Petrographic analysis of outcrops in the northern region of Great Smoky Mountains National Park, Tennessee

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Introduction

This study is designed to illustrate and describe the petrography of rock outcrops from seven trails, three roadside pull-outs, and two parking lots within Great Smoky Mountains National Park (GSMNP), and to examine the relationship between observed geology and the park's greater geologic history.

Collection Areas

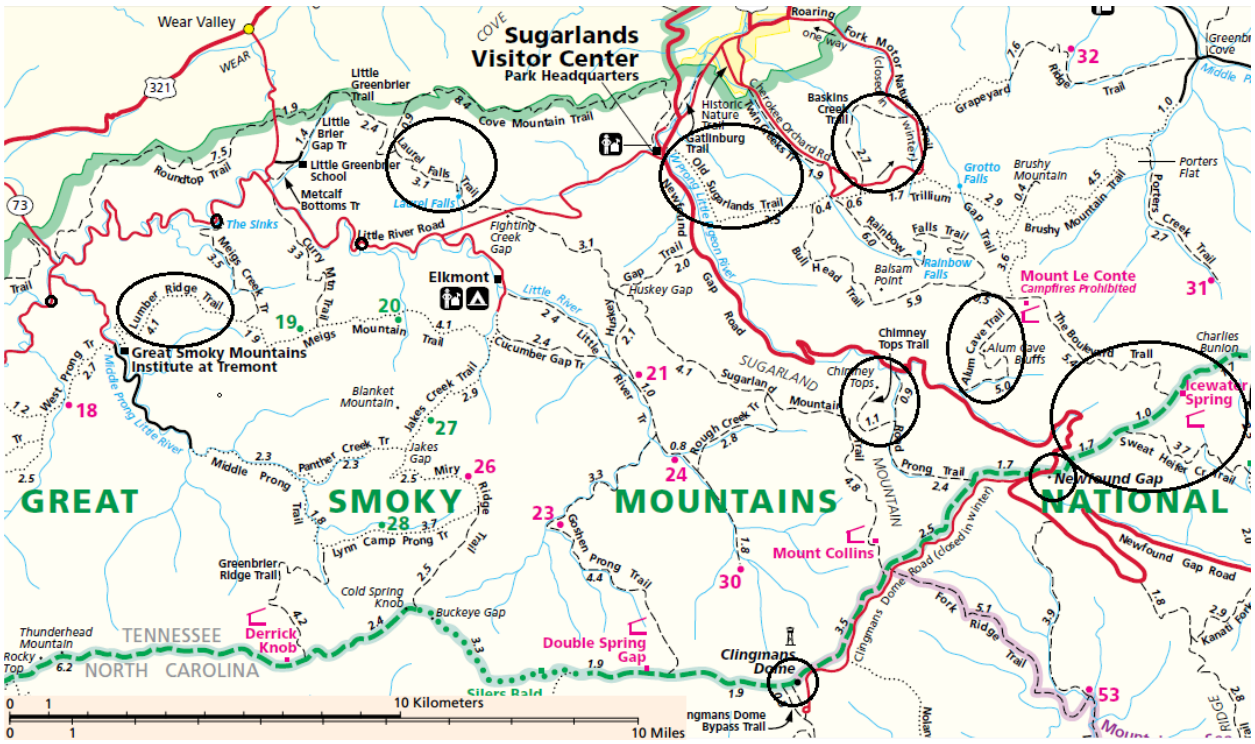

Figure 1: Map of Great Smoky Mountain National Park, with studied localities circled. National Park Service, 2013.

The study area is centered on the northern region of Great Smoky Mountains National Park, which is encompassed by the Western Blue Ridge Province. Rocks were collected within the park under scientific research and collecting permit GRSM-2013-SCI-2301, issued by the National Park Service. The grand majority of rock samples collected from the ten observed regions within the park are identified as belonging to the Great Smoky Group, 14,000 to 40,000 foot thick set of formations from the Neoproterozoic era, ranging from 1000 to 541 million years in age (Southworth and others, 2012). The Great Smoky Group consists of, in ascending order: Elkmont Sandstone, Thunderhead Sandstone, Cades

Sandstone, the Anakeesta Formation, Copperhill Formation, Wehutty Formation, Grassy Branch Formation, Ammons Formation, and Dean Formation. Of these, only Elkmont Sandstone (3 samples), Thunderhead Sandstone (5), Cades Sandstone (3), and the Anakeesta Formation (24) were represented in the collection.

A small percentage of samples collected represented formations within the Snowbird Group. While related to the Great Smoky Group in Neoproterozoic origin, the Snowbird Group consists of six different formations, in ascending order: the Wading Branch Formation, Longarm Quartzite, Roaring Fork Sandstone, Pigeon Sandstone, Metcalf Phyllite, and Rich Butt Sandstone (Southworth and others, 2012). One sample was collected from an exposed Roaring Fork Sandstone area and two samples were collected from a Metcalf Phyllite area.

Methods

After initial scouting, two to five stops were chosen for analysis at each trail. At each outcrop, GPS coordinates were noted, as well as any unique features that may together form a general picture of how the rocks within each outcrop formed or may be connected to nearby sites or to the park's general geologic history. Between one and five samples were collected from each studied outcrop. The likely rock formation type for each sample was determined by matching GPS coordinates taken at the collection location with the USGS's geologic map on ArcGIS.

Each sample was cut for thin section preparation. Ten thin sections were completed and their optical mineralogy described using a petrographic microscope. The results were compared with the likely formation type previously ascertained.

Sample Code	Trail	GPS Coordinates (UTM)	Map Code	Formation
1.1.1	Old Sugarlands Trail	17 270631 3952228	Qa	Alluvium (Holocene)
1.2.1	Old Sugarlands Trail	17 270631 3952228	Zrf	Roaring Fork Sandstone
2.1.1	Newfound Gap	17 0271028 3951465	Za	Anakeesta Formation
2.1.2	Newfound Gap	17 0280261 3943501	Za	Anakeesta Formation
2.1.3	Newfound Gap	17 0280261 3943501	Za	Anakeesta Formation
2.2.1	Newfound Gap	17 0280021 3943461	Za	Anakeesta Formation
2.2.2	Newfound Gap	17 0280021 3943476	Za	Anakeesta Formation
3.1.1	Clingmans Dome Trail	17 0273794 3937644	Zch	Copperhill Formation
3.2.1	Clingmans Dome Trail	17 0273794 3937644	Zch	Copperhill Formation
4.1.1	Laurel Falls Trail	17 0266094 3950674	Ze	Elkmont Sandstone
4.1.2	Laurel Falls Trail	17 0266094 3950674	Ze	Elkmont Sandstone
4.2.1	Laurel Falls Trail	17 0268994 3950753	Ze	Elkmont Sandstone
4.5.1	Laurel Falls Trail	17 0265481 3950690	Zt	Thunderhead Sandstone
4.9.1	Laurel Falls Trail	17 0265311 3951276	Zt	Thunderhead Sandstone
4.9.2	Laurel Falls Trail	17 0265311 3951276	Zt	Thunderhead Sandstone
5.2.1	Lumber Ridge Trail	17 0256296 3947825	Zm	Metcalf Phyllite
5.3.1	Lumber Ridge Trail	17 0256335 3947945	Zm	Metcalf Phyllite
6.1.1	Laurel Creek Road	17 0262578 3950000	Zt	Thunderhead Sandstone
6.2.1	Laurel Creek Road	17 0258979 3950486	Zc	Cades Sandstone
6.2.2	Laurel Creek Road	17 0258979 3950486	Zc	Cades Sandstone
6.3.1	Laurel Creek Road	17 0254716 3948910	Zc	Cades Sandstone
7.1.1	Baskins Creek Trail	17 0275849 3951149	Zrf	Roaring Fork Sandstone
7.2.1	Baskins Creek Trail	17 0275577 3952331	Zrf	Roaring Fork Sandstone
8.1.1	Appalachian Trail	17 0280787 3943597	Za	Anakeesta Formation
8.1.2	Appalachian Trail	17 0280787 3943597	Za	Anakeesta Formation
8.4.1	Appalachian Trail	17 0281721 3944270	Za	Anakeesta Formation
8.5.1	Appalachian Trail	17 0284810 3946333	Za	Anakeesta Formation
8.5.2	Appalachian Trail	17 0284810 3946333	Za	Anakeesta Formation
9.1.1	Chimney Tops Trail	17 0276343 3946148	Zt	Thunderhead Sandstone
9.1.2	Chimney Tops Trail	17 0276343 3946148	Za	Anakeesta Formation
9.2.1	Chimney Tops Trail	17 0275839 3945179	Za	Anakeesta Formation
9.3.1	Chimne Tops Trail	17 0275619 3945679	Za	Anakeesta Formation
9.3.3	Chimne Tops Trail	17 0275619 3945679	Za	Anakeesta Formation
10.1.1	Alum Cave Trail	17 0279221 3946329	Za	Anakeesta Formation
10.2.1	Alum Cave Trail	17 0279207 3946645	Za	Anakeesta Formation
10.3.1	Alum Cave Trail	17 0279017 3946656	Za	Anakeesta Formation
10.4.1	Alum Cave Trail	17 0278854 3946355	Za	Anakeesta Formation
10.4.2	Alum Cave Trail	17 0278854 3946355	Za	Anakeesta Formation
10.5.1	Alum Cave Trail	17 0278639 3946668	Za	Anakeesta Formation
10.5.2	Alum Cave Trail	17 0278639 3946668	Za	Anakeesta Formation
10.5.3	Alum Cave Trail	17 0278639 3946668	Za	Anakeesta Formation
10.5.4	Alum Cave Trail	17 0278639 3946668	Za	Anakeesta Formation
10.5.5	Alum Cave Trail	17 0278639 3946668	Za	Anakeesta Formation

Table 1: Sample code, location, and likely formation of each sample.

Results and Analysis (in alphabetical order, by location)

Alum Cave Trail

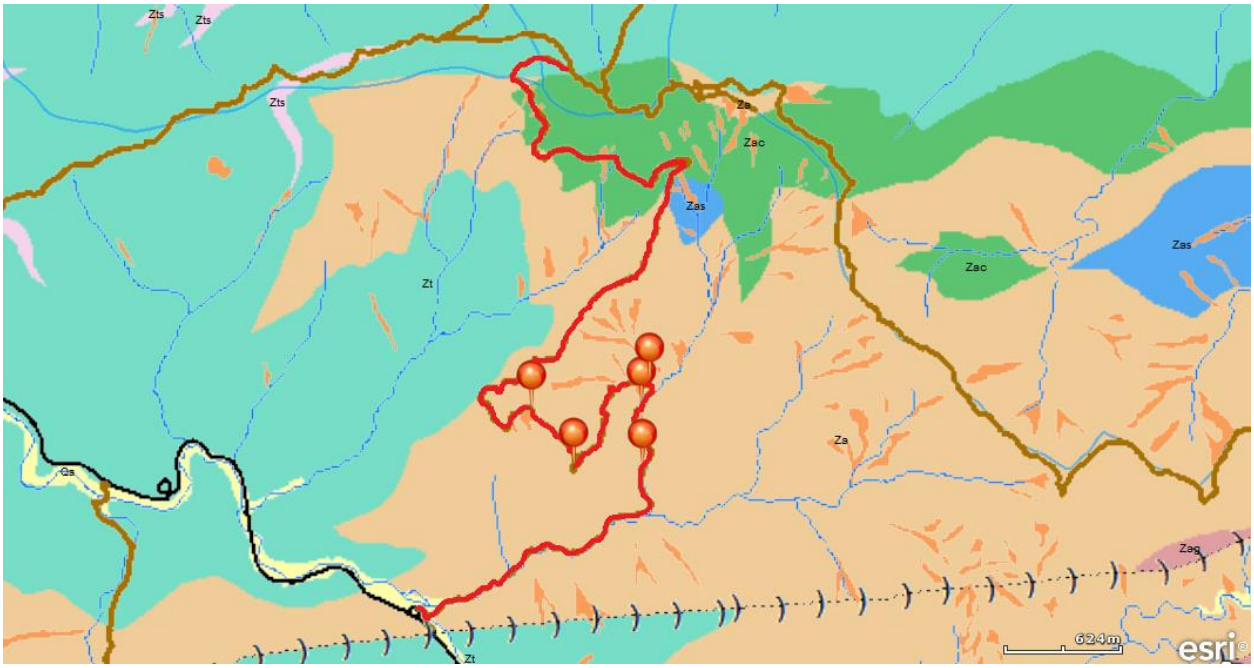

Figure 2: Geologic map of Alum Cave trail (marked in red) on ArcGIS. Tacks indicate locations with analyzed outcrops. The Mingus fault (dashed line with parentheses near bottom of figure) runs close to the trail, possibly resulting in the boudinage seen in Alum Cave Bluffs. Data from National Park Service (NPS) and US Geological Survey (USGS), 2012.

Sample 10.1.1

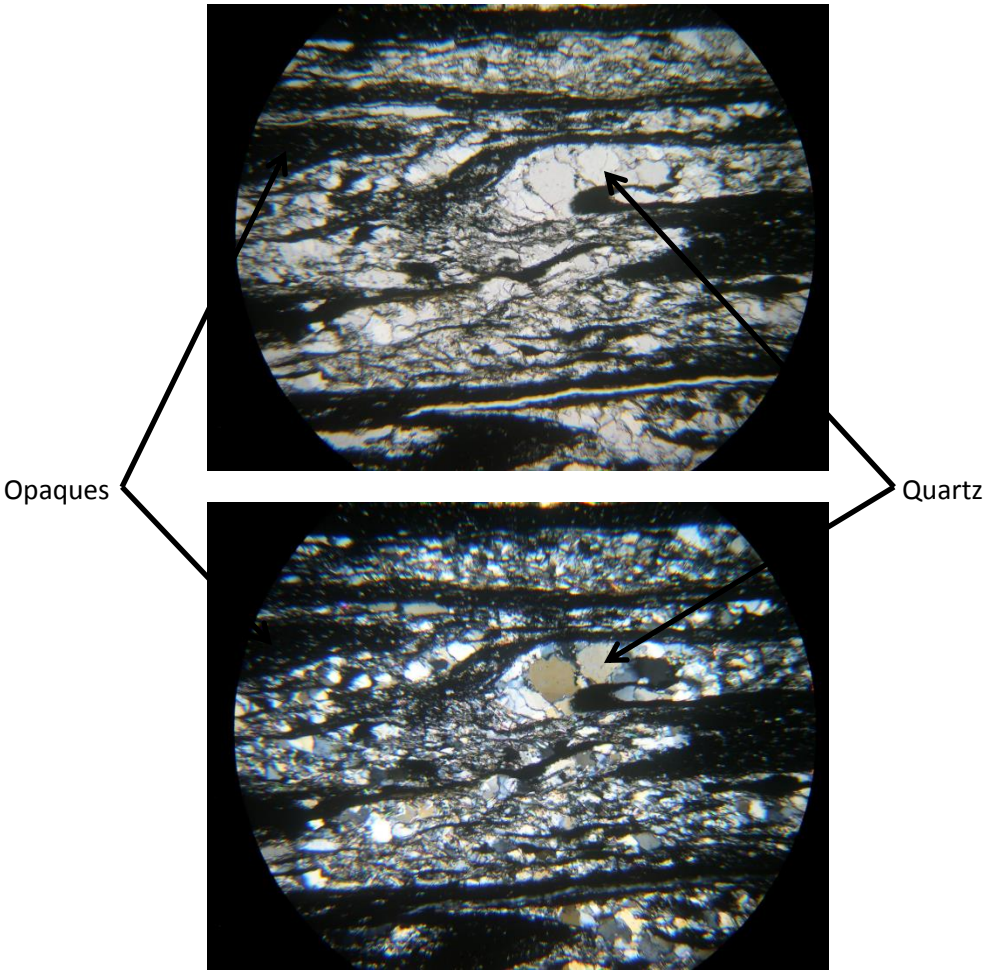

Figure 3: Thin section made from sample 10.1.1 viewed in plane polarized light (above) and cross polarized light (below). Magnification x100. Field of view: 2.0 mm.

Minerals found in thin section:

Quartz:

- Grain percentage of composition: 50%
- Subhedral crystals (0.1 mm)
- Colorless in PPL, first order white and gray under XPL
- Low relief
- No cleavage

Opaques:

- Grain percentage of composition: 50%
- Crystal shape and size uncertain
- Black in PPL and XPL

Bands of quarts appear to have been deformed among opaques, but in show no discernable pattern. Quartz grains are somewhat elongated at bending locations.

Sample 10.4.2

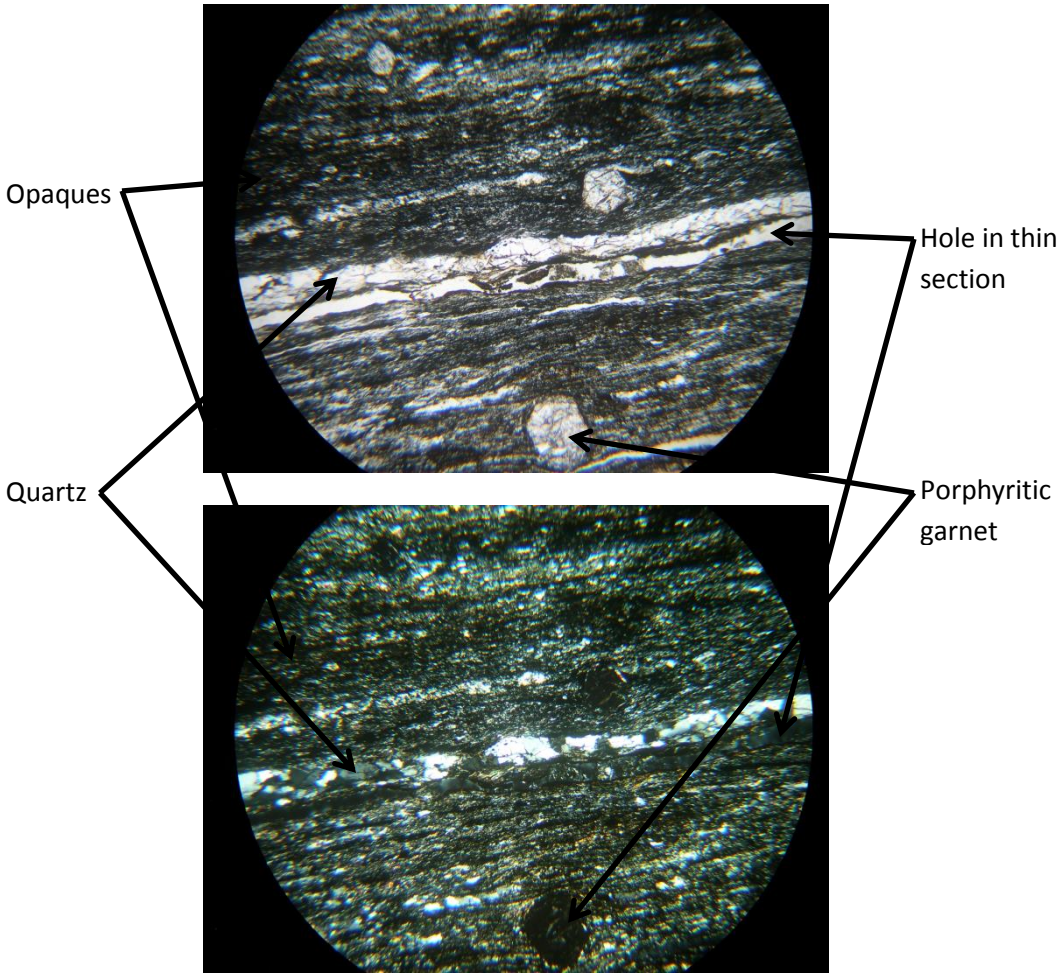

Figure 4: Thin section made from sample 10.4.2 viewed in plane polarized light (above) and cross polarized light (below). Magnification x100. Field of view: 2.0 mm.

Minerals found in thin section:

Quartz:

- Grain percentage of composition: 40%
- Subhedral crystals (0.1 mm)
- Colorless in PPL, first order white and gray under XPL
- Low relief
- No cleavage

Opaques:

- Grain percentage of composition: 60%
- Crystal shape and size uncertain
- Black in PPL and XPL

Garnet:

- Grain percentage of composition: <1%
- Subhedral crystals (0.15 mm)
- Isotropic - colorless in PPL, black in XPL
- High relief
- No cleavage

Distinct, planar layering can be observed. The rock's grains are poorly sorted. There are many holes in the thin section due to the rock's friable nature fracturing the rock during preparation. Garnets may exhibit zoning.

Sample 10.5.3

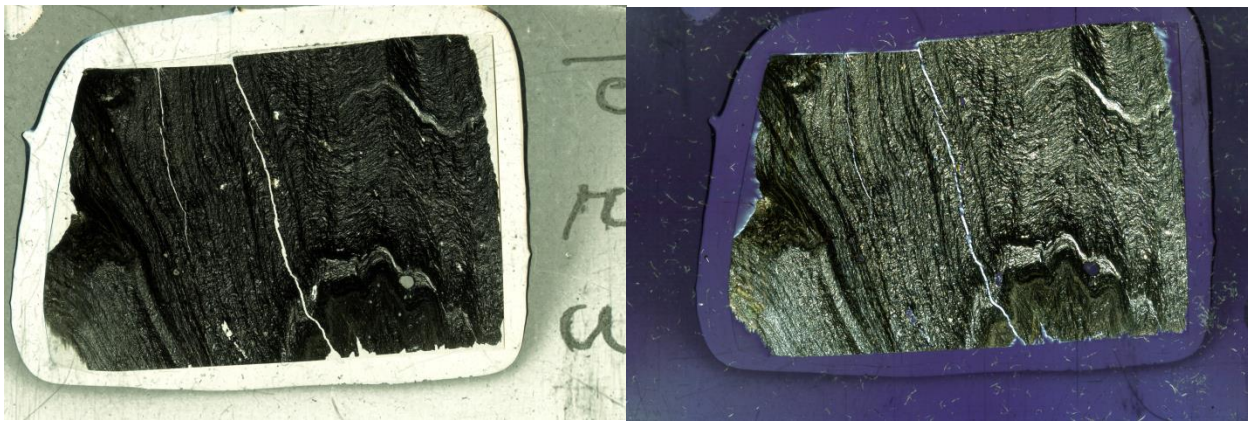

Figure 5: Thin section slide of sample 10.5.3 viewed in plane polarized light (left) and cross polarized light (right). Note pervasive kink banding. Field of view: 35 mm.

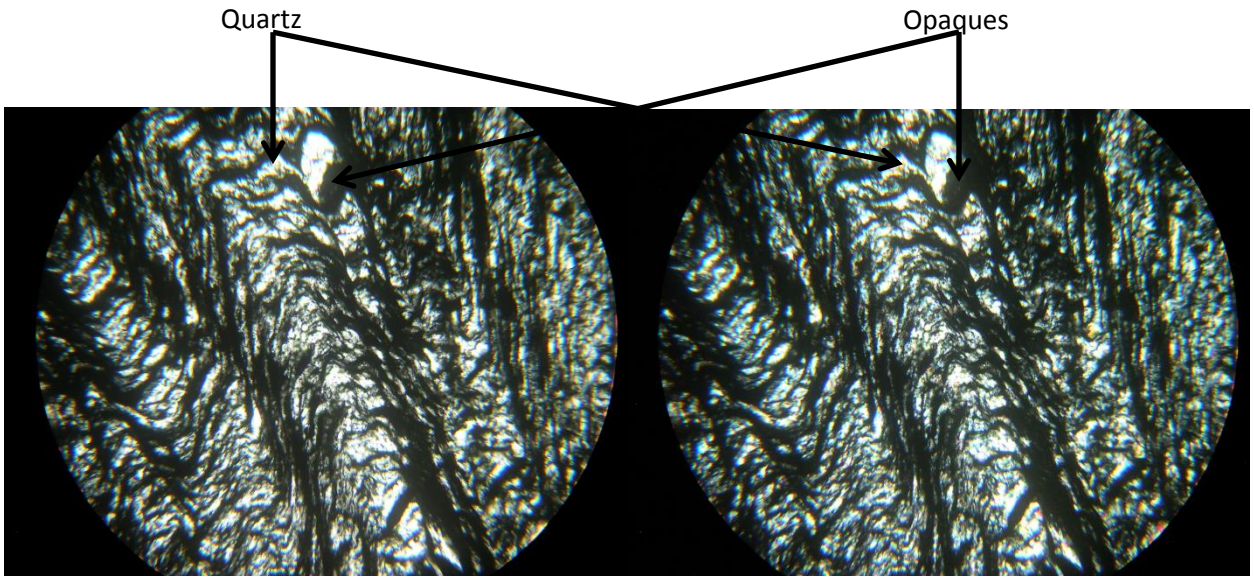

Figure 6: Thin section made from sample 10.5.3 viewed in plane polarized light (left) and cross polarized light (right). Magnification x100. Field of view: 2.0 mm.

Minerals found in thin section:

Quartz:

- Grain percentage of composition: 50%
- Subhedral crystals (0.05 mm)
- Colorless in PPL, high order pastels and gray under XPL (unusual)
- Low relief
- No cleavage

Opaques:

- Grain percentage of composition: 50%
- Crystal shape and size uncertain
- Black in PPL and XPL

In this sample, kink bands have formed at the granular level. While mica is more commonly found in kinking and the thin section's interference colors would indicate it is present as the main non-opaque mineral, these grains do not show any cleavage planes. A more likely scenario is that the thin section was cut too thickly (>0.03 mm), allowing quartz to exhibit higher levels of birefringence than usual. The mineral's composition can best be analyzed through probing with a DCP-OES machine.

Appalachian Trail

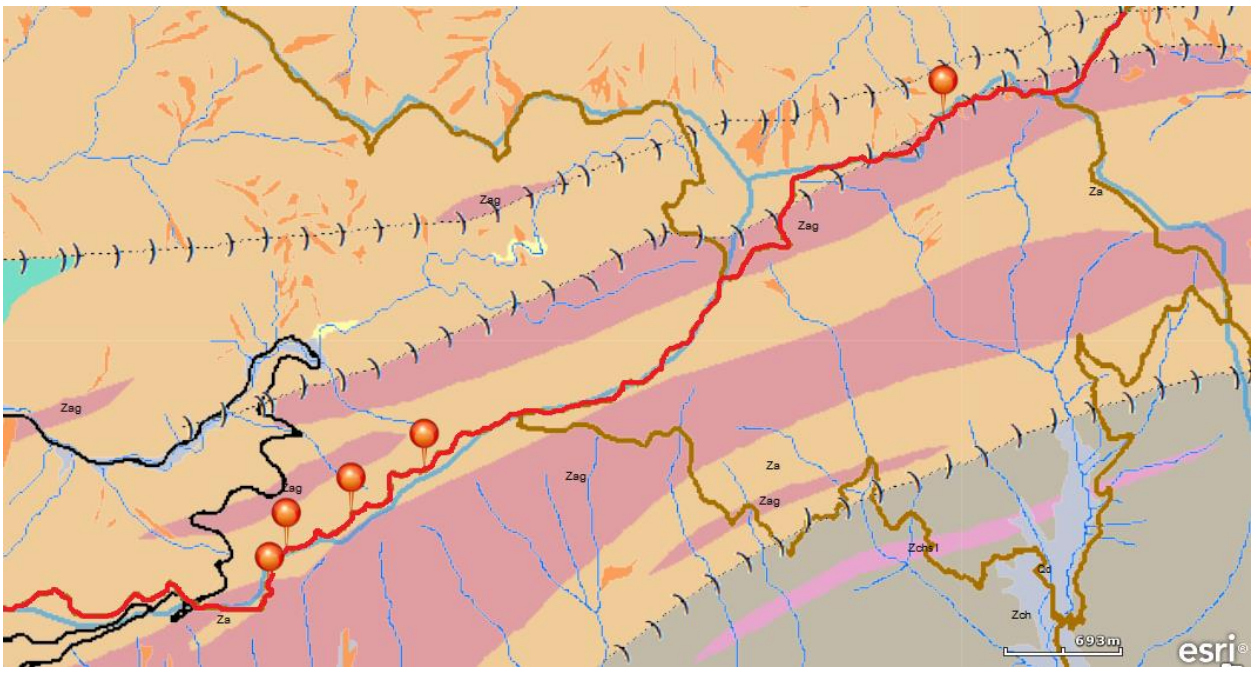

Figure 7: Geologic map of Appalachian Trail (marked in red) on ArcGIS. Tacks indicate locations with analyzed outcrops. Rightmost collection, location, Charlie's Bunion, is located one of the faults from the Mingus fault zone (dashed lines with parentheses indicate faults). Data from NPS and USGS, 2012.

Sample 8.5.2

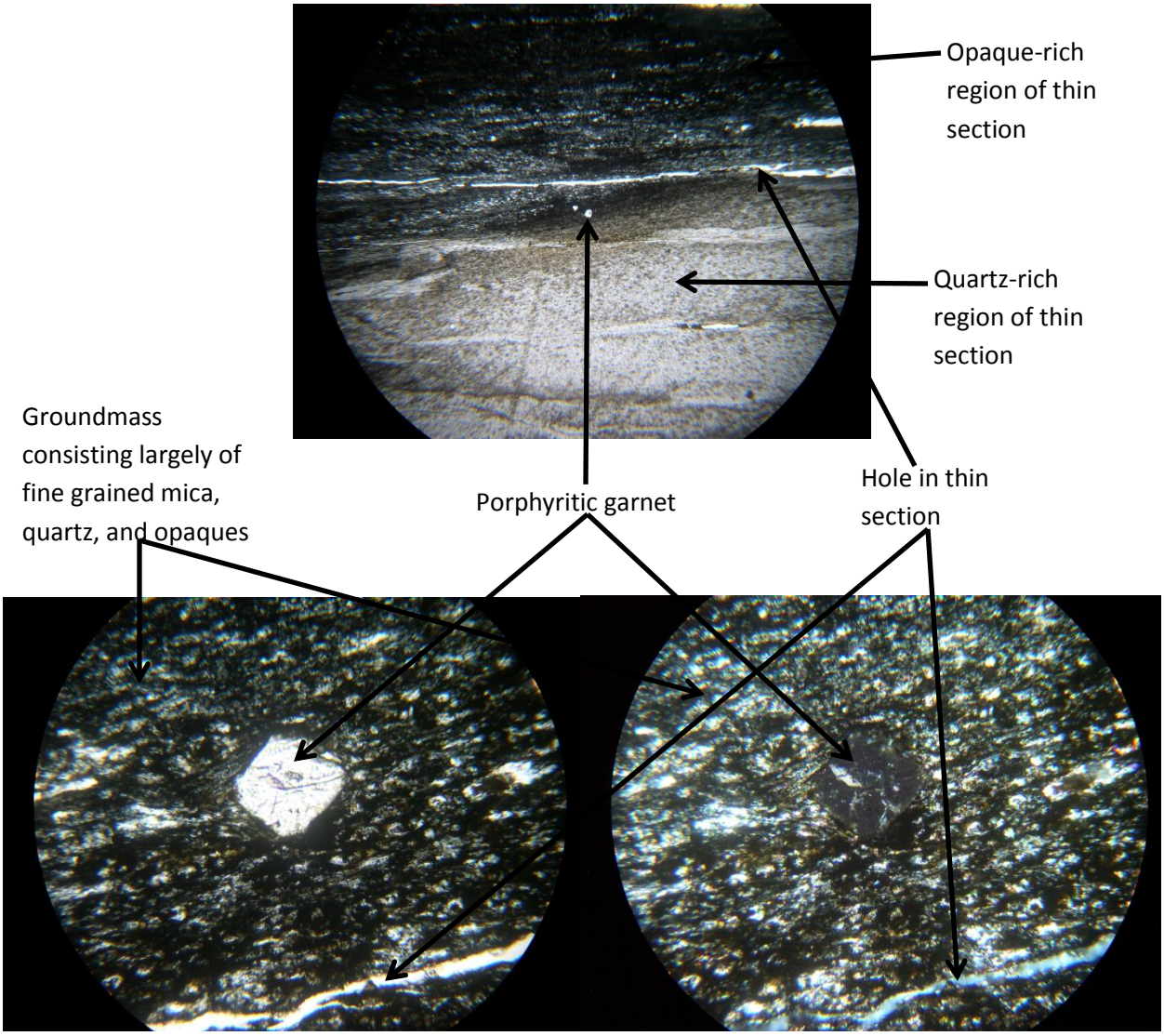

Figure 8: Thin section made from sample 8.5.2 viewed in plane polarized light (center above, bottom left) and cross polarized light (bottom right). Magnification is x25 for top image, x200 for bottom images. Field of view: 8 mm and 1.0 mm, respectively.

Minerals found in thin section:

Opaques:

- Grain percentage of composition: 54%
- Crystal shape and size uncertain
- Black in PPL and XPL

Quartz:

- Grain percentage of composition: 44%
- Subhedral crystals (0.08 mm)
- Colorless in PPL, first order white and gray under XPL
- Low relief
- No cleavage

Garnet:

- Grain percentage of composition: 2%
- Subhedral crystals (0.1 mm)
- Isotropic - colorless in PPL, black in XPL
- High relief
- No cleavage

The same percentages of garnets appear in the opaque-rich and quartz-rich regions of the thin section. Garnets may exhibit zoning. Some mica is expected to be found in the groundmass due to its metasedimentary state, but it is so fine grained that cleavage could not be found with which to identify it.

Baskins Creek Trail

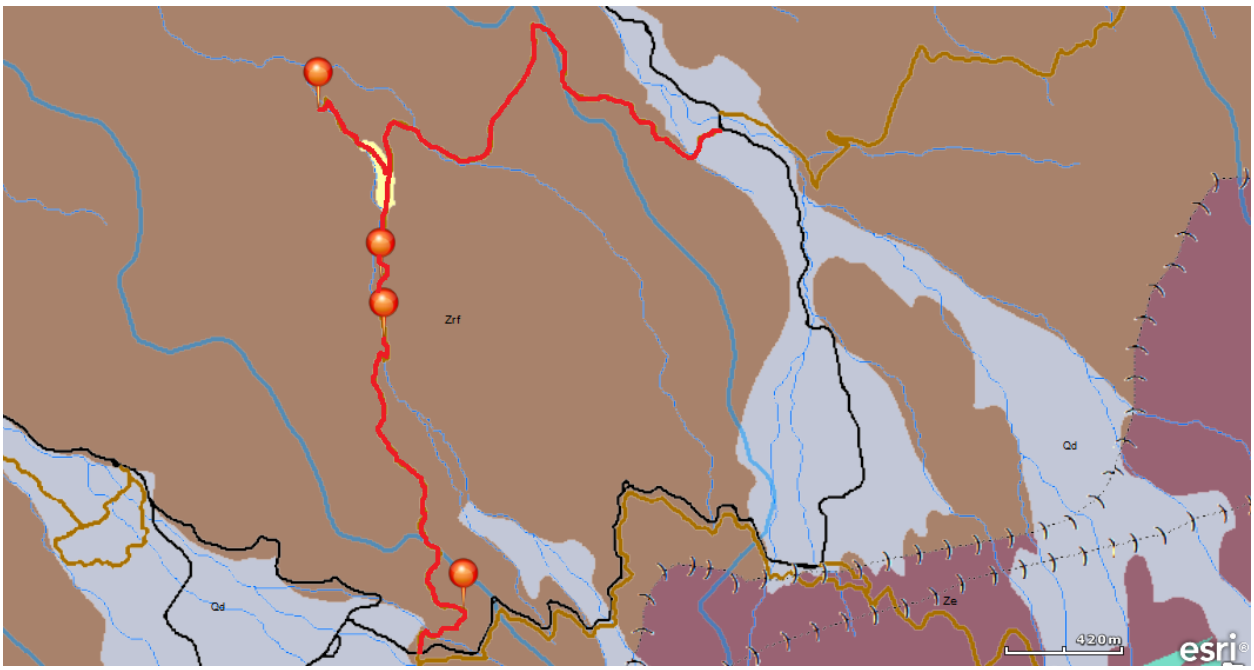

Figure 9: Geologic map of Baskins Creek trail (marked in red) on ArcGIS. Tacks indicate locations with analyzed outcrops. Data from NPS and USGS, 2012.

Chimney Tops Trail

Figure 10: Geologic map of Chimney Tops trail (marked in red) on ArcGIS. Tacks indicate locations with analyzed outcrops. Data from NPS and USGS, 2012.

Sample 9.2.1

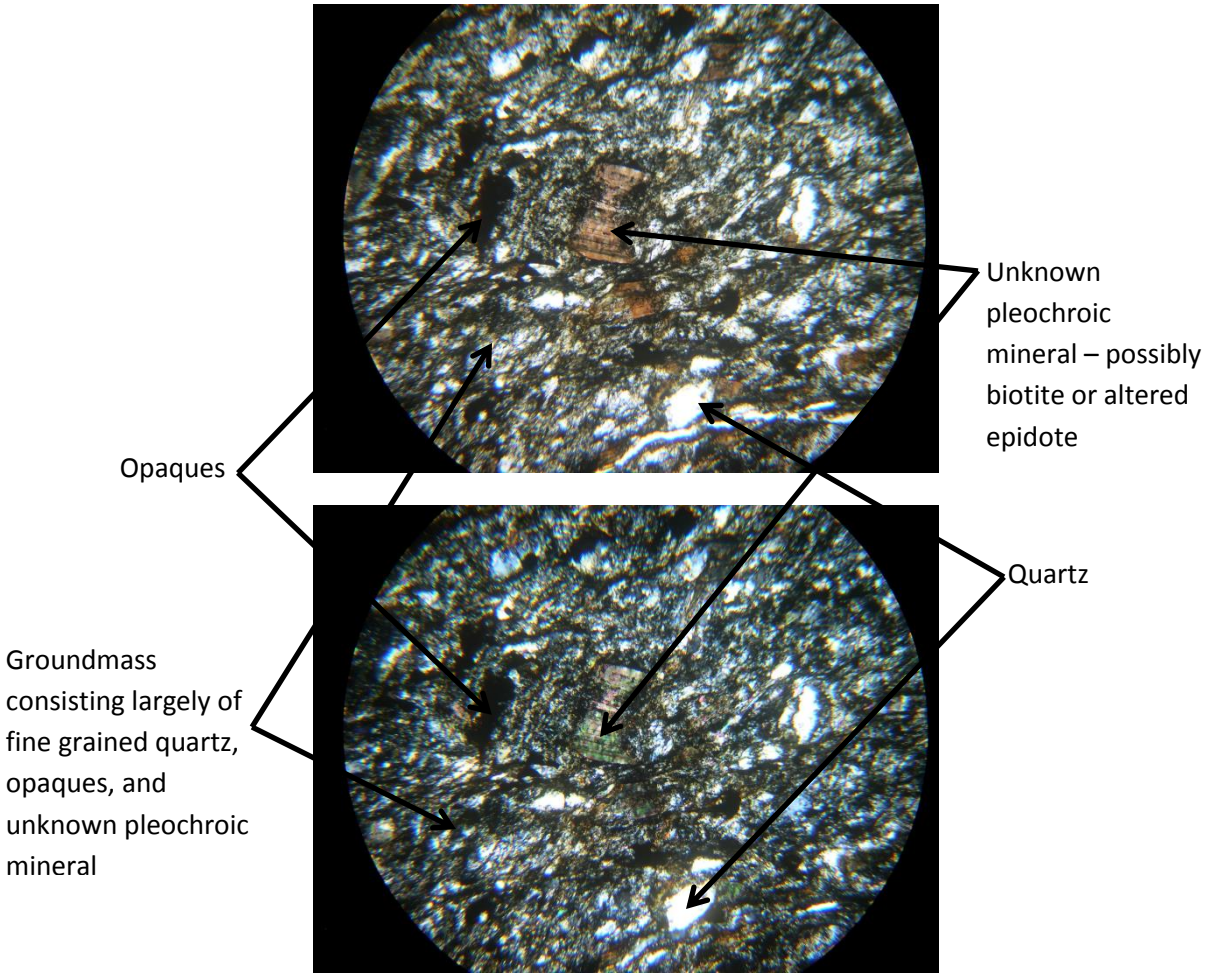

Figure 11: Thin section made from sample 9.2.1 viewed in plane polarized light (above) and cross polarized light (below). Magnification x100. Field of view: 2.0 mm.

Minerals found in thin section:

Quartz:

- Grain percentage of composition: 35%
- Subhedral crystals (0.15 mm)
- Colorless in PPL, first order white and gray in XPL
- Low relief
- No cleavage

Unknown mineral:

- Grain percentage of composition: 15%
- Anhedral crystals (0.15 mm)
- Brown and pleochroic in PPL, 90° extinction angle, third order pastels under XPL
- Single plane of stripes caused by exsolution
- No birds eye extinction

Opaques:

- Grain percentage of composition: 50%
- Crystal shape and size uncertain
- Black in PPL and XPL

Wispy, linear opaque strands are present, although they do not connect into full layers. This sample has very well sorted grain sizes.

Sample 9.3.3

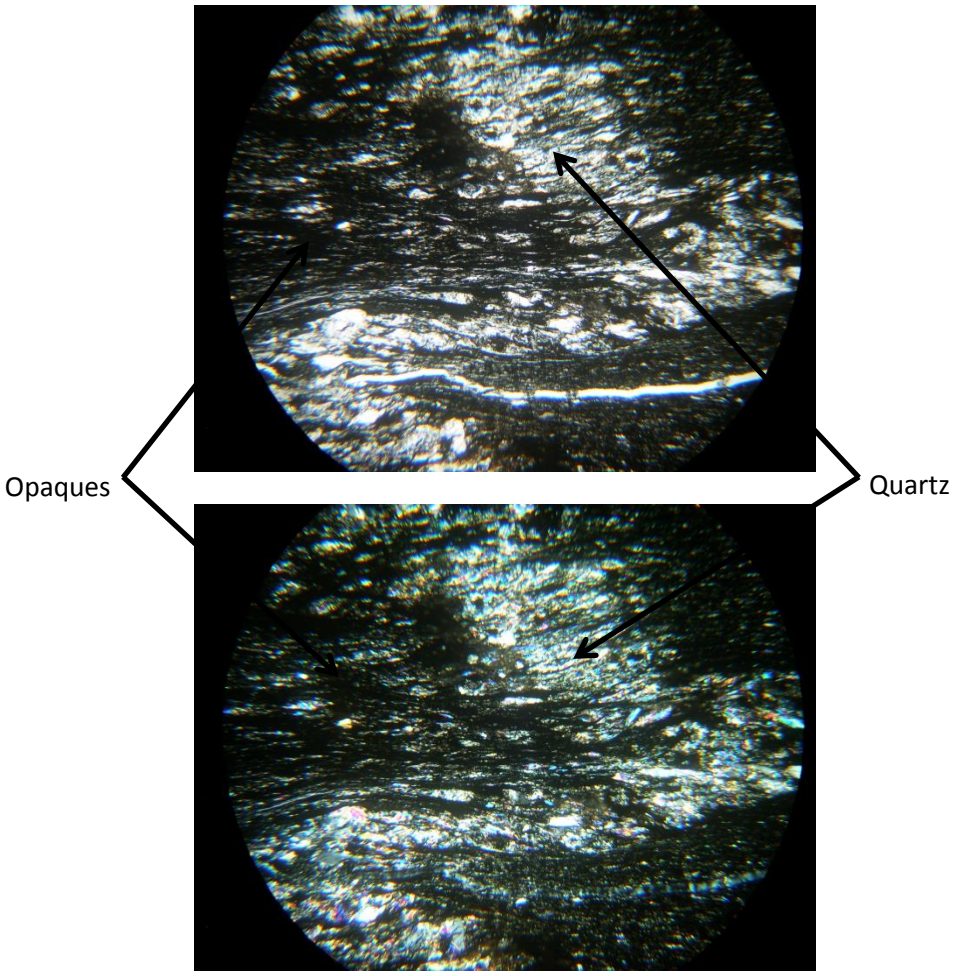

Figure 12: Thin section made from sample 9.3.3 viewed in plane polarized light (above) and cross polarized light (below). Magnification x100. Field of view: 2.0 mm.

Opaques:

- Grain percentage of composition: 50%
- Crystal shape and size uncertain
- Black in PPL and XPL

Quartz:

- Grain percentage of composition: 50%
- Subhedral crystals (0.1 mm in bands, 0.05 mm in matrix)
- Colorless in PPL, first order white and gray under XPL
- Low relief
- No cleavage

Some evidence of folding is present. However, only quarts grains seem to be deformed. Additionally, this thin section has multiple holes in the slide that can be mistaken for garnets unless observed closely.

Clingman's Dome

Figure 13: Geologic map of Clingman's Dome on ArcGIS. Outcrop near parking lot marked in red. Tacks indicate locations with analyzed outcrops. Data from NPS and USGS, 2012.

Laurel Creek Road

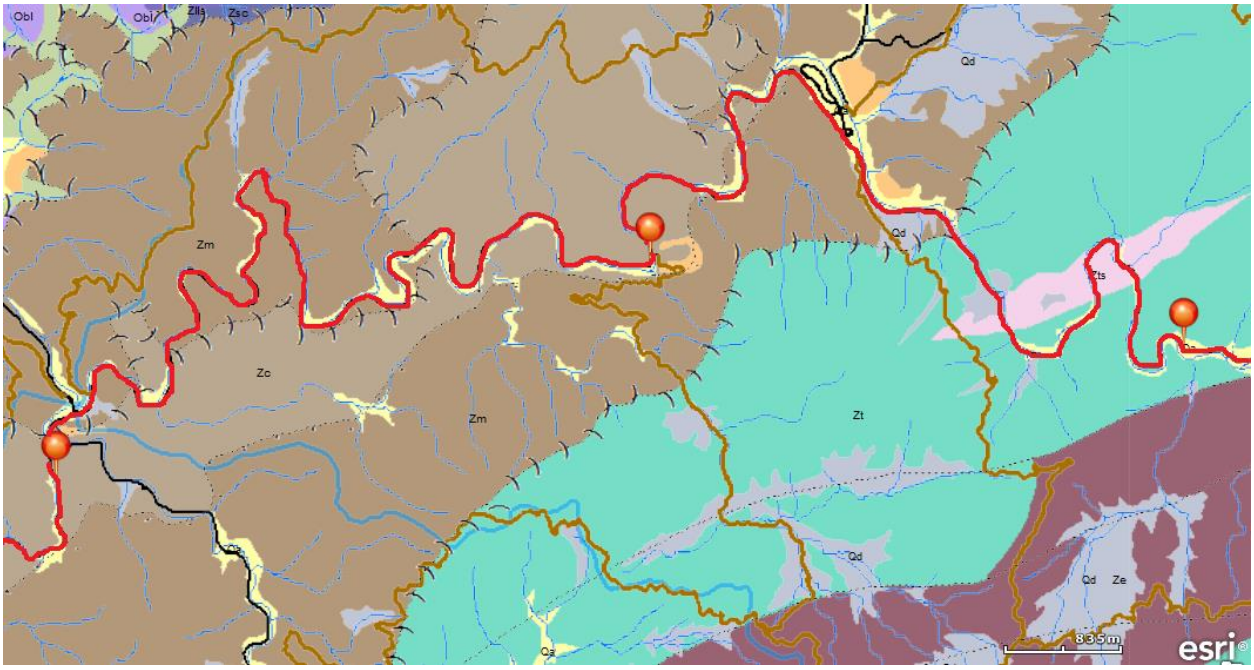

Figure 14: Geologic map of Laurel Creek Road (marked in red) on ArcGIS. Tacks indicate locations with analyzed outcrops. Data from NPS and USGS, 2012.

Sample 6.2.1

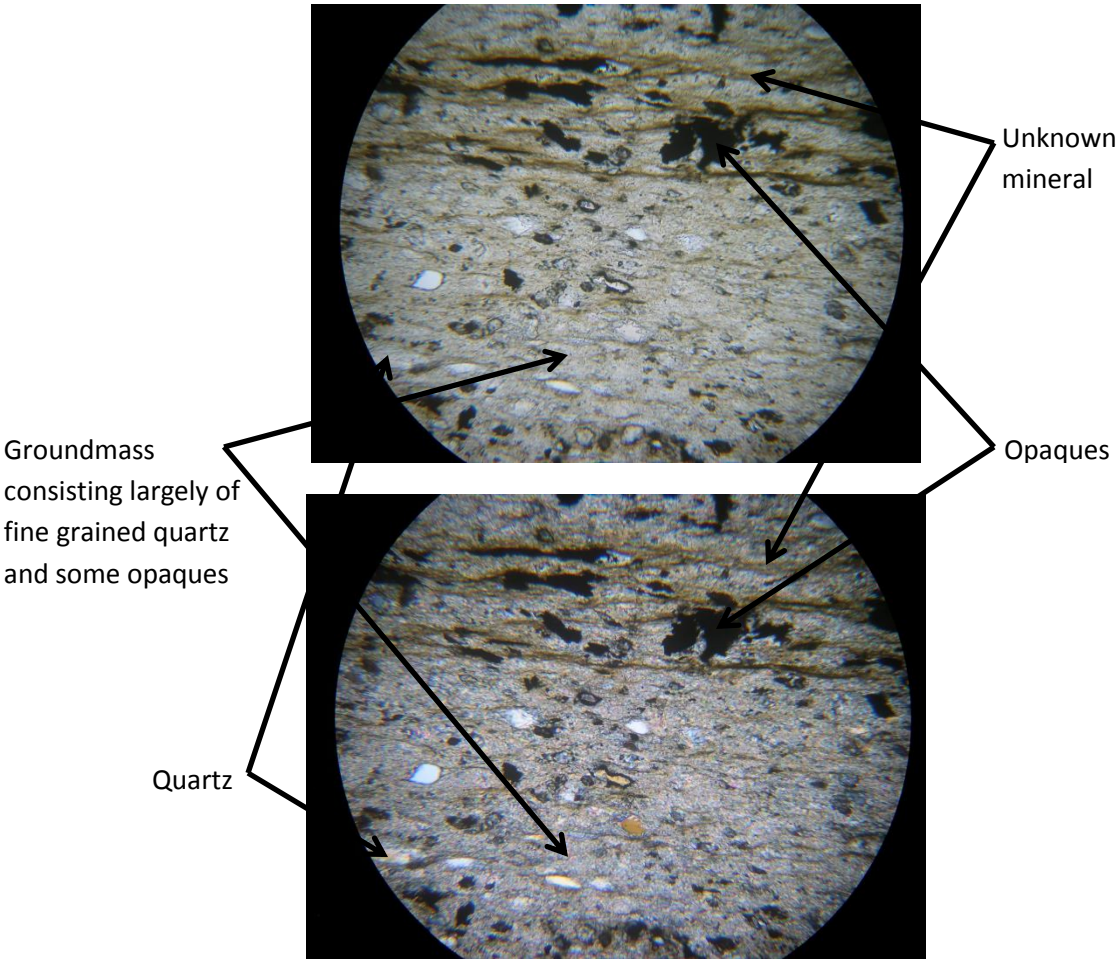

Figure 15: Thin section made from sample 6.2.1 viewed in plane polarized light (above) and cross polarized light (below). Magnification x100. Field of view: 2.0 mm.

Minerals found in thin section:

Quartz:

- Grain percentage of composition: 50%
- Subhedral crystals (0.2 mm)
- Colorless in PPL, first order white and gray under XPL
- Low relief
- No cleavage

Unknown mineral:

- Grain percentage of composition: 30%
- Size uncertain – wisps appear continuous
- Brown under PPL and XPL, no change in shade
- Low relief

Opaques:

- Grain percentage of composition: 20%
- Crystal shape and size uncertain
- Black in PPL and XPL

This slide was likely cut too thick (<0.03 mm), as its quartz crystals are birefringence order colors that are too high. The unknown mineral in this sample may be a weathered remnant of some previously altered mineral.

Laurel Falls Trail

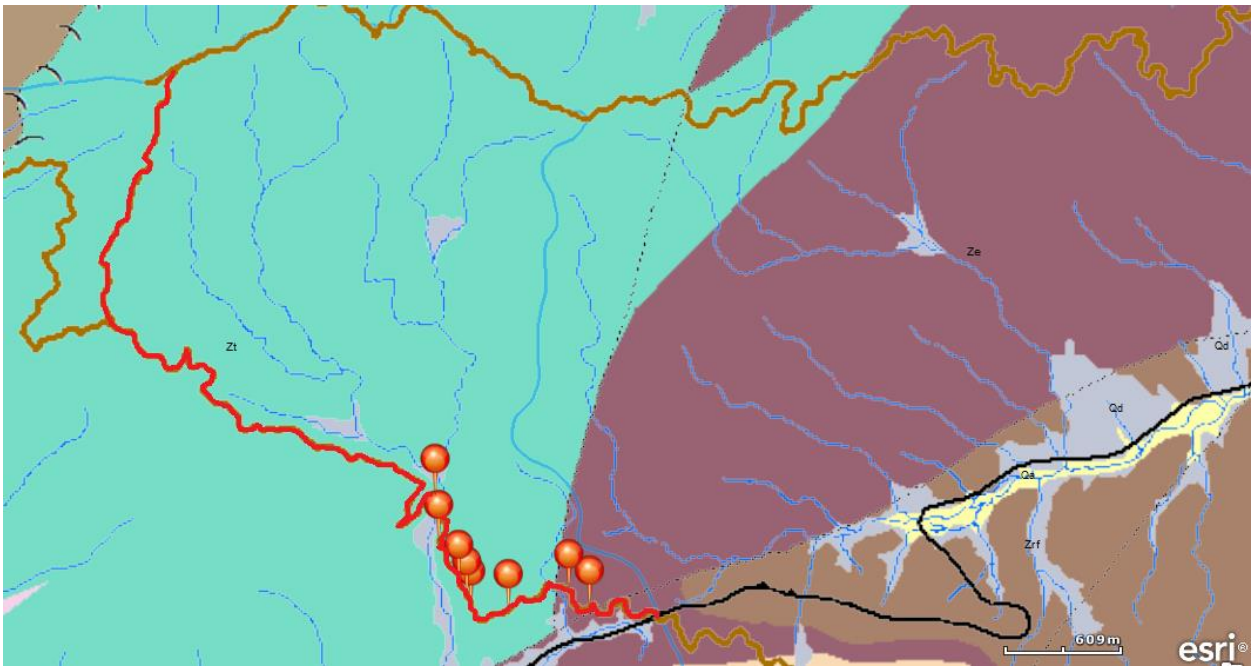

Figure 16: Geologic map of Laurel Falls Trail (marked in red) on ArcGIS. Tacks indicate locations with analyzed outcrops. Data from NPS and USGS, 2012.

Lumber Ridge Trail

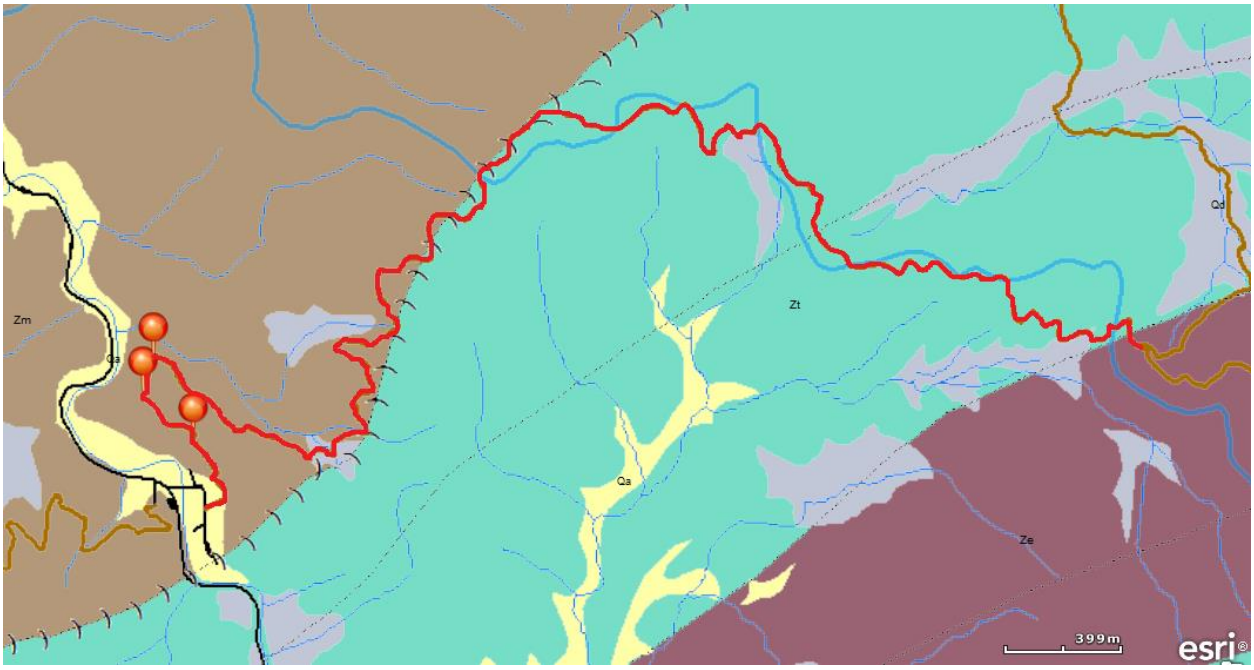

Figure 17: Geologic map of Lumber Ridge Trail (marked in red) on ArcGIS. Tacks indicate locations with analyzed outcrops. Notice that the Gatlinburg fault (dashed line with parentheses) crosses over the trail. At those locations, however, it is too covered by soil and foliage to be noticed. Data from NPS and USGS, 2012.

Sample 5.3.2

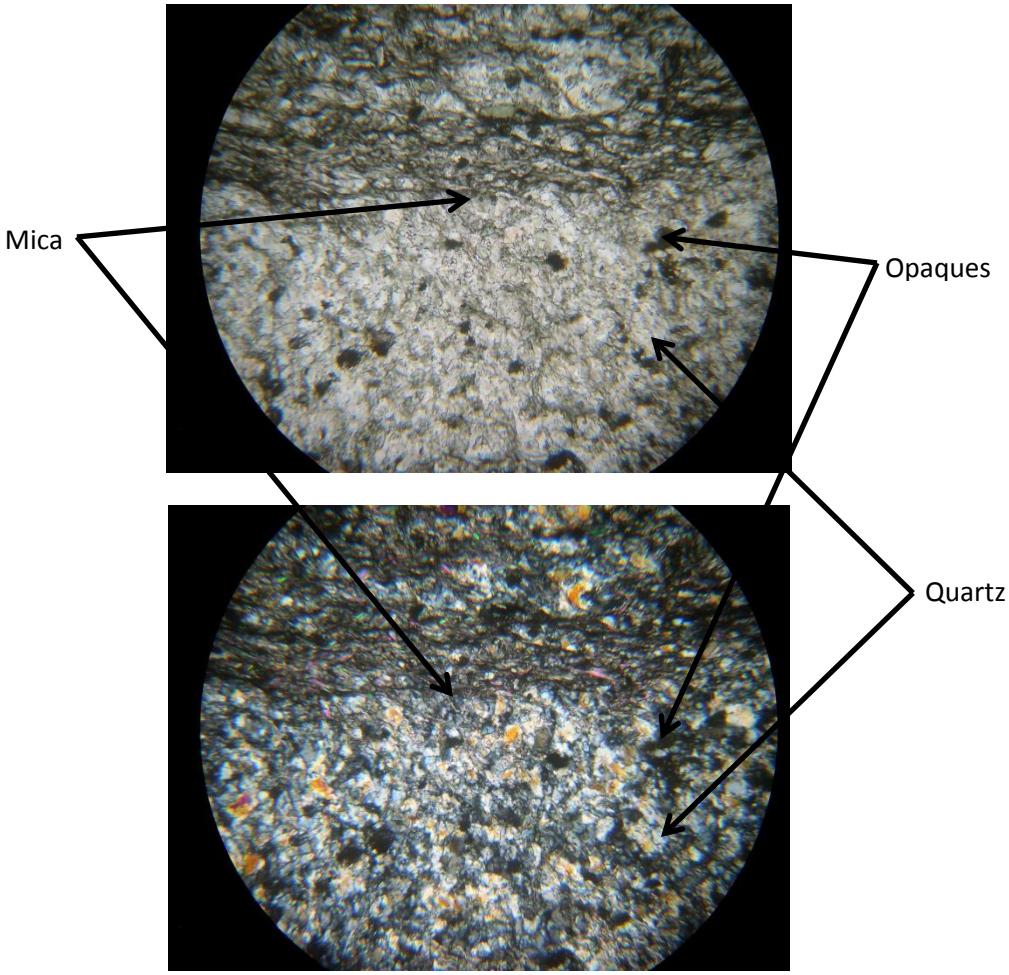

Figure 18: Thin section made from sample 5.3.2 viewed in plane polarized light (above) and cross polarized light (below). Magnification x100. Field of view: 2.0 mm.

Minerals found in thin section:

Quartz:

- Grain percentage of composition: 50%
- Subhedral crystals (0.1 mm in bands, 0.05 mm in matrix)
- Colorless in PPL, first order white and gray under XPL
- Low relief
- No cleavage

Mica:

- Grain percentage of composition: 40%
- Elongated, subhedral crystals (0.08 mm)
- Pale green in PPL, third order pastels in XPL
- Low relief
- 1 plane of cleavage, scarcely visible
- Bird's eye extinction

Opaques:

- Grain percentage of composition: 10%
- Crystal shape and size uncertain
- Black in PPL and XPL

Stripes of darker, smaller, and longer crystals are probably sericite. Gneissosity is also present, confirming this rock's classification as a phyllite by the USGS (Southworth and others, 2012).

Newfound Gap

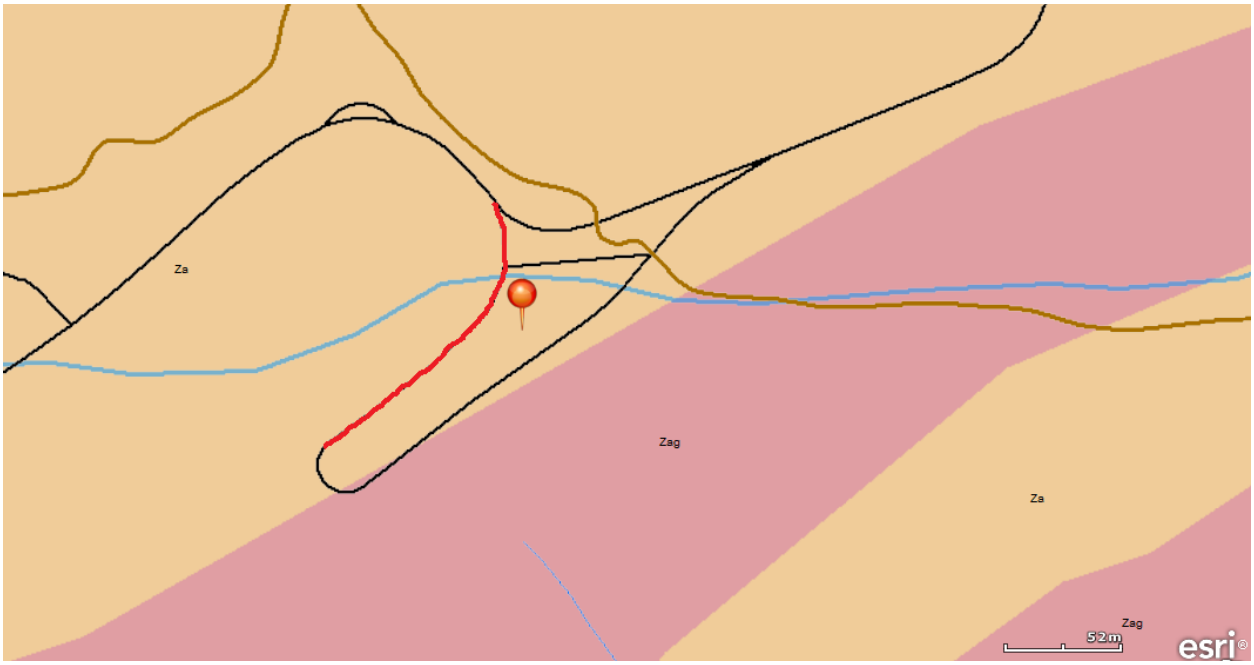

Figure 18: Geologic map of Newfound Gap on ArcGIS. Outcrop is found along the line marked in red. Tack indicates parking lot area. Data from NPS and USGS, 2012.

The outcrop at Newfound Gap runs from 17 0280274 3943510 to 17 0280203 3943510. Heavily weathered slate from the Anakeesta Formation is exposed at a strike and dip of 60° NE and 50° N, respectively. Very thin laminae are present in the rock, being less than 1 mm in thickness. Much of the outcrop's surface was fractured, as shown in Figure 4, owing to its friable layering. The rocks' grains are silt and clay sized and very well sorted.

Figure 19: Slate from the Anakeesta Formation at Newfound Gap. Pencil 15 cm.

Sample 2.1.2

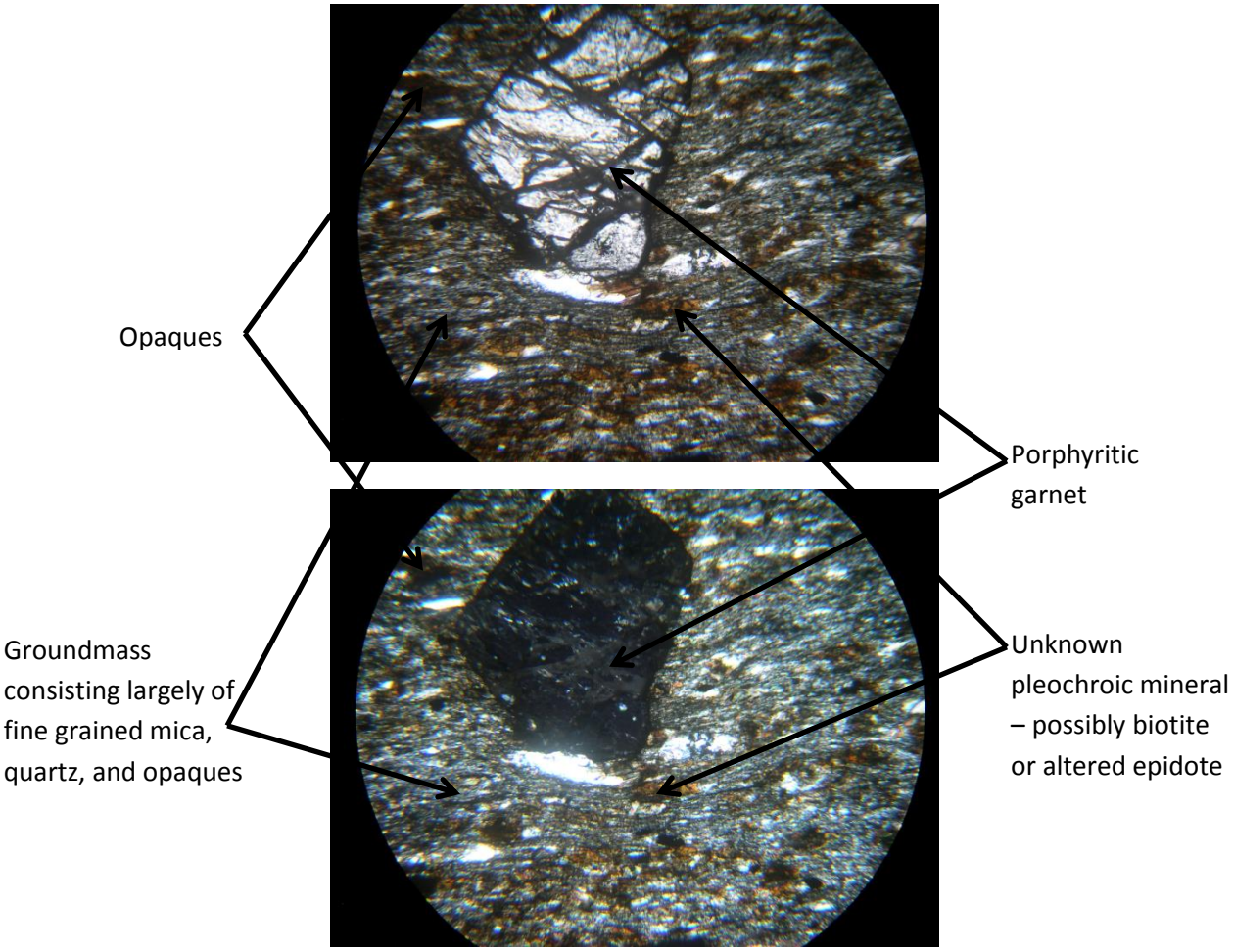

Figure 20: Thin section made from sample 2.1.2 viewed in plane polarized light (above) and cross polarized light (below). Magnification x100. Field of view: 2.0 mm.

Minerals found in thin section:

Quartz:

- Grain percentage of composition: 55%
- Subhedral crystals (0.08 mm)
- Colorless in PPL, first order white and gray in XPL
- Low relief
- No cleavage

Unknown mineral:

- Grain percentage of composition: 15%
- Anhedral crystals (0.1 mm)
- Brown and pleochroic in PPL, 90° extinction angle, third order pastels under XPL
- Single plane of stripes caused by exsolution
- No birds eye extinction

Opaques:

- Grain percentage of composition: 30%
- Crystal shape and size uncertain
- Black in PPL and XPL

Garnet:

- Grain percentage of composition: <1%
- Subhedral crystals (0.6 mm)
- Isotropic - colorless in PPL, black in XPL
- High relief
- No cleavage

Sample 2.2.2

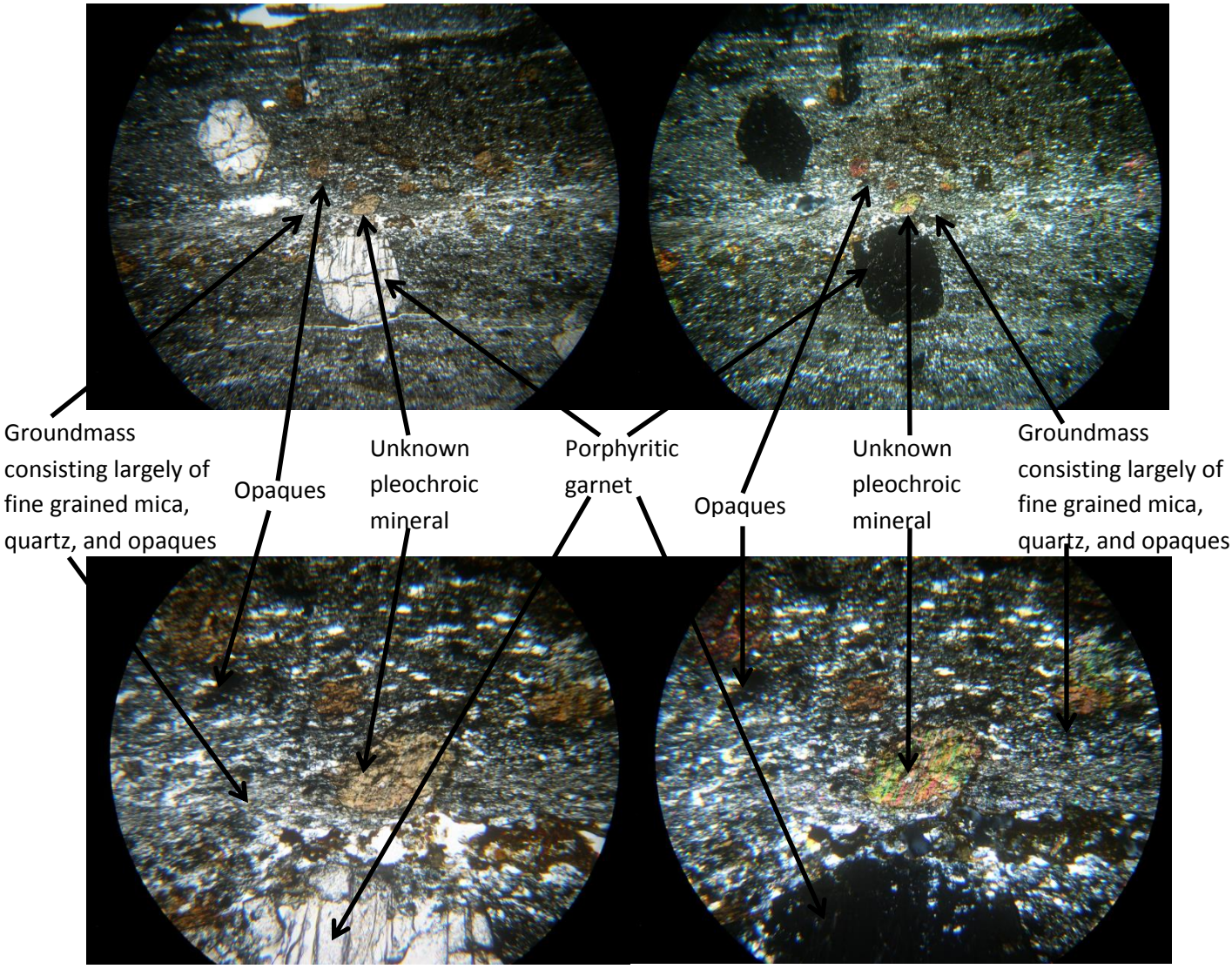

Figure 21: Thin section made from sample 2.2.2, at magnification x25 (top row) and x100 (bottom row). View under PPL on left, view under XPL on right. Field of view 8.0 mm (top row) and 2.0 mm (bottom row).

Major minerals found in thin section:

Quartz:

- Grain percentage of composition: 44%

- Subhedral crystals (0.08 mm)
- Colorless in PPL, first order white and gray under XPL
- Low relief
- No cleavage

Unknown mineral:

- Grain percentage of composition: 10%

Opaques:

- Grain percentage of composition: 5%
- Crystal shape and size uncertain
- Black in PPL and XPL

- Anhedral crystals (0.5 mm)
- Brown and pleochroic in PPL, 90° extinction angle, third order pastels under XPL
- Low relief
- Single plane of stripes caused by exsolution
- No birds eye extinction

Garnet:

- Grain percentage of composition: 5%
- Subhedral crystals (0.6 mm)
- Isotropic - colorless in PPL, black in XPL
- High relief
- No cleavage

The crystal sizes and matrix grains are smaller in 2.1.2 than in 2.2.2, but the difference is so minimal that it can be dismissed as normal variation within the formation. Garnets within the samples exhibit zoning.

Old Sugarlands Trail

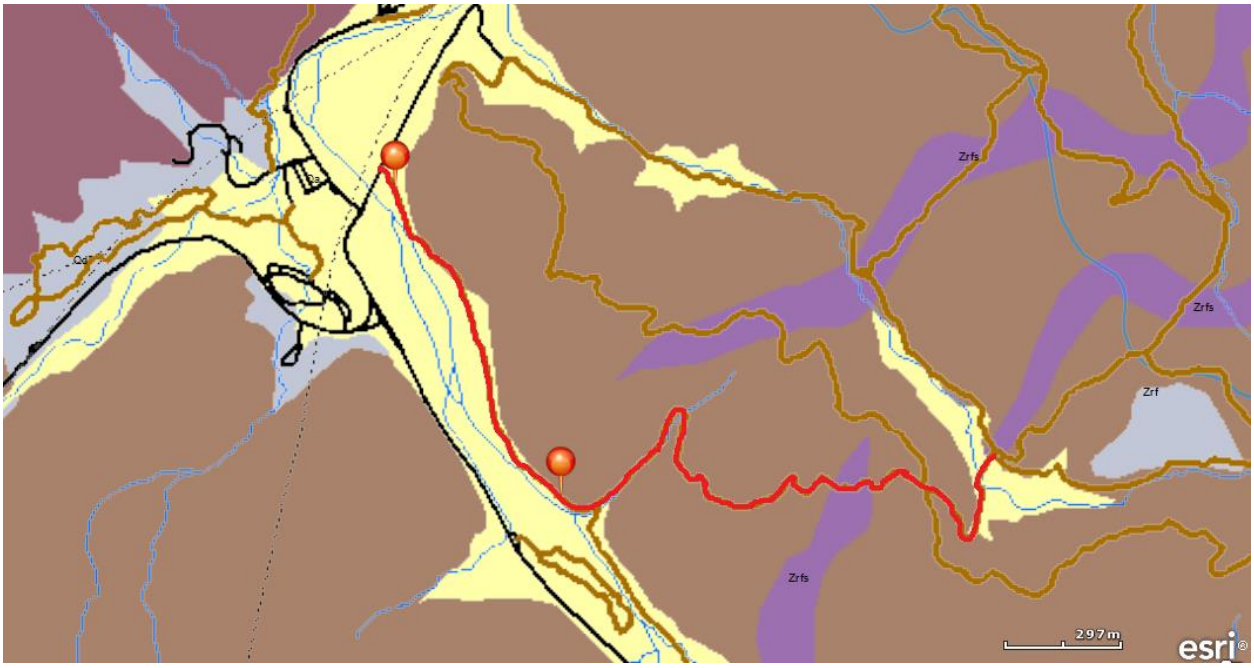

Figure 22: Geologic map of Old Sugarlands trail (marked in red) on ArcGIS. Tacks indicate locations with analyzed outcrops. Data from NPS and USGS, 2012.

Outcrop #1 is the site of a former rock quarry used for the first paved roads in the Smoky Mountains (Great Smoky Mountains Natural History Association, 1997). The outcrop runs from 17 0270628 3952231 to 17 0270655 3952131, and strikes 5° N. When viewed from left to right, its apparent dip runs from 10° E to 30° E, then back to 10° E, forming a gentle inflection. Bedding on the outcrop ranges from 25 cm to 125 cm. A concealed thrust fault, seen in Figure 2 as a dashed line directly to the left of the trail and likely part of the Gatlinburg fault zone, may have initially exposed the 20-meter tall outcrop. The fault's hanging wall corresponds with the side of the fault where the outcrop is found.

Outcrop #2 is an approximately 5-meter high, 10-meter wide outcrop with a more textually mature rock type. The rock's strike and apparent dip are 5° N and 30° E, respectively, matching that of Outcrop 1. The two outcrops differ, however, in that Outcrop #2 shows little to no bedding.

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