Geology of Natural Stone Bridge & Caves

Natural Stone Bridge and Caves are a group of related caves that carry an underground portion of Trout Brook. When we look at their geology we need to think about three different periods of time. The oldest of these is about 1200 to 500 million years ago (MYA). This is when the rocks we see were deposited and metamorphosed. The second period is unclear but may be as early as 125 MYA and as late as 5 MYA. This is when the rocks that form the Adirondacks were uplifted. The most recent period starts about 14,000 years ago and continues today. This is when the caves were formed.

To put this in another way, let's compress the Earth's history into a single year. If the Earth was formed on January 1 the moment the "ball drops," then the original rocks at Natural Stone Bridge and Caves were deposited on September 26 at 12:34 in the afternoon. They were metamorphosed by October 7 at 6:40PM. The Adirondacks started to rise on December 31 at 5:48PM and the caves formed the same day at about 2 minutes to midnight.

Let's first talk about *plate tectonics*. This will provide the needed background about why some things happened the way they did.

Plate Tectonics

Plate Tectonics explains why the Earth looks as it does. It explains why mountains and volcanoes are where they are. It explains why earthquakes occur where they do. It is the unifying theory in geology. There are many lines of evidence for the theory, but we will not go into them in this publication.

The earth's crust consists of seven or eight large plates with a number of smaller plates filling the spaces between them. Plates always have a base of basaltic, oceanic crust. Often there is a continental masses of granite "floating" on the basalt. (Granite is lighter than basalt and just as oil floats on water, the granite floats on basalt.) The plates are always moving – typically at about the same speed as one's fingernails grow. Because plates can break apart or disappear or lose parts to other plates, the names and sizes of the plates will change through time.

Plates meet in three different ways. Sometimes they slide past each other. An example of this is the San Andreas Fault in California where the Pacific plate is sliding past the North American plate. (The sliding is not a smooth motion, but more of a jerking one. Each jerk causes an earthquake.)

Some plates are separating. The mid-Atlantic ridge is a spreading center. It comes on land at Iceland and this is one reason for the volcanoes there. At the ridge the North American plate is being pushed west while the Eurasian plate is going east. Magma rising into the valley at the center of the ridge is one driving force.

Now we come to the plate contact that is important in understanding the geology of Natural Stone Bridge & Caves. The third plate margin is called a subduction zone. This is where one plate slides beneath another. The earthquake and tsunami at Fukashima in Japan in 2011 were located at one such boundary. Volcanoes are associated with subduction zones. (As the rock subducts into the mantle beneath the crust, some rock comes back to the surface as molten lava forming strings of volcanoes such as in southern Alaska and in Japan.)

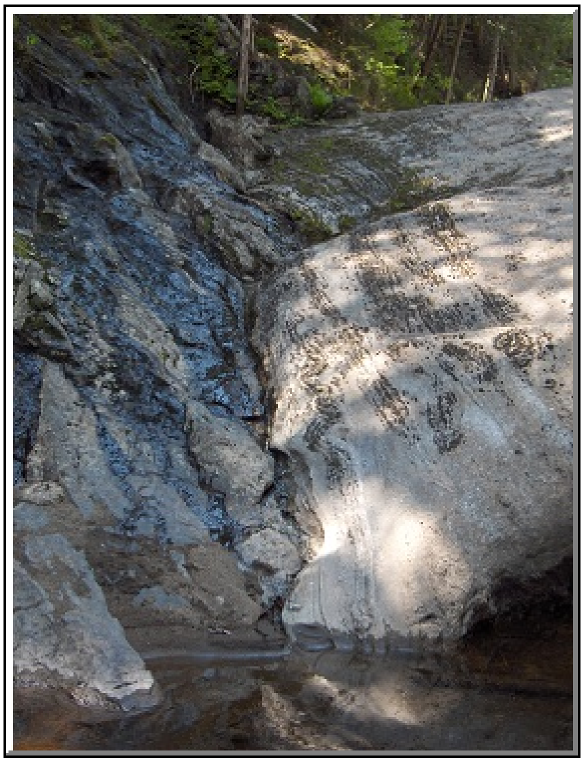
When two plates weld together we refer to the plates as being sutured. Such sutures are marked by mountains. So, when the Indian plate "smashed" into Asia, the Himalayas were formed. (Initially, the oceanic crust of the Indian plate slid beneath Asia, but when the two continents met, the mountains formed.)

Before getting into the actual story, let's make one more quick diversion and talk about the *rocks* at Natural Stone Bridge & Caves.

The Rocks

There are three kinds of rocks found at Natural Stone Bridge & Caves: marble, quartzite, and amphibolite. These are all types of metamorphic rock. The first two started as sedimentary rocks. We distinguish these from other metamorphic rocks by calling them metasedimentary rocks. The amphibolite is a meta-igneous rock and as you may surmise it started as an igneous rock. Let's first talk about metamorphism.

Sediments are turned to rock by some heat and pressure, but if existing rock is subjected to greater heat or greater pressure or both, the rock is changed or metamorphosed. For example, take shale. It started originally as mud. Metamorphose the shale, it first becomes slate. Continue the process and it turns to phyllite. More heat and pressure results in schist. (Young teen boys find this word very funny.) So, marble started as limestone, quartzite as sandstone, and amphibolite as basalt, a volcanic rock.



The marble (right) and quartzite (left) contact by Indian Maiden's Kettle.

At Natural Stone Bridge & Caves the most common rock and the rock in which the caves are formed is marble. When we think of marble, we typically think of the white rock used to make tombstones or on buildings. The rock at Natural Stone Bridge & Caves, however, is a crystalline marble. This means it was metamorphosed under tremendous heat and pressure. It is estimated that this happened 15 to 20 miles (20 to 30 km) below the surface. The resulting marble is not a nice solid white rock. It is loosely cemented calcite crystals that can be easily dissolved and eroded. In places one can rub the crystals off the rock with a bare hand. (Please don't do this.)

Along the south side of the park from the Photo Spot to where you view the Oyster Shell, the marble is in contact with quartzite. Unlike the marble, which can dissolve to form caves, the quartzite is not soluble.

The third rock is amphibolite. This likely started as an intrusion of molten rock into the existing sedimentary rocks. This may be seen on the west side of the waterfall by Serenity Point.

The Geology of Natural Stone Bridge & Caves

The tectonic plates move continuously and, while they don't move much in any given year, over millions or billions of years, the movement is astonishing. Many have heard of Pangea, a supercontinent that formed when all of the continents were all connected. Before they were connected, however, they were separate and before that they were connected at least two other times. (There may have been older supercontinents, but solid evidence has been largely erased by the continuous movement of the plates.)

The geological story of Natural Stone Bridge & Caves (NSB&C) starts when one of these supercontinents, called Rodinia, was coming together. At the time, about 1200 million years ago, the NSB&C area was south of the equator and in warm tropical seas. We know this because in crystalline marble of the same age, stromatolite fossils have been found on the west side of the Adirondacks. Today, stromatolites – a colonial algae – are found in the Bahamas and waters off western Australia where the water is warm and tropical. So, with the present as a guide to the past, we assume that the water was warm and tropical. The precursor to North America, geologists call it Laurentia, was laying on its side so that our east coast would have faced south. An oceanic plate was subducting beneath the Laurentian plate. (Actually a continent was riding on the plate, but that comes a bit later in the story.) As these plates interacted, two things happened. First, volcanoes formed. Remember the amphibolite is metamorphosed basalt. The vulcanism is probably the source of this basalt. Also, the sea got shallower. Into this shallow sea were deposited sediments. It was from these that the limestone and sandstones were formed. (In other Adirondack caves formed in the Grenville marbles we find schist which was deposited as mud.) In other parts of New York we can see much younger rocks that show alternating rocks like limestone, sandstone, and shale.

Stromatolites

Eventually, the two continental land masses collided. Since one continent won't subduct under another, the collision resulted in mountain building. When this happens, some of the rock goes up – the top of Mount Everest is marine limestone – while a lot of rock gets buried very deep, forming the roots of the mountains. It was this deep, deep burial that resulted in the extreme metamorphism we see in the rocks at NSB&C. Geologists call these mountains the Grenville Mountains. They were equivalent in height to the Himalayas. They are now gone, eroded away. As mountains erode, having less material weighing them down allows the land to rise, somewhat keeping pace with the erosion. (This process is called *isostatic rebound*.) With enough erosion, enough rebound, and time, the roots of the original mountains are exposed. The roots of the Grenvilles underlie much of eastern North American, Texas, and even parts of Mexico. In the Adirondacks, these Grenville rocks are at the surface.

The Grenville supercontinent was breaking up by 650 MYA. (Many of the faults seen in the Adirondacks, likely formed when the Grenville was pulling apart.)

The erosion of the Grenvilles was done by the end of the Cambrian period or about 500 million years ago. It was then covered by younger rock units. We know this because in a few places in deep valleys in the Adirondacks, like near Wells, NY, we still find some of much "younger" rocks only about 460 million years old (Ordovician aged).

It is unclear when or even why the Adirondacks started to form. Some say it was 125 MYA. Others say only 5 MYA. Yngvar Isachsen, who was the dean of Adirondack geologists, prefers the more recent date, so we'll go with that. For reasons still unknown, about this time the rocks began to dome up. (The Adirondacks are unusual in that they form a dome rather than linear mountains like the Rockies.) As the mountains arose, erosion removed the top layers of the younger Ordovician and Cambrian rocks. To achieve the currently seen mountains, an uplift rate of 1 to 3 mm a year is needed. Re-surveys of Adirondack's railroads support this rate. Thus, the Adirondacks are new mountains made from old rock.

Between the deep burial during the building of the Grenvilles, the rebound period, and the growth of the Adirondacks, the rocks of the area were "chewed up" with the resulting rocks showing up as, for lack of better words, large blobs. Geologists call this a mélange. Thus, the marble in which NSB&C are formed is relatively small, being no wider than from the Potholes to the far side of the parking lot and no longer than from the waterfall downstream to about

1000 feet below the Oyster Shell. (There is more marble about 3500 ft upstream but the two areas are not connected.)

As the mountains arose, the faults from the rifting of Rodinia began to influence water drainage. These zones of weakness came the preferred locations for streams. To this day, many streams and water bodies are found on these faults. Examples are Long Lake, Indian Lake, the Hudson River south of Newcomb, and the headwaters of Trout Brook – the stream that flows through NSB&C – and its two major tributaries: Minerva Stream and Alder Brook.

Before the glaciers that started about 2 MYA, these streams probably flowed southwest to meet the Hudson about 2.7 miles downstream of North Creek, NY. The glaciers, perhaps as thick as a mile, *deranged* stream drainage throughout the Northeast. By this we mean that the streams did not necessarily return to their former courses after the glaciers receded.

We can surmise the pre-glacial route of Trout Brook by looking at an area to the west called Bird Pond. Here we have an *underfit stream*. That means that the valley is far too big for the stream that now flows in it. (The valley is about 500 feet wide and the stream is only about four feet wide.) This typically indicates that at one time, a larger amount of water flowed here, i.e. the pre-glacial Trout Brook.

What seems to have cut off this drainage is a ridge on which Olmsteadville Road runs. This appears to be a section of glacial moraine. (A moraine is a rdige of glacial debris deposited at the toe or the sides of a glacier. A walk along the road and vicinity reveals no obvious bedrock, but plenty of glacial erratics, rounded boulders transported by the glaciers.

After the glaciers receded the water, unable find a route to the south, found a route to the east. The topography of the watershed downstream of Alder Brook suggests this area is more recent than the rest of the watershed. The stream basically followed the same course it does today with one notable exception. Upstream of the waterfall and the Sawmill site, the stream continued east rather than making the sharp turn to the south as it currently does. The valley that contains the Caveman Adventure Park, the maintenance building, and the playground & picnic area was the route of the stream. (The Fish Pond is also part of this channel.) As the stream continued to erode the area, it intersected the marble.

The marble at NSB&C is so extremely metamorphosed that it has been squeezed back to its constituent minerals. The calcite is almost pure. In between the calcite crystals are grains of quartz, graphite, and other minerals including tourmaline. The purity of the calcite makes it easy to dissolve and the loose cementing of the crystals makes it easy to erode.

Grenville-aged marble

The types of caves seen at NSB&C are formed primarily by solution. In pure water, calcite is only slightly soluble. Make the water acidic and it can dissolve easily. The water at NSB&C is made acidic by dissolving carbon dioxide (CO_2) in it to create carbonic acid. Carbonic acid is the same stuff people drink in soda pop, though clearly Trout Brook does not fizz like a bottle of soda water. Where does the water get the CO_2?

Upstream of the caves the drainage area of Trout Brook is about 90 square miles. All that water is been well-aerated at rapids and small riffles. (From Olmsteadville the stream drops over 100 feet to NSB&C. From its highest ponded source Trout Brook drops over 560 feet.) With this amount of aeration and with very few other carbonates in the watershed, the water becomes relatively acidic. (There is also tannic acid in the water which is what makes it brown. It is the tannic acid that causes the foaming often seen in the water like at the Whirlpool.) Thus, when it does encounter the marble, it's what we call solutionally aggressive.

This aggressive water started to dissolve the marble. As it did so, more of the water was pirated south into the marble and eventually its previous channel was abandoned. At NSB&C the oldest remaining parts of the caves are the highest, so Giant's Slide and the Barrel in Stone Bridge Cave and Peter Pan's Peephole in Noisy Cave are the oldest sections of the caves.

The water might have continued to flow south, but it encountered the quartzite described above. The water was forced east along the marble-quartzite contact. (It could not have gone west because there was no marble and it was uphill.) Noisy Cave, the Whirlpool, Cave of the Lost Pool, Echo Cave, and Garnet Cave are all formed along this contact.

Arrrr! Stream Piracy

When we talk of *stream piracy*, we are referring to a process by which one stream steals the headwaters of another. This happens in different ways. At Natural Stone Bridge & Caves, the initial trickle of water that flowed into the marble eventual stole all of Trout Brook's water.

The Power of Water

When you look upstream from the bridge leading over to Noisy Cave and beyond, there are many large boulders in the stream. Most of these boulders are from much farther upstream and have been washed downstream during flood events, getting rounded in the process.

This may seem hard to believe, but if you turn around and look at Lost Pool Cave, you'll see similar boulders near the base of the stairs and under the extended overhang. These were left here during high water events.

When you get to Lost Pool Cave take a close look at these. You will see that they are nothing like the marble on which they are sitting.

The Stone Bridge formed because the initial flow route was likely inefficient. Trout Brook is very dynamic and the flow is highly variable. Much of the time visitors can walk on the "stream bed" by the Potholes. At other times, a lot of water flows here. (See photos below.)

Lost Pool Cave and outflow channel on right at low flow.

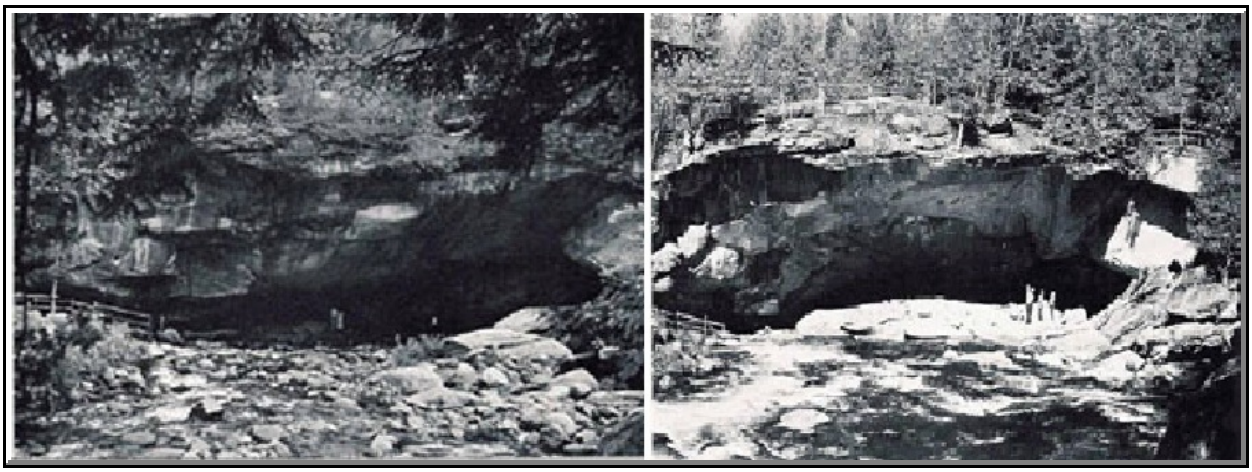
Lost Pool Cave and outflow channel on right at flood flow.

Potholes

Potholes are formed when sand, gravel, or larger rocks are swirled around by water forming circular holes. (At Moss Island near Little Falls, NY there are giant potholes where it was large boulders that milled out the potholes.) The best potholes at Natural Stone Bridge and Caves near the stairs down to Lost Pool Cave. Indian Maiden's kettle by Echo Cave is also a pothole, but is far larger than the others.

The water flowing under the Stone Bridge rejoins the stream at the Oyster Shell. This water flows beneath the gift shop. The water sinking into Noisy Cave – the reason it is noisy – restarts the stream at Garnet Cave.

The process of cave development continues today. Water chemistry shows that the passages are enlarging due to solution about 1 mm (0.04") a year. (Consider that over 13,000 years this would result in caves about 40 feet across which is about what we see.) Most of us think of geological features as fixed and unchanging. One only needs to think of November 1956, when a 1500-ton piece of rock fell from the Stone Bridge to know this isn't so. (See photographs below.)



Stone Bridge before (left) rockfall in 1956 and after (right)

To sum up, Natural Stone Bridge and Caves are a group of caves that carry an underground portion of Trout Brook. The water takes two distinct routes underground: from the Stone Bridge to the Oyster Shell and from Noisy Cave to Echo Cave via the Whirlpool and Lost Post Cave. (If this is hard to picture think of a stream going a around an island.) These cave are geologically recent and are still changing today.

What will the future bring? In several thousand years the caves will be gone. At present, a frequent visitor with a good eye and a better memory can see changes from year to year. So, visit often and see these geological processes first-hand.