BEDROCK GEOLOGY OF THE PORT HENRY AND NORTHWESTERN PORTION OF THE MIDDLEBURY QUADRANGLES

by

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INTRODUCTION

Location

The Port Henry and northwestern portion of the Middlebury Quadrangles are located adjacent to Lake Champlain in the central Champlain Valley of west-central Vermont. To the east of the field area lies the Middlebury Synclinorium and to the west, Lake Champlain.

The field area is geographically roughly located between the town of Addison to the north and the town of Bridport to the south. The western limit is marked by Lake Champlain, while the eastern limit is marked by state Route 17 in the northwestern portion of the Middlebury Quadrangle.

The study area comprises part of the western limb of the Middlebury Synclinorium. The bedrock geology includes Cambrian and Ordovician, carbonate and siliciclastic rocks, part of a belt that extends from Newfoundland to Alabama along the margin of the Iapetus Ocean. Units in the eastern part of the field area are contained on the upper plate of the Champlain Thrust, which has emplaced Cambrian rocks onto Ordovician limestones and shales. The Ordovician rocks make up most of the bedrock in the valley west of the Champlain Thrust.

Topographically, the general bedrock relationship (Champlain Thrust upper plate Cambrian rocks vs. Ordovician rocks) can be seen through the presence of north-south striking ridges of Monkton Quartzite and low-lying areas with rocks of Ordovician age. The ridges have been named previously from north to south; Buck Mountain, South Buck Mountain and Snake Mountain. The bedrock of the valley (Ordovician in age) underlies the Dead Creek Wildlife Management Area.

Procedures

Field work for this report began in June of 1993 and continued throughout the summer months. In addition, numerous days were used for field work during the Fall of 1993. Field work included reconnaissance work to determine the extent of outcrop and actual mapping of the bedrock. Exposure in the field area ranged from excellent (large cliffs of Monkton Quartzite on Snake Mountain) to poor (non-existent in the Dead Creek area). Creation of a bedrock geology map for the field area was conducted in the winter months concluding in the Spring of 1994. Bedrock data from Middlebury College senior thesis (Cashman, P. and Cashman, S., 1972) were added to map the southeastern portion of the field area. Drafting of the bedrock map was done at the University of Vermont, Department of Geology.

Previous Work

The following discussion includes information from Welby's (1961) report on previous work done in the field area.

The first recorded geologic studies in the field area were done during the nineteenth century. Work in the field area during this period of time included studies by Emmons (1842) and Adams (1846). Both Emmons and Adams studied the geology of Snake Mountain and concluded that there was a high angle fault west of Snake Mountain.

In the twentieth century Seely (1910) described the geology of Addison County, focusing on Snake Mountain. Seely's conclusions concerning the fault west of Snake Mountain were similar to that of Emmons and Adams. In addition, Cushman (1941) mapped in the region of the field area. One of the more significant pieces of work discussing the stratigraphy and structural geology of west-central Vermont was produced by Cady (1945). Cady mapped the area to the east of the Champlain Thrust throughout west-central Vermont. Most recently, Welby (1961) did a comprehensive geologic study of the central Champlain Valley, describing the bedrock geology as well as the structural geology. Welby described the bedrock to the west of the Champlain Thrust in the field area.

The sedimentology and stratigraphy of the units that outcrop in the field area have been studied in detail. The Cambrian stratigraphy of western Vermont has been interpreted to be a part of the western shelf sequence of Vermont (Dorsey, et. al., 1983). The Ordovician stratigraphy has been interpreted to be a part of the foundering taconic foreland basin (Baldwin and Mehrtens, 1976; Bechtel, 1993; MacLean, 1986). Specific units have been studied or are in the process of being studied by several individuals. For example, the Dunham Dolomite was studied in northwestern Vermont by Gregory (1982). The Crown Point Group was studied at the type section at Crown Point, New York by Baldwin and Mehrtens (1976). The Glens Falls limestone (Trenton Group) in the Champlain Valley was studied by MacLean (1986). The Cumberland Head was studied by Mehrtens and Delhanty (1987). The Stony Point and Iberville Shales were studied by Teetsal (1984). Work on the Monkton Quartzite is in preparation (Goldberg).

STRATIGRAPHY

The bedrock geology of the Port Henry and northwestern portion of the Middlebury Quadrangles includes stratigraphy from the Lower Cambrian to the Middle Ordovician periods. The following report, with the accompanying stratigraphic column (figure 1) will address the stratigraphy of the field area.

Lower Cambrian

DUNHAM DOLOMITE

Lithology

The Dunham Dolomite consists of dolomite that weathers gray colored with the fresh surface colored pink to buff. The unit is poorly bedded and can contain variable amounts of sand-sized quartz grains. The contact with the overlying Monkton Quartzite occurs in quadrant E6 of Plate 1 and is recognized as being the first bed of white quartz pebble sandstone. In the field area the Dunham Dolomite does not have the same appearance as it does in northwestern Vermont, where it is characterized by its mottled pink and white coloration. Whereas several distinct lithofacies can be recognized in the Dunham in northwestern Vermont (see Gregory, 1982), in this study area the Dunham bears no distinct lithologic features. The Dunham is the oldest formation to be mapped in the field area (figure 1).

Occurrence

The Dunham is confined to two locations on the map (Plate 1, E6) where it appears to be in depositional contact with the overlying Monkton Quartzite. The base of the Dunham is not exposed but is interpreted to be a small thrust sliver beneath the Champlain Thrust.

Thickness

In the field area there is approximately 15 m of dolomite and sandy-dolomite exposed on the northwest facing cliff of South Buck Mountain. To the north, in the Georgia area, the Dunham has been measured as 275 m thick (Gregory, 1982). In the Milton area of Vermont the Dunham Dolomite is approximately 400 meters thick (Gregory, 1982).

Age

In the Milton area occurrences of *Salterella conulata* (Gregory and Mehrtens, 1983) indicate that the Dunham is *Bonnia olenellus* zone, or Lower Cambrian in age. No fossils have been found in this field area.

MONKTON QUARTZITE

In the field area two subdivisions of the Monkton can be recognized, a lower white colored, quartz pebble rich sandstone and a upper red colored sandstone, siltstone and dolostone unit.

lower unit

Lithology

The lower unit consists of 10-100 cm thick, gray to white colored sandstone beds. Sedimentary structures include planar laminations, trough and planar crossbeds, graded beds and ripple cross-laminations. Contacts between beds are often abrupt and also exhibit erosional downcutting of several centimeters into the underlying bed. Although bedding is much more clearly displayed than in the underlying Dunham, beds are not always laterally continuous, pinching out laterally over several meters.

Occurrence

The occurrence of the lower unit is confined to South Buck Mountain, and a locally termed Ethan's Cliff immediately to the north (Plate1, E6).

Thickness

The thickness of the unit is approximately 45 m. This a minimal value because the upper and lower contacts are faulted.

Age

Shaw (1958) identified a fauna of the Monkton of *Bonnia olenellus* age from the area around Mallets Bay. No fossils were found in this field area.

upper unit

Lithology

The upper unit of the Monkton is more lithologically heterogenous, consisting of red colored sandstone and siltstone and buff colored dolomite. Interbedded with these lithologies are beds of white sandstone that are similar to the lower unit. Sedimentary structures in the upper Monkton are numerous including wave and current ripples, mudcracks and bioturbation. Dolomite beds exhibit cryptalgal laminations. Beds range from several centimeters to decimeters in thickness.

Occurrence

This portion of the Monkton makes up most of the unit in the field area with prominent exposures on Snake Mountain (Plate1, A5 to D5) and Buck Mt. (Plate 1, E6). In most places in the field area the upper unit of Monkton immediately overlies the Champlain Thrust, forming a prominent north-south ridge that extends the length of the field area.

Thickness

In the Colchester area of Vermont the Monkton is 500 meters thick (Stone and Dennis, 1964). In the southern part of the state the unit pinches out (Welby, 1961).

Age

Kindle and Tasch (1948) identified a fauna of the Monkton of *Bonnia olenellus* age in the upper portion of the unit from the Milton region of Vermont. No fossils were found in this field area.

Canadian Stage (Lower Ordovician)

BEEKMANTOWN GROUP: WHITEHALL AND CUTTING DOLOSTONES, AND CHIPMAN AND BRIDPORT FORMATIONS

The Beekmantown Group is composed of several limestone and dolomite units throughout the Champlain Valley. These units have been subdivided into formations and members, however, in the field area only units at formation status were mapped. These consist of, in ascending stratigraphic order: the Whitehall and Cutting Dolostones and the Chipman and Bridport Formations (undifferentiated)(figure 1). The Cassin Formation is not present in the field area.

WHITEHALL AND CUTTING DOLOSTONES, UNDIFFERENTIATED

Lithology

This unit is light gray colored, massively bedded limestone interbedded with dolomite. The limited exposure of these units in the field area does not exhibit the characteristic basal calcareous sandstone of the Whitehall or the sedimentary breccias of the Cutting. These formations were identified by their stratigraphic position.

Occurrence

The exposures of these units were limited to two outcrops located in a field near the Middle Branch of the Dead Creek Wildlife Management Area (Plate 1, C3).

Thickness

The Cutting ranges in thickness between 90-120 m in western Vermont. The Whitehall is approximately 90 m thick (Welby, 1961).

Age

The Whitehall has yielded a fauna of Lower Canadian age (lowest Ordovician) while the Cutting Formation is not fossiliferous in the Champlain Valley. However, the presence of *Ophileta* in the Cedar Island area indicates the Cutting to be Canadian in age (Welby, 1961).

CHIPMAN AND BRIDPORT FORMATIONS, UNDIFFERENTIATED

Welby (1961) described the Chipman as a Lower Ordovician formation which contained mappable horizons of limestone and dolomite (the Bridport, Beldens, Weybridge, and Burchard Members). In this field area the name "Chipman" was applied to limestone horizons while the term "Bridport" refers to the primarily dolomitic unit. Horizons of interbedded limestone and dolomite were called undifferentiated Chipman and Bridport.

Lithology

This unit is a light gray colored on the weathered surface, dark gray on the fresh surface, highly fractured limestone interbedded with dolomite. The dolomite is massively bedded and tan to buff colored on the weathered surface. In places, the limestone may contain fine-grained sand disseminated throughout.

Occurrence

A belt of undifferentiated Chipman and Bridport runs from Route 17, 1 km east of the intersection with Route 22A and north of Town Line road (Plate 1,C4 to E4) as well as in fault slices beneath the Champlain Thrust from (Plate 1, A5 through B5 and E5 through F6).

Thickness

Welby (1961) estimates the total thickness of the Bridport at 140 m in the Shoreham area of Vermont. Precise thickness estimates are difficult because of a lack of exposed contacts throughout the Champlain Valley. Estimates of thickness based on the map pattern and attitude of beds suggest a thickness of approximately 60 m in this field area.

Age

Fossil fragments found within the Bridport in the Champlain Valley indicate an Upper Canadian age (Welby, 1961).

Chazyan Stage (Middle Ordovician)

CHAZY GROUP, UNDIFFERENTIATED

The Chazy Group consists of three stratigraphic units in the Champlain Valley; the Day Point, the Crown Point and the Valcour Formations. Do to the abundance of the index fossil *Maclurites* in the field area, the Crown Point (the middle stratigraphic unit, see figure 1) was the only formation recognized.

Lithology

The Crown Point is a blue-gray colored, on the weathered surface and dark gray colored, on the fresh surface limestone. The limestone is well bedded and beds are often thick with thin layers of dolomite that weather out in buff colored laminae. Specimens of the index fossil, *Maclurites,* are common. Sedimentary structures include bioturbation. At a locality below the Champlain Thrust (Plate 1, E6) the Crown Point includes dolomite beds.

Occurrence

The Crown Point is found along the shore of Lake Champlain (Plate 1, B1) as well as in a belt in the middle of the field area (Plate 1, C4 to D4) and beneath the Champlain Thrust (Plate 1, E6 and F6).

Thickness

The entire Chazy Group is approximately 200 m thick in the Champlain Valley (Welby, 1961). Estimates of thickness based on the map pattern and attitude of beds suggest a thickness of approximately 60 m thick in this field area.

Age

The index fossil *Maclurites* indicates a Middle Ordovician, Chazyan Stage age for this unit.

Black River Stage (Middle Ordovician)

ORWELL LIMESTONE

Lithology

The Orwell is a limestone, light gray colored on the weathered surface and dark gray colored on the fresh surface. The limestone is massively bedded.

Occurrence

The Orwell is found in a thin belt south of Snake Mountain, beneath the Champlain Thrust (Plate 1, A5).

Thickness

Welby (1961) found the Orwell to be approximately 15 m in thickness. Precise thickness estimates are difficult because of a lack of exposed contacts throughout the field area.

Age

Faunal evidence is limited for the Orwell. This unit has been dated by others through lithologic correlation, as Middle Ordovician, Black River Stage in age (Bechtel, 1993).

Champlainian Stage (Middle Ordovician)

GLENS FALLS LIMESTONE

Lithology

The Glens Falls is a fossiliferous, dark gray micritic limestone. The limestone is well and thinly (1.5 - 10 cm) bedded. Specimens of the index fossil, *Prasopora*, are common.

Occurrence

The Glens Falls is found along the shore of Lake Champlain (Plate 1, C1 and D1) as well as in a belt in the middle of the field area (Plate 1, A3, B3 and B4) and beneath the Champlain Thrust (Plate 1, A5).

Thickness

Estimates of thickness based on the map pattern and the attitude of beds suggest a thickness of the Glens Falls Limestone of 300 m in the field area.

Age

The index fossil *Prasopora* indicates a Middle Ordovician, Champlanian Stage in age (Ross, 1967)(Mehrtens and Barnett, 1979).

CUMBERLAND HEAD FORMATION

Lithology

The Cumberland Head is a light gray colored, massively bedded mudstone. It can be distinguished from the underlying limestones of the Trenton Group on two criteria: 1) the paucity of fossils and 2) the micritic composition. The overlying Stony Point can be distinguished from the Cumberland Head because the Cumberland Head contains thicker beds of mudstone exhibiting planar laminations which are interpreted as limestone turbidites. The Stony Point is thinner bedded and more fissile. Mehrtens and Delhanty (1987) include detailed descriptions of both units at the Cumberland Head type section near Plattsburgh, New York. The Cumberland Head has never been recognized previously in this field area.

Occurrence

The Cumberland Head is found along the shore of Lake Champlain (Plate 1, C1 and D1). Two belts of Cumberland Head are located in the middle of the field area (Plate 1, B2, B3 and B4).

Thickness

Estimates of thickness based on the map pattern and attitude of beds suggest the thickness of the Cumberland Head ranges from 60-120 m in the field area.

Age

Mehrtens and Delhanty (1987) dated the Cumberland Head as Middle Ordovician (Champlainian) on the basis of *Prasopora simulatrix* occurrences at the type section.

Utica to Trenton Stage (Middle Ordovician)

STONY POINT AND IBERVILLE FORMATIONS, UNDIFFERENTIATED

Although these two units can be distinguished in the northern Champlain Valley, in this study area they are grouped together. The Stony Point, however, is a darker, more calcareous shale, often exhibiting extensive calcite veining, while the Iberville is more arenaceous in composition.

Lithology

This unit consists of two lithologies; 1) black colored, fissile, well-bedded, calcareous shale and 2) buff colored, well-bedded argillaceous shale.

Occurrence

Undifferentiated Stony Point and Iberville is found extensively throughout the field area. The shales are found along the shore of Lake Champlain (Plate 1, A2, D1, E1 and F1) as well as beneath the Champlain Thrust (Plate 1, A5, E4, E5, D4 and D5).

Thickness

The thickness of the Stony Point has been estimated by Welby (1961) at 230 to 260 meters along the shore of Lake Champlain. Riva (1974) measured the Stony Point at 200 meters in New York state. Precise thickness estimates are difficult to make because in most cases the upper and lower contacts are not exposed due to faulting. Evidence for the thickness of this unit suggests a thickness that is significantly larger than the amount indicated by Welby. The Iberville has a thickness of 250 meters in the northern Champlain Valley and 500 meters in southern Quebec (Teetsal, 1984).

Age

The Stony Point has yielded fauna of *Conulata spiniferous* and *Conulata americanus*, graptolites dated as Utica age (Upper Ordovician) to Trenton age (Middle Ordovician) respectively (Riva, 1974).

STRUCTURAL GEOLOGY

INTRODUCTION

The field area lies in the central Champlain Valley between the Adirondack Highland to the west and the Green Mountain "hinterland" to the east. Geologically, the field area lies partially within the Middlebury Synclinorium. The Champlain Thrust is the main structural feature in the field area. This particular fault creates topographic ridges (upper plate) and lowlands (lower plate) that extend the length of the field area.

There are two basic structural elements within the Port Henry and the northwestern section of the Middlebury Quadrangle; 1) folding and 2) faulting. The latter of the two dominates the structural style within the field area. The dominance of faulting is displayed in the complex network of faults both along the Champlain Thrust fault as well as in the central Champlain Valley.

Deformation has occurred predominantly in a belt between the undeformed craton (Adirondack terrain) and the metamorphic belt (Green Mountain terrain). This zone of deformation is termed a foreland fold and thrust belt. In most cases foreland fold and thrust belts include stratigraphic sequences of former passive margins (i.e. Iapetan margin).

Major Structures

FOLDING

Folding exists in two styles; 1) large-scale folding related to tectonic compressional forces and 2) small-scale folding related to localized thrust faulting. These folds are broken in numerous places by both longitudinal and cross faults. The first type of fold is represented in the field area by the Middlebury Synclinorium. The rocks present to the east of the Champlain

Fault (Cambrian Monkton Formation) are part of the western limb of the Middlebury Synclinorium and outcrop in E6 and F6 of Plate 1. This syncline, one of two large synclinoria in western Vermont, covers an area approximately 500 square miles, and plunges towards the south. The second synclinorium is the St. Albans Syncline located in northwestern Vermont. Deformation associated with these structures has been dated as late Taconic in age (Stanley and Radcliffe, 1985). Taconian deformation was characterized by foreland thrusting in the Champlain Valley. The large scale folding appears to have predated any faulting within the field area (Welby, 1961).

The small scale folds that are present are predominantly drag folds or folds that were developed as a result of the upper thrust plate being emplaced. Folds such as these are found primarily along the Champlain Thrust, on the upper thrust plate (Snake Mountain and Buck Mountain), within the Monkton (Plate 1, F6 and C5) and suggest a direct relationship to thrusting. Welby (1961) found an overturned syncline on the west face of Buck Mountain. Similar folds are found in fault slices beneath the Champlain Thrust within the Ordovician units (Plate 1, A5, B5, E6 and F6).

FAULTING

Welby (1961) recognized three generations of faulting within the central Champlain Valley; thrust faults, high angle longitudinal faults parallel to thrusting and "cross faults" that cut northerly striking structures. The thrust faults have been dated as Taconian while the longitudinal and cross faults appear to have developed initially during Taconian deformation with reactivation during the Mesozoic (Smith, p.c). Reactivation of these structures during the Mesozoic suggests a relationship to Triassic rifting (Smith, p.c.). In addition, Stanley and Radcliffe (1985) have suggested that movement could have occurred during the Acadian orogeny as well as during the Alleghenian orogeny.

The primary structural feature within the field area is the Champlain Thrust fault. The

Champlain Thrust strikes in a north northwesterly direction for approximately 200 miles (Stanley, 1987). The Champlain Thrust extends the length of the field area and in most cases emplaces sandstones of the Monkton Formation ontop of Ordovician limestones and shales. The exception to this relationship is at South Buck Mountain, where the fault surface moves down into the underlying Dunham Dolomite (Plate 1, E6). Welby (1961) suggests that these exposures of Dunham represent blocks of the upperthrust plate that have dropped down, with the fault exposed at the base of these blocks.

The plane of the fault is exposed in numerous places throughout the field area. Exposures of the fault are best seen along the front of Snake Mountain (Plate 1, B5, C5 and D5) and South Buck Mountain, at a cliff exposure termed in this report, Ethan's Cliff (Plate1, E6). In addition, the fault is exposed at various locations on Buck Mountain (Plate 1, F6).

Thrust related structure to the west of the Champlain Fault consist of fault slivers of Ordovician limestones that have been emplaced westward. Fault slivers are present as actual slivers beneath the Champlain Fault or klippe that have been carried some distance (1/4 km) to the west. There is one such klippe structure within the field area; the hill in the southeastern part of the field area composed of undifferentiated Chipman and Bridport (Plate 1, B4 and 5). Fault slivers can be found along most of the Champlain Fault. Precisely, these structures are found west of southern Snake Mountain with slivers being made up of Orwell, Glens Falls and Crown Point Limestones (Plate 1, A5 and B5). Welby (1961) identified overthrusting to be the mechanism for generating most of the structure to the west of the Champlain Thrust.

High angle longitudinal faults parallel the strike of the Champlain Thrust. The majority of these faults are normal. In some cases the stratigraphic throw on these faults can be considerable, dropping Stony Point next to Crown Point (Plate 1, B1 and 2). These faults "step up" stratigraphically, younging towards the west.

The high angle normal faults die out as they are cross cut by a series of east-west striking normal faults. Welby (1961) found stratigraphic throw on these faults to be as large as

2000 feet on the north end of Snake Mountain. The main cross-fault, which extends across the northern portion of the field area, intersects the Champlain Thrust on a hill off of Route 17 approximately 0.5 miles west of the intersection with Route 23 (Plate 1, E5). These cross-faults appear to cut across thrust faults suggesting that the development of the cross-faults was post-thrusting.

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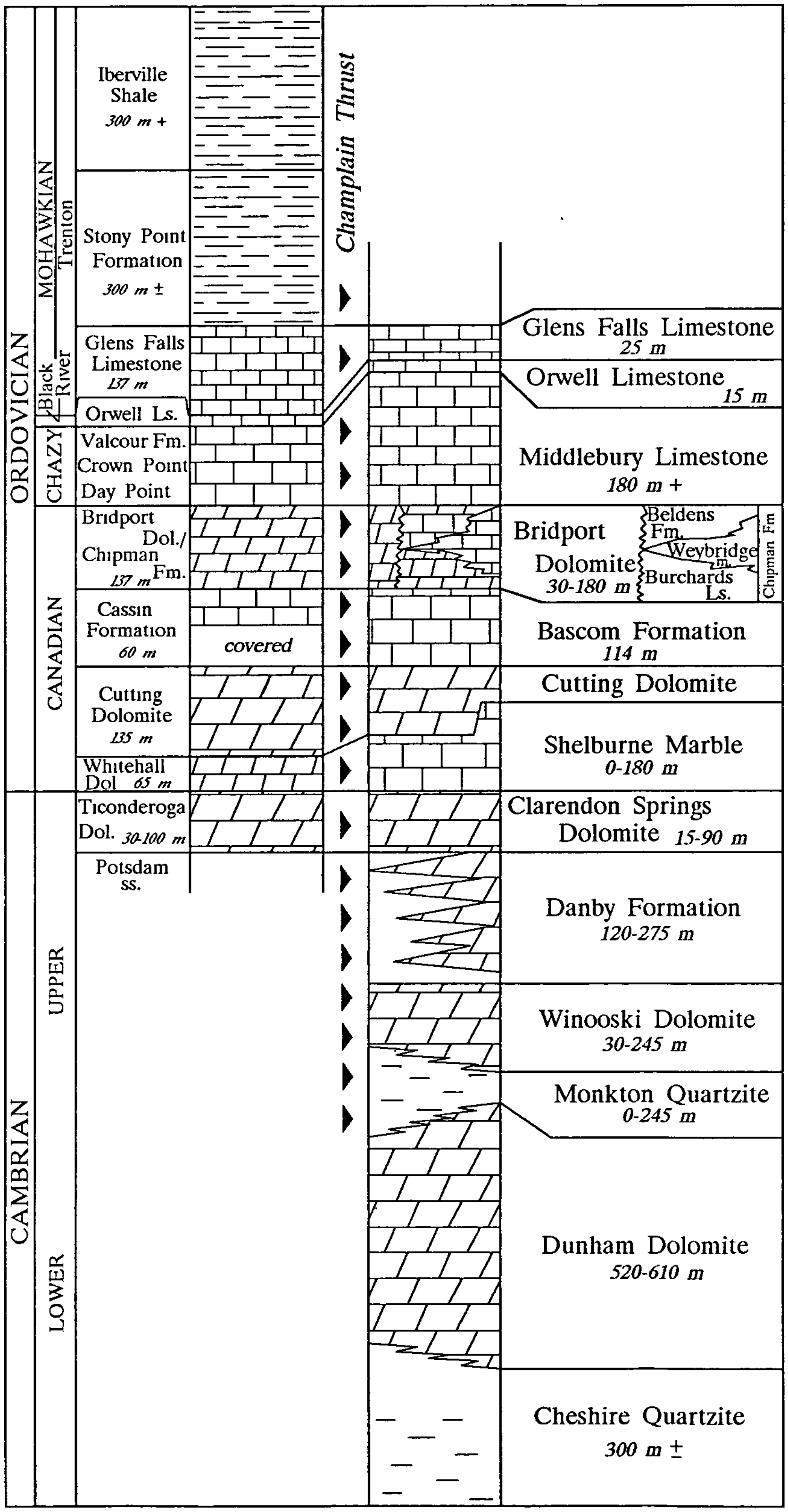
THE STRATIGRAPHY OF WESTERN VERMONT

adapted from Baldwin (1967)

Figure 1



EXPLANATION
lithic contact (dashed where inferred)
normal fault, D on downthrown side
thrust fault, teeth on upper plate (dashed where inferred)
representative outcrop
bedding
cleavage
TN
MN
14.5°
quadrangle location
MILES
KILOMETERS
SCALE
1:25000
Ospi
Stony Point and Iberville Formations, undifferentiated
Och
Cumberland Head Formation
Ogf
Glens Falls Formation
Oo
Orwell Limestone
Ocp
Chazy Group, undifferentiated
Ocbr
Chipman and Bridport Formations, undifferentiated
Ocw
Cutting Dolomite, and Whitehall Formation, undifferentiated
Єm
Monkton Quartzite
Єdu
Dunham Dolomite
Ordovician
Middle
Trenton Grp.
Lower
Chazy Grp.
Beekmantown Grp.
Cambrian
Middle
Lower
Bedrock Geology Map of the Port Henry Quadrangle and northwestern portion of the Middlebury Quadrangle
by Goldberg, J. and Mehrtens, C.
(map interpretations in the southeast corner by Cashman, P. and Cashman, S., Middlebury College)
44°07' 30"
73° 22' 30"
73° 15'
44°00'

PLATE 1