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# Henry's Land

Paul R. Bierman

Henry Moultroup is a 70-something Vermont farmer with two new hips and a well-used backhoe, a yellow, 1980-something, Extenda-hoe. He's a soft-spoken man with keen eyes, strong wrinkled hands, and many jobs. When Henry's not cutting trees, moving earth, boiling maple sap, or minding the cows, he's collecting back taxes for the town of Huntington.

Henry and his wife and three of his sons live on and from several hundred acres of rolling land in northwestern Vermont. They are Huntington Valley people. Their house sits on one side of the Huntington Road. Their barn sits on the other. Both sit on a terrace of the Huntington River, a flat stretch of land where the river once flowed, where cows have probably wandered for a hundred summers, and where Henry knows the backhoe will dig through ten feet of river gravel before he'll hit dense blue clay and water.

Theirs is both an old and a young landscape. When you walk the hills behind Henry's home, there is dull, wet, mossy gray schist that shines if you break it. The schist was mud once, just a half-billion years ago, mud at the bottom of a now-vanished ocean. Colliding continents compressed the mud, expelled much of the water, and buried the bits of silt and clay many miles down. At such depths, the rocks were slowly warmed by Earth's internal heat. What was once mud is now rock. As the rocks were heated, minerals stable at Earth's surface became unstable. New minerals grew at the expense of old, aligned in response to the motions of great tectonic plates and the weight of overlying material.

The rock developed a foliation—an alignment of minerals, mostly shiny mica. Now, several hundred million years later, it is the orientation of this foliation that dictates the location of Vermont's Green Mountains. Not only are the mountain ridges of today the result of a continental squeeze 400 million years ago, but the same squeeze helps determine where the groundwater flows and where it doesn't. Mica weathers easily in the humid Northeast, providing a means for water to enter the rock. More water means more weathering. More weathering means more water can enter the rock and so on.

The rock we see at the surface today isn't solid. It is riddled with joints—fractures that resulted from millions of years of tectonic squeezing. These joints are widest at the surface and tend to close up at depth. They are the conduits through which much of our groundwater moves. If you look at photographs taken from airplanes, the same photos used to make topographic contour maps, you can see these joints in the schist. You can trace their pattern across the landscape. Where you see two fractures cross, that is the place to go looking for water.

In Vermont, a rural state, most of the land isn't serviced by public water supplies. Fracture tracing is big business; so is dowsing. The schist is mica-rock to the local well drillers who collect nine dollars for every foot of it they drill in search of water. Often they collect for many feet: two hundred, three hundred, four hundred feet. Water can be surprisingly difficult to find in the hills of Vermont if you do not hit the right fracture.

Drill, come up dry. Dowse, trace fractures, drill again, and if you are lucky, find a quart of water dripping each minute into three thousand dollars of well. Maybe then hydrofrac, using tons of force to split the rock deep below the surface with the hope that fractures will open and allow just enough water to seep into the well bore. With luck, half a gallon a minute will fill a 6-inch wide, 400-foot puncture in a state where 30 to 40 inches of rain and snow falls from the sky almost every year. But it doesn't have to be this difficult. A trip to Waterbury, 20 miles down the interstate, will put you face to face with forty-some-thousand well logs, descriptions of just about every well drilled into Vermont since the early 1980s. You can view them town by town. If you are lucky, you can find the well from which you drink. See how deep it is. See what the driller saw as the rig churned. In all likelihood, you'll also see just how many feet of steel pipe go down from your backyard to the bedrock below.

Geology students from the University of Vermont look at these well records every year: sometimes for classes, sometimes for projects, sometimes just out of curiosity. Every one returns to Burlington surprised. Seventy, eighty, ninety percent of wells in most towns are drilled into rock that gives up its water grudgingly, a quart each minute, maybe a half gallon. But sometimes, just next door to a nearly dry hole is a well that didn't go so deep, a well that the driller stopped in gravel, never pushed on to the rock, cost its owner far less and gives its owner far more. In Underhill, beneath the shadow of Mt. Mansfield, one neighbor could water his lawn all day. His well, open to the gravel 100 feet below his acres, yields 20 gallons a minute. Next door, a 300-foot bedrock well would be dry after an hour of lawn watering.

Why is it that day in and day out, well drillers pound right through 100 feet of clay and then through 10, 20, 30 feet of water-filled gravel so that they can set their steel casing into bedrock? Why not gravel wells? In many valleys, they'll yield 10, 20, 30 gallons a minute. Common knowledge has it that a bedrock well is a good well. It will stay clean. People say, the water in rock wells has been filtered by the sand and gravel above. The water is pure. In some cases and places, this is right. In others, it's not.

Fourteen thousand years ago, the highest mountains in New England were just starting to peek out from a 3,281-mile thick blanket of ice, a blanket that had covered them for ten thousand years or more. As the glacier grew thinner, it was hemmed in by the hills, forced to flow only through the valleys. Think of the waning ice sheet as a frozen river, flowing, but slowly, a conveyor belt moving perhaps several feet each day.

As the climate warmed, the glacier that covered most of northern North America continued to melt away. Over time, the edge of the ice was located further and further north. In places, where there were deep valleys that opened northward, the ice formed a dam hundreds of feet tall. The ice dam held back the water derived from rain and from the melting ice. The valleys became lakes. Into these lakes flowed powerful streams of water choked with sediment. Water rushed off the hillsides, barren of vegetation. Water poured off the melting glaciers, from the surface and from tunnels in the ice. All this water carried sediment, fine clay and silt that tinted the lakes green-gray, coarse sand and gravel that became the aquifers from which water today flows at tens, sometimes hundreds of gallons a minute.

Nature did New England a favor. In many valleys, just after the ice left, gravel spilled from the glaciers into now-vanished lake waters. Slowly, as the ice continued to melt, more clay and silt settled over the gravel, cloaking it in a stiff, dense, almost impermeable blanket, tens, even hundreds of feet thick. Years ago, this glacial-lake clay was the raw material that filled the brickyards of the Connecticut, Hudson, Mohawk, and Hoosic river valleys. The clay of the glaciers' lakes held up mills of the industrial revolution, workers' homes, and capitalists' lavish mansions.

Today, most of the mills are condos but the glacial-lake clay is still important. It shields deep, drinkable groundwater from the hazards of modern industry. In many New England valleys, large rivers flow above 100 feet of clay. The clay is a cap over a thin layer of water-charged gravel at its base. This gravel, once poured off the melting glacier, now holds groundwater under pressure, an artesian aquifer. The clay keeps the pressure in and the pollution out. The clay separates the deep groundwater that once fell as rain on clean forested uplands from shallow groundwater that drained off urban parking lots.

Geologists spend a lot of time and a lot of money looking for clay. They walk streambeds, they poke their heads into gullies, they dig pits with shovels, and when that's not enough they bring in the heavy machinery. Backhoes dig trenches into which geologists scramble. Drill rigs turn bits tens of feet into the earth, bringing back small samples from below our feet. Samples of clay.

Samples of gravel. Samples that many times show that the cheapest place to put a well may be the best place.

But back to the Huntington River. It hasn't flowed past the Moultroup house for a while, before the pyramids were built to be more exact, sometime about 8,000 years ago. We know this because Henry unearthed a log several years back. He was running a new waterline from his spring up the hill to his house on an old river terrace. Maybe the old line wasn't buried quite deeply enough in the warm earth. Maybe it had frozen on one of those still, somewhat glacial, Vermont winter nights when the mercury bottoms out somewhere below zero and the snow squeaks underfoot.

The log, the first of two we unearthed, came from a layer of logs buried long ago by a flood of the Huntington River for which no written record survives. A year later, Henry and his backhoe dug out another one of these logs. Twelve feet below his pasture, pickled in groundwater, the log appeared looking hardly worse for the wear as the backhoe bucket brought it up into warm August sunshine. Using a technique that didn't exist when Henry milked his first cow, we knew the age of the log in just a few weeks.

We dried the wood and sent it overnight across the continent. In Livermore, California, a lab that got its start building bombs, burned a pea-sized piece of Henry's log. It met its end, at 1600°F, sealed in a quartz tube with a little bit of penny-colored copper oxide. For millennia, the wood sat below Henry's pasture. In a day, it was nothing more than a breath of carbon dioxide and water.

The next day, the carbon dioxide was converted into graphite—pure, black carbon—under the skilled hand of a chemist. The graphite, a few specks one could easily mistake for dust, was pounded into a steel target the size of a small bullet and set inside the business end of a once-retired, now-resurrected, particle accelerator. Traveling at a few percent of the speed of light, the carbon atoms were whisked around 160 feet of high-vacuum line, nothing more than a high-tech balance. Every hour, several trillion dollars of electronics weighs several million atoms.

Most carbon atoms weigh 12 or 13 atomic mass units and are stable. They have been around a long time and they will continue to be around a long time, billions of years. A few, very few, carbon atoms are heavier, weighing 14 atomic mass units. These heavy carbon atoms are unstable (radioactive) carbon-14, or radiocarbon. Carbon-14 is made in the atmosphere by cosmic rays, particles we'll never see, but which are all around us. Carbon-14 in the atmosphere ends up in carbon dioxide. Carbon dioxide ends up in plants. That's part of photosynthesis. So, plants are slightly, ever so slightly, radioactive. The same thing can be said of animals that eat the plants.

Living things contain radioactive carbon-14; living plants get it from the atmosphere and animals get it from eating once-living plants. At death, plants cease to respire and animals cease to eat. Without a source to replenish the ever-decaying radiocarbon, the level of carbon-14 radioactivity starts to fade, slowly, imperceptibly. The day a tree became Henry's log, the radiocarbon in its wood, in its bark, in the leaves still clinging to its branches began to decay, spontaneously emitting electrons and becoming nitrogen-14, just another atom of common nitrogen in our atmosphere. After 5,700 years, half the carbon-14 that was in Henry's log when it was a living tree was gone. Wait another 5,700 years, half of what's left would be gone and so on; every 5,700 years, half of what's left is gone. After 40 or 50 thousand years, it would be a challenge to find any carbon-14 in Henry's log.

How do we know how much carbon-14 Henry's log started with? Painstaking work by American chemist Willard F. Libby and his research group at the University of Chicago during the 1940s and 1950s demonstrated that living things contain similar concentrations of carbon-14 and that dating was possible. They started by measuring carbon-14 in sewage gas to show that biological materials include this rare isotope. Then, to prove that all living things contained similar concentrations of carbon-14, they measured biological samples from around the world. Finally, they proved the usefulness of carbon-14 by dating archeological samples of known age. All this work earned Libby a Nobel prize in 1960.

Take a small portion of an ounce of carbon from a tree just felled in a clearcut, a mouse caught last night in a trap, a lock of freshly cut hair. If you monitored the decaying carbon-14, you would find that all three of these samples would give you the same value, 13.7 disintegrations every minute. Livermore's lab work tells us that Henry's log contained only 38 percent of the carbon-14 you would expect to find in a modern tree. From this, it's an easy calculation and we know that the tree died about 8,000 years ago. It's been that long since the Huntington River flowed where the Moultroup house now stands.

One can't dig just anywhere and find eight–thousand-year-old logs. Most places we've dug on river terraces, we just find gravel, gravel, and more gravel. In the Northeast, preserving wood against the ravages of decay requires keeping it wet, cold, and away from too much oxygen. The best way to do this is to keep it below the water table, out of harm's way. For wood to survive any length of time, it needs to be buried, quickly and deeply.

On Henry's farm, nature found an interesting way to keep wood wet, buried, and preserved. Bury it beneath an alluvial fan. Alluvial fans are a favorite feature of many geologists, quite common in arid regions where they dominate the base of mountain fronts. Each is shaped like an inverted ice-cream cone, sloping away from the point of its cone where its source stream dispatches from the mountains. Some fans in the Southwest are as much as six miles long. They coalesce to form massive bajadas—like skirts around the bases of mountains—that slope gently up to the range front. But in New England, alluvial fans are small, rare, and usually isolated. They've never really been studied. They are very subtle features. Some are just a few yards tall, no more than 50 or 60 yards wide. If the fan isn't in a pasture, it's bound to get lost in the trees.

What's the recipe for a fan? Simple. Take a steep slope, make sure that the soil or rock is well loosened, and add water. Gravity will do the rest, pulling material downslope into small channels, which lead to and merge with bigger channels, and so forth. The water and sediment will keep moving until the downslope force of gravity is no longer strong enough to keep sediment moving downhill. Generally, this happens where steep slopes give way to gentle valley bottoms. There, on the flats, the material will be deposited. The big stuff drops out first. The fine material goes the farthest. The resulting deposit is fan shaped. The sediment is waterborne and the process termed alluvial. Thus, an alluvial fan is formed.

There's an alluvial fan behind Henry's house. It sits on the terrace in a pasture. It's often covered by cows and is fed episodically by flows of water and sediment from the steep slopes above it. Today, trees cover these slopes. My students and I found this, our first fan, five years ago and approached it with some curiosity, some trepidation, and two shovels. Henry laughed and offered the backhoe. He cut our first trench in July 1994. It was 25 feet long, 6 feet deep, and 10 feet wide. When we came back the next day, the trench held two feet of standing water. No wonder we found lots of wood in the walls of that trench, the wood had been soaked for thousands of years.

Over the past half-decade, Henry has opened six backhoe trenches for us on his fan. Among the trenches, there were similarities and differences. Every trench was well stratified, showing layers of sediment deposited by individual floods. Near the steep hillside, the fan material was coarse and thick with gravel. Farther down the fan, other trenches revealed mostly sand and silt and clay. Near the top of every trench, we found sediments that had been well stirred by plowing and contain charcoal, the legacy of clearing the land for farming. At the bottom of each trench, below the base of the fan sediments, we saw river terrace gravel and, often, wood. Between the uppermost material stirred by plowing and the gravels of the ancient Huntington River were several feet of alluvial fan sediment that, as we've learned to translate their stories, begin to tell us a history of slopes, erosion, and storms, stretching back 400 generations. Most important, these fans and their sediments detail a history of human impact, a history that we are doomed to repeat unless we understand it.

The history we are struggling to read is one of erosion. Sediment in the fans was once on the hillsides. Most days, that is where it stayed. Today most fans in New England are inactive. They have been turned into well-vegetated homes for cows, sheep, woodlands, and the occasional dwelling. During the average rainstorm, nothing much happens. But every once in a while, the exception happens. It rains for many days; or on a single day, it rains many inches. Then things get exciting. Water races over slopes, streams churn, landslides move, and alluvial fans grow. We search for these exceptional events in the fans.

Using radiocarbon, we have estimated times in the past when the fans were active, times when we presume that it was wetter or stormier or both. The first of these periods of activity was about 8,000 years ago. Again, about 3,000 years ago, sediment poured off some hillsides. But the most impressive erosion event, ten times bigger than anything that happened over the last 8,000 years, occurred within the last 200 years. It happened when settlers came to Vermont and cleared the forests. The fans provide a dramatic record of this clearance.

Get a shovel and dig into a fan. Chances are the first 10, 15, 20 inches will be pretty dull. Brown sand, a few pieces of charcoal, if you're lucky. But keep digging, because somewhere about 25 inches below the surface, things will change. The sediment will get darker, finer, more moist. In some places, it will be chocolate brown, filled with bits of organic material, rotted leaves, grass, twigs. Keep on digging and the material in your shovel will get redder. Keep digging, you'll be back to brown.

What you have encountered is the old surface of the alluvial fan and the soil that formed there. The soil is well developed, an indication that the fan surface was stable for at least hundreds of years. Trees lived and died, dropped their leaves, left their mark, and then, suddenly, the soil was buried by sediment sluicing off the hillsides above. A student from the University of Vermont dug holes in 22 alluvial fans. He found a soil buried in every one of them, quietly preserved out of sight—a mute testimonial to landscape change wrought inadvertently by Vermont settlers.

In the beginning, whenever we found the buried soil, we'd collect a piece of charcoal from just above it, gather a couple hundred dollars, and get a radiocarbon date. The first date was less than 200 years; the second date was less than 200 years. After our fifth young date, we stopped spending money and accepted the likelihood that whenever we found a well-preserved soil near the surface of a fan, that soil was young. Younger than our country.

So, why the buried soil? What happened within the last couple of hundred years? All the evidence suggests that we did it—well, not exactly us, but our ancestors, the non-Native American settlers who cleared the land, first for small subsistence farms, later for grazing sheep, and finally for timber. In 1770, Vermont was almost entirely covered by forest. By 1870, over 80 percent of the state was cleared land. Today, the majority of Vermont is again covered by trees. The correlation is clear, the trees were cut and sediment poured from the hillsides.

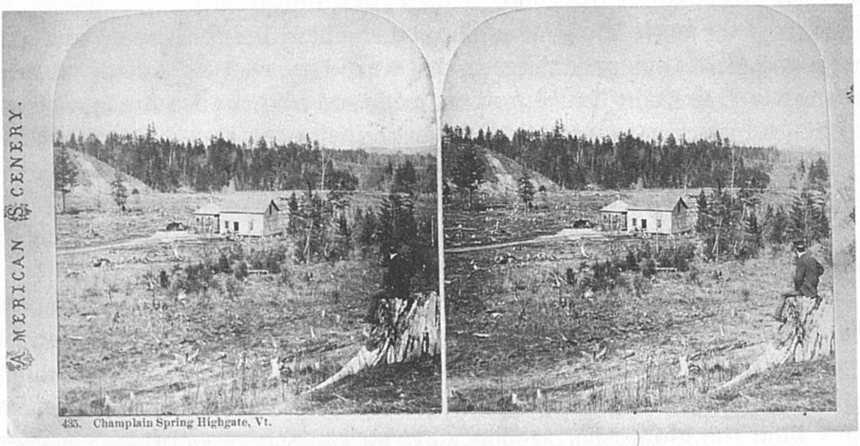
Deep in the bowels of the University of Vermont library are cases of old stereo view cards, cards that Victorian-era friends and lovers must have once passed around to one another. The cards are filed by town, so you can easily see what Burlington or Bennington or Brattleboro looked like with barren slopes. Find the Montpelier section and you can see views of the golden-domed state capital, which today glitters before a backdrop of dark green, tree-covered hillsides. In the middle to late 1800s, the slopes are clear to the ridges. Look closely at the old black-and-white photos; there are landslides and gullies just beyond the capital.

How do we know that eroding slopes are linked closely in time to deforestation? There are several strong arguments. Observations made today in the

Pacific Northwest show that deforestation and road building are very effective means of destabilizing slopes. Or, one can start from the fundamental physics of slope stability and use measured soil strengths to predict what will happen when trees are cut. Curiously, such a model predicts that landslides will follow clear cutting by five to ten years. Why the lag? Because it takes the better part of a decade for roots to rot and lose their strength, strength that helps to hold together soil perched on steep hillsides.

Our best evidence for rapid landscape response to clear-cutting was collected inadvertently by the clear-cutters themselves. Search through any large collection of nineteenth century photographic images and you are bound to find a smoking gun. In the collection of 20,000 or so images at the University of Vermont, there are several pictures of just-cleared fields studded with stumps. In the background of one image, behind an austere-looking farmer, behind his cabin, is a steep hillside. On that slope is a clearly defined landslide. There is a picture of the Clarendon Springs hotel probably taken to preserve memories of a summer holiday. At the hillside beyond the building there are eroding gullies and growing alluvial fans, captured in the act.

In Henry's fan, we found perhaps our most poignant evidence for the rapidity of slope failure after land clearance. Late fall 1997, just after dawn, I was alone making the final measurements along a 35-foot trench, the last of a series of trenches that my students and I have opened in the fan. Earlier, 30 of my introductory geology students had dragged trowels over the surface of the



An unknown Vermonter, sometime after 1867, looks out over newly clear-cut fields in the midst of which is a traditional Vermont cape-style house and gazebo. Beyond the fields of stumps, is a clear-cut hillside where shallow landslides have carried away soil and exposed sediments of glacial Lake Vermont that were deposited 12,000 to 14,000 years ago. The slide scars are evident in the stereo view photograph, Highgate, Vermont. (*Used by permission of the University of Vermont, Bailey Howe Library, Special Collections*) trench, searching for clues about the past in the moist earth. This was a cold, clear October morning, with frost still clinging to the wilted pasture grass. My trowel worked the west wall of the trench, into a corner not previously well explored. It hit something hard and stopped.

Two minutes later, I was holding in my hand a horseshoe. It had come from the buried soil, 30 inches below the current surface. According to Henry, who had shoed enough horses to know, it didn't come from a draft horse working the fields, but from a riding horse and a small one at that. Who had been riding in the field that day maybe 100, maybe 150 years ago? When did the rider notice that the horse had lost its shoe? Did the same rider return to the field after a storm hit? Did the rider stand out in the deluge, dripping wet and watch water pouring from the slopes as sand and gravel and silt and clay covered the horse's tracks and the lost shoe? Just what did this person think as the once-fertile field was buried by sterile sand and gravel ripped from the slopes above and left as mute meteorological testimony on the fan below.

The flood that buried the soil and the horseshoe came quickly. The geology tells us so. The top of the buried soil is not a smooth surface; rather, it undulates in predictable, sharp-crested waves. These waves are plow furrows, seen on end and frozen in time. They are buried by sand, sand that crept below their crests and filled every void. What we see in the trench walls is a snapshot of a day, maybe a week, but probably not a month, caught some time in the last century.

Trees were felled, their stumps burned or wrenched from the ground by oxen. A farmer plowed the field, breaking the sod. A horse moved across the open land, loosing a shoe. A rainstorm hit and water poured down the slope, carrying sand and silt and clay. The field was buried, the plow marks preserved. The field was never plowed again. It remains today a pasture, its richest soil nearly three feet below the cows.

We know that what happened on Henry's land was commonplace and the effects widespread. On every fan we have studied so far, the rate at which sediment poured off the hillsides increased by tenfold when settlers cleared them. But the sediment didn't stop on the fans and in the fields; it kept going right into the rivers of Vermont, including the Huntington, including the Winooski into which the Huntington drains. We know most about the Winooski River; draining much of Vermont's highlands, it responded dramatically to this flood of debris. The Winooski's flood plains filled with sediment, rising in some places five or six feet in the 1800s, before the river's flow subsided as trees regrew on barren hillslopes and the sediment supply waned. In 1870, at the height of deforestation, a wave of sediment moved down the Winooski River, causing the river's delta to grow dramatically into Lake Champlain. Sediment once covering rural hillslopes now extended the lakeshore. The delta has since returned to its original size; its historic addition beaten away by waves and currents. The sediment is now at the bottom of the lake.

Today, the Moultroup property is woods and fields, woods that used to be fields, and woods that are again becoming fields. The alluvial fans are mostly quiet. There are stone walls in the woods that mark the labors of years gone by. There are skidder tracks where just this fall Henry pulled logs to clear a site so that another one of his children could move home. Now, with winter fast coming to the Huntington Valley, the logs are rapidly becoming firewood. Henry's firewood is rumored to be the best in the valley. He and his sons sell a lot of it.

In Huntington, traces of the past are everywhere at the surface and below. Such is the case for most of Vermont and much of the northeastern United States. Today, New England is mostly forest. But things are changing. Logging is returning to the north woods as trees that were seedlings in the last century now mature. After years of slow growth, Vermont's population has expanded dramatically since the 1960s. Human impact on the landscape is growing again. Wal-Marts have come to Vermont. Trees fall before sprawling suburbs. Bills regulating clear-cuts barely pass the legislature and landowners howl in protest, closing their lands to the time-honored tradition of public access.

The Earth records its history and ours in many ways, we need only be aware and alert enough to understand what it is saying. Geology is a way of looking back and seeing into the past. The hope is that by looking backward, we can see into the future.