GEOLOGIC FIELD TRIP SITES FOR TEACHERS IN NORTHWESTERN VERMONT

by
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INTRODUCTION

The areas around Northwestern Vermont (Figure 1) provide a wealth of accessible geologic information for interpretation by school teachers and students. On this trip, teachers will learn about the geological history of Vermont through visits and hands-on exploration of four local sites. All of the sites are accessible to the general public (with prior permission) and are suitable for visits by groups of students. We will share our techniques for exploring these sites with young earth scientists.

Our trip begins at Redstone Quarry Natural Area (Burlington) in an ancient shoreline environment which we now view as the Monkton Quartzite. We will visit the famous Champlain Thrust Fault at Lone Rock Point (Burlington) and examine marine off-shore environments of the Iberville Shale and Dunham Dolostone Formations. The islands of South Hero and Isle La Motte provide two quarries for viewing some of the life forms preserved in the limestones of the ancient Iapetus Ocean. The Glens Falls Limestone at Lessor's Quarry (South Hero) shows bryozoa, brachiopods and other fossils, while the Crown Point Limestone at the Fisk Quarry Preserve (Isle La Motte) preserves an ancient reef ecosystem which contains such fossils as stromatoporoids, bryozoa, algae, gastropods, cephalopods, and others.

GEOLOGIC FORMATION OF VERMONT

Geologic timeline in Northwestern Vermont

The geologic history of Vermont is a story of ancient shoreline processes, oceanic sedimentation, plate collisions, mountain building, and subsequent weathering and erosion. Figure 2 summarizes the timing of major geologic events in the formation of Vermont. Although the geologic timeline depicted on the left in Figure 2 is to scale, the events in Vermont's history are represented only schematically along the right.

In summary, most of the rocks in Northwestern Vermont are approximately 550 to 420 million years old (Cambrian to Ordovician in age) and were originally sedimentary units deposited in the ancient Iapetus Ocean. North America was nearer to the equator at this time, and the sedimentary rocks are typical of warm, tropical oceans. Two major mountain building events called the Taconic and Acadian Orogenies created the Green Mountains in Vermont and other parts of the Appalachian Chain when continental land masses collided 450 million years ago (mya) and 360 mya, respectively. During the collisions, Vermont's sedimentary rocks were metamorphosed to varying degrees, with increasing metamorphism towards the spine of the Green Mountains. Long-term weathering and recent glaciations (the last 2 million years) have eroded and polished the rocks of Vermont, but have only served to accentuate the preexisting north-south topography created by the massive collisions.

Massey, C., and Snyder, S., 1999, Geologic field trip sites for teachers in northwestern Vermont; in Wright, S.F. ed., New England Intercollegiate Geologic Conference Guidebook Number 91, p. 159–177.

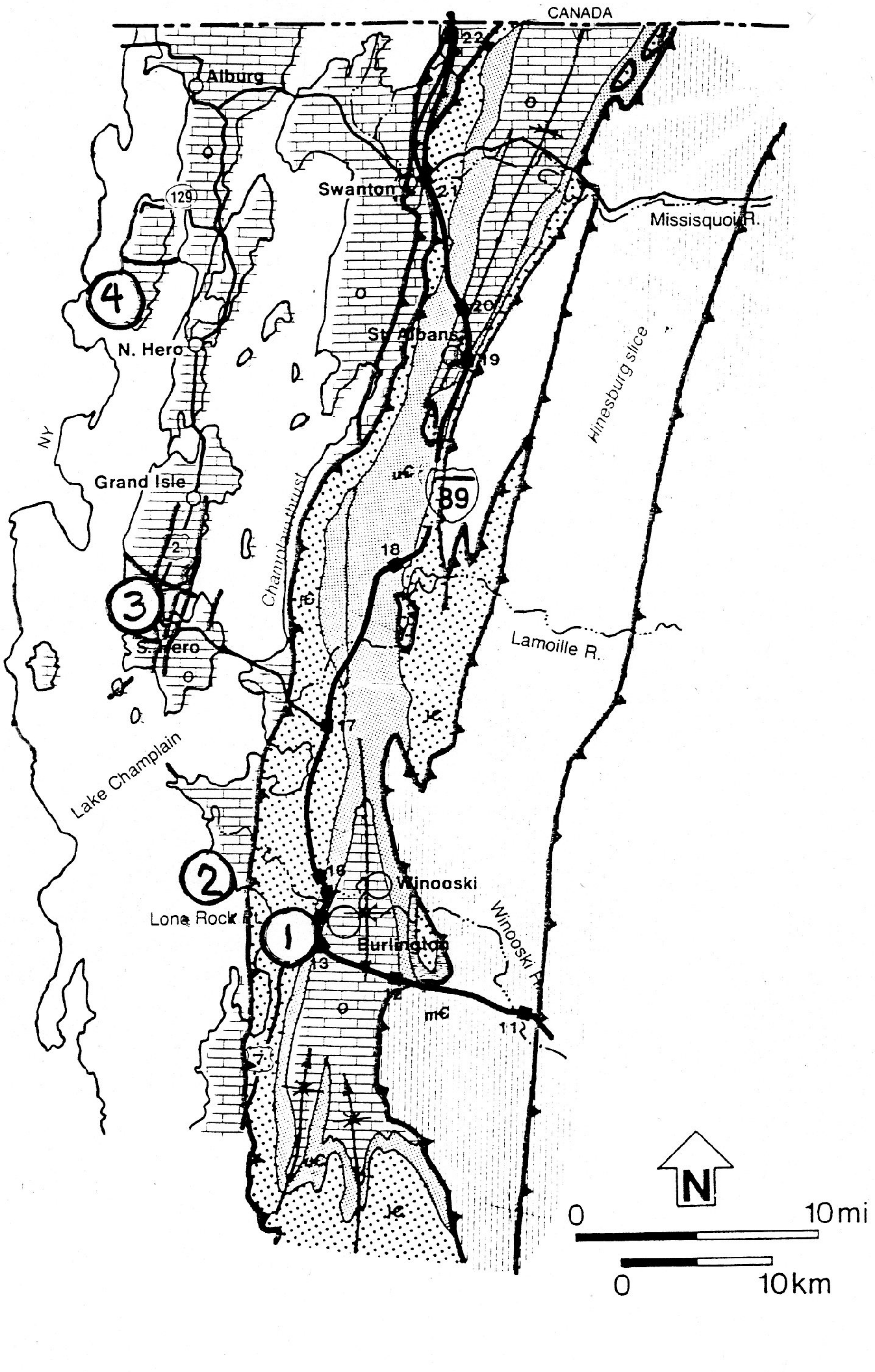
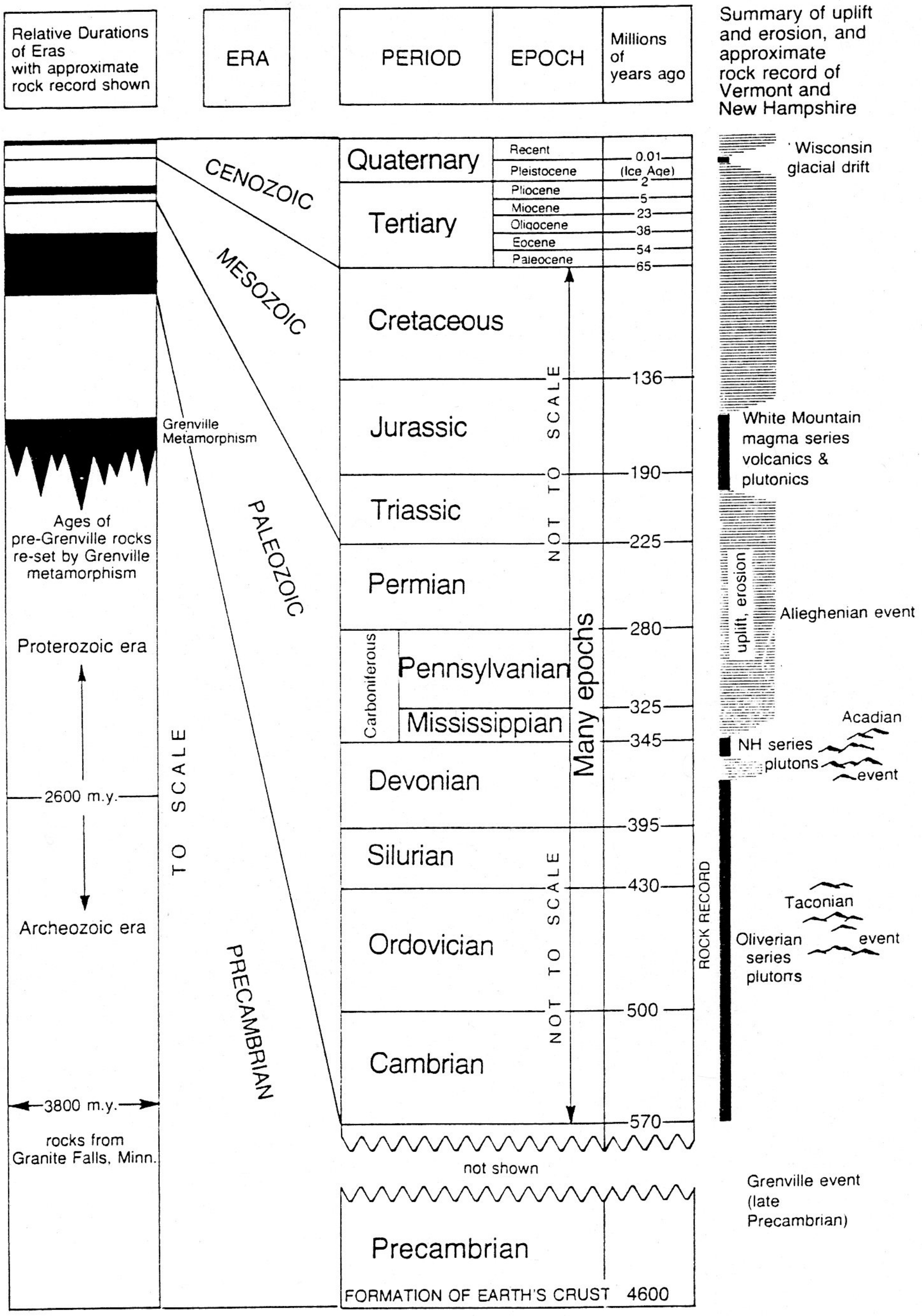


Figure 1. Location map for Redstone Quarry (1), Lone Rock Point (2), Lessor's Quarry (3), and Fisk Quarry Preserve (4) (after Van Diver, 1995).



The column on the left is scaled to the full length of Earth's history and the relative durations of the geologic eras, with black bars indicating the preserved rock record. The right column is not to scale, and shows time divisions and tectonic history of post-Precambrian time only.

Figure 2. Geologic timeline for Northwestern Vermont (Van Diver, 1995).

Tectonic History of Vermont

The continental landmass we call Vermont is part of the North American tectonic plate. In general, tectonic, or lithospheric, plates are buoyed up and float on top of the dense, partially molten material in the Earth's asthenosphere. The convection currents within the asthenosphere carry tectonic plates across the surface of the Earth—rifting plates apart, drifting them farther from each other, and also colliding them with each other in long-term cycles called Wilson Cycles. Figure 3 shows one such cycle in the geologic formation of Vermont.

An ancient continental landmass called the Grenville Supercontinent (also called Rodinia) began splitting apart during a plate tectonic rifting event approximately 700 mya. The rift occurred roughly along what is now the Vermont-New Hampshire border at a time when Rodinia was located nearer to the equator. When the continental crust thinned sufficiently, oceanic crust was formed by cooling lava emerging from the rift zone. The dense oceanic basaltic crust supported the Iapetus Ocean (proto-Atlantic) in the location we call Vermont today. Sediments on the shore and off the shore of the Iapetus Ocean were deposited during the drifting stage (widening of the Iapetus ocean). Sandstones formed near the shore while dolostones and limestones formed within the shallow, tropical ocean.

Around 500 mya, the plates of the Earth shifted and began a collision course centered in the Vermont region. Subduction occurred in the middle of the Iapetus Ocean due to the shortening, and caused volcanism. Continued subduction caused a deepening of the ocean near the proto-North American shoreline and dolostones and limestones covered the beach deposits. By approximately 420 mya, deep-water shales were deposited in the trench environment of the subduction zone near the proto-North American shoreline. A small chain of volcanoes collided with proto-North America during the Taconic Orogeny. Metamorphism of some of Vermont's ocean sediments occurred.

Around 360 mya, proto-Europe/Africa collided with proto-North America during the Acadian Orogeny and closed the final Iapetus gap. The new supercontinent formed from this collision is called Pangaea and marked the completion of a Wilson Cycle. Continued metamorphism occurred in the rocks of Vermont during the Acadian Orogeny, but spared the western-most sedimentary units from massive deformation. These "slightly" metamorphosed rocks, or meta-sediments, are most of what is exposed in Northwestern Vermont.

Stratigraphy of Northwestern Vermont

The meta-sediments of Northwestern Vermont record the deepening of the ancient Iapetus Ocean from a shoreline to a trench environment. Figure 4 shows the continuous sequence of sedimentary units.

The Dunham Dolostone is a gradual contact with an older quartz sandstone. We will see the Dunham Dolostone at Lone Rock Point (Stop #2), where it is in contact with the much younger Iberville Shale. The Dunham Dolostone exhibits characteristics typical of a stable continental shelf area similar to that found in today's Bahamas platform—a modern carbonate platform. The carbonate sediments are disturbed by burrowing life forms and have been transported from shallow to deeper waters. This disturbance is consistent with subtidal sediments. The Dunham Dolostone has shallowing-up cycles that indicate changes in the balance of sediment supply and change in sea level due to subsidence. The Dunham Dolostone outcrop at Lone Rock Point is some of the youngest dolostone in the unit.

We will see the Monkton Quartzite Formation at Redstone Quarry (Stop #1). The Monkton Quartzite represents a near-shore, intertidal zone with rippled sandstone, evidence of bioturbation, and desiccation marks. The quarry has one dolomite layer about 12 inches thick. Dolostone grains could have been washed up from deeper water along the continental shelf (Merhtens, 1985). The silica rich materials (quartz and feldspars) which make up the bulk of the pinkish quartzite are of terrigenous origin. The carbonate material (calcite and dolomite) originate off shore. The Monkton Quartzite, like the Dunham Dolostone, records deposition on a stable continental margin.

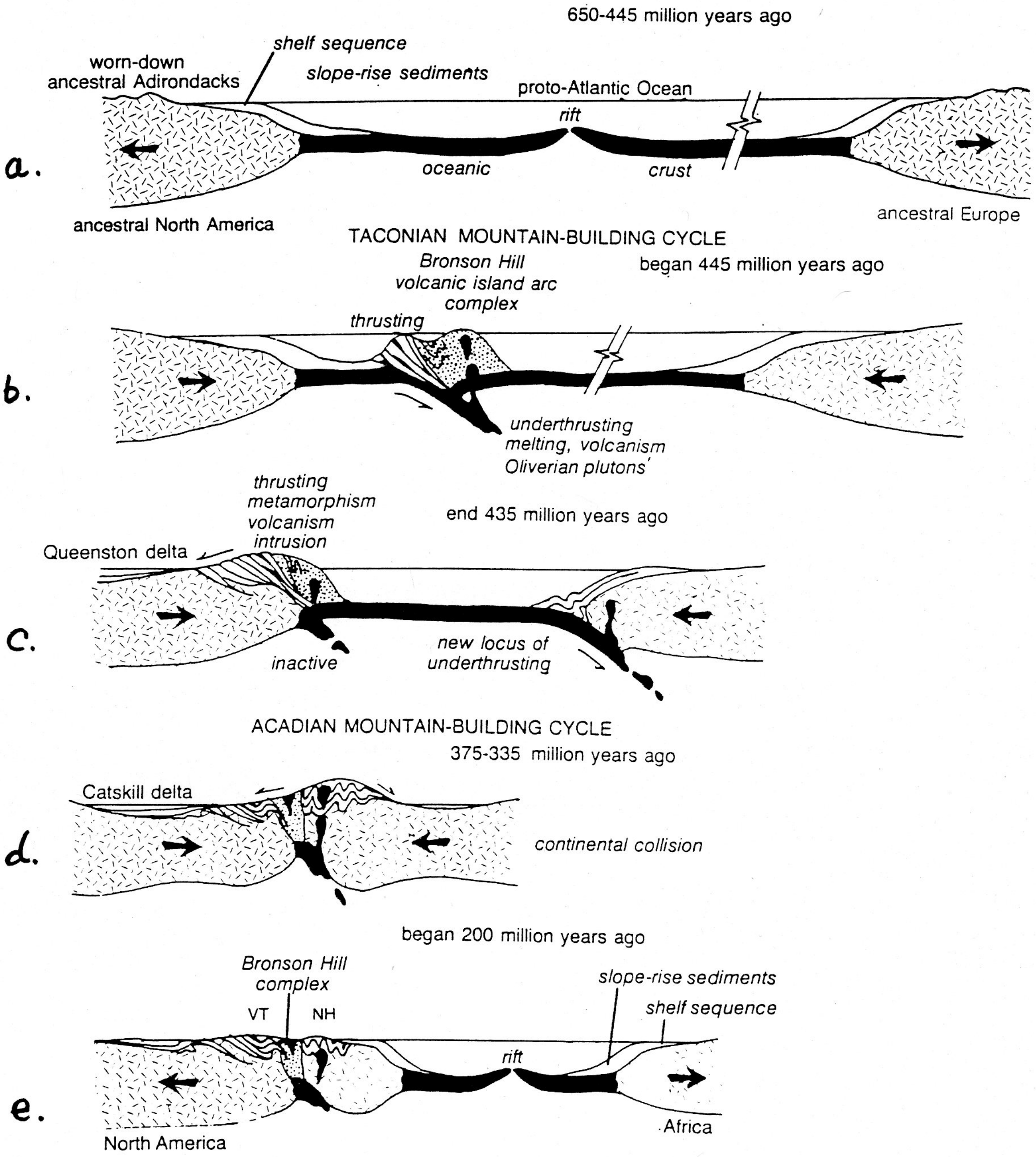


Figure 3. Geologic formation of Vermont showing the ancient Grenville Supercontinent (Rodinia) drifting apart to form proto-North America and proto-Europe/Africa after a rifting event (a), the subsequent closing of the Iapetus Ocean (proto-Atlantic) during the Taconic and Acadian orogenies (b-d), and new rifting and drifting to form the modern Atlantic Ocean (e) (after Van Diver, 1995).

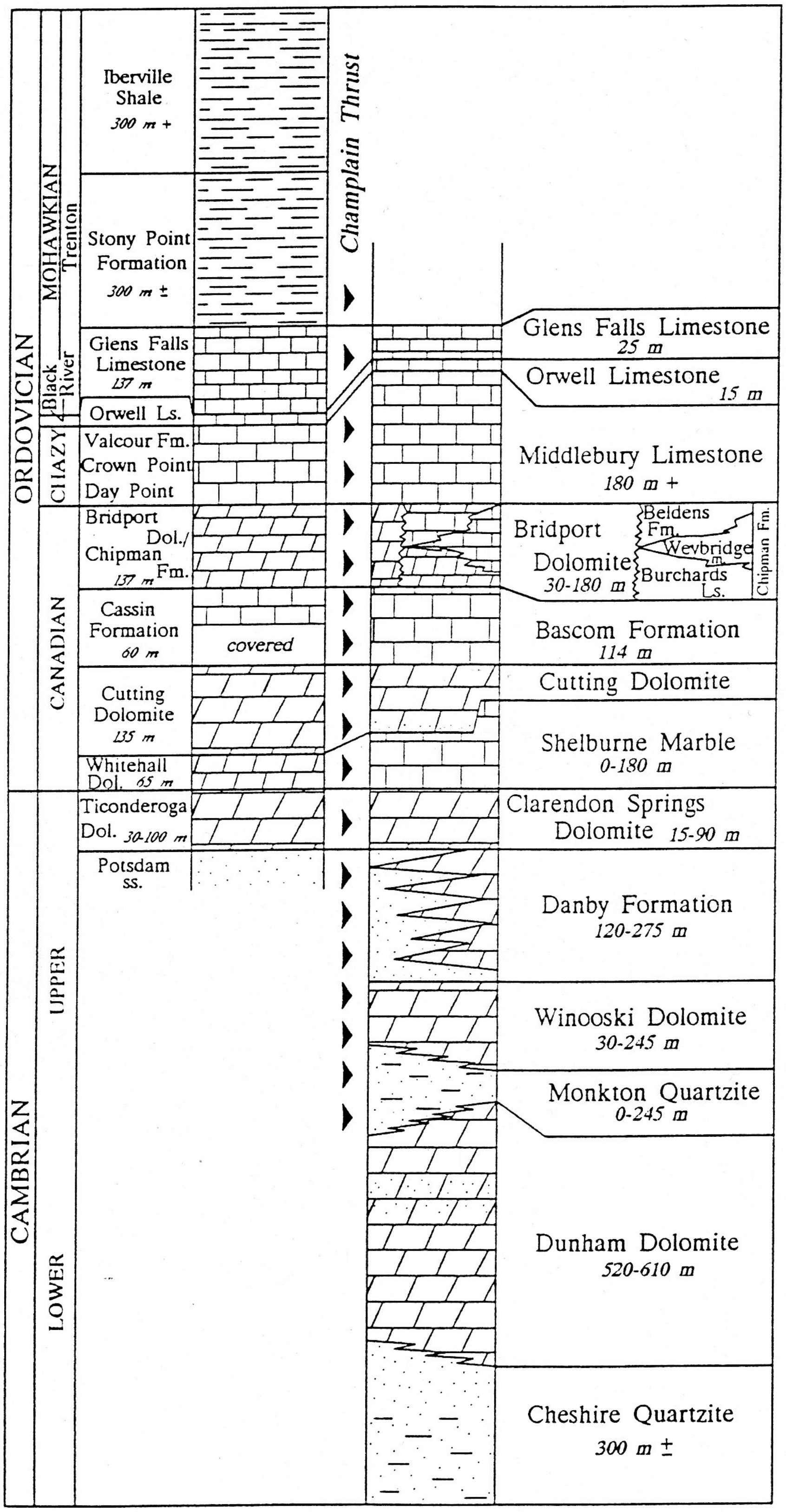


Figure 4. Stratigraphy of Western Vermont (Mehrtens et al, 1994; original from Coney et al, 1972).

The Crown Point Limestone found in the Fisk Quarry (Stop #4) is an excellent exposure of Ordovician reef deposits. The reef is composed of carbonate mounds and a fine-grained, muddy carbonate matrix with local concentrations of dolomite and quartz sands. On vertical quarry surfaces stromatoporoids (mounds of laminated carbonate formed by coral-like animals) are visible. Bedding surfaces often contain fragments of fossils (fossil hash) and/or the outline of large gastropods and cephalopods—organisms which lived on the reef. The Crown Point Limestone was deposited just below sea level on a stable continental margin. Other limestones (Day Point and Valcour) found on Isle La Motte show both shallower and deeper water reef deposits, respectively, as indicated by their fossil assemblages.

The Glens Falls Formation seen in Lessor's Quarry (Stop #3) is perhaps the most fossiliferous of the Ordovician rocks in the Champlain Valley. The limestone is shaly to silty in composition. The formation breaks in nearly orthogonal blocks. Silicified fossils (fossils replaced by quartz) are common on weathered surfaces and can be extracted in a mild muriatic acid bath. The disarticulated nature of the fossil layers suggest that fossil-laden sediments were deposited as they washed off the reef to deeper water below wave base. The deepening of the Iapetus Ocean is recorded in the Glens Falls Limestone.

The Iberville Shale contains only a few fossils (such as graptolites) which drifted into a deeper water environment. Graptolites are pelagic colonial organisms, which did not live in deep water. The Iberville Shale is fine-grained, black, platy and cleaves in thin sheets. This is typical of shale which have been metamorphosed. The Iberville Shale is in contact with the Dunham Dolostone at Lone Rock Point (Stop #2) only because of the Champlain Thrust Fault.

Invertebrate life in Northwestern Vermont

Life in the Cambrian and Ordovician seas in Northwestern Vermont was very different than it is today. At the end of the Pre-Cambrian, soft bodied life forms took an amazing divergence from what was common at that time. The advent of exoskeletons defines the beginning of the Cambrian Period from 570 million years ago. The Cambrian seas were teeming with invertebrate life. All of the major invertebrate phyla were present in the Cambrian. Primitive algae and variety of seaweed were grazed on by worms, trilobites, and gastropods which were in turn predated upon by carnivorous trilobites, cephalopods (nautaloids), and gastropods (snails). Passage into the Cambrian saw an increase in biodiversity and in numbers of individuals. This became a "self-feeding" cycle of increasing biomass in the oceans. The marine environment was supporting an increasingly diverse biomass but there was no land based life (Ward, 1992). The Ordovician era saw a continued expansion on the diversity of life on earth. The invertebrates responded to predation pressures by developing increasingly complex exoskeletons. The lancelet, a chordate, foretold the coming of the jawless fishes in the Ordovician (Parker, 1990).

Fossil evidence of Cambrian life can be seen in Redstone Quarry. There is evidence of algal matts and worm borrows. Later in the Ordovician sequence, in the Crown Point Limestone, there are reef dwelling organisms including stromatoporoids, crinoids, brachiopods, corals and sponges and a variety of larger organisms such as cephalopods and gastropods. The increase in diversity of fossils is evident in the rocks. Some of the typical Ordovician fossils present at Lessor's Quarry are shown in Figure 5. Fossils from the Fisk Quarry Preserve are shown in Figure 6. The presence of fossils allows us to interpret the paleoecology of the rock units.

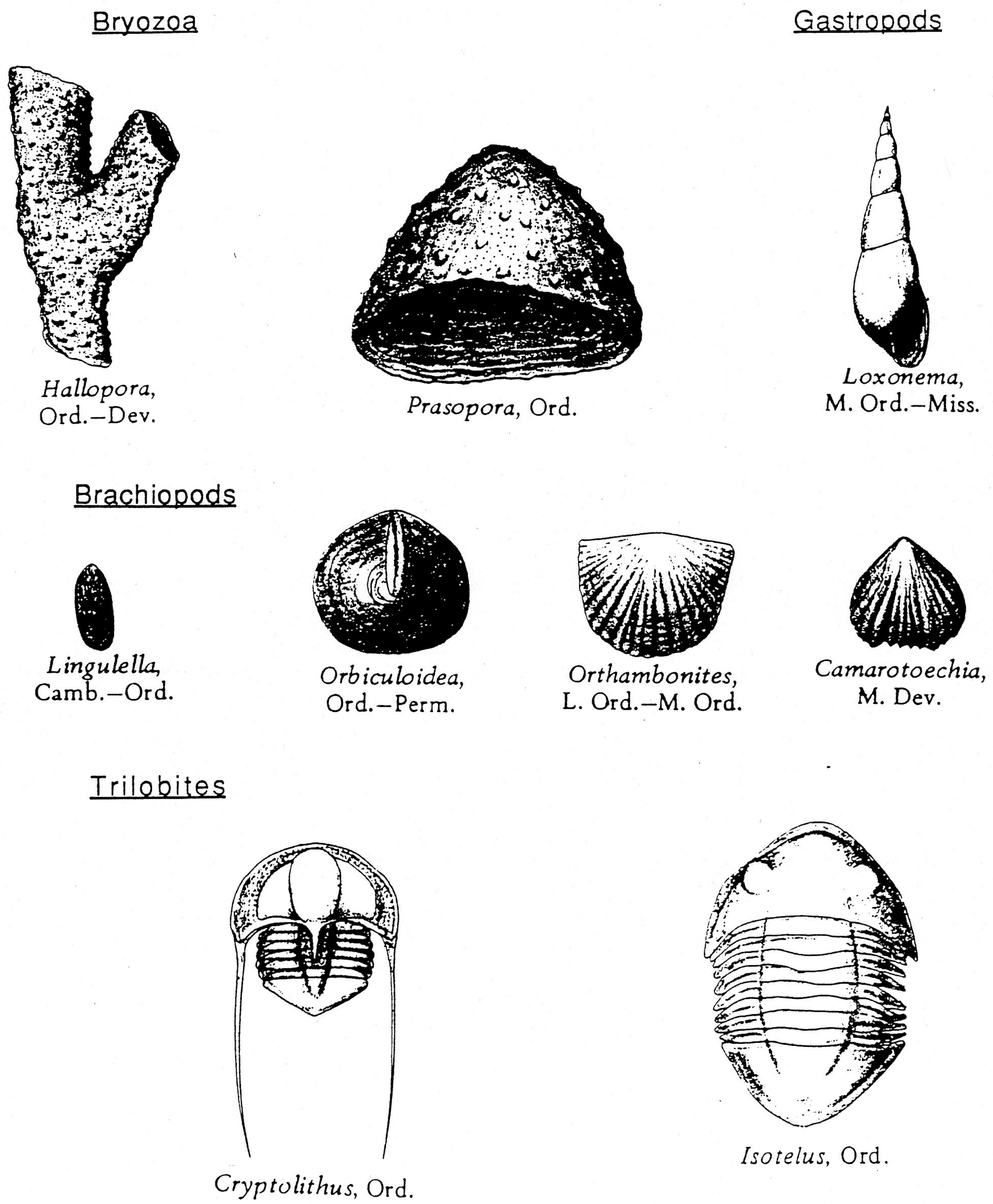
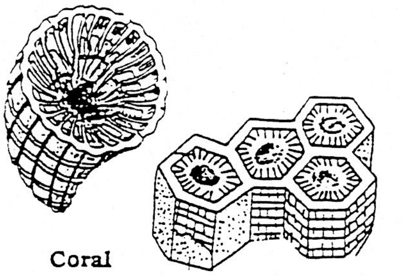
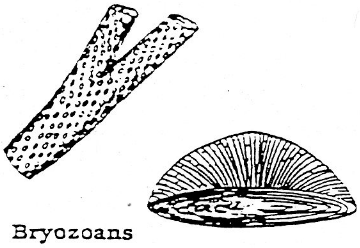


Figure 5. Typical fossils found at Lessor's Quarry, South Hero, Vermont (after Fletcher and Wiswall, 1987).



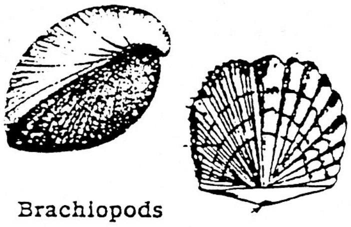
Coral

Corals are tiny flower-like animals that live in colonies. They are soft-bodied but secrete hard outer skeletons that form coral reefs. The fossils found in Vermont represent the first known species of coral.



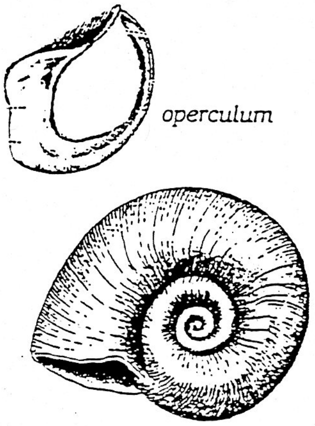
Bryozoans

Bryozoans are commonly called moss animals because of their appearance. Like coral, they are tiny soft-bodied animals that live in colonies. Each animal lives in its own chamber, giving the colony a honeycomb appearance. The most common bryozoan fossils here resemble twigs and gum drops.



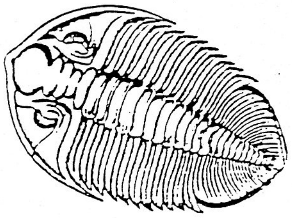
Brachiopods

Brachiopods are one of the easiest fossils to find. A brachiopod shell looks like a clamshell, but has a distinct ridge running down the center. There are no brachiopods living today.



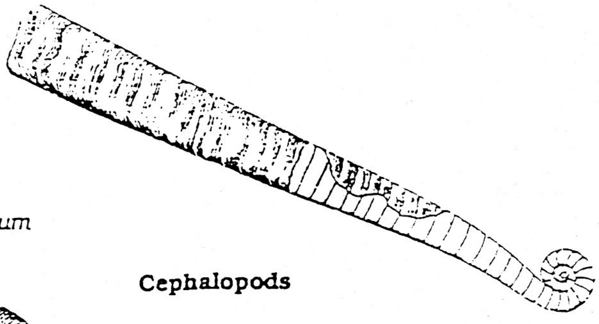
Gastropods

Gastropods or snails can be found in almost any habitat. All snails have a well-defined head with eyes and tentacles, a main body that houses the internal organs, and a foot. Many of the snail fossils of Lake Champlain are large. Sometimes all that remains is the operculum, a hard covering that protects the foot of the snail.



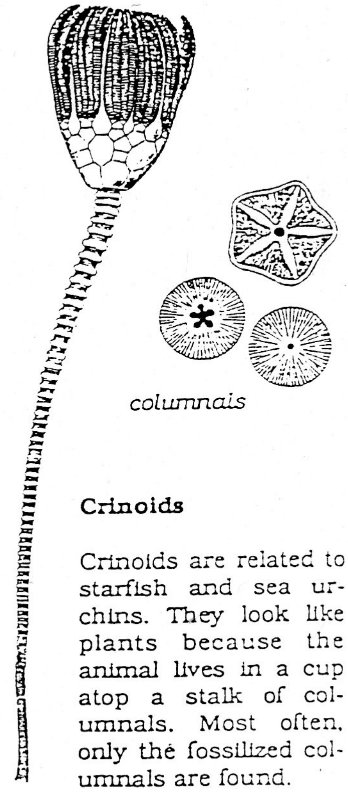
Trilobites

Trilobites, ancient lobster-like creatures, are true representatives of their time. They first appeared about 520 million years ago, reached their height about 440 million years ago, and were extinct 400 million years ago. Like lobsters and crabs, they shed their shell to grow, leaving behind many fragments to fossilize.



Cephalopods

Cephalopods are related to gastropods. Cephalopods lack feet and their shells are chambered. The cephalopods fossilized here are related to the chambered nautilus of today.



Crinoids

Crinoids are related to starfish and sea urchins. They look like plants because the animal lives in a cup atop a stalk of columnals. Most often, only the fossilized columnals are found.

Figure 6. Generalized list and description of typical fossils found in limestones of Western Vermont including the Fisk Quarry Preserve (after Perkins Museum, 1990).

Recent Geologic Change—Glaciations in Vermont

Within approximately the last 2 million years, during the Quaternary Period, over 40 glaciations occurred in North America, many covering the area of Vermont. We are still in the middle of the Quaternary Ice Age! Although we are currently in an "interglaciation," evidence of the most recent glaciation surrounds us in Vermont today.

The Most Recent Glacial Advance. During the last glacial event, ice advanced over New England as far south as Long Island and Nantucket Island, reaching the maximum extent approximately 21,000 years ago. Vermont was deeply buried in several kilometers of ice. The advancing ice entrained loose sediment and soil from the landscape and redeposited the sediment in hollows further to the south in the form of glacial till (unsorted material). In Vermont, we find glacial till whose origins are north and west, from New York and Canada. Sediment trapped in the ice acted like sandpaper on the local rock ledges and gouged out many glacial striations along the glacial flow paths. Most striations in Vermont trend NNW-SSE except in local valleys where existing topography controlled ice flow. Flowing ice followed the existing north-south contours of the New England landscape, flowing first through the valleys and then covering all of the mountain tops.

The weight of the ice caused isostatic depression of the landscape in New England. The asthenosphere below North America was able to "flow" out of the way as the "solid" rock of the North American lithosphere was pushed downward from the weight of the ice. Areas to the north experienced greater isostatic depression because the ice was thicker towards the center of the ice sheet in Canada.

Glacial Retreat. When the climate started warming 21,000 years ago, the toe, or terminus, of the continental glacier began retreating northward. Ice within the ice sheet still flowed south until the supply of new of ice material diminished in the north, however. By approximately 15,000 years ago, the southern parts of Vermont and the highest mountains were ice-free. As the ice melted, additional unsorted till deposits were laid down in Vermont along with individual glacial erratic boulders. In addition, melt-water streams emerging from the retreating glacier lobes reworked some of the till and sorted the sediment into outwash deposits. Meltwater ponded in front of the retreating glacier lobes in the form of pro-glacial lakes. Small pro-glacial lakes existed in the high mountainous regions of Vermont and environs, first in the south, and then later in the north as the ice retreated. Fine-grained lake sediments are found along with sandy deltaic deposits at elevations as high as 1,200 feet, recording the presence of these past glacial lakes in the upper reaches of the Winooski, Lamoille, and Missisquoi drainage networks, for example.

Lake Vermont. Although accurate dating is absent, limiting ages suggest that by approximately 13,000 years ago only the lowlands of the Champlain Valley and Connecticut Valley remained ice-covered. During continued ice retreat, large pro-glacial lakes formed in these valleys and were called, respectively, Lake Vermont and Lake Hitchcock. Both lakes drained to the south. In the Champlain Valley, icy Lake Vermont filled the lowland to an elevation of approximately 650 feet above modern sea level—or 550 feet above the modern Lake Champlain. Rivers from the surrounding ice-free mountains carried fine-grained silts and clays to Lake Vermont where slow settling occurred. Along the shore, sandy deltaic deposits formed at the mouths of entering streams. Now high and dry today, these deltas provide sand and gravel in the Champlain lowland.

Champlain Sea. Further northward retreat of the ice exposed the Champlain Lowland to the salt waters of the St. Lawrence Seaway. Marine water entered the Champlain Lowland because isostatic depression had lowered the land below sea level. The Champlain Sea was approximately 300 feet above sea level, or 200 feet above the modern Lake Champlain. Based on the dating of fossils found within the glacial marine clays and silts from the sea, the Champlain Sea existed in the lowland from approximately 12,500 to 10,000 years ago. Beluga whales also inhabited the Champlain Sea. The most famous beluga fossil remains are now the Vermont State Fossil—dubbed The Charlotte Whale—and are on display at the University of Vermont's Perkins Museum. The Champlain Sea was short-lived, and ended when isostatic rebound buoyed the land back up again. The ancient shorelines of both the Champlain Sea and Lake Vermont are now tilted on the modern landscape because the northern part of the basin has rebounded more. Deltaic sediments of the Champlain Sea are now high and dry and provide sand and gravel deposits for modern use, as well as an extensive area of flat landscape in Chittenden County—upon which the Burlington International Airport is built, among other things.

Lake Champlain. Currently, the fresh water of Lake Champlain drains to the north. Lake Champlain is modest in size compared with its ancestral beginnings. Evidence of the glacial lake and glacial marine sediments cover the valley floor of the Champlain lowland today, and provide fertile agricultural land for many farmers—part of the legacy left by the most recent glaciation.

ROAD LOG

Meet in the Perkins Geology Museum at the UVM Department of Geology at 8:30AM to pick up Perkins Museum educational resources. The Perkins Museum is located in Burlington off Colchester Avenue and next to the Fleming Museum. We will arrange carpools and depart at 8:45am. Bring a lunch. None of our stops have public facilities.

Mileage	
0.0	Start at the Museum. Leave Votey/Perkins parking lot by turning left (west) onto Pearl Street/Colchester Avenue (stay in the right lane).
0.4	Turn left onto Willard Street (Route 7) and travel to the end, about 1.25 miles.
1.6	Bear left (south) around rotary onto Shelburne Road (continuation of Route 7).
1.8	Turn left (east) onto Hoover Street (2nd left after rotary).
2.0	At the end of Hoover Street there is a parking area toward the right. Please do not park on the quarry floor.

STOP 1. REDSTONE QUARRY. (60 MINUTES)

Burlington, VT--7.5' Topographic Quadrangle

Redstone Quarry is located in Burlington, Vermont (Figure 7). Building stone was taken out of Redstone Quarry until the 1930's. As you travel through Burlington and visit the University of Vermont, you will notice that many foundations and buildings were built with this beautiful stone. Redstone Campus takes its name from the stone that many buildings and fences were constructed with. The quarry is currently owned by the University of Vermont and is classified as a Natural Area. Because of this classification, you are not allowed to remove any biotic or abiotic material from the area. Hammers are not allowed. To visit the quarry please contact:

Richard Paradis, Natural Areas Manager
Environmental Program,
151 South Prospect Street,
University of Vermont,
Burlington, VT 05405
(802) 656-4055, rparadis@zoo.uvm.edu

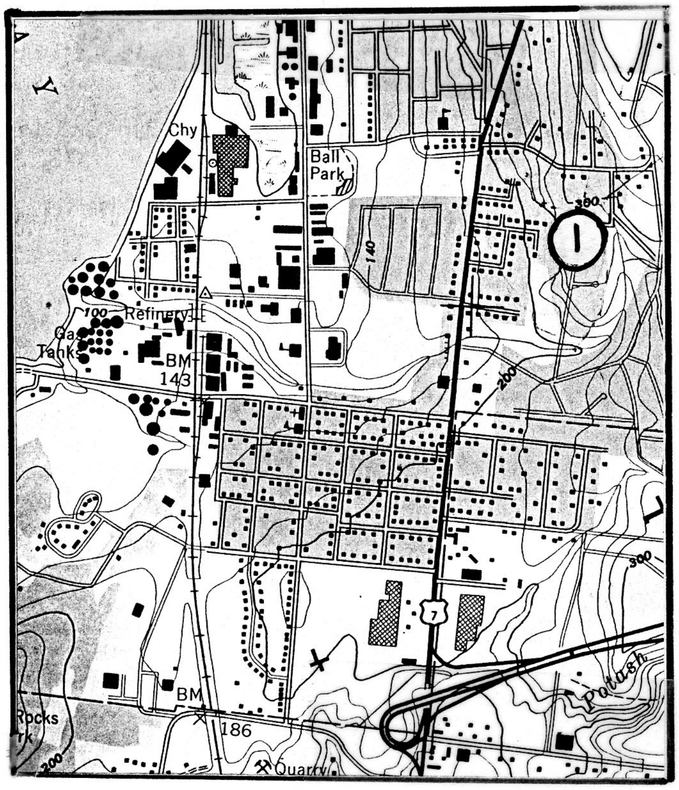


Figure 7. Location map for Redstone Quarry (1). Scale is 1:24,000 and contour interval is 20 feet.

Rock Type and Composition

The Monkton Quartzite Formation is a slightly metamorphosed sandstone and consists of two distinctive units. The lower, older unit is white quartzite inter-bedded with layers of dolostone and is found from Vergennes to Shelburne Bay. This rock unit may have been deposited below low tide to the intertidal zone. The rock that we see exposed at Redstone Quarry is the upper part of the Monkton Quartzite. The upper, younger unit is composed of quartz sand that ranges from pink to purple. Most of the sand is made of quartz and feldspar with small amounts of calcite ($CaCO_3$). The red color is due to iron oxides (mostly hematite) in clay coatings around the grains. The material is mostly coarse to medium grained sand with some silt and/or thin layers of clay. The quartz and feldspar sediments at Redstone Quarry are very mature, well rounded and of fairly uniform size. The sand is "clean" with little clay in it. This part of the Monkton Quartzite has many very thin layers of clay material draped on top of the quartz layers. This suggests that the red Monkton was formed in the intertidal zone.

Depositional Environment

Sedimentary features present include rippled sands, burrows, and scour channels. The sediments that form the Monkton Quartzite were deposited early in the Cambrian Period between 600 and 500 million years ago. The source rock was the Ancient Adirondack Mountains which were much higher during the Cambrian period. Rivers washed sediments from the flanks of the mountains to the shore of the shallow Iapetus Ocean to the east. At the time of deposition, the area which eventually became what is now Redstone Quarry was approximately 60-80 km (35-50 miles) to the east of its present location (Stanley, 1987).

The Monkton Quartzite rocks reflect a near-shore, stable continental shelf environment. Many invertebrate phyla were present in this shelf environment in the Cambrian Period. All of these organisms were aquatic, and lived in and on oceanic sediments. Geologists find evidence of trilobites, algal matts, and a variety of worms in the Monkton Quartzite.

Structure

The Cambrian rocks in western Vermont follow a north-south trending belt. The quarry is located on the west flank of a south plunging synclinal (concave) fold. This fold is the result of continental collision. Since the quarry is on the west flank of this fold, the beds (layers) all tilt to the east. There are many fractures visible on the quarry floor. They appear to be in four orientations. These fractures probably formed in one or both of two collision events, the Taconic (450 mya) and Acadian (360 mya) orogenies. There are basalt dikes associated with several orientations of fractures suggesting age differentiation of the fractures.

There is one large basalt dike that crosses the quarry floor. Outcrop of the dike can be found on the east wall and the western edge of the quarry. This dike is no longer clearly visible on the quarry floor but can be traced via the "no chive zone." This area is preferentially weathered and an area where chives do not grow.

The second type of fracture found in the quarry is radial in nature. These are artifacts of blasting associated with mining operations. They can be seen on the quarry floor as a radial fracture pattern or on the quarry walls at the bottom of bore holes.

Mileage

2.1	At the bottom of Hoover Street, turn right (north) onto Shelburne Road (Route 7). Stay in the left lane.
2.3	At the rotary, proceed left towards downtown Burlington on the main road.
3.1	Turn left (west) onto Maple Street at stop sign.
3.3	Turn right (north) onto Battery Street (last street before lakefront buildings). Follow Battery Street up the hill to Battery Park in Burlington.

3.9 Follow Battery Street left around park and bear right (north) onto North Avenue at the Police Station (@4.0 mile marker).
5.2 Turn left (west) onto Institute Road (at top of hill) and go past Burlington High School.
5.4 Turn right (north) between stone pillars into the Rock Point School driveway.
5.6 Park in the Diocese parking lot on right (past baseball diamond). We will pick up a grounds pass in the office here. We will be walking approximately 20-30 minutes along private roads and hiking trails down to the shore of Lake Champlain. Please respect the homes and yards of the people who live here by staying on the trails!

Bring your lunch, if you like.

STOP 2. LONE ROCK POINT. (120 minutes including hike to outcrop and back)
Burlington, VT--7.5' Topographic Quadrangle

Lone Rock Point is owned by the Episcopal Diocese of Vermont and is located in Burlington, Vermont (Figure 8). One of the most spectacularly preserved thrust faults in the world is preserved along the shore of Lake Champlain at this site. Hammers are not allowed. The property is also the site of the Diocesan offices, the Rock Point School, the Bishop Booth Conference Center, and several private homes. A naturalist works on the site and can often answer questions about your observations along the many nature trails on this private property. Prior permission for use of Lone Rock Point is absolutely necessary and visitors are required to carry a grounds pass with them at all times during their visit. Passes may be picked up at the Diocese office. To visit Lone Rock Point, please contact:

The Diocese of Vermont
5 Rock Point Road
Burlington, VT 05401
(802) 863-3431

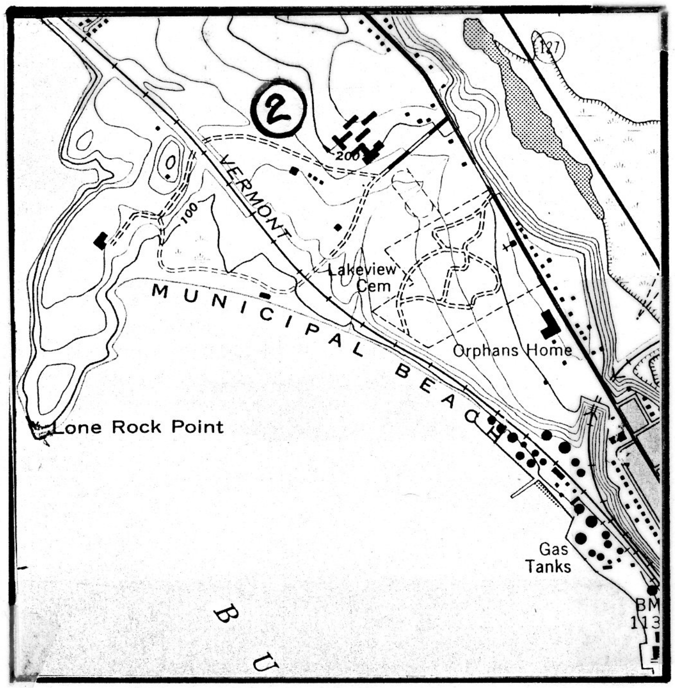


Figure 8. Location map for Lone Rock Point (2). Scale is 1:24,000 and contour interval is 20 feet.

Rock type and composition

The Champlain Thrust Fault at Lone Rock Point is located on the eastern shore of Lake Champlain just north of Burlington. The Champlain Thrust Fault may be part of a larger grouping of fault zones which extend almost 200 miles in length from New York through Vermont into Canada (Stanley, 1987). In Vermont, the thrust fault displaces older Cambrian rocks over younger Ordovician rocks in a west-over-east manner. At Lone Rock Point a spectacular display of the thrust fault is exposed with the basal section of the Dunham Dolostone (approximately 550 million years old) overlying the Iberville Shale (approximately 420 million years old).

Dolostone is made of the mineral dolomite ($CaMg(CO_3)_2$), and is closely related to another common carbonate rock, limestone, composed of calcite $CaCO_3$. This buff to pink-colored dolostone weathers in a blocky fashion and large blocks of dolostone litter the beach. Dolostone is relatively hard and acts as a resistant cover-rock over the softer, underlying Iberville Shale. The dolostone lies stratigraphically 2,700 meters (8,850 feet) below the shale (Figure 4). The thrust fault has moved the older dolostone at an angle of 10-20 degrees, 60-80 km (35-50 miles) westward from its original location (where the Green Mountains are now) up and over the younger shale (Stanley, 1987). The sedimentary units above the Dunham Dolostone (including perhaps the Iberville Shale) likely moved with it and have long been eroded away.

Shale is composed of fine-grained silt and clay particles cemented together. The charcoal to black-colored Iberville Shale breaks apart easily along planes of weakness called cleavage, and weathers typically into small planar stones. The shale was metamorphosed and contorted (small folds are visible) during the actual thrusting process. Deformation along the thrust fault was primarily taken up within the more pliable shale rather than the more competent dolostone. The cleavage patterns in the shale suggest that motion along the Champlain Thrust occurred both during the Taconic collision event (450 mya) and the Acadian collision event (360 mya). The fault has not been active since. Abundant white calcite veins (soft and react with dilute hydrochloric acid) are found within the shale and likely stem from dissolution and re-precipitation of calcite from other sources.

Depositional Environment

Some dolostones are formed in shallow marine waters by direct precipitation of ($CaMg(CO_3)_2$). Most dolostones were originally limestones and are products of alteration of $CaCO_3$ whereby some of the calcium is replaced by magnesium from circulating ground waters. By contrast, shales are fine-grained, clastic, sediments that settle slowly into deep-water basins. The fine-grained sediments may be cemented with carbonate or other binding agents. The Iberville Shale does not contain carbonate cement. However, secondary deposition of carbonate can be found in fractures. The Ordovician Iberville Shale, which lies stratigraphically above the Cambrian Dunham Dolostone by almost 130 million years, highlights the deepening of the Iapetus Ocean as a trench formed.

Mileage	
5.9	At Rock Point entrance turn left (east) onto Institute Road.
6.1	Turn left (north) on North Avenue.
6.5	Turn right onto Route 127 (entrance ramp) and take Rte. 127 North towards Mallet's Bay. Stay on Rte. 127 (turns into Prim Road @ 10.5 mile marker).
11.5	Turn right onto West Lakeshore Drive at the Harborview Plaza (still Rte. 127). Follow Rte. 127 North (becomes Blakely Road) over freeway to its end at Route 2 and Route 7 junction.
15.3	Turn left (north) on Route 2 West (Rte. 7 N) towards Milton.
19.8	Turn left (west) on Route 2 West towards the Champlain Islands. Go over causeway onto South Hero Island. Watch for pedestrian traffic on South Hero! Continue on Rte 2 W past Apple Farm Market @ 28.4 mile marker.
29.5	Turn left (southwest) onto Sunset View Road (dirt road).
30.1	Turn left on private dirt driveway (mailbox #65, Grimes residence) at power lines.
30.3	Turn left into quarry. Do not block private driveway!

STOP 3. LESSOR'S QUARRY (60 MINUTES) South Hero, VT--7.5' Topographic Quadrangle

Lessor's Quarry is located in South Hero, Vermont (Figure 9). The quarry is currently owned by the University of Vermont and is maintained by the Geology Department for educational purposes. Please make a reservation for class use so as not to conflict with UVM Geology course use. You are not allowed to remove any fossil material from the area without prior permission. Hammers are not allowed. Please stay on the quarry floor and work safely at all times. Parking is permitted only inside the quarry and not on the access road, which is a private driveway. Because of potential driveway damage, visits to Lessor's Quarry are not allowed during the winter and spring mud season. To visit Lessor's Quarry at other times, please contact:

The Perkins Museum
Geology Department,
University of Vermont
Burlington, VT 05405-0122
(802) 656-8694

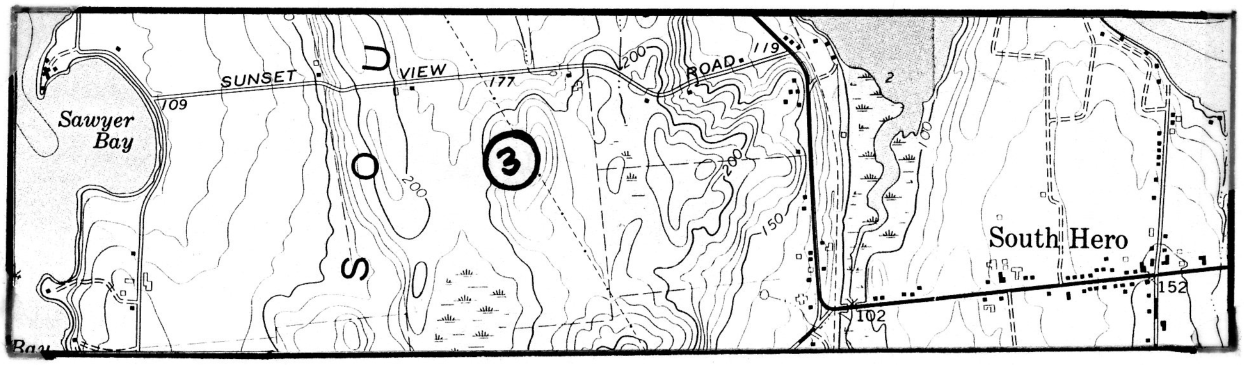


Figure 9. Location map for Lessor's Quarry (3). Scale is 1:24,000 and contour interval is 10 feet.

Rock Type and Composition

Lessor's Quarry is located in Ordovician limestone which is about 450 million years old. The quarry is in the Shoreham member of the Glens Falls Formation. The Shoreham member is made of thin layers of dark blue-gray limestones with fossils and occasional thin layers of darker shale. Bedding ranges from less than one foot to more than eighteen inches.

Depositional Environment

The environment for the formation of limestones requires that the climate is warm and shallow enough to support carbonate secreting organisms as well as inorganic precipitation of calcium carbonate directly from the sea water. In the Glens Falls Formation those organisms included bryozoa, brachiopods, mollusks, and echinoderms. The sediments are composed of the skeletal debris of organic origin and inorganic calcareous precipitates (Skinner, 1989).

The Glens Falls Formation may be the most fossiliferous formation of those in the Champlain Valley. Nearly all outcrops of the Glens Falls have fossils in them. The gum-drop shaped bryozoa *Prasopora* and the trilobite *Cryptolithus tesselatus* are common and considered to be index fossils for the Shoreham member (Welby, 1962). In addition there are other phyla present including other bryozoa and brachiopods. Occasionally the bryozoa Prasopora is found in the same position it was in during life. This is a good indication of the direction of "up" especially in the boulder size rubble on the quarry floor. In other areas, fossil fragments deposited in layers represent remains having been concentrated into layers by wave and current action transporting dead organisms from shallow water environments. When many bits of fossils are deposited in a layer, it is sometimes referred to as "fossil hash." In some cases at Lessor's Quarry, fining-upward sequences of fossil hash may indicate turbidite deposits composed of fossil material.

Faulting

Two types of faulting are seen in the quarry walls and reflect large scale regional patterns. There is a low angle thrust fault exposed on the north wall of the quarry. This probably formed at the same time as the Champlain Thrust (Taconic and Acadian Orogenies) seen in Stop 2. Quartz and calcite vein fillings are common, with some veins containing well formed crystals. Slickenlines indicate an E-W motion for the thrust fault. High angle faults on the south wall of the quarry were most likely active during the Mesozoic (240 to 65 mya). None of the faults are active now.

Mileage

30.5	Turn right at end of driveway back onto Sunset View Road.
31.1	Turn left (north) onto Route 2 West. Follow Rte. 2 to North Hero Island. Cross over a bridge @ 48.6 mile marker.
49.0	Turn left (west) onto Route 129 West towards Isle La Motte.

51.7	Turn left (west) onto causeway over to Isle La Motte. Stay on Rte. 129, past junction @52.8 mile marker and through the village of Isle La Motte. Travel until pavement ends.
56.9	Bear right onto dirt road (West Shore Road).
57.9	Park on right side at the Fisk Quarry Preserve lot.

STOP 4. FISK QUARRY PRESERVE. (60 MINUTES) North Hero, VT--7.5' Topographic Quadrangle

The Fisk Quarry Preserve lies on the western edge of Isle La Motte, Vermont (Figure 10). The quarry is maintained as a preservation area and the removal of plants, fossils, and rocks is not allowed. No hammers are allowed. The Fisk Quarry Preserve has a large interpretive sign at the main viewing area and a small trail which leads to more accessible areas of the quarry. Several quarries on Isle La Motte including the Fisk Quarry were quarried for a dark gray limestone used in the building stone industry. Vermont's State House in Montpelier has Isle La Motte stone used in the "black" floor tiles on the main floor lobby—an interesting place to fossil hunt! To visit the Fisk Quarry Preserve, please contact:

Linda Fitch
44 West Shore Road
Isle La Motte, VT 05463
(802) 928-3364

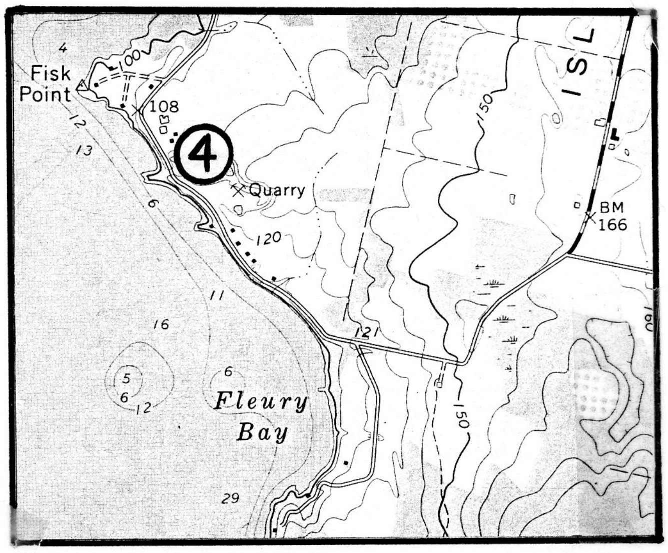


Figure 10. Location map for Fisk Quarry Preserve (4). Scale is 1:24,000 and contour interval is 10 feet.

Rock Type and Composition

The Fisk Quarry Preserve shows part of the Chazy reef ecosystem preserved in the Crown Point Limestone. This quarry is significant because the fossil remains here are some of the oldest preserved reef materials on the planet. Other limestones on Isle La Motte including the Day Point and Valcour Formations show other parts of this 480 million year old reef ecosystem (Figure 11). The Crown Point Formation at the Fisk Quarry Preserve is a dark gray, fossiliferous limestone made of fine-grained carbonate ($CaCO_3$) sediment and stromatoporoid mounds. Dramatic vertical slices through the stromatoporoid mound structures can be seen on the far quarry walls. Fossil gastropods *(Maclurites magnus)* and cephalopods are easily visible on horizontal surfaces of the quarry. Other less obvious fossils include crinoids and brachiopods.

Depositional Environment

Stromatoporoids are mounds of laminated carbonate made by sponge or coral-like animals growing in shallow, warm oceans. At other times in the development of the Chazy Reef, different organisms such as bryozoa or coral, provided the dominant mound framework in the reef (Figure 12). The mound structures of the reef are now connected to each other because carbonate sediments filled in the gaps. A reef composed of vertically-growing mounds has a very different structure than "typical" reefs which contain laterally continuous reef-building organisms.

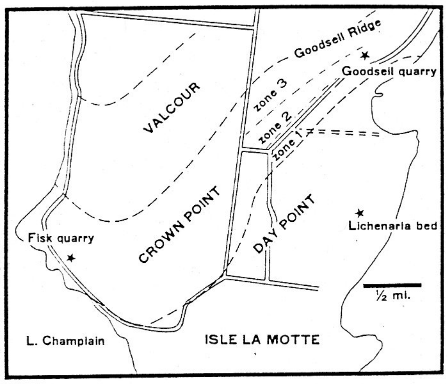


Figure 11. Limestones on southern Isle La Motte (Kapp and Stearn, 1975).

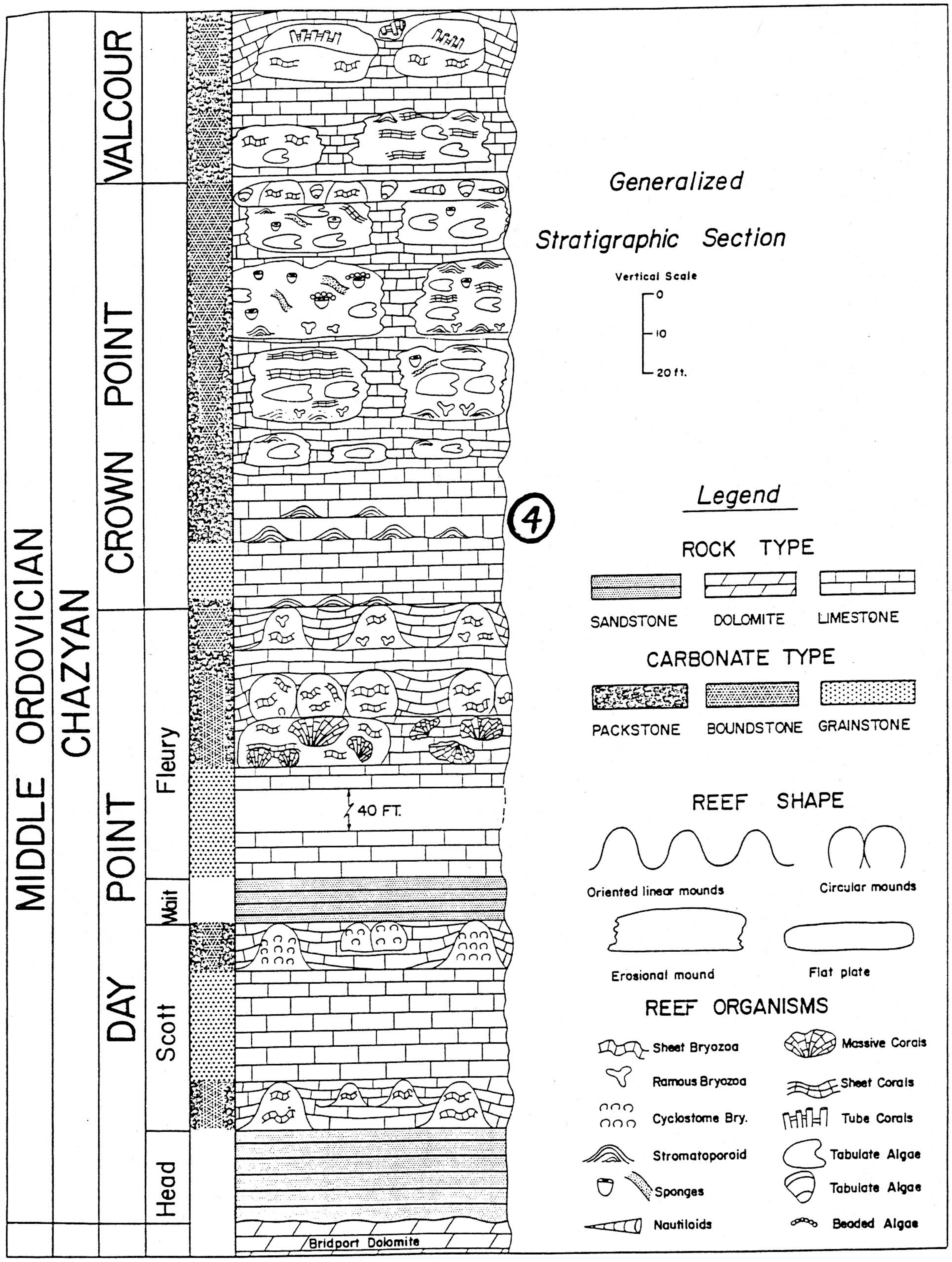


Figure 12. Generalized stratigraphic section of Chazyan limestones showing reef types (Pitcher, 1964).

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