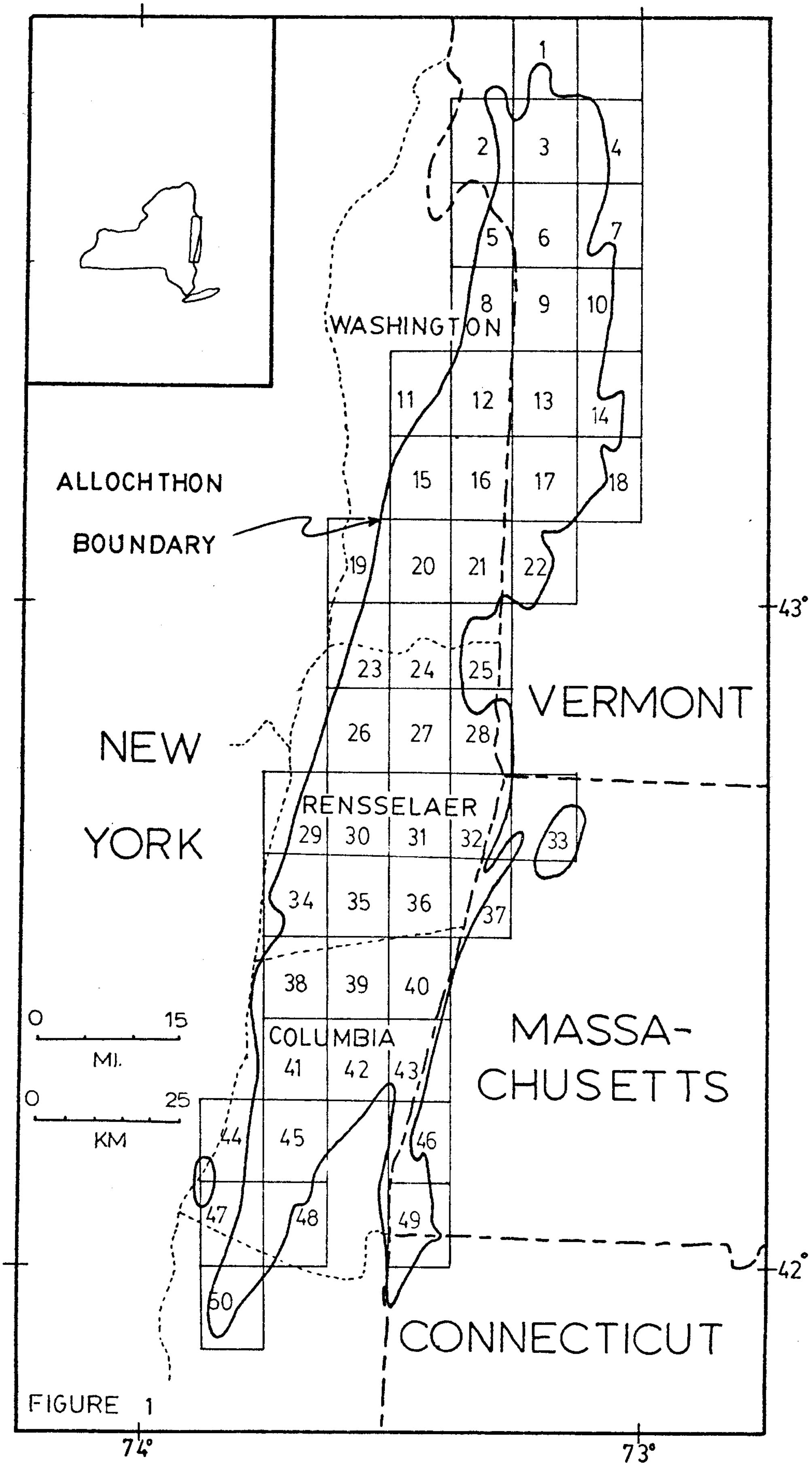

ALLOCHTHON
BOUNDARY
WASHINGTON
RENSSELAER
COLUMBIA
NEW
YORK
VERMONT
MASSA-
CHUSETTS
CONNECTICUT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
0 15
MI.
0 25
KM
43°
42°
74°
73°

FIGURE 1

Figure 2. The structural slices of the Taconic Allochthon. They are numbered in the order of emplacement with number 1 having been emplaced first.

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

(modified from Zen, 1967)

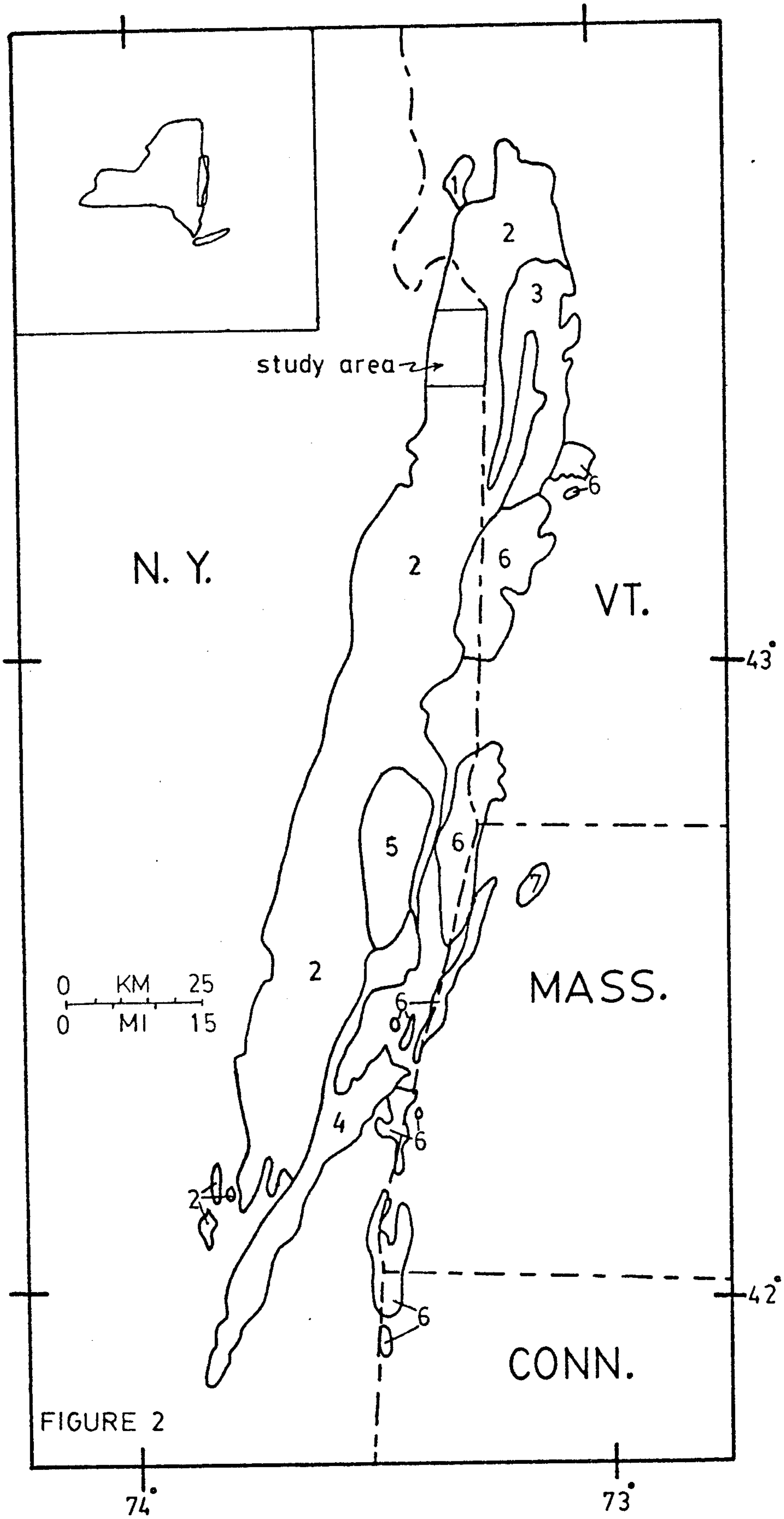


FIGURE 2

Figure 3. Stratigraphies of the different Taconic Allochthon slices. Successful correlations of units between the slices have been achieved despite the variation in metamorphic grade. Stratigraphic range and position in the emplacement series are converse; i.e. the slices emplaced earliest contain the youngest and broadest stratigraphic sequences.

(Zen, 1967)

		YOUNGEST ← SEQUENCE OF EMPLACEMENT → OLDEST					
		(Mutual Relations Uncertain)		(Mutual Relations Uncertain)			
		Dorset Mtn Slice and Greylock Slice	Rensselaer Plateau Slice	Chatham Slice	Bird Mountain Slice	Giddings Brook Slice	Sunset Lake Slice
ORDOVICIAN	Middle					Pawlet	Pawlet ?
					Indian River	Indian River	?
	Lower			?	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					

FIGURE 3

commercially quarried from four. The other major rock type is a hard green lithic wacke. In addition there are dolomitic sub-quartzose arenite, clean quartz arenite, limestone conglomerate and breccia, quartz wacke, chert, and gray lithic wacke. Most of the units (except the lowest ones) have good fossil control, and the ages range from Cambrian(?), i.e. conformably beneath lowest Cambrian, to middle Ordovician. There are a few later lamprophyre dikes, the only igneous rocks in the area.

The present study is based on 17 weeks of fieldwork (May - October 1976) done in northern Washington County, New York. The area is contained in the Granville and Thorn Hill 7 1/2 minute quadrangles. It extends from the Allochthon boundary (as mapped by Theokritoff, 1964) on the west to the New York-Vermont state line on the east, and from Route 22 on the south to Route 18 on the north (Figure 4). The area is an irregular square shape enclosing approximately 75 square km. Outcrop mapping was done on an air photo base to a scale of 1:12000, and topographic maps were used for supplementary location information.

Northern Washington County is an essentially rural area. The countryside is rolling, well-glaciated, and thoroughly vegetated (both naturally and by design). Because of the particularly heavy and persistent rain in summer 1976, extents of swamps were even more widespread than was seen previously or was noted on topographic maps (Figure 5). Relief varies almost 300 m in the area; however, even steep sided hills are often covered by glacial debris, and in one instance a hill was swamp-topped. The present main industry is dairy farming (see frontispiece). Scores of abandoned slate quarries in both Cambrian and Ordovician rocks are found here as constant reminders of an earlier

Figure 4. The study area in the Granville and Thorn Hill Quadrangles in northern Washington County, New York. The Mettawee River and the density of roads allowed cross-structure traverses to be made with reasonable location precision. The striking sharp bend in the Mettawee River from north-south to east-west is unfortunately unexplained because the area of the turn is well concealed by flood plain deposits.

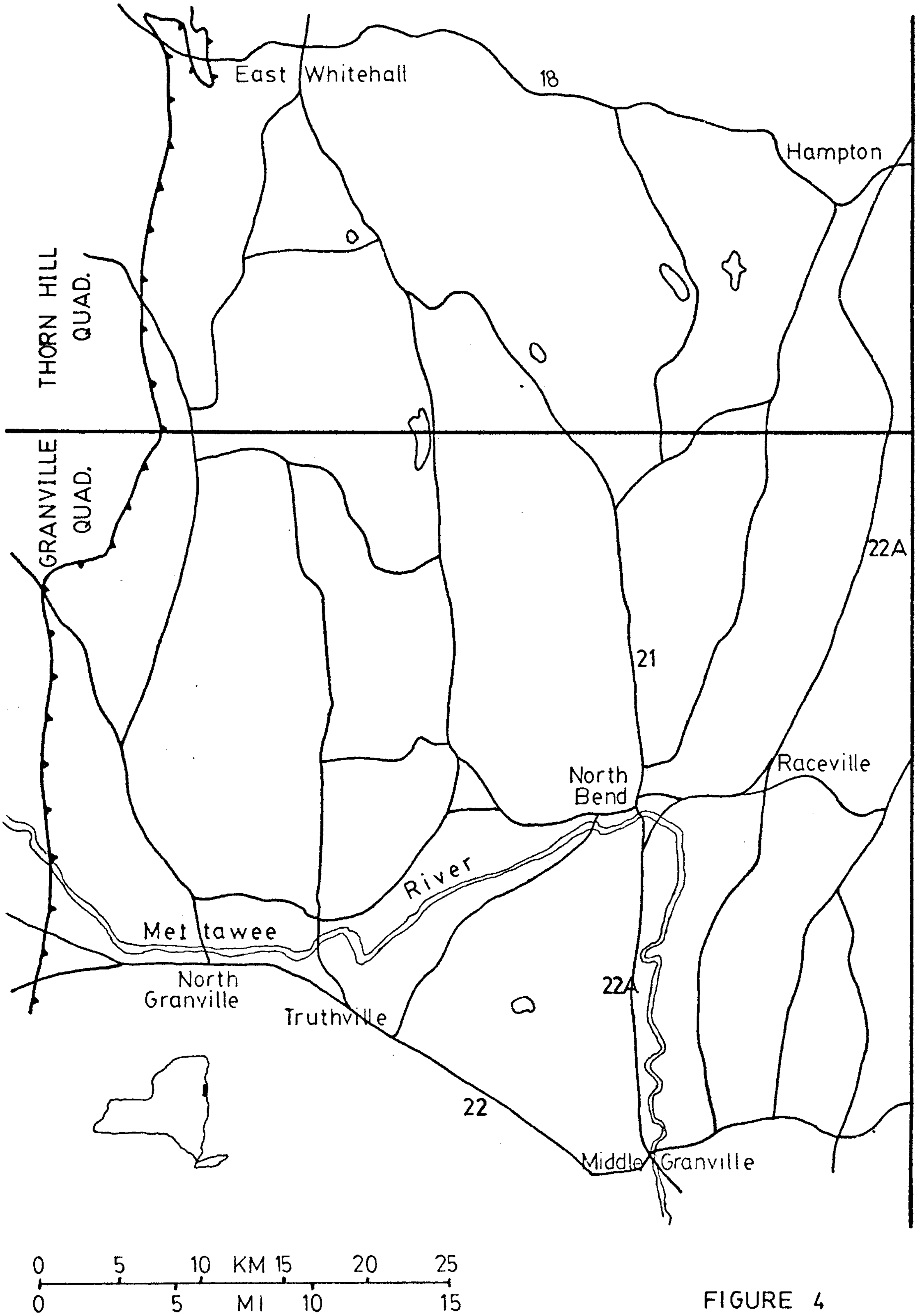

East Whitehall
18
Hampton
THORN HILL QUAD.
GRANVILLE QUAD.
22A
21
North Bend
Raceville
River
Mettawee
North Granville
Truthville
22A
22
Middle Granville
0 5 10 KM 15 20 25
0 5 MI 10 15

FIGURE 4

Figure 5. The study area with major areas of limited or non-existent outcrop outlined. Areas of cultivated fields were identified from aerial photographs. Swamps were picked off both aerial photographs and topographic maps. Most locations were verified at least in part in the field. The aerial photographs are dated 1968 and are therefore reasonably accurate and reliable. The topographic maps, however, were published in 1944 (Granville) and 1948 (Thorn Hill) and are more likely to be no longer accurate. The extensive pasturelands are not included on the map because outcrop is generally present in limited amounts, although it is often flat and indistinguishable unless one literally steps on it. For place names refer to the preceding diagram.

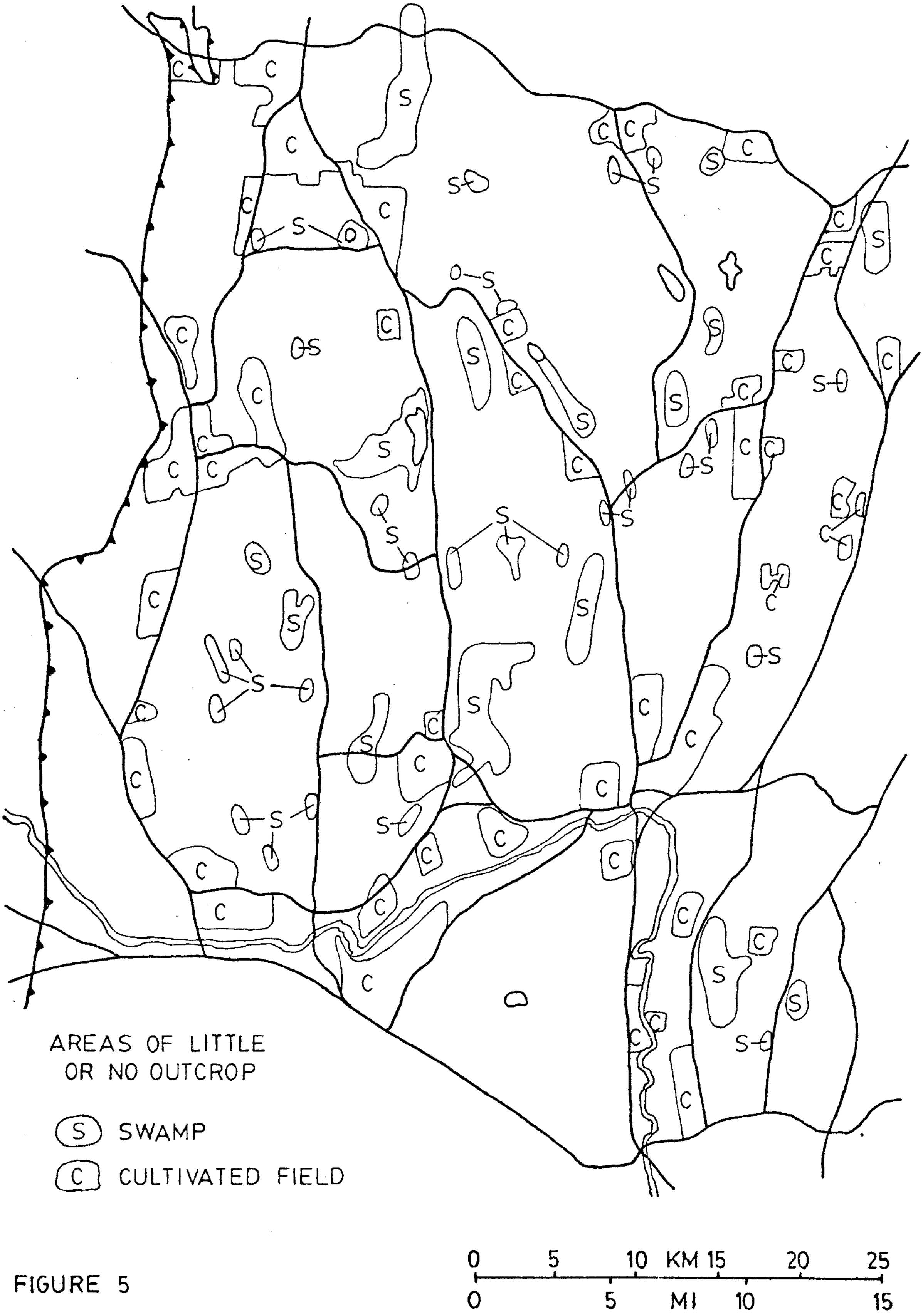

AREAS OF LITTLE
OR NO OUTCROP
S SWAMP
C CULTIVATED FIELD
0 5 10 KM 15 20 25
0 5 MI 10 15

FIGURE 5

more active time when the area was widely known for high quality decorative roofing slates. In the area studied only eight quarries are currently in operation. The quarries offer some excellent two and three dimensional exposures, although accessibility may be limited by waste piles and water. Roads and streams cut the area creating exposed rock. Other natural outcrop is generally good by comparison to more southern sections of the Allochthon. However, the outcrop was not adequate in many places to do as detailed a study as was needed. Because of the amount of area covered, much of the traversing was only on reconnaissance scale. Small, potentially key areas were then studied in much greater detail. Unfortunately, this procedure generally raised as many questions as it answered. Therefore, it is not known if outcrop-to-outcrop study confirms larger scale confusion, or if outcrop density is inadequate regardless of the thoroughness employed in mapping.

The study area was chosen for two reasons. Areal reconnaissance by the author in 1975 and by W.S.F. Kidd and members of the S.U.N.Y.A. Field Course in 1974 and 1975 showed that outcrop extent and evenness of distribution exceeds other comparable areas in the Allochthon. Other work (Dale, 1899; Theokritoff, 1964; Platt, 1960; Potter, 1972; Zen, 1961; Shumaker, 1967) in and near this area, particularly to the south, indicates that the complete stratigraphic section is exposed intact here while upper units are often missing elsewhere. In general, large scale structural coherence is maintained except in the southeast corner of the study area.

The intentions of the study were three-fold:

1) Make a detailed map of the area which would reflect a more precisely subdivided lithostratigraphic column than has been defined

previously. Extensive and detailed faunal stratigraphy (Walcott, 1888; Lochman, 1957; Theokritoff, 1964; Berry, 1972; Bird and Rasetti, 1968) has been done, and the author, not a paleontologist, has made no effort to check or duplicate this work.

2) Systematically record structural data in order to identify the different forms and to define accurately the large scale structures. Because the field area includes part of the western boundary of the Allochthon, it was also proposed to study the structures adjoining this boundary to discern the condition of the rocks at the time of emplacement.

3) Study sedimentary structures, horizontal and vertical sedimentary distribution, and the nature of the coarse clastic units in order to determine a provenance and an environment of deposition.

All three goals were achieved to some extent. The lithostratigraphy can be more specifically defined than was done by Theokritoff, 1964; Zen, 1961, or even by Dale in his definitive regional works in 1899 and 1904. The large scale structural picture has also been revised, although there was neither sufficient time nor obvious outcrop to study allochthon boundary features in the necessary detail. Except for recent sedimentologic work by Keith, 1975 and Keith and Friedman, 1977, only broad regional paleo-environmental conclusions have been drawn about the Taconics which are consistent with the plate-tectonic corollary framework for the lower Paleozoic northern Appalachians (Bird and Dewey, 1970). The present study does not contradict a continental rise deposition site for the original assortment of pelitic and coarser clastic sediments as was suggested by Bird and Dewey in 1970.

CHAPTER II   REGIONAL SETTING

History of Taconic Controversies

The Taconics have been intensively studied for a century and a half and have been the site and subject of several well-known geologic disputes. The Taconic System, as initially defined by Emmons in 1842, included several presumably autochthonous limestone and quartzite units in addition to the "taconic slate" and "magnesian slate." Subsequent fossil data demonstrated the beds were overturned and resulted in a reversal of order. However, despite both structural and paleontological evidence (Dana, 1888; Walcott, 1888) the relationship between the Potsdam Sandstone and rocks to the east was not fully resolved (Merrill, 1924) until the turn of the century. Despite cross sections that extended from the Taconics as far east as Richmond, Vermont, and Williamstown, Massachusetts (Emmons, 1842) a truly regional picture did not emerge until T.N. Dale's monumental works of 1899 and 1904.

Dale's study of the slate belt of New York and Vermont included stratigraphy, petrography, structure, geochemistry and economic geology. Despite the area covered, (he mapped the equivalent of 15 7 1/2 minute quadrangles in Vermont, Massachusetts, Connecticut and New York), and the understandable emphasis on marble and slate, the economic units, a detailed stratigraphy was defined. Except for dating problems with the Pawlet Formation and an apparent disregard for facies changes, most of Dale's stratigraphy is still recognizably correct today. Unfortunately, his maps concentrated on the economic units and did not reflect the detail of his stratigraphic descriptions. His comparably detailed work to the east on carbonates supplied data for the "klipenists" in the ensuing controversy, although Dale himself was a "non-klippenist."

The first serious suggestion that the abrupt change in lithology in adjoining rocks of the same age resulted from a fault contact came in Ruedemann's 1908 discussion of inlier types in New York. Up to then, and for a vocal faction who continued until about 1960, the opposing explanation was a non-allochthonous set of dual troughs or basins which would result in the adjacent radically different facies. Keith in 1913 produced the first detailed study that showed that five of his seven Taconic units were in contact with the surrounding limestone, and that at least in some of the exposures a fault contact was demonstrable. As study continued a definite geographic pattern emerged. Workers in the southern Taconics, where the contrast is less striking and the boundary faults implied rather than stated, tended to be "non-klippenists" (Balk, 1953; Lochman, 1956; Weaver, 1957; Craddock, 1957; Bucher, 1957). Workers in the northern Taconics were exposed to much better evidence and tended to be "klippenists" (Bird, 1969; Keith, 1913; Zen, 1968; Platt, 1960; Cady, 1968; Thompson, 1952; Kaiser, 1945; Rodgers, 1971). The main objections of the non-klippenists were 1) lack of a clearly defined continuing boundary thrust (Craddock, 1957), 2) lack of intense boundary deformation (Bucher, 1957) and 3) lack of a recognizable root zone for the thrust (Hawks, 1941). However, after the late fifties the once vocal non-klippenists ceased to publish. Their objections were legitimate and were dealt with by a newer theory that at least the western-most slices were emplaced by submarine gravity sliding (Zen, 1967; Cady, 1968; Bird, 1969). This would explain the discontinuous indistinct boundaries and the eye-catching wildflysch conglomerate found near the margins. It also eliminates the need for a root zone although several authors believed they had located one (Keith, 1932) or because of the higher grade of metamorphism and deformation to the east were not concerned that they had not (Kaiser, 1945). This theory seemed a good compromise to the emplacement controversy, although at least one worker, Sales, 1971, still advocated a rooted geosynclinal thrust and stated that the Green Mt.-Berkshire uplift resulted only in klippe isolating erosion, not detachment gravity sliding. He supports his hypothesis with models and continental ice sheets which purportedly show that the motion of allochthonous piles is a function of the morphology of the upper surface, not of the basement. However, he evades the questions of root zone location and poor boundary definition.

The "room problem" points out that there is not enough lateral extent across the Green Mts. and Berkshire Highlands to accommodate the pre-emplacement Taconic sequence. Following Kay's direction (1935), Zen (1967) estimates that unfolding and undeforming the Taconics would increase the maximum Taconic width from 30 to 50 km in contrast to 25 km across the mountains to the east. He ingeniously accounts for this extra width in several ways.

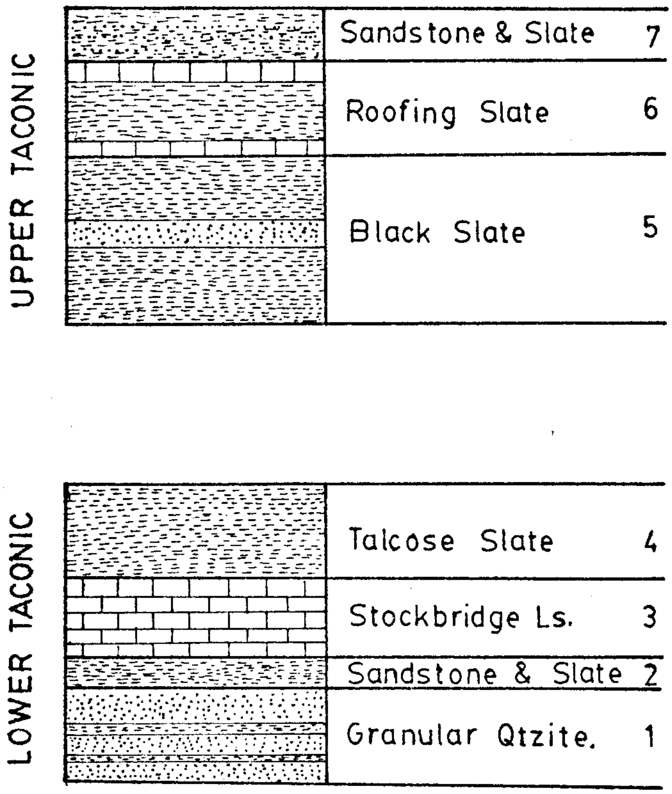
The estimated distance up over the mountains, the "circumference", adds approximately five km to the horizontal or "chord distance." Known displacement along the Berkshire-Paleozoic contact adds six km. Multiple shears with consistent east-over-west motion widen the original site by up to 12 km. These figures conveniently add up to 48 km; however, Zen admits that at some latitudes the pre-Cambrian is unusually narrow and presents a problem not yet resolved. Other variables are not well substantiated. Because of the shortening effects of major and minor faults and folds plus possible extension via "kneading," the actual amount of telescoping of the original width is very difficult to define precisely from the Allochthon preserved now. If the present author's study area is structurally representative (and most workers agree that if anything the deformation increases to the east: Wright, 1969; Lane, 1970; Zen, 1964; Thompson and Norton, 1968), a 100 per cent increase over the observed extent is a very conservative estimate. Also, the Green Mt. uplift started in earliest Middle Ordovician after the bulk of Taconic rocks had been deposited on a specific width of pre-Cambrian rocks. The uplift would attenuate the section, and in Zen's estimate the affect of this stretching has been accounted for twice unless additional stretching is postulated in later deformations. The "room problem" still exists. It may eventually be resolved, but number manipulation is not sufficient.

Development of Stratigraphic Thought

The development of Taconic stratigraphic thought passed through several phases, all with attendant reference frames and terminology. Fortunately in 1964 Zen compiled all the names, descriptions, and possible correlations into an invaluable reference work. Units are defined lithologically; where fossils are available they are dated paleontologically. As reported by Merrill (1924) many prominent nineteenth century geologists studied Taconic rocks and fossils, and by 1888 a strictly lithostratigraphic series (Emmons, 1855; Dana, 1888) and a fossil dated series (Walcott, 1888) had been proposed (Figure 6). Both included calcareous autochthonous rocks.

In 1899 Dale's comprehensive work on the slate belt was published including a fully detailed stratigraphic column based both on his own field work and the relevant previous work. Additional papers (1904a, 1904b) filled out a stratigraphy which has served since then as a framework for more specific work in smaller areas in all parts of the Taconics. Dale's only major error was the misplacing of the Hudson Grits. Graptolite studies (Berry, 1962) have shown the Pawlet/Austin Glen (as it is now named: Shumaker, 1967/Goldring, 1943) to be the youngest of the allochthonous series and also probably partly autochthonous in nature (Rickard and Fisher, 1973; Zen, 1967; Bird, 1969).

Dale tended to use letters and cryptic descriptions rather than formal names for his units. The first widespread "naming" was by Ruedemann in Cushing and Ruedemann, 1914. Others followed, particularly Swinnerton (1922), Keith (1932), Theokritoff (1959, 1964) and Zen (1961). Facies changes, certainly present but difficult to document because of



EMMONS' LITHOSTRATIGRAPHIC CHART

	AGE	FMS. from EMMONS
ORDOVICIAN	Middle	2=7
	Lower	4
		3
CAMBRIAN	UPPER	4
	MIDDLE	1=5+6

WALCOTT'S BIOSTRATIGRAPHIC REVISION

FIGURE 6

Figure 6. Two early Taconic stratigraphies. Emmons introduced the term "Taconic System" in 1842, and he defined a stratigraphy exclusively on the basis of rock type. Walcott was the first geologist (1888) to make extensive use of paleontological data (his own and others). He discovered that Emmons had failed both to order the sequence correctly and to recognize repeated units.

insufficient outcrop, also complicate litho-stratigraphic correlation. This multiplication of stratigraphic names and descriptions from different sections of the Taconics inevitably caused duplication, non-equivalence, and confusion. A few representative examples are mentioned below, and a number are tabulated in Plate IV.

The Zion Hill Quartzite, because of an early miscorrelation by Dale, has been assigned to Upper Cambrian and Cambrian (?) by different workers. The initial description obviously refers to the lower unit, but both have sensibly been replaced by the Hatch Hill (Theokritoff, 1959) and the Bird Mt. (Zen, 1961) respectively. The position of the Black Patch Grit (Dale, 1899)/Eddy Hill Grit (Cushing and Ruedemann, 1914) with reference to the Mettawee Slate is still not established; there is some evidence in the present study area that it appears both above and below. Dale's Unit J, Greenish Shale, (1904b) is generally unrecognized by other workers and has been offered as negative evidence to support an unconformity between the West Castleton and the Hatch Hill Fms. However, Platt (1960) identified a shale of similar color and stratigraphic position in the Cossayuna Quadrangle. He estimated the thickness at $\geq$ 100 m but did not name it because " . . . naming a geological formation which is largely invisible is of questionable value . . . " (p. 32). The Schodack Formation "has undergone extraordinary complications even for the Taconic region" (Zen, 1964, p. 75). Questions exist about which rocks are involved and how they relate to Dale's stratigraphy; in addition there are discrepancies between northern and southern descriptions. Theokritoff (1963) recommended that Schodack as a term be eliminated in favor of the more specific West Castleton. The position of the Austin Glen/Pawlet was established with fossils after an initial misplacement by Dale. However, the submarine slide emplacement hypothesis has helped to explain the varied nature of the unit as both autochthonous and allochthonous.

Bird and Dewey (1970, 1975) have utilized plate tectonic corollary principles to model the Appalachians. This hypothesis proposes the continental rise as a depositional environment for the Taconic sequence. Present day rise sedimentation observed in cores (DSDP, 1970-1977) and photographs (Bouma and Hollister, 1972) does not contradict this proposal. Surrounding and underlying contemporary carbonate units are identified as the autochthonous continental shelf sequence. Rise sedimentation is highly variable, and there is no unit of Taconic stratigraphy which could not have been originally deposited there.

CHAPTER III STRATIGRAPHY

Introduction

The area of this study is entirely underlain by allochthonous Taconic rocks. The full Taconic sequence is recognized here except for the units below the Bomoseen Wacke: i.e. Dale's 1904 units A-E, including the Rensselaer Graywacke, the Biddie Knob Formation, and the Bird Mt. Grit. Mapping done in nearby quadrangles to the east and to the south (Zen, 1961; Hewitt, 1961; Fowler, 1950; Platt, 1960; Potter, 1972; Shumaker, 1967) defines a fairly consistent although not always error-free stratigraphic column (Plate IV). Mapping done previously in the specific study area (Theokritoff, 1959, 1964) was fossil oriented and can be refined lithologically in the lower and upper units to make a more detailed column. The following descriptions of the stratigraphy from base to top and all field identifications of rocks are based entirely on lithologic definitions and nomenclature.

Bomoseen Formation

The wacke in the Bomoseen is a hard, dull, gray-green micaceous rock. It is often narrowly interbedded with siltier, slightly softer wacke (or silty slate) so that a weathered surface will appear ribbed. Ribbing can also result from cleaner, finely laminated quartz arenite lenses in the silty wacke (Figure 7). No substantial outcrop of the finer-grained material was seen, although it has been reported in other areas. The weathered surface is usually light tan. The dull purple slate noted by other workers (Theokritoff, 1964; Dale, 1899) was seen in only two locations in the area. In both instances the purple slate was near the possible base of the wacke (in the cores of anticlines), and may be the

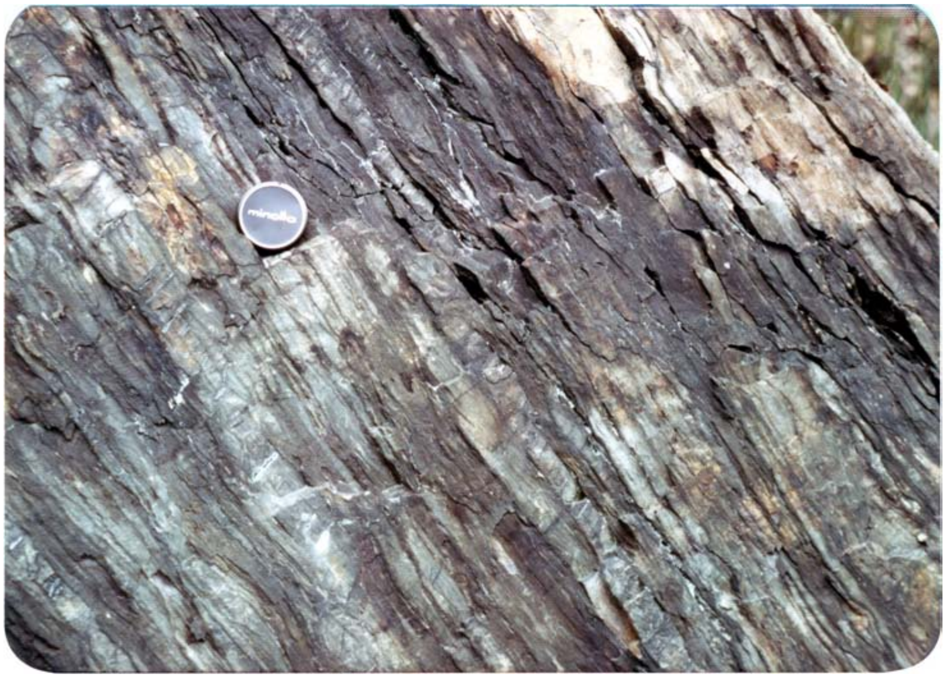


Figure 7. Bomoseen Fm. wacke with narrow quartz arenite beds.

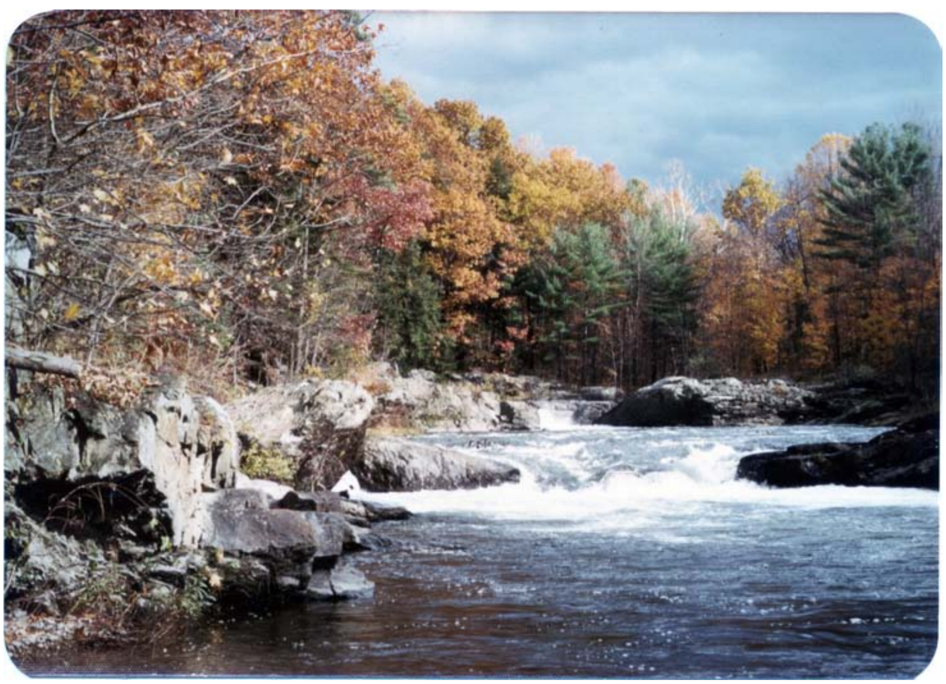


Figure 8. Typical Bomoseen Fm. wacke outcrop in the Mettawee River.

next lower unit, Dale's 1904a Unit E. As pointed out by Theokritoff (1964), Bomoseen wacke and silty wacke are characterized by mica "spangles" readily visible in hand sample. It is not the only unit to display these and should, therefore, not be used for positive identification, but it is the most consistently micaceous unit.

Slaty cleavage development is generally mediocre, although somewhat variable depending on the grain size. However, it is never a planar, readily measured feature, but rather an anastomozing network of mica films as has been described by Means (1976). The ribbing sometimes highlights folds, which are probably not more prevalent here, but instead more visible. Except for completely ambiguous but possible small cross beds and some regular bedding, no sedimentary structures were seen. Slumps and channel features have been reported, however (Kidd, pers. comm. 1977).

Bomoseen wacke is a very resistant rock and tends to form hills, waterfalls, etc. (Fig. 8). Its outcrop extent is fairly obvious because the next unit is a much less resistant slate and more likely to be marked by its absence unless "protected" by overhanging wacke.

The Bomoseen contains occasional substantial (commonly up to one meter) clean white quartz arenite beds (Figure 9). Surfaces show little brown stain which would indicate carbonate, and the mica, characteristic of the rest of the unit, is absent except on the margins. The arenites are massive and seldom show any sign of bedding or cleavage development. Grain size varies from silt to coarse sand. Theokritoff (1964) refers to these as "lenses" and states they are sometimes traceable as far as two km. The author did not attempt to trace any, but the map pattern suggests they can be extensive.

Dale (1899) referred to this unit as the Olive Grit. The name

Figure 9. Contact between Bomoseen Fm. wacke and Bomoseen Fm. arenite.

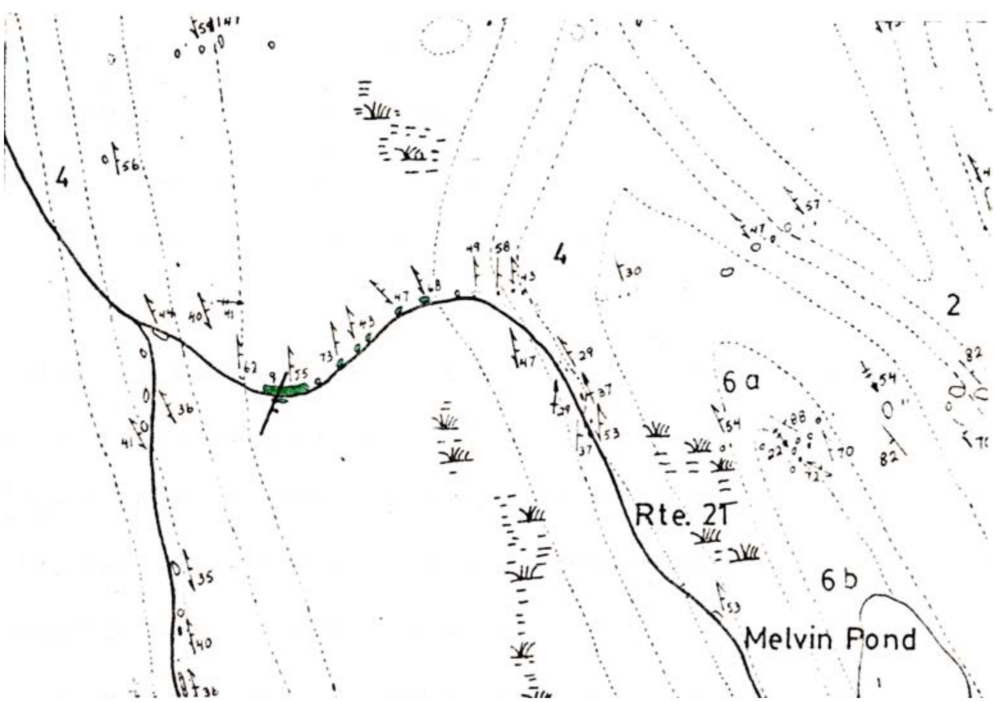


Figure 10. Location map for the reference section of the Bomoseen Fm. (colored outcrops)

Bomoseen was first used by Cushing and Ruedemann (1914) who used Dale's suggested type section on Lake Bomoseen, Vermont, and the name has been widely accepted since then. The best reference locality within the study area is a series of road outcrops on Route 21 less than 250 m east of the intersection with Holcombville Rd. (Figure 10). It is recommended that the Bomoseen's status be changed from Member to Formation because it is readily mappable in this area. This unit is the base of the sequence along the western margin of the allochthon, and it forms the cores of the anticlines. Its minimum preserved thickness is estimated at 150 m.

Truthville Slate Formation

The Truthville Slate Formation is a soft olive gray-green slate which is fissile and feels and looks silty. Despite an intermittent sheen it is not a quarryable unit. It may have small fragments of muscovite parallel to the cleavage and inferred bedding and narrow lensing sub-quartzose arenite bands near the base of the unit. The contact between this slate and the underlying wacke is gradational over about a meter. The weathered surface is also tan but an olive cast is always retained.

Slaty cleavage is fairly well developed as would be expected in a uniformly fine-grained rock. Bedding is presumably marked by the arenite layers where present. No other sedimentary structures were noted, but this may merely reflect the absence of contrasting beds. The outcrop quality of this unit is generally poor. It is best seen in river and road cuts (Figure 11), and less often in isolated forest and field outcrops. Despite its nondescript appearance it is fairly distinctive in the field when present, at least in contrast to adjacent units.

Figure 11. Road outcrop of Truthville Fm. slate showing narrow lensing quartz arenite layers.

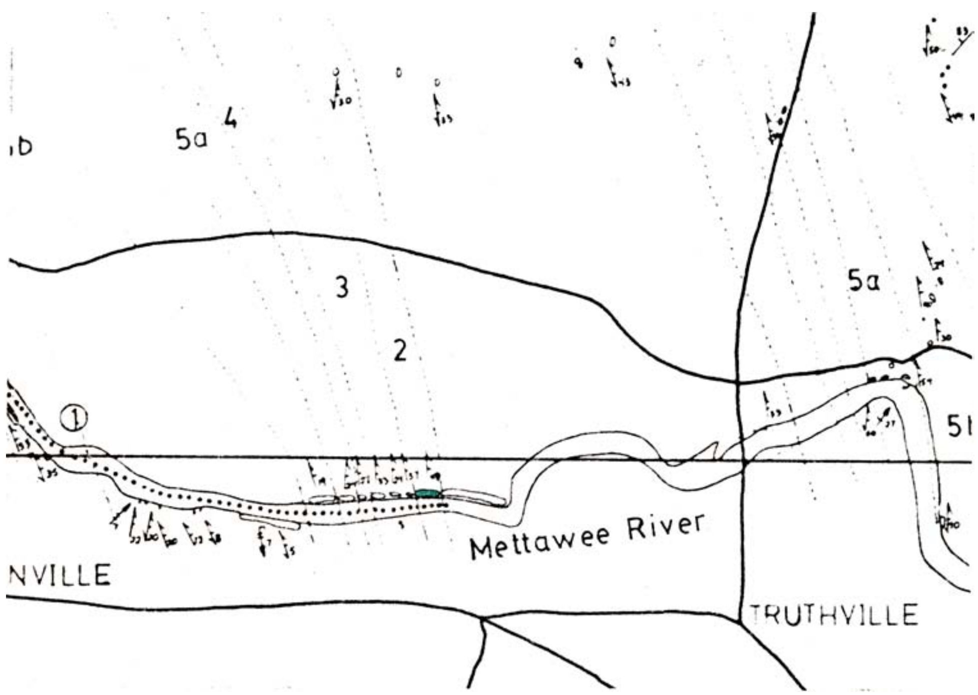


Figure 12. Location map for the type locality section of the Truthville Slate Fm.
(colored outcrop)

An extensive literature search found no mention of this slate as a discrete unit. However, Zen (1961) mentions several locations where the Bomoseen wacke is a gray-green coarse slate which grades into the Mettawee Slate and the Bomoseen wacke proper. He interprets this as a fairly local facies change. Apparently color and visible micas have resulted in its being grouped with the underlying wacke. However, it is much better cleaved and finer-grained than the "slatier" component of the underlying wacke. It is consistently present at this horizon, is distinctly mappable, and in the few locations where accurate measurement is possible, has an approximate thickness of 30 m; it is therefore proposed as a new Formation.

The two good (and only complete) exposures seen are on the north shore of the Mettawee River between North Bend and North Granville. The better of the two extends 480-525 m west of the Truthville bridge (Figure 12). The outcrop has no gaps, it is accessible for study, and it clearly shows both upper and lower contacts. It is proposed for the type section for the Truthville Slate Formation.

Browns Pond Formation

The Browns Pond Formation is a predominately black, intermittently calcareous, finely cleaved, rather fissile slate. Because of the color change, the contact with the underlying slate is sharp; however, it is very seldom exposed. The slate can include limestone, limestone conglomerate and breccia, calcareous quartz wacke, and one or two thick clean quartz arenites.

The limestone is compact, light gray, and sometimes finely bedded. It is generally in narrow (up to two cm), continuous bands or lenses, although beds up to 25 cm thick have been seen (Figure 13). The limestone is usually micritic, but it can be calcisiltite, or rarely, calcarenite. It appears intermittently throughout the slate and is not regularly distributed or concentrated at any level, although there is sometimes a substantial amount near the upper contact.

There are at least two types of conglomerate or breccia horizons. One has a black or gray slate matrix and contains jumbled slumped blocks of carbonate, lesser amounts of slate, and rarer quartz arenite and quartz wacke. The clasts vary widely in size and can be pieces of regularly bedded consolidated material or have irregularly lensing shapes suggestive of prelithification incorporation. The matrix is not well bedded and often shows tight, irregular possible slump folds and flow structures around larger blocks. The other type is a closely packed breccia of limestone clasts in a slaty or occasionally sandy dolomitic matrix. It looks like a bed broken and recemented with minimal transportation. There is little variety in clast size and type, and the proportion of matrix is much smaller. It only occurs at the top of the unit and can be well exposed in Mettawee slate quarries (Figure 14).

The calcareous quartz wacke is a very distinctive lithology. The medium to coarse, clear, rounded quartz grains look black in the outcrop. Mica and occasional lithic fragments (usually black slate) are also visible. The thickness of this sub-unit is unknown although it has been reported up to 12 m in other areas (Dale, 1899). It is often, but not necessarily associated with one of the thick massive quartz arenites in the lower half of the formation.

The quartz arenites are hard, white, clean, and only faintly rust-speckled. They are sometimes finely bedded and sometimes apparently

Figure 13. Bed of limestone marking the top of the Browns Pond Fm. Because of bed inversion the limestone is structurally overlying the Mettawee Fm. in this location.

Figure 14. Upper limestone conglomerate in the Browns Pond Fm. The clasts are dismembered limestone beds, and the matrix is sandy and dolomitic.

massive. One or two of these arenites, measuring three to ten meters thick, occur in the bottom half of the formation. The quartz grains are large and rounded.

None of the rock types weathers very distinctively except for a faintly rusty exterior. Slaty cleavage development is highly variable in the slate, rather poor in the wacke, and virtually non-existent in the limestone and quartz arenite. Folding is relatively common, and examples of both slump and tectonic folding have been seen (Figure 15).

The field appearance of this unit is highly variable because of the different rocks present. The slate component weathers away readily, but the arenite, limestone, and wacke provide good identification keys even as isolated outcrops. Only in road cuts and river sections are truly representative examples available. The thickness of the unit varies greatly and is difficult to measure, but has been seen in the Mettawee River sections from 21-52 m. Both of these outcrops are continuous and include upper and lower contacts so the difference is real; however, neither contains all the components. All the sub-units except the slump conglomerate are present in the proposed type section, but exposure is discontinuous, and only the upper contact is visible. The calculated thickness there is 130 m (Plate III, Columns 1, 4, and 6).

Because of poor outcrop and lensing sub-units it is impossible to know if these sub-units always recur in the same order. However, one can say that the close-packed breccia when present is always at the top of the formation. Usually one arenite is near, but not at, the base of the formation, and the second with associated black quartz wacke is near the middle. Because of these uncertainties none of these sub-units has been assigned member or marker bed status.

Figure 15. Slump folds in Browns Pond Fm. slate. Slate layers above and below the folds were undeformed prior to slaty cleavage development.

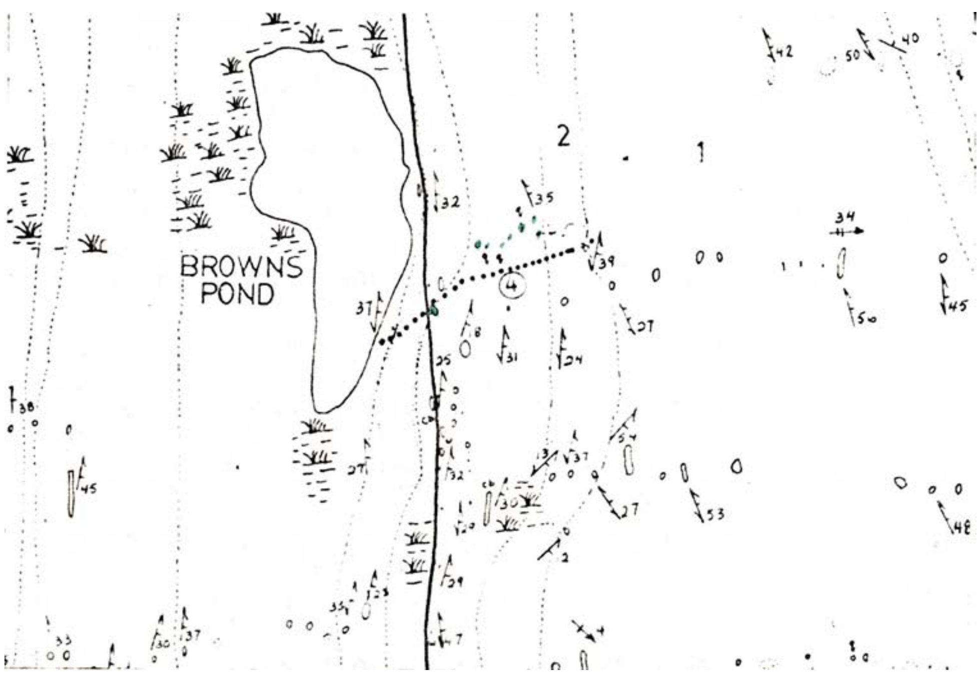


Figure 16. Location map of the type locality section for the Browns Pond Fm. (colored outcrops)

Theokritoff (1964) included this unit with the overlying Mettawee Slate. However, they are readily differentiated. Dale distinguished a Black Patch Grit (1899) and a Granular Quartzite, Unit G (1904a) which are almost certainly the arenite and wacke sub-units described above. Cushing and Ruedemann (1914) used the term Eddy Hill Grit for the wacke and Diamond Rock Quartzite for the arenite. Both terms caused confusion because the locality of the type section of the Eddy Hill Grit was temporarily lost, and because the nature of the Troy Shale overlying the Diamond Rock was never really clear. (It is probably correlative with the Mettawee Slate.) Zen (1961) proposed Mudd Pond Quartzite for the arenite and observed that locally it grades into the Eddy Hill lithology. Zen further noted that the Mudd Pond can be two quartzites separated by up to 15 m of "typical Mettawee slate" (Zen, 1964, p. 56). There apparently is no designation for the black slate and limestone unit as a whole, but only these separate distinctive beds. However, if the overlying multi-colored quarried slate is "typical Mettawee," the black slate definitely is not and should have an individual identity. In order to maintain this distinction the black slate with limestone, arenite, quartz wacke, and breccia and conglomerate is named Browns Pond Formation. The type section is from 10 m west of Holcombville Rd. at a point 1125 m north of the Holcombville Rd.-Crossroad intersection and continues east across the road to the first exposure of the Truthville Slate near the swamp (Figure 16). It is not a complete section because it lacks an exposed lower contact and any sign of a slump conglomerate. The best exposure of the conglomerate is in the continuous outcrop of the formation seen on the north side of the Mettawee River 510-600 m west of the Truthville bridge. This exposure shows both contacts, but is abbreviated.

Mettawee Slate Formation

The Mettawee Slate is a well-cleaved but non-fissile purple, green, and gray slate. The color changes do not necessarily coincide with cleavage planes or bedding (Figure 17). The contact with the underlying formation can be sharp if there is a limestone bed marking it, or gradual (over two meters or less) if there are only color and hardness changes. Color changes within the unit are inconsistent except that the upper few meters are usually gray slate with black bioturbation blebs and laminae. Narrow limestone and quartzite layers have been noted elsewhere (Zen, 1964) but were not seen in this area, but two quarries near Middle Granville contain a lensing limestone and/or phosphatic pebble conglomerate. Weathering mutes but does not change the colors; the purple is distinctive even in a small isolated outcrop.

The slaty cleavage is very well developed, and the rock is widely quarried. Bedding is assumed to parallel cleavage, and no other sedimentary features were noted. In quarries exposure is, of course, excellent; natural outcrops tend to be small, low and unremarkable, especially if the slate is gray or dull green. The thickness is variable and has been measured from 10 to 50 m. The distinctive purple slate component is not always present.

Dale (1899) called this unit the Cambrian Roofing Slate. Cushing and Ruedemann (1914) first used the name Mettawee, and chose a type locality in the southern part of the present study area (Figure 18). Their original description specifies a purple and green slate or mudstone, and so subsequent inclusion of the underlying black slate, etc., is incorrect. The name Mettawee Slate Formation has been retained as appropriate and consistent and is used in its limited sense to conform

Figure 17. Colors in the slate of the Mettawee Fm. Changes do not necessarily parallel slaty cleavage which in this location is assumed to have the same orientation as bedding. Even when color changes do parallel bedding and cleavage, they may reflect subsequent weathering along planes of weakness rather than a change in the original depositional setting.

with the original description.

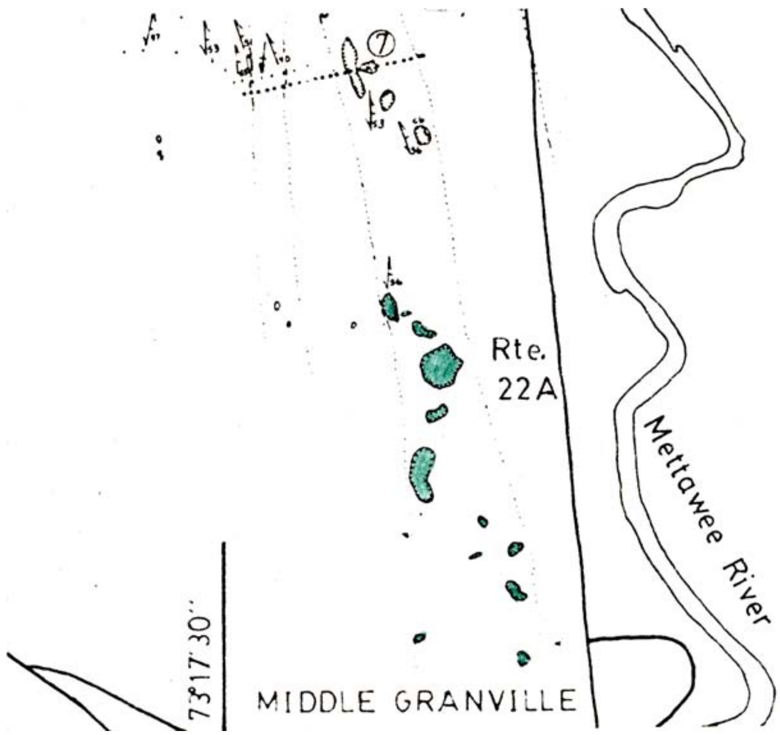


Figure 18. Location map for the type locality section of the Mettawee Fm. as designated by Cushing and Ruedemann, 1914. (colored outcrops)

Undifferentiated West Castleton - Hatch Hill Formation

The next two formations, the West Castleton and the Hatch Hill, are placed together. There are two reasons for this decision 1) They share a lithologic common denominator: one is black slate and gray limestone, and one is black slate and dolomitic arenite. 2) The lower unit is known to be lensing and in addition is very poorly exposed in the field; its mappability, a prerequisite for formation status, is borderline. The exposure of the upper Hatch Hill Formation is generally good, and its formation status is unquestioned in this area. Therefore, it would not be a solution to assign both units member status in a formation, but the West Castleton cannot stand as an independent formation here as it can in other areas (see Discussion).

There is only one location in the field area where a full section of continuous outcrop is exposed: along the north shore of the Mettawee River between Truthville and North Granville (Figure 19). However, the Hatch Hill is anomalously thin in this location (compare Column 2 in Plate III with other columns), and it would not be a good reference locality, but is the best available.

The literature was searched to find an appropriate pre-existing name. Workers in the southern Taconics have used the term "undifferentiated West Castleton - Hatch Hill" (Bird and Rasetti, 1968, Bell, pers. comm., 1977). The problem in the northern Taconics is not one of distinguishing the units, but of finding exposures of one of them; however, this name does refer to the same rocks and seems a reasonable compromise.

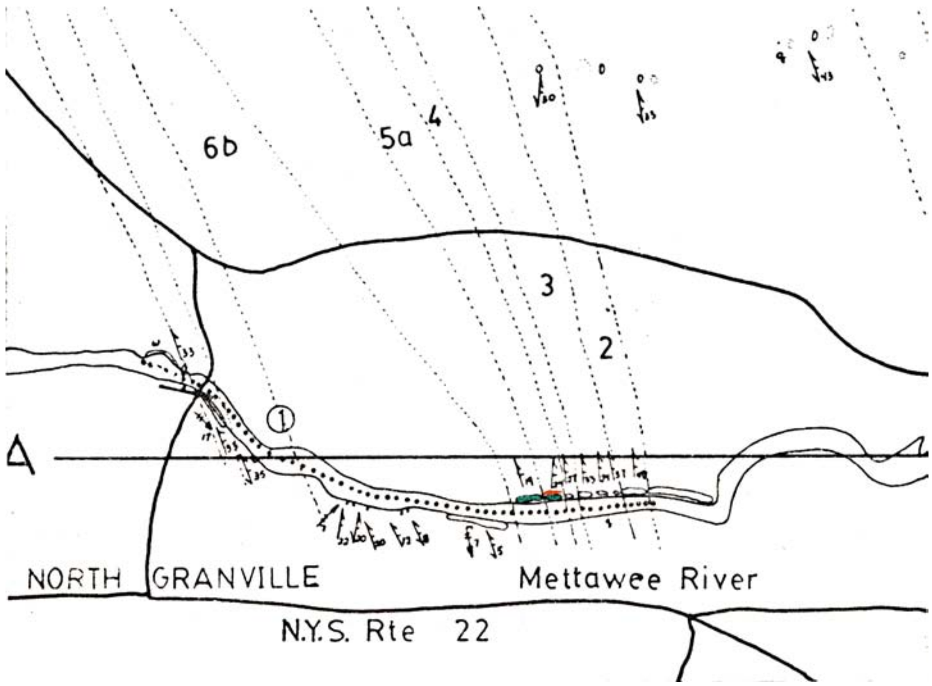


Figure 19. Location map for the reference locality for the Undifferentiated West Castleton-Hatch Hill Formation and for the West Castleton Formation. (colored outcrops)

West Castleton Formation

The West Castleton Formation is interbedded fissile black slate and fine to medium grained, medium to dark gray limestone with occasional dolomitic quartz arenite or wacke layers. Pyrite is a frequent component. The contact with the underlying slate is sharp although seldom exposed. (There is one excellent example in a Mettawee Slate quarry south of Hills Pond just west of Hills Pond Rd.) Weathered surfaces are not distinctive, and weathered outcrops are badly deteriorated. For this reason this is probably the worst exposed unit in the area. The thickness has been estimated as 26 to 46 m, but some of this variability could be from uncertain location of boundaries.

Slaty cleavage is well developed in the slate but not particularly well in the limestone. No other structures were noted, but this could be a function of outcrop scarcity. Narrow, but coarse dolomitic quartz arenites (2 to 5 mm) were seen in one location and black quartz wacke like that in the Browns Pond Fm. in one location. (Both instances were in indisputable West Castleton rocks.) The location of the Black Patch/Eddy Hill Grit has been extremely controversial over the years. (See Plate IV.) There are two contributing confusions: 1) It is difficult to differentiate West Castleton slate from Browns Pond slate, and it is therefore necessary to known whether the Mettawee Fm. is above or below. 2) Both units apparently contain wacke. The author observed a number of occurrences of wacke in the lower unit, often associated with a thick arenite. However, a similar wacke has also been observed in the upper unit. Misidentification of this upper example would result in misassigning the Black Patch/Eddy Hill Grit to the West Castleton, and possibly confusing the West Castleton with the Browns Pond or vice versa (Theokritoff, 1964; Fowler, 1950; Larrabee, 1939).

Dale (1899) referred to this unit as Cambrian Black Slate and Limestone. Cushing and Ruedemann (1914) named it Schodack Shale and limestone. However, Schodack rocks in the northern and southern Taconics were not the same unit. Theokritoff (1963) discussed this unfortunate situation and advocated that Schodack be limited to its southern Taconic application, and West Castleton (Zen, 1961) be adopted for the northern Taconic rocks. West Castleton Formation will be used in this paper, and the aforementioned reference section for the Undifferentiated West Castleton-Hatch Hill (Figure 19) will be used for the West Castleton also because it is the only complete section seen.

Hatch Hill Formation

The Hatch Hill Formation is interbedded fissile rusty black slate and thick, coarse-grained dolomitic sub-quartz beds arenite (Figure 20). The arenite weathers very deeply, despite its hardness, so that non-rusty samples are difficult to obtain. Quartz and carbonate filled veins are very extensive and give outcrops a distinctive cross-hatched appearance. The arenite is sometimes finely laminated. In one location a closely packed silica-cemented arenite breccia was seen (Figure 21).

The contact between this unit and the underlying one is taken as the first appearance of a substantial dolomitic arenite band. This uncertainty may in part explain the calculated thickness variation of 46 to 100 m. A number of workers have identified this contact as an unconformity or disconformity (Theokritoff, 1964; Platt, 1960; Bucher, 1957; Lochman, 1956) usually on paleontological grounds. The West

Figure 20. Hatch Hill Fm. quartz arenite and slate.

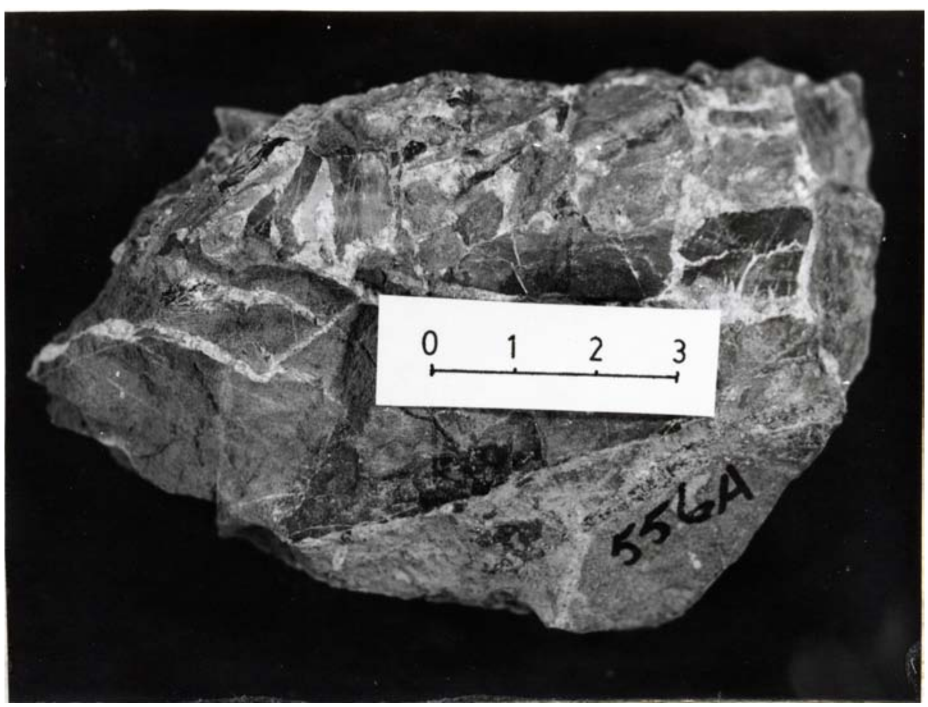


Figure 21. Quartz arenite and black slate breccia seen locally in the Hatch Hill Fm. This breccia was observed in only a few locations. It is very close-packed, and the matrix is entirely crystalline quartz. The scale bar is in centimeters.

Castleton has lower Cambrian fauna, and the Hatch Hill has upper Cambrian fauna, and so their contact has been asserted to be a middle Cambrian gap. Bird and Rasetti (1968) have demonstrated that at least in the southern Taconics there are a few representative middle Cambrian fossils. They suggest that faunal absences known elsewhere may be a function of unfavorable lithology and non-preservation rather than a break in the record. There is some unconformity supporting structural data but nothing which is really compelling. Shumaker (1967) puts an unconformity in his column, but avoids specific discussion in the text. Zen (1961) points out that a facies overlap could produce an apparent unconformity and Potter (1972) mentions that in his area the West Castleton is lenticular in shape. Both Platt (1960) and Theokritoff (1964) show map patterns which look unconformable, but neither actually saw the unconformity. Of course, an unconformity or disconformity is possible, but it is not necessary, and so the units are grouped lithologically.

Slaty cleavage is well developed in the slate and poorly or not at all in the arenite. Rare cross-bedding allowed determinations of tops and in one location possible soft sediment deformation was seen (Fig. 22). Because the arenite is so much more resistant, outcrops usually consist of arenite blocks, sometimes still in rows with gaps between where slate had been.

Dale (1899) called this Unit D, the Ferruginous Sandstone. Unfortunately, he correlated it in part with the Zion Hill, a much lower arenite so that some later workers (Larrabee, 1939; Cushing and Ruedemann, 1914; Fowler, 1950) called both units the Zion Hill. The two arenites have now been distinguished, and the upper one has been

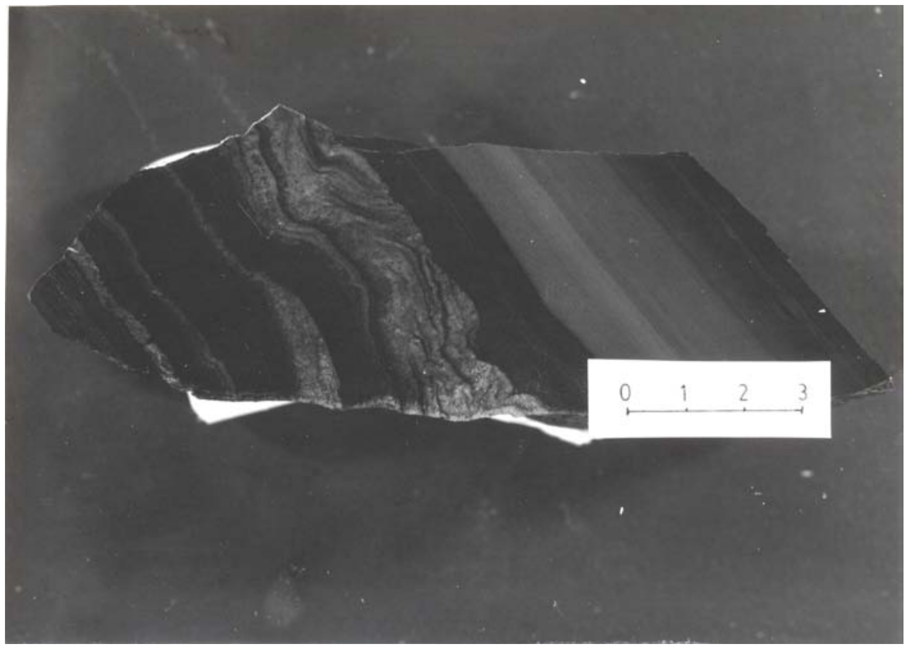


Figure 22. Soft sediment deformation in the Hatch Hill Fm. The slate and quartz arenite layers above and below the folded layers are essentially undeformed. The scale bar is in centimeters.

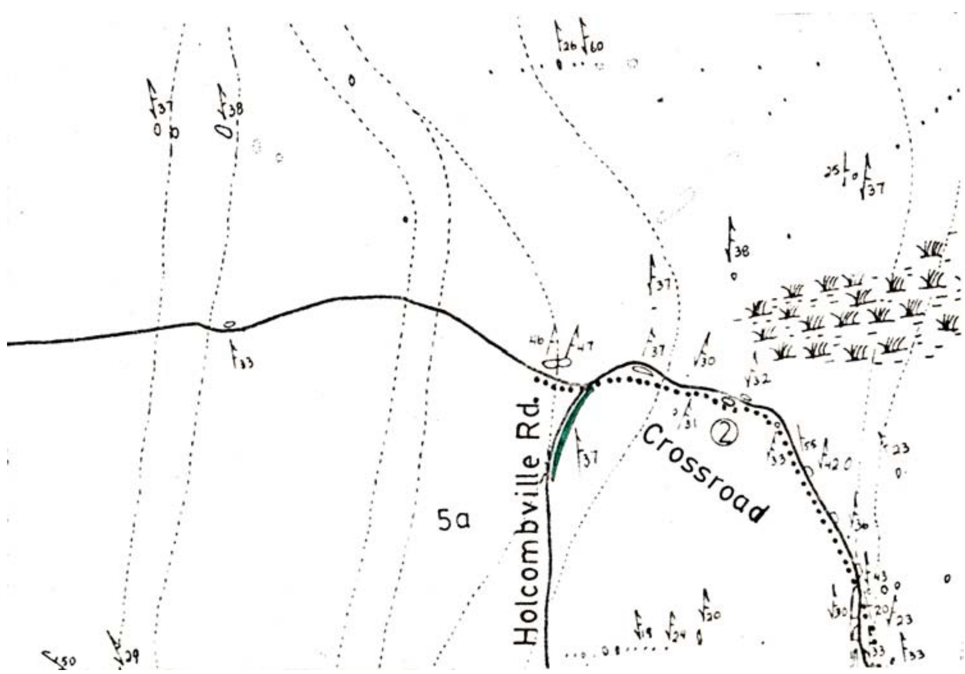


Figure 23. Location map for the type locality section of the Hatch Hill Fm. as designated by Theokritoff, 1959. (colored outcrop)

fossil-dated and renamed the Hatch Hill (Theokritoff, 1959). Theokritoff's type locality is in the present study area and is retained (Figure 23).

Poultney Formation

The next two units are analogous to the last two because the lower one is lensing and poorly exposed in the field, and the upper one is a well-defined mappable formation. In the past the two have been considered members of the Poultney Formation (Theokritoff, 1964; Potter, 1972; Zen, 1964; Platt, 1960). Because of the ambiguity and in the interests of consistency that name is continued here even though the upper member could be mapped as an individual formation. Theokritoff (1964) called the units "A" and "B", Platt (1960) called them Lower and Upper, and Potter (1972) gave them formal names, White Creek and Owl Kill Members. This author prefers formal member names but hesitates to use Potter's because 1) his descriptions do not exactly fit the rocks in this area and 2) the two areas are widely separated and the use of the same names would presume a correlation that cannot be demonstrated. Dunbar Member and Crossroad Member are the new names; descriptions and type localities are below.

Keith (1932) first used the name Poultney but included the present Hatch Hill within it. He emphasized the chert component of the unit, but this may have been a misidentification of the arenites because they can weather similarly. Since then the Poultney has been established as overlying the Hatch Hill and the name is widely used (Platt, 1960; Theokritoff, 1959; 1964; Zen, 1967; Shumaker, 1967; Potter, 1972).

The type locality is near but not in the present study area, and the original description implies that the full variety in the Poultney was not represented. A more representative reference section was selected along an unnamed crossroad west of its intersection with Holcombville Rd. (Figure 24). This shows the Dunbar and the Crossroad Members on the east side of a syncline and the Crossroad Member alone on the west (see also Columns 2 and 3, Plate III).

Dunbar Member

The Dunbar Member is a fissile dark gray to black, thinly cleaved slate with gray limestone beds that are medium to fine grained and sometimes silty (Figure 25). The contact with the Hatch Hill is marked by the end of the dolomitic quartz arenites and the beginning of the limestones.

As in other units the slaty cleavage development is related to the proportion of pelitic material in the original rock. No sedimentary structures were noted except bedding. The rock deteriorates readily and is not well exposed except for road cuts. The unit is known to be lenticular in shape (Theokritoff, 1964), but the extent cannot be determined because of the poor outcrop. A maximum thickness of 23 m was determined at one location.

Dale (1899) referred to this unit as the Calciferous. Keith (1932) first used the name Poultney, but his definition may not have included this calcareous section. Later usage (Theokritoff, 1964; Zen, 1967; Platt, 1960; Shumaker, 1967) definitively included the limestone and slate, and Potter (1972) named it the White Creek Member of the Poultney. It has also been known as Unit 6 of the Mt. Hamilton Group (Zen, 1961).

The best exposure in the study area is along the north side of

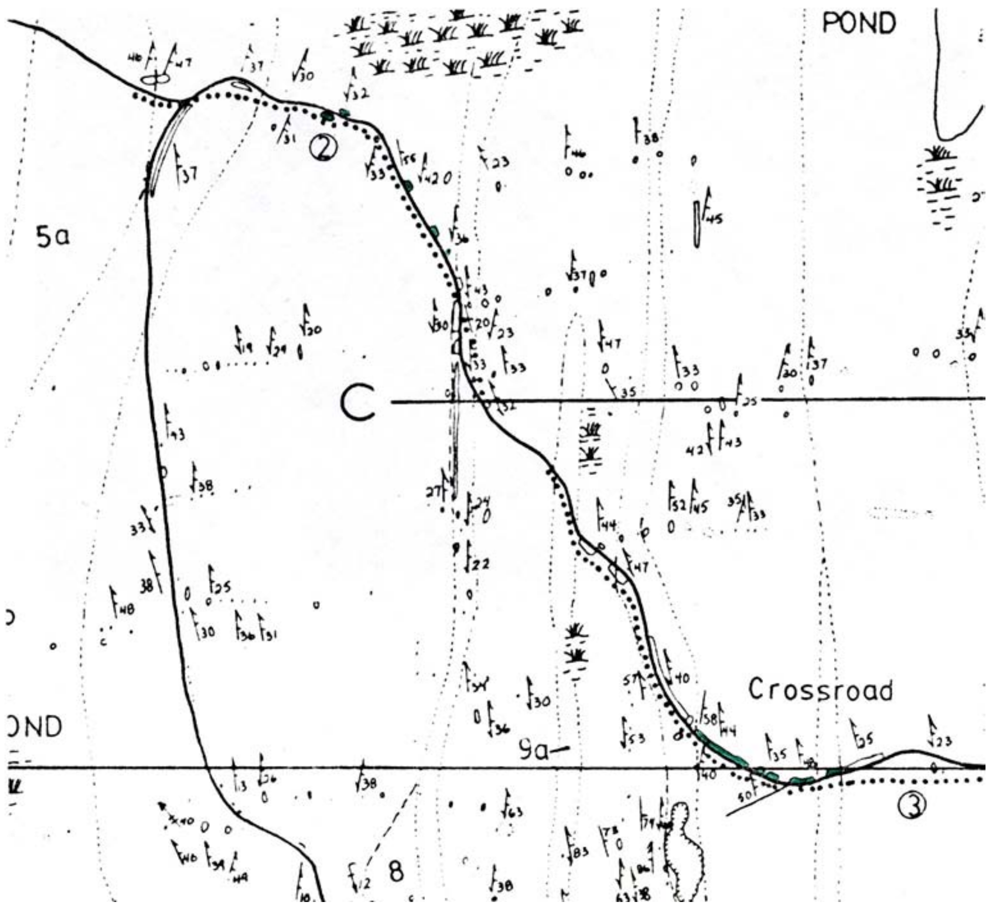


Figure 24. Location map for the reference locality section of the Poultney Fm. (colored outcrops)

Figure 25. Slate and limestone of the Dunbar Mbr. of the Poultney Fm. The highly weathered nature of the outcrop demonstrates why it is seldom preserved. Folds are visible in the left side of the photograph.

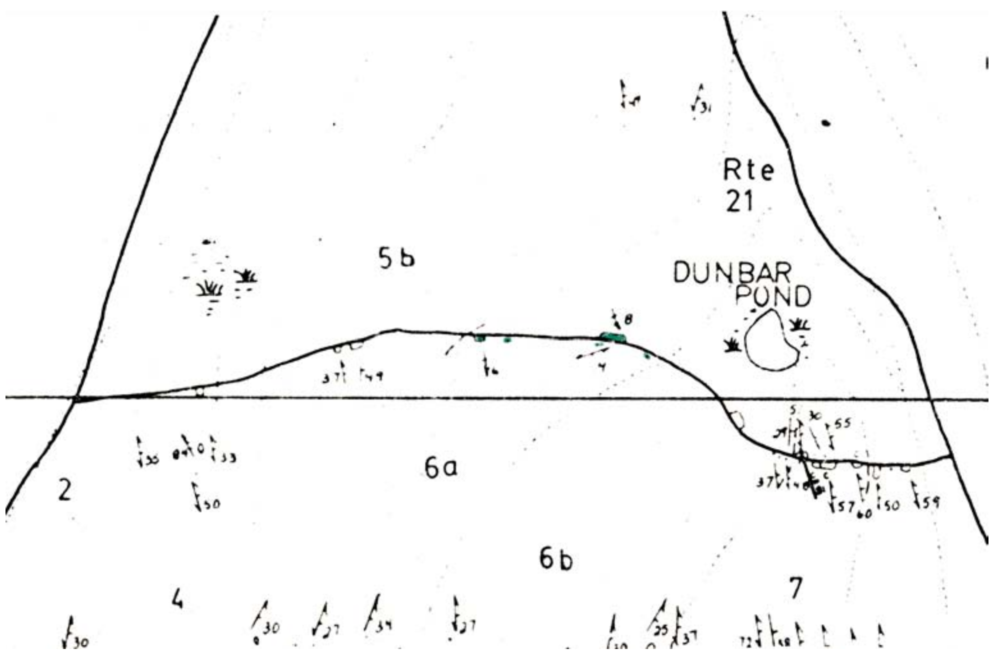


Figure 26. Location map for the type section locality of the Dunbar Member of the Poultney Formation. (colored outcrops)

Dunbar Rd. 400 to 600 m west of Rt. 21 (Figure 26). Neither contact is exposed and because of folding this location cannot be used for thickness calculation. However, it has been designated the type locality for the Dunbar Member.

Crossroad Member

The Crossroad Member is usually a hard, medium gray, not very fissile slate; however, the color can vary from very light gray to green. The contact with the Dunbar Member is seldom seen; it is dependent on the change from characteristic limestone to characteristic narrow quartzites and a gradual hardening of the slate. The slate can contain narrow (approximately 1 cm) "ribbon" quartz arenites, coarser, wider quartz arenites (up to 30 cm), gray chert and very narrow (1 to 2 mm) black slate layers. The color of the slate, though predominantly shades of gray, can be gray-green, green, black, or red (rare). Although unusual, there are also examples of two different limestone conglomerates.

The ribbon arenites are clean, fine-grained, white to pale pink, and often lensing (Figure 27). They are found intermittently throughout the unit associated with different colored slates. The narrow black slate bands are found in gray or gray-green slate and are often, but not exclusively associated with the ribbon arenites. They are frequently disturbed by probable bioturbation. The chert, which is the same light to medium gray as its associated hard slate, occurs less regularly. When present it tends to be near the top of the unit, although there is one locality where a small amount of chert was seen near the base. The wider arenites vary in appearance and grain size.

Figure 27. Ribbon quartz arenites in the Crossroad Mbr. of the Poultney Fm.

Some are expansions of the ribbon arenites, and some are coarser and resemble Hatch Hill arenites although they are less rusty. The weathered surfaces of the slate and the harder arenite or chert look ribbed. The chert looks white on weathered surfaces, but the other colors merely dull.

Two types of conglomerate were seen. In one the limestone beds have been disrupted and recemented in place (Figure 28). The other type has a greater variety of clasts including phosphate pebbles. The clasts are rounded, and there is no semblance of bedding (Figure 29). The limestone and slate do not weather distinctively, but the conglomerate nature is emphasized because the clasts tend to be harder than the matrix.

Because of the hardness of the slate it is much less closely cleaved than softer units. The overall hardness of the rock provides relatively extensive outcrop, often scores of meters long. The thickness varies from 150 to 175 m.

Dale (1899) referred to this unit as the Hudson Shales and the Hudson Thin Quartzites. Keith (1932) first used Poultney; subsequent workers have subdivided the unit into two or three sub-units, of which the upper one or two correspond to the unit described here.

The best outcrop example of this member is part of the reference section for the Poultney Formation. It shows all the features described except the conglomerates, which are highly localized. This crossroad has been picked as the type locality for the Crossroad Member (Figure 24). In addition, the road outcrop at Raceville should be mentioned because of the outstanding exposure of one of the limestone conglomerates.

Figure 28. The limestone clast conglomerate in the Crossroad Mbr. of the Poultney Fm.

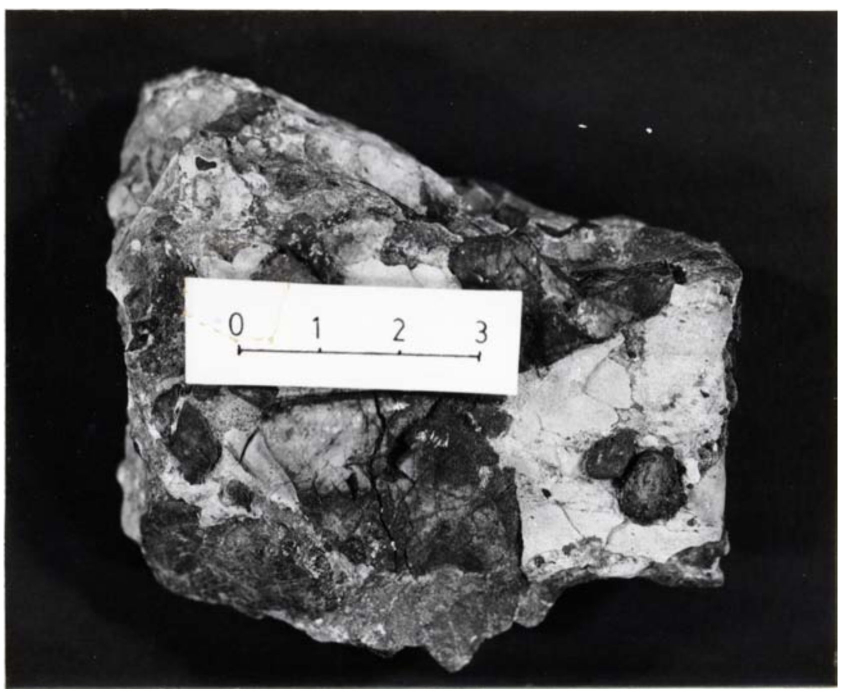


Figure 29. Phosphate pebble conglomerate in the Crossroad Mbr. of the Poultney Fm. This horizon is distinctive but very localized, and the origin of the phosphatic pebbles is not known. The scale bar is in centimeters.

Indian River Formation

The Indian River Formation is a strong, well cleaved, red and green to blue-green, and rare gray slate (Figure 30). The colors do not necessarily change across bedding or cleavage planes. It contains rare narrow white silty quartz arenites, and red and green chert bands. A few quarry exposures show white or yellow weathering flinty slate beds in the upper part of the unit which are probably silcic tuffs (Kidd, pers. comm., 1976). Unfortunately, these were not common enough to serve as useful time markers (Figure 31). The sharpness of the contact with the underlying Crossroad Member depends on whether the lowest Indian River is red or green. Theokritoff (1964) advocates putting the base at the first strong persistent red slate, but this author believes a more consistent map pattern emerges if one picks the first red or green layer, even though the latter may involve a meter of color gradation from gray.

Gray slate when present within the unit is always located at the top above the red and green slate and below the black chert of the overlying unit. Berry (1962) describes a gray mudstone and black shale member of the "Normanskill" which lies between the red and green shale and chert and the black and green chert. He groups it with the overlying member and notes that it is "almost indistinguishable in southeastern Washington Co." (page 712). Its position in the study area is the same but the textural descriptions do not correspond; a facies change may be present. However, here the gray slate is texturally identical to the green and red and has been grouped with them.

The red Indian River Slate is the most vividly colored rock in the area, and its appeal as a decorative tile is easy to understand.

Figure 30. The Indian River Fm. red slate.

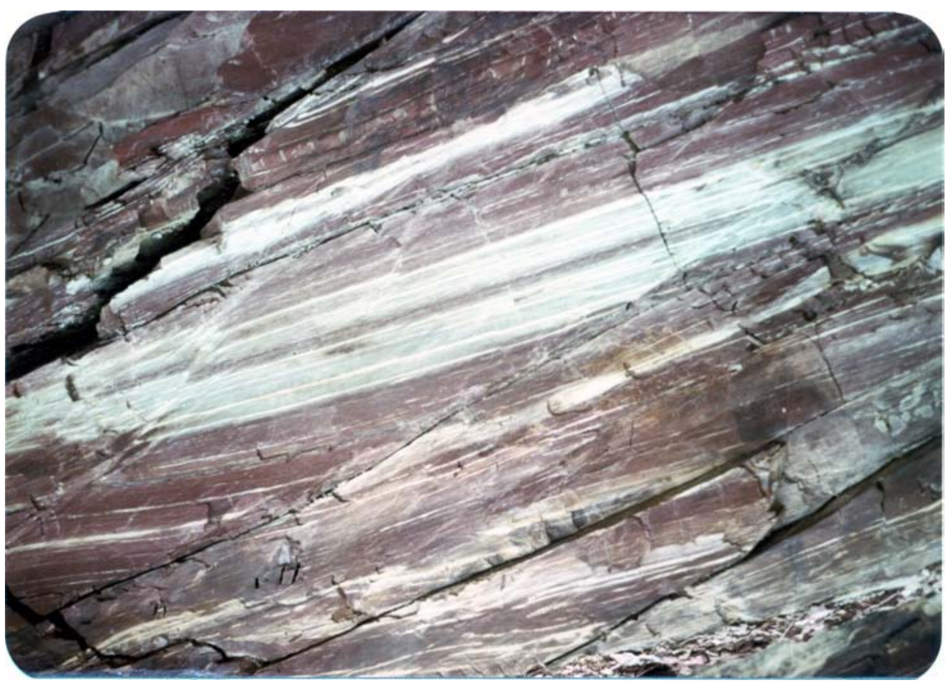


Figure 31. Probable tuff bands in the Indian River Fm. These layers differ from the adjacent slate layers in both color and texture; the average width is one to two centimeters.

Even rotten weathered outcrops are easily recognizable. The other colors are also only dulled somewhat by weathering, and the chert weathers white. Natural outcrop is limited, but man made outcrop is outstanding. The thickness varies from 20 to 55 m.

Dale (1899) called this the Hudson Red and Green Slates. Keith (1932) introduced the name Indian River, and it has subsequently been used by others. Some workers have used the name Normanskill Formation to include this unit and the overlying ones (Larrabee, 1939; Fowler, 1950; Berry, 1962) an unfortunate practice because no lithologically similar rocks occur in the type Normanskill. Platt (1960) followed the Ruedemann (1942) nomenclature and grouped the red slate with the overlying dark chert in the Mt. Merino Formation. However, in this area it is clearly a mappable formation, and the name Indian River Slate Formation has been retained. The Hilltop Quarry north of Truthville shows excellent exposures of the Indian River including the upper contact and has been designated a reference locality (Figure 32). The outcrop along the eastern end of Dunbar Rd. has the best example of both slate and chert in the study area.

Mt. Merino Formation

The Mt. Merino Formation contains both black (predominant) and dark green chert in three to five cm thick beds separated by minor black slate. Pyrite is present in moderate amounts. The contact with the underlying Indian River is very sharp because both color and rock type change (Figure 33). This well-defined contact is the other reason for including the sometimes present gray slate with the underlying red

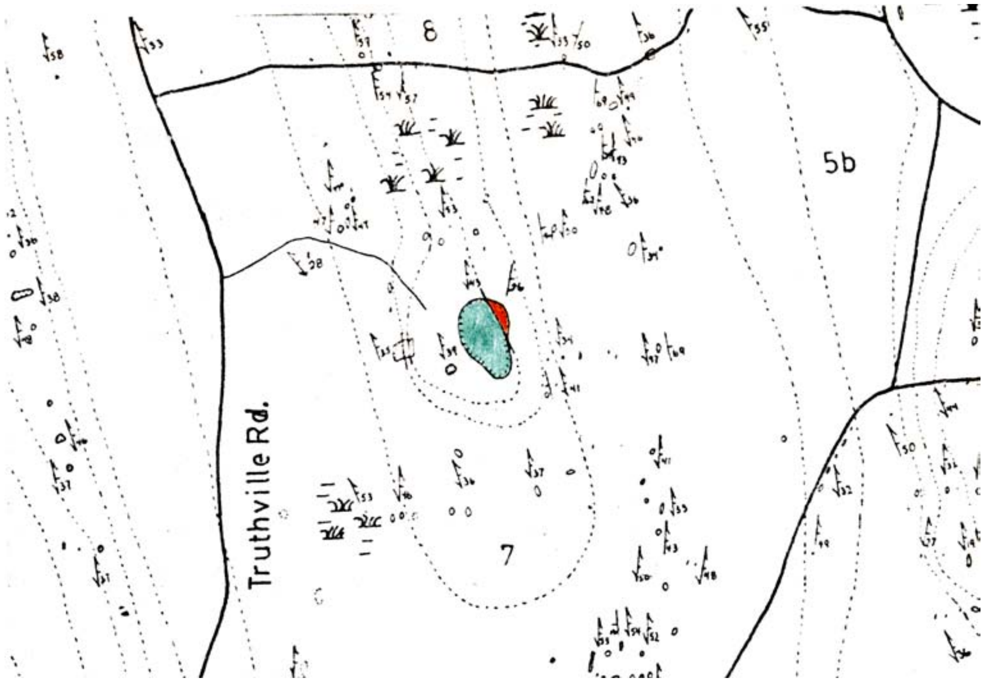


Figure 32. Location map of the reference sections for the Indian River Fm. and of the Mt. Merino Fm. (colored outcrop)

Figure 33. The contact separating the Indian River Fm. from the overlying Mt. Merino Fm. Because of the large number of red slate quarries this is the best exposed contact in the area.

and green slate. The chert characteristically weathers chalky white, and the intervening slate weathers away giving a broad ribbed appearance on weathered surfaces (Figure 34).

The slaty cleavage is well developed in the slate, but virtually not at all in the chert. When cleavage does not parallel bedding it is somewhat refracted by the chert beds. No other sedimentary feature was noted except worm trails. The rock's hardness makes it one of the more visible units, and extensive quarrying of Indian River has produced excellent exposures of the lower contact.

Dale (1904) included this unit in with his Hudson Shales, and Cushing and Ruedemann (1914) included it in their Normanskill Formation. Ruedemann (1942) first used Mt. Merino to name this unit and the underlying red and green slates. Berry (1962) described it as the middle two members of the Normanskill, and Keith (1932) referred to it as the black slate overlying the Indian River. There is some geographic correlation with the nomenclature: northern Taconic workers use Indian River to refer to both (Theokritoff, 1964) and southern workers use Mt. Merino to refer to both (Platt, 1960). Even though the formations are developed to different degrees in different areas it is important to recognize, acknowledge, and label both when present (Potter, 1972). Therefore, the Mt. Merino has been elevated to formation status in this area. The best exposures are in Indian River quarries when the dark chert directly overlies red slate so that the contact and lower few meters are exposed. Therefore, the Hilltop Quarry mentioned previously can also serve as a reference locality for the Mt. Merino Fm. (Figure 32).

Figure 34. Fresh and weathered Mt. Merino Fm. chert and slate.

Pawlet Formation

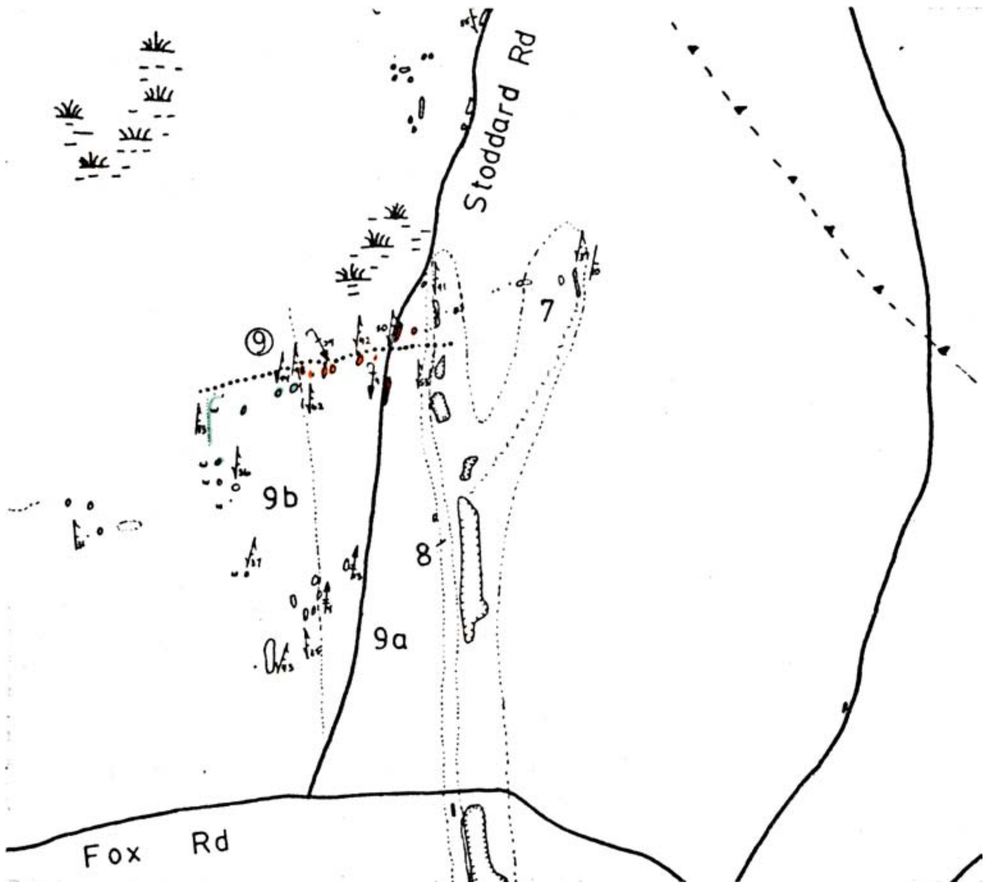
In this area the Pawlet Formation, although very limted in outcrop, appears to have at least two distinct members, a lower coal black, graptoliferous slate, and an upper green-gray to gray slate and black slate interbedded with wacke. This formal distinction has not been made elsewhere although a fossiliferous black slate has been mentioned by several (Shumaker, 1967; Berry, 1962).

Because this is the highest formation in the sequence, it is eliminated by erosion in most locations. The only complete section available for a reference section is west of the northern most Indian River Slate quarry east of Stoddard Rd. (Figure 35). Secondary folding made accurate thicknesses impossible to determine. The members of the Pawlet Formation are named Stoddard Rd. Member and Fox Rd. Member.

Stoddard Rd. Member

The Stoddard Rd. Member is a coal black, well cleaved, graptoliferous slate without associated rock types. The lower contact was never seen, but an unconformity has been identified in the Pawlet Quadrangle to the east (Shumaker, 1967). Weathered outcrops look very similar to fresh ones. Slaty cleavage is very well developed, and bedding is sometimes marked by layers of graptolites. The softness of this slate plus the absence of a supporting rock type results in very poor outcrop. The maximum possible thickness is 75 m, and this may include some repetition by folding.

This member has not previously been considered separately, and it is discontinuous although probably from erosion (Plate I). However, it is strikingly different both in texture and color from the overlying



Figures 35 & 36. Location map of the reference section for the Pawlet Fm. and of the type sections for both the Stoddard Rd. Mbr. and the Fox Rd. Mbr. of the Pawlet Fm. (colored outcrops) slate, and where present it appears consistently at the same horizon. Berry (1962) mentions a graptoliferous slate component in his highest Normanskill member, the Austin Glen. Platt (1960) describes a very similar sounding rock; however, he places it between the red slate and the black chert. Potter's (1972) Mt. Merino is interfingered bedded chert and black slate which can be locally mapped as separate units. The slate which sometimes overlies the chert, is sooty black and graptoliferous and is apparently the same. Zen (1964) mentions that in the northern Taconics the chert beds are largely absent (not true in this area, but it was chosen for maximum exposure of the sequence) and that the black slate may belong stratigraphically to the overlying Pawlet.

The only good exposure is across Stoddard Rd. 750 m north of the Junction with Fox Rd. from 60 m to the east to 130 m to the west (Figure 36). The outcrop is discontinuous but better than elsewhere; neither contact is exposed. There are some excellent examples of graptolites to be found (Figure 37). Therefore, this is designated the type locality of the Stoddard Rd. Member.

Fox Rd. Member

The Fox Rd. Member is green-gray, gray, and black well-cleaved slate and coarse, gray-brown micaceous lithic wacke. Minor basal limestone is seen in the area between Rt. 21 and Quivey Hill Rd. The lower contact is not exposed, but it appears to be a fairly abrupt change in both color and texture. The slate has a pale sheen, and the gray and the pale green-gray have both been quarried. Some of the green-gray slate shows irregular purplish patches that may be analogous to the small amounts of reddish slate in the Crossroad Member and the Mt.

Figure 37. A bedding plane of the Stoddard Rd. Mbr. of the Pawlet Fm. showing single and double branched graptolites.

Figure 38. Wacke and slate of the Fox Rd. Mbr. of the Pawlet Fm. Near perpendicularity of the beds and the slaty cleavage indicate that this outcrop is located near the core of a fold.

Merino Formation. Unlike the other quarried units, the major color changes appear to parallel bedding planes.

The wacke comes in beds 30 to 50 cm thick interbedded with gray and black slate (Figure 38). It always first occurs after a sizable interval of slate and does not comprise more than 25 percent of the unit except in the North Granville bridge section. This contrasts sharply with the first published description (Zen, 1961) which specifies equal amounts of slate and wacke, and with the original type section area which is approximately 70 percent wacke (Shumaker, 1967). In two locations within the study area a narrowly banded gray slate and limestone was seen. Shumaker (1967) noted a few basal limy beds and a few outcrops of impure limestone. He does not describe the limestone, and it is not mentioned by anyone else, except possibly Dale (1904) who includes in his Hudson Slates a black and gray shale with limestone and conglomerate which overlies black cherty slate and underlies black and gray slate with grit.

There are several possible explanations for these discrepancies in rock type and proportions. 1) The variations are real and are a result of facies changes. 2) The area has unsuspected faults which thicken the slate section and place limestone (probably from the Dunbar Member) out of stratigraphic order. 3) Folding is identified in the area of Stoddard Rd., and these folds may thicken the slate considerably. 4) The wacke is much harder and more resistant than the slate; therefore, weathered outcrop contains a disproportionate amount of wacke which may distort the rock type percentages.

Slaty cleavage is well developed in the slate and irregularly developed in the wacke. Graded bedding sequences clearly show younging directions. This unit is not prominent in the field. The lower slates, if visible at all, tend to have low flat outcrops, and the wacke oftens "free-stands" in rows (similar to the Hatch Hill), because the intervening slates have weathered away.

Dale (1899) referred to this unit as the Hudson Grits. Larrabee (1939), Berry (1962), and Fowler (1950) described it as the upper part of the Normanskill. Ruedemann (1942) named it the Austin Glen Member of the Normanskill, a term used by Platt (1960), Potter (1972), and others. Northern Taconic workers use Pawlet Formation for rocks which are lithographically, stratigraphically, and paleontologically correlative (Shumaker, 1967; Zen, 1961; Theokritoff, 1964).

The only possible type locality is a westward extension of the type locality for the Stoddard Rd. Member (Figure 36). The outcrop is intermittent, but it is still the only place in the area where the progression from pale green-gray slate to medium gray slate to interbedded wacke and black slate can be seen. The member is named Fox Rd. Member after the next nearest prominently named landmark.

Justifications

The stratigraphy described above is based on the largest number of units which can be readily, definitely, and consistently identified in the field for they should define the clearest, fullest map pattern and column (Figure 39). However, identification is often not definite on any absolute scale because of the overlapping variation between so many units. For example, almost every unit studied contains some black slate; seven of the units contain gray slate; four of the units contain gray-green slate which is particularly susceptible to subtle color changes from weathering. Zen (1961) mentions this problem with particular reference to the black slates; he had no answers. Even supposedly distinctive units can be misleading. Red slate does not automatically signify Indian River, because minor red slate has also been seen in the Crossroad Member of the Poultney, the Mt. Merino, and the Fox Rd. Member of the Pawlet. Unfortunately, a small outcrop can be a small piece of representative rock or a relatively large piece of a minor component. The coarser clastics, particularly the wackes, are less ambiguous. Ribbon quartz arenites are helpful because except for very limited examples, they characterize the Crossroad Member of the Poultney; however, the four units with thicker arenites are not always readily differentiable. The limestones are also similar in appearance and must often be identified by position in the sequence. This need introduces a distressing circularity, for the stratigraphic framework must have been initially established somehow.

The other major criterion for this stratigraphic column is to remain as consistent as possible with the established unit names and boundaries. Despite excessive multiplicity of names the general

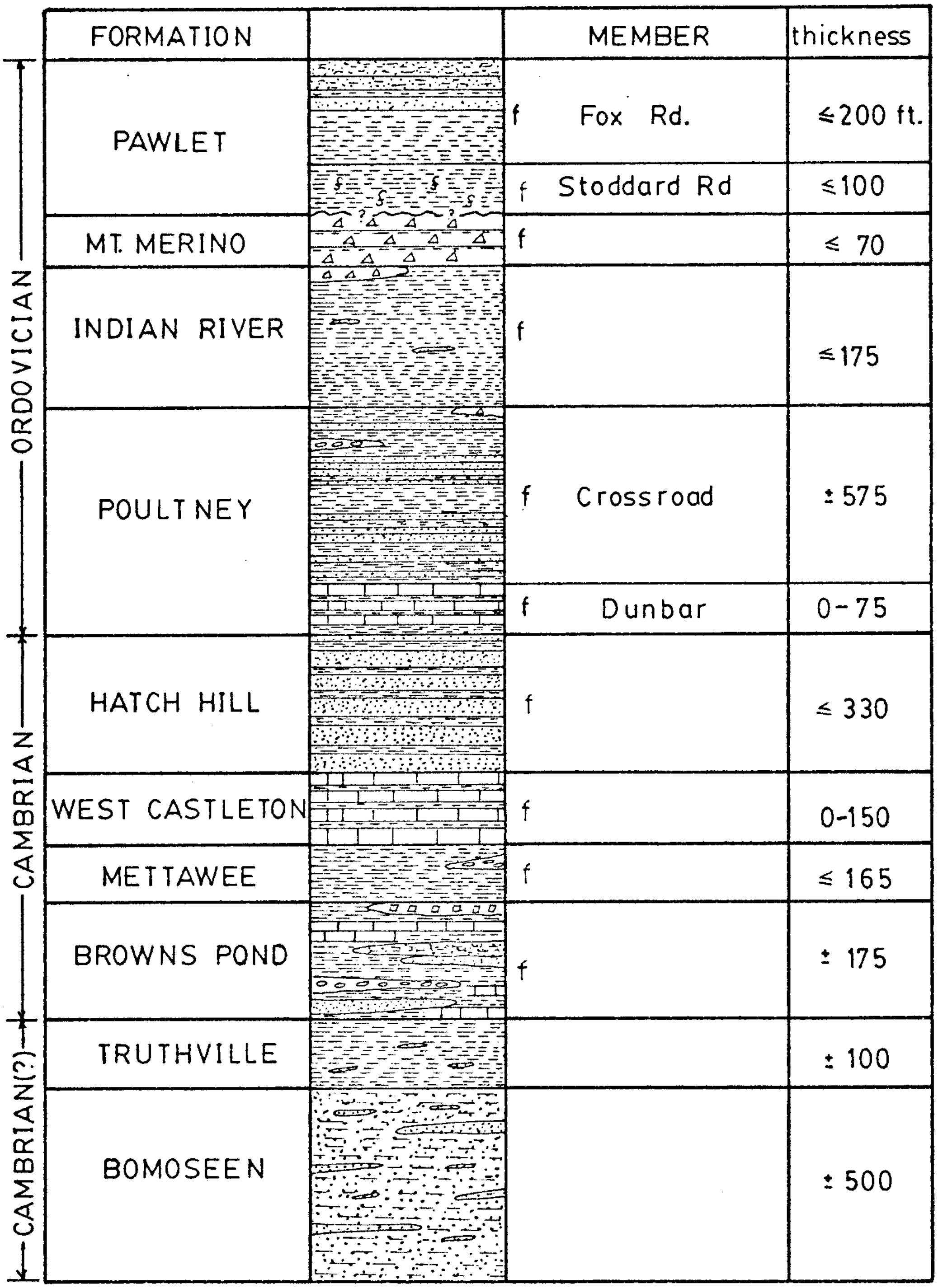


FIGURE 39

Figure 39. Schematic stratigraphic column of the study area. Conventional lithologic symbols have been used to show key units and the horizontal and vertical extents of the different rock types. An f marks the units where fossils have been found.

Taconic sequence is now somewhat systematized (Zen, 1967, 1964); the literature is not error free, but the errors are often recognizable. Taconic stratigraphy does not need any additional nomenclature; therefore, pre-existing names were used wherever possible, and new names were introduced only for newly designated units or for units whose original description was not clear or whose type localities were too far away to be certain of correlation.

CHAPTER IV

Petrography and Sedimentology

Introduction

The Taconic sequence involves only six sedimentologically discrete rock types: slate, arenite, limestone, wacke, chert, and conglomerate or breccia. However, the variety of these rock types, both within and between formations, is impressive. Hand sample and microscope descriptions were made to determine if possible, the nature of this variation, and to see if any consistencies in sedimentary structures or characteristic clastic assemblages exist within formations. The sequence as a whole was studied to check for similarities, systematic variations, or possibly significant lateral and/or vertical distribution patterns. The smaller scale (intraformational) variations probably reflect facies changes which are known to exist, but because of outcrop and location problems are difficult to pinpoint. The larger scale (interformational) dissimilarities probably reflect major environmental patterns.

Arenites

The arenites seen in the Taconic sequence range from pure, mature, silica-cemented quartz arenites to carbonate cemented sub-feldspathic arenites to arkosic arenites (Figure 40). Accessory clastic mineral grains can include microcline, plagioclase, assorted carbonates, muscovite, opaques, and zircon; lithic fragments are uncommon. The accessories are generally small sand size to silt size and sub-angular (except the zircon which is invariably round) even when the accompanying quartz grains are larger and rounder. Quartz grains run the full size gamut from granule to silt (approximately 3 mm to .025 mm): however, two

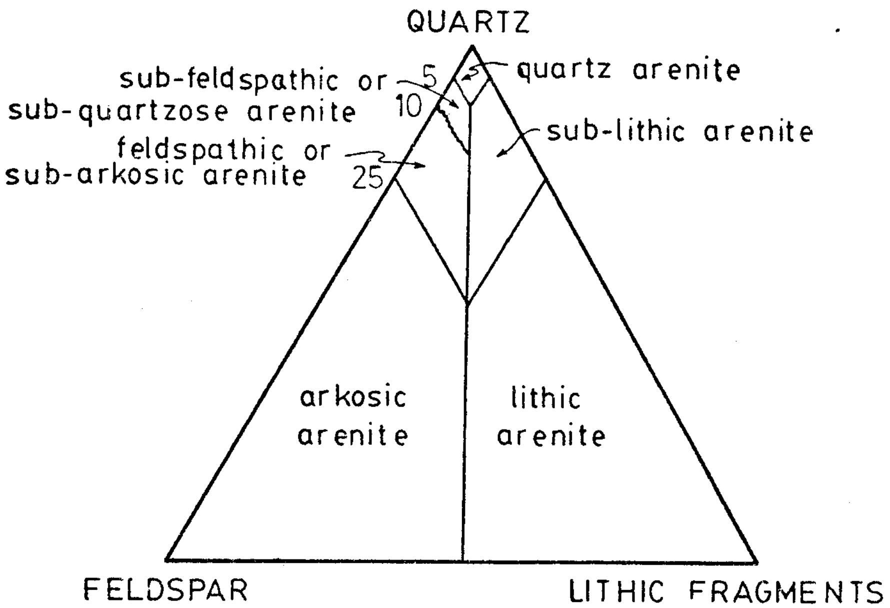


FIGURE 40

Figure 40. Arenite classification diagram. The general divisions are from Pettijohn (1976). However, the area of the diagram which most refers to the rocks studied has been subdivided more specifically using the definitions of the AGI Glossary.

narrow size ranges which vary in absolute dimensions are often favored, implying a bimodal distribution which is not reflected in the other grains (Figure 41). Texturally the quartz ranges from sub-angular to round with degree of rounding increasing with size. The quartz is generally clear, but may contain tiny needles which could not be identified because of size.

Arenite layers occur in lenticular beds as thin as a few millimeters and in beds up to ten meters thick. They are interlayered with assorted slates and wackes and may show very finely spaced laminae or none at all. All degrees of recrystallization textures are represented: quartz and feldspar grains can show straight extinction, undulatory extinction, serrated grain boundaries or recrystallization mosaics (Figure 42). Recrystallized carbonate cement appears as relatively coarse, well cleaved grains or perfect rhombs (Figure 43).

Significant arenite is contained in the Bomoseen Formation, the Browns Pond Formation, the Hatch Hill Formation, and the Crossroad Member of the Poultney Fm. In the Bomoseen both narrow lensing quartzites and thick massive arenites occur. The thick examples are very clean, carbonate free, well-rounded, coarse, low matrix quartz arenites. The small lenses are finer grained, less mature, also carbonate free, but contain some characteristic Bomoseen muscovite. They are a very clean version of the Bomoseen wacke or, more formally, a sub-quartz arenite.

In the Browns Pond there are thick arenites that in field identification may be confused with the underlying unit, except for an occasional pattern of small rust spots. In thin section, however, several differences are apparent. The grain size, though variable, clusters

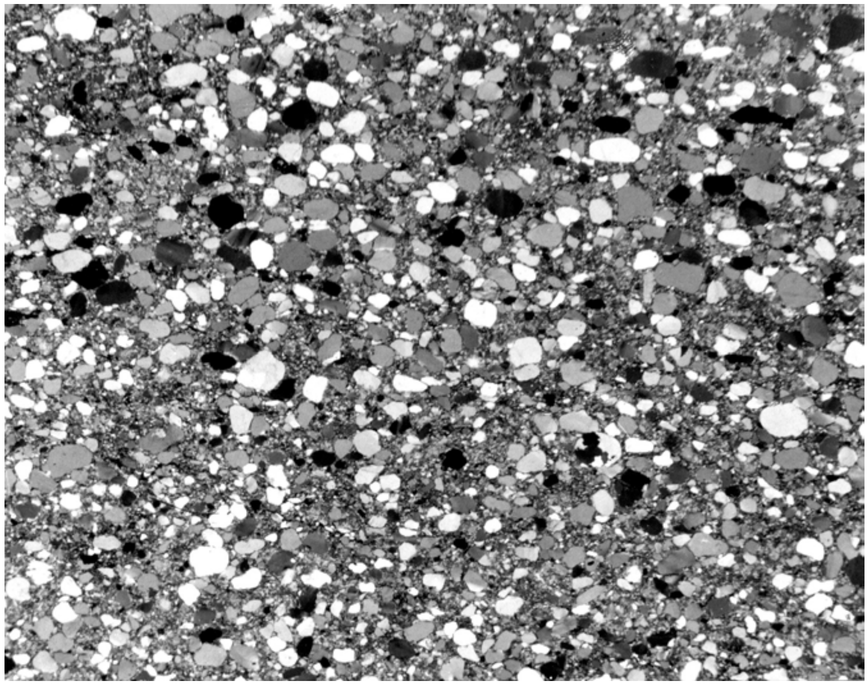


Figure 41. Bimodal distribution of quartz grains in the Hatch Hill Fm. quartz arenite. X10, crossed Nicols.

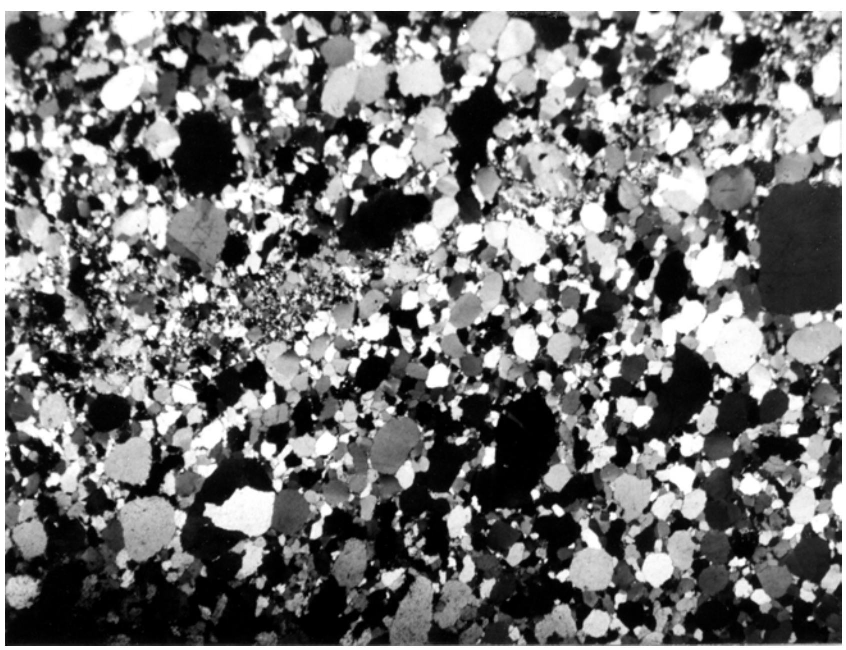


Figure 42. Recrystallized quartz grains in Bomoseen quartz arenite. Serrated grain boundaries and very fine grained quartz mosaics both suggest recrystallization. X10, crossed Nicols.

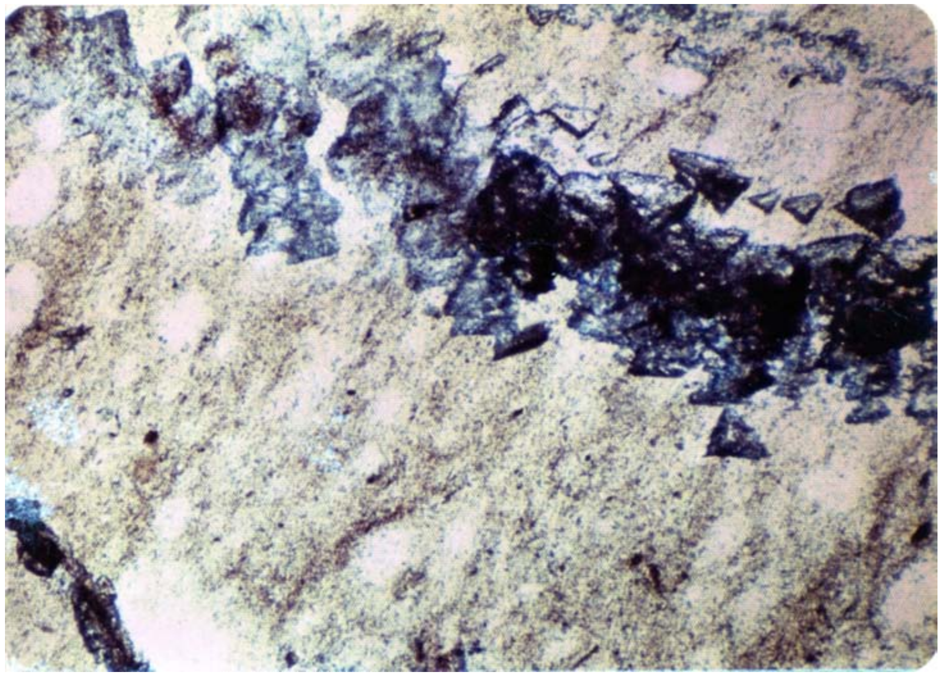


Figure 43. Pleochroic carbonate rhombs in Mt. Merino chert. Similar appearing rhombs are seen in some arenite cement. X30, plane polarized light.

around 0.1-0.2 millimeter without apparent bimodality. Grains are sub-angular and include feldspars and micas in minor amounts. The cement is almost exclusively a colorless, non-pleochroic carbonate which is presumed to be calcite because dolomite would leave a rustier weathered surface.[1]

The Hatch Hill is identified by thick (up to 3 meters) hard, light-blue-gray arenite beds that weather deeply rust brown. The quartz shows the same apparent bimodality seen in the Bomoseen with larger (0.5 mm) rounded grains and smaller (0.25 mm) sub-angular grains. There are minor amounts of clastic feldspar, micas, opaques, and mafics, so that the rock is somewhat though not considerably less pure than the arenites of the lower unit. The cement is exclusively crystalline brown carbonate, some of which must be recrystallized original matrix (clastic grains) for some of the quartz grains are free-floating rather than in networks. The carbonate displays light to dark brown pleochroism. Both rhodochrosite ($MnCO_3$) and magnesite ($MgCO_3$) can show rare pleochroism.[2] There are occasional dark pelitic lithic fragments, but these are presumably from the associated black slate.

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[1] Microscopic differentiation of the carbonates is very difficult because of the closeness of the identifying properties. Substitution between the different end members intensifies the problem by creating overlapping ranges between properties like relief and birefringence. Cleavage, which is common, may occur along different planes, but is usually rhombohedral in outline. Euhedral form suggests, but does not prove, dolomite. Rusty brown color, indicative of iron, suggests siderite or ankerite, but chemical analyses show (Table I) that most carbonate minerals contain only traces of iron.

[2] Magnesium is, of course, a constituent of dolomite, and manganese can substitute for magnesium in small amounts so that minor magnesite and rhodochrosite could both be present. Table 10-4 on page 327 of Pettijohn (1976) shows that only limestones with more than 1.0% MgO also contain significant MnO.

TABLE I.

Carbonate analyses compiled from Deer, Howie, and Zussman, page 474 (1967).

	Cc	Mag	Rhod.	Sid.	Dol	Ank	Arag
FeO	0.00	0.56	0.77	58.81	0.22	12.06	----
MnO	tr.	0.12	60.87	2.86	0.00	0.77	----
MgO	0.04	46.62	tr.	0.20	21.12	12.85	0.03
CaO	55.92	0.43	0.51	0.08	31.27	29.23	55.96
CO_2	43.95	51.93	38.26	38.08	47.22	44.70	43.95
Totals	99.91	99.96	100.41	100.03	99.97	100.23	100.07

The Crossroad Member of the Poultney contains two forms of arenite: narrow ($\leq$ 2 cm), fine grained, lensing arenite beds interlayered with slate and thicker (up to 50 cm) coarser arenites that are rare. Both types can be very finely laminated although this is more commonly seen in the thin bedded variety (Figure 44). These laminae, often less than one millimeter thick, are perfectly planar and can be continuous on an outcrop scale. This feature in addition to being significant for the interpretation of mode of deposition, strongly suggests a local absence of organic life, because bioturbation often effectively disrupts much thicker beds (Figure 45). There are transitions seen between the two types, especially west of Hills Pond. Sub-angular, large silt sized (.03-.1 mm) grains characterize all Crossroad arenites. Most grains have a high ratio of grain to grain contact so that cement percentage is low. Other clastics (predominantly microcline, albite, and clear carbonate, and occasionally brown carbonate, zircon, and assorted opaques and mafics) are present in varying amounts. The rock type varies from a quartz arenite to a subfeldspathic arenite; one unusual arkosic arenite was found and is discussed in Chapter VI. In general, there is less carbonate (except for the Bomoseen) and more fine-grained opaque material than in the lower arenites.

Wackes

The wackes seen in the Taconic sequence all have distinctive appearances and major components (Figure 46). One is the major rock type of a unit (Bomoseen), another is a significant rock type of a unit (Fox Rd. Mbr. of the Pawlet Fm.), and the third is a distinctive marker bed in a unit (Browns Pond). The three are widely separated in the stratigraphy.

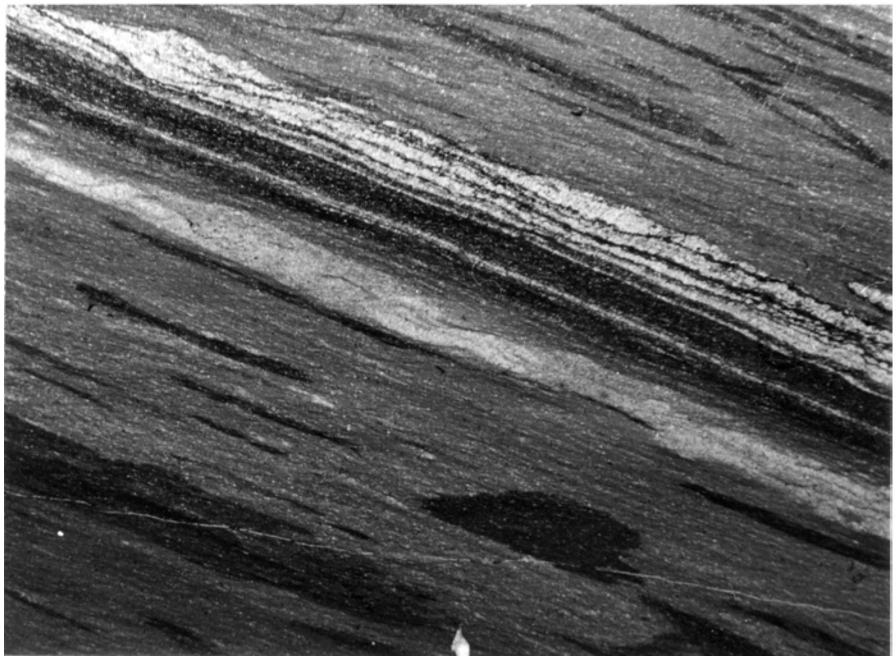


Figure 44. Very fine quartz arenite laminae in the Crossroad Mbr. of the Poultney Fm. Note that cleavage is oblique to bedding. X9, plane polarized light.

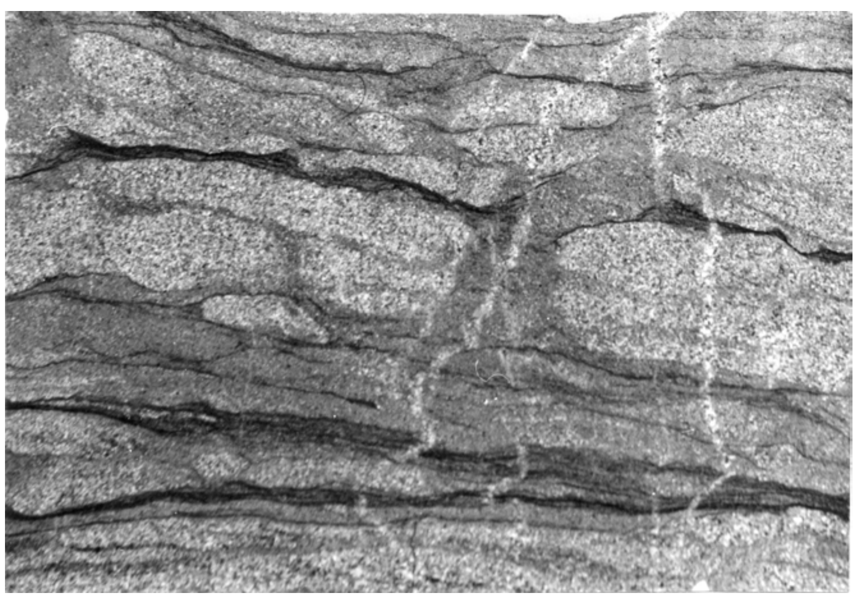


Figure 45. Probable bioturbation in the Crossroad Mbr. of the Poultney Fm. The arenite layer has a gap which was filled in with mud. X6, plane polarized light.

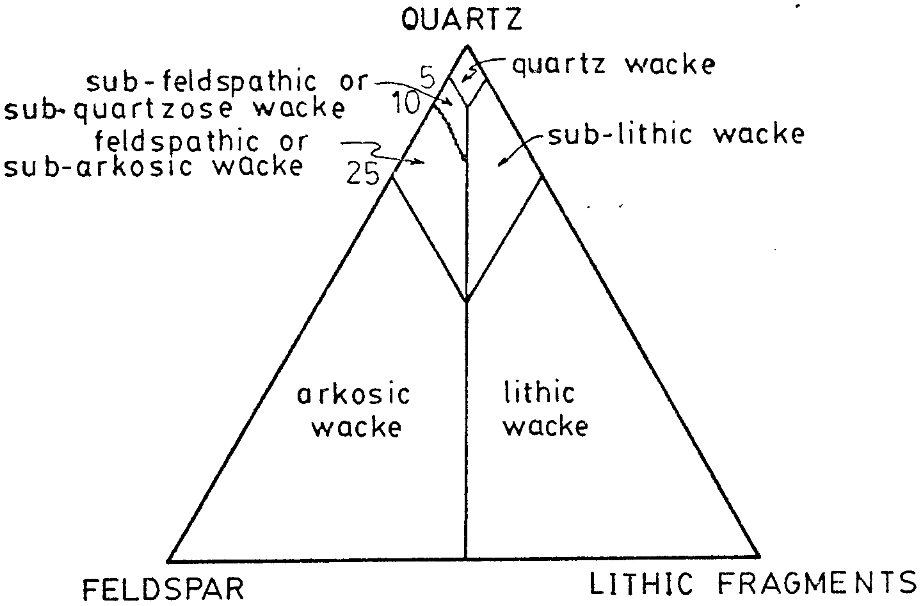


FIGURE 46

Figure 46. Wacke classification diagram. Like the preceding figure this diagram is derived from Pettijohn (1976) with specific details from the AGI Glossary.

Wacke in the Bomoseen Fm. is a hard, green, quartz-rich, non-calcareous, micaceous rock. The quartz has an apparent bimodal distribution, but the larger round (1 mm) size fraction is very rare (Figure 47). The color (which distinguishes this rock from the other coarse clastics) results from chlorite in the matrix although in thin section the matrix looks more brown than green. The mica, which is visible to the naked eye, is seen in thin section to define a vague anastomozing cleavage. No lithic fragments are evident but plagioclase, opaques, muscovite, and minor mafics and zircon are present. The rock falls on a "triple junction" in the classification diagram and is best described as a sub-quartz wacke.

Wacke in the Fox Rd. member of the Pawlet is a lithic wacke. It contains quartz and lesser amounts of lithic fragments, micas, carbonates, feldspars, opaques, and minor zircon (Figure 48). The quartz grains are sub-angular to rounded and generally larger than the other particles, though absolute sizes vary. They contain occasional inclusions of zircon and a needle shaped mineral, possibly sillimanite or rutile. The lithic fragments are mainly dark slate and are the only grains with a consistently elongate shape. The micas are in flakes which with brown clay stringers define a fair to moderate slaty cleavage. Both clear and brown carbonates are present, the former in irregular blobs and well cleaved grains and the latter in rhombs. Although the wacke beds are very distinct from the interbedded slate they grade upward into them texturally. Therefore, the grain size is highly variable, but in any one sample the same relative size distribution is maintained. The quality of slaty cleavage development, of course, correlates with this changing grain size. The appearance of the carbonate cement and

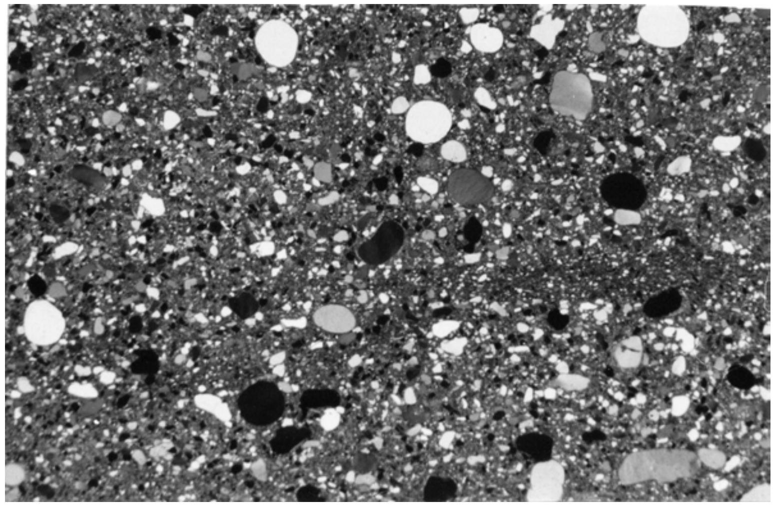


Figure 47. Wacke in the Bomoseen Fm. X10, crossed Nicols.

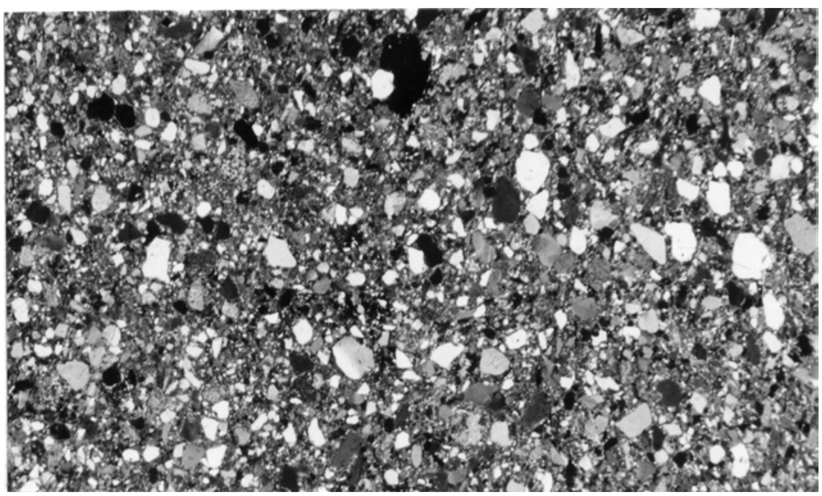


Figure 48. Wacke in the Stoddard Rd. Mbr. of the Pawlet Fm. X8, crossed Nicols

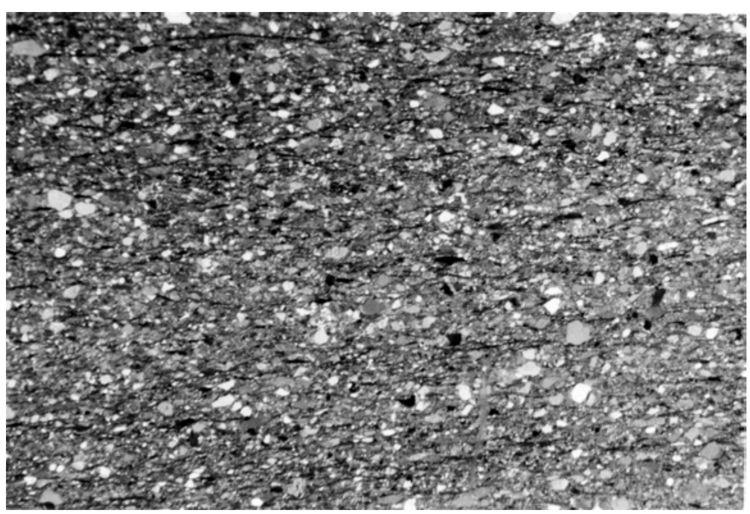


Figure 49. Wacke in the Browns Pond Fm. X10, crossed Nicols

the occasional lack of a clastic framework suggests that the matrix is recrystallized and in part secondary.

The wacke of the Browns Pond Fm. is a sub-quartz wacke. Past workers (Fowler, 1950; Zen, 1964) have noted the similarity to the wacke in the Fox Rd. Mbr. of the Pawlet Fm.; however, in this area, at least, they are usually distinguishable at both outcrop and thin section scales. The rock contains quartz, carbonates, feldspars, lithic fragments, micas, opaques, and minor zircon, essentially the same components as the Fox Rd. Mbr. of the Pawlet Fm. (Figure 49). However, proportions and appearance differ considerably. There is more carbonate and feldspar and less mica than in the Fox Rd., and clasts are black slate or calcareous siltstone. The quartz is most consistent and distinctive. Some grains are large (0.4-0.8 mm), clear and rounded and in outcrop look like tiny black spheres. These grains and a second population of smaller (0.1-0.2 mm) sub-angular grains show up clearly in thin section. This second group resemble the quartz in the associated arenite which shows a much narrower range of sizes and shapes. The grains are held together by a combination of carbonate cement and dark clay.

Limestones

Limestones are a relatively minor rock type in the Taconic sequence; they are present in three (or possibly four) units, but they are not the major component of any unit. When present, they are in most cases interbedded with dark gray to black slate. Carbonate minerals are also seen as minor components of arenite, slates, and cherts. The Browns Pond and the West Castleton Fms., and the Dunbar Mbr. of the Poultney Fm. are limestone bearing units. The West Castleton Fm. and the Dunbar Mbr. are discontinuous units, although the extent is little understood because of poor outcrop. In two locations: west of Raceville and south of Hampton limestone was seen in a position suitable for it to be near the base of the Pawlet Formation; however, it could be from the Dunbar Mbr. of the Poultney because the exact locations of the thrust faults in those areas are unknown and a mention but no description exists of limestone in the Pawlet in the literature (Shumaker, 1967). Taconic limestones range from silty micrite to finely sandy sparite (Figure 50). All units show a fine clastic component and a range of grain size so that field identification is primarily by the overall lithologic sequence and association.

Limestone in the Browns Pond is a very silty sparite with both clear and (minor) brown carbonate. Sub-angular to rounded quartz is the predominant accessory clastic, but there are also minor opaques and feldspar, and rare mica and brown clay. The latter two define a moderate cleavage. Pyrite appears to be the dominant opaque. Some quartz is partially recrystallized and presumably much of the carbonate is also because rhombs and cleaved grains are common. Therefore, it is very difficult to distinguish clastic and chemical calcite. This problem characterizes all the limestones for indisputably clastic carbonate is rare, and so only chemical limestone nomenclature is used.

Limestone in the West Castleton is even more silty than the Browns Pond particularly in opaque content. One slide shows good slaty cleavage and finely disseminated rather than crystalline calcite. It is not known if this is a representative example of West Castleton limestone.

Limestone in the Dunbar Mbr. of the Poultney varies in grain size from micritic to sparitic and similarly in clastic content. Accessory

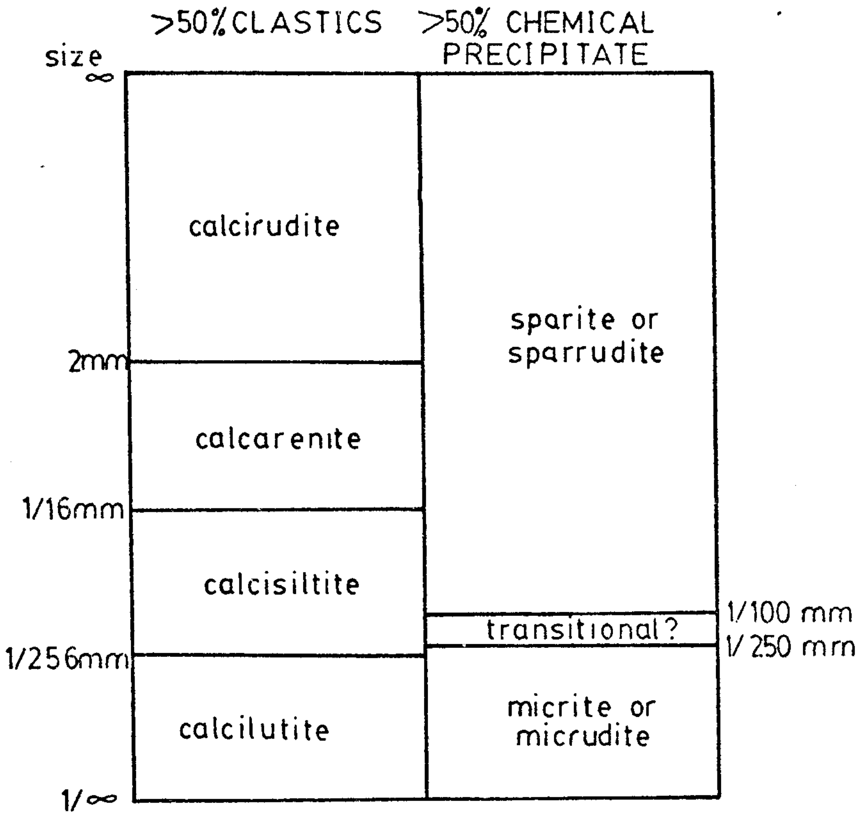


FIGURE 50

Figure 50. Limestone classification diagram. In the absence of extensive fossil debris the distinction between chemical and detrital carbonate can be very difficult, especially when textures suggest recrystallization. Therefore, the rocks studied were assigned almost exclusively to the right side of the chart. The definitions are from Pettijohn (1976) and the AGI Glossary.

quartz is ubiquitous and present in clots and isolated sub-angular grains. Some quartz and some carbonate show recrystallization and these larger (0.1 mm) grains are surrounded by very fine carbonate and brown clay. Some of the carbonate grains, especially the rhombs, are brown and pleochroic suggesting a dolomite component; however, the rock does not show the distinctive brown weathered surface.

No slides were made of the possible basal Pawlet limestone. However, in outcrop it is a medium gray fine-grained silty limestone and not distinguishable from that in the Dunbar Mbr. of the Poultney.

Conglomerates and Breccias

Conglomerates and breccias are not common in the Taconic sequence, but they have a particularly striking appearance and are good marker beds. The matrix varies in different units, but the majority of clasts are some type of limestone. These significant conglomerates and breccias are found in the Browns Pond, the Mettawee, and the Crossroad Mbr. of the Poultney. Additional breccia lenses have been seen in the Hatch Hill, but they are apparently very localized. Conglomerates have been extensively reported in the West Castleton and the Dunbar Mbr. of the Poultney (Theokritoff, 1964; Zen, 1964; Potter, 1972; Platt, 1960) but no certain examples were seen in this area.

As noted in Chapter III the Browns Pond contains three conglomerates. The conglomerate located low in the section has a very silty calcareous dark gray to black slate matrix. It is full of silt sized, sub-angular to sub-rounded quartz, serrated opaques, altered calcite, and muscovite. The clasts are highly variable in size and are predominantly black slate, wacke, and light gray limestone which sometimes contains large round quartz grains. One organic-appearing circular object was enclosed in a limestone clast (Figure 51). In large exposures (maximum seen was 2 m thick) tight, unsystematically oriented folds suggest slump features. In contrast, the upper conglomerate occurs in several beds, each not more than one meter thick, separated by regularly bedded slate and limestone. The clasts are tightly packed pieces of silty micrite and the matrix is a sandy calcitic and dolomitic sparite which was probably originally clastic. Other than accessory quartz, both clasts and matrix are fairly clean. The distinctive black quartz wacke is sometimes conglomeratic in that it can contain black slate clasts.

The Mettawee has a very distinctive, but infrequently seen, lensing conglomerate near the top of ten unit. In the study area it was only seen in two quarries near Middle Granville, and in the northern exposure the conglomerate decreases in thickness from two meters to zero over approximately 15 meters (Figure 52). The matrix is a silty sparite with quartz and minor opaques and a rusty exterior which suggests a dolomite component. The clasts are micrite and generally oval or long and narrow suggesting dismembered and jumbled beds. They have dark stylolite outlines. A few smaller (~ 5 mm) round black clasts were also seen; they are hard, fine-grained, and break irregularly, are not slate, chert, or limestone, and may be phosphate pebbles.

The Crossroad Mbr. of the Poultney has two striking conglomerates of apparently limited extent as they are seen in only a few locations, most noticeably on and west of Quivey Hill Rd. Yet they appear to be fairly resistant layers. One has a matrix of relatively coarse (~ 5 mm) calcite grains with finer quartz and opaques and rare muscovite.

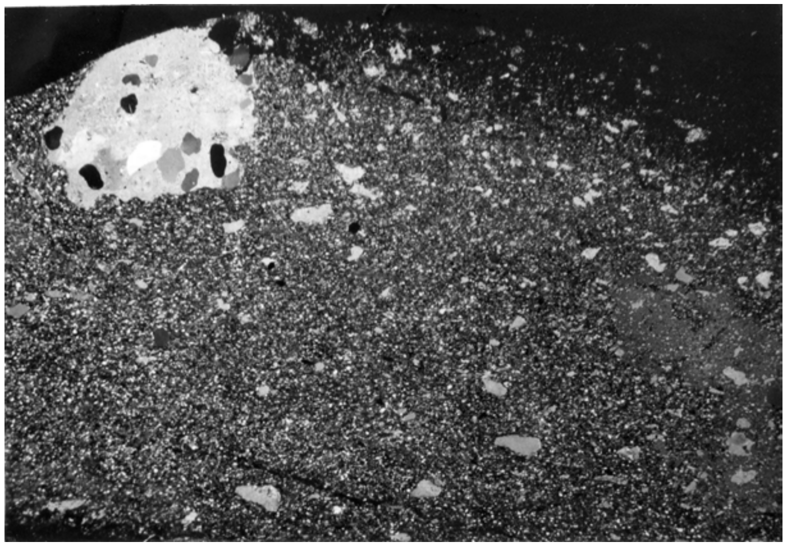


Figure 51. An example of conglomeratic quartz wacke in the Browns Pond Fm. X8, crossed Nicols.

Figure 52. Intraformational conglomerate in the Mettawee Fm. It lenses from approximately two meters thick to nothing over a short distance.

The most noticeable clasts in a hand sample are the small, dark, hard pebbles which in thin section are "mini-conglomerates" containing quartz silt and tiny brown pebbles (Figure 53). However, the volumetrically dominant clast is sub-rounded fine-grained limestone. Minor components are dark slate fragments and granules of recrystallized quartz. The other conglomerate has a fine to coarse calcite matrix with both aggregates and angular grains of quartz and opaques. The clasts are sub-rounded and variable in size and include fine-grained, non-silty (except for minor opaques) limestone and silty wacke; at least one possible fossil fragment was also seen. The limestone clasts have stylolitic outlines. This horizon is apparently variable as a nearby outcrop (approximately 500 m away) has light gray dismembered limestone beds in a darker gray matrix. The two outcrops are not directly on strike and may be lenses or they may be entirely different horizons. It is also possible that they lie on opposite sides of an indefinitely located thrust fault and bear no determinable relation to each other.

Chert

The cherts in the Taconic sequence vary mainly in color. They are usually, although not invariably, interbedded with slate of the same color. Chert bands are seldom more than 5 cm thick and despite original color they all weather chalky white. They constitute the main rock type of the Mt. Merino and are sporadic minor components of the Crossroad Mbr. of the Poultney, the Indian River, and the Fox Rd. Mbr. of the Pawlet.

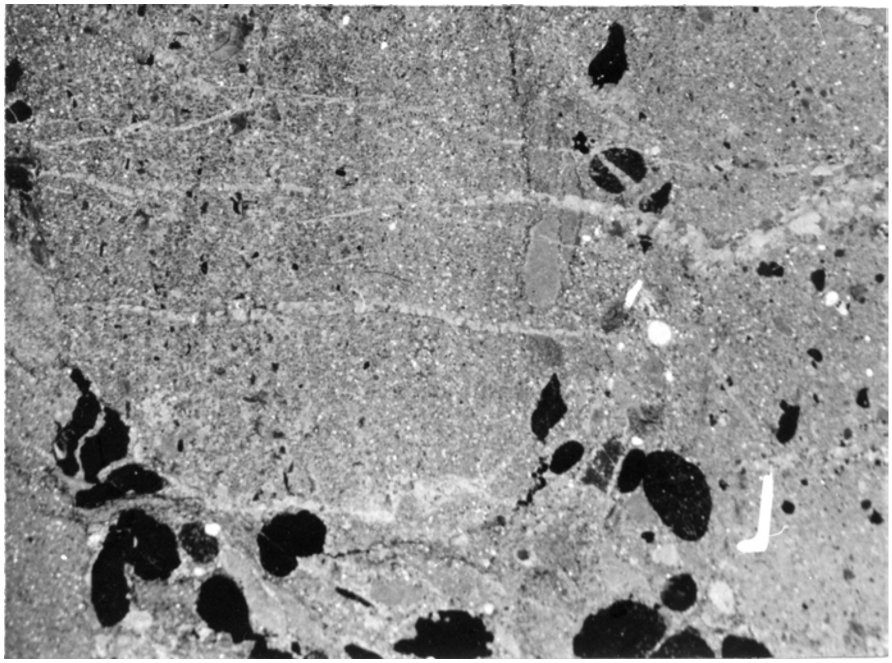


Figure 53. Phosphate pebble limestone conglomerate in the Crossroad Mbr. of the Poultney Fm. X6, crossed Nicols.

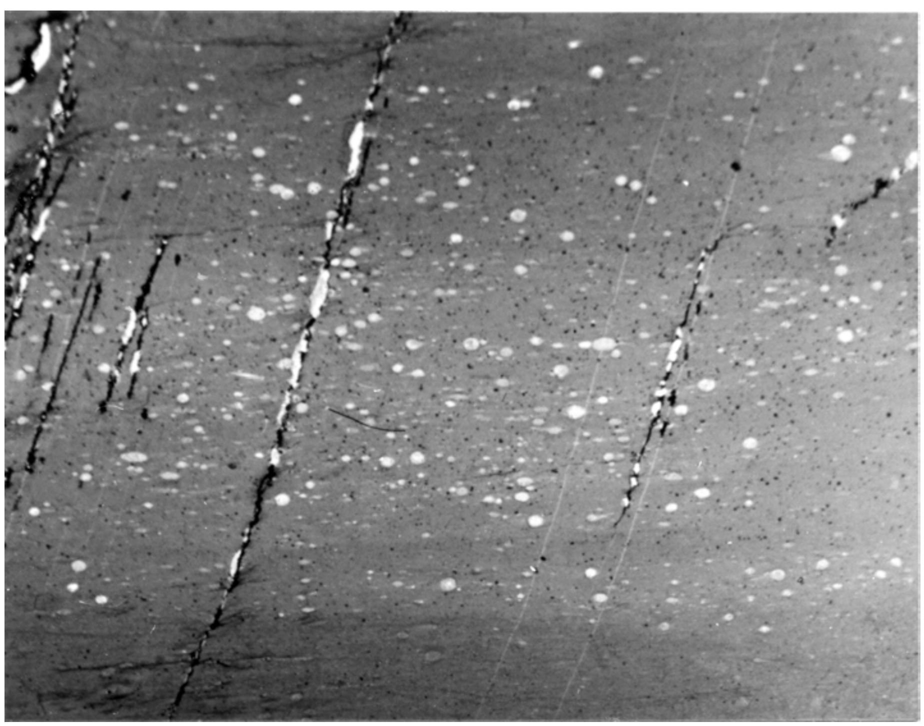


Figure 54. Possible deformed and undeformed radiolaria in Mt. Merino Fm. chert. X15, plane polarized light.

Chert in the Mt. Merino is usually black, occasionally dark green, and rarely red. It contains silt sized square opaques (pyrite), brown, pleochroic carbonate rhombs and oval quartz aggregates which may be once circular fossils that were flattened in the plane of the cleavage. However, many of such aggregates remain circular, and it is common to see both in the same section (Figure 54). Some examples show very fine muscovite and/or chlorite which define a moderate cleavage. In hand samples no cleavage is visible in the chert.

Chert in the Indian River is red and green like the slate and generally located in the upper part of the unit near the Mt. Merino contact. It is usually in thin bands although south of Dunbar Pond an impressive 2 1/2 meters of chert were measured. It has ellipsoidal quartz aggregates and some clear and brown carbonate, but no opaques.

Light gray chert in the Crossroad Mbr. of the Poultney was observed primarily northwest of Raceville. Outcrops look and act like pure chert, but thin sections show a finely laminated silty chert with finely disseminated quartz and opaques. The distinctive elliptical and circular quartz aggregates are absent.

Chert in the Fox Rd. Mbr. of the Pawlet Fm. was seen in only one location. No thin section was made; in outcrop it was light gray and very similar to that in the Crossroad Mbr. of the Poultney Fm.

Slate

Every unit in the Taconic sequence contains some slate. Colors include black, gray-green, olive green, purple, red, green, blue-green, and a full spectrum of grays. Slaty cleavage is generally well developed, but fissility is highly variable. Cleavage may be defined (or highlighted) by mica flakes, stringers of brown clay, opaque concentrations, and inequant clastic grains (Figure 55). Slate can be interbedded with other rock types on the scale of millimeters to meters. There is almost always an angular to rounded silt size component which can include quartz, feldspar, carbonates, and opaques (Figure 56). Microscopically there is no consistent distinctive difference between quarried and non-quarried slates. The only other petrography of the slates available is Dale's work in 1899. Unfortunately, he dealt only with the economic units, but he determined that the major accessories were quartz, calcite, barite, chlorite, pyrite, and rhodochrosite, and his drawings also show feldspar and muscovite (Dale, 1899, p. 226-259). All except barite were noted in this study.

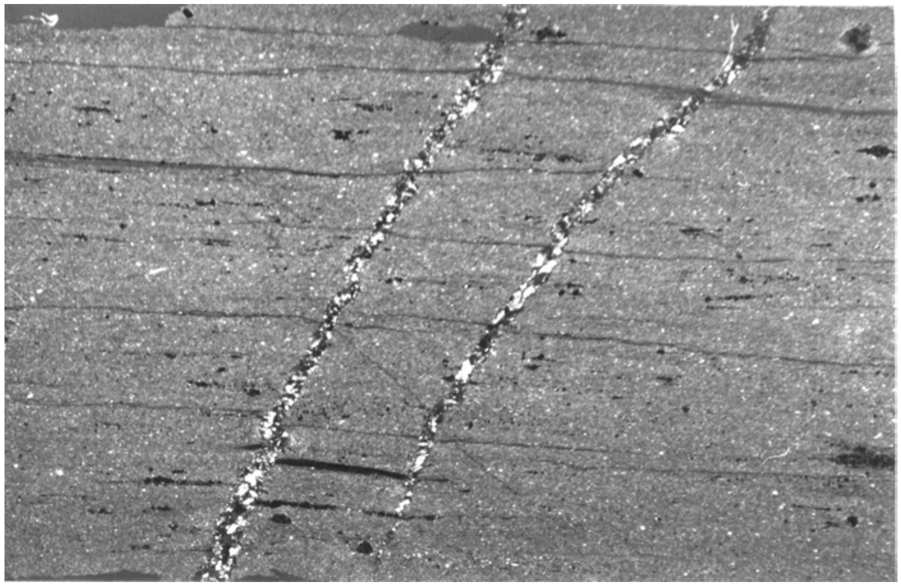


Figure 55. Well-defined slaty cleavage in the quarried slate of the Fox Rd. Mbr. of the Pawlet Fm. X10, crossed Nicols.

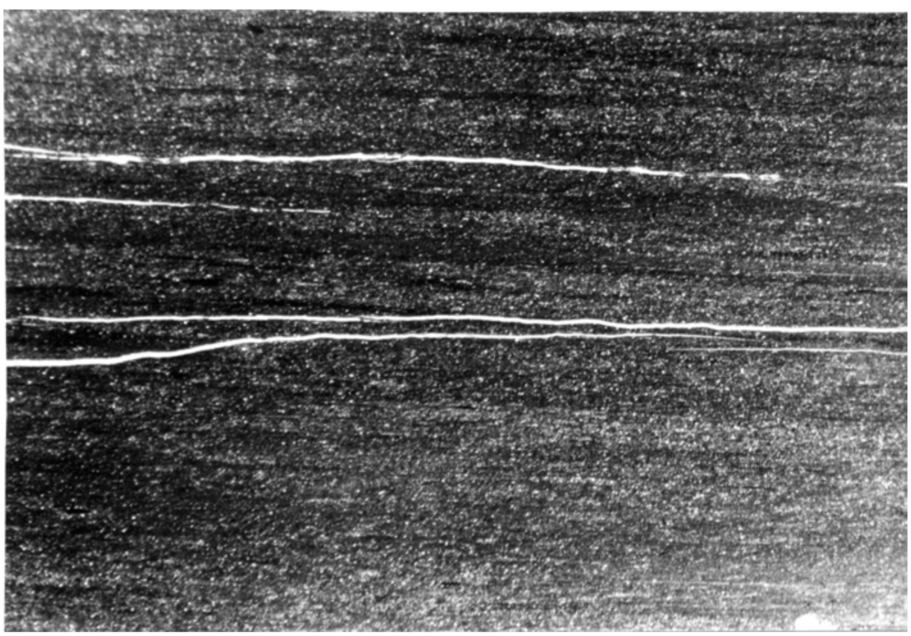


Figure 56. Silty slate from the Indian River Fm. X10, plane polarized light.

Summary

Rock type distribution in the Taconics raises some questions. Quartz is a ubiquitous silt sized accessory even in limestone and slate. However, varieties of quartz arenite only occur in units up through the Crossroad Mbr. of the Poultney; (very rare narrow arenites have been seen in the Indian River.) These arenites vary considerably in form and degree of maturity, but not with any progression that could be attributed to multiple cycles. Some of the arenites show bimodal size distribution possibly indicative of a dual source or of unusual sorting.

Limestones occur in the mid-sequence from the Browns Pond Fm. to the Dunbar Mbr. of the Poultney Fm. (and not every unit in the interval contains limestone). The limestone is almost always associated with dark gray to black slate, and although the units are not identical, they show strong similarities. The conglomerates and breccias, not surprisingly, show a similar distribution. The matrices are not always obviously related to nearby limestone units, and the clasts are often, but not necessarily Taconic rock types.

Chert is also a restricted lithology as it appears only in the upper three formations. Except for color changes it is notably uniform. Ellipsoidal to circular quartz aggregates, often containing internal structures, support an organic origin.

The wackes in contrast show little internal similarity. They occur infrequently, but are spaced throughout the sequence which implies some repetition in conditions.

Slates are the only common denominator lithology in the sequence. They are also the overwhelmingly dominant lithology and show much internal similarity apart from color change which reflects chemical differences in the depositional environment or sediment supply changes. This strongly implies a uniformity of something (source, depositional conditions, topography?) which existed throughout the time of accumulation of the sequence, and which will be discussed in Chapter V.

CHAPTER V

Depositional Environment and Sediment Source

Introduction

The original depositional site of the Taconics should be discernible. The rocks, although somewhat metamorphosed, retain many sedimentological and paleontological features which provide clues to the environment. The original sedimentary rock type is always readily discernible and slumps, channels, bioturbation, cross beds, graded beds, very fine undisturbed laminae, and soft sediment folding have been seen. On a microscopic scale the mineralogy of clastic components, the size and shape of mineral grains and rock fragments, the nature of the cement and/or matrix, and the degree of maturity of clastics have all been examined. In addition diagenetic changes, secondary recrystallization, cleavage development, and various evidence of deformation are visible.

All of these features were studied in the context of their distribution in space and time coupled with the knowledge that some of the variability was a function of inconsistent preservation. In addition, estimates were made of the relative volumetric proportions of different rock types. The picture that emerged was compared with the major modern environments of sedimentary deposition and was found to compare best, (although not perfectly), with the upper and lower continental rise. This suggestion was first made specifically by Bird and Dewey (1970) in their comprehensive Appalachian development figure although Zen described, but did not name a possible "rise-like" environment several years earlier (1967).

Previous Work

The recognition that sedimentary rocks suggesting very different origins (slates versus carbonates and arenites) were both adjacent and contained same age fossils was first made by Walcott in 1888. The assorted tectonic explanations for this juxtaposition were reviewed in Chapter II. However, there has also been controversy regarding the original type of deposition site of the sediments, and several hypotheses have emerged which are related to, but not entirely dependent upon whether or not the sequence is allochthonous. A literature survey indicates that only a few studies are firmly based on sedimentologic/faunal observation, and the following review is restricted to these more specific discussions.

Ruedemann (1929) initially proposed dual north-south troughs in the Appalachian geosyncline separated by a pre-Cambrian land barrier that persisted throughout Cambrian and Ordovician times. He stated that these parallel channels filled with disparate lithologies and fauna strongly suggested that sources were in the opposite directions. Dating of the units showed the troughs were alternately submerged and exposed at least four times (Figure 57).

In 1942 Ruedemann expanded the multiple trough theory to include three different sequences. He still vaguely attributed the formation of these troughs and their periodic, often deep submergence to "deeper seated factors" (page 171). However, the depositional significance of different sediment types and structures is discussed for the first time. Lower Cambrian clastics indicate variable ocean currents, depths, and distances from shore. Schodack (West Castleton) conglom-

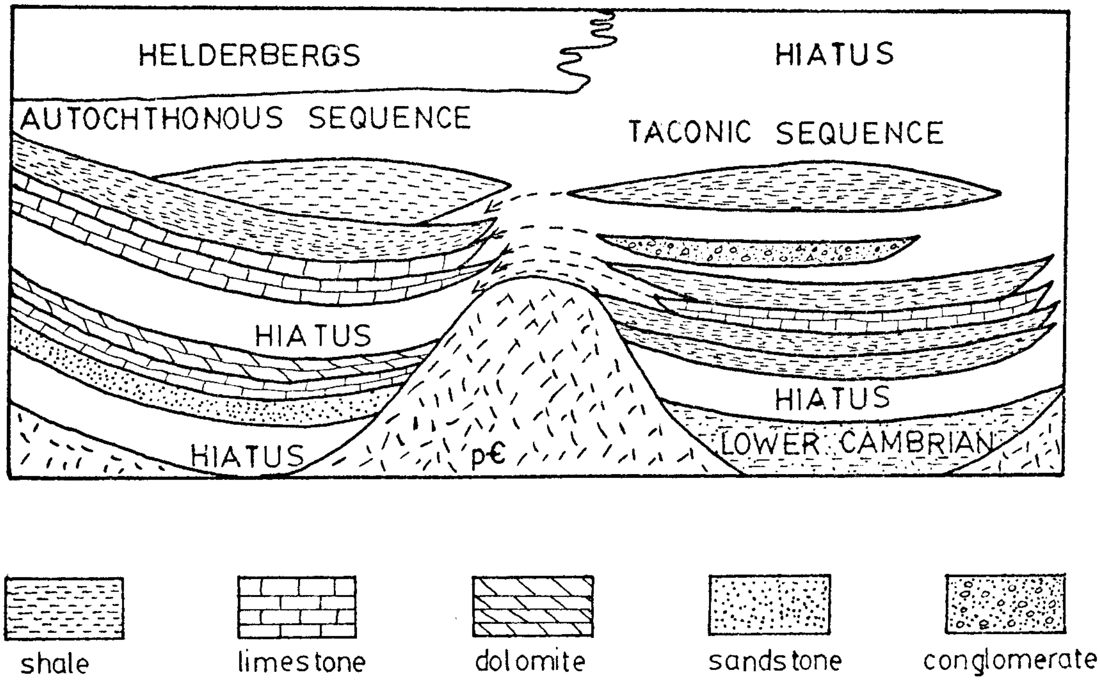


FIGURE 57

Figure 57. The dual trough hypothesis. (Modified from Ruedemann, 1929.)

erates show a steep grade. Frosted sand grains suggest a windy desert on shore. Iron ore (Burden Formation) and different colored shales mean generally shallow, sometimes oxidizing conditions. Mt. Merino chert overlain by Pawlet wacke shows a radical depth change from abyssal to near shore. Ruedemann also recognizes a certain unity throughout the geosyncline near the top of the sequence which had previously been explained away by faulting. The picture is neither complete nor consistent and it appears simplistic by today's paleoenvironmental studies, but it is important as an early attempt to describe the depositional environment.

Bucher (1957) explains Taconic rock type distribution by a series of three marine transgressions which deposit sediments on a warped surface. Therefore, the basal clastics are clean quartzites on higher elevations and banded quartzites and shales in deeper areas with Schodack (West Castleton) blanketing all. Two episodes of warping later resulted in a spotted pattern of intermittent deposition and erosion of carbonates. In late Canadian time (Lower Ordovician) the entire area was submerged (sand and limestone, shales), then deeply submerged (chert and graptolite shales), and finally less deeply submerged as warping began again (wacke and shale).

Bucher's description sometimes lacks clear stratigraphic reference, and he acknowledges that correlation problems arise from his hypothesis. There is unquestioned difficulty with the stratigraphy given the lithologic similarities of many Taconic units; however, one wishes Bucher had included some evolution diagrams to show how the apparently interfingering relationship resulted from his revised Taconic plus carbonate stratigraphy.

Lochman (1956) advocates facies changes in a single basin and uses faunal affinities for support. Her paleontologic data shows that both Atlantic and Pacific province fossils are present in the eastern New York-western Vermont section. This mixed assemblage requires that the beds enclosing characteristic shallow coastal fauna (Pacific province) and those enclosing deeper water fauna (Atlantic province) be deposited in the same relative positions they are seen today. To accomplish this Lochman visualized a deep basin in the coastal shelf with two passageways to the offshore deep ocean.

The lithofacies changes are less satisfactorily explained. Actual interfingering between the Taconic slate belt rocks and the valley sequence of carbonates and arenites was hypothesized but never seen. Lochman's observation that the difference is not of rock type but of percentage is partially true, but rather misleading. There is no arkose in the Autochthonous sequence and quartzite is not present throughout the Taconic sequence as stated. The implication that shale (slate), which comprises more than half of the Taconic rocks but only forms narrow partings between massive beds of carbonate and quartzites in the Autochthonous sequence merely shows different degrees of the same processes is a massive oversimplification.

Lochman asserted that the basin had a continental land mass to the west and an island archipelago to the east. The water was moderately turbulent, 300 to 600 feet deep, warm, and poorly lighted and provided an environmental barrier to Pacific province fauna. The depression had little seasonal range in physical and chemical properties. Sporadic turbidity currents brought in sand and arkose from both directions, and siliceous muds were derived from arc volcanics to the east. Unfortunately there are no suggestions how the basin formed, where the transitional lithologies are, and what happens to the coastal shelf to the east.

Shumaker (1967) briefly discussed the sedimentology of each unit in terms of depositional depth and water movement, and he constructed a geologic history. In today's context his discussion suffers from out-dated concepts of sediment transportation and deposition. However, he did suggest that the Pawlet wacke and slate indicates tectonic activity, sudden uplift and sediment derived from the east, an observation of great importance. Regionally, Shumaker believes the Taconic sequence fits best as a transition zone between the miogeosyncline and the eugeosyncline. This accommodates the paleontologic data as well as Lochman's hypothesis does.

Zen (1967) noted, as have others, that the Taconic sequence is remarkably thin considering the length of time of deposition. In contrast the east Vermont sequence of the same age span is approximately ten times as thick, has much recognizably igneous material and little quartz rich or carbonate rich rocks. This qualifies as a classic eugeosynclinal assemblage and therefore strengthens the regional picture for an intermediate setting for the Taconics. However, he stated that if the Taconics received slump deposited carbonate blocks from the miogeosyncline on the west, the site of deposition must be along the deepest part of the trough. It is hard to understand how under this scheme the Taconics could be an order of magnitude thinner than the same age flanking sequences (Figure 58).

Cady (1967) places the Taconic rocks on the structurally emerging Vermont-Quebec geanticline. This accounts for both the thinness

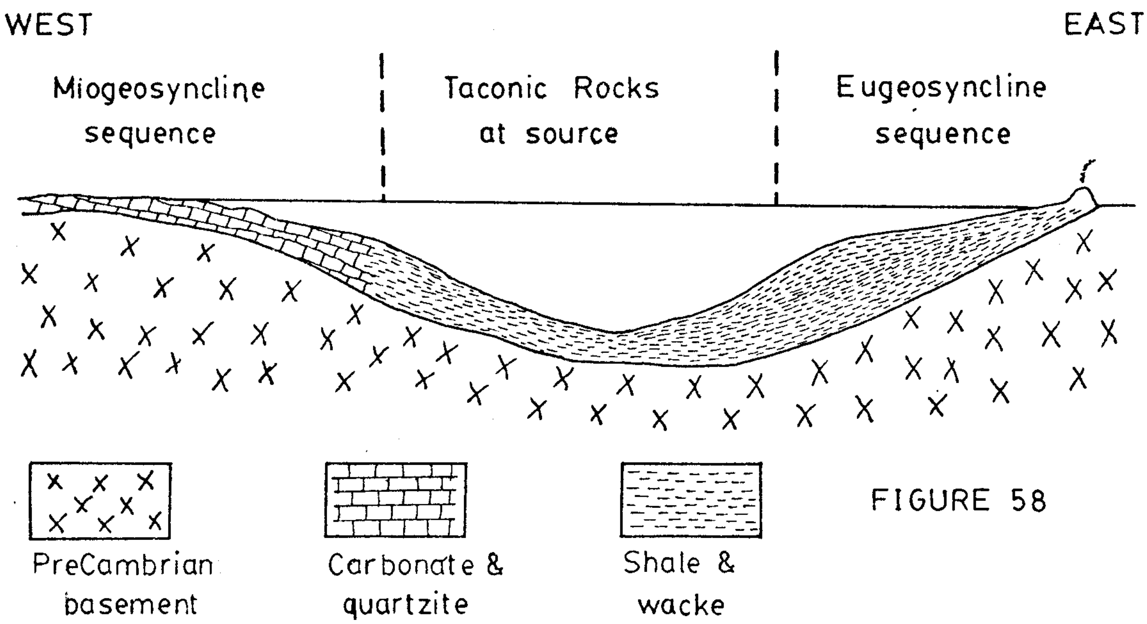


Figure 58. The original geologic setting of the Taconic rocks. (Zen, 1967)

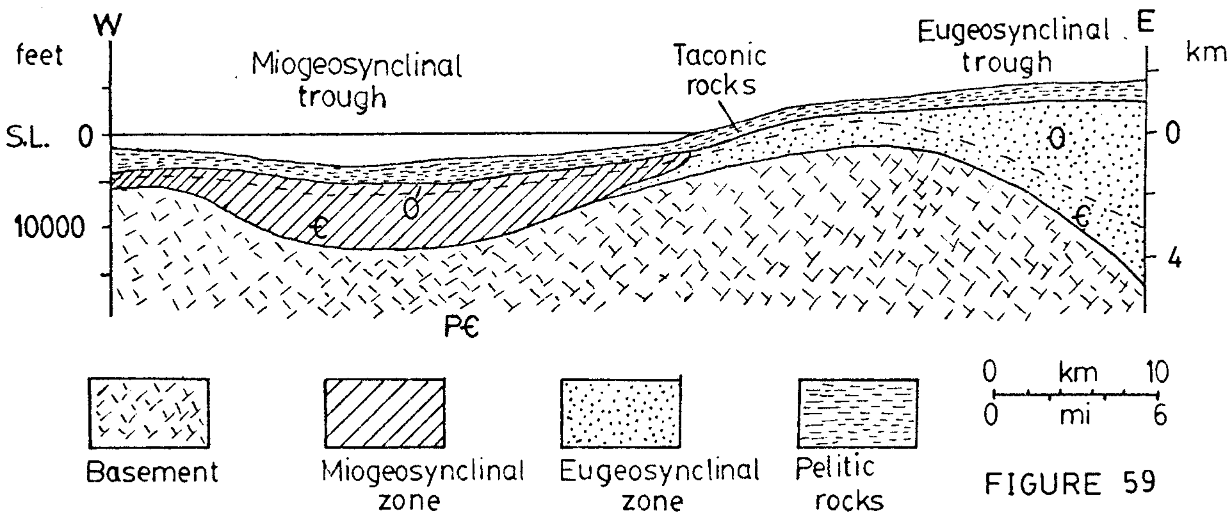


Figure 59. The original geologic setting of the Taconic rocks. (Cady, 1967)

of the sequence and the distinctively different characteristics of the eugeosynclinal and miogeosynclinal sequences to east and west. The Taconic rocks, though more eugeosynclinal than miogeosynclinal in character have affinities with both. The geanticline is dated as early Paleozoic and was therefore in existence for all of the Taconic sequence except possibly the anomalously thick Bomoseen wacke (see Figure 59).

Bird and Dewey (1970) were not the first to suggest that inadequate supply ("starved conditions") was the cause of the relatively thin Taconic sequence (Elam, 1960). However, they were the first to place the Taconic deposition site in the context of the current stable continental margin terminology. In their model for the evolution of the Appalachian orogenic belt, the Taconics were originally part of the continental rise (Figure 60). This paper was a very broad synthesis of data from many sources and did not directly involve specific or detailed sedimentologic analyses. This thesis is in part based on such analyses which support with qualification Bird and Dewey's (1970) conclusion regarding the original site of the Taconic rocks.

The only other recent, detailed work is Keith's (1974) and Keith and Friedman's (1977) reconstruction based on the study of 69 outcrops of Cambrian rocks mainly from the southern half of the Taconic Allochthon. Using primary sedimentary structures and petrology they define six lithofacies of carbonates and sandstones and construct a specific mini-environment where each could be deposited: debris flow for carbonate clast conglomerate, proximal turbidites for coarse massive sandstone, distal turbidites for graded sandstones and limestones, channel edge deposits for parallel laminated sandstones and

Figure 60. The northeastern North American continental margin in the lower Paleozoic. The rock types to the left of the line labeled "bank edge" refer to continental shelf sedimentation. "Coarse clastics" and "sands" refer to the Bomoseen Wacke and parts of the Browns Pond Fm. The "starved section" is the sequence from the Mettawee Fm. through the Mt. Merino Fm., and the "flysch" refers to the Pawlet Fm. Allochthon 1 is the two structurally lowest slices the Sunset Lake and the Giddings Brook, and Allochthon 2 is the higher thrust emplaced slices.

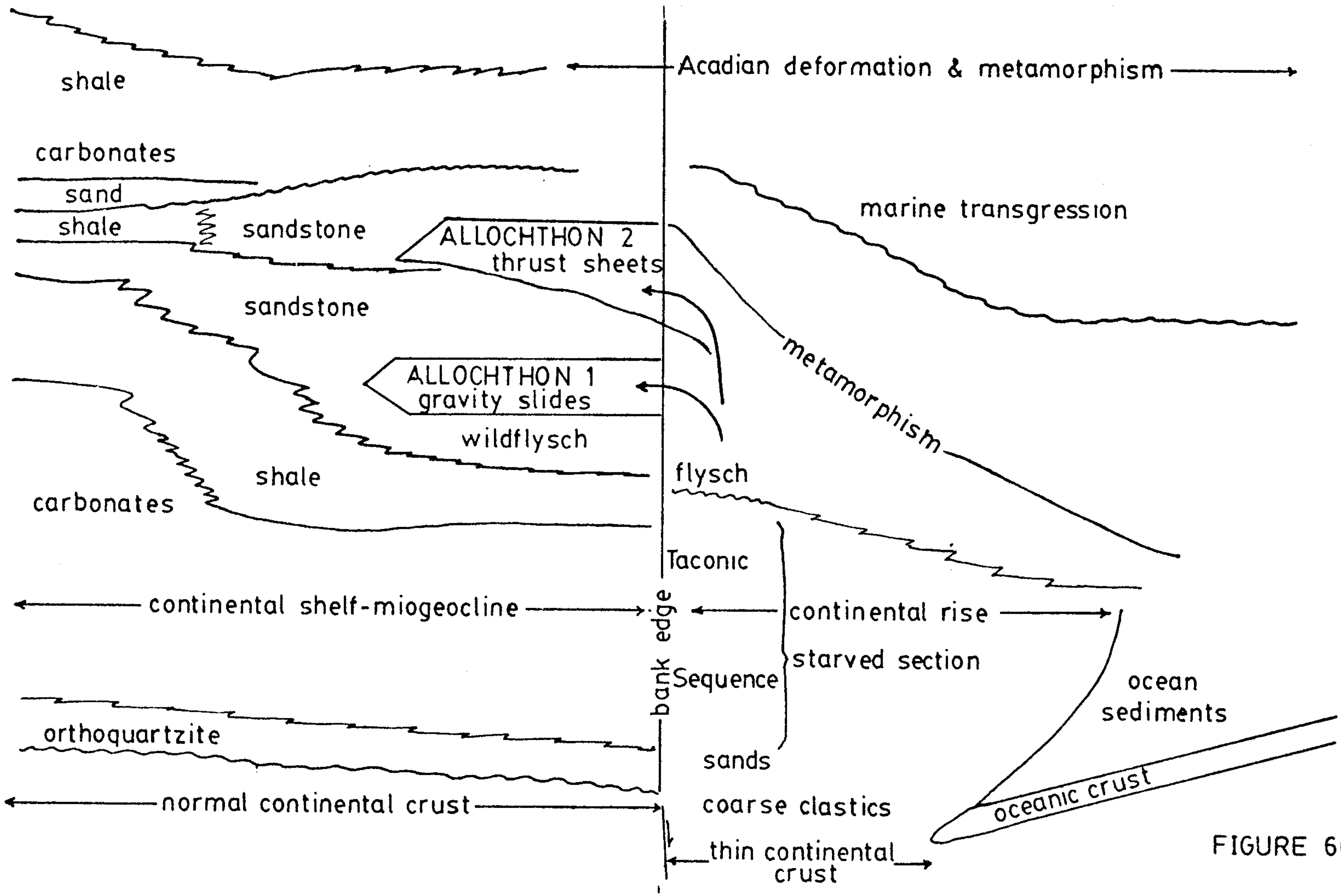

Acadian deformation & metamorphism
shale
carbonates
sand
shale
sandstone
marine transgression
ALLOCHTHON 2
thrust sheets
sandstone
metamorphism
ALLOCHTHON 1
gravity slides
wildflysch
shale
carbonates
flysch
Taconic
continental shelf-miogeocline
bank edge
continental rise
starved section
Sequence
ocean
sediments
orthoquartzite
sands
normal continental crust
coarse clastics
oceanic crust
thin continental
crust

FIGURE 60

limestones, suspension and possible contour currents for thin structureless micrites, and submarine overbank levee deposits or distal turbidites for current rippled, laminated sandstones and limestones. In a composite section they conclude that these rocks all originated in a "slope" and "base-of-slope" environment. Unfortunately, it is not entirely clear from either text or figures exactly what section(s) of a stable rifted margin are referred to.

In some ways this is a careful piece of work but it involves a number of biases which unavoidably obscure the results and conclusion. 1) The Taconic Allochthon contains rocks from Cambrian(?) to Middle Ordovician, but no Ordovician rocks were sampled or studied. 2) Sixty-nine sample localities is sparse for an approximate area of 2500 square km, and only six of these localities were in the northern half. 3) The interval sampled involved six formations and 100 million years. No specific attempt was made to identify or date most of the samples so that understanding of horizontal and vertical distribution, essential to environment reconstruction, seems to be limited. 4) The Taconic rocks are primarily pelites with accessory arenites and wackes, and minor limestones, cherts, and conglomerates. All of Keith's lithofacies classifications included limestone and/or sandstone, but slate (or shale) was never mentioned. Of course, the presence of minor rock types has environmental significance, but the vast amounts of silt and mud also have an importance which is, in my view, underemphasized.

Observations

Horizontal Distribution

Large scale variations in horizontal distribution or facies changes are attributable to three causes: channels, erosional disconformities and variable distribution of the effect of contour currents. Because of outcrop scarcity none is readily defined and indisputable outcrop examples are rare. However, map pattern distribution (Plate I) does outline discontinuities in the distribution of the West Castleton Fm. and the Dunbar Formations Mbr. of the Poultney Fm. The Mt. Merino chert is also sporadically present, but this may be exclusively erosional rather than depositional as it is at the top of the continuous (?) sequence. Some other formations (notably the Browns Pond, the Mettawee, the Hatch Hill, and the Indian River) show major variations in thicknesses. Both phenomena may be attributed to deposition on an irregular channeled surface which is then emphasized by redistribution and/or variation in sediment supply. None of these explanations requires a major change in depositional environment. The lower rise in particular has an uneven surface from longitudinal ridges noted especially on Leg 44 in the Western Atlantic. Their origin is controversial (D.S.D.P. Hole 388 vs. McGregor, 1976), but their existence is unquestioned.

A facies change, a lateral change in lithology of rocks of the same age does require a change in depositional environment. Poor outcrop and similar-looking rocks often make location within the stratigraphic column difficult and facies changes are therefore often suspected, but difficult to confirm. Exposed contacts or the absence of a usually resistant lithology provide the most definite clues.

Quarries are helpful as there are a number which show the base or top of the Mettawee or the top of the Indian River and a few meters of the adjoining unit. Therefore the top of the Browns Pond is known to vary from massive limestone to limestone breccia to black calcareous slate. The top of the Mettawee can be highly variable in color from purple to gray, and may be overlain by the West Castleton or Hatch Hill. The top of the Indian River can be highly siliceous, even cherty, in some locations, and the uppermost beds are occasionally gray. Complete sections of a formation are very rare, but the Browns Pond along the Mettawee River contains only one thick arenite while two are present in the type section and other areas. The Crossroad Member of the Poultney is the most variable unit in the area, and it contains rare chert, a distinctive limestone conglomerate, intermittent quartz arenites, and a wide variety of colored slates although gray predominates. Examination of Columns 2 and 3 in Plate III which are opposite limbs of the same syncline, shows the amount of variation possible over a short distance. Color change (which will be discussed later) is poorly understood and may not alone indicate a facies change because it is not necessarily a function of original depositional environment.

Vertical Distribution

No previous study has been done on the changes in lithologic distribution with time. These are far easier to identify and compile than facies changes because formation boundaries have been lithologically established (Chapter III), and fossil work has shown that boundaries generally do not transgress time lines (Berry, 1962; Theokritoff, 1964; Bird and Rasetti, 1968). The major rock types in the different units are shown in Table II. Some interesting patterns are apparent. Limestones and arenites are found only in the lower 2/3 to 4/5 of the section where they do not occur together. (In the only apparent exception, the Browns Pond, limestone in thin bands is distributed intermittently throughout the unit while the arenite is localized in one or two thick beds.) The conglomerates and breccias, which contain predominantly limestone clasts, are also limited to this part of the section; most but not all of the clasts are locally derived. Chert conversely is only seen in the upper 1/5 of the section and shows no appreciable overlap with either limestone or arenite. Some major change in depositional environment, particularly depth and/or source material occurred in the Middle Ordovician (middle Champlainian).

The slate and wacke distribution, however, suggest some type of stratigraphic coherence or even repetition. Slate is found throughout the sequence and comprises 50 to 100 percent of all the units except the Bomoseen, the Browns Pond, the Hatch Hill, and the Mt. Merino; in no unit is it less than 15 percent of the total rock. Wackes (as discussed in Chapter IV) occur in three widely separated formations and though compositionally dissimilar and suggesting different types of source material, imply some consistency in deposition conditions. Wacke and slate can both coexist with each of the other rock types.

Sedimentary Structures and Characteristics

Sedimentary structures are preserved in these low grade metasediments, but the degree and quality of preservation are highly variable. Therefore, such structures and other characteristics when present, are useful indicators of depth, paleoslope, and degree of turbulence.

TABLE II.

Vertical distribution of rock types by units.

	SLATE	ARENITE	LIMESTONE	CGL/BREC	WACKE	CHERT
FOX RD	↑					x
STODDARD RD	|				↕	
MT. MERINO	|					↕
INDIAN RIVER	|					x
CROSSROAD	|	↕		x		
DUNBAR	|		↕			
HATCH HILL	|	↕				
WEST CASTLETON	|		↕			
METTAWEE	|			x		
BROWNS POND	|	↕	↕	x	x	
TRUTHVILLE	|					
BOMOSEEN	↓	↕			↕	

However, their absence should not be accorded equal importance because it may not be original. Recrystallization can alter grain size, slaty cleavage and transposed layering can obscure bedding, and folding can render channels, cross beds, and slump folds unrecognizable. In addition, different lithologies reflect variable deposition conditions and retain various structures to different degrees.

Table III shows which sedimentary structures were observed in which units. There is no noticeable pattern or consistency in the distribution. Sedimentary structures can represent very small scale "mini-environments" of deposition. Graded bedding implies a quiet, level, probably deep setting. Five undisturbed laminae require current sorting action but no other descriptions. Cross bedding needs a depositing current. Bioturbation can only occur in chemical and physical environments conducive to life. Slumps and channels suggest a slope and/or a strong directional current. Contradictory occurrences such as undisturbed laminae and bioturbated beds both seen in the Crossroad Mbr. of the Poultney or undisturbed fine laminae and cross beds in the Bomoseen are examples of apparent contradiction. Such occurrences only mean that a given horizon is not characterized everywhere by the exact same depositional environment. Unfortunately, little current direction data could be obtained, so the paleocurrent picture is not defined. Predominantly slaty units (eg. the Truthville Fm. and the Stoddard Rd. Mbr. of the Pawlet Fm.) show few or no structures because lack of lithologic contrast and grain size variability lower both the potential of these units to develop such structures and the visibility of these structures when they are developed. The apparent dearth of sedimentary structures in the West Castleton and the Dunbar Mbr. of the

TABLE III

Vertical distribution of sedimentary structures by unit.

Unit	Graded Beds	Slumps/ Folds	Channels	XB eds	Fine-grained Undisturbed Laminae	Bio-turbation
FOX RD	X					X
STODDARD RD						
MT. MERINO						X
INDIAN RIVER						X
CROSSROAD			X		X	X
DUNBAR						
HATCH HILL	X	X		X	X	
WEST CASTLETON						
METTAWEE			X			X
BROWNS POND		X	X	X		X
TRUTHVILLE						
BOMOSEEN		X	X	X	X	

Poultney reflects the limited outcrop. Conversely, those units with lithologic variety and/or narrow contrasting beds (eg. the Bomoseen, the Browns Pond, and the Hatch Hill) contain several structural types. In some instances tectonic structures can mimic sedimentary features: transposed vs. sedimentary layers, tectonic vs. sedimentary cross beds, and tectonic vs. sedimentary folds. The problems of distinguishing these genetically different types will be discussed in Chapter VI.

Distribution of the different colored slates is tabulated in Table IV. A number of outcrops show different colors in irregular splotches suggesting post-depositional alteration. There are also numerous examples of color changes which parallel possible bedding and may therefore be original. The following generalizations have been seen in the literature (Shumaker, 1967; Ruedemann and Wilson, 1936) relating color change to environment. Gray is commonplace and presumably has a relatively low iron content, purple and red contain oxidized iron, green and gray-green contain reduced iron, and black indicates an organic rich anaerobic environment. Unfortunately only one set of chemical analyses exist for the slate belt (Dale, 1899), and these include only the economic units (Table V). The iron oxidation generalizations are confirmed, and the sulphur and carbon contents of the black slate far exceed any of the others. In addition, the apparent magnesium/manganese relationship mentioned in Chapter IV is supported by these figures.

Sedimentary Petrography

Some of the sedimentologic aspects discussed in Chapter IV offer insights into depositional environment and the nature of the sedimentary

TABLE IV

Slate color distribution by unit.

Units	Gray	Black	Red	Green	Purple	Gy-Gn
Fox Rd. Mbr.	X	X			X	X
Stoddard Rd. Mbr.		X				
Mt. Merino Fm.		X	X			
Indian River Fm.	X		X	X		
Crossroad Mbr.	X	X	X	X		X
Dunbar Mbr.		X				
Hatch Hill Fm.		X				
West Castleton Fm.		X				
Mettawee Fm.	X	X		X	X	X
Browns Pond Fm.		X				
Truthville Fm.						X
Bomoseen Fm.					X	X

TABLE V

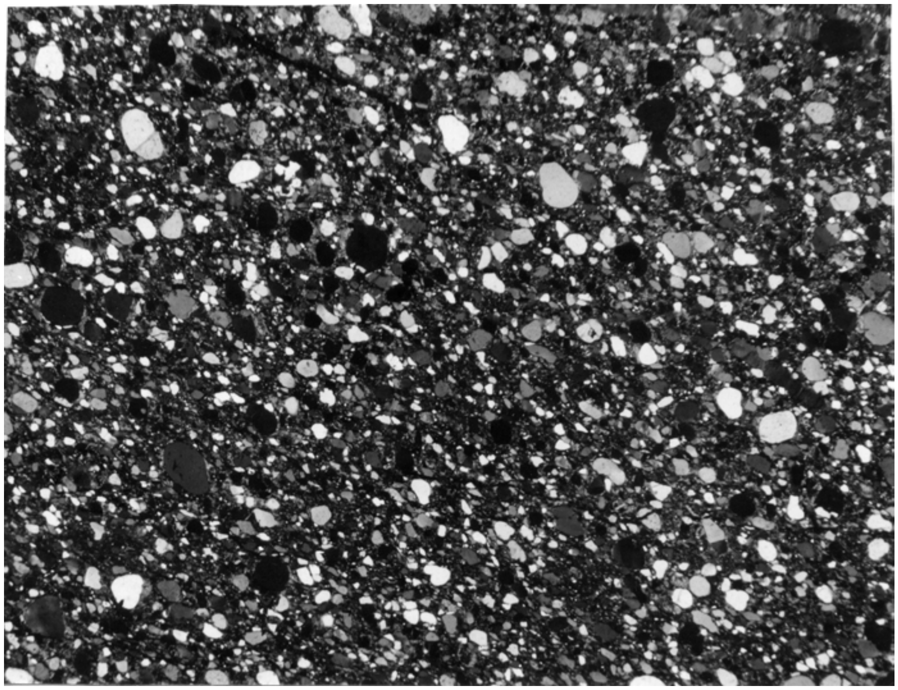
Chemical analyses of slates, compiled from Dale (1899).

	Mettawee Green (2 sples.)	Mettawee Purple (3 sples.)	Indian R. Red (4 sples.)	Indian R. Green (1 sple.)	Reduction Center R im. (1 sple.)	Reduction Center Center (1 sple.)	Unidentified Fm. Gy.-Gn. Sl. (1 sple.)	Unidentified Fm. Bk. Sl. (1 sple.)
SiO_2	59.38	60.94	63.88	67.89	64.59	65.44	63.33	59.70
TiO_2	1.01	.82	.52	.49	.51	.52	.73	.79
ZrO_2	tr	tr	NA	NA	NA	NA	NA	NA
Al_2O_3	18.52	16.98	11.78	11.03	10.23	9.38	14.86	16.98
Fe_2O_3	1.18	3.94	4.57	1.47	1.79	1.09	1.12	.52
FeO	6.69	3.48	1.32	3.81	1.19	1.06	4.93	4.88
MnO	.1	.08	.2	.16	.26	.32	NA	.16
NiO	tr	tr	tr	tr	tr	tr	NA	tr
CoO	tr	tr	tr	tr	tr	tr	NA	tr
SrO	tr	NA	NA	NA	NA	NA	NA	NA
CaO	.49	.5	2.24	1.43	4.07	4.53	1.20	1.27
BaO	.05	.03	.1	.04	.05	.06	NA	.08
MgO	2.34	2.76	4.56	4.57	5.12	4.92	2.98	3.23
K_2O	3.78	4.87	3.94	2.82	3.70	3.57	4.06	3.77
Na_2O	1.61	1.43	.49	.77	.23	.22	1.22	1.35
Li_2O	tr	tr	tr	tr	tr	tr	NA	tr
H_2O-	.25	.21	.36	.36	.28	.25	.69	.3
H_2O+	4.01	3.37	2.82	3.21	2.29	2.10	3.37	3.82
P_2O_5	.1	.16	.08	.1	.08	.08	NA	.16
CO_2	.3	.38	3.14	1.89	5.84	6.55	1.41	1.40
FeS_2	.14	.06	.02	.04	tr	.04	.11	1.18
SO_3	tr	tr	tr	NA	NA	NA	NA	tr
C	----	----	----	----	NA	NA	tr	.46
Fl	.04	NA	NA	NA	NA	NA	NA	NA
Σ	99.99	100.01	100.02	100.08	100.23	100.13	100.01	100.05
ΣS	.07	.03	.01	.022	tr	.022	.06	.63

source. Some samples in some of the arenites show a bimodal size and texture distribution in the quartz grains. Accessory grains when present do not mimic this sorting but are part of the smaller size group. In some pre-deposition phase the sand must be sorted and at least the larger size fraction cleaned. The two size ranges represent either two distinct well-sorted sources or a single source whose middle size fraction has somehow been preferentially removed.

The degree of textural and mineralogical maturity in arenites is interdependent but highly variable. Zircons, when present, are invariably highly rounded. Quartz can be sub-angular to round, and other accessory minerals are generally sub-angular to sub-rounded. None of the grains shows specific evidence of sub-aerial transport, although other aspects particularly rounding point to a beach or dune sand origin. The rocks range in mineralogy from almost pure quartz arenites to arkosic arenites. There are no characteristic mineral assemblages to suggest a provenance, but a few quartz grains contain inclusions that suggest an igneous or high grade metamorphic terrain. The rounded quartz and zircon may represent multi-cycle sedimentologic history. Almost all lithologies contain finely dispersed sub-angular quartz silt. This ubiquitous silt suggests wind transport from an arid land mass.

Wackes by definition are poorly sorted and inconsistently immature. They also lack a distinctive or characteristic mineral assemblage, but the rock fragments in the lithic varieties are mainly sedimentary. Some of the sand grains, particularly in the Browns Pond, are highly rounded displaying a maturity perhaps achieved via earlier cycles. Textural contrast between a closely associated quartz arenite and



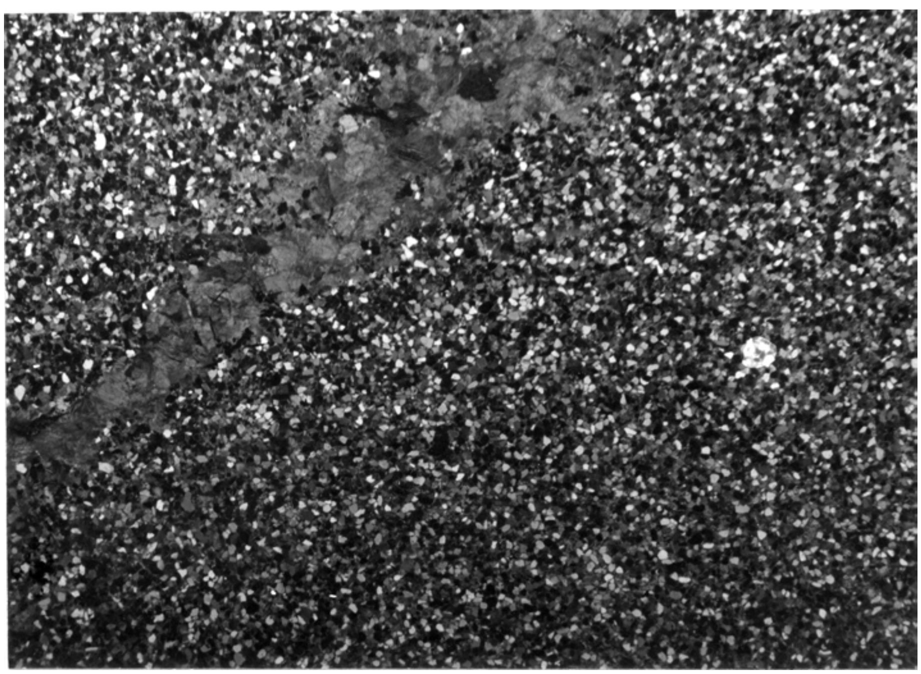


Figure 61 A & B. Quartz arenite and lithic wacke from the Browns Pond Fm. These two samples were taken from the same location, but have distinctly different quartz grain distribution. The scale is the same. X15, crossed Nicols.

lithic wacke can be striking (Figure 61).

Rock Type and Thickness Proportion

Rock type distribution by thickness has been estimated and tabulated in Table VI. These figures use maximum thickness data for each unit and do not directly consider lateral variation and are therefore very approximate. The sequence which was considered goes from the (never seen) base of the Bomoseen to the probable unconformity at the base of the Pawlet. The thickness estimates come from Chapter III. The percentages confirm that the sequence is dominantly pelitic with some arenite and wacke and minor limestone and chert. Addition of figures for the Pawlet Formation slate and wacke does not significantly alter the proportions. Theokritoff's unit thicknesses for the same area (1964) are included for comparison. Considering the problems of unit distinction and sparse outcrop they are rather close.

Because modern depositional rates can be measured and are known to vary with environment, an attempt was made to calculate "paleo-depositional" rates. Using Eo-Cambrian to Lower Caradocian (155 million years) and a total thickness of approximately 700 m, an average deposition rate of 4.5 mm/1000 yrs. was obtained. Tectonic thinning is real but difficult to account for. Using Wood's data (1972) the calculated rate is tripled to 1.4 cm/1000 yrs. If the sequence actually contains no hiati (a question which may never be answered), this is a slow accumulation rate and must represent a starved environment. (Starving can occur either because no source area exists or because it exists only on the other side of a barrier.) In modern abyssal depths red clay accumulates at 1 to 5 mm/1000 yrs. and carbonate ooze accumulates at 2 to 5 cm/1000 yrs. The modern

TABLE VI.

Rock type distribution by maximum thickness per unit and by volume per cent of the entire sequence.

	Bomo-seen	Truth-ville	Browns Pond	Metta-wee	West Castleton	Hatch Hill	Dunbar	Cross-road	Indian River	Mt. Merino	Σm.	Σft.	%Whole
Slate	15	30	20	48	30	25	12	100	52	5	337	1112	48
Arenite	20		15			75		67			177	584	25
Limestone			10		16		11				37	122	5
Conglomerate			4	2				5			11	36	2
Wacke	115		3								118	389	17
Chert								3	3	15	21	69	3
Σ m.	150	30	52	50	46	100	23	175	55	20	701	2313	100
	495	99	171	165					180	66			
Σ ft.	594		336		152	330	76	578	246				
Theokritoff (1964)	600		400		150	350	100	400	200			2200	

Conversion used: 3.3 ft./m.

rise has a highly variable deposition rate ranging from net erosion to 20 cm/1000 yrs. (Fox, pers. comm., 1976). However, the geologically recent Pleistocene has exaggerated a "normal" rise, and there is a compaction factor that will reduce thickness during lithification.

Summary

The site of deposition for the Taconic sequence was a highly flexible and variable environment which allowed for the broad range of observed rock types, structures, and characteristics. The sediment source(s) is more consistent, and a basic, fairly simple and limited mineralogy characterizes each rock type; textures are more variable. Fossils indisputably label the environment marine. The dearth of carbonate and shallow water sedimentary structures disqualifies the continental shelf, and the substantial presence of non-pelites disqualifies the abyssal plain. The continental slope is an escarpment of shelf sediments with a thin and discontinuous cover of pelagic and hemi-pelagic sediments. Process of elimination leaves the continental rise.

Whatever model is constructed, it must explain the following observed phenomena and be consistent with their suspected causes.

1) Some formations are known to lens. There is no independent evidence of unconformities, and it is assumed to be an original feature which results from deposition on an uneven, probably channeled surface.

2) Rapid and repeated lithologic change suggests that a given depositional environment can be very limited in extent and transient in existence.

3) Different colored slates may reflect different or changing oxygenating environments that would have been a function of both depth and turbulence.

4) Approximately 25 percent of the rock in the sequence is arenite of varying form (layers < 1 cm to > 10 m thick) and grain size (silt to granule). These rocks require an intermediately deep and distant site.

5) Approximately 5 percent of the rock in the sequence is limestone which probably must be deposited above the carbonate compension level (approximately 4000 m).

6) Approximately 3 percent of the rock in the sequence is chert which usually requires an abyssal (> 4000 m), nutriment-rich, silica-producing environment.

7) Approximately 1 percent of the rock is conglomerate or breccia, sometimes with slump structures. A slope is needed within a reasonable distance.

8) Approximately 15 percent of the rock is wacke. At least one formation (the Pawlet) shows graded bedding from medium sand to clay sizes which suggests turbidity flows, which also require a slope.

9) Sections of at least three units show very narrow, planar, undisturbed bedding which suggest a relatively calm and quiet deposition site; other sections (of the same and other units) show beds disrupted by fauna and small scale cross laminations which indicate some current activity (as well as burrowing organisms).

10) Narrow (≤ 2 cm) alternating beds of clay and silt sized materials (seen particularly in the Crossroad and the Bomoseen) indicate post-depositional sorting.

11) Massive, thick (~ 10 m) clean arenites require a) pre-

depositional sorting, and b) a method of rapid, large scale deposition. Modern ocean bottom current readings and sediment patterns in cores indicate that post-depositional sorting in the deep sea is possible only for silt and smaller sized sand grains in layers up to several cm thick.

12) The estimated thickness for the entire sequence up to the base of the Pawlet is approximately 700 m. This conforms closely with the only other determined thickness for this area, 665 m, (Theokritoff, 1964). This covers about 155 my of deposition or an average of 4.5 mm/1000 yrs. before tectonic deformation. Any model for Taconic sequence deposition must explain this unusual thinness.

The Modern Continental Rise

The continental rise is a marine topographic feature that normally lies seaward of the continental slope and landward of the abyssal plain along a stable rifted margin. Its upper limit is marked by a slope discontinuity with the continental slope, but the base is hard to define because the relief gradually decreases to the level abyssal plain. The continental rise is typically 80-160 km wide and lies in water 1000-5000 m deep. It has two sections, an upper and a lower rise, which are separated by a slight change in slope (Figure 62).

The modern rise, particularly off eastern North America, has been extensively investigated by geophysical techniques and coring (Emery, et al., 1970; LePichon, et al., 1975; DSDP, 1970-1977). Seismic refraction, supported by gravity data, defines a deep sedimentary trough. The trough contains up to six km of sediments which show a two-layer velocity structure. Seismic reflection identifies planar, gently dipping beds and also slumped sequences which may comprise up to one half the volume of rise sedimentation. The deposition rate for the Mesozoic sediments of the rise is highly variable, but averages 1 cm/1000 yrs. Deposition has been more rapid since then: approximately 1.5 cm/1000 yrs., and in the Pleistocene to Recent can vary from net erosion to 20 cm/1000 yrs. (Emery, et al., 1970).

Pre-DSDP there were very few pre-Pleistocene holes drilled into the continental rise sedimentary prism (Ericson, et al., 1961; Schneider, et al., 1967). Since 1970 six DSDP legs (#11, 14, 25, 41, 44, and 48) have drilled a total of eight holes into the eastern and western Atlantic continental rises. These holes range in length from 340-1000 m and show approximate deposition rates of 4-26 mm/1000 yrs. These

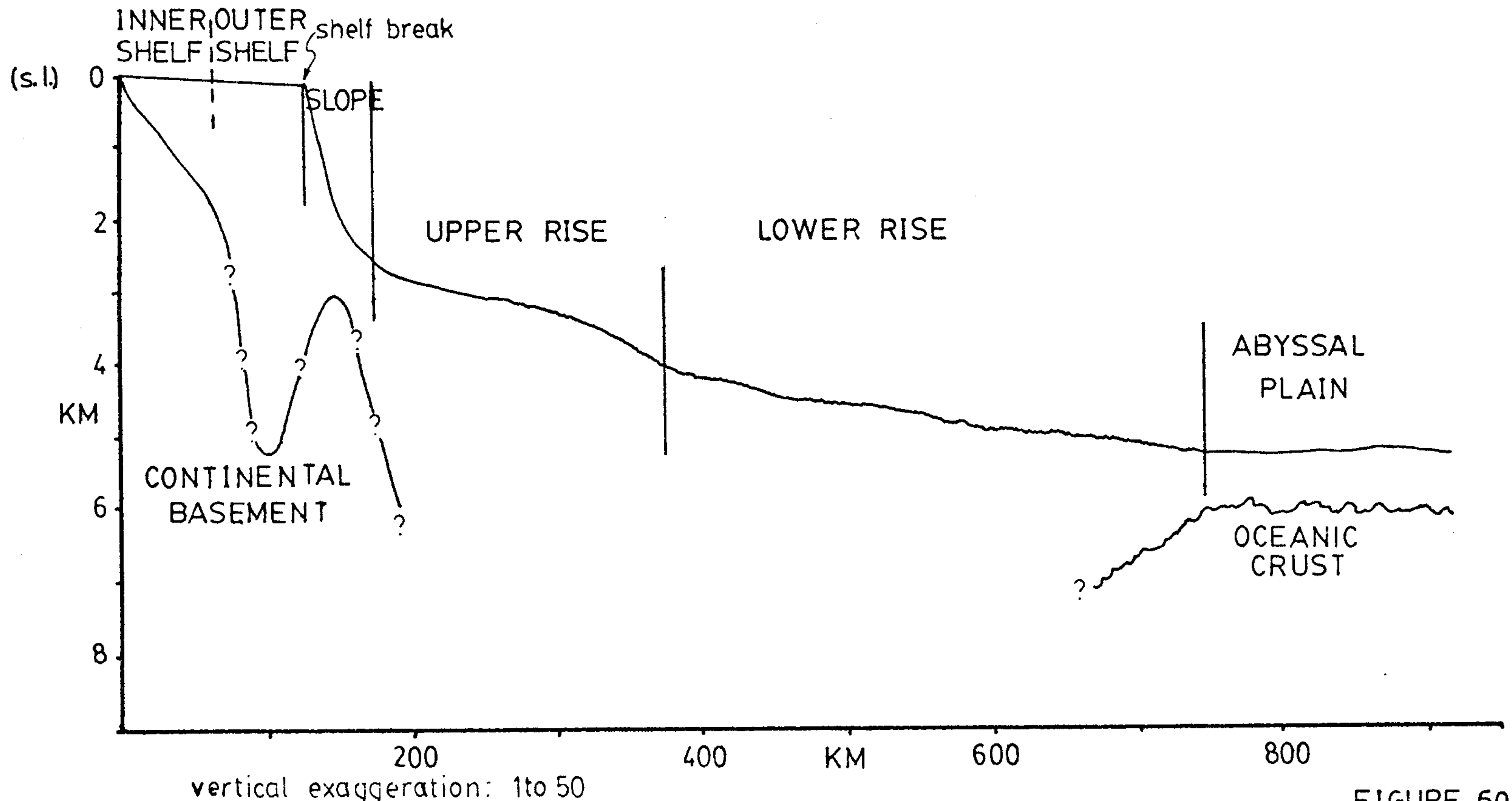


FIGURE 60

Figure 62. The topography and structure of a modern stable rifted margin.

cores, which can include sediment as old as Lower Cretaceous, are predominantly clay, silty clay, and marl with minor limestone, chert and sand. In general, there is less sand than observed in the Taconic sequence, and there does not seem to be much channel deposit or proximal turbidite material although recognition of these features may require more closely spaced drill holes than has been done.

A number of workers have done precise work to obtain data for the continuing literature discussion regarding the relative merits of turbidity flows, contour currents, grain flows, channel and debris flows, and slumps as methods of transporting, shaping, and sorting the rise and its sediments (Schneider, et al., 1967; Zimmerman and Hollister, 1976; Embley, 1976; Stanley and Unrug, 1972; Pilkey and Field, 1972; Bouma and Hollister, 1972). Some characteristics overlap, and positive identification is not always possible, but there are probably examples of each of the above in the Taconic sequence.

Proximal turbidites have sand sized grains at the base and may be missing the upper fine-grained layers; quality of grading and thickness of beds show great variation. A probable example is the wacke in the Browns Pond. Distal turbidites have silt at the base and grade upward to clay (Horn, et al., 1971). This description fits the Fox Rd. Member of the Pawlet except that the base has sand sized grains. Contourites consist of narrow alternating bands of clean quartz silt and clay which have been sorted and reworked by contour currents (Fritz and Pilkey, 1975). Currents up to 25 cm/sec have been measured on the lower rise (Zimmerman and Hollister, 1970). Sections of the Crossroad Mbr. of the Poultney and the Bomoseen show this style of banding. Channel deposits or fluxoturbidites (Stanley and Unrug, 1972) are coarse, thickly bedded, and poorly graded (if at all). The only coarse, thickly bedded Taconic rocks are the arenites in the Bomoseen and Browns Pond. Channel deposition is essentially instantaneous so these would not qualify unless they were pre-sorted and pre-cleaned. Beach sand would suffice, but that would require a channel cut very close to shore. This has been seen in the Pacific (Shepard and Dill, 1966), but is not known to be common on aseismic margins. Debrites are giant slides of slump folded pebbly mudstones with sharp angular contacts (Embley, 1976). There are no full sized debrites in the Taconic sequence, but the mud matrix conglomerate in the Browns Pond meets all the description except scale. The relative importance of these mechanisms is not important here because no one disagrees that they can all contribute to rise sedimentation. What is important is that they all appear to contribute to the Taconic sequence.

Remaining Problems and Speculative Conclusions

Not all the Taconic lithologies and their distribution readily fit into the conventional continental rise framework or are obvious analogues to cored samples or geophysically defined features. The Bomoseen wacke, the Mt. Merino chert, the conglomerate bearing formations which do not contain significant limestone (Mettawee Slate and Crossroad Member of the Poultney), the thick clean arenites in the Bomoseen and the Browns Pond, and the vertical lithologic distribution discussed earlier all still require explanation.

The narrowly interbedded wacke and slate with sporadic arenites seen in the Bomoseen Fm. does not conform to descriptions of either proximal or distal turbidites. Not all workers, however, subscribe to an exclusive relationship between turbidites and wackes (Cummins, 1962). The size, shape and distribution of wacke and quartz arenite beds and the relationship between them and the adjacent slate beds are very similar. Only the rate of occurrence differs strikingly; the quartz arenite beds are relatively uncommon and look like "housecleaned" wacke beds. This observed distribution of wacke, slate, and arenite was undoubtedly accentuated by the sorting effects of bottom currents so that the rock is really a hybrid turbidite-contourite. Sedimentary structures suggest that slumping also contributed.

Banded chert and slate, as seen in the Mt. Merino, has a controversial origin. However, microscope study of these rocks revealed some radiolarians which favors a bio-organic origin. Sea water normally contains only four ppm silica and is, therefore, intensely undersaturated. Only when silica (or the appropriate nutrients for siliceous organisms) is locally available in large quantities, can substantial chert form. Lang (1969) favors volcanism as a source for the silica which would stimulate radiolarian production. This is supported by probable tuff beds in the underlying Indian River and the presence of contemporary Ammonoosuc Volcanics to the east. Most bedded cherts are presumed to be abyssal and Ruedemann and Wilson (1936) estimate a minimal depth of 3660 m for the formation of the Mt. Merino based on the depth of modern radiolarian ooze. This is within the range for modern rise depths. The absence of clastics and the presence of pyrite suggest a starved depositional environment and a restricted basin. The former has already been suggested by other criteria and the latter may result entirely from depth because it is difficult to envision a physically closed deep basin in the open ocean unless caused by the proposed arc in the east. Modern rise sedimentation in the western Atlantic contains a widespread acoustically distinctive horizon which is known in places to be Upper Cretaceous to Lower Eocene chert.

Limestone pebble and matrix conglomerates have been seen in the Mettawee and the Crossroad Mbr. of the Poultney, two units which do not otherwise contain limestone. These conglomerates are not located adjacent to limestone units; in addition, they sometimes contain exotic black phosphatic pebbles that are not derived from any known Taconic rock. The conglomerates appear to be local and are attributed to channels or slumps of shelf carbonate off the edge of the continental shelf. Some of the other pebbles, neither slate nor chert, may be phosphatic and are probably also shelf derived. No associated slump structures have been observed with these conglomerates, but they are seen elsewhere in the sequence.

The thick clean massive coarse arenites found in the Bomoseen and the Browns Pond have been tentatively attributed to channel flow material. The only known possible modern analogue was also cited earlier. No possible similar features have been encountered in the core log literature of the modern rise with both the thickness noted and the well-sorted monomineralic clastic character. Contour currents can sort quartz silt layers only a few centimeters thick. Therefore, pre-depositional sorting is essential and the beach or desert dunes are the logical possibilities. However, if the shelf width approximates today's width (~ 80 km), sediment transportation could only be accomplished in a channel which cut across the shelf as well as the slope, a possible but uncommon occurrence. In order to create the observed arenites a network of such must have existed for over 50 my.

The main contributors to the unusual vertical distribution perhaps were changes in ocean circulation depth and changes in the nature and availability of the sediment. The carbonate compensation level varies with temperature, but carbonate rocks are generally in jeopardy below 4000 m. However, 4000 m is a minimal depth for bedded chert so that depths apparently increased somewhat during the deposition of the Indian River Slate. The Indian River's color cannot be attributed to shallow deposition; it is probably a function of sediment supply. It could not have been so deep that oxygenating circulation was precluded because burrowing is extensive.

The Crossroad Member is the highest unit with significant sand-sized clastics although quartz silt continues to be finely and ubiquitously dispersed to the top of the sequence. (The Fox Rd. Mbr. of the Pawlet wacke has a different tectonic setting.) Pelites continued to be deposited so there was not a complete barrier, but there was either a barrier which selectively retained the coarser fraction or a well-eroded source area which only contributed clays. Lang (1969) prefers the latter, but without compelling evidence.

The choice of a continental rise similar to ones seen today as a depositional environment for the Taconic sequence is not entirely satisfactory. It is in part a process of elimination, in part a successful comparison with observed modern features, and in part a theoretical justification of processes which could have happened there. The question is not fully resolved, but the proposed answer is not contradicted by any unresolvable incompatibilities.

CHAPTER VI

STRUCTURE

Introduction

Structure, like other features in the Taconic area, is obscured by sparse and unrepresentative outcrop, although some quarry exposures are spectacular. The rocks in the sequence vary greatly in physical and mechanical properties so that folds which external evidence (eg. number, nature, and orientation of cleavage(s) suggest are of the same generation may have different forms. Therefore, folds lacking identifying folded and/or cross-cut cleavage often cannot be grouped morphologically. Quality of cleavage development, particularly slaty and crenulation cleavage which require phyllosilicates, is also highly variable because it parallels the rock type variation. Slaty cleavage is often beautifully developed in slates and non-existent in stratigraphically nearby quartz arenites or clean micrites. Faults by their nature "self-destruct" in that they create zones of weakness in the rock which are then preferentially eroded. Therefore, they often display no direct positive field evidence but must be deduced from an irregular map pattern. The exception to this is the quartz cemented fault breccia which is hard and highly resistant and has been mapped in a few locations. Even this tangible evidence gives few hints of magnitude, direction of movement, or the other important descriptive facets of faults.

Other smaller pieces of structural evidence include the deformation of reduction centers and radiolaria, both of which are presumed by some to have original sphericity. Therefore, their change in dimensions may reflect amounts of strain in the rocks. The area was affected by one (Lane, 1970) or possibly two (Zen, 1972) episodes of relatively low grade metamorphism. In addition, there are a few later (middle to upper Cretaceous) lamprophyric dikes; in addition, there is one outcrop on Rt. 22A that displays cross-cutting silicic bodies which might be igneous. They are very rare and structurally unimportant.

These features will be described and discussed below, along with regional conclusions, insights, and speculations gleaned from the map and cross sections (Plates I and II). Assorted topics that hopefully will contribute to a better understanding of Taconic structure will be discussed and any possible major conclusions outlined. The structural features observed and the history determined previously (see next section) is not questioned, but some observations are added and/or interpreted. The emplacement controversy, which is intimately involved with one or possibly two deformation episodes will not be discussed further, because the present study brings no new data to bear on the subject (see Chapter II for historical review).

Previous Work

Many geologists have studied and puzzled at the structure in the Taconics just as they have considered other facets. The range of opinions and conclusions, and therefore controversy, is much less extensive; most structurally discordant thoughts in the area relate to the allochthon/autochthon question and the nature-of-emplacement (if any) question. A number of workers (Zen, 1968; Cushing and Ruedemann, 1914; Balk, 1953; Fisher, 1961; Bucher, 1957; Cady, 1967, 1968a, 1968b) have done fairly broad regional structural syntheses; however, only those who included specific descriptions of folds, cleavages, faults, and bedding identification criteria have been included in this review (Table VII).

Dale's cross sections (1899) are extensive, but like his maps, lack the detail of his text, both structurally and stratigraphically. Dale believed bedding is generally discernible and lists the following criteria for identification: change in rock type (always indicative), fossil annelid trails and microscopic mineral grain alignment (sometimes indicative), and color change (possibly indicative). He found the slaty or "flow" cleavage generally not parallel to bedding (an observation not confirmed in this study which is admittedly based on a much smaller area) and the second or "strain-slip" cleavage not parallel to either earlier foliation. Dale saw no faults except a few small ones exposed in quarries. However, his map pattern implies the presence of faults which are not mentioned. Regionally he noted that slaty cleavage and the folds to which it is axial planar dip uniformly to the east.

TABLE VII

Structural features studied and discussed by Taconic geologists.

Name	Date	Soft Sediment Deformation	First Tectonic Deformation	Second Tectonic Deformation	Intraslice Thrust Faults	Normal Faults	Kinks	Joints
Dale	1899		X	X			X	
Wright	1969	X	X	X				
Zen	1972	X	X	X		X	X	
Shumaker	1967		X	X	X			X
Platt	1960		X	X	X	X		X
Lane	1970		X	X (sub-divided)	X			
Potter	1972		X	X	X	X		
Ruedemann	1942		X	X	X	X		

Larrabee (1940), another geologist whose main focus was economic, made essentially the same observations as Dale regarding bedding and cleavage distinction, except he had more faith in color change indicating bedding (misplaced faith, the present author believes; Figure 63). He also noted that while there was not a fixed relationship between bedding and slaty cleavage, they were often parallel on the limbs, and that quarries in these areas showed less waste than when located on the hinge. Larrabee located some northeast trending faults, not by direct observation, but from unit juxtaposition in the map pattern. Parasitic folds seen on the limbs of major folds can document relative movement of different types of beds and are associated with fracture cleavage. Grain, an "obscure striation" (Larrabee, 1940, page 50), but economically very important, is formed by the alignment of platy minerals in a plane perpendicular to slaty cleavage, and it therefore shows as a lineation on it.

Ruedemann (1942) in his work on the Catskill Quadrangle concentrated on the large scale faults and folds although he did describe flow/slaty cleavage and boudinage. He found numerous thrust faults, and normal and cross faults and also overturned isoclinal folds (which look very much like some seen in northern Washington Co.). The main geometry, described as a continuation of linear, north and south plunging, overturned folds with parallel thrust faults, also sounds very similar to those in the study area.

Hawkes' (1941) map shows few faults probably indicating that like others he saw few actual faults in the field and did not find indirect evidence compelling. Like others he equated the variable but ubiquitous slaty cleavage with axial plane cleavage. He noted widespread,

Figure 63. Color change in the Indian River slate. The diameter of the circle is approximately one meter.

but not dominant, fracture cleavage and a strong lineation (possibly grain) in addition to bedding-cleavage intersections.

Platt's (1960) description differs from the others in that in the Cossayuna Quadrangle fracture cleavage is extensive and parallels axial planes. He points out that different rock types show a variable susceptibility to cleavage development, but he does not imply a correlation. There is no explanation why the first cleavage in this area is fracture instead of slaty. Deformation intensity increases to the east and this quadrangle is on the western edge of the allochthon, so it seems rather unlikely that this is a later cleavage and that an earlier one has been obliterated. Folds also have variable morphology, isoclinal to open; shape is related not to rock type as might be predicted, but to geography in that folds to the east are larger and more open. The other noticeable difference with other descriptions is the presence of normal faults that cut the sole of the boundary thrust.

Zen (1961) equivocates somewhat on the bedding identification problem. He initially states that bedding is safely defined by change in rock type but not color, and that transposed layering is not a problem. However, he later describes examples of "quartzite-like bands" in slate which cut "unquestioned bedding" and are presumed to result from intense shearing. This sounds like a potentially deceptive situation. He notes two types of cleavages, slaty which parallels bedding except in the hinges of the folds to which it is axial planar, and a later, spaced fracture cleavage. Because there are two cleavages, bedding-cleavage relationships are difficult to use, but Zen mentions pencil cleavage and minor folds (presumably only one generation) as indicators of orientation and closure direction.

Two workers in the Castleton Quadrangle have identified three not necessarily unrelated deformation events. It is not certain if this is the only area where this particular sequence exists (unlikely), the only area this sequence is well exposed (possible), or the only area which has been approached with this particular working hypothesis (probable). The wide geographic separation of this area from the Cambridge Quadrangle where three groups of structures were also identified (Lane, 1970) is consistent with the noncorrelation of the two groups and the extent of the variations seen throughout the allochthon.

Wright (1969) distinguishes a pre-lithification soft sediment deformation characterized by isoclinal folds, diapiric and slide structures, and slump breccia with no associated cleavage, although a "planar structure" (page 21) of oriented but not recrystallized platy minerals parallels some axial planes. Some but not all of the description fits the pre-lithification deformation concept. The large scale structural geometry and regional slaty cleavage were formed next. The folds have variable form depending on the rock type involved, and they are distinguished from the earlier set by scale and presence or absence of slaty cleavage or distinctively sedimentary features. The third phase is also recognized in part by its relationship to the earlier ones; it deforms slaty cleavage and develops a fracture cleavage. The folds are much smaller scale, and the deformation intensity, particularly in the third phase, markedly decreases to the west; this is consistent with the present study in a section of the western most allochthon where second folds and cleavages are infrequently seen.

Zen (1964, 1972) in the same general area saw the same features but by 1972 had proposed a more regional structural setting. Event I occurred during the gravity sliding emplacement of the two structurally lowest slices. Event II, dated as late Ordovician to early Silurian, resulted from the emplacement of the higher slices and included a regional low grade metamorphism. Event III which includes a possible second metamorphism (Wright disagrees) is probably part of the Acadian Orogeny of early to middle Devonian age. Radiometric dates of dikes demonstrate that these were intruded much later (middle Cretaceous).

Lane (1970) who worked in the Cambridge Quadrangle to the southeast of the Granville area also discovered three sets of structurally related features, but they are not a duplicate set to Zen's and Wright's. The earliest observed are large, recumbent folds with a slaty cleavage parallel to the axial planes. The next group is comprised of smaller, open, north to northeast trending folds with strain slip cleavage. The youngest group closely resembles the previous one except that the folds trend south to southeast. No sedimentary deformation (Zen, 1972, Event I) was seen, and Lane hypothesizes that it was destroyed by later activity. His earliest structures probably correlate with the second group of Zen (1972) and Wright (1969). His second and third groups sound like a subdivision of the last event of Zen (1972) and Wright (1969) which may not be sufficiently developed in other areas to make the same distinction.

Regional metamorphism in the area has not received widespread attention except as a component of some of the deformation events. It is generally agreed (Zen, 1960; Thompson and Norton, 1968) that the chlorite zone includes the study area and extends approximately ten kilometers to the east (Figure 64); the beginning of the biotite zone is marked by the first presence of biotite or chloritoid depending on

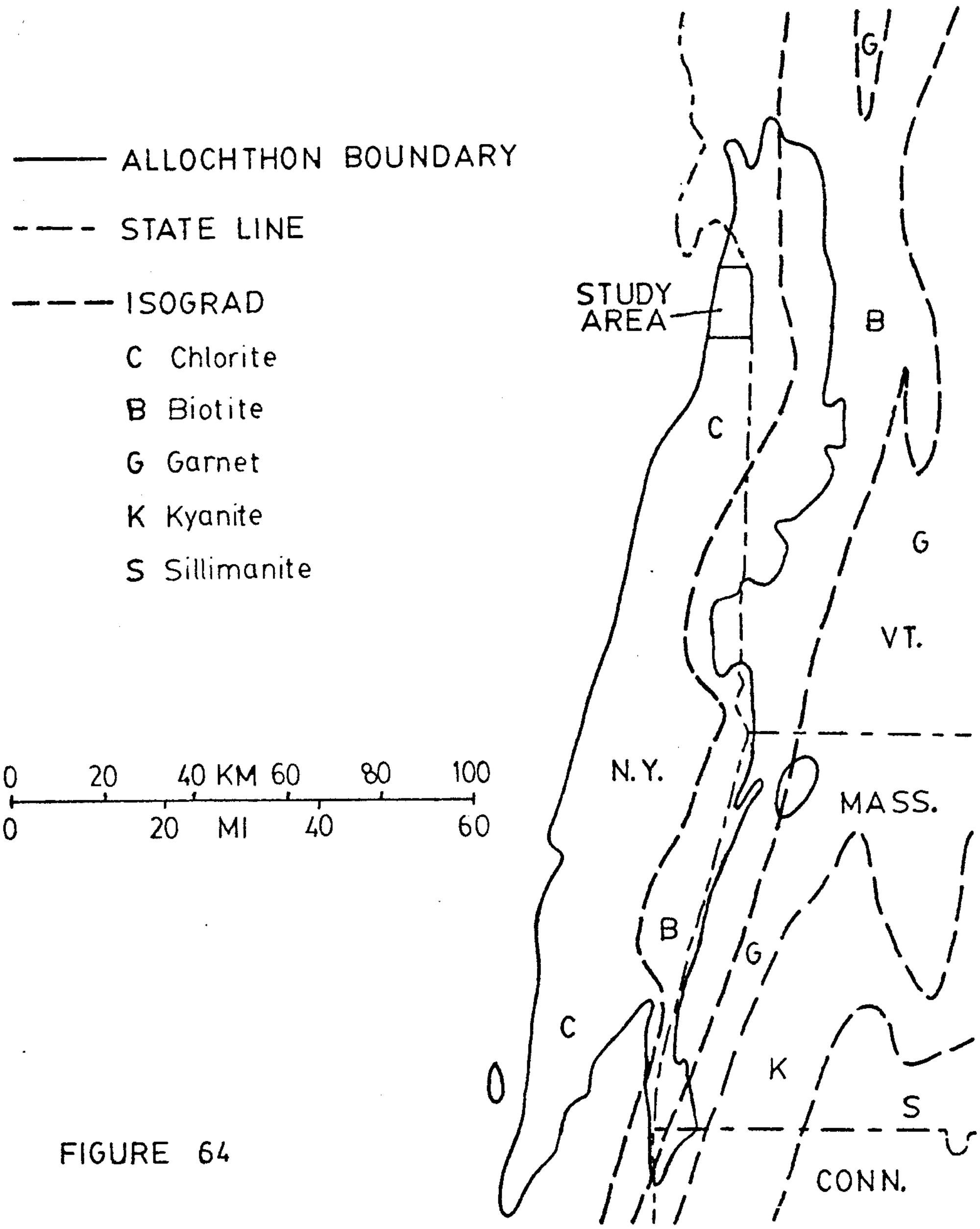


FIGURE 64

Figure 64. Distribution of metamorphic grades in eastern New York and western New England.

(after Thompson and Norton, 1968)

rock type. Unfortunately, only one-third of Zen's 40 x-ray and microscope analyses were done on rocks from formations found in the area of this study. He found ubiquitous chlorite and discussed only three carbonates (calcite and dolomite-ankerite).

The foregoing review points out that the major geometry (essentially north-south trending linear folds overturned to the west) is consistently recognized, and does not change appreciably with geography. However, the form of the folds, the nature of the associated cleavage, the presence or absence of faults, second cleavage, and soft sediment deformation, and the ease and certainty of bedding identification all greatly vary in description. Part of this variability is a function of the focus, scope, and thoroughness of the observer, but part is also real.

Observations: Megascopic and Microscopic

Introduction

The present study attempted to cover an area small enough to be mapped in detail in the period of time available and large enough to be representative of the northern Taconics. Like the different formations of the stratigraphy, the structures have some common origin, but conditions at and since the time of formation have produced a variety of results across the area. Therefore, some of the literature descriptions and photographs sound and look very familiar, and some are completely unfamiliar. Unfortunately, as in other subject areas, lack of outcrop was an irritating fact of life. Its absence was felt particularly keenly in the area north-northeast of Truthville where rapidly changing orientations suggest extensive folding which could not be specifically discerned. Another frustrating area was the southeast corner of the map (Plate I) around Raceville where major discontinuities are suspected, but unconfirmed.

The assorted styles, types, and forms of cleavages, faults, and folds actually seen will be described below, and their similarity or dissimilarity to previous descriptions noted. Other deformation evidence, tension gashes (Figure 65), joints, flattened reduction centers, and radiolaria, have been noted, but not measured. Others, particularly Wood (1973), have assumed initial sphericity for the latter two and used the deformed dimensions to calculate the amount of shortening in the rock and to determine strain values and possibly mode of origin and/or depth of formation. Wood (1973, 1974) measured reduction centers in slate in western Vermont and determined an

Figure 65. Tension gashes in the Indian River Fm. green slate. The cracks are filled with calcite.

average shortening of 75 percent perpendicular to slaty cleavage and axial surfaces. No mention was found of analogous work with Taconic radiolaria, which is unfortunate because radiolaria are known 1) to pre-date deformation and 2) to begin as a sphere.

The study area is all in low grade metamorphic terrain with chlorite the only definitely identified and widespread mineral present. The region is criss-crossed by a number of later, relatively small, usually lamprophyric intrusives. Dale (1899) studied 22 slides (analcities and camptonites) in the slate belt both petrographically and structurally. He related dike orientation to joint systems and "hogbacks" (broad kink bands) and assumed the two to be genetically related. Dates have since proven this very unlikely. One (possibly two) dikes in the field area (others are reported, Dale, 1899) and one dike approximately four kilometers to the south were examined in outcrop and thin section.

Cleavages

Three types of cleavages are well defined in the area; one, slaty cleavage, is ubiquitous (rock type permitting) and the other two, fracture and crenulation cleavage, are rare. The slaty cleavage is axial planar to the major north-south trending folds and therefore has a reasonably consistent orientation with a moderate easterly dip. The quality of slaty cleavage development is completely dependent upon rock type composition and therefore varies from excellent (in uniformly fine-grained slates) to wretched (in very clean coarse limestones and arenites). In rocks with layers of different strengths, cleavage, well-developed in slaty layers, may be deflected by adjacent uncleaved-layers (Figure 66).

In thin section slaty cleavage shows as medium brown threads, sometimes regular, planar, and finely spaced (Figure 55) and sometimes anastomosing and discontinuous (Figure 49). The brown material is presumably a clay. It may be accented by planar mineral concentrations, especially quartz or opaques. Because this silt or dust is not composed of oriented elongated grains, it could be micro-bedding coincidentally paralleling the cleavage. Less frequently muscovite flakes contribute to the slaty cleavage, but these are also clastic particles.

Fracture cleavage and crenulation cleavage are evident in a limited number of outcrops. There is no obvious strong geographic or stratigraphic pattern, although reports of others would predict an increase in occurrence to the east. They are contemporaneous, and they are always later than the slaty cleavage with their distribution determined by lithology: crenulation cleavage in fine-grained sheet silicate-bearing rocks (slates) and fracture cleavage in cleaner, coarser arenites and limestones. Morphologically, they are end members of a continuous gradational series between the two types. These cleavages are presumably axial planar to a second set of folds. Such folds were occasionally seen (and will be discussed below) but seldom with their axial plane cleavage definitely visible on an outcrop scale.

In a few locations, particularly between Rte. 21 and Quivey Hill Rd., indisputable second cleavage was seen which looked disconcertingly like the slaty cleavage which characterizes the first tectonic deformation. These examples are known to be second cleavages because the outcrops also contained bedding with parallel slaty cleavage at an angle oblique to the second cleavage. This unsettling observation

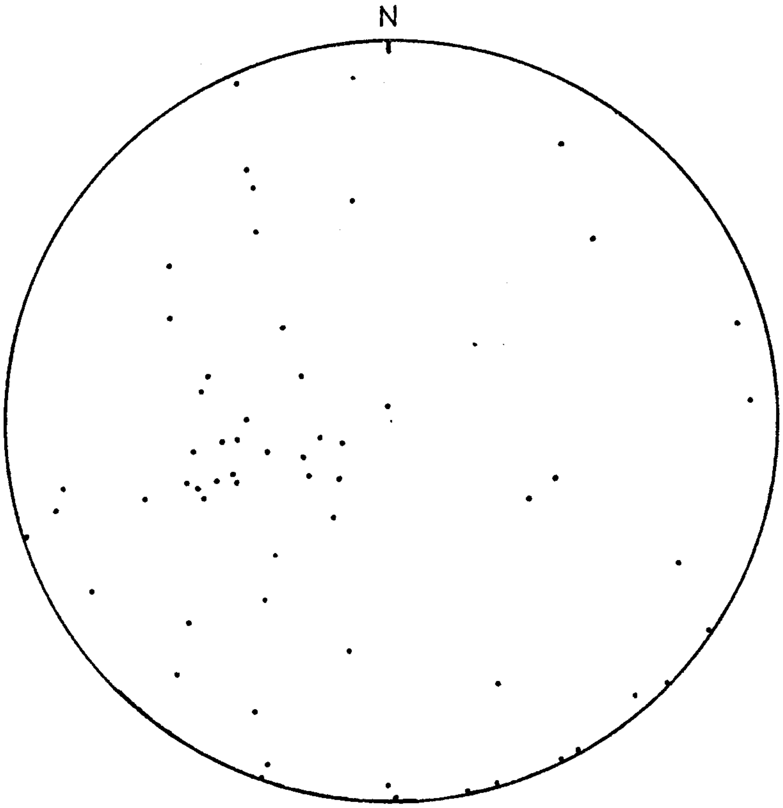
Figure 66. Bedding-slaty cleavage relationship in the Indian River Fm. This outcrop is of slate and chert which occur near the top of the formation and in the core of a syncline.

raises the possibility that a single slaty cleavage in an outcrop could have resulted from either the first or second tectonic deformation.

The distinction between fracture cleavage and joint systems was impossible, and the line was therefore arbitrarily drawn. If parallel fractures were separated on the average by one inch or less, they were labeled fracture cleavage; if the distance was greater than one inch they were joints. The differentiation is probably important as Platt (1960) unsuccessfully attempted to use joint orientation to elucidate structure near faults. However, the separation made here is probably not valid as an equal angle stereo projection of poles to second cleavage (both fracture and crenulation) shows a broad scatter, with only a hint of concentration in a N20W strike and moderate eastward dip (Figure 67).

Folds

Fold morphology runs the full gamut from tight and isoclinal to open. In general, fold shape is more a result of, and therefore correlative with rock type, than of geography or deformation generation. Tight folds are most often found in slate although they may not be visible if there are no strongly contrasting layers (Figure 68). Both tight and open folds were seen in units of thick arenites, wackes, cherts, limestones, or conglomerates (Figure 69). The most visible folds are in narrowly interbedded slate and arenite as the Crossroad Mbr. of the Poultney (Figure 70). Three different deformations were identified though many folds could not be conclusively assigned to one of them. Although fold form is variable, a few generalizations may be made. Independently identified second tectonic deformation



63 points

FIGURE 67

Figure 67. Equal angle stereonet projection of second generation cleavage. Both fracture and crenulation cleavage are included on this plot because their difference is based on the rock type in which they occur. The broad scatter implies no consistency or pattern of orientation.

Figure 68 A. The core of a syncline exposed in a quarry. The Indian River-Mt. Merino contact is plainly shown by the color change from red to black (weathers white).

Figure 68 B. Fold in Indian River Fm. red slate.

Figure 69 A. Folds in the Hatch Hill Fm. This Z fold suggests that the anticline is to the east.

Figure 69 B. Tighter Z folds in slate and quartz arenite of the Bomoseen Fm.

Figure 69 C. Fold in both intact and conglomeratic layers of the Browns Pond Fm.

Figure 70 A. Side view of small multiple folds in the Crossroad Mbr. of the Poultney Fm.

Figure 70 B. Open fold in the Crossroad Mbr. of the Poultney Fm.

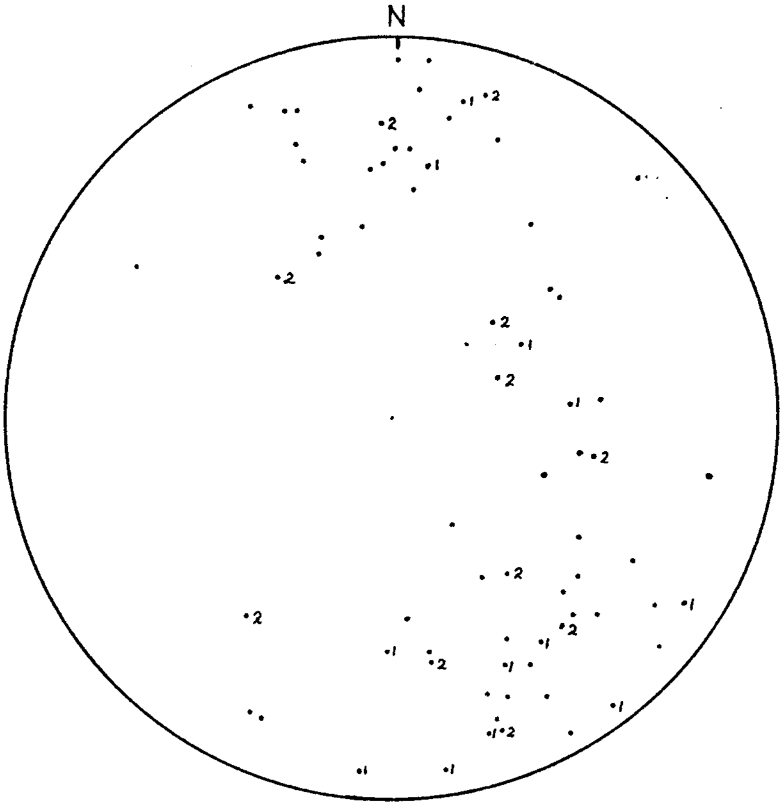
folds are usually open while the earlier folds are tight to isoclinal if rock type permits. No examples of undisputed refolding were seen, but one probable slump fold series has their axial planes parallel to regional slaty cleavage and were presumably intensified and perhaps even reoriented (Figure 15). Because shape is not always diagnostic, the criteria used were presence or absence of 1) axial plane cleavage, 2) folded slaty cleavage, and 3) deformation in overlying and underlying beds. The earliest folds are pre-lithification (Figure 22), and the other two are tectonic with their accompanying axial plane cleavage which unfortunately is not always visible to the naked eye or to hand lens magnification. Apparent dismembered folds have been seen in both the Bomoseen and the Crossroad where they are highlighted by narrow alternating wackes or arenites with slates. Fold hooks and fully detached "rolled" pieces of arenite (Figure 71) are present. Bioturbation may in part be responsible.

An equal area stereo projection of fold axes of the tectonic deformation folds (differentiated by generation where possible) shows a broad scatter with two vague concentrations: S25E±10 degrees with plunges of 15-40 degrees S and N5E±10 degrees with plunges of 15-30 degrees N (Figure 72). The sequence labeled points do not show any distinctive distribution which might pinpoint which tectonic deformation was responsible for all the unlabeled points. On the map, Plate I, unknowns are arbitrarily but consistently assigned the symbol of the middle generation because this is the most prominent and consistent fold-maker and responsible for the regional map pattern.

Faults

Most major faults were located by map patterns of formations or

Figure 71. Deformation in the Crossroad Mbr. of the Poultney Fm. The scale bar is in centimeters.



69 points

FIGURE 72

Figure 72. Equal angle stereonet projection of fold axes. First and second generation fold axes are labeled where known. No soft sediment deformation data were knowingly included. No pattern emerges which allows unlabeled points to be assigned to a particular deformation generation.

lineaments on air photos (and will be discussed in the next section). A few small faults were seen in major road, river, and quarry outcrops (Figure 73), and in some places thick (up to two meters) vein containing rock fragments implies fault zones. Direction of motion is generally indeterminable so that the faults are referred to as strike or cross faults depending on their geometric relationship to the predominant north-south folds. Some of the strike faults are bedding plane faults where beds moved past and slickensided each other during folding; these are often vividly exposed in Indian River Slate quarries.

Some of the extreme thickness variations in units could result from intraformational parallel faults. Because there are other explanations (deposition on an irregular surface, uneven compaction, facies changes, etc.) for these thickness changes, faults are not invoked without compelling independent evidence, but their possible presence is certainly acknowledged.

Deformed Reduction Centers and Fossils

Objects of known original shape (öolites, reduction centers, fossils, vesicles, spherules, nodules, etc.) when flattened and/or deformed can supply information about the deformation. Original sphericity is more precise because original relative demensions are known exactly. The Taconics contain two of these initially spherical, now (sometimes) ellipsoidal objects, reduction centers and radiolaria. Of the two, radiolaria are theoretically more reliable markers because it has not been conclusively demonstrated that reduction centers are invariably initially spherical, or that they form prior to deformation.

Reduction centers are fairly common in red mudstone and shales.

Figure 73. Normal fault in the Crossroad Mbr. of the Poultney Fm. The displacement is approximately half a meter.

They have green centers with purplish rims and are very striking. The one chemical analysis available (Dale, 1899, see Table V) shows that from red slate to purple rim to green center, SiO_2, CaO, and CO_2 increase and Fe_2O_3 and Al_2O_3 decrease appreciably. A slight and possibly insignificant increase was noted in MnO and slight decreases were recorded in FeO, K_2O and Na_2O. The reduction center nucleus is probably calcite. Reduction centers are particularly good markers because they have the same physical properties as the surrounding slate. They are seen in the Mettawee and Indian River slates.

Possible radiolaria are found in various colored cherts from the Indian River and Mt. Merino Formations and were seen as a very minor component in one slide of quarried cherty gray slate from the Fox Rd. Mbr. of the Pawlet Fm. They consist of recrystallized quartz and some show the remains of an internal structure. Some, but no all, of the fossils are flattened to ellipses along planes of slaty cleavage (Figure 54). This inconsistency may arise from a combination of inhomogeneities in the radiolaria and the enclosing rock.

Metamorphism and Intrusives

There is dispute about the number of metamorphic events (one or two) affecting the area, and the present study has no data on this question. However, the dikes are definitely much younger, and they have little or no contact metamorphic effect on the country rock. The metamorphic grade increases to the east, but the area covered is not broad enough to see a difference microscopically. Chemical analysis might reveal a change in chlorite composition (the only prevalent metamorphic mineral) because Fe^{++}/Mg decreases with increasing temperature.

Of the three possible intrusives two are mafic and one is silicic, but they vary widely in texture and mineralogy. One of them beautifully exposed in a large quarry south of Hampton has been previously described (Dale, 1899) as an analcitite. It is a medium gray, medium-grained rock with prominent (up to 2 cm) feldspathoid and carbonate filled vesicles. The matrix is sub-ophitic, highly altered, and dominantly made of plagioclase, brown hornblende, opaques, and some clinopyroxene (Dale reports augite). Accessory minerals include zircon, apatite, biotite, muscovite, pumpellyite, chlorite, and olivine (Figure 74). It fits the description of augite-camptonite, and was previously named analcitite for the primary matrix analcite (possible, but not confirmed here).

The other mafic intrusive is a dike (Figure 75) seen in a roadcut on Rte 22A west of Granville. It is dark gray, fine-grained, vesicular, and contains small ($\leq$ 3mm) subhedral brown hornblende phenocrysts and smaller ($\leq$ 1 mm) euhedral very pale green orthopyroxene phenocrysts. The matrix is trachytic plagioclase with minor opaques, orthopyroxene, and apatite, and secondary chlorite and carbonate (Figure 76). It is a basalt and very different from the dike 15 km north.

The igneous nature of the third example is uncertain. It was seen in a large outcrop of the Crossroad Member of the Poultney on Rte. 22A north of Middle Granville, where it looks like the well cemented, fine-grained silty quartz arenite common to that unit; however, it clearly truncates gray and black interbedded slate and suggests intrusion (Figure 77). It also appears to truncate cleavage, but it is difficult to be sure. There is no layering in the slate which parallels the "dike" and no structure in the "dike" paralleling the banded

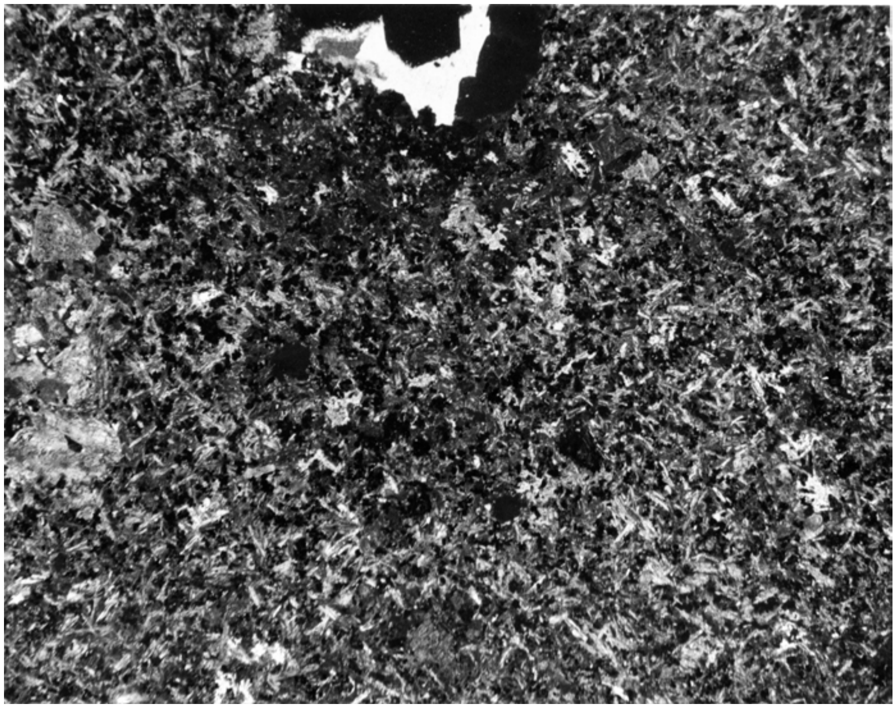


Figure 74. Lamprophyre dike known to intrude the Indian River Fm. X8, crossed Nicols.

Figure 75. Lamprophyre dike intruding the Mt. Merino Fm. In this exposure the intrusion is locally a sill, but the regional picture is a cross-cutting one.

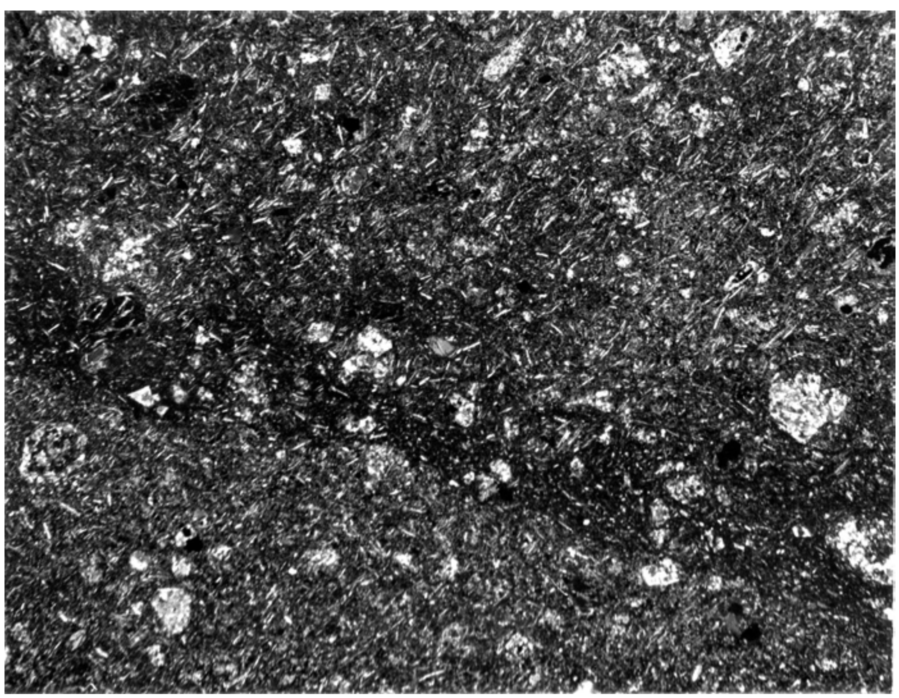


Figure 76. Dike with trachytic texture. X8, crossed Nicols.

Figure 77. A cross-cutting "feldspathic arenite" layer in the Crossroad Mbr. of the Poultney Fm.

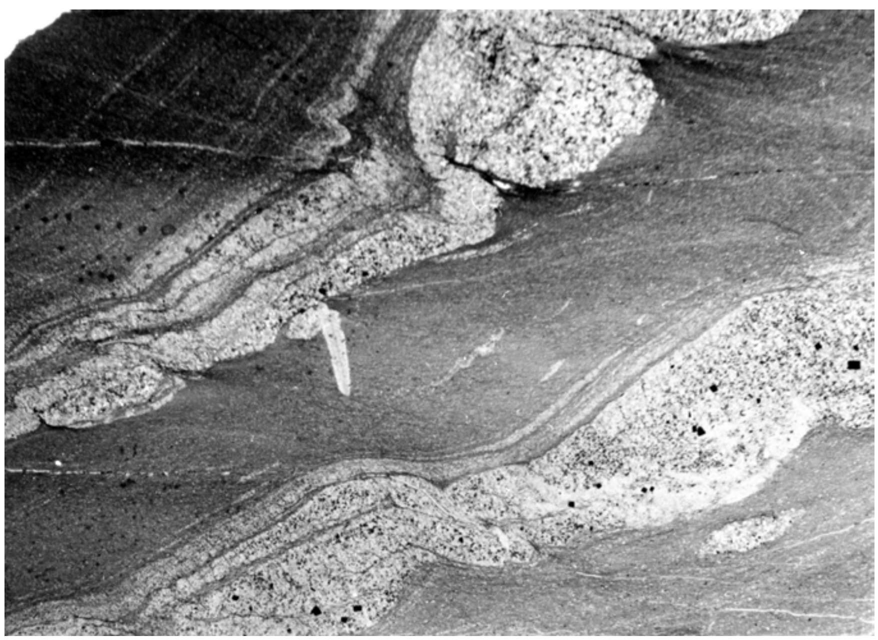


Figure 78. Possible miniature sandstone dike in the Crossroad Mbr. of the Poultney.
X7, plain polarized light.

slate. Thin section examination showed a fine-grained (~ .1 mm), low matrix rock with equal amounts of quartz and microcline and minor quartz and carbonate veins. No distinctive mineralogy or texture identify it as anything other than an arkosic arenite. However, the feldspar content is higher than seen in other Crossroad arenites (approximately 50%) and the two structures commonly seen elsewhere, fine laminae and bioturbation, are both absent here. A sandstone dike would explain the structure although it is larger than other examples reported in the northeast (Maxwell, 1962; Geiser, 1974), and no other examples were discovered, although they tend to occur in groups. However, one thin section of the same unit but from a different outcrop showed a tiny sandstone dike, approximately 2 mm long (Figure 78). Discovering it was entirely fortuitous because it was two small and obscure to be recognized in hand sample.

Observations: Regional

Introduction

A single outcrop map (Plate I) was prepared for the entire area which utilizes all the accumulated stratigraphic and structural data and that includes the resulting inferences. Air photos rather than topographic maps were used for the base because outcrops had originally been plotted on air photos and could be more accurately transferred; therefore, there is no topographic information on the map. The large areas of Quaternary cover are not noted on the map because Figure 5 and outcrop density outline these areas. The degree of uncertainty in contact location is reflected by the contact symbol. The 25 year gap between topo map and air photo offers some indication of the usefulness of cultural and other landmarks. Roads and lakes have not significantly changed while many smaller streams appear to have altered their position and are not included on the map. It is hoped that a reasonable balance between insufficient location reference and unnecessary clutter was achieved.

Three cross sections (Plate II) were drawn east-west (i.e. cross-strike) through the best exposure in the southern, central, and northern parts of the field area. Two short ones were added to complete the sections. They were aligned around the core of a central major anticline to show the on-strike variation.

Map

Outcrop distribution, regional slaty cleavage, and small scale structures all contribute to a regional picture that is consistent with former work and conclusions. The large scale structure consists of north-south trending overturned folds with axial surfaces dipping moderately to the east and axes plunging gently to the north and/or south. There are irregular areas, particularly north of North Granville, north of Truthville, and east of Quivey Hill Rd., but these may result from the subsequent vaguely and inconsistently developed deformation.

The outcrop pattern indicates three faults, two of which are not exposed in the field. East of Ryan Pond the Mt. Merino is probably in fault contact with the Crossroad Mbr. of the Poultney because the intervening Indian River is missing. Geometrically, the observed result could have been created by a number of different movements including a parallel normal fault with a dip greater than bedding or a thrust fault with a dip less than bedding. A thrust fault would be more consistent with the regional picture, but there are no specific data. However, several workers (see Table VII), have confirmed both thrust and high angle normal faults.

East and north of North Bend the Indian River-Mt. Merino contact is offset slightly in two places by cross faults, one left lateral and one right lateral. Fortunately, outcrop is reasonable in this area so that both faults are definite. They probably do not extend westward to the base of the Indian River, but it is not known how far eastward they extend because of poor outcrop. None of these three faults is marked on Theokritoff's 1964 map of the same area. His less detailed stratigraphy prevented their recognition. Conversely, Theokritoff located a major normal fault northwest of Melvin Pond for which no positive evidence was found in the present study.

The stratigraphic sequence maintains good structural coherence except for the southeast corner which shows some internal consistency, but which does not match up with the rest of the area. The limestone tentatively labeled 9a (Stoddard Rd. Mbr. of the Pawlet) could belong to the Dunbar Mbr. of the Poultney. Rocks north of Raceville are definitely identified as belonging to the Crossroad Mbr. of the Poultney, but they contain a unique conglomerate layer and cannot be traced northward. Likewise a series of the upper units (the Indian River and the Mt. Merino) cannot be traced south into the area around Raceville. In the entire area south of Raceville there is only one small subarea near Fox Rd. of bona fide stratigraphic coherence. Most of the rest of the rocks are of the varied lithology of the Fox Rd. Mbr. of the Pawlet. They have been understandably mistaken in the past for slates of the Crossroad Mbr. of the Poultney (Theokritoff, 1964). These major discontinuities can be located only generally. The western one must exist but its location is conjectural. The eastern one is a highly visible lineament on air photos, and there are rocks undisputably belonging to Crossroad Mbr. of the Poultney to the east (M. Lassonde and J. Young, pers. comm., 1977).

The outcrop deficient area between the Mettawee River and the location of Column 9 is probably a single syncline. The unusual width across it and the anomalous thickness of Fox Rd. Mbr. of the Pawlet could result from intense parasitic folding (J. Sullivan, pers. comm., 1976) or from thrusting.

These intra-slice thrusts subdivide the slice into slivers. This configuration has not previously been suggested for this area and is not seen in the quadrangles to the east: Equinox (Hewitt, 1961) and Castleton (Fowler, 1950; Zen, 1964) with the possible exception of the Pawlet (Shumaker, 1967). However, the Shushan Quadrangle

(N.Y.S. Geol. Map, 1972), the Cossayuna (Platt, 1960), and the Hoosick Falls area (Potter, 1972) all contain substantial parallel thrust faults. The proximity of the sole of the Bird Mt. Slice, approximately four kms to the east of the Raceville area, may explain this disruption.

Cross Sections

The cross sections show the very tight to isoclinal folds which are required to explain the very consistently moderately eastward dipping beds. Only actually across fold hinges is bedding seen to approach horizontal or to dip west, and it is only in these positions that bedding does not parallel slaty (axial planar) cleavage. Parasitic folds are present and in part dependent upon rock type for both formation and visibility. They are not included on the sections because they are small scale, their distribution is not well understood, and a merely schematic addition would clutter the diagram.

Sections B-B' and E-E' offer an explanation for major thickness changes over short distances. A fold pair, eroded to the proper level would result in sudden apparent three-fold increase in unit thickness. Unfortunately, in no location did field measurements of bedding attitudes conclusively support this hypothesis, but it was not contradicted either.

Cross sections of the Taconics do not generally show folds as tight as those on Plate II, although text descriptions often use the term "isoclinal". The pictures may be valid geometric examples of what shape structures are found in those areas; however, Theokritoff's (1964) cross sections in the Granville and Thorn Hill Quadrangles do not fit the data from the present study. Unfortunately, Theokritoff's map shows only bedding-cleavage intersection orientations which give plunge and trend of the fold axis and no feeling for the frequency of parallelism between bedding and slaty cleavage ("isoclinalism").

Others report that deformation intensity increases to the east, but this increase is always measured by the increasing prominence of the cleavage and folds of the second tectonic deformation, not the tightening of folds from the earlier one. Therefore, there is no obvious reason why the folds in the study area should not be representative for that generation unless proximity to the western boundary fault has an affect not recognized or understood.

Discussion

Number of Deformations

Evidence for the major tectonic deformation which resulted in the large scale fault and fold geometry is ubiquitous and indisputable. Evidence for two other deformations, pre-lithification and later tectonic, is not so widespread but is also undeniably present. The earliest deformation is marked by folds only; no associated cleavage has been seen although cleavage has been reported in undeformed sediments (Williams, et al., 1969) and even unlithified sediments. The latest deformation is marked by boths folds and a fracture or crenulation cleavage although the two are seldom seen together.

Bedding-Slaty Cleavage Relationship

In some units, particularly those with a single rock type (eg. Truthville Slate, Mettawee Slate, Indian River Slate, and Stoddard

Rd. Slate Member of the Pawlet) bedding may not be visible. However, as the cross sections (and independent measurements where bedding is apparent) show, the slaty cleavage and bedding are parallel or near parallel on the limbs of the folds. Therefore, for rocks not located in the cores of folds, it is a valid assumption to presume bedding parallel to slaty cleavage when more direct evidence is lacking. This is a very useful generalization and one which is difficult to misuse because the map distribution should pinpoint the danger areas (i.e. core areas) where this assumption must be used with care, if at all.

Differentiation of Sedimentary and Tectonic Features

Folds, real and apparent, cross-bedding, and lithologic layering can all result from sedimentary or deformation processes. Sometimes, but not always, genesis can be surmised from the appearance of the structure or from associated features.

In theory bedding and transposed layering are readily distinguishable: bedding has characteristic sedimentary structures: channels, flute and load casts, cross beds, graded beds, etc., while transposed layering has folds, fold hooks, or evidence of an earlier layering. Unfortunately, some lithologic layers exhibit none of the above, and in low to medium grade metasediments either process could be the cause. All rock types are susceptible to this type of redistribution. In the study area lithologic layering, where evidence of transposition was lacking, was assumed to be primary. Sedimentary structures were more prevalent than definite transposition, but positive signs of the latter were seen very locally in the Bomoseen and the Crossroad Mbr. of the Poultney.

Both soft sediment and tectonic folds have been described previously. Tectonic folds should have an axial plane cleavage while soft sediment folds may not. However, neither is a certainty; in the study area tectonic folds without associated cleavage were seen, although no pre-lithification cleavage was observed. The key to differentiation is the adjoining beds; if they contain obvious slump structures or if they are planar above and below the folding, the folding is probably soft-sediment deformation. Lack of consistent orientation alone is not enough to distinguish them. The fold axis trends of both the tectonic deformations are generally within 20 degrees east or west of north or south, but there are exceptions.

Cross-bedding, either sedimentary or tectonic, is less often seen than either folds or layering. Tectonic cross beds result during transposition when discontinuities cut a fold hinge so that layering is truncated in a sedimentary-like manner. Cleavage parallel to truncated layers or closely associated fold hooks suggest a tectonic origin; in the absence of these indications sedimentary structures were assumed.

CHAPTER VII SUMMARIES AND CONCLUSIONS

STRATIGRAPHY

The Giddings Brook Slice covers the widest area and contains the most complete stratigraphy in the Taconic Allochthon. The study area contains all but the lowest most units of this stratigraphic sequence. The exposure is good by the standards of this well glaciated, well vegetated region; numerous slate quarries, a sizeable river, and several major roads are all locations of outcrop. Some problems remain in distinction of units, and possibly always will, but a stratigraphy has been recognized and defined in this area which is more detailed than any previous single version.

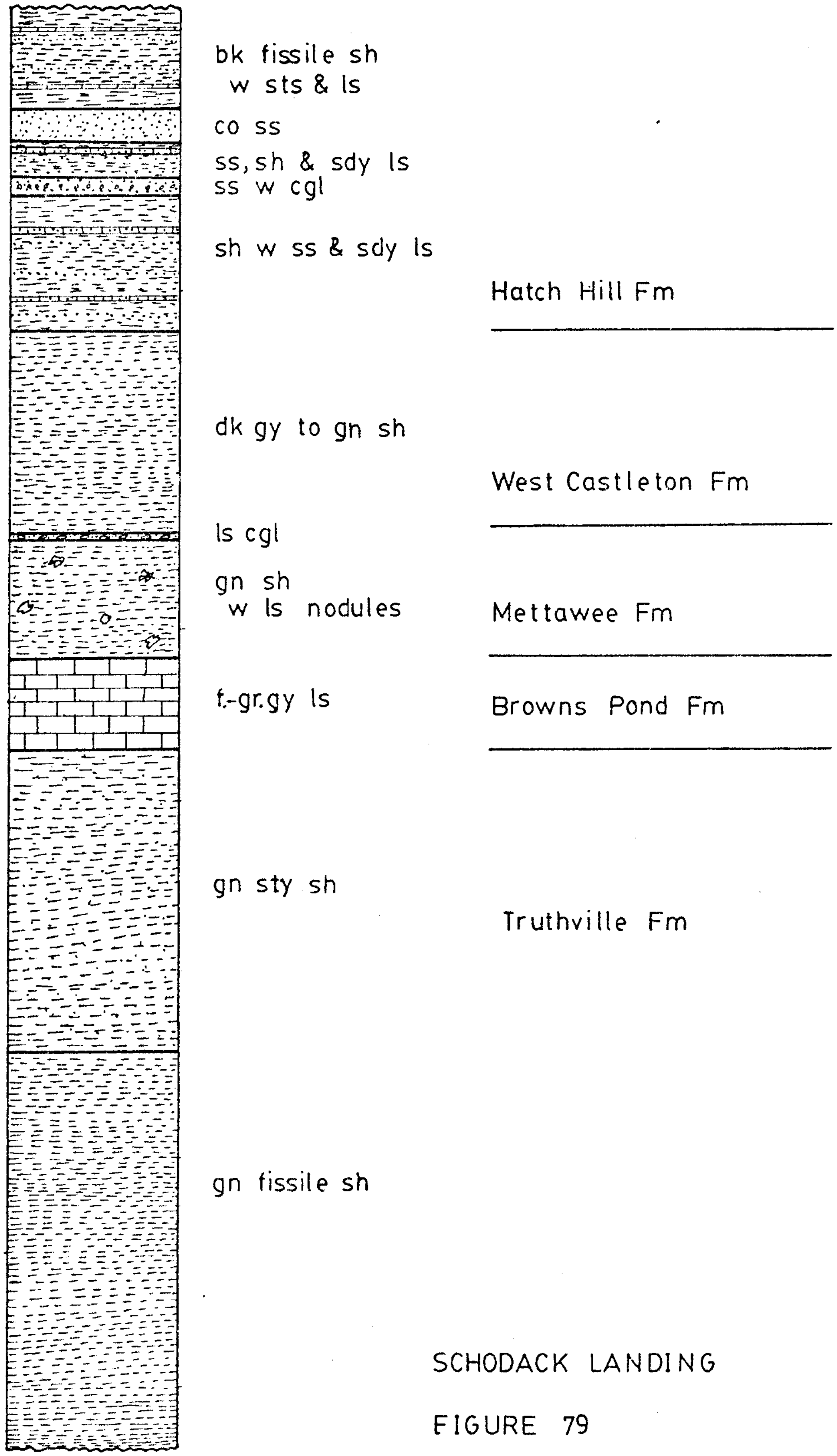
Extensive literature survey, aided by Zen's invaluable 1964 catalogue of Taconic nomenclature, indicate that the units defined here generally correlate by description with other areas of the Taconics. This is true even to the south which had traditionally used different names with the justification that the rocks were sufficiently different. The section delineated by Potter for the Eagle Bridge, Hoosick Falls, Grafton, and North Pownall Quadrangles, the most thorough work in the central Taconics, matches very closely (see Plate IV). Thicknesses vary, of course, and names are local, but everything is easily recognized and in its proper order. For the southern Taconics Bird and Rasetti (1968) have measured six Cambrian sections; Keith and Friedman (1977) measured four of the same Cambrian sections plus a section from south of Hudson, NY. These are the only known measured sections from the Taconics except for the present study and four sections of single units in Platt's (1960) thesis. Although none penetrates the Ordovician, they are probably the most detailed information available from the southern Taconics (specifically Ravena, Hudson North, and East Chatham Quadrangles).

Four of Bird and Rasetti's columns have been reproduced with correlation in Figures 79, 80, 81 and 82. These were chosen instead of Keith and Friedman's because detailed faunal data made comparison with northern Taconic studies, particularly Theokritoff (1964) easier and more precise. The author has only visited two of these localities, Judson Point and Schodack Landing, and therefore had to rely entirely on description for correlating the other two.

The only contact in common between the four is the Mettawee Slate-West Castleton Formation boundary. It is recognizable by color change but variable in limestone content, further substantiating the presence of minor facies changes. The Schodack Landing section shows the most extensive stratigraphy, and it appears to contain equivalents of the Truthville Slate, the Browns Pond, the Mettawee, the West Castleton, and the Hatch Hill. If these are correct identifications it is extremely thin even for the Taconics which are known both to have unusually thin sequences and to be highly variable in unit thicknesses. The minimum accumulation rates for Lower and Middle Cambrian rocks at Schodack Landing are 3 and 4.5 mm per 10^3 years respectively. The Browns Pond Formation equivalent is conspicuously incomplete, while the Mettawee contains a limestone conglomerate near the top (here called the Ashley Hill). It resembles the conglomerate seen in the slate quarries near Middle Granville in position; lithologically (except for the slate color) it looks like the Crossroad's conglomerate layer exposed at Raceville Corner and in the Mettawee River near Middle Granville in the study area.

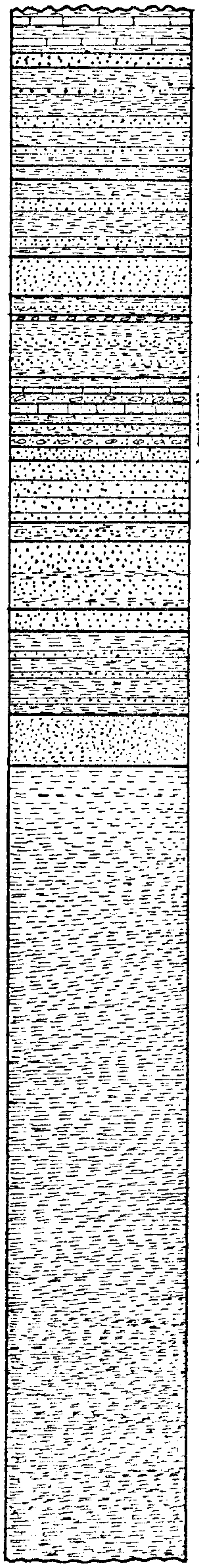
Figures 79. - 82. Four detailed Cambrian sections from the central Taconics. They have the same vertical scale (one inch equals twenty-five feet) and were constructed from the detailed descriptions of Bird and Rasetti (1968). The definitions used are:

bk -	black	lt -	light
sh -	shale	calc -	calcareous
sts -	siltstone	fos -	fossiliferous
ls -	limestone	gy -	gray
co -	coarse	gn -	green
ss -	sandstone	f gr -	fine grained
sdy -	sandy	sty -	silty
cgl -	conglomerate	bn -	brown
dk -	dark	st -	silt



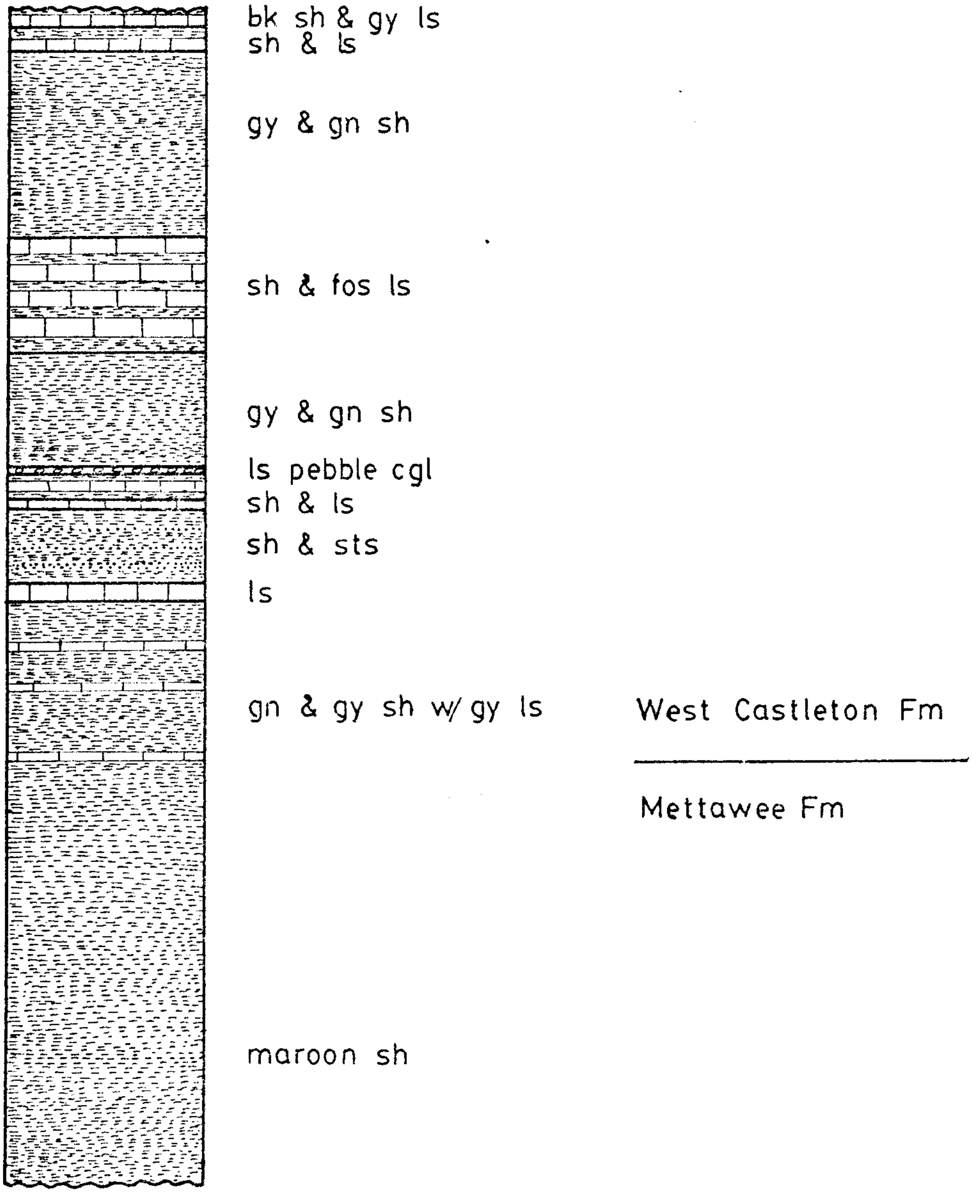
SCHODACK LANDING

FIGURE 79



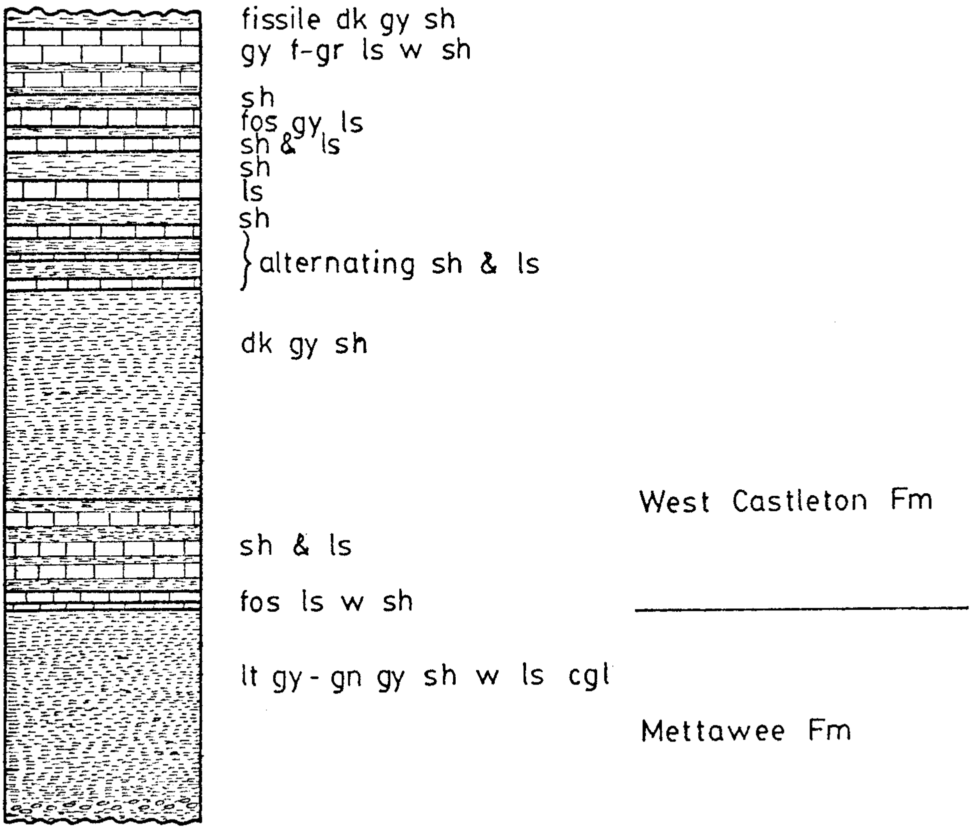
JUDSON POINT

FIGURE 80



MALDEN BRIDGE

FIGURE 81



GRISWOLD FARM

FIGURE 82

The other three columns contain only two formations, and the sequence at Judson Point shows why southern Taconic workers often are unable to definitively subdivide one of them and so resort to an Undifferentiated West Castleton-Hatch Hill Formation designation. It is, of course, possible that the same conclusion would be drawn from the other three columns if there were more exposure upward in the sequence. Unlike northern Washington County, equivalents of the West Castleton are consistently and conspicuously present. None of the columns contains exposed unconformities or even suspected disconformities or fossil defined gaps.

The only Cambrian or older unit included in the study area stratigraphy which is not exposed in these columns is the Bomoseen Formation. Fisher (1961) believes it is not part of the sequence south of Troy. However, Bird and Rasetti (1968) include it in their Columbia County stratigraphy without question as a mappable unit in the Nassau Fm., a distribution very like Potter's (1972).

Unfortunately, only two authors have treated the southern Taconic Ordovician section in recognizable detail: Fisher (1961) and Craddock (1957). They concur completely in the description and extent of their uppermost formation, the Normanskill; its three-part division is indisputable Indian River, Mt. Merino and Pawlet. The intervening section is more variable, has fewer distinctive components, and, therefore, is much more difficult to specifically define and recognize. Both authors opted for non-recognition and new definition.

Fisher (1961) divided the sequence into the Germantown and the Stuyvesant Falls which presemably correlate with the Hatch Hill Fm.-Dunbar Mbr. of the Poultney and the Crossroads Mbr. of the Poultney respectively. The inclusion of the Hatch Hill is not absolutely certain, however. Fisher mentions a unit called the Diamond Rock Quartzite whose description strongly resembles the Hatch Hill. Limited outcrop makes definite stratigraphic positioning impossible and the fossil date of Early Cambrian is also tentative. Subsequent study (Zen, 1964) strongly but not conclusively indicates that the Diamond Rock correlates with the arenite in the Browns Pond Formation. It is tentatively suggested that the Germantown corresponds to the Hatch Hill plus Dunbar Mbr. of the Poultney, although the distinctive thick rusty dolomitic arenites that characterize the Hatch Hill in the north and central parts of the allochthon are not present here.

Stuyvesant Falls is differentiated from the underlying rocks by color change in slate from black to green, and is described simply as "interbedded green fine-textured argillite" (Fisher, 1961, p. D9). Unfortunately, the promised complete descriptions were apparently never published. Much of the Crossroad slate is gray-green so the colors match, but the omission of any mention of the distinctive ribbon arenites would be more distressing if the description were not so cryptic. Fisher's study covers the entire southern half of the Taconics and his map is highly generalized (scale 1:250000). There may be a major important shift in lithologies and therefore deposition conditions from north to south, but existing descriptions are insufficient to be sure.

The other relevant detailed work (Craddock's 1957 study of the Kinderhook Quadrangle) does not entirely clarify the situation. An additional problem is the Chatham Fault which transects the quadrangle and dismembers the stratigraphic sequence. However, to the west of the fault below a complete "Normanskill" section (i.e. underlying the Indian River Slate), Craddock describes an 840 foot thick sequence of interbedded slate and quartzite. This description is regrettably undetailed, but it does mention quartzite, and it does not mention any other lithology or distribution which would contradict a correlation with the section defined in northern Washington County.

The Taconics show extensive horizontal and vertical variation, and to be applicable and to have any real value, a reference section must contain enough detail to uniquely define each unit but enough breadth not to exclude any of the recognized lithologic variation. After a century and a half of stratigraphic provincialism a single column with a single set of descriptions and a single set of names would represent an important step toward treating the Taconic Allochthon as a single entity. Both Dale (1899, 1914) and Zen (1967) have devised one (or two) such columns, but they lack sufficient detail to fulfill either of the aforestated objectives. It is proposed to adopt the definitions and names in this thesis as a reference section for the Cambrian(?) to Middle Ordovician rocks of the entire Giddings Brook Slice of the Taconic Allochthon. It is entirely possible that rocks to the east in structurally higher slices are also in part correlative with that section (see Figure 3), but increasing intensity in both deformation and metamorphism makes such correlation very tenuous.

Depositional Environment

None of the variations noted in the preceding section between descriptions of rocks from the northern, central, and southern Taconics preclude the continental rise as a depositional environment. However, as noted in Chapter V the continental rise on a large scale is a transitional environment between shelf and abyssal plain and as such contains a mixture of some elements from each. It is an area subject to changing sources, currents, morphology, and other conditions. This lithic flexibility flatly precludes only a few rock types or rock type combinations. Conversely it is equally difficult to make positive statements regarding a unit's inclusion into a rise sequence. Bird and Rasetti's (1968) and Keith and Friedman's (1977) detailed sections are particularly useful in the consideration of depositional environment. The detailed Cambrian descriptions, especially Keith and Friedman's which subdivide by lithofacies and concomitant depositional processes, allow for specific comparison with analyses from the north. They identify sheet or channel debris flow material, fluidized sediment flow of proximal turbidites, transitional to distal turbidites, channel edge deposits, hemipelagics carried in suspension by the nepheloid layer, submarine overbank levee deposits, and contourites. All of these processes were identified as possible causes of sedimentary structures and assemblages in the study area except channel edge deposits and overbank levee deposits. Channel edge deposits, which to Keith and Friedman explain parallel laminated sandstones and limestones, cannot be supported by field evidence of close association with mid-channel conglomerates. Overbank levee deposits are virtually indistinguishable from distal turbidites unless, as stated above, association with other channel elements is possible; Taconic outcrop is characteristically insufficient. In particular, their conclusions that 1) channels were a common sediment transport device and 2) the continental shelf in Early and Middle Cambrian times was much narrower (25-30 km) than today concur with the author's tentative conclusions regarding the thick massive arenites seen in the Bomoseen and the Browns Pond Formations.

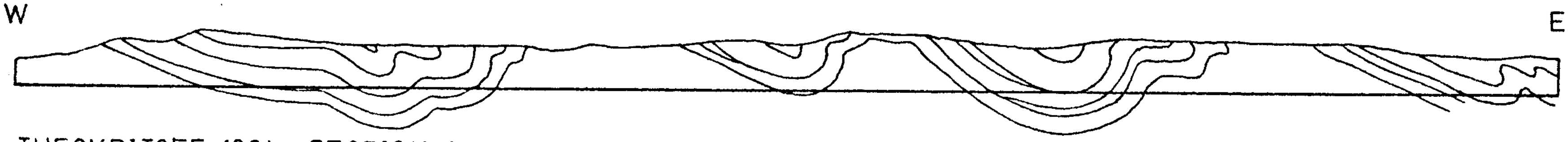
Keith (1974) and Keith and Friedman (1977) conclude that at least for the Cambrian section a lower slope and base-of-slope environment explains the observed distribution of sedimentary lithologies and structures. Nomenclature differences again arise, but Keith (1974) is following Stanley and Unrug's (1972) model and terminology in which upper, mid-, lower, and base-of-slope correlate with upper and lower rise as used in this paper. Therefore, it appears that he limits the Taconic environment to lower rise and abyssal plain transition areas. Contour current reworking and the abundance of pelitic material certainly require that the lower rise be included; however, the vast amounts of sand-sized clastics and slump and channel deposits, especially in the Bomoseen, the Browns Pond, and the Hatch Hill (all of which figure in the Keith study), require that the upper rise adjacent to the continental slope also be part of the site of deposition.

Structure

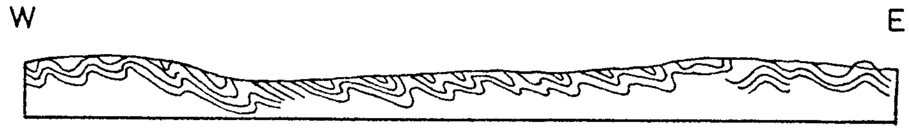
The Giddings Brook Slice is characterized by the same style of deformation throughout, although the intensities of the different phases of deformation, particularly the second tectonic deformation, are highly variable both in relation to rock type and to geographic location. Three different deformations have been recognized although not all are visible in all locations. The first is pre-lithification, and the second and third are both tectogenetic. All three are characterized by folding and the latter two also involve faulting and cleavage development.

The deformation responsible for the large scale structural geometry is the first of the two tectonic phases. In the study area it is only slightly modified by the most recent deformation. The orientation of the major folds is consistent with the determinations of others; however, the fold geometry is not. Two of Theokritoff's (1964) sections cross the study area. The major synclines and anticlines are too open and rounded, although the parasitic folds shown are generally isoclinal and somewhat asymmetric. His structural text is very brief and includes no description of fold forms or the cleavage nature. The only other detailed work in this region is Dale's (1899), and two of his cross sections also are specifically in this area. The folds shown are tight, almost isoclinal, and agree with the present study. However, the main synclines and anticlines are not defined and the absence of stratigraphic sub-division (except for the two economic units) is confusing. A geometric composite of these two earlier works would approximate the conclusions of this study (Figure 83).

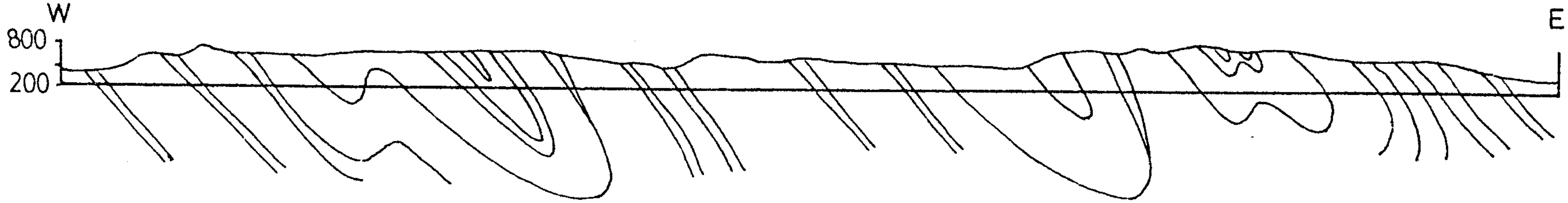
Figure 83. Three cross sections from the Middle Granville area. All three cross sections were drawn without vertical exaggeration, and all were redrawn to the same horizontal scale. They are essentially on strike and are located within a total north-south distance of two miles. Theokritoff and Jacobi show the same large scale structure but different fold morphology. Dale and Jacobi show approximately the same fold forms, but Dale lacks a large scale syncline-anticline sequence.



THEOKRITOFF, 1964 SECTION C



DALE, 1899 SECTION II



JACOBI, 1977 SECTION B

no vertical exaggeration

FIGURE 83

The study area is structurally intact except for a few minor normal and cross faults and a major dismemberment in the southeast. This large branching thrust fault has not been mentioned by previous workers. Unfortunately, much of it cannot be located accurately because of extensive flood plain cover, but its existence is required by the structural and stratigraphic discontinuities to the north and northwest. Air photo lineaments and topography also help to define its location and extent. This fault is located at least six kms from the boundaries of the Giddings Brook Slice, and no specific continuation is noted to the east in the Pawlet Quadrangle (Shumaker, 1967). However, without distinctive topography or indisputable truncation of key beds it might be very difficult to recognize and trace. Platt (1960) notes that only in a few locations can his Murdock Mt. Thrust be specifically located; otherwise it is bounded either by the same formation or by stratigraphically adjoining ones. The exact location of much of the Chatham Thrust in the southern Taconics has also long been in doubt (M. Bell, pers. comm., 1977). However, major intraslice thrusts have been mapped in the central and southern Taconics (Platt, 1960; Potter, 1972; Elam, 1957).

These all suggest that the Giddings Brook Slice may be more extensively faulted than previously believed and may even be somewhat slivered. Although fairly large pieces do show the stratigraphy and structure intact, other areas of major confusion may result from thrust-faulted structural isolation.

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