STOP 2. Youngest structural features in the Hopewell fault zone at Mercer County Park, 41 Valley Road, Hopewell Twp., Mercer County, NJ

WATERPROOF BOOTS AND/OR A CHANGE OF SOCKS ARE RECOMMENDED FOR THIS STOP!!

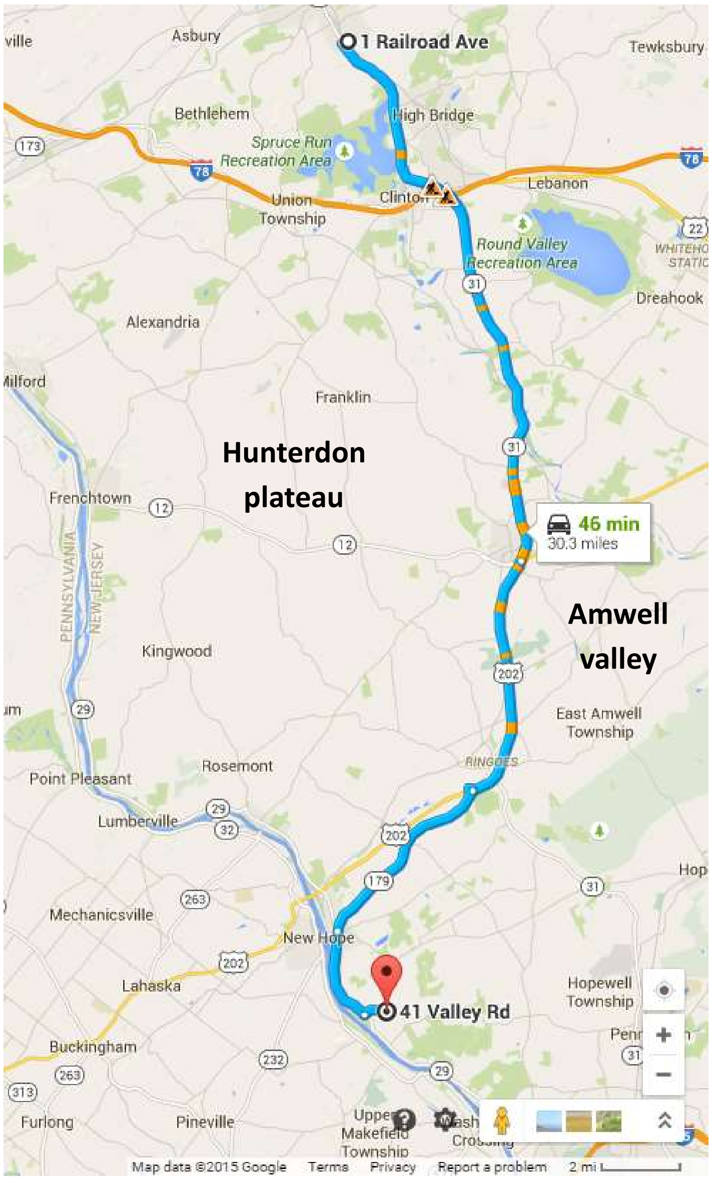


Figure 16. Google maps display of the route from STOP 1 to STOP 2. From Railroad Ave in Glen Gardner take Route 31 South to Route 202 South at Flemington towards, then Route 179 South to Valley Road.

In leaving the Glen Garner quarry, we proceed south along NJ Route 31 South to US Route 202 South towards Lambertville, NJ and STOP 2 at 41 Valley Road (fig. 16). We are using Mercer County Park at Valley Road (fig. 17) for STOP 2 and lunch afterwards. STOP 2 is a traverse in and along the stream running alongside the western side of the park. After this hike, we get out of the stream bed near the pavilion for lunch. Afterwards, we'll drive a very short distance to STOP 3 to collect some minerals in Trap Rock Industries (TRI) Moore's Station quarry.

The route from STOP 1 to STOP 2 crosses the boundary between the Highlands and Piedmont physiographic provinces that correspond with the system of border faults separating crystalline uplands of the Reading Prong from shale lowlands of the Newark Basin. After crossing the border fault near Clinton, NJ, we drive south along the Flemington fault system. To your right is the Hunterdon Plateau, an upland propped up by the relatively resistant, indurated black, gray and red argillite of the Lockatong Formation, a thick, deep-lacustrine mud rock deposited in deep lakes within the subsiding Newark rift basin. This unit was once deeply buried and has been uplifted or structurally inverted to its present position sometime after it was deposited and buried during the Triassic period. Beneath you and to your left, red shale of the Passaic Formation underlies most of the Amwell Valley in the hanging-wall block of the Flemington fault.

We take the NJ Route 29 (Lambertville-Stockton) exit off of US Route 202, and proceed about 3.5 miles South on Daniel Bray Highway (NJ Route 29) to Valley Road. We turn left onto Valley Road and drive east for ~0.8 miles to 48 Valley Road. The park entrance will be on your right (fig. 17A). Figure 17B shows the pavilion where we end STOP 2 and assemble for lunch.

Figure 17. Photographs of Mercer County Park

A. Entrance looking south from Valley Road.

B. South view of the picnic area just beyond the park entrance. The stream runs North to South in the tree line to the right (west).

Figure 18 details the bedrock geology in the area and places STOPS 2 and 3 in perspective with the Hopewell fault system. As seen in figures 18 -20, the main traces of the Flemington, Hopewell, and Furlong faults are highlighted to show how they branch, splay, and interconnect as part of an intrabasinal *fault system*.

STOP 2 is a walk within and along the creek bed of a tributary to Moore's Creek that cuts across the main Hopewell fault trace and reveals the many complexities surrounding the Hopewell fault system (figs. 21 and 22). Prior versions of the 1:100,000 –scale bedrock geology (figure 18; Owens and others, 1998) have lately been modified based on more recent detailed mapping at the 1:24,000 scale (figs. 20-22). This year's conference highlights this recent work and ties together strata and structures across the river into Buck's County Pennsylvania (fig. 19) with a new interpretation that includes LiDAR hill-shaded imagery (fig. 19 and /www.ganj.org/2015/Data.html). With these updates, mismatch stratigraphic units across the river have tentatively been resolved, and more accurate depictions of the fault system are available for review and interim use in GE (www.ganj.org/2015/Data.html).

STOP 2 begins by crossing Valley Road and entering the tributary on the North side of the bridge abutment. Lockatong argillite is exposed intermittently in the stream here that strikes at high angles to the fault trace and dips steeply west (figs. 21-22). It can be difficult to see bedding in these rocks for they are highly fractured and strained. Our primary goal is to proceed as quickly and quietly as we can up the stream for about 500 meters, while keeping mindful of the slippery rock conditions. There will be a few places where you will need to cross the shallow and intermittently flowing stream to proceed among the bank flora.

Our destination is a series of ~1-meter high benches and bedrock ridges running parallel to the stream that show late-stage, cross-cutting compressional structures discordantly cutting and offsetting all earlier fault, bed, and fold structures (fig. 23). This sequence of Lockatong beds is probably a middle section of the roughly, 2000-ft thick argillite sequence of the Lockatong Formation (fig. 20). The member exposed here has not been determined. One can best see sedimentary bedding on the joint faces striking normal to the stream when looking North (upstream). Many primary sedimentary features are apparent including mud cracks and other desiccation features within dark- and light-gray, red, and tan argillite that is severely fractured.

The benches and ridges that we focus on dip about 45^{o}W and spatially bracketed by the more steeply dipping beds to the SE (~65^{o}W) and more gently dipping beds to the NW (~22^{o}NW). Regional, gentle dips less than 20^{o}NW occur at a distance of over 600 meters from the trace of the Hopewell fault into the footwall block to the NW, and attests to the distributed, penetrative nature of the strain along this complex fault system (figs. 21-22). In addition to the late-stage (neotectonic?), folded joints, we also see brittle deformation zones occurring from isolated fault splays striking parallel to the main trace of the Hopewell fault here (~N40E) and other later-stage faults generally showing southeastern to eastern normal and oblique slip (figs. 20-24).

The late-stage structures are small and upright, but moderately plunging crenulations and mineral veins in bedrock (figs. 23-24) that qualify, from my perspective, as the relatively

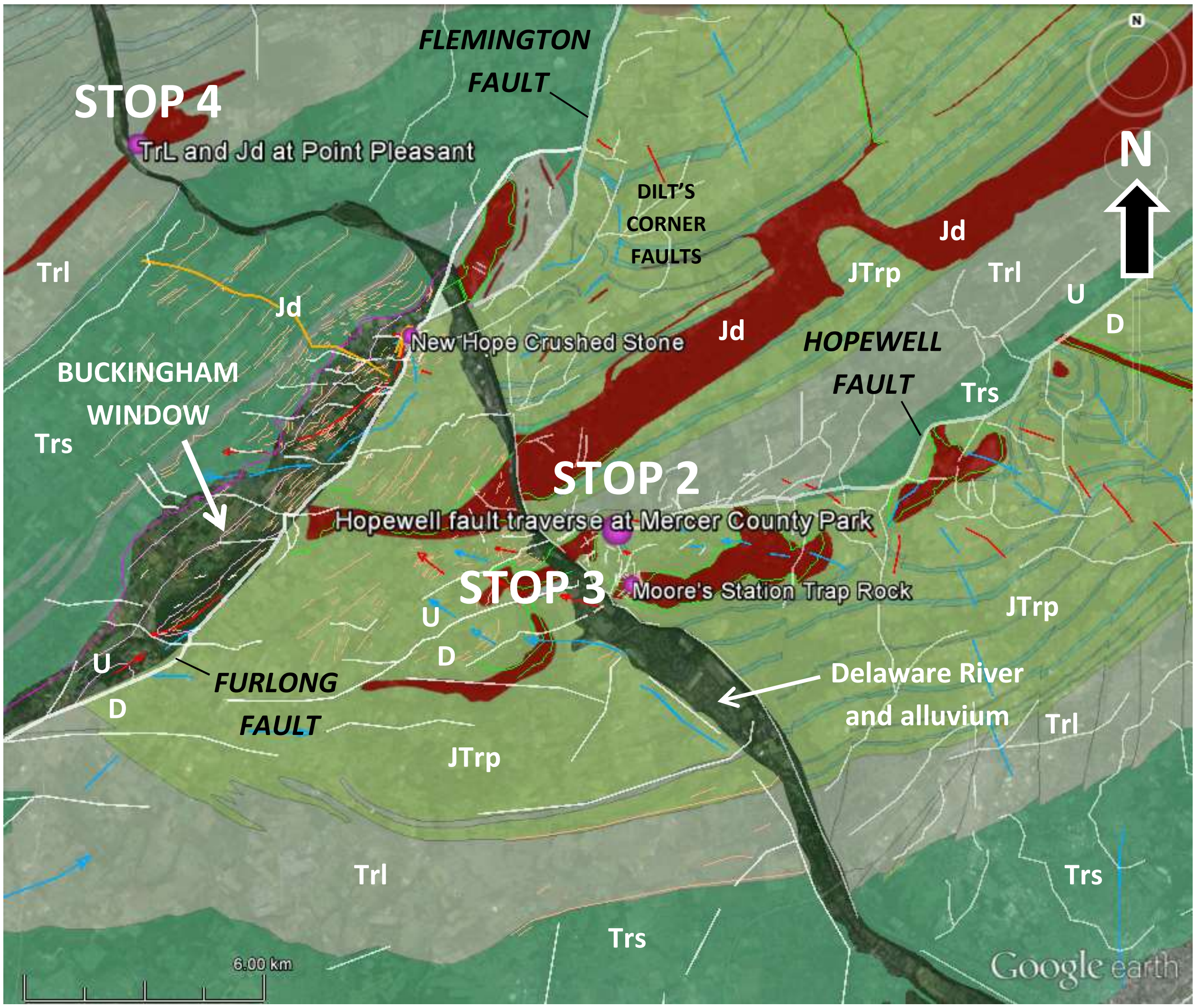


Figure 18. GE map showing the integrated USGS bedrock geology of the Delaware River valley near STOPS 2 and 3 and the confluence of the Flemington, Furlong, and Hopewell faults. Lower Paleozoic carbonate and quartzite crop out in the Buckingham window, whereas the course of Delaware River is covered by water and alluvium. The colored and white line traces are structural interpretations that used LiDAR hill-shaded imagery, as shown in figures 19 and 22. Line colors: Green – contacts, Tan - bedrock ridges, Red – anticline, Blue – syncline, White - faults. Note the varying fault interpretations in the lower right hand corner between prior and revised interpretations. Jd – Jurassic dolerite, JTrp – Passaic Formation, Trl – Triassic Lockatong Formation, Trs – Triassic Stockton Formation. The darker-green striping in the Lockatong and Passaic Formation are gray-bed sequences.

youngest tectonic structures seen in Triassic rocks. They have not been absolutely dated;

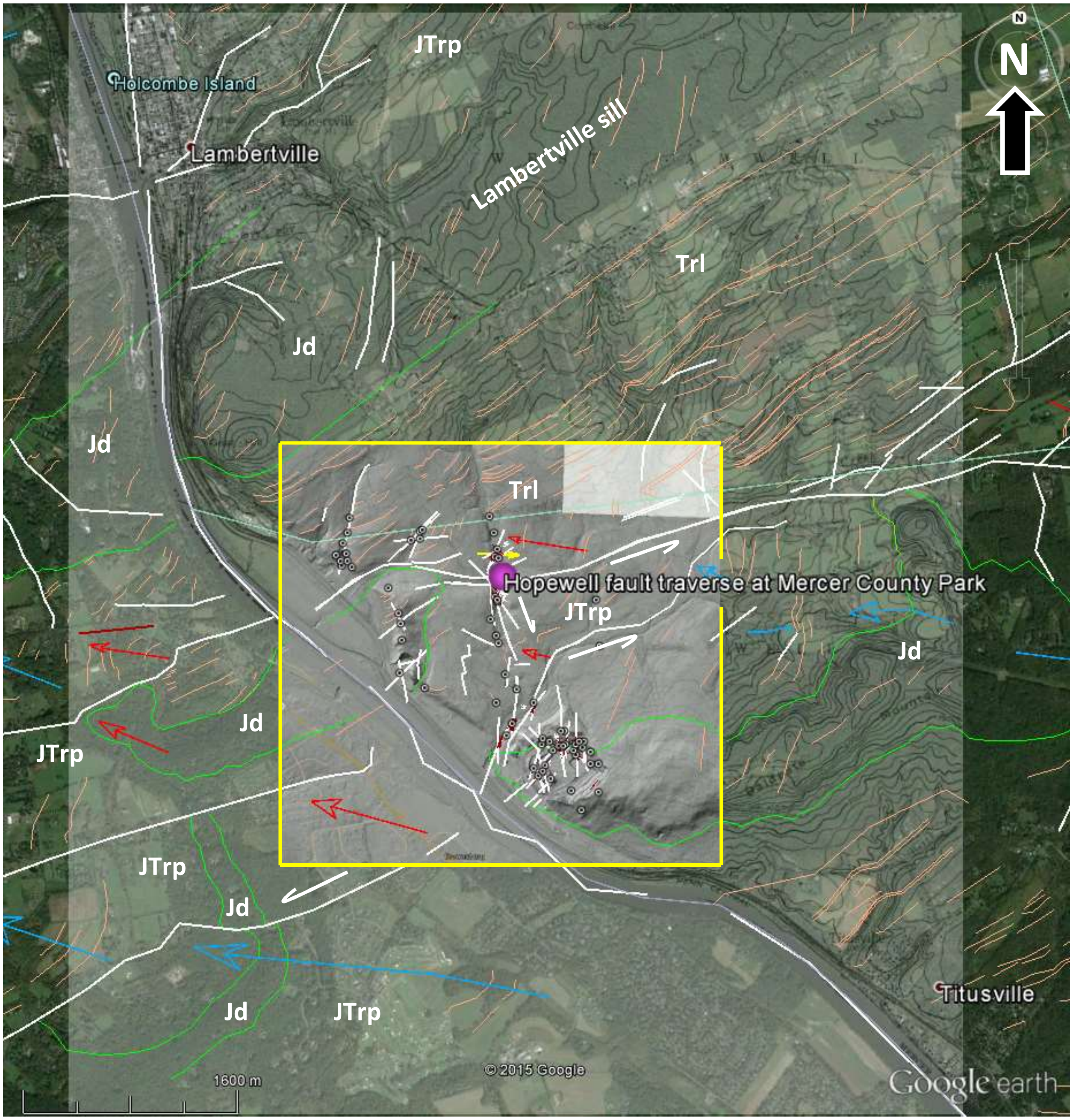


Figure 19. GE map of the area of focus for STOP 2 and 3 showing PASDA LiDAR hill shade imagery and geological interpretations, including structural details of component faults within the Hopewell fault system. Note the apparent stratigraphic offset of the sedimentary contact with trap rock (green lines) across the Delaware River and the likelihood of having river-parallel shear fractures accounting for the offset. Unit abbreviations and line colors are the same as those noted in figure 18.

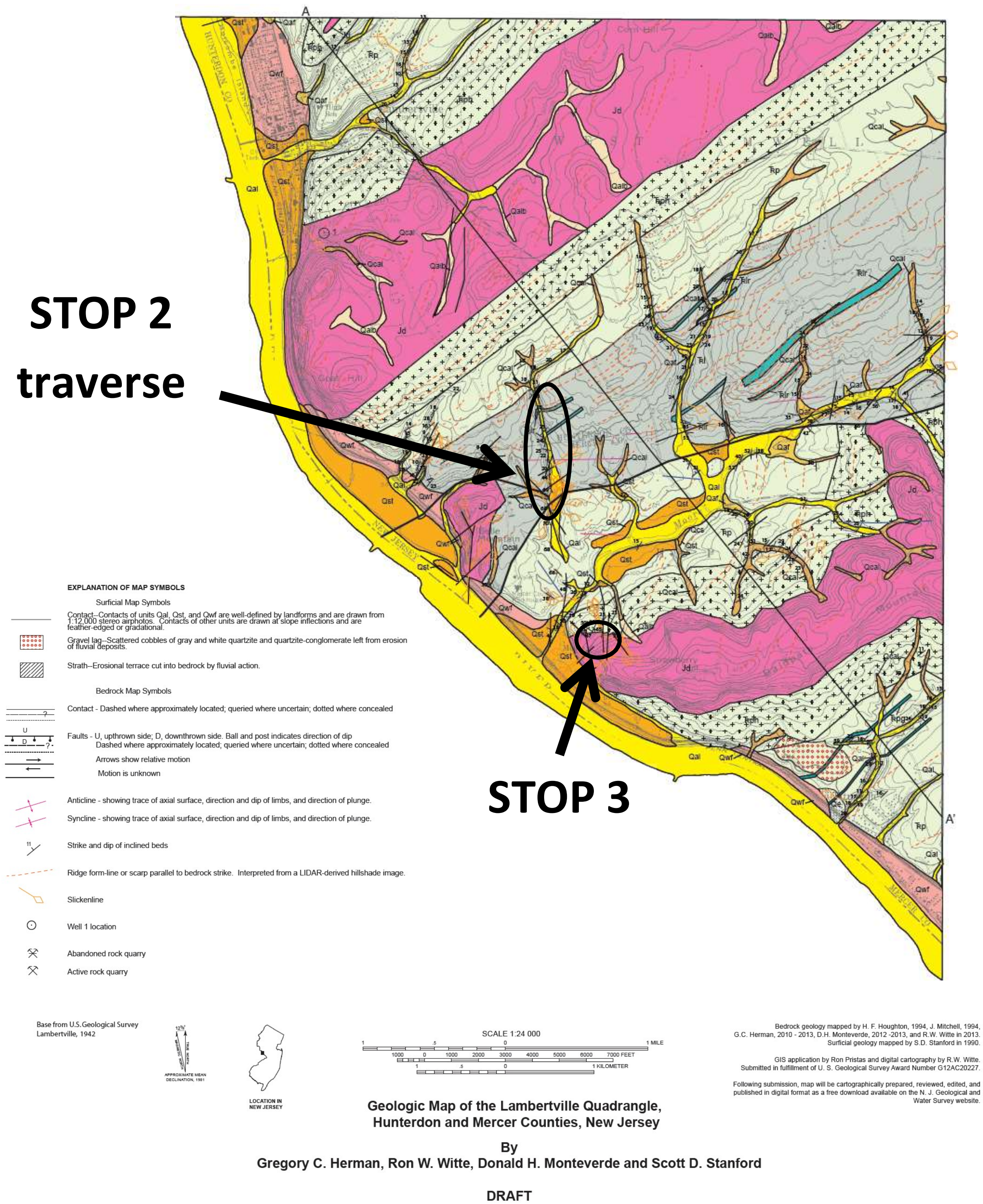


Figure 20. Excerpt from part of the draft, open-file NJGWS 1:24,000-scale Geological Map of Lambertville Quadrangle, showing the locations of STOPS 2 & 3. Unit legend is on opposite page.

DESCRIPTIONS OF MAP UNITS

Qal Alluvium -- Silt, pebble-to-cobble gravel, minor fine sand and clay. Moderately to well-sorted and stratified. Contains minor amounts of organic matter. Color of fine sediment is reddish-brown to brown, locally yellowish-brown. Gravel is dominantly flagstones and chips of red and gray shale and mudstone with minor pebbles and cobbles of basalt, diabase, sandstone, and hornfels. Silt, fine sand, and clay occur as overbank deposits on floodplains along low-gradient stream reaches. Overbank silts are sparse or absent along steeper stream reaches. Gravel is deposited in stream channels and is the dominant floodplain material along steeper stream reaches. Flagstone gravel typically shows strong imbrication. As much as 10 feet thick.

Qalb Alluvium and boulder lag -- Silt, sand, minor clay and organic matter, dark brown, brown, yellowish-brown, reddish-yellow, moderately sorted, weakly stratified, overlying and alternating with surface concentrations (lags) of rounded to subrounded diabase (and, in places, hornfels) boulders and cobbles. As much as 10 feet thick (estimated). Formed by washing of weathered diabase and hornfels by surface water and groundwater seepage.

Qcal Colluvium and alluvium, undivided -- Interbedded alluvium as in unit Qal and colluvium as in unit Qcs in narrow headwater valleys. As much as 10 feet thick (estimated).

Qaf Alluvial fan deposits -- Flagstone gravel as in unit Qal and minor reddish-brown silt and fine sand. Moderately sorted and stratified. As much as 15 feet thick. Form fans at mouths of steep tributary streams.

Qst Stream-terrace deposits -- Silt, fine sand, and pebble-to-cobble gravel, moderately sorted, weakly stratified. Deposits in the Neshanic River basin are chiefly reddish-yellow to reddish-brown silt with minor fine sand and trace of red and gray shale, mudstone, and sandstone pebble gravel, and are generally less than 10 feet thick. They form terraces 5 to 10 feet above the modern floodplain and are likely of late Wisconsinan age. Deposits along the Delaware River are chiefly yellowish-brown silt and fine sand as much as 25 feet thick that form a terrace 15 to 20 feet above the modern floodplain. They rest on a strath cut into the glaciofluvial gravel (unit Qwf) and so are of postglacial age. Deposits along Wickecheoke Creek are dominantly flagstone gravel and minor reddish-brown silt and fine sand. They are as much as 15 feet thick and form terraces 5 to 10 feet above the modern floodplain. They are likely of both late Wisconsinan and postglacial age.

Qe Eolian deposits -- Silt and very fine-to-fine sand, reddish yellow. Well-sorted, nonstratified. As much as 5 feet thick. These are windblown deposits blown from the glaciofluvial plain in the Delaware River valley.

Qwf Glaciofluvial deposit -- Pebble-to-cobble gravel and pebbly sand, moderately to well-sorted and stratified. Sand is yellowish-brown, brown, light gray. Gravel includes chiefly red and gray mudstone and sandstone, gray and white quartzite and conglomerate, and some gray and white gneiss, dark gray chert, and dark gray diabase. As much as 40 feet thick. Forms an eroded plain in the Delaware River valley with a top surface about 35-40 feet above the modern floodplain. Deposited by glacial meltwater descending the Delaware River valley during the late Wisconsinan glaciation.

Jd Diabase (Lower Jurassic) -- Fine-grained to aphanitic dikes (?) and sills and medium-grained, discordant, sheet-like intrusion of dark-gray to dark greenish-gray, sub-ophitic diabase; massive-textured, hard, and sparsely fractured. Composed dominantly of plagioclase, clinopyroxene, and opaque minerals. Contacts are typically fine-grained, display chilled, sharp margins and may be vesicular adja-cent to enclosing sedimentary rock. Exposed in map area in sills, southeast of Stockton and east of Lambertville, and in the Sourland Mountain diabase sheet on the southern edge of the mapped area. This sheet may be the southern extension of the Palisades sill. The thickness of the Rocky Hill diabase in the quadrangle, known mainly from drill-hole data, is approximately 1,325 feet.

Ʀp **Ʀpg** **Ʀph** Passaic Formation - (Lower Jurassic and Upper Triassic) (Olsen, 1980) - Interbedded sequence of reddish-brown to maroon and purple, fine-grained sandstone, siltstone, shaly siltstone, silty mudstone and mudstone, separated by interbedded olive-gray, dark-gray, or black siltstone, silty mudstone, shale and lesser silty argillite. Reddish-brown siltstone is medium- to fine-grained, thin- to medium-bedded, planar to cross-bedded, micaceous, locally containing mud cracks, ripple cross-lamination, root casts and load casts. Shaly siltstone, silty mudstone, and mudstone form rhythmically fining upward sequences up to 15 feet thick. They are fine-grained, very-thin- to thin-bedded, planar to ripple cross-laminated, fissile, locally bioturbated, and locally contain evaporate minerals. Gray bed sequences (JƦpg) are medium- to fine-grained, thin- to medium-bedded, planar to cross-bedded siltstone and silty mudstone. Gray to black mudstone, shale and argillite are laminated to thin-bedded, and commonly grade upwards into desiccated purple to reddish-brown siltstone to mudstone. Thickness of gray bed sequences ranges from less than 1 foot to several feet thick. Several inches of unit have been thermally metamorphosed along contact with Orange Mountain Basalt (Jo). Thicker thermally metamorphosed sections(JƦph) exist on the southern flank of Sourland Mountain, on the southern part of the mapped area. Unit is approximately 11,000 feet thick in the map area.

Ʀl **Ʀlr** Lockatong Formation (Upper Triassic) (Kummel, 1897) - Cyclically deposited sequences of mainly gray to greenish-gray, and in upper part of unit, locally reddish-brown siltstone to silty argillite (Ʀlr) and dark-gray to black shale and mudstone. Siltstone is medium- to fine-grained, thin-bedded, planar to cross-bedded with mud cracks, ripple cross-laminations and locally abundant pyrite. Shale and mudstone are very thin-bedded to thin laminated, platy, locally containing desiccation features. Lower contact gradational into Stockton Formation and placed at base of lowest continuous black siltstone bed (Olsen, 1980). Maximum thickness of unit regionally is about 2,200 feet (Parker and Houghton, 1990).

however, as shown here, they cross-cut all other structures and fold pre-existing extension fractures (joints). The simple fact that they are discordant structures that plunge the opposite direction from encompassing, large bed flexures and folds in Triassic bedrock, suggests that these features stem from a completely different stressor, one seemingly reflective of a crustal contraction event directed about N-S.

After spending about ½ hour at the northern end of this traverse (fig.22 location A) we return back down the stream, and either walk under the bridge, or if the stream flow is too high, go up and over the bridge to continue southward in the creek to see fault-proximal Lockatong gray breccia and sheared red shale of the Passaic Formation (fig. 22 traverse B). Immediately after passing under the bridge, brecciated and tectonized gray argillite of the Lockatong Formation is seen in about a 20-meter span, before crossing over the concealed Hopewell fault and further on to fractured red beds of the Passaic Formation (fig. 24). This section of sheared red mudstone is a middle section of the Passaic Formation about 11,000-foot thick in the region (fig. 20). As for the footwall at location A, the formation member here is undetermined.

The most noticeable features in the first outcrops of red beds that we see are the network of brittle, steeply-dipping, slickensided shear planes that form irregular faces paralleling the stream banks dip steeply (fig. 24A). The planes are mineralized with streaks of green epidote and chlorite, and white calcite that are streaked with slickenlines plunging gently to moderately east to northeast. Bedding is difficult to see here, as the fracturing is dominant and causes the red beds to break and spall into the creek. Be careful when hammering these rocks, especially with other people around you as they can easily spill into the creek and onto feet in a crowd. Figure 24B shows the next outcrop located about 50 m south along the creek bed, but these outcrops are commonly overgrown or laden with debris from storms, so we will probably not venture beyond the first set of red beds before climbing up the eastern bank of the creek and heading over to the pavilion for lunch.

An MS-Excel worksheet including field stations, their spatial coordinates, and measured structures for this area is available at www.ganj.org/2015/Data.html. This worksheet covers the area of STOPS 2 and 3 and contains 256 structural readings, geospatial coordinates in WGS84 decimal degrees, and lists of structural attributes. Three-dimensional (3D) planar objects were plotted in GE, where they were measured in outcrop using the same methods as outlined for STOP 1. Figures 21 and 22 show the results of generating 2D bed symbols and 3D planes representing igneous compositional layering (pink) and faults (red) and using them in GE to help map geological structures.

For lunch, we will take about 45 minutes to eat and cleanup before heading back to the bus for departure to STOP 3.

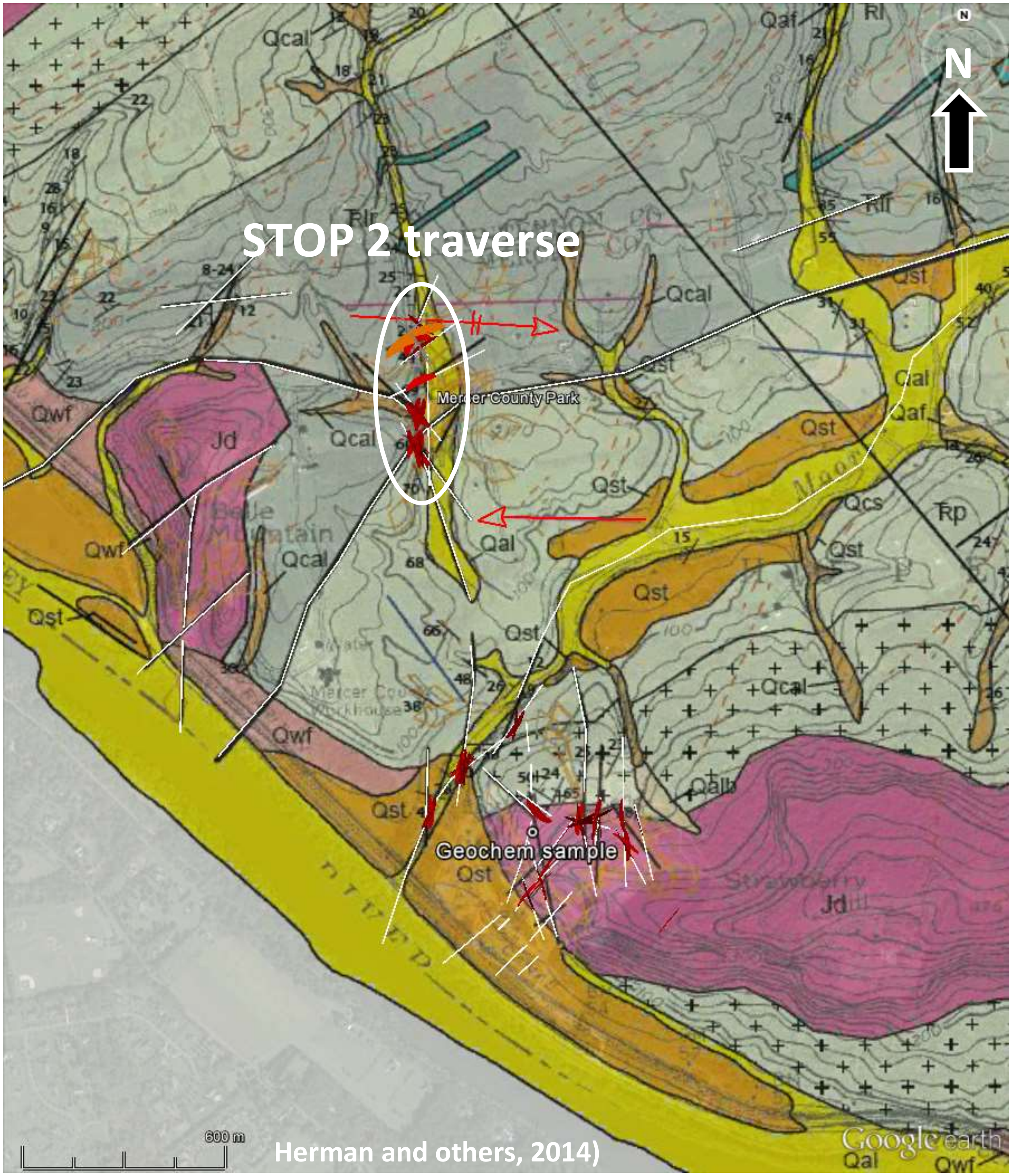


Figure 21. Part of the NJGWS Lambertville Geological Map (fig. 20). A JPEG version of the Open-File, digital map was register in GE and is shown here with traces of faults (white lines) digitized in GE, and 3D fault that are portrayed using 100 x 50 m red ellipses (collada 3D circle object model s scaled with a 2:1 strike:dip aspect ratio). *Note* the faint, pink line on the map below the words 'STOP 2 traverse' is the draft version of the late-stage fold trend. The map legend key is included on figure 20.

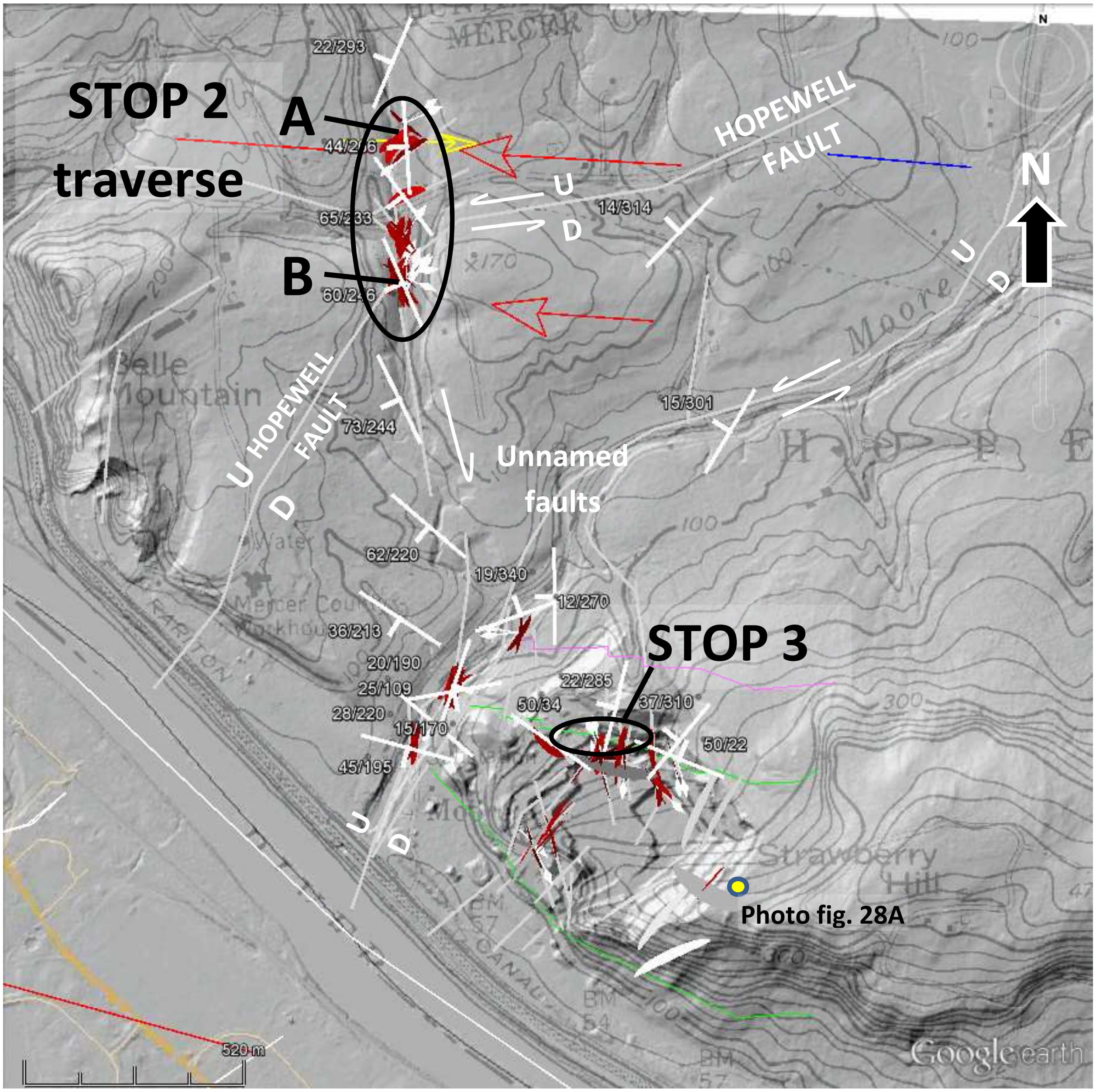
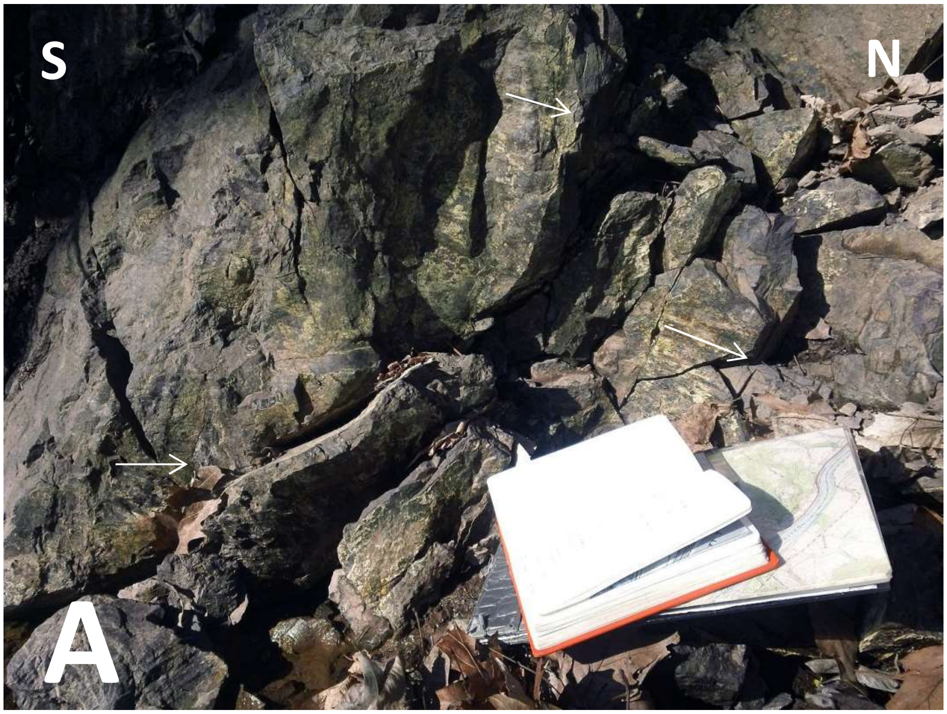


Figure 22. GE display of the area covering STOP 2 and 3. A PASDA LiDAR, gray, hill-shaded image is overlain by a monochromatic, 1:24,000-scale, Lambertville, NJ-PA 7-1/2' USGS topographic quadrangle set at 50% transparency. The topography reflects old quarry activity on the west end of Strawberry Hill, with more recent bench cuts visible south of STOP 3. The upper contact of the Jd sill with superjacent Passaic Formation hornfels dips gently to moderately northwest in contrast with the steep-southeast-dipping compositional layering in the trap rock. White bed symbols use dip/dip azimuth notation. 3D colored disks are measured faults (red) and compositional layering (gray).

Figure 23. Outcrops near point A in figure22 in the footwall of the Hopewell fault.

A. Folded joints generally striking N63E/60-65 SE with small anticline-syncline pair plunging moderately eastward and opposed to westward-plunging bed folds (fig. 22). Note small shear faults showing bed duplication and contraction in the core of the anticline and associated, localized fracture cleavage. Bedding in the view is dipping 47° W toward the viewer and is not apparent.

B. Bed-discordant brittle deformation zones of S1 fault orientation (Herman, 2009) have shear morphology involving localized, band-normal fracturing showing a component of left-lateral (sinistral) slip.



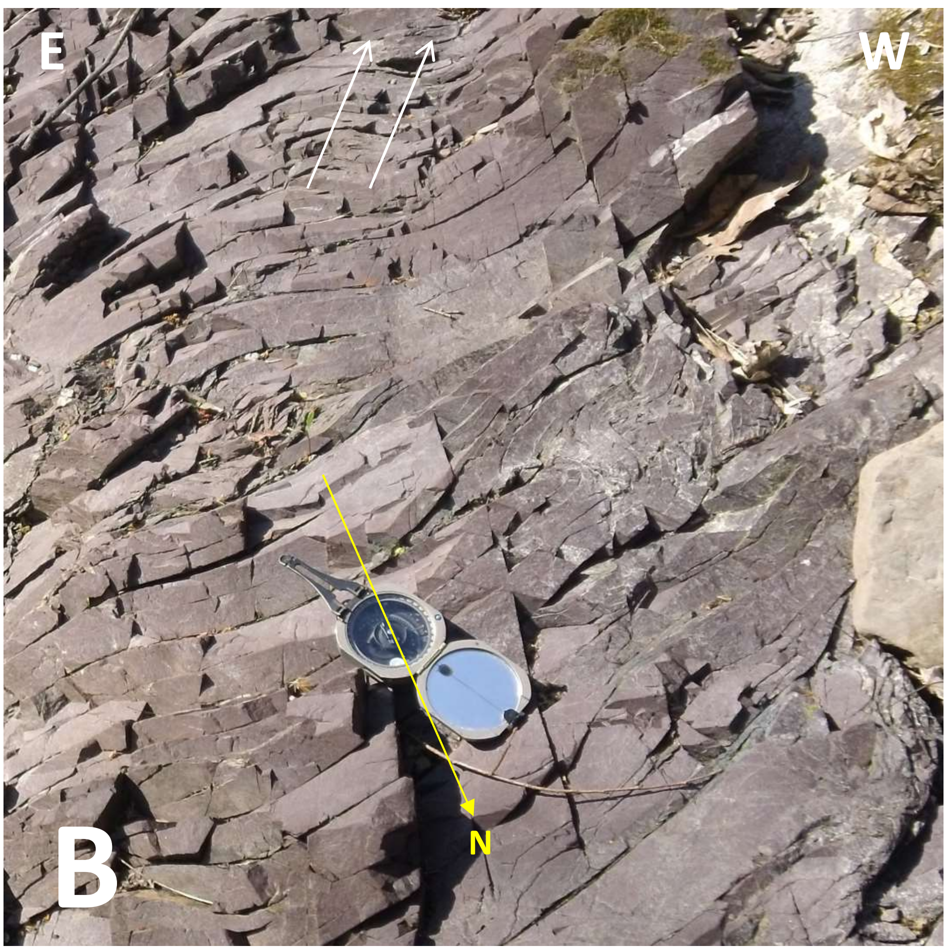


Figure 24. Outcrops of fractured and sheared red mudstone of the Passaic Formation. These outcrops are the first seen in the hanging-wall fault block and show complex incremental strains including slickensided shear planes with calcite (white) and epidote (green) mineralization.

A. Folded and compressed joint sets.

B. Slickenlines show left-lateral and normal oblique slips plunging shallow NE to SE (see fig. 22 STOP 2B).