GEOLOGY OF THE MOUNT INDEPENDENCE STATE HISTORIC SITE, ORWELL, VERMONT

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INTRODUCTION

History

(The following history is condensed from the Mount Independence information brochure.) Mount Independence is a Revolutionary War site. A fort was built here to guard against British attack from Canada because Fort Ticonderoga, across Lake Champlain, offered a poor view to the north. Lake Champlain narrows considerably between Mount Independence in Vermont and Mount Defiance in New York, and it was assumed that whoever controlled the lake here would have a natural advantage over the opposition.

American troops began clearing land on Mount Independence in June of 1776. By autumn, three brigades (12,000 men) had established camps, and had built two batteries and a picket fort. The combined strength of Mount Independence and Fort Ticonderoga caused the British to retreat quickly to Canada in October, 1776. Many American soldiers went home that winter, reducing the force at Mount Independence to 2,500. Many of those remaining fell ill, and a number froze to death during the winter. Not many replacements reached the camp in the spring, so when British troops staged an attack in July, 1777, the Americans had to evacuate Mount Independence. British and German troops remained there until learning of the British surrender at Saratoga in October, 1777. They retreated back to Canada, burning the structures on Mount Independence as they left.

Mount Independence is a National Historic Landmark, containing the remains of batteries, blockhouses, barracks, a hospital, and other historic features. Archaeological work continues and the trails are being modified and improved to incorporate more of the historical significance and natural beauty of the site. (Note: this trail improvement may mean that, in the future, some stops in this field guide may no longer correspond to described trail markers.)

Geologic Setting

The rock formations found at Mount Independence are typical of Cambrian and Ordovician sedimentary deposition on the passive margin that developed on the east coast of ancient North America (Laurentia). The following description of the geologic history and geologic setting of Mount Independence is taken from various sources, including Fisher, 1984; Rankin, et al., 1989; Thompson, 1990; Selleck, 1997; and Isachsen et al., 2000.

Beginning in the Late Proterozoic, rifting of a supercontinent began, leading to the formation of the Iapetus Ocean (forerunner of the present-day Atlantic Ocean) with Laurentia as the landmass to the west. Approximately 600 m.y. ago, sediment, at first of continental origin, began to accumulate on the eastern margin of Laurentia. As rifting continued, sedimentation on the developing passive margin became of shoreline and shallow marine affinity. The earliest of these sedimentary units occurring in western Vermont (Dalton, Cheshire, Dunham, Monkton, and Winooski Formations) are not found at Mount

Independence; here, the oldest unit is the medial Late Cambrian Potsdam Formation, a quartz sandstone which unconformably overlies the Proterozoic metamorphic rocks of the Adirondack massif just to the west. (An excellent exposure of this unconformity is described in Selleck, 1997). Overlying the Potsdam Formation is the Late Cambrian Ticonderoga Formation, a sandy dolomite which marks the transition from a shoreline to more of a shallow marine environment. Overlying the Ticonderoga Formation is the Late Cambrian/Early Ordovician Whitehall Formation, which is mostly a massive dolomite, and then the cross-bedded sandstone at the base of the Early Ordovician Great Meadows Formation. The Whitehall and Great Meadows Formations belong to the Beekmantown Group. All formations dip gently to the north, at angles of between 4 and 10°, averaging 6 or 7°.

To the east of Mount Independence are numerous exposures of dolomites, limestones and shales of the overlying Chazy, Black River and Trenton Groups. The thick sequence of Cambrian and Early Ordovician clastic and carbonate rocks indicates that water depth throughout this time was quite consistent. Water depth did not increase substantially until the Middle Ordovician, when this deepening water heralded the onset of the Taconic Orogeny.

Mount Independence is offset from rocks immediately to the east by a high-angle normal fault, which brings the Cambrian Ticonderoga Formation in contact with the Early and Middle Ordovician Providence Island and Middlebury Formations. While there is no outcrop for at least a mile to the east of this high-angle fault, there is no doubt that the rocks to the east are indeed younger than the rocks of Mount Independence. The age of this high-angle fault is debatable; pre-Silurian movement is likely, although there may have been re-activation of the faults in the Mesozoic related to rifting that produced the present-day Atlantic Ocean.

STRATIGRAPHY

The rock formations found at Mount Independence have been given a variety of names and descriptions, depending on the focus of the worker. As Rankin et al. (1989) state (in discussion of the sedimentary evolution of the passive margin), "usage of the many local formation names has hindered understanding of regional patterns" (p. 42). The formations of Mount Independence were first described by Brainerd and Seely (1890) for the central Champlain Valley of Vermont; these descriptions have been expanded upon and modified by many other researchers working in the general region, including Cady (1945), Welby (1961), and Fisher (1984).

In 1890, Ezra Brainerd and H. M. Seely of Middlebury College published "The Calciferous Formation in the Champlain Valley" (Brainerd and Seely, 1890). They used the term "Calciferous" to describe the rocks found stratigraphically between the Potsdam Sandstone and the limestones of the Chazy Group. They divided the Calciferous into five "Divisions"; Divisions A and B and the lowermost member of Division C are found on Mount Independence. Their descriptions are as follows (p. 2):

> Division A: Dark iron-grey magnesian limestone, usually in beds one or two feet in thickness, more or less silicious, in some beds even approaching a sandstone. Nodules of white quartz are frequently seen in the upper layers, and near the top large irregular masses of impure black chert, which, when the calcareous matter is dissolved out by long exposure, often appears fibrous or scoriaceous. Thickness..........310 ft.

> Division B: Dove-colored limestone, intermingled with light grey dolomite, in massive beds; sometimes for a thickness of twelve or fifteen feet no planes of stratification are discernible. In the lower beds, and in those just above the middle, the dolomite predominates; the middle and upper beds are nearly pure limestone; other beds show on their weathered surfaces, raised reticulating lines of grey dolomite. Thickness...... ....295 ft.

> Division C, unit 1: Grey, thin-bedded, fine-grained, calciferous sandstone, on the edges often weathering in fine lines, forty or fifty to the inch, and resembling close-grained wood. Weathered fragments are frequently riddled with small holes, called *Scolithus minutus* by Mr. Wing.........60 ft.

They describe the geology of Mount Independence as follows (p. 10):

> In the northwest corner of Orwell...is a hill known as Mount Independence. It rises nearly 200 feet above Lake Champlain, and is about a mile in length, the top along the north half being a smooth plane sloping gently to the north....The promontory on which [Fort Ticonderoga] was built is but a continuation of Mount Independence, after an interval of eighty-eight rods of water, and extends for over a mile further northwest.
>
> This whole tract of historic ground consists of Calciferous strata over 1300 feet in thickness, dipping north at an angle of 6°, and overlying 170 feet of Potsdam sandstone....The plateau on the north end of Mount Independence is the top of Division B, the thin-bedded sandstone at the base of Division C having been removed by glacial action, not only here, but farther north, where is now the channel of the lake. The upper layers of B are largely quarried and used for flux in the iron-furnaces....Along the east side of Mount Independence...are marked indications of a downthrow of the strata on the east.

The mapping done by Brainerd and Seely (1890) at Mount Independence is largely correct. The only changes to be made are that (1) Division B is mostly dolomitic (this is an example of the spatial variations seen in many units in the region), (2) there is a fault at the southern end of the peninsula, and (3) the base of Division C *does* occur on Mount Independence.

More recent workers have been more specific, of course, about naming formations for type localities, but this has meant that lateral variations in rock type has meant lateral variations in formation names as well. Because Mount Independence has more in common, geologically speaking, with eastern New York State rather than with the rest of Vermont, the New York stratigraphy will be used here. As a general rule, lithologies found to the west of the Champlain Thrust will be named after their New York counterparts. Comparisons with time-equivalent formations to the east of the Champlain Thrust will be given with individual formation descriptions. Table 1 on the next page gives the correlation between formation names.

The following lithologic descriptions are based on field observations for this study. More complete descriptions of these units in their various other occurrences are found in Cady (1945), Welby (1961), Fisher and Mazzullo (1976), Fisher (1984), Washington and Chisick (1988), and Selleck (1997).

New York – Champlain Valley	Vermont – Middlebury Synclinorium	Brainerd and Seely (1890)
Great Meadows	Cutting	lowest strata of Division C
Whitehall	Shelburne	Division B
Ticonderoga	Clarendon Springs	Division A
Potsdam	Danby	Potsdam

Table 1. New York and Vermont stratigraphic equivalents and corresponding units from Brainerd and Seely (1890).

Several samples of the Ticonderoga and Whitehall Formations were analyzed for their clastic quartz content by determining the insoluble residue remaining after the samples were crushed and dissolved in 3 M HCl. After all reaction had ceased, the residue was filtered, washed and dried. The weight percentage of insoluble residue was then calculated.

Potsdam Formation

The upper portion of the Potsdam Formation occurs at Mount Independence. It is dominantly a pink, tan and gray quartz-cemented quartz sandstone with some thin shaly layers. Sand grains are smooth and rounded and range from fine to coarse size; some show evidence of transport by wind. Fresh surfaces display a vitreous luster. The unit is mostly medium bedded (approximately 0.5 m thick). Some beds contain abundant worm burrows. Layers of pure quartz sandstone weather smooth, while those with variable grain size and bioturbation weather to a rough, moth-eaten texture. Cross-bedding is prominent is some layers, and shows up particularly well on weathered surfaces.

The composition and sedimentary structures suggest that this portion of the Potsdam Formation was deposited in a shoreline environment, where both wind and wave action could take place. The thin shaly layers could represent mudflats. Minor fluctuations in sea level could produce sometimes more sub-aereal, sometimes more sub-aqueous conditions.

The equivalent formation in the Middlebury synclinorium and northwestern Vermont is the Danby Formation, described by Cady (1945) and Mehrtens (1985) as interbedded sandstone and dolomite, representing intertidal to platform edge sedimentation. The Potsdam Formation differs from the Danby Formation in that its depositional environment appears to be limited to intertidal and subtidal zones.

The contact between the Potsdam and Ticonderoga Formations has been described as gradational (e.g. Selleck, 1997), with an increase in carbonate and decrease in quartz marking the transition. At Mount Independence the contact appears to be an erosional surface, with a coarse-grained dolomitic layer lying on top of a wavy surface with truncated cross-beds.

Ticonderoga Formation

The Ticonderoga Formation is a light- to medium-gray, siliceous dolostone. Bedding ranges from medium to fairly massive. It is the thinner beds that are used, in part, to differentiate this unit from the overlying Whitehall Formation. Texture varies from finely to coarsely crystalline, and many layers contain rounded and often frosted quartz sand and more angular quartz silt. Some beds are more correctly described as dolomitic sandstone, containing over 50% insoluble residue. Terminated quartz crystals in vugs and coarse-grained white calcite knots are characteristic of some layers. On a fresh surface luster is subvitreous, and the quartz sand grains protrude as smooth, rounded and opaque-looking beads. Dark gray and blue-black chert occurs in patches and thin, discontinuous layers. Weathered surfaces are various shades of gray, and sometimes have a pitted appearance; the chert weathers out in high relief.

The likely sedimentary environment of deposition was a shallow ocean bottom with considerable current activity (Welby, 1961). A near-shore environment is required because of the abundance of rounded quartz sand grains. The frosted surface of many quartz grains suggested they were windblown into the shallow ocean.

The equivalent formation farther east, the Clarendon Springs Formation, is described by Cady (1945) as a uniform gray dolomite with "numerous geodes and knots of white quartz" (p. 536), with some sandy beds and patches of chert. Therefore, there is great similarity between the Clarendon Springs and Ticonderoga Formations, but, as suggested by Welby (1961), it is more consistent to use the name Ticonderoga Formation for rocks west of the Champlain Thrust.

The contact between the Ticonderoga Formation and the Whitehall Formation is not easy to find. Welby (1961) suggests a gradational contact between the two, and acknowledges that the contact can be difficult to discern. At Mount Independence, the contact is placed just below the limestone beds that are described in the next section.

Whitehall Formation

At Mount Independence, the lowermost section of the Whitehall Formation contains a small interval of light- to medium-gray limestone or calcic dolostone, which weathers white and contains large, rounded, frosted quartz grains, patches of dark blue-gray chert, rounded chert pebbles, and (especially visible on weathered surfaces), what appear to be stromatolites. The matrix is occasionally earthy-looking. Outcrops are often covered by thick moss. This limestone layer probably corresponds to the Warner Hill Limestone Member as described in Fisher (1984). Welby (1961) also discusses at length the nature of the lowermost unit of this formation. At Mount Independence it appears to be about 3 – 5 m thick.

The rest of the Whitehall Formation at Mount Independence is a thick- to massive-bedded dolostone, the Skene Dolostone Member (as described by Fisher, 1984). It is medium- to dark-gray, sometimes mottled or laminated in light and dark shades, and fine- to medium-grained. It weathers various shades of gray. Black chert occurs as nodules and layers. Rounded quartz sand grains are quite common, and a few layers approach being a dolomitic sandstone. The fine-grained, darker-colored layers have a vitreous luster on a fresh surface, and the fresh break has a slightly fetid odor, perhaps the same as described by Welby (1961) as indicative of certain layers of the Whitehall Formation (although he describes the odor as "strongly fetid" (p. 45)). Within the massive layers, bedding is indicated by laminations, but it is very difficult to get reliable structural measurements of the attitude of bedding.

The percentage of insoluble residue ranges from less than 7% to greater than 55%, with an average of about 10%. Some of this material is rounded quartz sand grains and some is angular quartz silt. Welby (1961) suggests that it is the quartz silt that gives many layers of this formation a vitreous luster.

The equivalent lithology to the east is the Shelburne Marble, which is described by Cady (1945) and is a significantly different rock type. Therefore, the use of the name Whitehall Formation is appropriate, as suggested by Welby (1961).

Great Meadows Formation

Only the basal unit of the Great Meadows Formation is found at Mount Independence. This unit, the Winchell Creek Member, is described by Fisher (1984) as a medium-bedded, cross-bedded, calcareous siltstone. This is the lithology described as resembling "close-grained wood" by Brainerd and Seely (1890). At Mount Independence, even though its exposure is quite limited, the Great Meadows Formation is recognized by a distinctive cross-bedded, fine-grained sandstone with a slightly dolomitic matrix, and also by a sedimentary breccia consisting of fragments of cross-bedded material several centimeters long jumbled about in a dolomitic matrix.

The equivalent unit east of the Champlain Thrust is the Cutting Formation, whose type locality at Cutting Hill in East Shoreham is only about ten miles from Mount Independence. The basal unit is called the C-1 member by Welby (1961) in deference to Brainerd and Seely's (1890) letter designations, and is described by Welby (1961) as follows: "...the most characteristic single feature of the member is the breccia at the base; another striking feature is the cross-bedding associated with the sandstones at the base...." (pp. 53-54). This description is identical to what is found at Mount Independence, but for consistency the name Great Meadows Formation is used here.

ACKNOWLEDGMENTS

This work was funded in part by grants from the Lake Champlain Basin Program and the Vermont Geological Survey. My thanks to Elsa Gilbertson, Regional Historic Site Administrator for the Vermont Division for Historic Preservation, for her support, and to Tim Grover of Castleton State College for his geological expertise and technical know-how.

ROAD LOG

Mount Independence is located in Orwell, Vermont, five miles west of the intersection of Vermont Routes 22A and 73. From that intersection, go west on Rt. 73 (toward Lake Champlain and away from the village of Orwell). In about 0.3 miles, Rt. 73 curves to the right (north); bear left on the road to Mount Independence (there's a sign). Continue to the end of this road. Just after the road turns to dirt, there is a fork in the road. Bear left, up a steep little hairpin turn. The parking lot for the Mount Independence State Historic Site is on the south side of the road (on your left) and the museum is on the north side (it's the building that looks like a boat). Park in the parking lot.

Note: 1.8 miles after the intersection of Rts. 22A and 73, as you head toward Mount Independence, you will go down a short, fairly steep descent. This marks the Champlain Thrust, one of the largest structural features of western Vermont.

Note: Bring a lunch and something to drink. There is nowhere to purchase supplies closer than the village of Orwell, which is six miles away.

This tour is done entirely on foot, and follows the colored and numbered trails of the State Historic Site (make sure you get a trail guide brochure). Therefore, instead of mileage notations, trail numbers and stop location descriptions will be given in this guide. Approximate compass directions will be given for orientation purposes. The trip will take three or four hours, and includes a fairly leisurely 3.5 mile walk and a little scrambling up talus slopes and through the trees.

Warning: Mount Independence is well endowed with poison ivy! Be vigilant!

Warning: Mount Independence is a State Historic Site. To the untrained eye, many of the historically important building remains bear a striking resemblance to scattered outcrops. Please make sure you know what rocks you're looking at before you start examining them too closely!

Start of trip

On the southern side of the parking lot is a signpost. This is where the field trip begins. Field trip stops are shown on Figure 9, which also shows the geology of Mount Independence.

From the signpost, follow the Southern Defense Trail to the east (left). Walk across the grassy area to the stairs. At the base of the stairs is an outcrop of Ticonderoga Formation, showing one of the more massive layers of this unit. We'll see more of the Ticonderoga at a later stop. Continue along the path to a solitary step, about 5 m before a signpost at a junction in the trail.

The flat area around the signpost marks the top of the Potsdam Formation. The rubble upslope is the lowermost Ticonderoga Formation. Continue along the path, and go left at the junction (downhill). From here there is a beautiful view south down the southern end of Lake Champlain. Continue downhill along the path, and go down first a set of three steps, then a set of six steps.

STOP 1. POTSDAM FORMATION. This "stop" begins here and continues down to the water. Typical upper Potsdam sandstone is displayed in the numerous outcrops along this trail. It is in general a pinkish, tan, and gray quartz-cemented quartz sandstone. Fisher (1984) terms this upper arenitic unit the Keeseville Member.

Figure 1 is a photomicrograph of a representative sample, showing the well-sorted, well-rounded nature of the quartz grains. Many of the grains are laced with fluid inclusions; the salinity and temperature of homogenization of the fluid inclusions may help suggest the source rock of the quartz sand.

As the trail descends to the Carillon dock at the water's edge, various features of the Potsdam Formation are visible both in outcrop and in the steps, including grain size differences, shaly layers, worm burrows and cross-bedding. Some of these features cause the rock to weather with a moth-eaten appearance. In other beds, pure quartz-cemented quartz sandstone has the appearance of a quartzite. These various characteristics of the Potsdam Formation suggest an established, mostly intertidal sedimentary

Figure 1. Photomicrograph of Potsdam Formation. Crossed polars. The quartz sand grains are well rounded, and show numerous fluid inclusions. In most cases, the quartz cement is optically continuous.

environment of deposition, with current action producing the cross-bedding, mudflats forming the thin shaly layers, and bioturbation by near-shore/beach-dwelling organisms.

After completing Stop 1, return to the trip starting point, walk down to the road, and then follow the road to the east (in the direction of Orwell) to the hairpin curve. The outcrop in the inside of the curve is the next stop.

STOP 2. TICONDEROGA FORMATION. This outcrop is approximately on strike with the Ticonderoga Formation seen at the base of the first staircase on the Southern Defense Trail. The outcrop displays most of the main features of this formation. It is a light- to medium-gray siliceous dolostone, weathering various shades of gray. It contains rounded quartz grains and scattered knots of white calcite and quartz. Some terminated quartz crystals are also present.

Figure 2 is a photomicrograph of a sample of Ticonderoga Formation taken from one of the lower layers. All features indicate that deposition occurred in a shallow, warm, marine environment, near a quartz sand beach. The rounded, frosted quartz sand grains are windblown from the beach into the water. The peloids (rounded dark masses 75 - 100 μm in diameter) are probably aggregates of carbonate mud (Blatt et al., 1980). The oolith (center of picture) indicates warm, carbonate-saturated water and strong, periodic bottom currents, such as those found in a tidal bar or tidal delta environment (Blatt et al., 1980).

Cross-bedding is also found elsewhere in the Ticonderoga Formation, supporting the notion of strong currents. Figure 3 shows cross-bedding in an upper unit of the Ticonderoga Formation, found on the east side of Mount Independence.

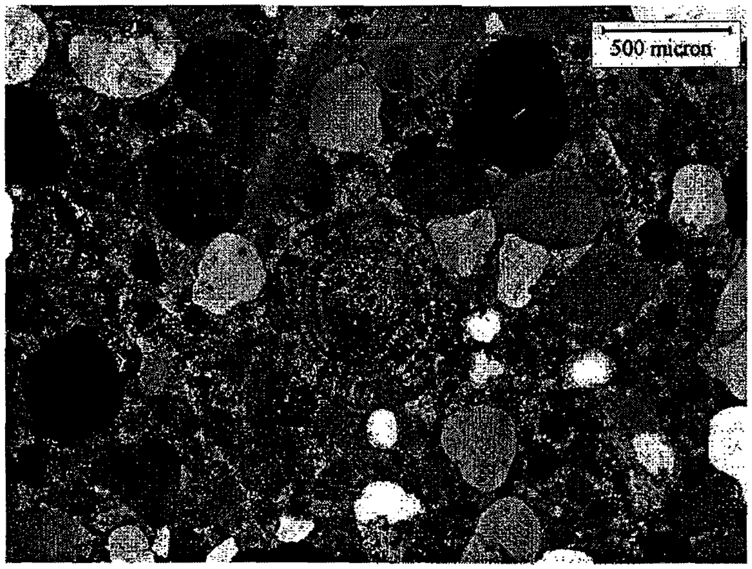

Figure 2. Photomicrograph of Ticonderoga Formation. Crossed polars. Note large, rounded quartz grains, peloids (small, rounded, dark masses), and oolith in center, showing characteristic radial structure around its core.

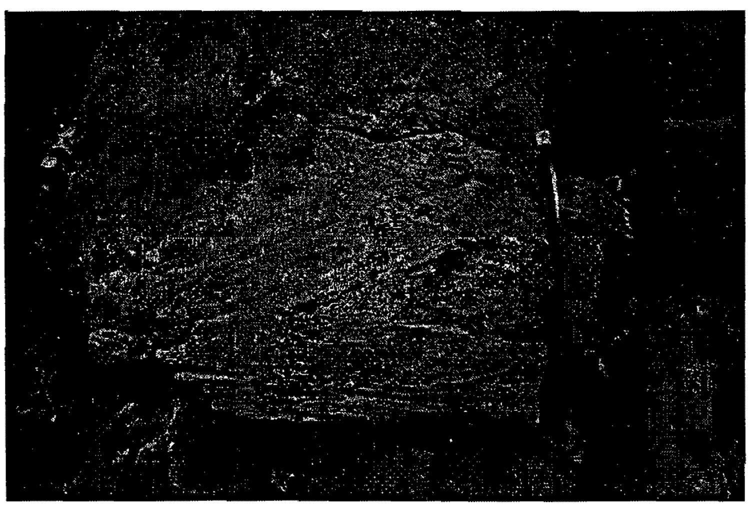

Figure 3. Cross-bedded Ticonderoga Formation, found in upper layer of unit on east side of Mount Independence.

Microscopic examination of the quartz content of the Ticonderoga Formation shows a bimodal distribution, with larger, rounded quartz sand grains and smaller, more angular quartz silt. Figure 4 is a photomicrograph of another sample taken near the one shown in Figure 2. Note the subparallel layering of the coarser and finer particles. This bimodal size distribution may represent the interplay of wind and fluvial or storm deposition.

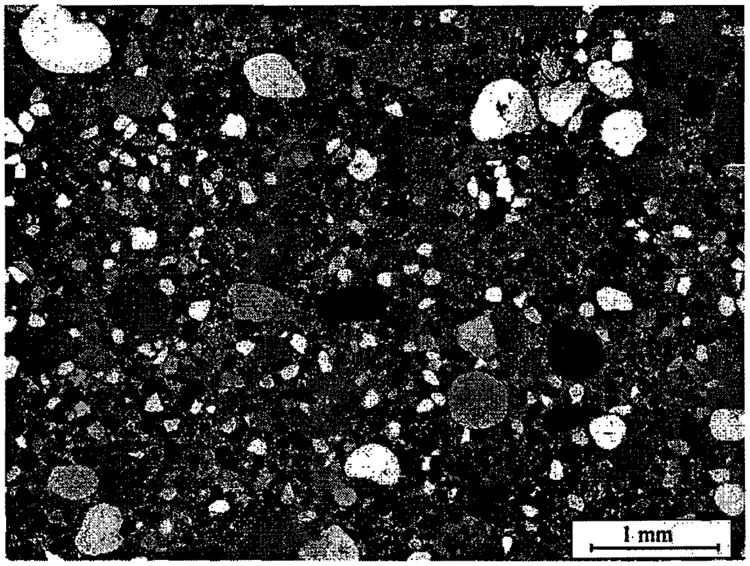

Figure 4. Bimodal distribution of quartz sediment in Ticonderoga Formation, with rounded sand grains and angular silt grains. Note subparallel arrangement of sand and silt layers (angled approximately 30° counterclockwise from horizontal in this particular view). Crossed polars.

Cross road to north and go into the woods at the end of the split rail fence. Be careful of old strands of rusty wire. Go straight uphill and slightly left (west). The outcrop here is of Potsdam Formation with some excellent cross-bedding, structurally higher than the outcrop of Ticonderoga Formation just seen at Stop 2. Therefore, there is a fault between the two outcrops.

This fault continues to the west, just south of the road leading to the marina (see geologic map, Figure 9). All along the fault, Potsdam Formation is on top of Ticonderoga Formation, although the actual fault surface is not visible anywhere. Because the trace of the fault is approximately parallel to contacts, this appears to be a dip-slip fault, either in keeping with the Ordovician "cross-faults" identified by Hayman and Kidd (2002) or the early Mesozoic faults of Stanley (1980) for other sections of the central and northern Champlain Valley of Vermont. As the road approaches the marina to the west of the entrance to the State Historic Site, the land flattens out, forming a terrace-like surface. This flat area is probably underlain by Ticonderoga Formation, although there is no outcrop between an occurrence of this unit at the water's edge and outcrops at the base of the cliff. The coincidence of this rock type (less resistant than the Potsdam Formation below and above) with the approximate level of the surface of the lake suggests that this flat area is indeed a terrace, carved into the softer rock when the lake surface was 5 or 10 m higher than present. Higher lake levels have occurred for much of the last 13,000 years, beginning with the waning of the Wisconsin stage of the last Ice Age (Hunt, 1980).

Walk back up the road to the entrance to the State Historic Site. Go left (west) of the museum and walk up the gravel path, past a low exposure of Potsdam Formation (on strike with what we just saw in the woods).

Note: The Museum and Visitor's Center is excellent and well worth a visit.

Continue up the grassy slope, following the sign to "Trails." The outcrop to the left (west) is also Potsdam Formation. After about 100 m, the trail flattens out briefly. To the right is a small marshy area containing an outcrop.

STOP 3. TICONDEROGA FORMATION. Somewhere in the last 50 m or so just traversed is the contact between the Potsdam and Ticonderoga Formations. This outcrop is therefore near the bottom of the Ticonderoga Formation. The flat surface of the outcrop is approximately equal to bedding, and contains a raised ridge of quartz sandstone. Three possibilities for the origin of this sandstone are:

1. clastic dike
2. sand filling a paleokarst solution cavity
3. sand filling a crack (either a desiccation crack or one tectonically formed)

If either (2) or (3) is correct, this implies a proximal source of sand that could wash into the cavity or crack. While the Ticonderoga Formation does contain quartz sand (as the main rock type of this very outcrop shows upon close examination), it appears to be windblown into the sediment rather than washed in by currents. For scenario (1), the source of the quartz sand would be <u>below</u> the dolomitic sediment. The proximity of the underlying Postdam sands makes this a reasonable prospect, especially if the Ticonderoga sediment was being deposited rapidly on as-yet-unconsolidated Potsdam sand, applying pressure and causing some of the sand to be squeezed upward.

Continue up the path toward the Trail Information Outpost. Approximately halfway between Stop 3 and the Information Outpost, a mown trail heads around a boulder on the right (east) and goes in a southerly direction, at a 30° angle to the trail you just walked up. This is the White Trail, but because we are walking it backwards, the trail markers are only visible if you turn around and look back.

Follow the path downhill through the woods (over ledges of Ticonderoga Formation, showing the medium-bedded nature of this unit), looking back every now and again to see the White Trail markers. The trail goes around a large curve, heading east, and large slabs of rock lie next to and across the trail. About 5 m into this rocky section, a grassy glade is visible downhill and ahead, containing White Trail Stop 3 (Southern Battery). A large, squarish slab of Potsdam formation is on the upslope side of the Trail, and contains some good cross-bedding. Straight ahead along the contour is an outcrop.

STOP 4. POTSDAM/TICONDEROGA CONTACT. This outcrop contains the contact between the Potsdam and Ticonderoga Formations. The contact is taken to be the undulating surface where gray quartz-cemented quartz sandstone (containing truncated cross-bedding) is overlain by pinkish-tan coarse-grained sandy dolostone. This suggests a period of erosion of the Potsdam sands before deposition of the dolomitic sediment; however, if the interpretation of the clastic dike at Stop 3 is correct, the Postdam sediment was not yet lithified when it underwent erosion. Figure 5 is a view of this outcrop, with the contact highlighted.

Continue along the White Trail, past White Trail Stop 2 (Foundation) and uphill over ledges of Ticonderoga Formation. Follow the White Trail to the Information Outpost, and continue west along the Red and Blue Trails. Where these trails diverge, follow the Red Trail (left) all the way to the end (Red

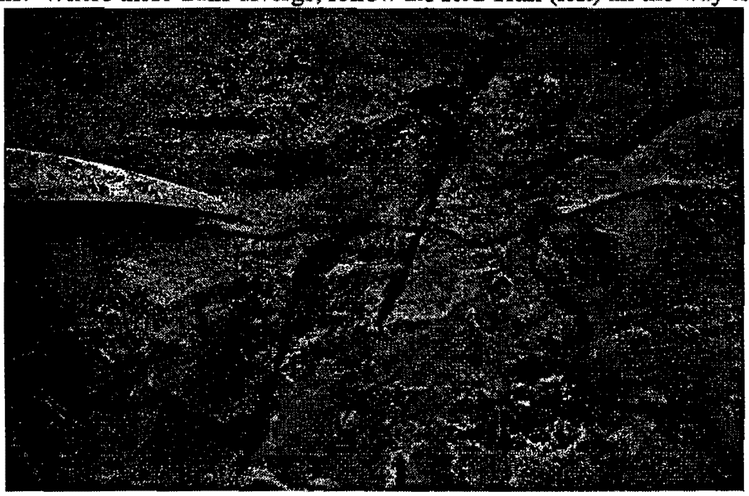

Figure 5. Potsdam/Ticonderoga contact, at level of pick point, highlighted for clarity.

Trail Stop 3). Here there is a lovely view of Mount Defiance west across Lake Champlain, and of Fort Ticonderoga to the north. The large road cuts at the base of Mount Defiance are in Proterozoic metamorphic rocks of the Adirondack massif. Therefore, the high-angle normal fault that bounds the massif on its eastern side lies somewhere under the lake. The boulder of pink granite near the bench is likely from the igneous rock of the massif, transported here by Ice Age ice sheets.

The outcrop just below the overlook is of dolostone containing chert, sandy layers/lenses and laminations. This outcrop is considered to be Whitehall Formation on the basis of the laminations and slightly fetid odor on a freshly broken surface, although the many similarities with the Ticonderoga Formation (dolomitic matrix, sand layers, chert) illustrate the difficulty in placing the contact between the two formations, especially in relatively flat areas where outcrop is discontinuous.

Take the Red Trail back to the junction with the Blue Trail. Go left (north) on the Blue Trail to the first outcrop on the left (west) side in the woods.

STOP 5. WHITEHALL FORMATION – WARNER HILL LIMESTONE MEMBER. This rock is a thick-bedded, light- to medium-gray limestone or calcic dolostone containing large, rounded, frosted quartz sand grains and having an almost conglomeratic appearance. Weathered surfaces are almost white, and contain wavy raised lines that resemble the stromatolites seen in the Warner Hill Limestone Member of the Whitehall Formation in Whitehall, New York. There are patches and pebbles of dark blue/gray chert, and occurrences of coarse calcite crystals stained yellow-orange by iron oxide.

To the east, on the other side of the Blue Trail and in the woods, are numerous discontinuous and moss-covered outcrops of limestone/calcic dolostone with iron oxide staining, occurrences of earthy-looking matrix, patches and stringers of chert, white weathering and variably fetid odor on fresh breaks.

Another feature that is taken to be indicative of the Whitehall Formation is the thick to massive bedding, which makes it very difficult to take structural measurements. (In contrast, the Ticonderoga Formation is mostly medium-bedded, with well-defined bedding planes).

Continue north and downhill along the Blue Trail. Note that the trail is stabilized by black slate that has been brought in from elsewhere. The trail flattens out as the land opens up a bit. About 50 – 100 m past the two-log bridge, there is a Blue Trail marker on a tree on the left (west) side of the trail. Directly across the trail and about 5 m into the woods is a very large boulder of almost pure black chert. Welby (1961) discusses the genesis of the chert in the dolostones, concluding that is was formed penecontemporaneously with the dolostone, and transported by currents as semi-solid masses.

The talus slope to the east at the base of the cliff contains boulders of stromatolitic limestone and "two-tone" mottled and laminated dolostone, all indicating that the cliff is made up of Whitehall Formation.

Where the Blue Trail gets closest to the water (Catfish Bay), there is a Blue Trail marker on the left (west) side of the trail. (This is about 40 m south of Blue Trail Stop 7.) Walk directly east through the trees along a vague trail that climbs up the talus slope to the base of a steep cliff.

STOP 6. WHITEHALL FORMATION – SKENE DOLOSTONE MEMBER. The outcrop is of massive dolostone with layers of chert containing nodules of dolostone, iron oxide staining on groundwater seeps, and a dark shaly layer. The dolostone is mostly medium- to dark-gray and finely crystalline, with a slightly fetid odor on a freshly broken surface. The massive bedding is characteristic of this part of the Whitehall Formation.

Continue north along the Blue Trail. Blue Trail Stop 5 (Spring) has steps made of slabs of laminated Whitehall Formation. Continue along to Blue Trail Stop 4 (Quarry). The rock here is a calcareous dolostone (it reacts weakly without scratching to dilute hydrochloric acid) suggesting it is near the top of the Whitehall Formation, as the reappearance of more calcareous layers is characteristic of the upper portions of the formation.

Continue north along the Blue Trail to its end, at a junction with the Orange Trail. Go left on the Orange Trail, toward the northernmost point of Mount Independence.

STOP 7. LUNCH. The "beach" here is a large outcrop of the fairly featureless, massive gray dolostone that typifies a large part of the Whitehall Formation. Coarse calcite is visible in some cracks. A floating bridge once connected Mount Independence and Fort Ticonderoga at this point. There is also a geological connection, because Fort Ticonderoga is in the direction of dip; the stratigraphy is continuous from this stop, under the water, and onto the other shore, as noted by Brainerd and Seely (1890).

Continue along the Orange Trail (east and south) to Orange Trail Stop 4 (Horseshoe Battery).

STOP 8. GREAT MEADOWS FORMATION – WINCHELL CREEK MEMBER. The basal unit of the Great Meadows Formation, the Winchell Creek Member, occurs all around the Horseshoe Battery in scattered outcrops on the slopes. To the north, along a now-abandoned section of the Orange Trail, are a few small outcrops of the distinct cross-bedding that exemplifies this unit (Figure 7).

Figure 7. Cross-bedding in Winchell Creek Member of Great Meadows Formation. Lens cap for scale.

Bedding orientation is difficult to ascertain, but it appears that this unit is lying conformably above the Whitehall Formation. Other outcrops contain a sedimentary breccia that is also characteristic of the lowermost Great Meadows Formation (it is described for the equivalent Cutting Formation by Welby, 1961). The fragments in the breccia are laminated and cross-laminated. Figure 8 shows an outcrop of this breccia, with two fragments outlined for clarity. The structure of both the cross-bedding and the breccia show up best on weathered surfaces, and are almost invisible on fresh breaks.

Figure 8. Breccia in Winchell Creek Member of Great Meadows Formation. Two cross-laminated fragments are outlined for clarity.

The Winchell Creek Member in its type locality is described by Fisher and Mazzullo (1976) as a cross-bedded quartzofeldspathic siltstone with thin lenses of sandstone, containing ripple marks, desiccation cracks, and trace fossils. Prolonged weathering accentuates the sedimentary structures (giving the look of "fine grained wood" of Brainerd and Seely, 1890). Fisher and Mazzullo (1976) give a Gasconadian (Early Ordovician) age for this unit, and conclude that the sedimentary environment of deposition was low- to high-energy tidal flats. Therefore, it appears that the sedimentary environment did not vary greatly throughout the deposition of the Ticonderoga, Whitehall and basal Great Meadows Formations. Indeed, Welby (1961) and Fisher and Mazzullo (1976) conclude that this tidal-intertidal environment continued at least until deposition of the limestones of the overlying Fort Cassin Formation (Bascom equivalent).

Continue south along the Orange Trail. Stop 2 of the Orange Trail (Crane) has beautiful views of Mount Defiance and Fort Ticonderoga, as well as outcrop of upper Whitehall Formation. The rock here is a medium- to light-gray, coarsely crystalline dolostone with a slightly fetid odor on a fresh surface.

Continue south along the Orange Trail to where is bends to the east (an unused portion of the trail continues straight). Scattered about the trail are numerous moss-covered boulders and discontinuous outcrops of Winchell Creek breccia, indicating that the contact between the Whitehall and Great Meadows Formations is somewhere between the Crane and this location. Continue along the Orange Trail. At an overlook with a log bench, the outcrop is of fine-grained, vitreous, dark gray dolostone, indicating that the Whitehall/Great Meadows contact has again been crossed.

The Orange Trail continues all the way back to the Trail Information Outpost (about 15 minutes). Continue walking south to get back to the museum and parking lot.

Figure 9 is the geologic map of Mount Independence, on air photo base. The stops of this field trip are also shown in this figure. Figure 10 is a schematic cross section from south to north.

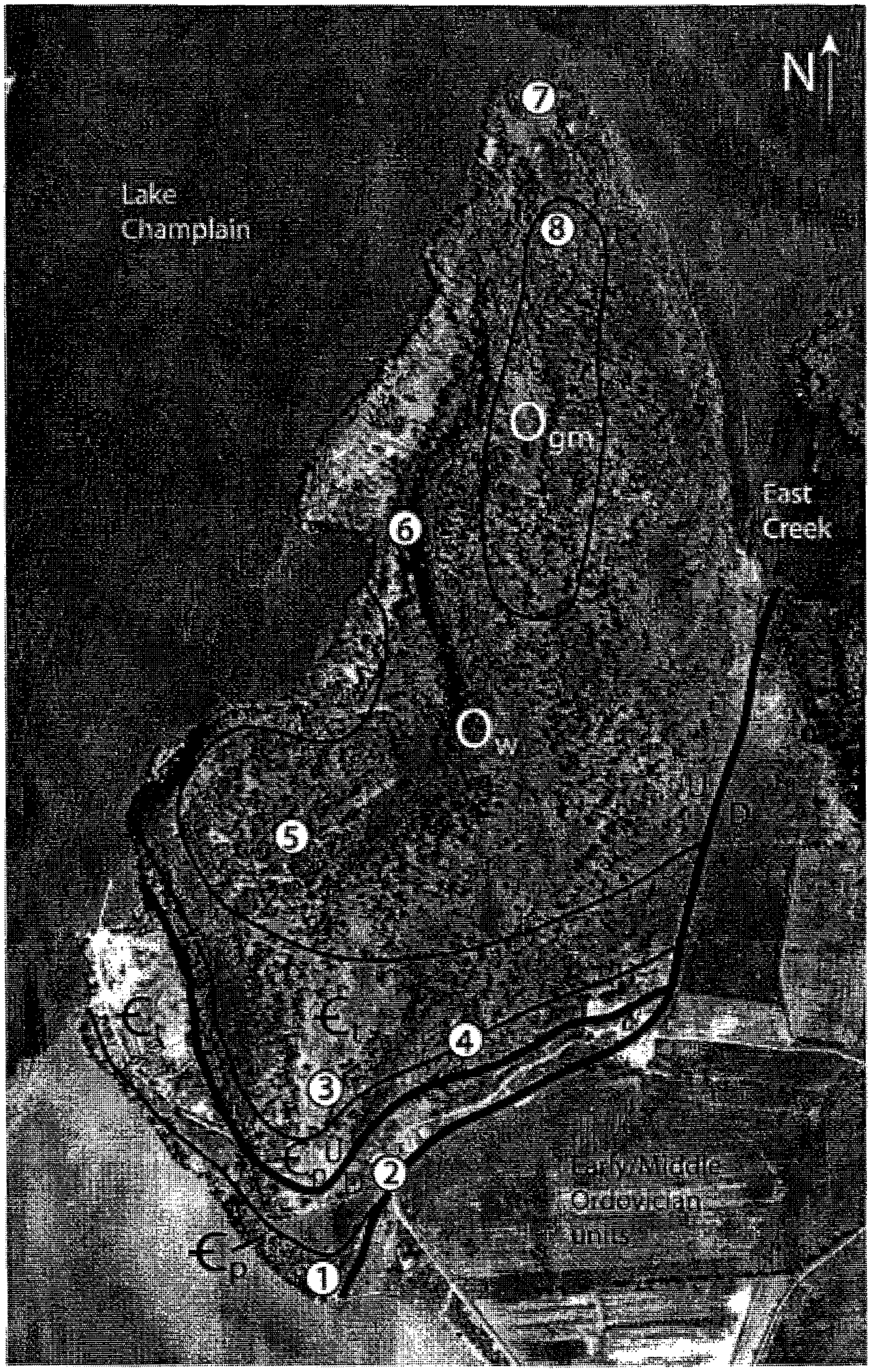

Figure 9. Geologic map of Mount Independence, showing stops of this field guide (numbered circles). Mount Independence is approximately 2 km from north to south and 1 km wide.

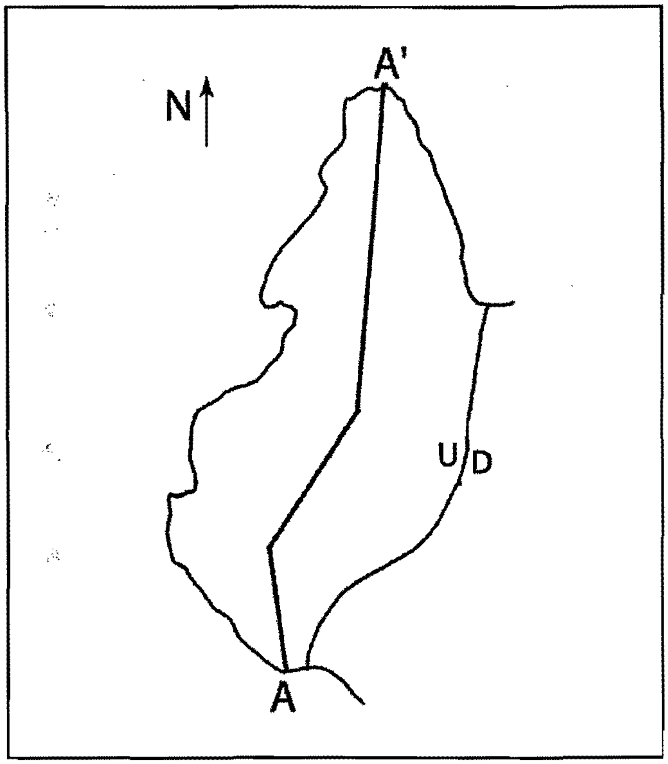

Figure 10 (a). Cross-section line A-A', for geologic cross-section shown in Figure 10 (b).

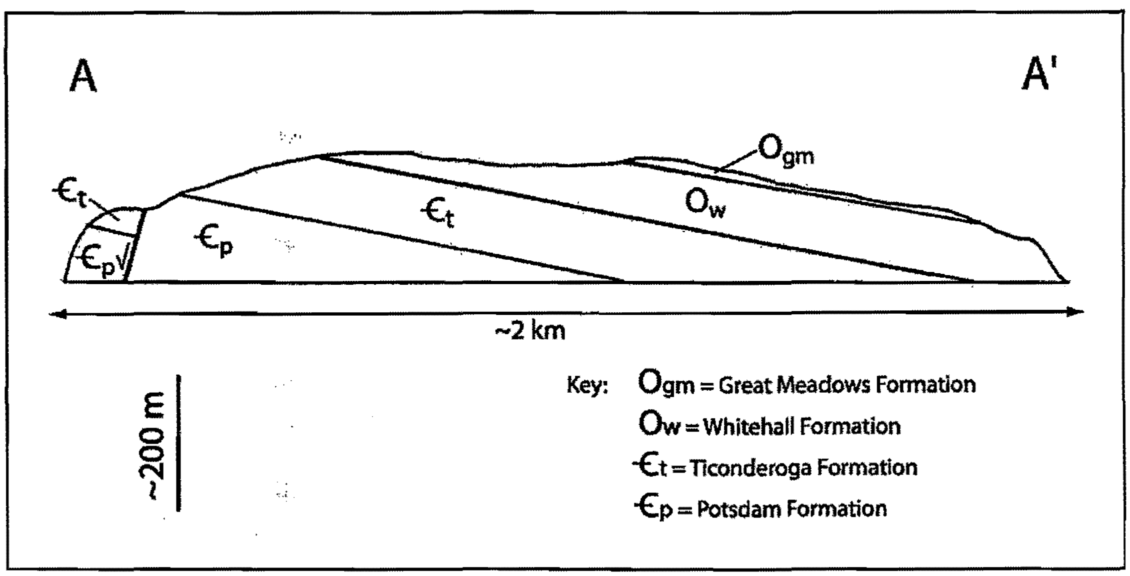

Figure 10 (b). Schematic cross-section of Mount Independence along the line A-A'.

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