Trip A

SEDIMENTARY CHARACTERISTICS AND TECTONIC DEFORMATION OF MIDDLE AND UPPER ORDOVICIAN SHALES OF NORTHWESTERN VERMONT NORTH OF MALLETTS BAY

by

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INTRODUCTION

The central lowland of the Champlain Valley is underlain by Cambrian and Ordovician sedimentary rocks, bordered on the west by the Adirondack Mountains of Precambrian crystalline rock upon which Cambrian sandstone lies unconformably, and against which sedimentary rocks have been dropped along normal faults. The lowland is bordered on the east by low-angle thrust faults on which massive dolomite, quartzite, and limestone, as old as Lower Cambrian, from the east over-rode weaker Ordovician shale and limestone. The westernmost thrusts, the Highgate Springs thrust in the north, and the overlapping Champlain thrust in the south, trace an irregular line a few feet to 3 1/2 miles inland from the east shore of Lake Champlain. For most of the distance between Burlington and the Canadian border, the high line of bluffs marking the trace of the Champlain Thrust are composed of the massive, Lower Cambrian Dunham dolomite.

The shales, youngest rocks of the autochthonous lowland sequence, outcrop on most of the islands in Vermont, and the mainland between the thrusts and the lake. Although exposures on almost continuous shore-line bluffs are excellent, there are few outcrops inland because of glacial cover and low resistance of the shales to weathering. Fossils are rare in the older calcareous shale (Stony Point) and absent in the younger non-calcareous shale (Iberville). The lithic sequence was established almost entirely on structural criteria. Where it can be found, the Hathaway submarine slide breccia structurally overlies the Iberville.

DESCRIPTION OF FORMATIONS

Glens Falls Limestone

Kay (1937, p. 262-263) named the lower Glens Falls the Larrabee member, found it to be 72 feet thick on the Lake Champlain shore in the northwestern part of South Hero Township, Vermont, and to be composed there of thin-bedded, somewhat shaly limestone. Fisher (1968, p. 27) has found the Larrabee member to be 20 to 30 feet thick in the vicinity of Chazy, N.Y., and to be coarse-grained, medium- to thick-bedded light gray limestone full of fossil debris (brachiopods, crinoids, pelecypods, and trilobites).

The upper Glens Falls was named the Shoreham member by Kay (1937, p. 264-265), and described as the zone of Cryptolithus tesselatus Green, a distinctive trilobite. He found 30 feet of the Shoreham exposed in the lakeshore in northwestern South Hero Township. Fisher (1968, p. 28) prefers to call this the Montreal limestone member, following Clark's usage for the Montreal area (1952), and has described it as medium dark gray to dark gray argillaceous limestone with shale partings, fossiliferous with trilobites, brachiopods, molluscs, and bryozoa. He estimates it to be 150-200 feet thick in Clinton County, N.Y.

Cumberland Head Formation

The "Cumberland head shales" was a term used, but not carefully defined by Cushing (1905, p. 375), referring to the interbedded shale and limestone forming a gradation between the Glens Falls and the overlying Trentonian black shales. Kay (1937, p. 274) defined it as "the argillaceous limestones and limestone-bearing black shales succeeding the lowest Sherman Fall Shoreham limestone and underlying the Stony Point black shale". He measured 145 feet on the west shore of South Hero Island, Vt., just south of the Grand Isle-South Hero town line. The lower 30 feet have 8- to 12- inch beds of gray argillaceous limestone interbedded with dark gray calcareous shale. Above that the shale is predominant, but limestone beds are abundant, 3 to 12 inches thick with undulating surfaces, interbedded with half-inch to 12-inch layers of black calcareous shale. Less than one third of the Cumberland Head has more than 50 per cent shale, and about half has more than 60 per cent limestone beds. Some units as thick as 15 feet have 80 per cent limestone beds. The proportion of shale increases gradually but not uniformly upward.

of silt and argillaceous material in harder argillaceous limestone varies greatly. Intricate, fine, current cross-bedding occurs in four thin zones, indicating currents flowing northeastward.

Above this zone rich in laminated argillaceous limestone the proportion of calcareous shale increases, and 239 feet near the top of the Stony Point is composed entirely of calcareous shale. This shale section, 1.4 miles S 37° W from Long Point, North Hero, Vt., is assumed to represent the uppermost part of the Stony Point because it lies on the nose of a long, northeastward-plunging anticline between a thick argillaceous limestone section to the southwest, and a large area of Iberville shale to the north and northeast.

In this field area it is not possible to measure the entire thickness of the Stony Point, but from piecing together several measurable sections a minimum thickness is 874 feet. The total thickness is estimated to be 1000-1500 feet, allowing for probable thicknesses that could not be measured in the middle and upper parts of the Stony Point (Hawley, 1957, p. 83). In the log of the Senigon well near Noyan, Quebec, about 4 miles north of the international boundary at Alburg, shale apparently equivalent to the Stony Point is 924 feet thick (Clark and Strachan, 1955, p. 687-689).

Iberville Formation

The Iberville formation was named by Clark (1934, p. 5) for its wide outcrop belt in Iberville County, southern Quebec, about 10 miles north of the international boundary at Alburg, Vt. Clark (1939, p. 582) estimated the Iberville to be 1000-2000 feet thick in its type area.

The base of the Iberville has a gradational contact and was chosen on the basis of lithic criteria by which it can be most easily distinguished from the Stony Point. The Stony Point is entirely calcareous shale and argillaceous limestone with occasional beds of light-olive-gray weathering, dark gray fine-grained limestone. Above the lower transition section, the Iberville is composed of interbeds of medium to dark gray noncalcareous shale (1-12 inches, usually 2-4 inches), moderate-yellowish-brown weathering, dark gray laminated dolomitic siltstone (one quarter inch to 10 inches, usually 1/2 - 1 1/2 inches), and occasionally moderate-yellowish-brown weathering, dark gray fine-grained dolomite. The most conspicuous change from the Stony Point is the appearance of the yellowish-brown weathering dolomite beds, and the

Stony Point Formation

The Stony Point shale was defined by Ruedemann (1921, p. 112-115) as "hard, splintery dark bluish-gray calcareous shale" at Stony Point, 1 1/2 miles south of Rouses Point, N.Y., on the west shore of Lake Champlain, and correlated faunally with upper Canajoharie shale of the Mohawk Valley (Middle Trentonian).

The base of the Stony Point is exposed on the lake shore 0.55 miles south of the breakwater at Gordon Landing, the eastern end of the Grand Isle-Cumberland Head ferry. Deposition was continuous from the Cumberland Head up into the Stony Point, and the contact is somewhat arbitrarily chosen where the proportion of shale increases upward, and the wavy, irregular limestone bedding of the Cumberland Head gives way upward to smooth, even limestone beds of the Stony Point. The 215 feet of Stony Point formation exposed here is interbedded dark gray calcareous shale with light-olive-gray weathering, dark gray fine-grained limestone in beds of 1 to 12 inches, about 70 per cent shale. Two units about 9 feet thick are about 80 per cent limestone beds.

The thickest and least deformed measurable section of Stony Point begins 0.6 mile north of Wilcox Bay and extends for 1.8 miles northward along the shoreline bluffs of northwestern Grand Isle (Hawley, 1957, p. 59, 87-89). In this section of 635 feet, there are a few gross vertical lithic variations which are recognizable throughout this field area. Above the lower 215 feet, as described above, the percentage of calcareous shale decreases upward. Olive-gray to light-olive-gray weathering, dark gray argillaceous limestone appears in increasing proportion through the upper 400 feet of this section, where the percentages are: argillaceous limestone, commonly silty, 66 per cent; calcareous shale, 29 per cent; fine-grained limestone beds, 5 per cent.

The argillaceous limestone commonly occurs in thin, even beds (one quarter to three quarters of an inch) with fine lighter- and darker-gray laminae, but occasional beds reach 10 inches. Thicker-bedded zones suggest cyclic deposition: from calcareous shale (1 to 4 inches) upward through 5 to 6 inches of laminated argillaceous limestone, to a 1- to 3-inch bed of fine-grained limestone; then through 4 to 5 inches of argillaceous limestone to 1 to 4 inches of calcareous shale. Where the interval between calcareous shale beds is thinner, the fine-grained limestone bed in the middle is missing. The proportion noncalcareous shale which is more brittle and more lustrous cleavage surfaces than the calcareous shale. The transition section is at least 72 feet thick at Appletree Point in northern Burlington (Hawley, 1957, p. 64), and may be as thick as 200 feet. A section from Stony Point to Iberville is almost continuously exposed, though somewhat deformed, along the lakeshore southeastward for a half mile from Kibbee Point, in northeastern South Hero Township, Vt. The base of the Iberville is defined as the first appearance of the noncalcareous shale and dolomite beds.

Iberville shale and dolomitic siltstone show remarkable rhythmic bedding. The base of each cycle is a sharp contact, sometimes a slightly scoured surface, on which a thin bed (0.25-0.75 inch) of yellowish-brown weathering, dark gray laminated dolomitic siltstone was deposited. The typical siltstone layer becomes finer-grained upward with decreasing quartz and dolomite, and increasing argillaceous and carbonaceous material, and grades into dark-gray noncalcareous thin-cleaving shale (1-4 inches). Usually at the top is an eighth to three quarters of an inch of grayish-black shale interlaminated with the dark gray. Occasionally the dolomitic siltstone may be missing at the bottom of the cycle, or the grayish-black shale laminae missing at the top. Ripple-drift cross-lamination is a common feature of the dolomitic siltstone layers. In some beds only a single storey of ripples were built, but in others down-current ripple drift continued long enough to form two, and occasionally three or four tiered beds. Current directions indicated by the ripple cross-lamination are invariably southwestward in the Iberville, in contrast to northeastward in the Stony Point.

Six thicker (5-10 inches) non-laminated graded siltstone beds with 1 mm.-long shale flakes in their lower parts are found on northeastern Burton Island, southwest of St. Albans Point. They grade finer upward, and some are laminated above the lower third. One has large (5 by 1 1/4 inches is the largest) angular shale fragments in the mid-portion. They commonly have contorted lamination in the middle, above which lamination is more marked, and they are topped with drift ripples grading upward into shale.

The thickest measurable sections of the Iberville are 732 feet, with an estimated 2200 depositional cycles, on the west side of Woods Island, and 304 feet with an estimated 1215 cycles on Clark Point, southwestern Hog Island, West Swanton, Vt. The cyclic character of the Iberville layers, the graded beds, graded laminated beds, and convolute laminae, are all characteristic of sedimentation by turbidity currents (Kuenen, 1953; Bouma, 1962, p. 48-54).

Hathaway Formation

The Hathaway formation, named for Hathaway Point on southeastern St. Albans Point, Vt. (Hawley, 1957, p. 68), designates argillite and bedded radiolarian chert, commonly intensely deformed, with included small fragments to large blocks of quartz sandstone, coarse graywacke, dolomite, limestone, and chert. Some fragments strongly resemble dolomite and dolomitic siltstone beds of the underlying Iberville, but the coarse sandstone, chert and graywacke are unlike any strata in the autochthonous formations of the Champlain lowland. Where the Hathaway and Iberville are in contact or close proximity, there is marked disparity in intensity and nature of their deformation. The Hathaway appears to have deformed by flowage without the development of good cleavage, commonly with disintegration of less mobile beds into blocks and boulders. The Iberville has undergone much less intense folding and faulting, of a type normally associated with the regional structure. For these reasons, the Hathaway is inferred to be a submarine slide breccia initially deformed while its muddy constituents were still soft.

The best accessible exposures of the Hathaway are on Hathaway Point, and extending north for 1200 feet from Beans Point on the east shore of the lake, in northwestern Milton Township, Vt. As fate would have it, the most impressive and extensive exposures of the Hathaway are on Butler Island, between St. Albans and North Hero, accessible only by boat. Almost all of Butler Island is composed of the Hathaway, which is usually a mashed, streaky light and dark gray argillite with inclusions of dolomite, dolomitic siltstone, and occasionally black chert and graywacke, from 1 by 2 to 8 by 24 inches. On the southeast side of Butler Island are found the largest inclusions in the Hathaway: blocks of dolomitic siltstone up to 3 by 20 feet, and coarse-grained graywacke up to 15 by 50 feet. Argillite foliation wraps around these blocks, and around innumerable smaller pebbles and boulders. Hawley has described in detail these and other localities (1957, p. 68-75).

SUMMARY OF DEPOSITIONAL HISTORY

The fossiliferous limestones of the Glens Falls and older formations in this area indicate rather shallow, clear-water carbonate deposition, often in an environment of considerable wave and current turbulence (reefs, coarse calcarenites, and cross-bedding in the upper Chazyan). In the Cumberland Head formation fossils are much scarcer and there is a transition from the shallow water carbonate environment to a muddier, deeper water depositional environment. The lower two hundred feet of the Stony Point is 70 per cent calcareous shale, and the next 400 feet is laminated argillaceous limestone (66%) interbedded with calcareous shale (29%) and hard, purer fine-grained limestone (5%) in a somewhat cyclic pattern. Current cross-lamination indicates flow toward the northeast. The complete absence of primary structures associated with shallow water, and the fine lamination of the argillaceous limestone, and the paucity of fossils, suggest a deeper, quieter, muddier depositional environment.

Through the lower hundred feet (or more) of the Iberville, a marked change in the character of the rock appears with dolomite replacing limestone as the hard, fine-grained interbeds, and noncalcareous shale replacing the calcareous shale of the Stony Point. At some unknown distance above the base, a section of at least 730 feet shows cyclic interbedding of noncalcareous shale and graded, laminated dolomitic siltstone commonly with current cross-lamination. The currents flowed toward the southwest. This suggests the changed character of the rock is at least partly the result of a change from a westward source of sediment (for the Stony Point), to an eastward source for the Iberville, and that turbidity currents dominated the depositional character of the Iberville. Uplift of deep sea bottom east of the Champlain Valley in late Mohawkian and early Cincinnatian time could have provided the new source of sediment and the westward slope down which the turbidity currents flowed. Some simultaneous deepening of the Champlain Valley region also occurred.

The Hathaway formation, composed of argillite and bedded radiolarian chert, chaotically deformed, with included masses of limestone, dolomite, dolomitic quartz siltstone and sandstone, coarse graywacke, and chert, is interpreted as a submarine slide breccia. Some of the types of inclusions, particularly the graywacke and chert, are unknown in autochthonous underlying formations of the Champlain Valley, nor in regions to the south and west. The slide (or slides?) seem to have come from the east, down the slope suggested by the direction of flow of turbidity currents which deposited sediment in the Iberville. The Taconic orogeny was occurring at this time, and some believe that the major thrusts of western and northwestern Vermont accompanied this orogeny. If this be true, thrust fault escarpments on the sea bottom to the east of the Champlain Valley could account for the slides and the assemblage of inclusions in the Hathaway. Earthquakes associated with the Taconic orogeny may have triggered the turbidity currents of the Iberville.

TECTONIC DEFORMATION

The shales are complexly folded and sheared, with fold axes trending a little east of north in the southern part of the area, and swinging more toward the northeast (N 20° - 30° E) in the north. Although elongate narrow belts of intense deformation parallel fold trends, separated by broader belts of more gentle folding, general intensity of deformation increases toward the Champlain and Highgate Springs thrusts. In areas underlain by shale, particularly in North Hero and Alburg, the topographic "grain" of long, low hills accurately reflects the trends of fold axes. From Grand Isle northward the smaller folds plunge northward and southward, but the pattern of structural elements and formational boundaries indicates the northeastward plunge is more prevalent and perhaps a bit steeper. The area might be visualized as having northeastward trending folds imposed on an eastward regional dip, though there are many individual exceptions to this generalized picture.

Fracture cleavage is nearly everywhere present in the more argillaceous beds of the Stony Point and Iberville formations. The term is used here as defined by Swanson (1941, p. 1247), "the structure is due to closely spaced planes of parting a certain small distance apart," and "as a rule it is possible to see that the rock between the planes of parting . . . has no structure parallel to them, or at most any parallel structure is confined to a thin film along the parting planes." In these shales, cleavage planes are more closely spaced in belts of intense folding, and, under the same structural conditions, they are more closely spaced in more argillaceous beds than in more calcareous beds. Fracture cleavage plates in the argillaceous limestone of the Stony Point formation commonly range from one half inch to 5 inches thick. Fracture cleavage in calcareous shale is finer, and in the noncalcareous shale of the Iberville the planes are so close as to resemble flow cleavage (Swanson, 1941, p. 1246), but in thin section cut perpendicular to the finest cleavage, it is seen to be composed of somewhat irregular and discontinuous joint-like fractures 0.02 to 0.06 mm. apart. Bedding displacements of 0.01 to 0.04 mm. occur along the cleavage planes (Hawley, 1957, p. 82).

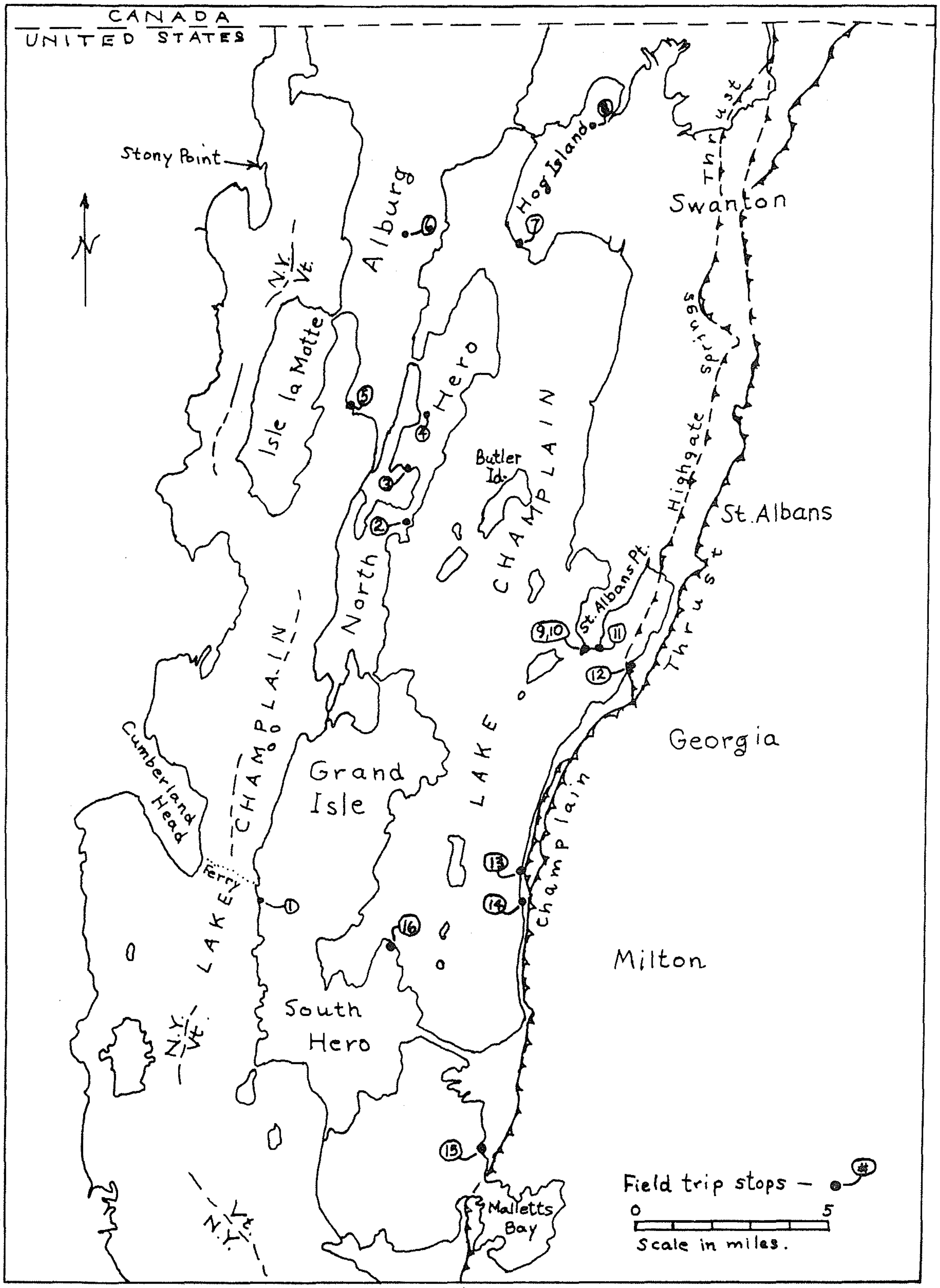

Figure 1. Trip A Stops

Although innumerable faults cut the shales, only a few displace them enough to juxtapose different formations. On most faults the rock of both walls is so similar that only minor displacement can be assumed. Block faulting typical of the western and southern Champlain Valley is distinct only in the older Trenton, Chazy, and Canadian formations of western South Hero, where Kay and his former students have mapped them (personal communication). Shear along bedding surfaces, cleavage surfaces, and at varying angles to both is very common. In more intensely folded belts, multiple shears occur along crests and troughs of folds. The bearing of slickensides is remarkably constant, regardless of the attitude or type of surface on which movement occurred. Of 119 slickensides bearings measured in this area, only three lay outside the arc between N 25 W and N 85 W (Hawley, 1957, p. 81).

FIELD TRIP STOPS

The best exposures of the shales and limestone are along the lakeshore bluffs. During the spring months the lake may be as much as five feet higher than normal, and many of these exposures may be inaccessible. They are listed for those who use the guidebook in the future, but some may have to be omitted on the initial field trip. THE STOPS ARE ON PRIVATE LAND. PERMISSION HAS BEEN OBTAINED FOR THE STOPS WE WILL VISIT. THOSE WHO MAY WISH TO VISIT THESE LOCALITIES IN THE FUTURE SHOULD GAIN PERMISSION FOR EACH VISIT. GIVE GEOLOGY A GOOD NAME BY BEING VERY THOUGHTFUL.

Stop 1. West shore of South Hero Island, extending for one mile southward from the breakwater at Gordon Landing. The lower 215 feet of the Stony Point formation is exposed between the breakwater and the top of the Cumberland Head formation, 2900 feet to the south. In the next 2300 feet of shoreline, the upper 145 feet of the Cumberland Head formation is exposed. These sections are described in the text article. The south end of this section is cut off by a right lateral wrench fault striking N 59° W, dipping 79° NE. South of the fault the interbedded limestone and shale (about 79% ls., 30% sh.) have been mapped as the Shoreham member of the Glens Falls formation (Erwin, 1957) on the basis of lithology and the presence of *Cryptolithus*.

Stop 2. Road cut on east side of U.S. 2 halfway between City Bay (North Hero Beach roadside park) and Carrying Place. This outcrop shows the interbedded laminated argillaceous limestone and calcareous shale typical of the middle section of the Stony

Point formation. It lies close to the axis of a major, northeastward plunging anticline.

Stop 3. Middle point on north side of Carry Bay, North Hero, 2000 feet east of Blockhouse Point. Typical Iberville cyclic bedding is exposed for about 1500 feet along this shore, extending eastward from the place where the access road meets the shore. From west to east are: an asymmetrical syncline, an asymmetrical anticline , and to the east of a covered interval is the east, overturned limb of a large syncline. These folds are in the axial area of a large, northeastward plunging, overturned syncline. Relationships of cleavage to bedding, axial surfaces, and direction of plunge are well shown. Small-scale current cross-lamination on some beds indicates southwestward flow.

Stop 4. Quarry in Iberville (mislabelled "gravel pit" on No. Hero Quad. map), 1.6 miles S 10° E from east end of North Hero-Alburg bridge. The beds are almost flat-lying, and only about 15 feet of section is exposed, but it is typical cyclic deposition, and the details are well shown, as described in the text.

Stop 5. Unnamed promontory 1300 feet WNW of Coon Point, south Alburg. Upper-middle Stony Point beds measuring 258 feet (Hawley, 1957, p. 60, 89-91), with the base of the section on the southern tip of the point. It is composed of: olive-gray weathering, dark-gray argillaceous limestone, frequently silty, with light olive-gray weathering bands and laminae, in units of 3 inches to 40 feet, making up 96 percent of the section; light olive-gray weathering, dark-gray fine-grained limestone in beds of half an inch to 12 inches, making up 4% of the section. There are four thin (1/4 inch to 1 1/4 inch) beds of medium light-gray weathering, medium gray fine-grained crystalline limestone. Pyrite concretions are common. Trilobites (Triarthrus becki) are fairly common on a few bedding surfaces, and a few unidentifiable graptolite fragments were found. This stop is relatively inaccessible, may be cut off by high water, and may have to be omitted.

Stop 6. A small quarry, 3.3 miles north of Alburg-North Hero bridge on the west side of highway U.S. 2. Stony Point argillaceous limestone-rich section as described for Stop 5, including a fair scattering of Triarthrus becki.

Stop 7. Upper Iberville beds on the south and west sides of Clark Point, at the south end of Hog Island (Vt. Hwy. 78 crosses

Hog Island), west Swanton. A 304-foot section has been measured here (Hawley, 1957, p. 91-92). It is 97.8 per cent thin-cleaving noncalcareous shale (1 to 3 inch beds) with thin laminated dolomitic siltstone (1/4 inch to 2 inch beds, occasionally thicker) and homogeneous fine-grained dark gray dolomite, weathering yellowish-brown, in beds up to 14 inches, at intervals of 3 to 50 feet. Cyclic deposition is prominent here, with an estimated 1215 cycles in this section. The thin dolomitic siltstone beds commonly show cross-lamination and ripple drift, with southwestward currents indicated.

Stop 8. Upper Iberville beds in quarry (mislabelled "sand and gravel pit" on East Alburg Quad. map) 1800 feet north of Vt. Hwy 78 and 600 feet west of Campbell Road, northern Hog Island, west Swanton. The rock is similar to that described for Stop 7. The quarry exposes an overturned anticline, thrust faulted on the upper, eastern limb, with adjacent syncline immediately westward, also faulted.

Stop 9. Southernmost tip of St. Albans Point, on property of Camp Kill Kare. Northeastward plunging asymmetrical anticline with linked small syncline northwest of it, in Iberville noncalcareous and calcareous shale with dolomitic interbeds.

Stop 10. Between Camp Kill Kare's access road and the lake, about halfway between the private cottages and the Camp buildings. There are 31 feet of white weathering, grayish-black chert in beds of 2 to 6 inches, dipping steeply (69°) southeastward on the southeast flank of the anticline at Stop 9. Structurally overlying the chert beds is black siliceous argillite in which bedding is not apparent because of its irregular, chippy foliation. The argillite contains rounded pebbles (avg. 1 by 2 inches) of gray dolomite and fragments of chert. Some graptolites were found in the argillite, but smearing precluded identification. This is part of the Hathaway formation. It is likely that the chert beds here represents a larger mass involved in a submarine slide.

Stop 11. Hathaway Point, at the south end of St. Albans Point. This is the type locality for the Hathaway formation. It has a matrix of pale-greenish-yellow weathering rock seen on a polished surface to be composed of small, irregular, curdled masses of greenish-gray to olive-gray argillite. Streamed and isoclinally folded in the matrix is black siliceous argillite similar to that associated with the chert beds at Stop 10. "Floating" in the matrix are small masses of grayish-black radiolarian chert which are commonly angular, as well as masses of bedded chert measurable in tens of feet. Fragments of dolomite and dolomitic siltstone occur in the western part of the Hathaway point exposure. Numerous slickensided tectonic shears are present in a variety of orientations. One 40-foot wedge between shears is composed of isoclinally folded calcareous and noncalcareous shale with occasional boudinaged masses of fine-grained limestone, resembling the transition beds at the base of the Iberville. Both of the islands east of Hathaway Point, in the middle of the bay, are composed of chaotically deformed argillite and chert. It is assumed that St. Albans Bay may lie over a deep synclinorium.

Stop 12. Lime Rock Point, on the southeast side of St. Albans Bay. At the base of the bluff composed of the Beldens (Upper Canadian) crystalline limestone with buff-weathering dolomitic beds, there is a dramatic exposure of the Highgate Springs overthrust; Lower Ordovician Beldens Limestone over Upper Ordovician Iberville calcareous and noncalcareous shale with occasional beds of yellowish-brown weathering fine-grained dolomite and silty dolomite. At the base of the high, steep bluff about one half mile to the east is the Champlain overthrust, on which the lower Cambrian Dunham dolomite is thrust westward over the Beldens. South of Lime Rock Point the Highgate Springs thrust slice is overlapped by the Champlain thrust for two and a half miles. It reappears for four miles, and then disappears again under the Champlain thrust, southeast of Beans Point. This is as far south as the Highgate Springs slice can be traced.

Stop 13. Beans Point, east shore of lake in northwest Milton. The Hathaway crops out intermittently for 1200 feet north from Beans Point. This is in a zone of intense deformation close to the Highgate Springs thrust, the trace of which is covered, probably about 600 feet back from the shore. The base of the steep bluffs 2000 feet back from the shore marks the trace of the Champlain fault, on which lower Cambrian Dunham dolomite has been thrust over Beldens crystalline limestone and dolomite of the Highgate Springs slice.

The Hathaway is composed of boulders and fragments "floating" in mashed argillite. The argillite is mottled olive gray to dark greenish gray to greenish black. On a polished surface cut perpendicular to foliation the mottled colors are seen to represent original bedding which has been folded most intricately, and sheared with no development of slickensides or breccia. The small-scale shearing has completely healed, and some minute fold crests merge into the adjacent bed, a streaming of one bed into the next with no sharp boundary. Included in the argillite are rounded fragments of moderate-yellowish-brown weathering, dark gray fine-grained dolomite and cross-laminated dolomitic siltstone, sub-angular to rounded, up to 4 by 7 by 20 inches in size. The long axes of the boulders are approximately parallel, plunging about 55° toward S 45° E. Foliation causes the argillite to split into irregular tapered chips. Thirty-six feet of cover separates the north end of the Hathaway outcrop from cyclic-bedded upper Iberville which lies overturned, dipping 46° northeastward.

Stop 14. Camp Watson Point, 3/4 mile south of Beans Point (Stop 13). The core of a large, overturned syncline is exposed on the point, plunging 18° toward N 56° E. The overturned limb, dipping 29° southeastward, is exposed for 200 feet or more along the shore to the south. The rock is lower Iberville transition, with interbedded calcareous and noncalcareous shale, argillaceous limestone, and silty laminated dolomite.

Stop 15. Clay Point, between Malletts Bay and the Lamoille River, east shore of lake. THIS PROPERTY IS POSTED, AND PERMISSION MUST BE OBTAINED. In the transition beds in the lower Iberville (interbedded calcareous and noncalcareous shale, with argillaceous limestone, argillaceous dolomite, fine-grained dolomite, and silty-laminated dolomite with current cross-bedding) there is a small, overturned anticline cut by small thrust faults. The relationship of cleavage to bedding, plunge of the fold, identification of tops by cross-bedding, and the faulting make this a worthwhile stop for a structural geology class.

Stop 16. From Kibbee Point (northeastern South Hero) southeastward along the shore for 2500 feet, is exposed the transition from Stony Point to Iberville formations. With a few minor rumples the dip is southeastward all the way to a deep gully and small bay which separate a steep bluff-point to the east from the shore northwestward to Kibbee Point. This bluff, 2800 feet SE of Kibbee Point is composed of Stony Point argillaceous limestone and calcareous shale, overturned and dipping 55° southeastward. Thus, the gully conceals the faulted core of an overturned syncline. The fault is very likely a thrust, east side up.

West of the gully is Iberville, about 90% finely cleaved noncalcareous shale, with interbedded silty cross-laminated dolomite. Northwest from here to Kibbee Point the proportion of noncalcareous shale and silty laminated dolomitic interbeds decrease and the proportion of calcareous shale increases. About 220 feet southeast of Kibbee Point the southeastward-dipping beds are massive calcareous shale (Stony Point fm.). About 900 feet south of Kibbee Point on its west shore the Stony Point beds still lower in the section are predominantly argillaceous limestone, interbedded with calcareous shale.

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