

A Geology Hike in Sourland Mountain Preserve Somerset County, New Jersey

Sourland Conservancy
May 30, 2015

Leader: David Harper



Roaring Brook Boulder Field

Acknowledgements

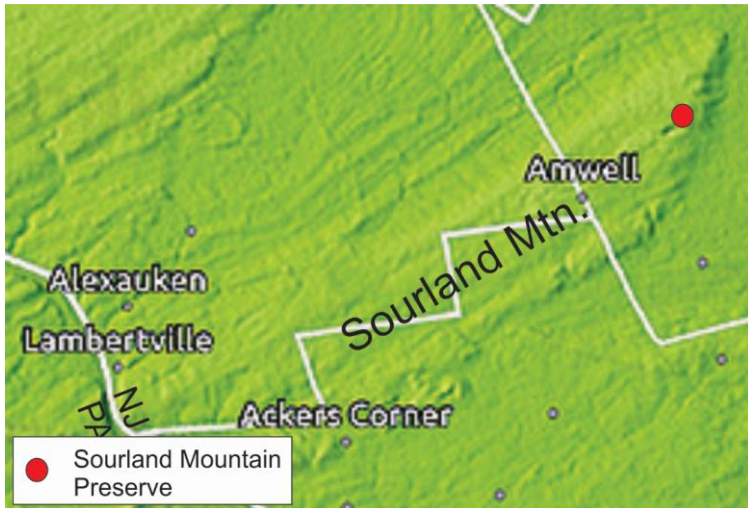
I thank the Sourland Conservancy for giving me the excuse to walk the woods, see things I never saw before, read, think, crystallize ideas on things I only imperfectly understood, and change my ideas on things I only thought I understood.

I have approached the guide as an informal educational pamphlet and did not burden it with references to source material. Thanks to all those whose work I have used without attribution.

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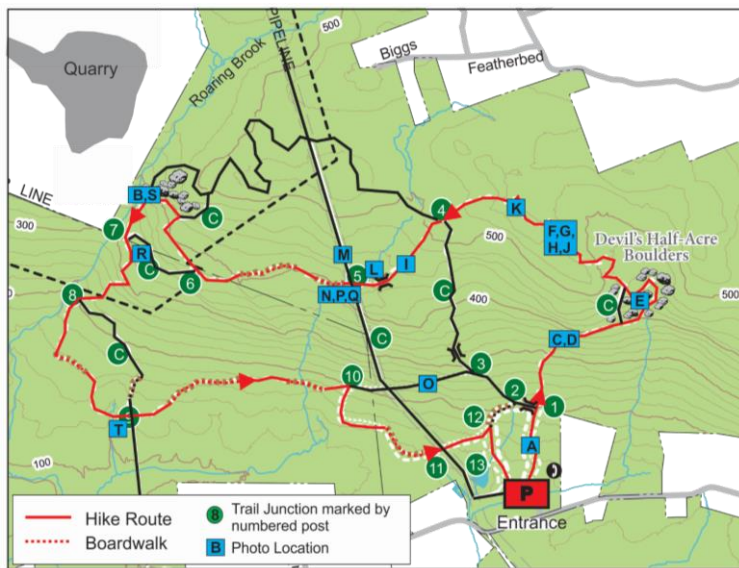
Enjoy the geology!

Sourland Mountain

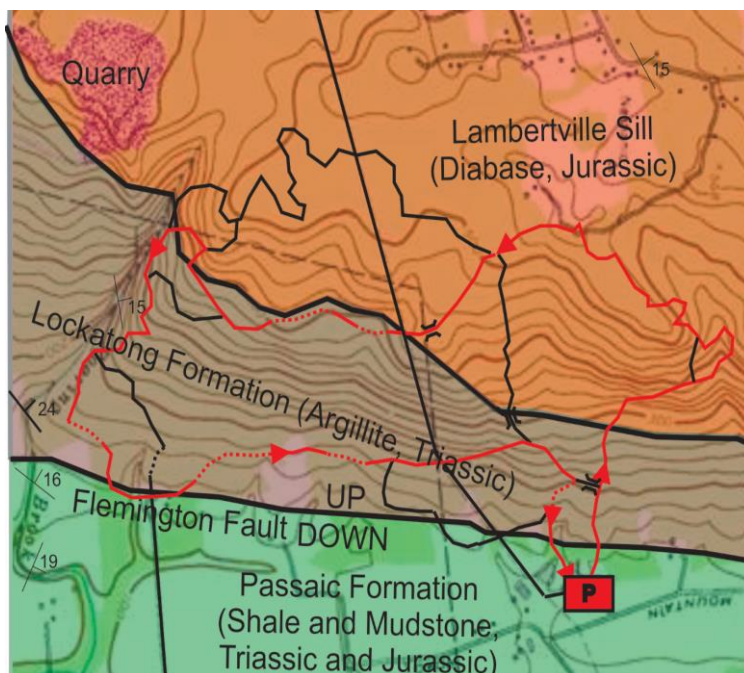


Sourland Mountain is a ridge of erosion-resistant rock, mostly diabase of the Lambertville Sill and argillite of the Lockatong Formation. The diabase is an igneous rock. The argillite is a sedimentary rock. Lowlands to the northwest and southeast are eroded into softer sedimentary rock, mostly shale and mudstone of the Passaic Formation. The hike starts at the Sourland Mountain Preserve parking lot and follows the Ridge Trail.

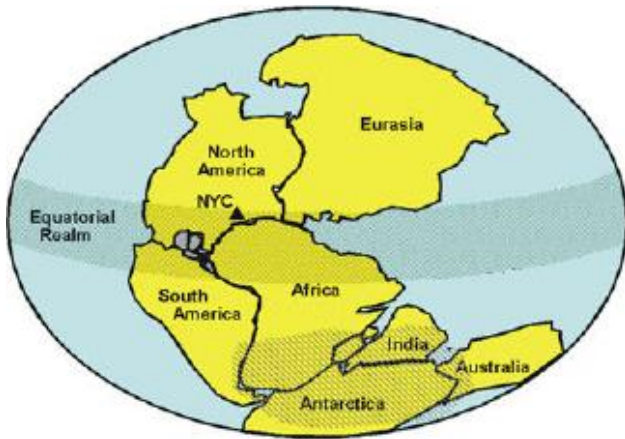
Sourland Mountain relief map



Sourland Mountain Preserve trail map



Sourland Mountain Preserve geologic map



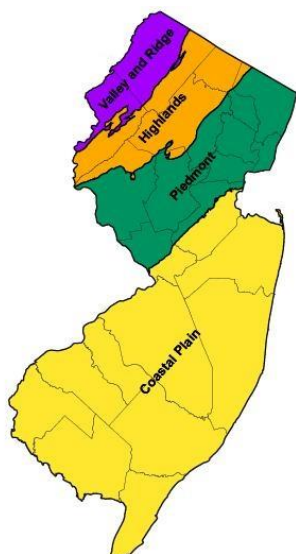
Pangea (225 Million Years Ago)

The story of Sourland Mountain begins with the breaking apart of the supercontinent of Pangea. Until about 225 million years ago, eastern North America was nestled against northern Africa, both parts of Pangea. The two continents had collided and welded together some 50 million years earlier, but were beginning to split apart along the weak crust where they had been sutured together. As the continents pulled apart, long, narrow rift valleys similar to the Great Rift Valley of East Africa opened along the margins of both continents and the centerline between them. The North American rift valleys extended from Maritime Canada to the Gulf of Mexico. They were mirrored by rift valleys along the west coast of Africa from Morocco southward. Northern New Jersey was crossed by the 125-mile-long, 20 to 25 mile wide Newark Basin rift valley. Rifting continued from about 225 million years ago in the Triassic Period until about 195 million years ago in the Jurassic Period when the continents split completely apart and the Atlantic Ocean was born. The Atlantic has grown to its present width over the past 195 million years.

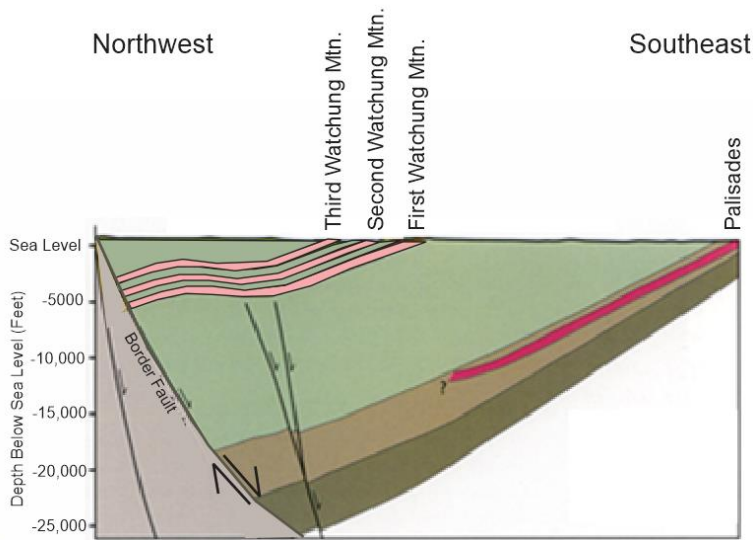
Sourland Mountain is underlain by Newark Basin rocks. Some are sedimentary, washed into the valley from highlands to the west. Some are igneous, cooled from magma which welled up through the Earth's crust as it stretched, thinned, and finally broke apart.



East coast rift basins



Newark Basin, New Jersey (green)



Cross section through the Newark Basin. Volcanic rocks are in pink. The Palisades/Rocky Hill/Lambertville Sill is in red. Sedimentary rocks are in brown and green.

The floor of the Newark Basin rift valley dropped downward along a series of "border faults" along the northwestern margin of the basin. The best known is the Ramapo Fault of northern New Jersey and Rockland County, New York. The floor of the valley dropped more than 25,000 feet, and more than 25,000 feet of sediment washed in to fill the depression. The border faults are curved, not straight, and the layered rocks tilted northwestward as the block of crust slid downward along the curve.

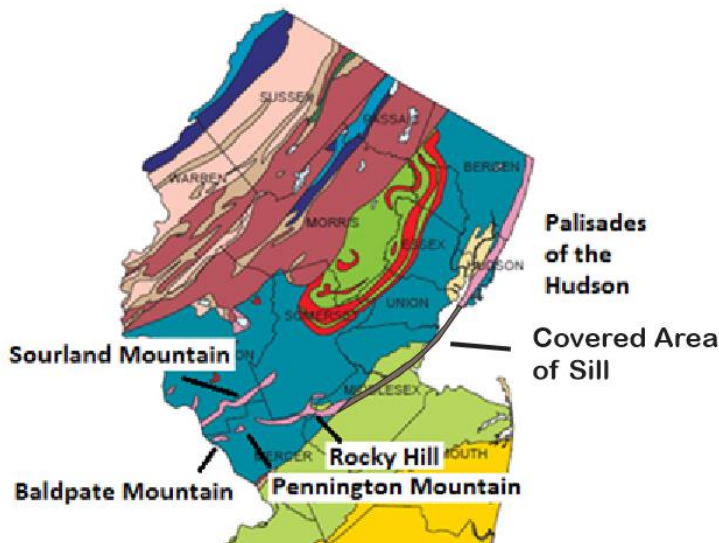
Much of the time the floors of the east coast rift basins were subsiding, the basins were closed depressions filled by large lakes. Today's rift valley Great Lakes of Africa are comparable in size to our Great Lakes. Lakes of the Newark Basin rift valley were similar in size.

Late during the downdropping, soon before the continents completely separated, magma rose up through fissures in the stretched crust.



Icelandic volcano

The magma of the rift basins was highly fluid, like that of Iceland. It did not build steep mountains like Mt. Fuji and was not prone to explosive eruptions like Vesuvius. Some was erupted a few tens of feet into the air, then flowed to lava lakes miles across. When the lava lakes cooled and hardened they became layers of the igneous rock known as basalt (pink on the cross section above). The exposed edges of the subsequently tilted layers now stand up as the Watchung Mountains. Some magma intruded between sediment layers thousands of feet below the surface and cooled to tabular layers known as "sills" of the igneous rock known as diabase (red on the cross section). A sill forms the spine of Sourland Mountain.



Exposures of the Palisades/Rocky Hill/Lambertville diabase sill

The diabase spine of Sourland Mountain is part of an immense sill. It is exposed today as the Palisades of the Hudson, Pennington Mountain, and Baldpate Mountain as well as Sourland Mountain. The sill is continuous between the Palisades and Rocky Hill, but is deeply eroded and buried beneath more recent sedimentary deposits

The Hike



A. Boulder field – Diabase boulders in an area of argillite bedrock

Soon on entering the woods above the parking lot, the trail starts up a boulder field. The boulders are diabase of the Lambertville Sill. The bedrock below the boulders is argillite, a sedimentary rock. The boulders did not come from where they now rest. They are from diabase outcrops higher up the mountain and moved downslope several hundred to a thousand feet across the argillite. They are not moving much now. Most of their downslope movement came during ice ages which periodically affected New Jersey over the past million or so years. Continental glaciers advanced into northern New Jersey at least three times, but never came as far south as Sourland Mountain. The mountain was, however, affected by permafrost (year-round freezing of the soil). Under permafrost, water is unable to percolate downward through the soil to the water table. Instead, it freezes and, over time, the soil becomes saturated with ice. In the summer months, the top few feet of ice-saturated soil melted and became water saturated mud. In one view of the origin of the boulder field, the unstable soil on the slopes of Sourland Mountain flowed downward carrying the boulders. The boulders were unable to move across flatter ground beyond the foot of the slope, but the soil washed further leaving the boulders exposed. Boulders can move downslope in many ways, however, and the explanation given here may not be correct for Sourland Mountain.



B. Unweathered diabase at Roaring Brook

The diabase of Sourland Mountain intruded between sedimentary rock layers thousands of feet below the surface and was insulated from quick cooling by the overlying rock. It stayed hot and molten for, possibly, as much as 10,000 years. This was enough time for crystals of the minerals composing the diabase to grow in size to somewhat larger than rice grains. The two predominant minerals in the Lambertville Sill are feldspar (the white grains) and hornblende (the black grains). The basalt of the Watchungs is composed of the same minerals, but the lava was exposed to the atmosphere and cooled quickly without time for large crystals to grow. The crystals in basalt are usually too small to see without magnification.



C. Differential weathering of feldspar-rich and hornblende-rich flow band layers

Layering is commonly thought of as characteristic of sedimentary rock, but igneous rocks can be layered as well. As the magma intruded through the sedimentary rock, "flow banding" developed in the Lambertville Sill from the separation of crystals into feldspar-rich and hornblende-rich layers. The feldspar rich layers weather a bit more slowly than the hornblende layers and, in some places, stand up as small ridges.



Many of the boulders along the trail to the Devil's Half Acre are rounded even though they have not been tumbled along in a stream or river. Instead, the rounding is the result of "spheroidal weathering". Spheroidal weathering is common in coarse-grained igneous rocks like granite and diabase. The boulders were initially bounded by cracks and fractures, and were rectangular blocks. Water soaking its way into the rock reacts with feldspar and hornblende in the diabase, changing it to clay. The clay takes up a larger volume than the unweathered minerals and its pressure causes spalling off of surface rock. The spalling is fastest at corners and edges where weathering attacks the rock from more than one direction. Spalling of the corners and edges gradually rounds the angular blocks into spheroids.

D. Boulder rounded by spheroidal weathering



As diabase cools from a melt it contracts. This causes tension which often splits the rock into vertical columns. The columns on the face of the Palisades of the Hudson are good examples. Those on Wyoming's Devils Tower are better examples. Some of the diabase of Sourland Mountain split into vertical columns. If there were higher cliffs along Sourland Mountain, vertical columns like the one shown to the left would be more apparent.

E. Column created near the Devil's Half Acre by tension and vertical fracturing during cooling of the Lambertville Sill.



Along with the boulders rounded by spheroidal weathering, there are flat boulders like the one on the cover photo of this guide. These may have been broken loose by "sheeting". Sheetting is the splitting of homogeneous rock into flat layers. The cause of sheeting is not entirely clear. Some have attributed it to the release of vertical pressure as overlying rock is weathered and eroded.

F. Rock being broken apart by sheeting



G. Fractures likely formed by tectonic forces

Igneous rock can be fractured by the stress of tectonic forces in the earth's crust as well as by spheroidal weathering, sheeting, and tension from cooling and shrinkage. Before North America and Africa fully separated and the Atlantic began widening, the Newark Basin was under tension. After continents separate, the forces along continental margins commonly change from tension to compression. When this happens, rift basins undergo "basin inversion", shifting from tension and subsidence to compression and uplift. After North America and Africa separated, the Newark Basin experienced basin inversion. Fractures like those in the photo to the left could have been caused by either tension during rifting or compression during basin inversion.



H. Fractures widened by tree roots.

Once fractures are there, they can be enlarged by frost wedging, gravity movement of rock down a slope, weathering, or, as seen here, tree roots.

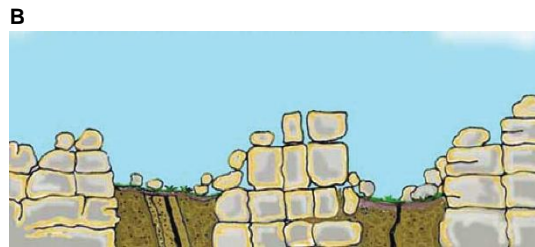
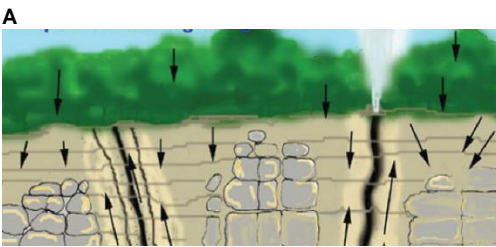


I. Boulder wrenched loose in a tree fall.

Thousands of trees in the preserve were blown over during Hurricane Sandy. Some wrenched rock loose from their outcroppings. Once loose, the rocks are more easily moved downslope. The light brown color of this rock is a surface coating of clay and iron oxides. In time, it will wear away leaving the rock grey like the rest of the diabase boulders in the preserve.



The rocks here appear to have moved apart, but may not actually have moved at all. These may instead be “tors”. Tors are isolated blocky hilltop outcrops at which the rocks do not appear to have moved from where they originated. Tors are commonly explained as the result of climate changes in the geologic past - the result of a long period of warm moist climate (illustration A, below), as New Jersey had through much of the early Cenozoic Era, followed by frigid climate, as New Jersey had at least three times in its ice ages (illustration B, below). Through the warm, moist times, diabase weathers to thick soil, particularly along fractures. When the climate becomes frigid and there is permafrost, the soil becomes unstable. The top few feet thaws in the warmer months, becomes waterlogged mud, and moves downslope. The gaps between the boulders here may have been filled with soil which developed along fractures when the climate was warm and moist, then washed out when there was permafrost.



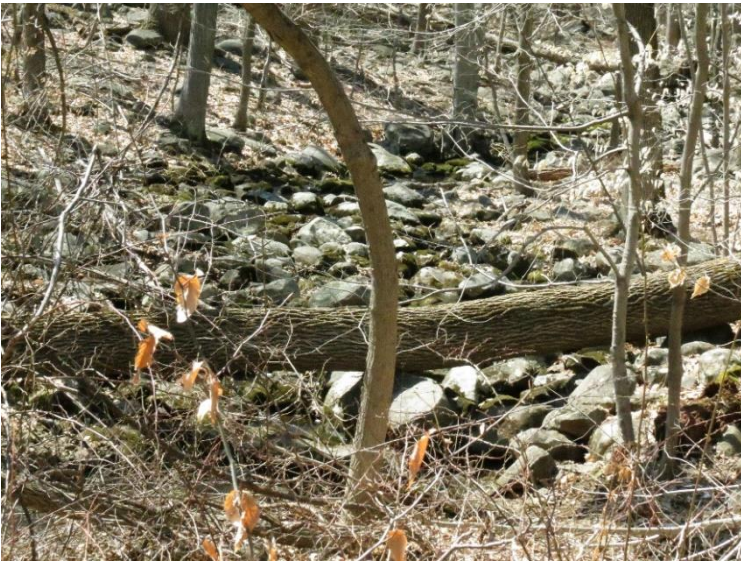
J. Tor (above) and tor formation (below). A. Weathering and deep soils develop when the climate is warm and moist. B. The soil becomes unstable and washes away when the climate becomes frigid.



K. Flat surface near crest of Sourland Mountain

Northern New Jersey has been above sea level and eroding for close to 200 million years, ever since North America separated from Africa and rifting, tension and subsidence gave way to basin inversion, compression, and uplift. The rock has not, however, been eroding at the same rate through the entire time. Erosion can be sped up by uplift of the land or by lowering of the “base level”, the lowest elevation that rivers can cut down to. In New Jersey, base level is at sea level. As of about 15 million years ago, the land and sea near New Jersey had been stable for many millions of years, and erosion had reduced the land to a gently rolling surface sometimes referred to as the Schooley Peneplain. Peneplain is an older term based on early 20th century theories of landform development and is avoided by most geologists. Still, a gentle landscape did develop through a long period of stability and erosion. Relief was on the order of 300 feet. Then, about 15 million years ago, base level in New Jersey dropped in large part due to the growth of glaciers in Antarctica and the accompanying removal of water from the oceans and drop in sea level. Valley floors have been cut deeper, but summit areas like the crest of Sourland Mountain are distant from streams and isolated from erosion. In these areas the relatively flat Schooley surface is more or less preserved. The height of Sourland Mountain was thus increased from probably about 300 feet to about 500 feet not by uplift of the mountain, but by deepening of the valleys.

A



Erosion is advancing into Sourland Mountain by headward erosion of streams and gullies. Erosion is rapid and valley walls are steep up to a "knick point". Upstream from the knick point, older topography is isolated from erosion and relatively intact.

L. Contrasting appearance of stream upstream (A) and downstream (B) from knick point

B



M. Texas Eastern Pipeline National Historical Site. Two pipelines crossing the preserve here were built in a near-miraculous 18 months at the height of WWII. They were originally known as Big Inch (24-inches in diameter, carrying crude oil) and Little Inch (20 inches in diameter, carrying refined products). They delivered oil from Texas to the East Coast without submarine hazard and were a major contribution to the war effort. After the war, the pipelines were modified to carry gas. The entire length of the pipelines is a National Historical Site.



N. Near the pipeline crossing, the trail crosses from diabase onto the sedimentary Lockatong Formation. The Lockatong is predominantly argillite. Argillite is like shale in that it does not split into thin layers along bedding planes. The Lockatong accumulated in lakes in closed basins in a semi-arid environment. Similar to the alkali lakes of our semi-arid southwest, the lakes in which the Lockatong accumulated were laden with chemicals. While layering is easily visible in the Lockatong (ignore the confusing tree shadow), chemicals precipitated along with the sediment and bound the much of the layering together, transforming the rock from easily split shale to solid argillite.



O. The lakes of the Newark Basin periodically dried when the climate became more arid. These fossil mud cracks are from one of the dry times.



P. Unlike the minerals in diabase, some of the minerals in the Lockatong Formation are slightly soluble in water. Weathering out of these minerals can give the Lockatong a distinctive pitted appearance. Preferential erosion of beds of slightly greater solubility can cut grooves into the rock.

While the Lockatong is more prone to dissolution than the diabase, it does not develop spheroidal weathering. Also, fractures are more closely spaced in the Lockatong than in the diabase. Through the remainder of the hike, except near Roaring Brook, boulders along the trail are mostly from the Lockatong Formation. They are smaller and blockier than those from the diabase.



Q. Knife-edge fracturing (Lockatong Formation)

Some layers within the Lockatong Formation break with knife-edge sharpness and were quarried by the Indians for tool-making. The fracture in this photo is unweathered and is probably from after European colonization.



R. Possible Indian Quarry

To me, this exposure of the Lockatong Formation does not appear natural. Also, the rock is slightly weathered as though it has been exposed for a few hundred years. I am not trained to recognize Indian quarries, but my guess is that this is one.



S. Roaring Brook Boulders

Roaring Brook Boulder Field. Near Roaring Brook, we cross back over the contact between the Lockatong and the diabase. At the contact there is an abrupt steepening of the slope where we pass from the more easily eroded Lockatong Formation and climb onto the overlying diabase layer.

From the contact and for several hundred yards upstream, Roaring Brook runs beneath immense diabase boulders which probably could not have moved far down the slope. In this photo, the rectangular block the kids are sitting on likely was at one time part of a single slab including the two similar-appearing boulders just upslope and a couple of others nearby. It might have looked like the slab on the cover of this guide. Roaring Brook runs about 10 or 15 feet below the boulders and is continuing to erode into the underlying Lockatong Formation. Collapse in place or nearly in place seems a more likely explanation for this boulder field than the hundreds of feet of downslope we saw at the boulders below Devil's Half Acre at the start of the hike.

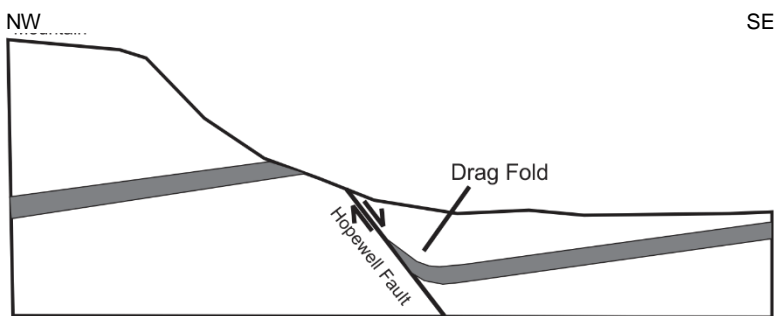
Most of the boulders are weathered, but freshly-broken blocks up to three feet across are scattered in the woods. These were blown here by an accidental explosion many years ago in the quarry across the brook. Presumably rocks would have landed in the brook as well, but have been cleaned out.



T. Passaic Formation showing drag folding

T. Crumbly red shale of the Passaic Formation is exposed at the foot of the mountain in a stream-bed just downstream from an abandoned mill dam. A glance will convince you that the shale will erode more easily than diabase or the Lockatong argillite. The Passaic Formation underlies the valley to the southwest of Sourland Mountain. The valley is there because the Passaic Formation eroded more deeply than the more durable rocks of Sourland Mountain.

Bedding in the shale here slopes about 45 degrees to the southeast (away from Sourland Mountain). Usually the layering of rock in the Newark Basin slopes about 10 degrees to the northwest (this would be towards Sourland Mountain). On the geologic map on page 1, you can see that this location (T) is immediately southeast of the Hopewell Fault. The layering was probably "drag folded" to its unusual orientation during faulting. The red rock in the photo dropped downward several thousand feet relative to the rocks of Sourland Mountain. Bedding layers which initially sloped towards the mountain were bent upward when the rock began to deform, then dragged further upward after the rock broke along the fault and moved downward.



Reversal of bedding slope from northwest to southeast by drag folding.



U. Probably an abandoned mill dam. The mill may have been at a stone wall along the trail. Before steam engines, water mills were built even along small streams like this one.