GEOLOGY OF ANTOINE PEAK CONSERVATION AREA
A LIMITED FIELD STUDY

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INTRODUCTION

Antoine Peak Conservation Area ("APCA") is 1,296 acres of mountainous terrain between Forker and Campbell roads north of Spokane Valley. The Spokane County Parks and Recreation Department administers APCA. For more information on the park location, directions to the three entrances, rules, and uses, visit the Spokane County Conservation Futures website.

The terrain is rugged and hilly with intersecting ravines and an elevational range from 2,200 ft. to 3,366 ft. at Antoine Peak (Figure 1). Vegetation on the southern and western side of the mountain consists mostly of conifers and drought tolerate shrubs and grasses. The north side is a shady, heavily forested area of conifers, deciduous trees, and dense undergrowth. Douglas fir, Western larch, Western hemlock, Grand fir, and Pacific yew populate this area. There is a five-acre pond (Leland Pond) along the Canfield Gulch Trail fed by seasonal streams.

Four rock types make up the bedrock geology at APCA. The two most common in the study area are the ***metamorphic*** rocks, Newman Lake Gneiss and Hauser Lake Gneiss. Two granitic ***igneous*** rocks intrude the bedrock, Rathdrum Mountain Granite, and an unnamed light-colored igneous unit characterized by its coarse-grained texture that we will refer to as "***pegmatite***."

Each of these four rock types show varying degrees of deformation related to APCA's location within the Spokane dome mylonite zone of the southern section of the Priest River complex (a ***metamorphic core complex***, Figure 2). A discussion of the Priest River complex is in the section below, "Overview of Regional Geology and Historical Context."

The purpose of this study was to create geologic maps of the area, describe the local bedrock units, and interpret rock types, textures, and structures at APCA within the geological context of the Priest River complex. Included also is a "What You Will See" section providing summary descriptions of the geology seen hiking along the marked trails.

Because of the size of APCA, we divided field mapping into three units: Emerald Necklace Trail (EN), Canfield Gulch Trail (CG), and the Arrow Leaf/Lost Apple Trails out of the Trentwood Trailhead (TW). Separate geologic maps for each unit are in Appendix I. Geological terms used in the report are highlighted in bold and italics and included in Appendix II – Glossary.

Figure 1. Rugged terrain along the Emerald Necklace Trail

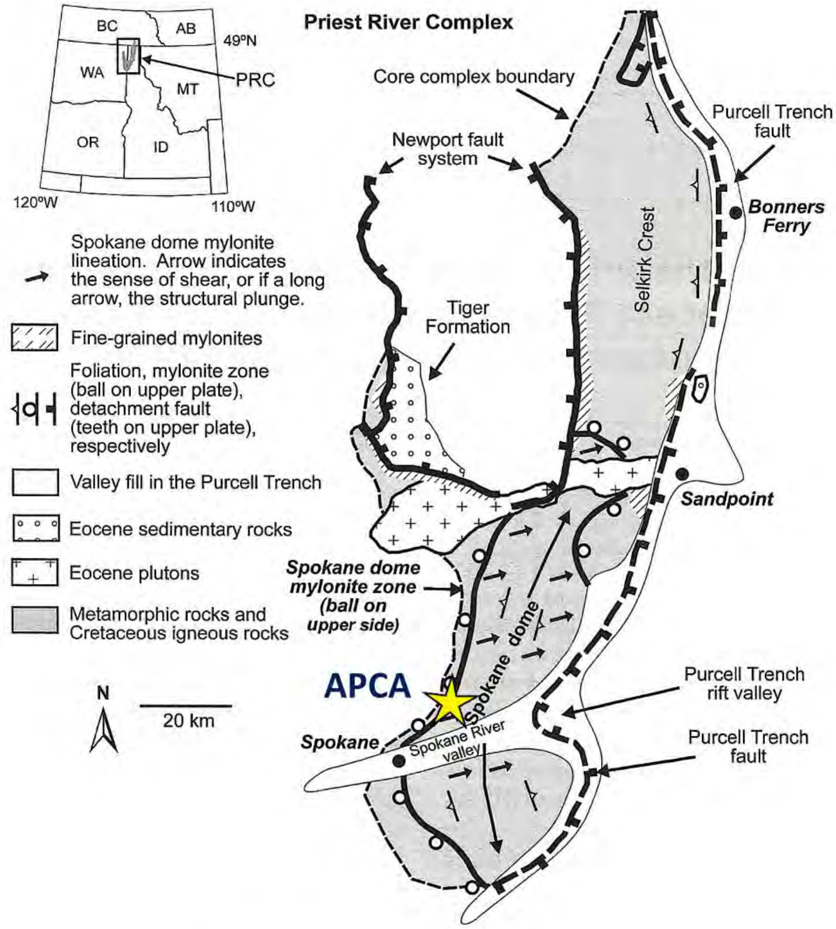

Figure 2. Park location from schematic of the Priest River complex, from Doughty et al., 2016.

METHODS AND LIMITATIONS

The fieldwork for this project was conducted from August through October of 2022 and April 2023. We studied only outcrops adjacent to marked trails, following hiking etiquette, and to avoid the remote chance of encountering a skunk, a cougar, or a bull snake. ***Lineation*** directions and ***strike and dip measurements*** were taken using a Brunton compass (Figure 3). We described hand samples from representative sites using a standard optical microscope. Thin sections taken from three rock types, Newman Lake Gneiss, Hauser Lake Gneiss and Rathdrum Granite, were analyzed for mineral content using a ***petrographic microscope***.

Non-field work consisted of reading peer reviewed papers and non-peer reviewed papers, including those prepared by other SCC students (Peterson and Buddington, 2014; Taylor and Buddington, 2014).

Limitations

As previously stated, the study area was restricted to marked trails. For example, the pegmatite units described below were largely found only as ***float*** in the study areas. To ascertain the origin of those rock fragments requires going off trail. Also, a more complete mineralogical study would ordinarily require analysis of multiple thin sections, rather than one per rock type allowed for in this report.

Lastly, no geochemical analysis was done, which may have allowed for a more robust analysis of how the rocks of APCA relate to the Priest River complex.

This study is reconnaissance in nature, building on similar student reports prepared on Mirabeau Point Park, Saltese Uplands Conservation Area, and McKenzie Conservation Area.

Figure 3. Taking strike and dip measurements using a Brunton compass.

THE ROCKS OF ANTOINE PEAK CONSERVATION AREA

The bedrock geology of APCA is largely made up of two metamorphic rock types, Newman Lake Gneiss and Hauser Lake Gneiss. Smaller amounts of two igneous rock types occur in the form of ***dikes*** and ***sills***. Those are Rathdrum Mountain Granite and an unnamed light colored granitic rock characterized by extraordinarily large crystals. In this report, we refer to this rock unit as pegmatite. Rocks of APCA show varying degrees of ***foliation***, ***mylonitization***, and ***lineation***, discussed in greater detail in the section below, “Rock Textures, Fabrics and Structures.”

Newman Lake Gneiss

The most common bedrock unit at APCA is the Newman Lake Gneiss, named after its type location at Newman Lake (WA) by Weis (1968). Its color is light to dark gray and may weather to tan. It is a coarse-grained, ***megacrystic***, moderately to well-foliated ***orthogneiss*** of ***granodiorite*** composition. Orthogneiss is the term given ***to high-grade*** (pressure-temperature) metamorphic rocks that formed from the ***recrystallization*** of an igneous parent ***(protolith***). In the case of Newman Lake Gneiss, the original parent rock before metamorphism was an igneous granodiorite. (Rhodes, 1986, Stevens et al, 2015).

The mineral ***assemblage*** of Newman Lake Gneiss from ACPA samples is as follows:

quartz - orthoclase - plagioclase - biotite

The occurrence of large megacrysts (crystals up to 10 cm) of orthoclase is the key identifying characteristic throughout the unit.

Large outcrops of Newman Lake Gneiss are at Antoine's Peak (site EN-3), and along the south side of the Emerald Necklace Trail. Smaller outcrops are located along the western side of the Canfield Gulch Trail. Outcrops of Newman Lake Gneiss are recognizable by light to dark gray or tan coloring, spheroidal weathering (discussed below), and blocky megacrysts of orthoclase. (Figure 4).

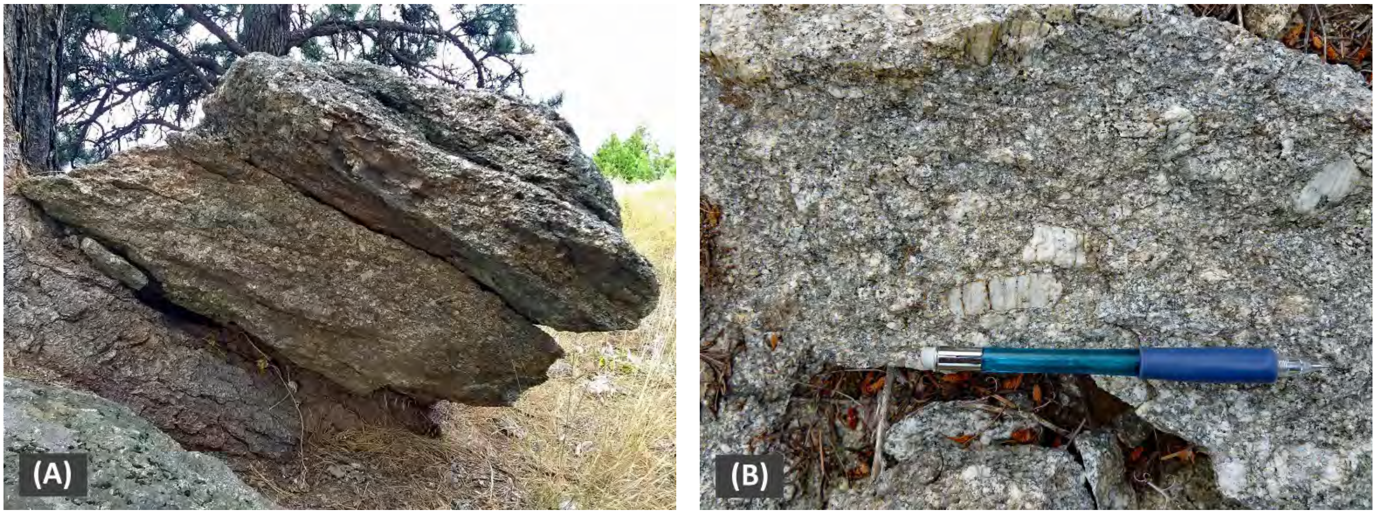

Figure 4: (A) Newman Lake Gneiss showing megacrysts and both tan and gray weathering (EN-1).
(B) megacrysts in Newman Lake Gneiss.

Hauser Lake Gneiss

Hauser Lake Gneiss is a gray to tan colored high-grade ***paragneiss*** that weathers to rusty brown. Paragneiss is the term given to metamorphic rocks that formed from the recrystallization of a sedimentary parent. The Hauser Lake Gneiss is composed of medium to coarse grained ***quartzo-feldspathic gneiss*** with interbedded sections of biotitic schist. Regionally, ***Mesoproterozoic***-aged ***amphibolite*** sills occur within Hauser Lake Gneiss**,** (Doughty et al., 1998), however none were observed within the APCA boundaries in this field study.

The mineral ***assemblage*** of Hauser Lake Gneiss from ACPA samples is as follow:

quartz - plagioclase - orthoclase - biotite- muscovite - sillimanite (whitish, fibrous form)

Garnet was also observed in the ***migmatitic*** Hauser Lake Gneiss described below. In thin section, accessory amounts of zircon were observed.

Sillimanite is the key mineral in this assemblage for identifying Hauser Lake Gneiss. It occurs only in aluminum rich metamorphic rocks formed in a high pressure/high temperature setting. Furthermore, its high aluminum content is an indicator of a sedimentary rock protolith (Klein and Philpotts, 2017).

Two general forms of Hauser Lake Gneiss are discernible in APCA. The ***schistose*** form consists of thin plates with plentiful mica minerals muscovite and biotite. White sillimanite often is visible with the naked eye in hand samples. Narrow dark and light parallel bands less than one centimeter wide characterize these samples. The light bands consist mostly of white or cream colored feldspar, quartz and sillimanite and the dark bands consist of biotite and gray to dark gray quartz (Figure 5).

The ***gneissic*** form of Hauser Lake Gneiss is characterized by dark and light bands that are generally thicker, less platy, and more distinct. The alternating coarse and fine grain layers with slightly different mineral compositions appear to be indicative of the sedimentary rock protolith displayed in Hauser Lake Gneiss (Figure 5).

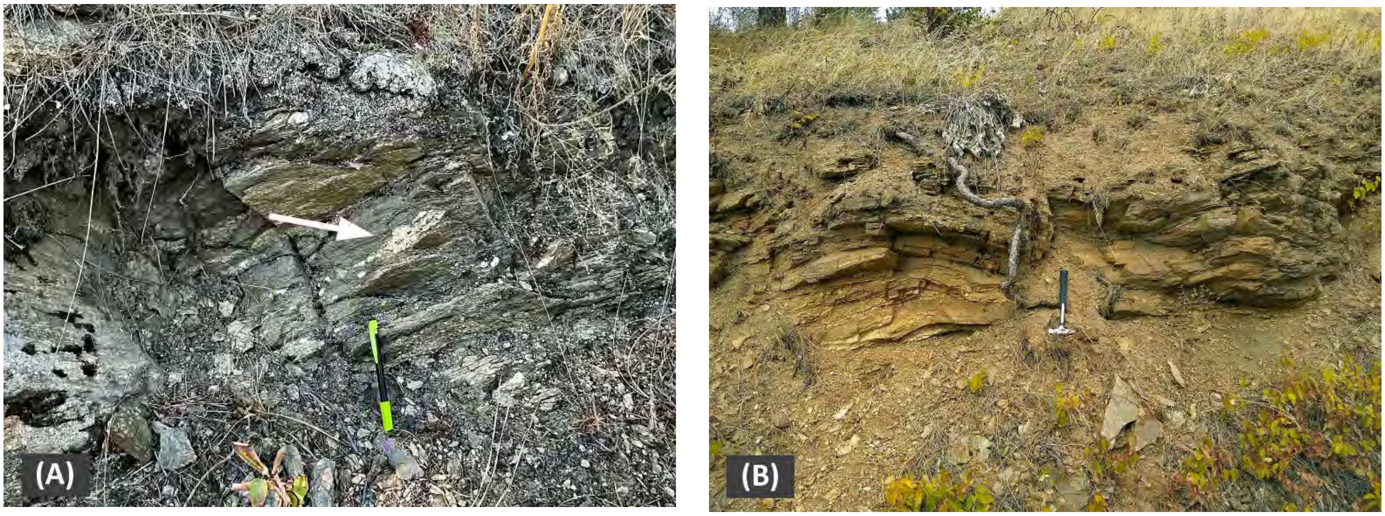

Figure 5: (A) dark gray, schistose Hauser Lake Gneiss with a small ***boudin*** (site CG-4); (B) gneissic Hauser Lake Gneiss with rusty brown weathering and indicating ductile deformation (site TW-7).

Migmatite. Hauser Lake Gneiss is a ***high-grade*** metamorphic rock, which means it formed under conditions of high temperature and pressure. At its maximum pressures and peak temperatures, the sedimentary protolith was metamorphosed under 9.6 to 10.3 kilobars of pressure (10,000 times the pressure at Earth's surface) at 700-800 degrees Celsius (1290 - 1470 degrees Fahrenheit). These extremes of pressure and temperature equate to its formation 35-40 kilometers below Earth's surface (Stevens et al., 2016, Doughty et al., 2016). At these extremes of heat and pressure, selected constituents of the metamorphic rock begin to melt, a process referred to as "partial melting," forming a new rock called "migmatitic gneiss." Since the protolith for Hauser Lake Gneiss is sedimentary, it is called a "migmatitic paragneiss." Geologists have identified partial melting in Hauser Lake Gneiss in the Priest River complex (Doughty, et al, 1998, Stevens et al., 2016). Outcrops are characterized by discontinuous lenses of quartz and feldspar, and concordant pegmatites containing quartz, feldspar, biotite, muscovite, and garnet. Stevens et al. (2016) suggests that 25%-40% of the rock (quartz-feldspar lenses) is the result of in-place migmatitic partial melting.

Outcrops of schistose and gneissic Hauser Lake Gneiss are located on the south side of the Emerald Necklace Trail, on the Canfield Gulch Trail within a quarter mile in either direction from the trailhead, and on the Arrow Leaf Trail near its intersection with the Emerald Necklace Trail. Migmatitic Hauser Lake Gneiss makes up the bedrock along the Arrow Leaf and Lost Apple Trails out of the Trentwood Trailhead.

Rathdrum Mountain Granite

Rathdrum Mountain Granite is a ***felsic*** igneous rock comprised of quartz, orthoclase, plagioclase, biotite, and minor muscovite. It is fine to medium-grained with ***equigranular*** crystals weathering pinkish to yellowish brown. Biotite makes up less than 5% of the rock. Mild foliation is indicated by the alignment of quartz and feldspar crystals. The few outcrops of Rathdrum Mountain Granite exposed along the Emerald Necklace Trail (EN-8) appear to indicate this unit forms intrusions no more than 3 meters wide within the Newman Lake Gneiss and Hauser Lake Gneiss. It shows modest foliation and lineation (Figure 6). Other exposures of Rathdrum Mountain Granite occur as narrow, concordant sills within the Hauser Lake Gneiss.

A thin section from the outcrop EN-8 revealed a ***myrmekitic*** micro-structure that others have also identified in the Rathdrum Mountain Granite (Derkey et al., 2004). Accessory minerals observed in thin sections are zircon, epidote, and apatite.

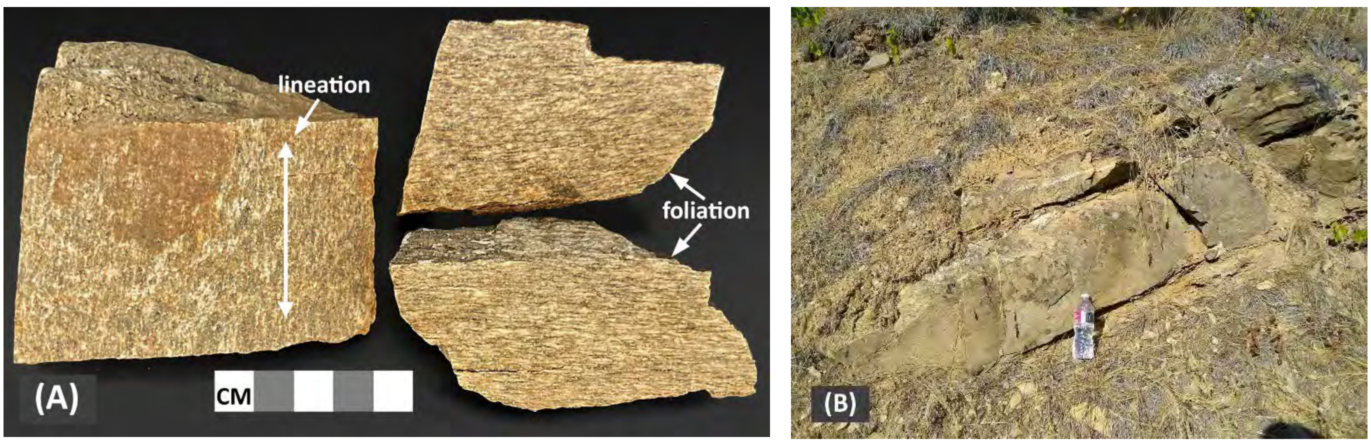

Figure 6: (A) hand sample taken from site EN-8, showing lineated and foliated textures. These textures indicate that this unit likely formed concurrently with the formation of the Priest River complex (see discussion below on Regional Geology and Historical Context); (B) outcrop at site EN-8.

Pegmatite

Occurring throughout APCA are ***leucocratic*** (light colored) gatherings of pegmatite float. Pegmatite is a very coarse-grained crystalline rock texture usually of granitic composition. Hand samples from APCA have mineral crystals up to 5 cm in size (Figure 7). Others show indications of deformation such as reduced crystal size and lineations. This rock unit is composed of quartz, orthoclase feldspar, plagioclase feldspar, muscovite, and small amounts of biotite. Only one outcrop of exposed pegmatite was documented (TW-7.5), but sporadic groups of float may be observed along all the trails.

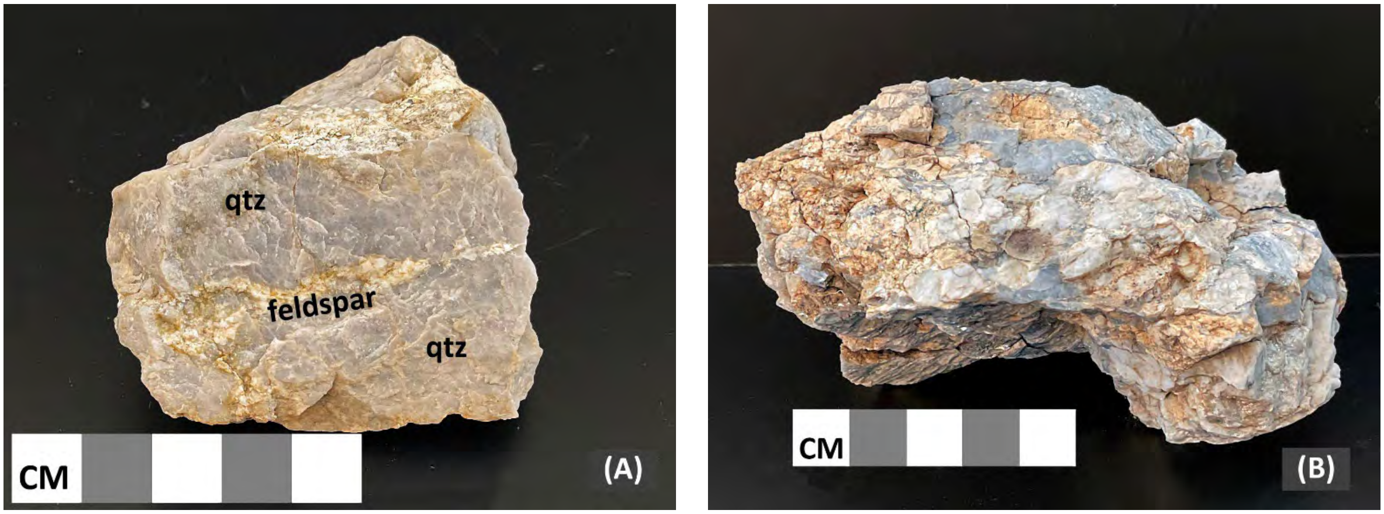

Figure 7: (A) hand sample of pegmatite float taken from the Canfield Gulch Trail near site CG-10, quartz crystals up to 5 cm (2”) across, (B) float sample from the Emerald Necklace Trail (EN-9).

ROCK TEXTURES, FABRICS, and STRUCTURES

Geologists use metamorphic textures observed in hand samples and thin sections to make inferences about the metamorphic history of a rock. By providing clues about deformation mechanisms, the texture of a metamorphic rock provides information about the protolith and thus the rock's metamorphic history, (Frost & Frost, 2019). Below are textures, fabrics, and structures observed in the rocks of Antoine Peak Conservation Area.

Foliation

The most common fabric element observed in APCA is foliation resulting from metamorphic recrystallization. Minerals in foliated rock show a preferred parallel alignment or planar pattern. The foliated textures in the Newman Lake Gneiss and Hauser Lake Gneiss indicate high pressure/high temperature ***regional metamorphism*.** The Rathdrum Mountain Granite shows a modest, but clearly observable, foliated texture with lineations (Figure 6 above).

Lineation

Another fabric observed in the rocks at APCA is extensive mineral stretching referred to as lineation. Lineation is defined as a linear orientation (vs. planar) pattern of minerals or features within a rock. Lineations composed of elongated, stretched minerals are most often associated with shearing or shear zones related to faulting. At APCA, lineations plunge gently (15º-30º) with an average trend of 250º. Lineated textures are observable in each of the four rock types described above.

Mylonite

Mylonite is a metamorphic rock texture that forms from the intensive shearing, grinding, and/or crushing of preexisting rocks deep below the surface. Mylonites are typically fine-grained (small crystals) and exhibit variable degrees of ***ductile deformation*** and recrystallization. The fine-grained nature of mylonite is the result of pulverization during the process of formation. Mylonites are foliated and lineated because of shearing within major fault zones, and individual crystals or ***porphyroclasts*** may exhibit smearing or rotation. Mylonites can form from any rock that has undergone intense tectonic stress and large-scale movements of deeper-level fault zones within Earth's crust. Varying degrees of mylonitization occur from ***protomylonite*** (early stage), to mylonite, to ***ultramylonite***. Ultramylonite is the most intense or highest degree of mylonite formation. Ultramylonites are very dense and "flint-like" due to extreme grain-size reduction. The original rock minerals and textures are essentially impossible to see in an ultramylonite (Figures 8, 9, and 10).

At APCA, most of the rocks have been "mylonitized" to some degree with more well-developed or intense mylonite (ultramylonite) occurring in narrow bands generally less than a meter thick. These ultramylonite bands or zones occur sporadically throughout the area and represent localized, higher strain zones within the Spokane dome mylonite zone itself.

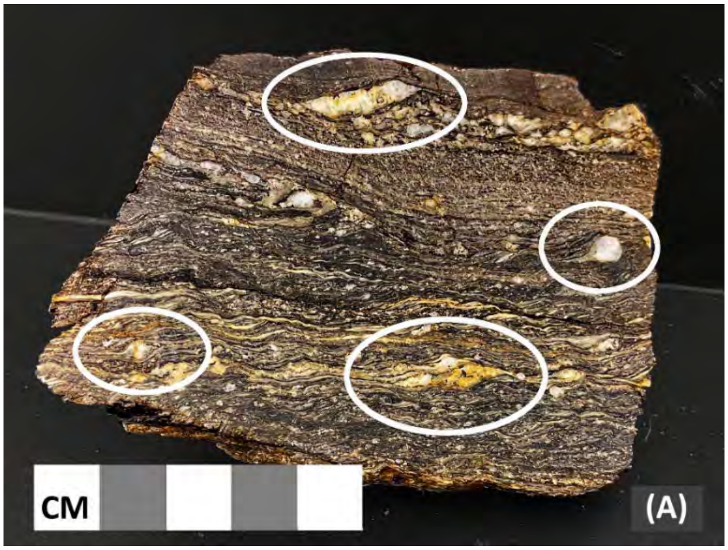

Figure 8: Both samples shown above are from the Canfield Gulch Trail in a high strain shear zone near the contact with Newman Lake Gneiss (CG-4). (A) ultramylonite of Hauser Lake Gneiss demonstrated by elongated, wavy minerals of biotite, quartz, feldspar, and sillimanite with porphyroclasts (circled). Porphyroclasts are larger deformed crystals (feldspar) surrounded by fine-grained, stretched out, groundmass minerals. Based on the shape of porphyroclasts, structural geologists can determine the direction of shear and start to make inferences about the geologic structure of a unit or region. (B) ultramylonite of the Hauser Lake Gneiss.

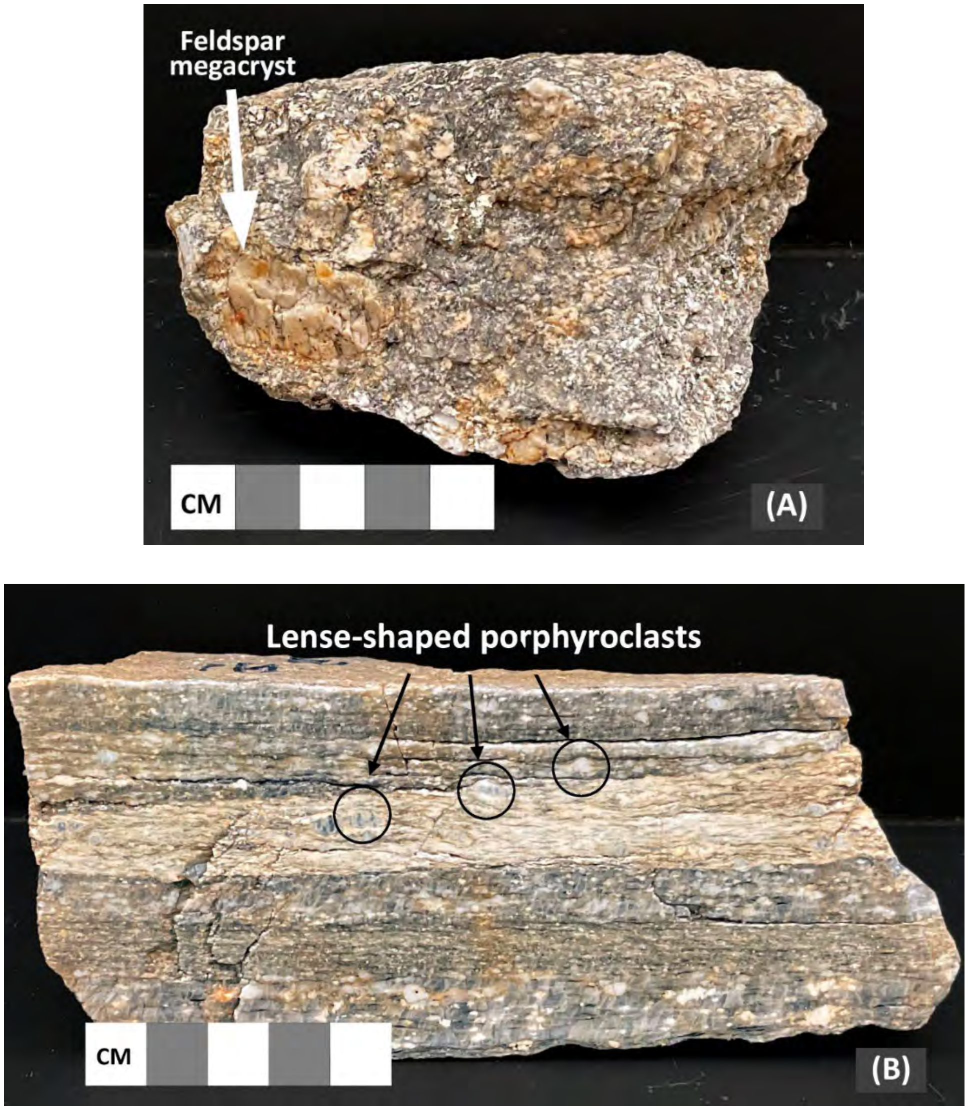

Figure 9: (A) Newman Lake Gneiss from the Emerald Necklace Trail (EN-1), with 1-3 centimeter megacrysts and minor deformation, (B) ultramylonite texture within Newman Lake Gneiss from the Canfield Gulch Trail (CG-17). The ultramylonite is indicated by minerals of reduced crystal size stretched into distinct bands. Small lens-shaped porphyroclasts are surrounded by crushed and stretched quartz and feldspar grains. Site CG-17 is near a high strain shear zone adjacent the contact between Newman Lake Gneiss and Hauser Lake Gneiss.

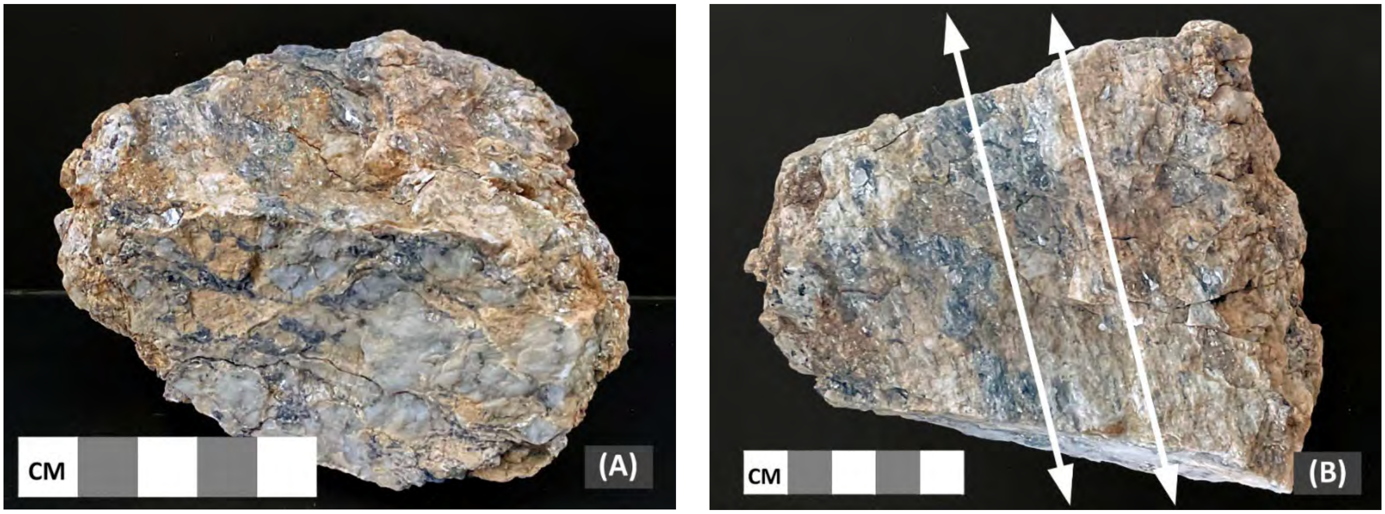

Figure 10: Hand sample of pegmatite taken from the Emerald Necklace Trail (EN-14). (A) photo angle is from the side showing large subhedral to euhedral feldspar crystals and anhedral quartz crystals indicating minor deformation, (B) photo angle from the top of the same hand sample showing lineations consisting of elongated and deformed quartz. The combination of the two textures indicate less intense shearing that might be characterized as protomylonite.

Boudins

The term boudin comes from the French word for sausage, referring to the peculiar shape of these structures. Common in deformed sedimentary and metamorphic rocks, boudins form in a high strain, usually shearing tectonic setting. As shearing takes place, resistant minerals gather as weaker minerals around them are sheared, stretched, and flattened out. The result of this elongation is a geologic structure that resembles the shape of a sausage link as seen below (Figure 11). These structures may occur at the micro level under thin section or at macro levels of the hand sample or larger. Examples observed in this study in both Hauser Lake Gneiss and Newman Lake Gneiss outcrops range in size from less than 1 centimeter to over 5 centimeters.

Figure 11: boudin consisting of quartz and feldspar within foliated Hauser Lake Gneiss (site TW-11).

Spheroidal Weathering

Spheroidal weathering is a surface weathering pattern affecting Newman Lake Gneiss (Figure 12). Spheroidal weathering is the result of in-place chemical weathering of rock that occurs at or near the surface. Rock masses that have undergone spheroidal weathering typically exhibit a characteristic rounded or spherical shape via a chemical process involving no movement or transport of the rock. Chemical weathering by water will occur more rapidly along the corners or edges of an initially angular rock mass. With time, the chemical attack along the corners and edges causes the rock to develop into a rounded shape.

The best places in the park to examine spheroidal weathering are along the south side of Emerald Necklace Trail, and at Antoine Peak where outcrops of Newman Lake Gneiss have undergone variable levels of spheroidal weathering.

Figure 12: Newman Lake Gneiss with spheroidal weathering, Emerald Necklace Trail.

TEXTURE AND FABRIC: DISCUSSION

The combination of well-developed foliation and lineation along with mylonitic fabric indicates that the rocks at APCA have undergone significant deformation from being subjected to intense stresses, probably during multiple geologic events (Doughty et al., 1998, Stevens et al. 2016). The lineated and mylonitic fabric seen here is typical of rocks from other parts of the Spokane dome mylonite zone of the Priest River complex. The foliation and lineation data are consistent with studies done from other parts of the Spokane dome mylonite zone and the Priest River complex in general (Doughty, et al., 2016).

The mylonitic texture of the rocks at APCA is evidence of a large shear (fault) zone that occurred at depth within mid-levels of Earth's crust (Doughty, et al., 1998). This shear zone formed as portions of the deep crust were being uplifted and sections of the upper crust began to detach causing intense shearing pressures. The original Newman Lake granodiorite was caught up in this deep shear zone metamorphosing it into gneiss and causing it to become mylonitized. Less common, narrow ultramylonite zones represent more localized, high intensity strain zones within the overall shear zone.

Studies indicate that this process occurred between 40 to 50 million years ago (Doughty, et al., 1998). Eventually the entire portion of the Priest River complex, including APCA, was uplifted and eroded by surface processes to expose what we see today (see “Regional Geology and Historical Context” below).

WHAT YOU WILL SEE ALONG APCA TRAILS

Canfield Gulch Trail (Canfield Gulch Map)

Heading south from the kiosk near the East Trailhead you will see several small outcrops of Hauser Lake Gneiss along the switchbacks as you gain elevation (Figure 13). Turning west after the last switchback, forest vegetation covers any geologic features until you reach the junction with the Antoine Summit Trail at about 2900 feet elevation. To the left the Antoine Summit Trail winds through a beautiful, forested area but little geology is exposed (Figure 14). To the right, heading north on the Canfield Gulch Trail, Newman Lake Gneiss predominates with two areas of pegmatite float. The trail leads you past Leland Pond, (Figure 15), passing through more beautiful forest vegetation. At around 2400 feet (elevation) you again see small outcrops of Hauser Lake Gneiss until reaching the kiosk and trailhead. An alternative to the route past Leland Pond is to turn right at the Middle Trail junction heading downhill. Along the Middle Trail are small outcrops of Newman Lake Gneiss. Passing views of forested hills to the north you reach the approximate Newman Lake Gneiss/Hauser Lake Gneiss contact near sites CG-17, CG-9, and CG-8. In this area there is evidence of intense mylonitization, and lineation in both the Newman Lake Gneiss and Hauser Lake Gneiss rock texture. (See Figures 8, 9, and 10).

Figure 13: a small outcrop of Hauser Lake Gneiss covered with vegetation. Most of the outcrops along the Canfield Gulch Trail are small and covered with vegetation.

Figure 14: a portion of Antoine's Summit Trail approaching the Emerald Necklace Trail from the junction of the Canfield Gulch Trail with Antoine's Summit Trail.

Figure 15: Leland Pond.

Emerald Necklace Trail and Antoine Peak (Emerald Necklace Map)

From the West Trailhead, take either Antoine's Summit Trail or Tower Road to the junction of Antoine's Summit Trail and Emerald Necklace Trail. Going straight takes you to the peak. Take the right hand fork to the south side of the Emerald Necklace Trail. Most of the geological features on the Emerald Necklace Trail are in this area and at Antoine Peak. Several large outcrops of dark gray Newman Lake Gneiss showing spheroidal weathering (sites EN-1, EN-14, EN-13) are on this trail. Just east of site E-9 is a small partial exposure of light brown Rathdrum Mountain Granite (Figure 6B above). Continuing east on the trial, at site EN-7 both Newman Lake Gneiss and Hauser Lake Gneiss are exposed together. Our tentative interpretation of this outcrop is that after the rocks were formed, tectonic forces caused the interleaving of older Hauser Lake Gneiss between two units of the younger Newman Lake Gneiss. (Figure 16). Shortly after E-7 the trail turns to the north. Site EN-4 is an outcrop of reddish brown Hauser Lake Gneiss (Figure 17). Based on observations at sites EN-12, EN-10, EN-7, and EN-4, it appears that this part of the trail is near a Hauser Lake Gneiss/Newman Lake Gneiss contact. The trail northward is a pleasant hike into a forested area of conifers and deciduous trees, but only a few outcrops of Newman Lake Gneiss occur.

Large outcrops of spheroidally weathered Newman Lake Gneiss are at Antoine's Peak (EN-3).

Figure 16: Hauser Lake Gneiss interleaved between units of Newman Like Gneiss (Site EN-7).

Figure 17: outcrop of Hauser Lake Gneiss (Site EN-4).

Arrow Leaf and Lost Apple Trails from the Trentwood Trailhead (Trentwood Map)

Head north from the Trentwood trailhead and pass through a gate. Up the road to the left is site TW-11, an outcrop of migmatitic Hauser Lake Gneiss with several easily viewable boudins. Go back down to the hiking trail and continue 0.10 mile up to the junction of Lost Apple and Arrow Leaf Trails. Bear right to the Arrow Leaf Trail, which is a series of switchbacks heading up through a forested area. There are several outcrops of migmatitic Hauser Lake Gneiss along the way, but they are highly weathered, and lichen covered. Lineations may be observed in float rocks lying near the larger outcrops. At site TW-3, which is migmatitic Hauser Lake Gneiss, tennis ball sized boudins are on the lower section of the outcrop (Figure 18). Continuing north, as you approach the intersection with the Emerald Necklace Trail (site TW-6), a sill of Rathdrum Mountain Granite occurs within schistose Hauser Lake Gneiss (Figure 19). The Hauser Lake Gneiss outcrop exhibits a schistose texture that appears to wrap around the Rathdrum Mountain Granite. Returning down the hill, at the intersection with the Lost Apple Trail, turn right. The Lost Apple Trail is mostly vegetation-covered as you pass through a meadow of tall grass with nice views of Antoine Peak to the north.

Figure 18: site TW-3 migmatitic Hauser Lake Gneiss with quartz-feldspar bands and tennis ball sized boudins.

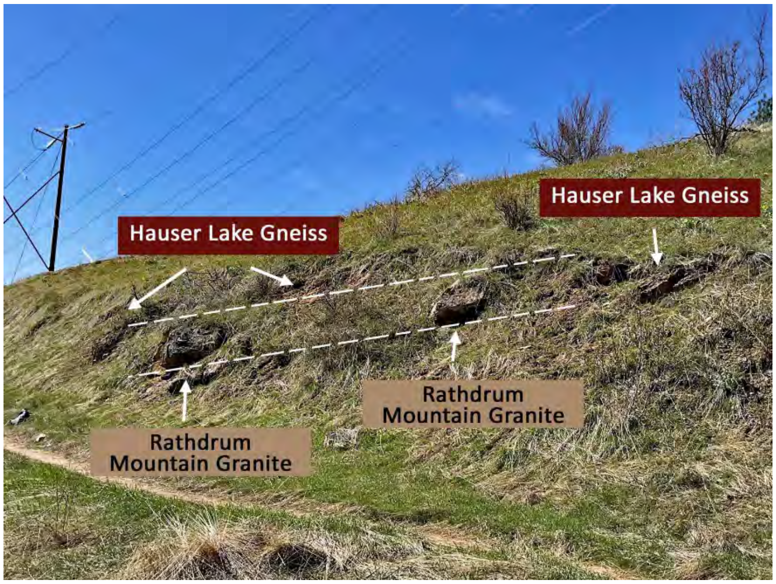

Figure 19: site TW-6, Rathdrum Mountain Granite sill intruding Hauser Lake Gneiss.

OVERVIEW OF REGIONAL GEOLOGY AND HISTORICAL CONTEXT

The region of northeastern Washington and northern Idaho has experienced a long-lived and complex history of geologic events.

Mesoproterozoic *Time: Prichard Formation of the Belt Supergroup*

Between 1.4-1.5 billion years ago, northeastern Washington, northern Idaho, and western Montana was covered by a large inland sea that formed between two continents, Laurentia (later to become North America) on the east and another continent to the west (possibly Antarctica, Australia, or Siberia). This inland sea, known as the ancient Belt Sea, accumulated sediments shed from the adjacent continents over a period of approximately 100 million years. Those sediments ultimately became a 15-kiliometer thick package of sedimentary rocks called the Belt Supergroup (Lonn et al., 2020). The lower six-kilometer portion of the Belt Supergroup is called the Prichard Formation, consisting of alternating layers of medium to coarse-grained quartz sands and fine-grained silts and clay that eventually ***lithified*** (cemented) into thinly interbedded ***siltite***, ***argillite***, and thicker quartzite layers. (Cressman, 1989). The Prichard Formation is the protolith for the metamorphic Hauser Lake Gneiss (Doughty, 2008).

Mesozoic Era*: Intrusion of Igneous Plutons*

Fast forward to about 65-100 million years ago, during the ***Cretaceous*** Period of the late ***Mesozoic Era***. Collision of tectonic plates from the west caused the deep burial of the sedimentary layers along with compression of the crust. This tectonic activity led to extreme temperatures and pressures within the crust that resulted in regional metamorphism (metamorphism of rocks over a large geographic area). These “high-grade” metamorphic conditions are evidenced by the visible recrystallized, parallel alignment of minerals (foliation) leading to the well-foliated Hauser Lake Gneiss.

Simultaneously, offshore subduction from the colliding plates created large magma bodies called ***plutons.*** The plutons rose into the middle crust and intruded the metamorphosed sedimentary layers deep underground. One of the many plutons crystallized into a coarse-grained igneous rock called granodiorite, which became the parent rock (protolith) of Newman Lake Gneiss. The Newman Lake Gneiss was recently age-dated at 65 million years ago (Buddington, et al., 2019).

Cenozoic Era*: Priest River Complex*

About 55 million years ago during the ***Eocene Epoch*** of the ***Cenozoic Era***, tectonic forces changed again from compressional to extensional. This is the very nature of plate tectonics. The plates, miles beneath our feet, are constantly moving, shifting course, and reshaping our Earth. Over the next 15 million years, this change in tectonic activity led to a regional uplift of lower crust, including the previously buried Hauser Lake Gneiss and Newman Lake Gneiss. Extensive faulting of the uplifted crust began to occur during this period. A large low-angle fault, termed a ***detachment fault***, developed deep in the crust as it was being uplifted (Figure 20). The detachment fault allowed the crust to separate and slide during uplift, with the upper portion of the crust detaching and sliding off the rising lower, deeper crust. This detachment and resulting shearing motion (and stress) caused the mineral lineations and mylonitic textures in the rocks at APCA. This detachment fault is part of the large, uplifted area in northeast Washington and northern Idaho known as the Priest River complex

(Doughty, et al., 1998). This "core" complex represents the deep crust that domed up during this period of crustal extension. The greatest shearing stress is just below the detachment fault in the four-kilometer thick Spokane dome mylonite zone that separates the upper portion ("suprastructure") from the lower portion ("infrastructure"). It is in this this zone of immense shearing and uplift that APCA is located.

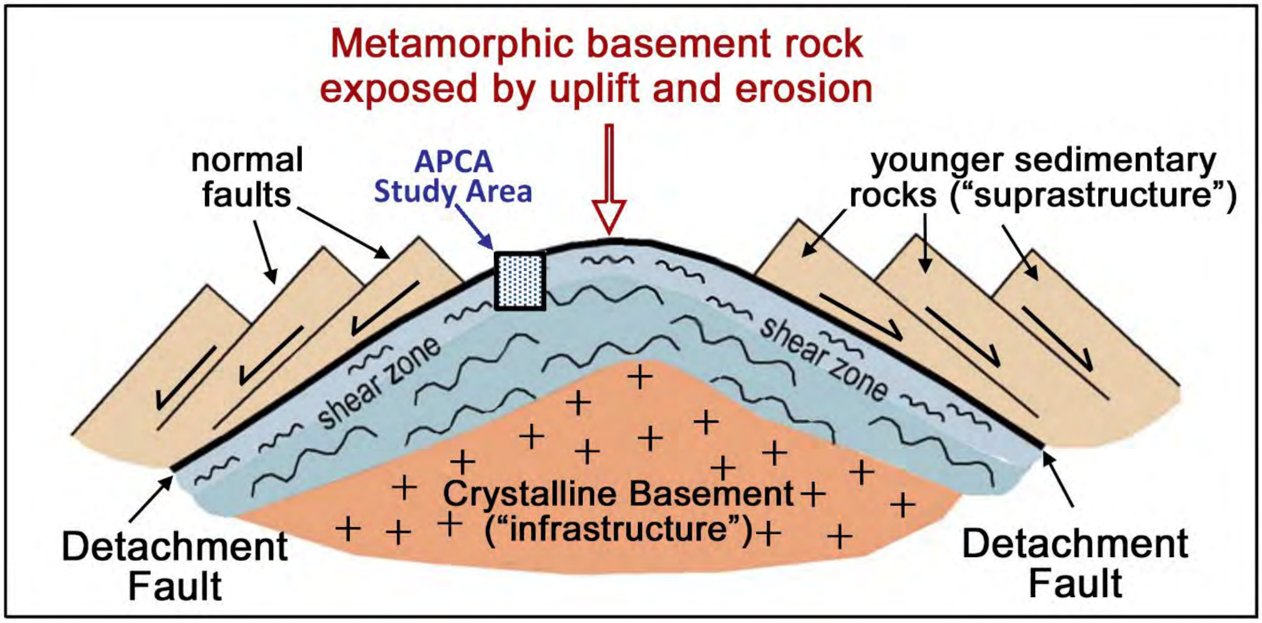

Figure 20: structure of the Priest River complex. Modified from Link and Phoenix, 1996.

During the period of extension and exhumation of the metamorphic core complex, fractures in the constantly moving bedrock allowed for new igneous intrusions into the region represented by the Rathdrum Mountain Granite exposed at APCA. The uplift of the Priest River complex ended approximately 40 million years ago.

In the last forty million years, other geologic events took place in the region such as the inundation of the Columbia River Basalt Group 17-6 million years ago, and the ice age Missoula floods. These events are not recorded at APCA.

SUMMARY

The geologic history of a region profoundly affects the composition, texture, and microstructures of the rocks there. Inversely, analyzing these rock constituents provides important clues geologists use to reconstruct that geologic history. This is apparent in the composition, textures, and microstructures of the rocks of Antoine Peak Conservation Area.

The Hauser Lake Gneiss exhibits metamorphic banding due in large part to compositional layering inherited from the original sedimentary protolith, the Prichard Formation, which formed 1.4 billion years ago (Buddington et al., 2016). The granodiorite protolith of Newman Lake Gneiss formed from an igneous pluton deep underground much later during the late Mesozoic Era. During this time, a period of compression caused by the convergence of tectonic plates likely contributed to metamorphic nature and the foliated textures in the rocks. And lastly, the detachment fault of the of the Priest River complex created intense shearing in the Spokane dome mylonite zone evidenced by boudins, lineations, and mylonitic textures in the rocks. Fractures in the bedrock allowed for the intrusion of a new set of igneous intrusions represented by the Rathdrum Mountain Granite and possibly the pegmatites. These rocks, textures, and structures are all identified in this report.

By mapping the area within the park, we identified zones of intense mylonitization at Newman Lake Gneiss-Hauser Lake contacts along the Emerald Necklace and Canfield Gulch Trails and immediately outside park boundaries to the southeast.

Further Inquiry

The genesis of the pegmatite is poorly understood. Comprehensive geochemical analysis and age dating of the pegmatite could provide a more accurate description and understanding of this rock unit. It could also allow for comparison to other similar units within the area including melted constituents of the migmatite paragneiss along the Arrow Leaf and Lost Apple Trails out of the Trentwood Trailhead.

An interesting finding in this study is the relative abundance of the mineral muscovite in the outcrops of Hauser Lake Gneiss at APCA. Little muscovite is reported at the nearby Saltese Uplands Conservation Area (Buddington et al., 2015). This implies different pressure-temperature conditions at APCA resulting in a different mineral assemblage. Further analysis of a larger suite of samples from APCA, and comparison with rock data at other locations in the region may clarify these differences.

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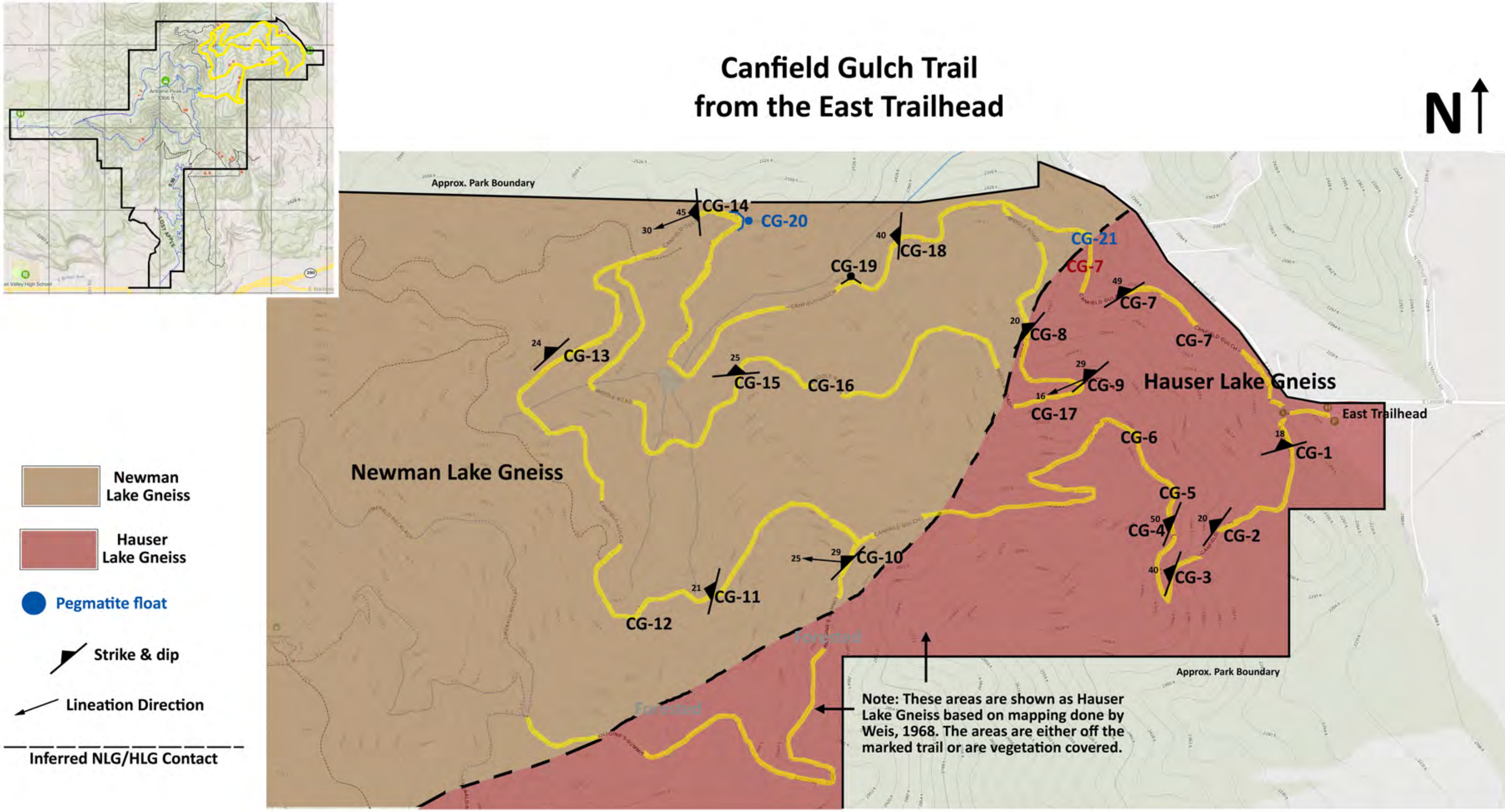
APPENDIX I – MAPS

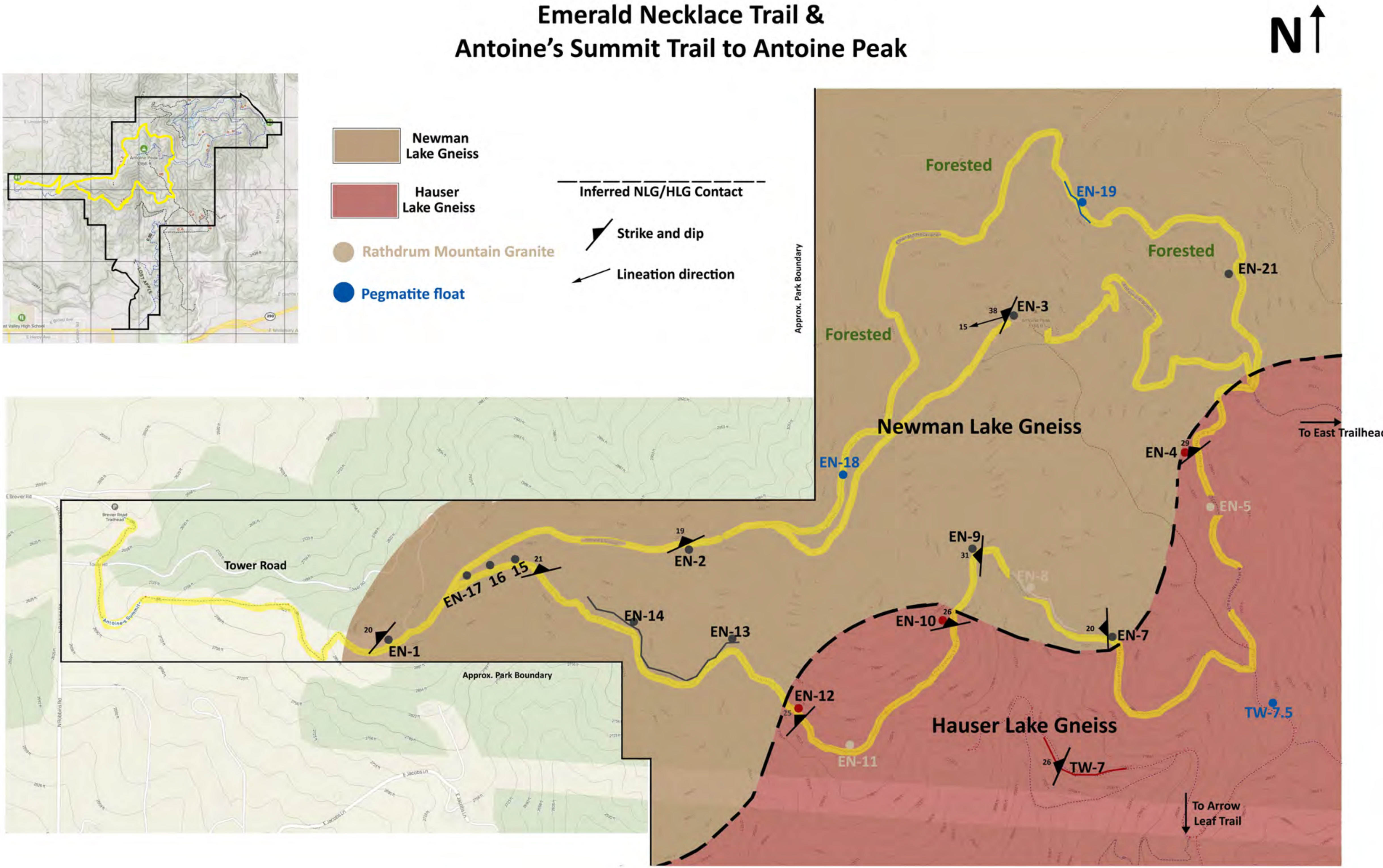
AllTrails

The base layer of the maps was created from the All Trails App. We also used the All Trails App on our phones, which showed our position when we were in the field. Field notes containing rock descriptions and strike and dip information for each outcrop shown on the maps are available by contacting the corresponding author by e-mail at: andy.buddington@scc.spokane.edu.

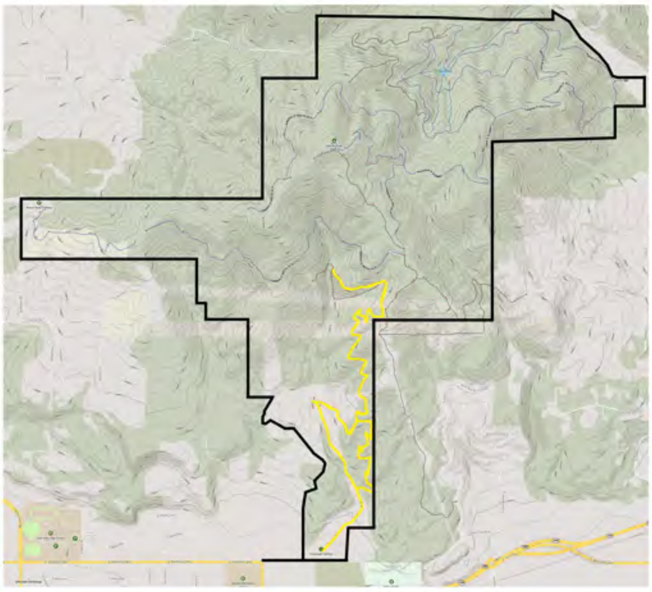
Canfield Gulch Trail from the East Trailhead

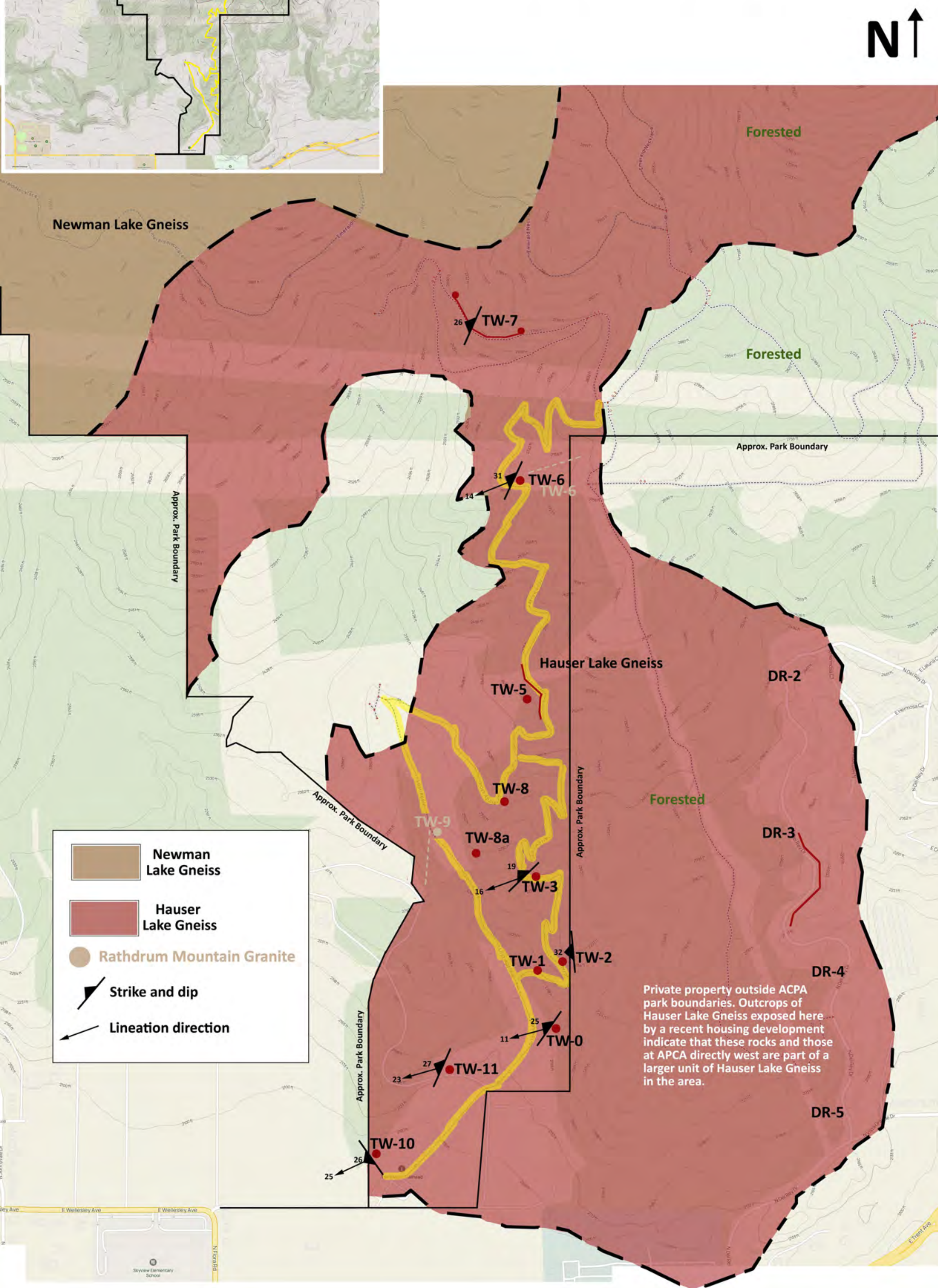


Emerald Necklace Trail &
Antoine's Summit Trail to Antoine Peak



Arrow Leaf & Lost Apple Trails
(Trentwood Trailhead)





APPENDIX II - GLOSSARY

amphibolite: a dark-colored (mafic) metamorphic rock whose protolith is basalt.

anhedral: a term describing the shape of a mineral that is not bounded by crystallographic faces.

argillite: a mudstone with variable amounts of silt-sized particles composed predominantly of indurated (hardened) clay particles.

assemblage: in the context of metamorphism, an assemblage is an association of minerals that is interpreted to have approached a state of equilibrium during metamorphism.

bedding: the layering as seen in a sedimentary rock. A single layer is called a bed. When different rock types are interlayered with each other, they are described as interbedded. There are no sedimentary rocks in APCA; however, the protolith for Hauser Lake Gneiss is a sequence of interbedded layers of sedimentary rocks formed from muds, clays, and quartz sandstone. Even though they were subjected to intense metamorphism, interbeds may still be recognized in some Hauser Lake Gneiss samples.

biotite: a platy dark mica mineral common in both the Hauser Lake Gneiss and Newman Lake Gneiss in APCA.

boudin: a deformation structure in which competent layers of rock neck down and pull apart to form lenses in less competent rock resembling sausages.

Cenozoic Era: a block of time from 66 million years ago to the present.

Cretaceous Period: a block of time during the ***Mesozoic Era*** from 145 million years ago to 66 million years ago.

detachment fault: a low angle normal fault associated with large scale tectonic extension.

dike: tabular bodies of igneous rock that form when magma solidifies within a subterranean fracture. Dikes can range from centimeters to kilometers in thickness, although shallow-level dikes tend to be in the order of meters. At APCA dikes are small and difficult to find near the marked trails.

ductile deformation: said of a rock or mineral that can sustain deformation before fracturing or faulting. Ductile deformation mechanisms most likely occur in higher Pressure–Temperature conditions at middle-to-lower crust and upper mantle environments.

Eocene: an episode of geologic time during the Cenozoic Era from 55 million years ago to 38 million years ago.

equigranular: crystals within a rock generally of equal size.

feldspar: the most common rock forming mineral in continental rocks. It is composed of varying amounts of silicon, potassium, sodium, calcium, and aluminum. It includes plagioclase feldspars and potassium feldspars. Feldspar is a common mineral in all the rocks at APCA.

felsic: a descriptive term for igneous rocks indicating light coloring. The term is a combination of “feldspar” and “silicon” as felsic rocks consist mostly of feldspar and quartz (silicon).

float: pieces of rock that have been removed and transported from their original outcrop.

foliation: a term used to describe any planar feature of a rock, including primary layering, such as bedding, or a secondary feature caused by deformation.

gneiss: metamorphic rock from either a sedimentary or igneous protolith formed under conditions of high temperature and pressure**.**

gneissic texture: a texture or structure with foliation defined by alternating layers of light and dark minerals with generally more widely spaced bands than that of a **schistose** texture.

granodiorite: a coarse-grained intrusive igneous rock with intermediate mineral composition between granite and diorite.

high-grade: a term used to describe the temperature pressure conditions forming a metamorphic rock. High-grade refers to either high temperature, pressure, or both.

igneous rock: rock that crystallized from the cooling of molten magma. Igneous rocks at APCA are limited to hard-to-find narrow dikes (no more than three feet wide) that intruded the Newman Lake Gneiss and Hauser Lake Gneiss.

intrusion: the process of emplacement of magma in pre-existing rock.

K-spar: a colloquial name for the mineral orthoclase. It is a feldspar mineral that contains potassium (chemical symbol "K"). It is an abundant rock forming mineral in all rocks at APCA.

leucocratic: light-colored; applied to igneous rocks that are relatively poor in mafic (dark) minerals such as biotite. The percentage of mafic minerals necessary for a rock to be classified as leucocratic varies among petrologists but is usually given as less than 30% to 37.5%.

lineations: a metamorphic rock texture characterized by parallel lines in a specific direction, consisting of elongated minerals or clasts. At APCA, a lineated texture is an indicator of shearing metamorphism.

lithify: to change to stone; to consolidate from a loose sediment to a solid rock.

megacrystic: a rock texture characterized by large mineral crystals surrounded by a fine grained matrix.

Mesoproterozoic Era: episode of geologic time from 1,600 million years ago to 1,000 million years ago.

Mesozoic Era: a block of geologic time from 251 million years ago to 66 million years ago. The Mesozoic Era ("middle life") is between the Paleozoic ("ancient life) and Cenozoic ("recent life") Eras

metamorphic core complex: the ***high-grade*** metamorphic rocks exposed at the surface after the overlying low-grade rocks slid off them along a shallow ***detachment fault***.

metamorphic rock: rock that is formed by the process of recrystallization of either a sedimentary, igneous, or metamorphic rock in its solid state (without melting) due to heat and pressure or heat alone. Depending on the amount of heat and pressure (its grade), minerals in a metamorphic rock may be deformed without changing their composition, or new minerals may arise and previous minerals in the rock may be eliminated. See also protolith, foliation, lineation, and mylonite textures.

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muscovite: a glassy or silvery, flakey, mica mineral containing relatively large amounts of potassium and aluminum. Muscovite is common in igneous, sedimentary, and metamorphic rocks. At APCA muscovite may be observed in the Hauser Lake Gneiss, the Rathdrum Mountain Granite, and in the pegmatite assemblages.

mylonite: a rock texture characterized by stretched minerals, reduced mineral size, or obliteration of minerals. Rock textures like these are usually related to shearing or a shear zone.

myrmekite: a microscopic worm-like intergrowth of quartz and plagioclase (a feldspar mineral) that may indicate the chemical transformation of rock composition in the presence of hot hydrous fluids. It was observed in a thin section of Rathdrum Mountain Granite taken from APCA.

orthoclase: See “K-spar” above.

orthogneiss: a gneiss that was derived from an igneous protolith.

paragneiss: a gneiss that was derived from a sedimentary protolith.

pelitic schist: a schistose metamorphic rock derived by metamorphism of an argillaceous or a fine-grained aluminous sediment.

pegmatite: an unusually coarse grained igneous rock, usually of a granitic composition, with individual crystals exceeding one centimeter, but may also be measured in meters. The pegmatite samples at APCA are up to 4 centimeters in length.

petrographic microscope: a microscope specifically fitted with optical polarizers and other mechanical accessories for identifying optical properties of minerals viewed in thin sections of rock sliced to 30 microns thick. A micron is one millionth of a meter.

plagioclase: a felspar mineral consisting of variable amounts of calcium and sodium, as opposed to orthoclase (“K-spar), which contains the element potassium.

pluton: a body of igneous rock (less than 100 km^2) that crystalized at depth in the crust.

plagioclase: a form of feldspar consisting of varying amounts of sodium (Na) and calcium (Ca). It is a common rock forming mineral and is part of the composition of all the rocks at APCA.

porphyroclast: single crystal exceeding the average size in the surrounding matrix and inferred to represent a remnant of an originally coarse-grained rock. Common in mylonites, its deformation is due to mechanical grinding as opposed to growth by chemical recrystallization.

protolith: Also known as the “parent rock,” it is the unmetamorphosed igneous or sedimentary rock that is the subject of later metamorphism.

protomylonite: weakly to moderately deformed rock in a shear zone, transitional between the undeformed wall rock and a mylonite. 10-50% of composition in protomylonite is fine matrix.

quartz: a common rock forming mineral consisting solely of silicon and oxygen, SiO_2. It is common in all the rocks at APCA whether igneous or metamorphic.

quartzo-felsdspathic: metamorphic rocks abundant in feldspars and quartz. Newman Lake Gneiss and Hauser Lake Gneiss are examples at APCA.

recrystallization: rearrangement of mineral crystals to a modified set of crystals by migration and modification of grain boundaries. Recrystallization may or may not involve chemical changes. It usually involves a decrease or increase in the crystal sizes.

regional metamorphism: metamorphism that takes place on a regional scale as a result of increasing temperature and pressure region wide. It is usually associated with deformation related to tectonic plate convergence.

schist: a metamorphic rock in which medium to coarse grained platy minerals such as micas or needle-like amphiboles create a prominent foliation or alignment. It can usually be readily split into thin flakes. Schistosity is seen in the Hauser Lake Gneiss containing platy micas and aluminosilicates, also called a “pelitic schist” referring to its sedimentary origin.

sill: an igneous intrusion that parallels the planar structure or bedding of the host rock.

sillimanite: a white, fibrous aluminosilicate mineral formed only under conditions of extreme heat and moderate to high pressure. It is found only in metamorphic schist and gneiss and is used to identify Hauser Lake Gneiss at APCA.

siltite/siltstone: a fine grained sedimentary rock made up of mostly silt-sized clasts and clay.

strike, dip, and lineation measurements: measurements taken in the field to ascertain structural features of an outcrop or multiple outcrops to make inferences about tectonic movements and structures in a local area.

ultramylonite: extremely fine-grained mylonite with 90-100% matrix and 0-10% porphyroclasts.