GEOLOGY OF VERMONT

Brewster Baldwin
Middlebury College
Middlebury, VT 05753

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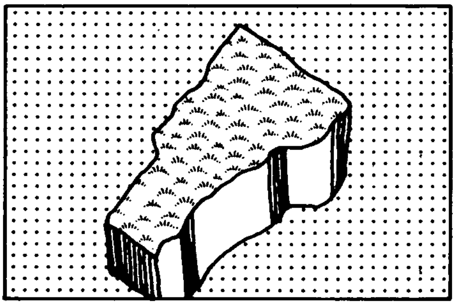
Vermont is a very small state, but its geology is remarkable in variety and character. The surficial geology is the story of deglaciation, and the bedrock evolution is the result of the opening and closing of an ancient proto-Atlantic Ocean.

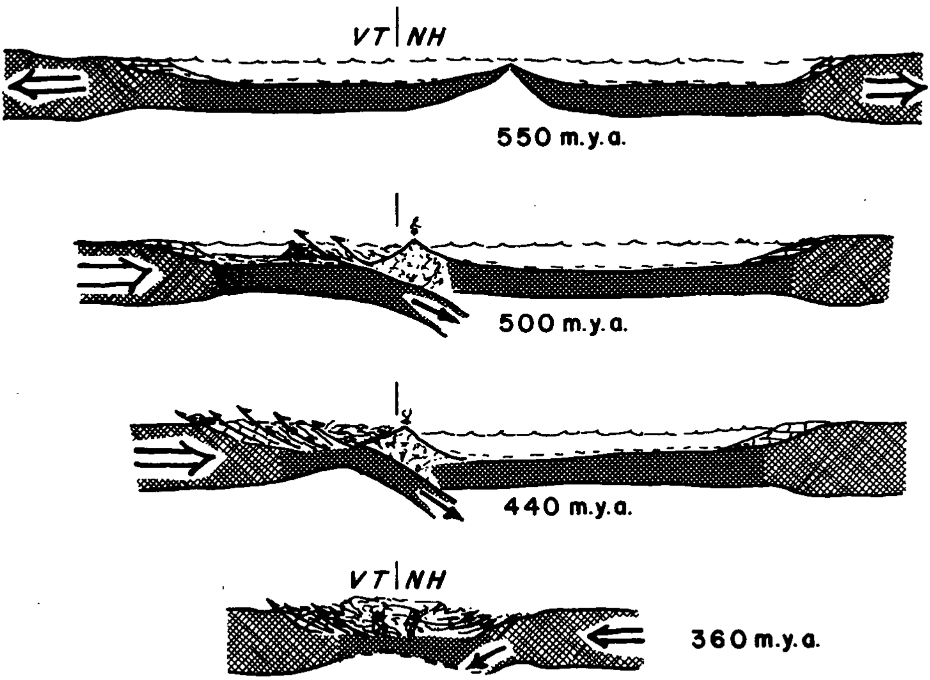
Pleistocene ice sheets covered Vermont more than once. The last ice sheet moved south to Long Island about 75,000 years ago, and by 17,000 years ago it was melting northward faster than the ice itself was oozing south. By 13,000 years ago the ice had largely melted from the mountains of Vermont, but one lobe remained in the Champlain Valley. Weight of the ice had depressed the crust so that ancient Lake Vermont formed against the south end of the lobe. The lake drained south into the Hudson Valley and extended across the Champlain Valley from the Green Mountains on the east to the Adirondacks on the west. Now many active sand and gravel pits are being worked in the discontinuous bench that was formed along the Green Mountain front by meltwater flowing into Lake Vermont. Farther west, away from the shore, clay deposits covered the lake floor.

About 12,000 years ago, the ice lobe melted north to the St Lawrence lowlands, and the lake drained. For a short time, the level may have dropped below the present level of Lake Champlain. However, as meltwater from the continents flowed back into the oceans, sea level rose and water flooded back to form the 'Champlain Sea'. A whale skeleton in the University of Vermont geology museum testifies to that, as do microfossils in the clays.



The sea lasted until about 10,300 years ago, after which it was cut off by glacial rebound. That tilted the shoreline features (water planes), which rise northward. Relicts of Lake Vermont's shoreline are about 160 m above sea level at the same latitude as Middlebury, and about 210 m at the Canadian border. The water plane of the Champlain Sea also rises northward. At the latitude of Middlebury, the features are about 30 m above the present level of Lake Champlain, or about 60 m above present sea level. The sea water has been flushed out and a rock-ledge barrier has risen to form the outlet at the north end of Lake Champlain, just north of Vermont.

Bedrock geology is a different—and older—story. The proto-Atlantic ocean began opening about 700 million years ago, and sediments and volcanic materials accumulated on the continental margin and ocean floor. Plate motion reversed and the ocean began closing, perhaps in Cambrian time (570-500 million years ago). Late in the Ordovician, about 440 million years ago, the continent collided with the volcanic arc that lay to the east; that was the Taconic orogeny. (Orogeny is mountain formation from structural disturbance of Earth's crust, especially by folding and faulting. The Taconic orogeny is named for the Taconic Range of eastern New York.) By mid-Devonian time, about 360 million years ago, the ocean beyond that arc had closed, so that the continents collided, in what we call the Acadian orogeny.



The cross-sections show the opening and closing of the proto-Atlantic Ocean.

This cross-section illustrates the subsurface geology between Burlington and St Johnsbury.

When publication of the *Centennial geologic map of Vermont* was celebrated at a meeting in 1961, one geologist commented that the map indeed was accurate in showing the kinds of rock and where they occur, but he was not so sure about the stratigraphic interpretation—the age relations of one unit to another. We have only recently come to suspect that the sequence of successively 'younger' formations mapped east of the Green Mountains is not depositional but, rather, a series of fault slices of rocks that are about the same age.

Precambrian basement rocks are exposed in the Green Mountains, and also in domes south of Chester, just east of the Green Mountain axis. The Precambrian gneiss, schist, and marble were formed in an earlier stage of geologic evolution. They are more than 1 billion years old and are related to rocks found in the Adirondacks.

About 2 km of limestones, dolostones, and quartzites are seen in the Champlain Valley, and they accumulated on a continental shelf in the Cambrian and Ordovician periods. The setting was like today's warm shallow water of the Bahama platform, and most of the beds are carbonate rocks. However, erosion of an area to the west provided quartz sand that forms several formations. Each one spread across the shelf when a temporary drop in sea level caused the shoreline to move eastward. The east edge of the shelf was just east of the Green Mountain front. Late in the Ordovician, a thick (1,400 m) section of shale was deposited on the shallow-water shelf sediments, signalling a change in tectonism.

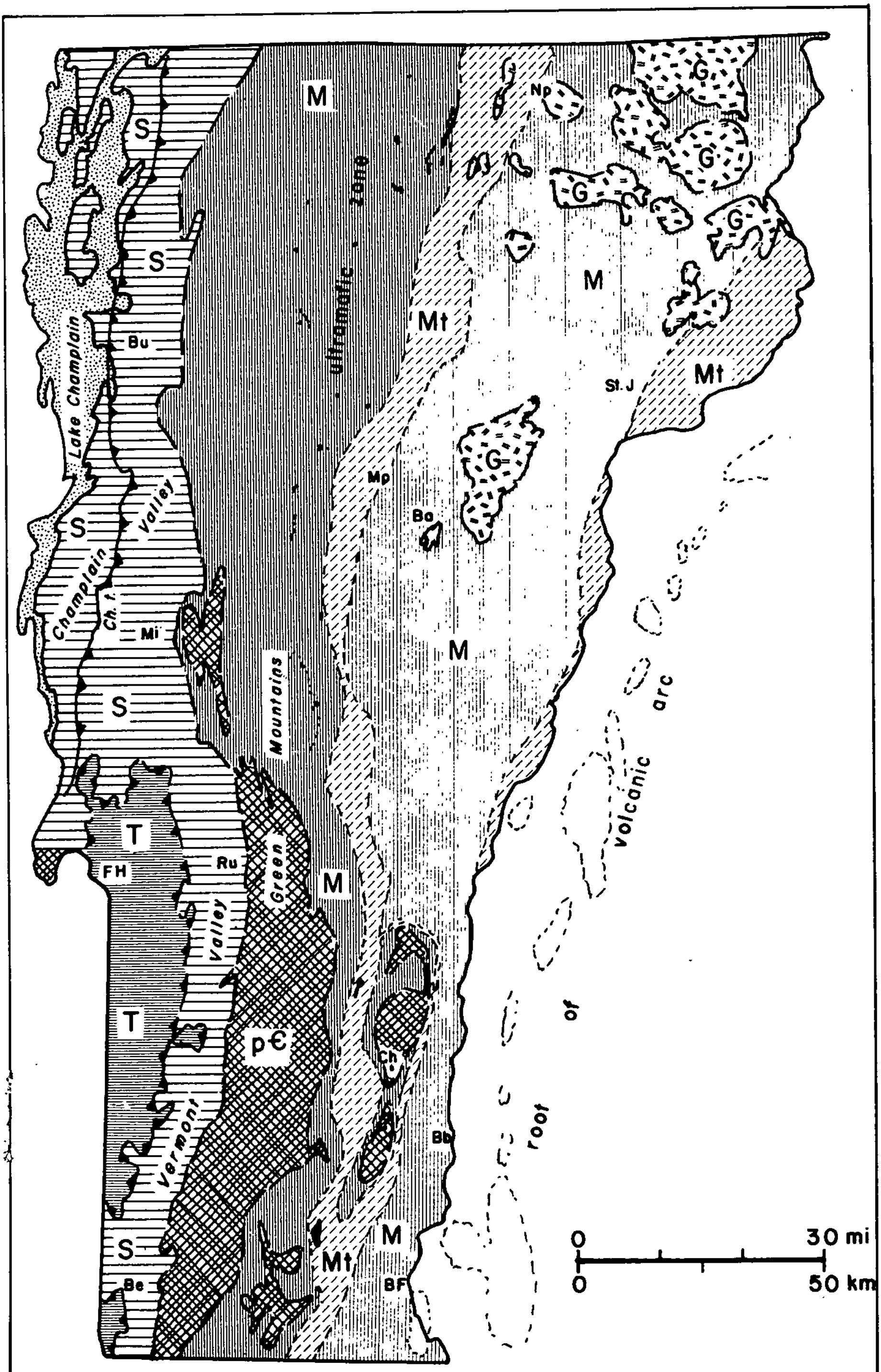
The continental shelf sediments are now folded, sheared, and cut by several thrust faults. That includes the Champlain thrust. The 'Eastern Overthrust Belt' is being explored by deep seismic profiling. In 1980, the Cocorp research project, out of Cornell University, made profiles across Vermont, and some profiles are being run this year by companies searching for gas. Tentative results suggest greater thrusting than previously thought. Perhaps less-deformed sediments underlie deep thrusts and contain reserves of natural gas.

As for other mineral resources, one formation consists of marble that is being quarried for building stone and for calcite powder. The limestone, dolostone, and quartzite have all been used in building, well displayed on the campuses of Middlebury College and the University of Vermont, Burlington.

South of Middlebury, the folded strata of the continental shelf are buried beneath a thrust mass of green and black slate and schist about 1 km thick. The rocks now form the Taconic Mountains of southwest Vermont and supply green and purple slate from quarries near Fair Haven, where outcrops show turbidites with quartz and carbonate grains derived from the shelf. The rocks are the same geologic age as those of the continental shelf and must have been deep-water sediments that accumulated very slowly at the base of the continental slope.

North-trending belts of schist make up central and eastern Vermont. The schists are greenish (with chlorite and amphibole) or dark grey (from graphite). Schists west of the transition belt are late Precambrian to mid-Ordovician (640?-440 million years ago) in age; they are exposed in deep roadcuts of Interstate 89 from Burlington southeast to Montpelier. Most of the rocks were probably sands and muds from a continental source, but some were basaltic flows. From Montpelier east, almost to the Connecticut River, the schists are Silurian to Early Devonian (435-380 mil-

These 5 main groups of rock record Vermont's geologic history. Interpretations here reflect the growing understanding of environments of sediment deposition, geochemistry of the rocks, and deep structure, all in the context of plate tectonics. Symbols: p€ = Precambrian basement rocks. Ch = Chester. G = granite. S = shelf sediments. Mi = Middlebury College. UVM = University of Vermont. Bu = Burlington. T = Taconic allochthon. FH = Fair Haven. M = schists. Mp = Montpelier. Ch.t. = Champlain Thrust. Mt: transition


M
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G
G
G
G
ultramafic zone
M
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Lake Champlain
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lion years ago) in age. The muds had evidently been deposited in the fairly shallow ocean between the continent and arc after the collision.

In central Vermont, many tiny lenses of serpentinized ultramafic rocks yield talc, soapstone, asbestos, and verde antique. These lenses form a zone that trends north to the large asbestos deposits of Thetford Mines in Quebec. Those mines are in a huge mass of ultramafic rock. Along with associated pillow basalts and ocean-floor cherts and argillites, the rocks constitute a flake of ancient ocean crust, now emplaced on the margin of an ancient continent. Almost certainly the tiny ultramafic lenses in Vermont also occur as fault slices; that is consistent with faults now being recognized and mapped in the schists.

The line of gneiss domes in New Hampshire, just east of the Connecticut River, is evidently the root of a former volcanic arc associated with subduction. The location of the arc, and the occurrence of ultramafics farther west, suggest that the subduction zone dipped east (not west, as had been suggested in early reports of plate tectonics and the Appalachians).

As the ocean closed and the ocean crust was subducted, the sediments and pieces of ocean crust were caught and stacked into an accreting wedge. The several schist belts were probably about the same age, but had been deposited on different parts of the ocean floor.

By mid-Ordovician time, about 450 million years ago, the east edge of the continent reached the trench and began to subside rapidly, and thick shale was deposited. (The modern analog is the Australian platform, which is rapidly subsiding as it enters the trench by Timor, so that shallow-water mid-Pliocene limestone is now down 2.7 km!) At the same time, the continental margin started to wedge beneath the 'pre-assembled' stack of schist belts, which therefore became emplaced on and against the continental margin. As noted above, the Taconic allocthon was emplaced on the folded and sheared continental shelf sediments. The collision with the arc probably caused movement on the Champlain thrust and faulting of the Precambrian basement. Sediments and volcanics of the transition zone probably formed during the collision. Events associated with the continent-arc collision, in the last 15 million years of the Ordovician, constitute the Taconic orogeny.

We have found no record after that until about mid-Silurian (about 415 million years ago); probably the post-collision uplift made it a source area for sediments shed westward into New York. From Montpelier east, the rocks are mid-Silurian to mid-Devonian dark grey schists with some limestones that accumulated between the continental margin and arc. In New Hampshire, similar rocks were evidently deposited east of the arc, in the remaining ocean. Rocks in southeast New Hampshire and the Boston area are continental basement that had been on the far side of the proto-Atlantic ocean.

The sediments were folded and metamorphosed in the Acadian orogeny of Middle and Late Devonian age, due to collision of the continents. In southern Vermont the closure was extreme, and the formations were stretched to thin belts.

Grey granite bodies intruded the Silurian and Devonian schists in northeast Vermont; the deep quarries at Barre are famous for the quality of stone. The granite magmas were probably from melting of deeply buried sediments during collision of the continents. Erosion of the resulting uplift supplied red alluvial and shore-zone sediments that are now exposed in the Catskill Mountains of New York.

Vermont geology gives glimpses of post-Devonian history, but that record is better seen in other parts of New England. Some structures and small igneous intrusions are related to the opening of the present Atlantic Ocean, and some are related to the White Mountain magma series of New Hampshire.

Brewster Baldwin
Department of Geology, Middlebury College, Middlebury, Vt., 05753