STOP 4. Faulted and shattered Triassic Lockatong argillite and Jurassic dolerite at Byram-Point Pleasant, NJ-PA along the Delaware and Raritan Canal State Park Trail, Route 29, Hunterdon County, NJ

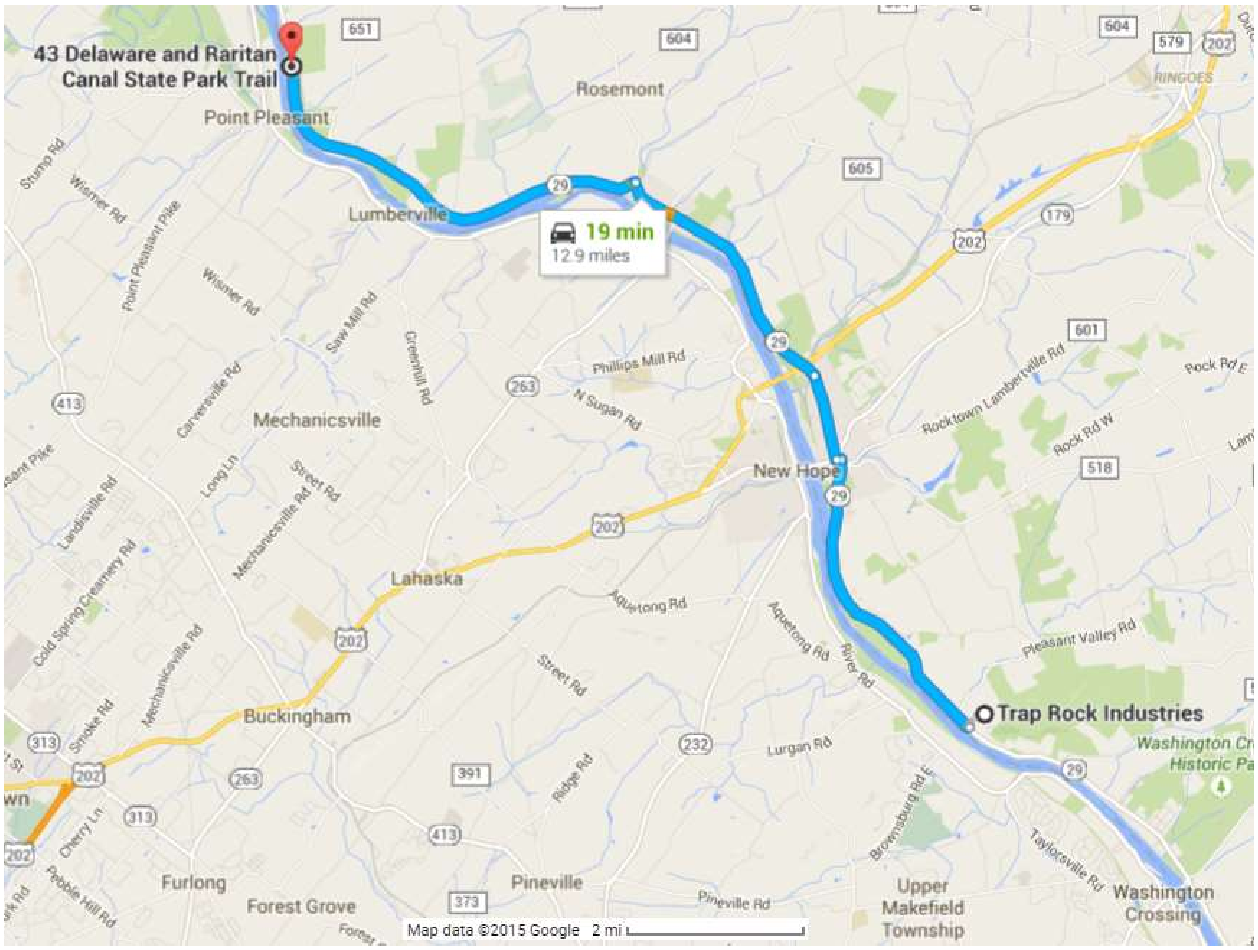

Figure 32. Google maps route from 48 Valley Road, Hopewell Township, NJ to 43 Delaware and Raritan Canal State Park Trail.

Our final STOP is in faulted and shattered dark-gray argillite of Lockatong Formation and overlying dolerite of the Byram sill (Van Houten, 1987). It includes outcropping, late-stage normal faults that cut, offset, and repeat the sill. This area is part of the Lumberville, PA-NJ US Geological Survey 7-1/2' topographic quadrangle. The geological mapping is being updated by the NJGWS as part of their STATEMAP 1:24,000 scale mapping project. Don Monteverde asked me to join in mapping this area because of the structural complexity seen along the stream gorge in which that the D&R Canal trail is developed. The 'trail' is poorly marked; it's actually three different trails that require scrambles up either the banks of the ravine or the creek bed. An old quarry road flanks the ravine on the north and ascends to an abandoned argillite quarry.

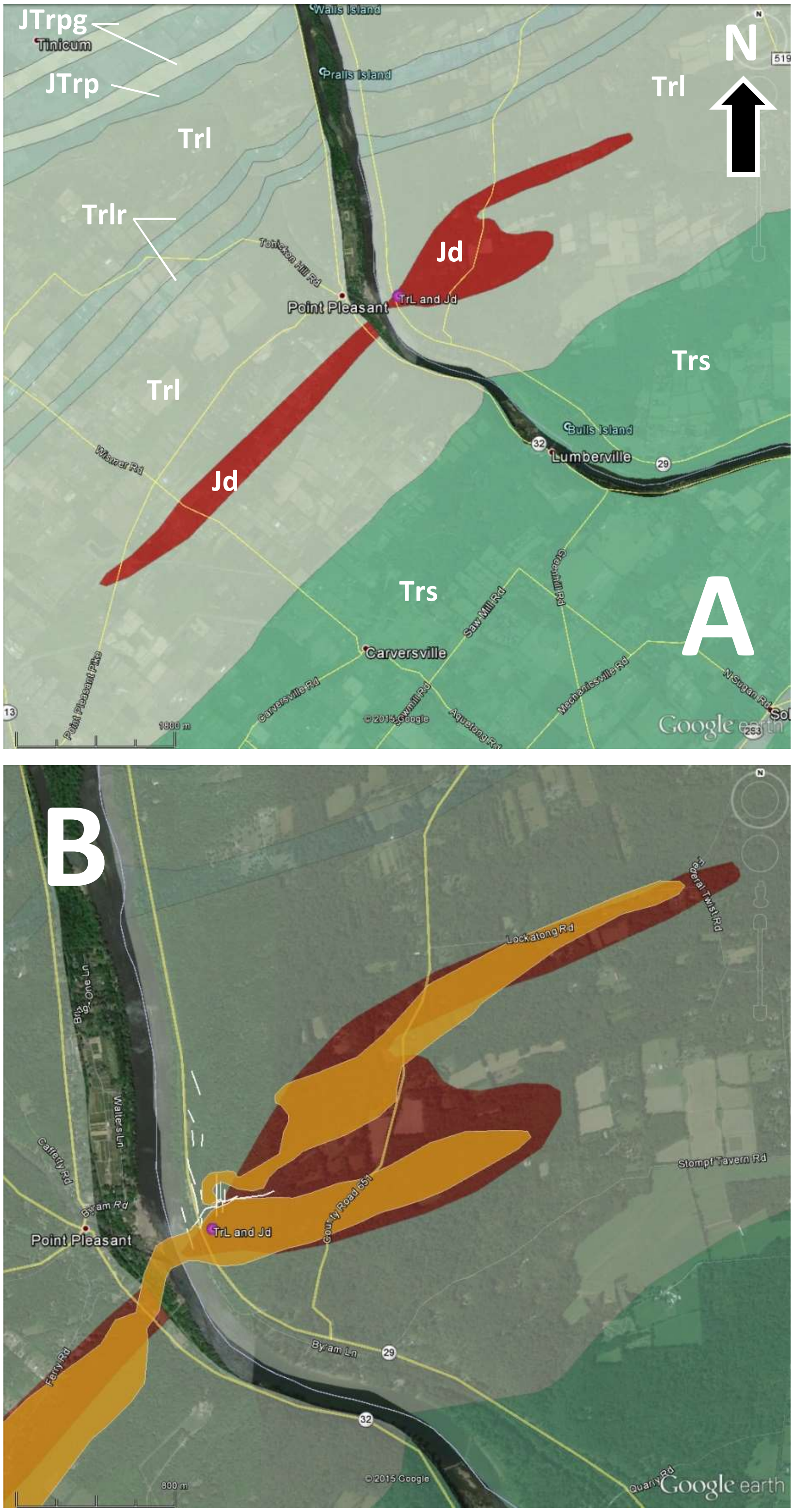

Figure 33. A comparison of old (A) and new (B) geological mapping near Point Pleasant, PA and Byram, NJ.

A. Bedrock geology as currently mapped in Pennsylvania (Berg and others, 1980) and New Jersey (Owens and others, 1998). Jd – Jurassic dolerite. JTrp –Triassic-Jurassic Passaic Formation, JTrpg – Passaic Formation gray bed, Trl – Triassic Lockatong Formation (argillite), Trlr – Triassic Lockatong Formation red bed, Trs – Stockton Formation (sandstone).

B. The contacts between the Lockatong Formation and the Byram sill in the old (red) and new (orange) forms. The new work by NJGWS stems from a combination of mapping outcrops in the Lumberville quadrangle at the 1:24,000 scale and using LiDAR hill-shaded imagery (fig. 35).

South of the ravine, a moderately steep bank follows the fault and hanging-wall contact upstream between the overlying trap (Jurassic dolerite – Jd) and the footwall argillite (Lockatong Formation – TrL).

The creek bed is strewn with sub-rounded to sub-angular boulders of trap rock that have cascaded down from cliffs that flank both sides of the stream. All three trails are difficult to navigate to varying degrees, but the features that occur here are unique and worth a patient, steady walk up a 30 meter elevation (~100 ft) over about a 0.2 km (0.12 miles) distance. If the day is dry and the path is clear, the walk up the stream bed is the preferred path. Once past the boulder talus and alluvial apron at the creek's mouth, fractured and shattered Lockatong Formation outcrops can be seen continuing up the stream for over 1 kilometer. This sequence of argillite has some unique brittle structures that obscure a late-extension stage or river-parallel faulting (fig. 35A), and a brittle overprint of some shatter cones with unusual tension gashes that may stem from an ancient bolide (asteroid or meteor) impact (see Chapter 4; Herman, 2015).

Prior Work

This area of the Delaware River valley has been previously studied and noted by many workers, including Lewis (1909) in a report regarding building stones of New Jersey. He described the Lockatong Formation within the quarry immediately north of this STOP as the 'Byram argillite':

"... dark slate-colored to brownish-black argillite, which is more massive that that at Princeton and Lawrenceville, and does not readily split into flat slabs or blocks suitable for building. Hence it is crushed for concrete, railroad ballast, etc. Beds occur 10 to 40 feet thick, which are entirely massive, and the stone breaks with a conchoidal fracture like dense flint… The beds dip 8 degrees toward the north (strike N. 80^o E). Calcite veins and pyrite nodules are abundant in parts of the quarry. Many of the joints are lined with beautiful radial clusters of the mineral laumontite, which quickly loses its water of crystallization on exposure to the air and crumbles away….Under the microscope this rock crystallized into a dense aggregate of fine flakes of brown mica and granular scapolite, feldspar, and calcite --- a typical hornfel."*

* $CaAl_2Si_4O_{12}\cdot 4H_2O$ – Zeolite tectosilicate

The geological popularity of this area is spurred on by the extensive bedrock cliffs and ledges flanking the Delaware River and deep ravines cuts into the flanking Hunterdon Plateau by creeks, including the Lockatong and Wickecheoke. These conditions have facilitated close inspection of the Triassic strata in this central part of the basin as a continuous section. Dean

McLaughlin with the University of Michigan in the 1930's and 40's and Franklin Van Houten of Princeton University in the 1960's through 80's developed representative stratigraphic sections for this area as part of their work on formalizing the Triassic section in the basin. McLaughlin (1946) mentioned the creeks cutting deep gorges in the escarpment since their rejuvenation by uplift and "their upper courses have cut but little below the old erosion surface". They both noted the nearby stratigraphic transition from a lacustrine setting for the dark gray, muddy argillites of the Lockatong Formation into the subaerial mudflat environment for the red shale of the Passaic Formation.

McLaughlin (1944) also noted here that the two river-bank sections correlate closely with no appreciable offset of the beds from cross-strike faulting (in the river), but then he also asserts that "the evidence is equally convincing as regards absence of significant strike faults." As noted below, this is not the case, as we will see evidence of multiple, cross-strike faults paralleling the river here, as well as strike-parallel faulting noted by Van Houten (1987). The latter documented these cuts for a centennial field guide for the Northeast Section of the Geological Society of America. He noted that this section contains the 'Byram sill' in predominantly dark-gray and brown argillite that is only a few hundred feet above the lower

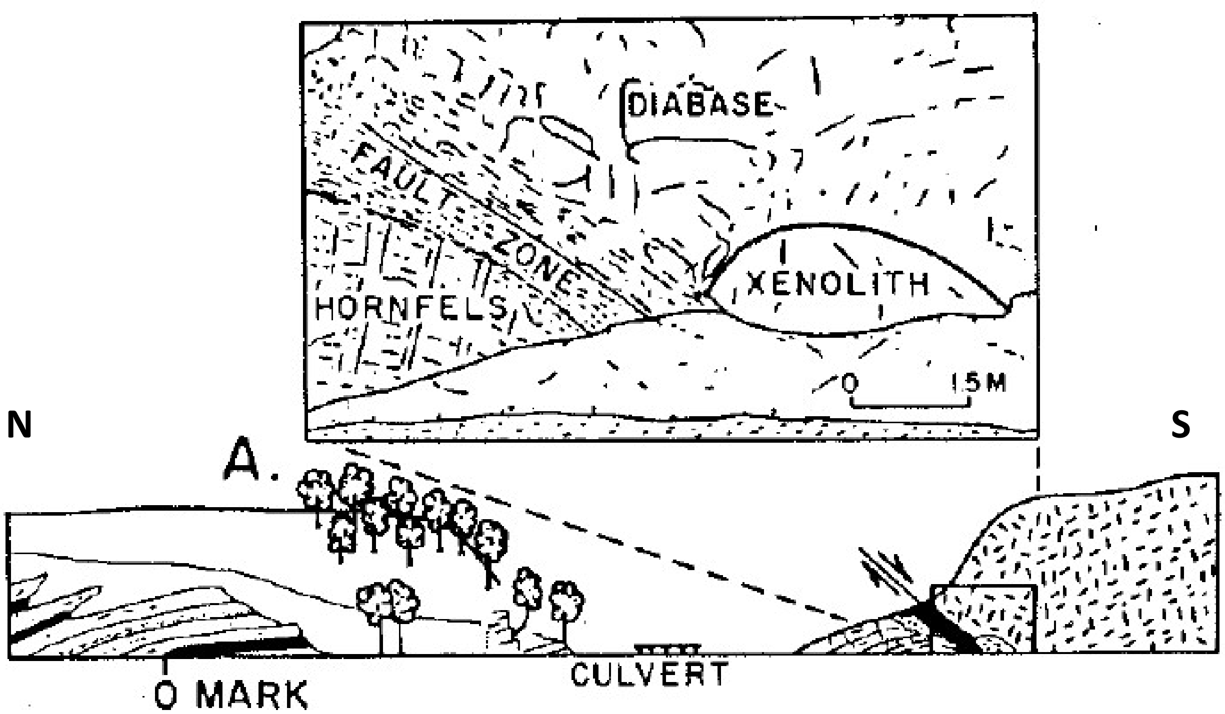

Figure 34. N-S cross section by Van Houten (1987) along Route 29. Note the synthetic, normal fault to the SE dropping dolerite down in contact with the Lockatong Formation. The detailed inset shows a Lockatong xenolith in the basal trap along the fault. We will visit this fault first before heading east up the trail.

contact with the Stockton Sandstone. He depicted this sill as being ~35 m thickness as part of a representative stratigraphic section. His cross section for this site parallels the river (NNW-SSE) and depicts a normal, synthetic fault cutting, offsetting, and repeating the sill (fig. 34). He also notes the occurrence of what he called "upward-concave surfaces and thin zones of shearing in tent-like structures 6 to 12 in (15 to 30 cm) high recurring laterally in wave lengths of 1.5 to 3.0 ft (0.5 to 1 m)", but offered no sketches or pictures of these features.

Michael Hozik has been using this site as a field laboratory for his Stockton University Field Geology class for many years. In addition to the obvious easterly-striking normal fault along the stream, they have documented several north striking oblique slip faults. Evidence for these will be presented as we hike up the stream.

NJGWS 1:24,000 Map Data

As noted previously, detailed geological mapping in the New Jersey part of the Lumberville 7-1/2' quadrangle is currently underway by the NJGWS for publication. The structural data presented here represent a small subset of the data collected in September 2014. These data are available for download at www.ganj.org/2015/Data.html. Figure 33B shows that the mapped shape of the trap body has been redefined and figures 37-39 detail some of the structural relationships mapped and photographed here.

STOP 4 Traverse

PLEASE BE CAREFUL, PROCEED SLOWLY, and DON'T HESITATE TO ASK FOR ASSISSTANCE IN NAVIGATING THE LEDGES AND BENCHES.

This stop includes a moderately difficult hike up the stream bed that will include hopping on boulders to cross the stream if you want to keep your feet dry. If not, plan on becoming wet and bring a change of dry socks and shoes. Hiking boots are a must as this hike involves climbing a 3 to 5-ft crevace cut through bedrock ledges and benches in the creek bed. Once we arrive at the upper level, across the fault trace, the argillite beds dip gently NW, and the creek flows along the bed tops.

THESE BEDS ARE SLIPPERY SO AGAIN, PLEASE PROCEED WITH CAUTION.

If you are not up for the hike up the creek bed, there is an alternative trail just to the North of the creek, along Route 29. This trail follows up a short, steep bank uphill to the old

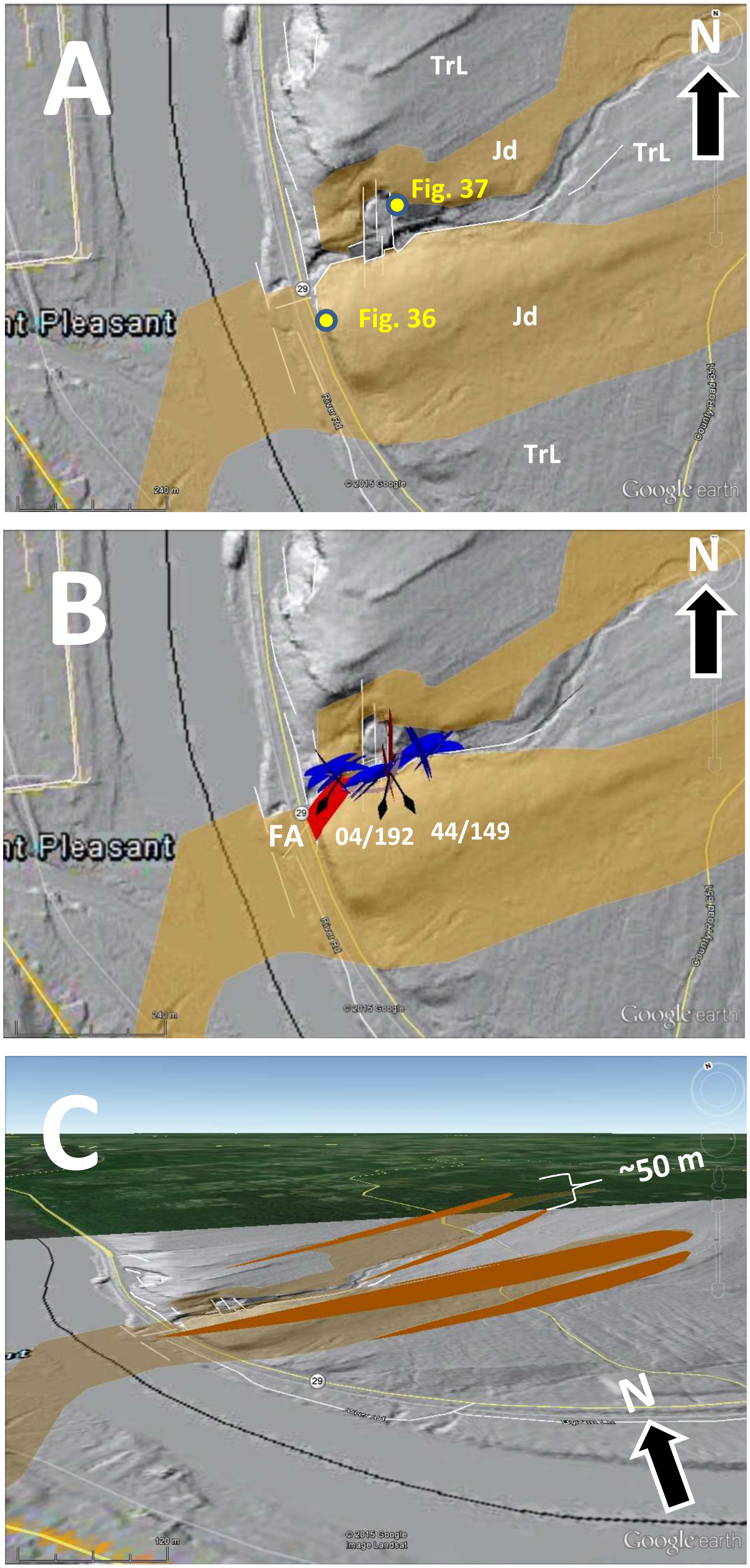

Figure 35. GE displays of STOP 4. **A.** PASDA LiDAR grayscale hill-shade image overlay with dolerite bodies mapped at the 1:24,000 scale as light-orange polygons. Note the locations of photographs shown in the next two figures. The stream largely follows a long, thin splinter of Lockatong Formation argillite (Trl) along a fault that offsets a thin dolerite sill. This body had been previously mapped as a continuous sill, as shown in fig. 33A. White, straight lines highlight two faults sets, one striking E-W along the stream, and many other's running N-S parallel to the river.

B. Same view as A but showing the 3D colored ellipses representing joints (blue) and faults (red). 2D black arrows represent a fold axis (FA) and slip lineation, or slickenlines noting plunge and trend. Each structural is about 100-m long. Elliptical planes are scaled 50% in the dip direction to accentuate strike

C. Obliquely tilted view looking NNE of the faulted and tilted sill. Orange circular disks were manually fit to the nonconformities to show that the body is about 50 meters thick here.

quarry trail. You can can follow this trail about a kilometer but will still need to descend down to the creek from above. This alternative trail can be very challenging as well.

Or, if you are hesitant to embark on a hike of moderate difficulty, we recommend sitting some or all of this hike out. You won't be bored if you do; the road cuts in the dolerite here are very interesting and include blueberry-sized black tourmaline nodules in the compositional layering seen at road level (fig. 36).

Before we start up the stream channel, it is worth walking a short distance to the south to view the major normal fault in outcrop. Our first stop, located near the entrance to the D&R Trail, is marked by a wooden sign and bulletin board. Outcrop along the road immediately to he south show gently dipping dolerite overlying and in fault contact with the argillite to the NW as portrayed in cross section by Van Houten (fig. 34). The southerly dip of the fault is obvious,

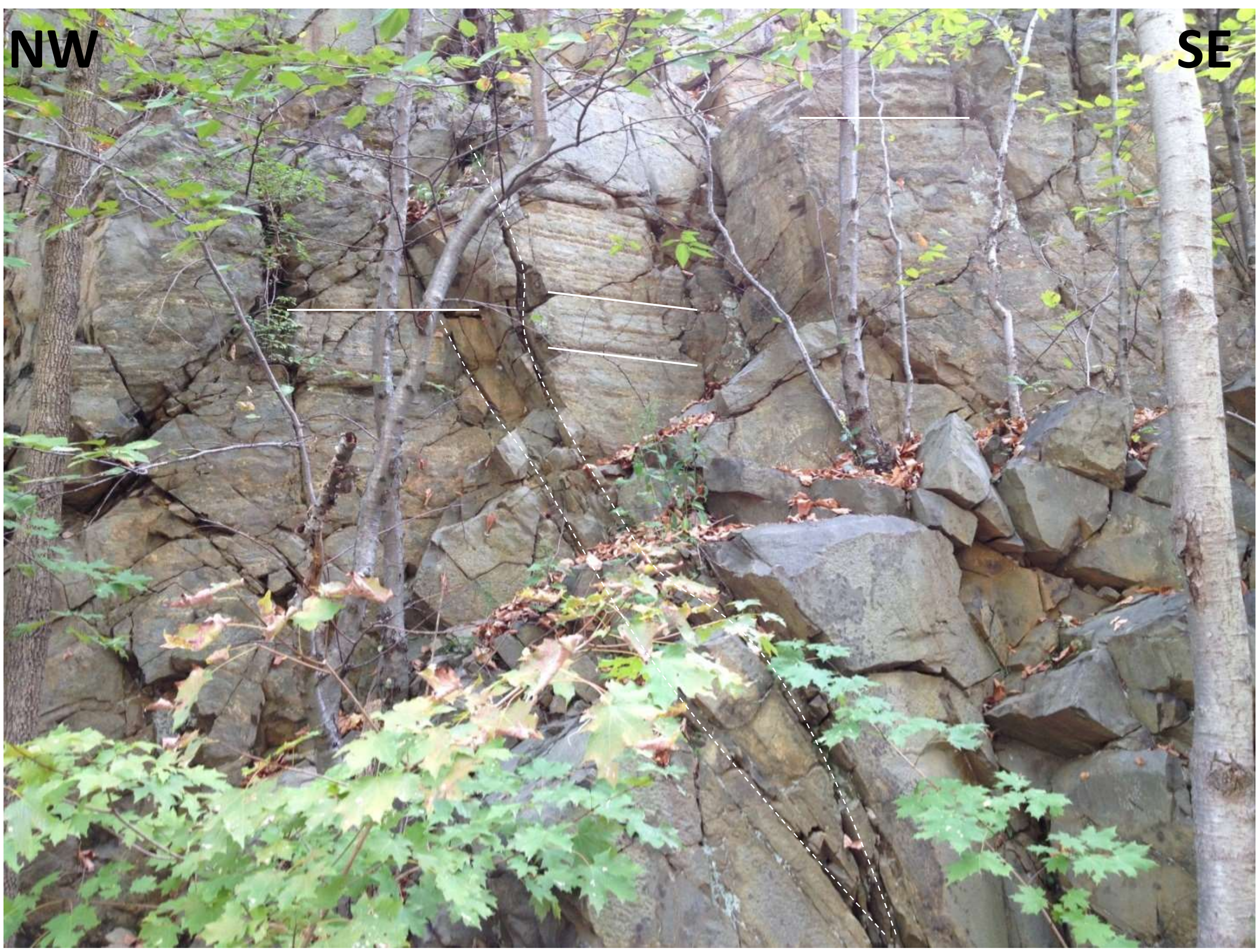

Figure 36. Outcrop along Route 29 North showing compositional layering highlighted with solid white lines dipping gently NE and small splay faults with normal slip dipping steeply SE that highlighted with white dashed lines.

Figure 37. Outcrops location noted in re along the upper bench on the Northeast cut face. The shatter-cone features occur at different places throughout the Lockatong for the full length of the stream and fault to the point where outcrop is lost under alluvium. The dark gray argillite is so dense that no discernible internal structure can be seen other than a peculiar, rolling, linear fracture pattern. The argillite splinters when the rock is cracked open.

A. Certain sections are shattered on steeply dipping planes and sub-horizontal, bed-sub parallel gashes**.**

B. The conical features radiate inward from gash edges and meet along suture lines where cones merge with flat tops (center by folded eyeglasses).

C. When they remain open and do not meet, they terminate as cones.

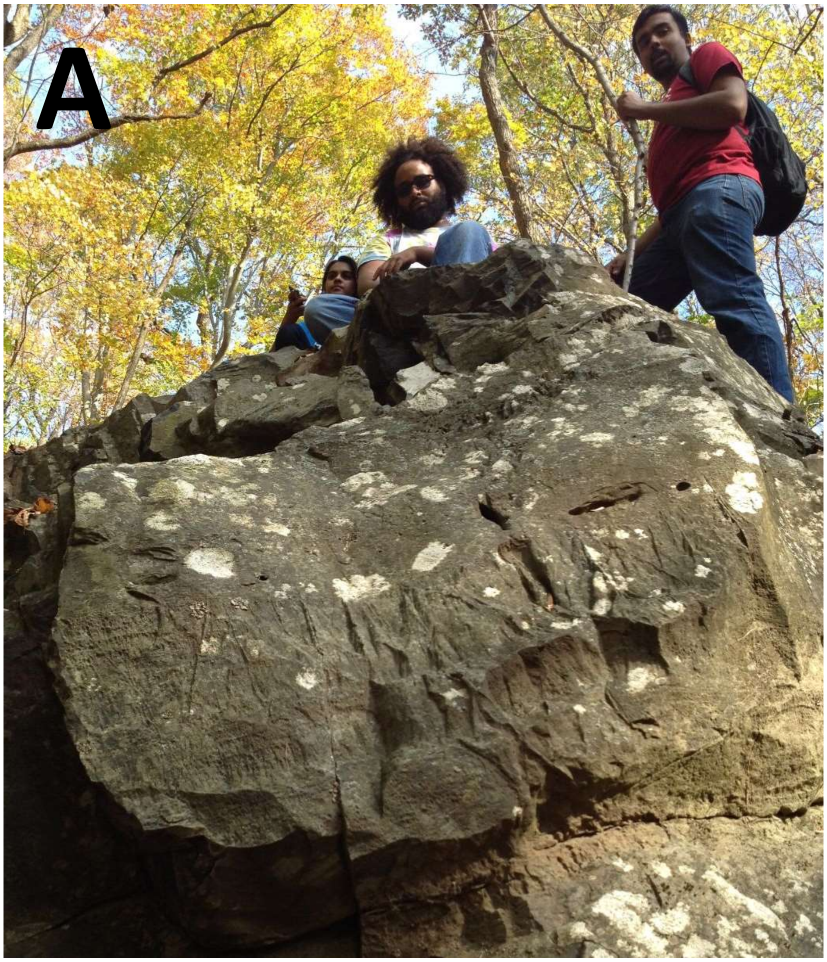

Figure 38. Photographs of the shattercones.

A. View looking NE of a Lockatong bed dipping gently NW. Atop the bed are Rider University geology students Suvarna, Paul, and Muhammad. Note the cone-shaped fractured patter in the lower meter of the bed and the sutured lower contact.

B. A large piece of shattered argillite float found in the stream bed showing some of the best morphology of these cone structures that we could photograph.

as is parallel fracturing in the diabase. More importantly, the bedding in the argillite is dragged toward parallelism with the fault, indicating normal motion on the fault.

Soon after the wooden sign, the trail breaks uphill and the scrambling begins. Prcoceeding up the ravine, Lockatong argillite is first seen as a gently NW-diping pavement in the stream bed. Some of the first of a set of unusaul, cone-shaped structures are visible at the very base of the northern stream in joint faces immediately below the lower nonconfomrity mapped about 1/3 of the way up the stream on the north side. These small, subtle features are only teasers for the more pristine versions exposed farther up the traverse as shown in figure 37 and 38. From here the traverse remains completely in argillite, except for the dolerite

A short way up the stream, the channel widens into a pool. The east side of the pool is dolerite, and if we are able to proceed eastward along the stream there is dolerite on both the north and south sides of the channel. Hozik interprets this as evidence for a north-striking oblique-slip fault intersecting the main east-striking normal fault. In this section of channel, it is worth noting the extensive jointing.

Continuing eastward along the stream, the channel gets steeper, and we will reach a prominent step that has to be climbed. On top of this bench are more of the features mentioned near the start of the traverse. Additionally, the north wall of the channel is argillite, while the east wall is dolerite float. Hozik interprets this as indicative of a second north-striking oblique-slip fault. Slickenlines measured on a fault in the quarry on the bench above this locality plunge gently to the south.

Continuing farther up the stream, nearly to the level of the base of the dolerite, one can observe that the bedding in the argillite has a much less steep dip than in the north wall of the channel. Hozik interprets this as drag indicating normal motion on the east-striking fault in the vicinity of the stream. If we have sufficient time to continue farther upstream, we will see a small area where argillite again crops out in a small area. Hozik suggests that this is another indication of a third north-striking oblique-slip fault.

We finally return to the buses and proceed back to the parking lot in Flemington.

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