A Geologic Excursion Through the Sierra Foothills Metamorphic Belt Along the Historic Amador Central Railroad

Speeder Cars to Accretion

Prepared for the Amador Central Railroad geology fieldtrip excursions with contributions from the staff of the California Geological Survey

Department of Conservation
California Geological Survey

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Introduction

The Amador Central Railroad (AMC) is a good example of the hundreds of short-line railroads that sprang up throughout America in the late 19th and early 20th centuries. The impetus to build these short-line railroads was primarily to access and exploit mineral resources in remote undeveloped areas and to supply raw materials to the heavy industries in rapidly developing urban centers. The AMC was one such valuable rail transportation corridor in Amador County (Figure 1) for both freight and passenger traffic. It was a welcome replacement for relatively inefficient horse-drawn wagons over dirt roads, especially during the rainy seasons.

With the opening of the AMC in 1905-1906 and the sudden appearance of efficient railroad transportation to various commodities markets, important clay and aggregate deposits in and around Ione, California became a competitive source of mineral materials. In addition, the mining industries extracting gold and copper ores further east in the Sierra Nevada foothills metamorphic belt were able to import heavy mining equipment, as well as export metal ore for processing.

Remnants of abandoned mine activities that were once served by the railroad are still visible along the route. They illustrate the historic legacy and sometimes negative impacts left on the landscape and natural environment. Remediation of some of these mining sites is still an issue in the modern era.

Although passenger rail traffic waned in the latter years of operation, the railroad continued to be economically viable into the 1990's due to the export of various mineral and natural resource commodities occurring in the foothills of Amador County. Thus, it is only fitting to offer this unique opportunity to view interesting Sierra foothills geology and the historic mineral resources from the vantage point of the historic AMC railroad tracks.

This fieldtrip along the historic Amador Central Railroad by way of vintage track inspection cars (aka "motor cars" or "track speeders") offers a unique opportunity to view the complex geology of the central Sierra Nevada foothills. The rock exposures in the railroad grade cuts are often superior to road and highway exposures and many times provide a 3D view of the geology where the railroad cuts have exposed rock outcrops on both sides of the track. Plus, the associated safety hazards of busy highway traffic are eliminated. While some of the geologic features that we'll see on this trip may be seen in other regions of the Sierra foothills, this railroad route offers the ability to see interesting features of most of the adjacent rock units in a nearly continuous transect along the rail route—an extraordinary opportunity.

This historic railroad is now preserved and operated by the Amador Central Railroad Corporation—a 501c3 non-profit consortium of volunteer railroad and history enthusiasts. This unique fieldtrip opportunity is offered through the time and efforts of these dedicated volunteers.

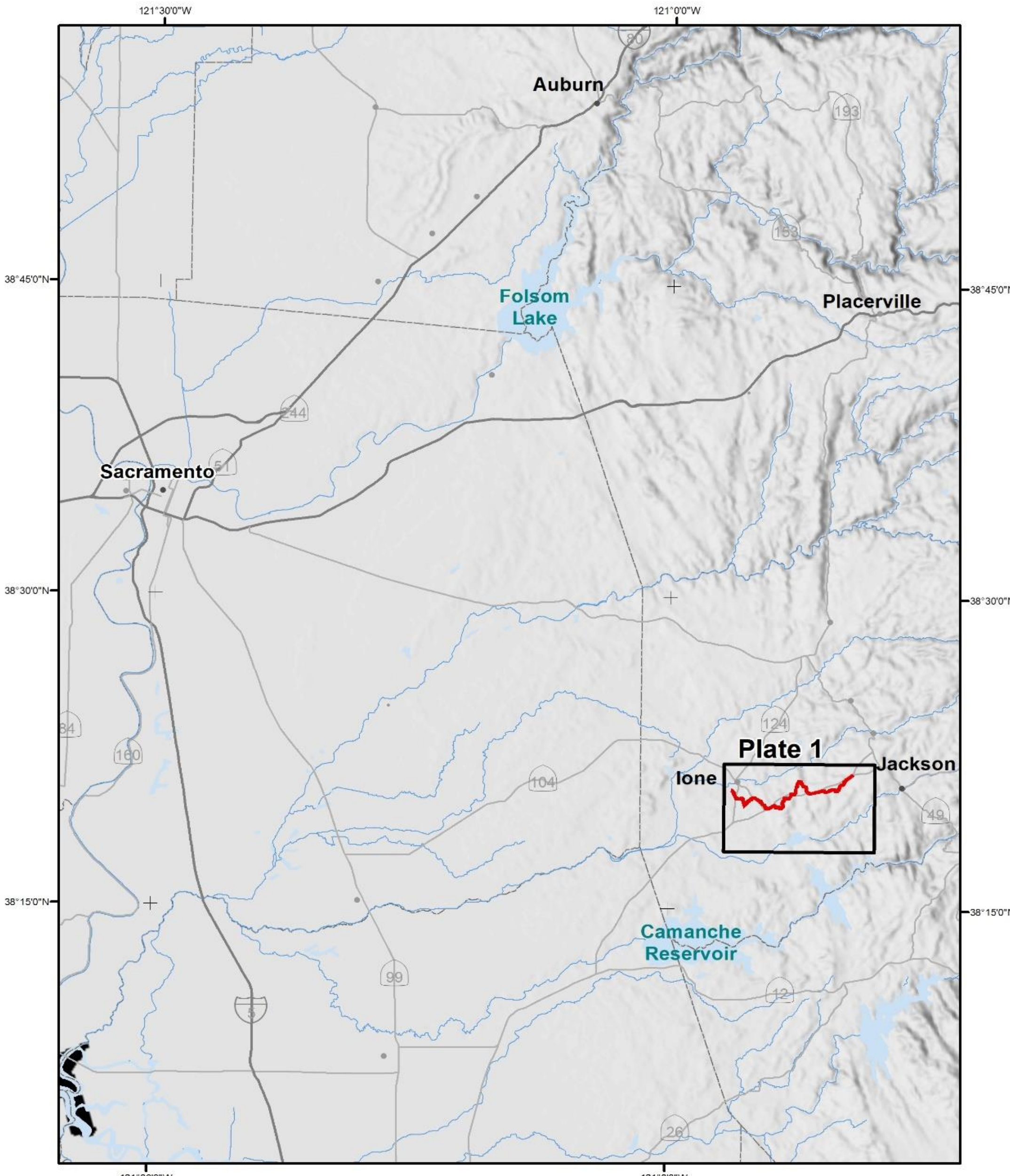

Figure 1. Vicinity map of the Amador Central Railroad line and geologic excursion.

Field Trip Overview

This guidebook presents a discussion of the various rock units as they are presented as stops along the route. We've included photos and some data to enhance the descriptions and interpretations. We've chosen outcrop stops that are particularly informative about the rock units or ones that display unique features, some not seen anywhere else in the foothills. This field trip is a work in progress and the guidebook is updated with each trip outing as new outcrops and features are discovered or better understood.

Because of the diversity of backgrounds of our fieldtrip attendees, from geologic laypersons to geology students to professionals in particular fields of geologic expertise, we've offered the rock unit descriptions and concepts to be understandable to this wide variety of observers. We encourage the trip participants to read the guidebook before the trip outing to gain a basic sense of the geology to be seen along the route and prepare to pose questions or share comments during the trip.

Since 2014, the California Geological Survey has been conducting detailed geologic mapping efforts in Amador and Calaveras Counties producing preliminary geologic maps for updated 7.5' quadrangles. This railroad trip traverses portions of two maps—the Preliminary Geologic Map of the Ione Quadrangle (2015) and the Preliminary Geologic Map of the Jackson Quadrangle (2019). Many new details were added to these maps that were previously unrecognized or unmapped. The railroad cuts and exposures offer unique views of these rocks that are not found in other exposures in the foothills.

Ten or so principal stops are presented along the railroad trip to view notable rock outcrops. Other bonus stops will be added as time allows. We have organized the field trip stops to view the older Mesozoic bedrock series on the first half of the trip heading eastbound. The younger Tertiary sedimentary rock series are viewed on the return leg of our rail journey back to our starting point. Our lunch break occurs at the end of track between our up and down trips.

At each stop, please be aware of where you step as you exit the railroad cars and watch your footing for loose rocks and other tripping hazards on the tracks. Look out for occasional poison oak plants as you walk toward the outcrops along the railroad grade. The railroad right of way is generally limited to 50 feet from the track so please remain close to the railroad tracks to avoid trespassing on private property.

We hope you enjoy this unique historical and geological field trip on the Amador Central Railroad in our vintage track speeders …ALL ABOARD!!!

General Geology Along the Route

The geology exposed along the AMC route is generally comprised of a Mesozoic metamorphic bedrock sequence with Tertiary (Eocene to Pliocene) sedimentary rocks mantling the bedrock in various sections of the route (Plate 1). The encountered rock units are representative of important geological events that occurred in the ancestral Sierra Nevada province through time. The schematic geologic cross section below shows the geologic formations discussed on the field trip.

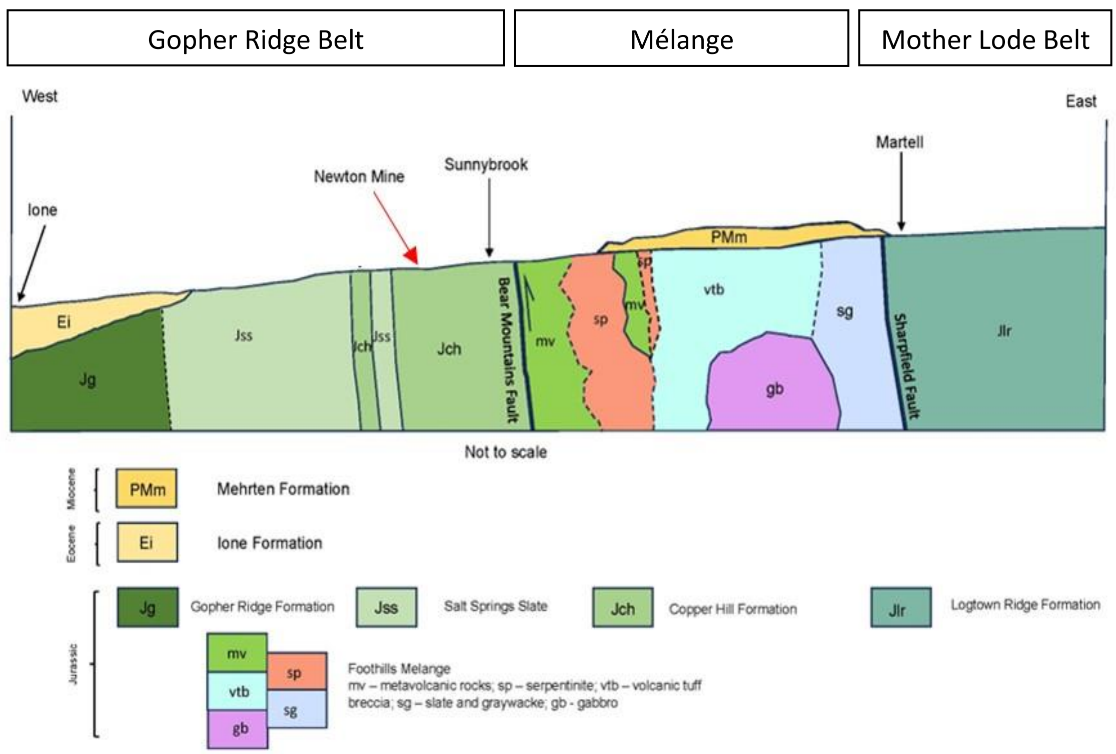

Figure 2. Schematic cross section of the geology along the railroad transect.

Basement Rocks—Bedrock Series

The Amador Central Railroad traverses a portion of the Foothills terrane of the Western Sierra Nevada Metamorphic province. Rocks of the Foothills terrane are considered to represent deposits of an oceanic island arc system and deep-water sediments that were complexly deformed and metamorphosed in a subduction zone in Late Jurassic time (Schweickert, 2015).

The island-arc volcanic rocks in the Foothills terrane are composed of basaltic to andesitic tuff breccia, lava, and lesser rhyolitic tuff. The Foothills terrane is composed of a western belt, referred to as the Gopher Ridge Belt, and an eastern belt, the Mother Lode Belt. Age dating of volcanic rocks within the Foothills terrane range from late Triassic (≥200 Ma) in the Peñon Blanco Unit of the Mother Lode Belt to late Jurassic (~160 to 156 Ma) in the Gopher Ridge-Copper Hill-Logtown Ridge volcanic units (Sharp, 1988).

The Gopher Ridge Belt, per Schweickert (2015), consists of the Middle Jurassic Gopher Ridge arc volcanics overlain by clastic rocks (including the Salt Springs Slate, Stop 1) and volcanic rocks (including the Copper Hill Volcanics, Stop 2). Gopher Ridge arc volcanics are not exposed along the AMC route. The Gopher Ridge Belt extends northward and laterally transitions into the Smartville Complex north of Sacramento (Day and Bickford, 2004).

The Mother Lode Belt, per Schweickert (2015), consists of Triassic-Jurassic ophiolitic (including ultramafic basement) and arc rocks exposed in the Red Hills to the south (Morgan, 1976). These are overlain, in increasing stratigraphic order, by siliciclastic rocks, and the volcanics of the Jurassic Logtown Ridge Formation (Stop 5), which may be a lateral equivalent of the Gopher Ridge volcanics of the Gopher Ridge Belt (Schweickert, 2015). Logtown Ridge volcanics are overlain by the sandstones and shales of the Mariposa Formation, which are exposed east of our lunchtime stop.

The two belts are separated in map view by a mélange zone that is 5 to 6 kilometers wide along the AMC. The west side of the mélange is in fault contact with the Gopher Ridge Belt along the Bear Mountains Fault Zone, while the east side of the mélange is in fault contact with the Mother Lode Belt along the Sharpfield fault (Gutierrez et al., 2015), named after the original proposition in Sharp and Duffield (1973). The mélange consists of blocks of metavolcanic rocks, serpentinite, volcanic tuff breccia, slate and graywacke, and gabbro. Amphibolite blocks in mélange north of the Cosumnes River have provided K-Ar ages on hornblende of 302 ± 35 Ma and 150 ± 3 Ma (Behrman, 1978). Radiolarians from chert in the mélange provide Middle Jurassic ages (Graymer and Jones, 1994). The outward-bound section of this field trip will stop at mélange exposures of metavolcanic rocks and siliceous slate (Stop 3), serpentinite (Stop 4) and, time permitting, other lithologies along the upper portion of the route.

Sedimentary rocks interlayered with the volcanic rocks are slates and graywackes, the metamorphic equivalents of mudstones and turbidites deposited in a deep oceanic basin. Fossil bivalves, ammonites and belemnites found within these slates in other regions indicate these rocks are middle to late Jurassic in age (166 to 152 Ma). Abundant outcrops of Salt Springs Slate are found along the AMC and will be viewed and discussed at Stop 1.

The bedrock series in the Western Sierra Nevada Metamorphic province generally has a steeply east-dipping structural grain. The Foothills terrane is interpreted to represent one or two oceanic island-arc systems, originally 150 to 200 km wide, that was folded and underthrust beneath the North American continental margin during the Nevadan Orogeny (~160 to 153 Ma.; Schweickert, 2015). Figure 3 presents a conceptual cross section of the current configuration of the deformed Foothills terrane rocks that was formed by thrust imbrication of an ophiolite-arc-sedimentary sequence. Structural analyses suggests that at least 100 km of Late Jurassic shortening has occurred across the belt (Schweickert, 2015).

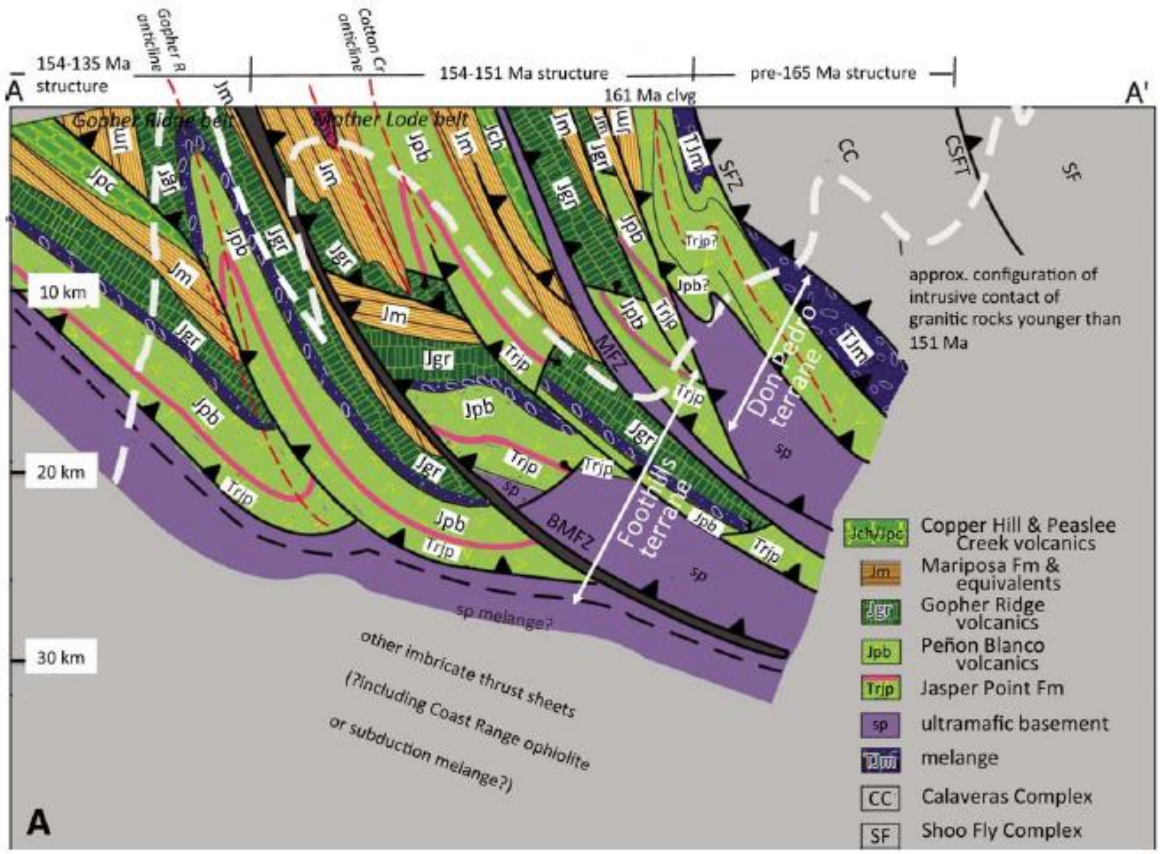

Figure 3. Conceptual cross section across the Western Sierra Nevada Metamorphic province south of the Merced River showing structural imbrication and repetition of units in the Foothills and Don Pedro terranes. No vertical exaggeration. Modified from Schweickert, 2015.

Tertiary Sedimentary Rocks

Sedimentary and volcanic rocks of Eocene to Miocene age are uncomformably deposited on basement in the Sierra Nevada foothills. The westernmost portion of the AMC passes through exposures of the Eocene Ione Formation (Ei) in the valley and rolling hills near Ione (Creely and Force, 2007; Allen, 1929). These sediments were deposited by one of the many parallel ancestral river systems that drained a subdued landscape to the east during a long period of tectonic quiescence and tropical climatic conditions (Cassel and Graham, 2011). The Ione Fm has long been mined for a number of industrial minerals, namely, kaolin clay products, silica glass and lignite coal. Ione Fm will be discussed in detail at Stops 10 and 11.

The other Tertiary formation encountered along the AMC is the Miocene to Pliocene Mehrten Formation (PMm on the Jackson Quadrangle and MPm on the Ione Quadrangle). Outcrops of

Mehrten encountered along the middle to upper reaches of the AMC line are fluvial deposits of tuffaceous siltstone, sandstone and conglomerate of andesitic volcanic detritus. These volcaniclastic deposits originated from volcanoes that were active near the crest of the Sierra Nevada from ~12 to 4 million years ago (Ma) (Busby et al., 2008). This field trip will look at the Mehrten Fm at Stops 6, 7 and 8 on the second half of the trip.

A significant sedimentary unit that is not preserved along this route is the Oligocene Valley Springs Formation. Valley Springs Formation typically includes tuffaceous sandstone, siltstone, mudstone and conglomerate with interbedded rhyolitic tuff. These volcanic and volcaniclastic rocks have been shown to have originated from several large calderas in central Nevada and traveled long distances down the same river channels as the Eocene Ione Fm (Henry and John, 2013). These sediments were either not deposited in paleochannels at this location or were removed by later erosion by younger stream scouring.

OUTBOUND TRIP - IONE TO MARTELL
MESOZOIC ROCK UNITS

Stop 1: Salt Spring Slate (milepost 3.0)

Salt Spring Slate exposed at Stop 1 is oriented in typical bedrock fashion in the Sierra Nevada foothills—steeply dipping to the east. This rock, of Oxfordian to Kimmeridgian (163.5 to 152.1 Ma, Late Jurassic) age based on invertebrate fossils originated from sediment deposition in a deep marine environment of a volcanic arc setting (think modern Aleutian Islands) as shale and to a lesser extent sandstone and conglomerate (Clark, 1964; Gutierrez, 2015). This rock is deposited on top of the Gopher Ridge Volcanics (not exposed along the AMC) and in turn interfingers with and is overlain by the Copper Hill Volcanics that we'll see at the next stop. These rocks may also be equivalent to the Mariposa Formation of the Mother Lode Belt (Schweickert, 2015; Miller and Paterson, 1991). Soon after deposition the volcanic arc collided and accreted to the North American continent. Heat and pressure from deep burial caused the rocks to be metamorphosed and deformed into their current upright position.

This railroad cut also exposes quartz veins that cut the slaty foliation. Vein quartz is often associated with the occurrence of vein or lode gold in the Sierra Nevada foothills. A steeply dipping fault cuts across the quartz vein. See if you can match the offset quartz vein across the fault trace. A parallel secondary fault is visible in the extreme right side of this photo. Drag folding indicates the relative direction of movement across this fault. The block of rock between these two faults appears to have dropped in relation to the two outside blocks representing a small graben structure.

Figure 4 - Salt Spring Slate at MP3: Minor faults indicated by red lines, offset quartz vein (left trace) and drag folding (right trace) give sense of movements.

Another interesting geomorphic feature visible in the cut slope on the south side of the railroad track is evidence of soil creep that has altered the jointing orientation of the slate exposed at the surface. Here, you can see the hazard of relying on the jointing or bedding orientation at the ground surface to map regional structural geology.

Further along the tracks other lithologic features are worth noting as we pass by. Outcrops at milepost 3.2 expose slate displaying tight folding features due to regional compression and shearing. The railroad cut at milepost 3.5 (after crossing the Highway 88 trestle) displays additional examples of intrusion of Salt Springs Slate by veins of white quartz.

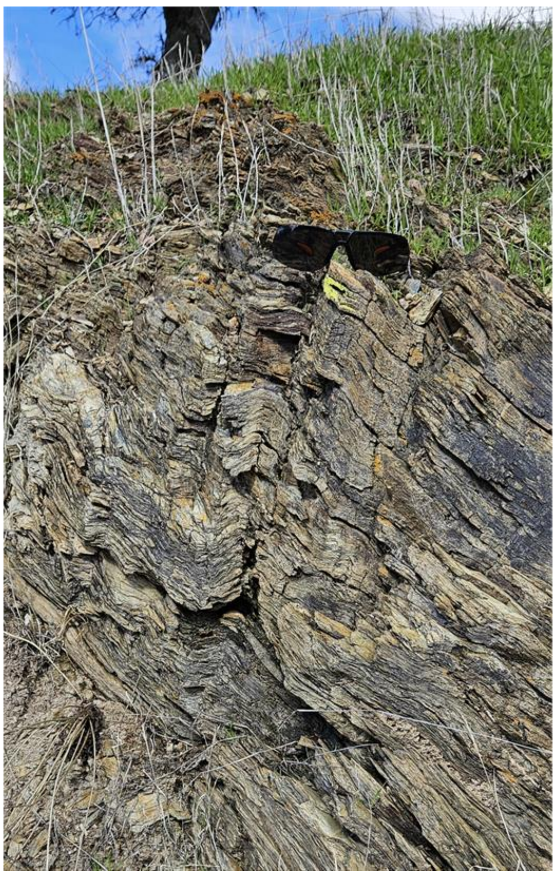

Figure 5(a) - *Tight folding in slate at MP 3.2* *Figure 5(b) - Quartz veins in slate at MP 3.5*

Enroute Point of Interest: Copper Hill Formation Tombstone Rocks (milepost 4.0)

The Copper Hill Formation (aka Copper Hill Volcanics; Clark, 1964) formed as a Jurassic age volcanic and sedimentary island arc sequence. These rocks include the metamorphosed equivalents of rhyolitic and andesitic volcanic rocks and agglomerate breccias with interbedded turbidite sandstones and shales. These foliated lithologies often appear in outcrop as resistant “tombstone rocks” such as those visible in Bovine Meadow at milepost 4.0 (Figure 6).

Figure 6 - Copper Hill Volcanics at MP 4.0: Tombstone rocks next to the tracks in Bovine Meadow.

Stop 2 - Newton Mine (milepost 4.5)

This stop at milepost 4.5 provides a good overview of the site of the Newton Mine, Amador County’s greatest copper producer. In 1863, a copper mine was established here by J. Newton on the Jackson Road (CA-88). Between 1863 and 1946, the mine was worked intermittently ultimately achieving a depth of 550 feet with 10 levels (Heyl and Eric, 1948). The ore body is an eastward dipping massive sulfide lens of pyrite and chalcopyrite oriented along a north trending fault zone. Copper ore reached up to 21% Cu.

The host rocks are amphibolite schists and greenstone metavolcanics of the Copper Hill volcanics, named by Clark (1964) for outcrops along the Cosumnes River and at the nearby Copper Hill Mine, the second largest copper producer in Amador County. Along the Cosumnes River, 21 km (13 miles) to the northwest, Clark (1964) was able to demonstrate that Copper Hill volcanics are stratigraphically higher and interlayered with Salt Springs Slate. Hyel and Eric (1948) found graded bedding in Copper Hill volcanics in the vicinity of the Newton Mine that suggests the east-dipping rocks hosting the ore are overturned in the west limb of an anticline.

Between 1877 and 1887, the Newton Copper Mining Company, Inc. constructed an 8-mile-long ditch to bring water from the foothills to operate machinery and hoisting works. Ore was heap roasted for up to 8 months (sulfides within the ore, ignited by wood at the base of the heap, provided the fuel source for roasting) and was then leached using water sprinklers to produce an enriched copper sulphate leachate. The leachate was collected in large vats and wooden sluices where scrap iron (replaced every 24 hours) was placed for ion exchange and the production of copper cement/precipitate (sluices cleaned out every month). In 1889 and 1899, smelting was attempted using an 80-Ton Smelter but proved unsuccessful. Between 1945 and 1947, the mine was reopened by Pacific Mining Co. to extract supergene enriched ore near the surface for the War effort. It was reported approximately 3.6 million pounds of copper was produced during that period. Ore was shipped via rail, the same rail you are on today, to ASARCOs smelter for processing in Tooele, Utah (Heyl and Eric, 1948).

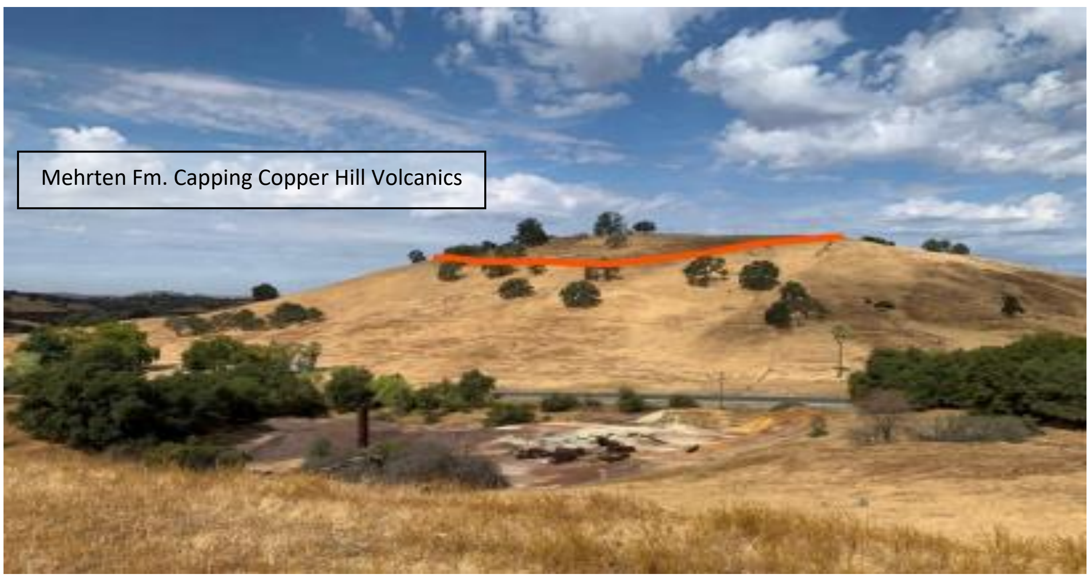

Figure 7 - Newton Mine site at MP 4.5: View of the Newton Mine site from the AMC RR tracks; camera view to the north. The headframe is just out of sight beyond the trees at the right. The hill across the highway is capped by resistant Mehrten Formation (above the orange line).

Figure 8 - Town of Ranlett (background) and the Newton Mine (foreground) Circa 1890s. The town appears to have been named for Col. Horace D. Ranlett, resident of the town and owner of the Newton Copper Company starting in 1886 (California State Mining Bureau, 1902).

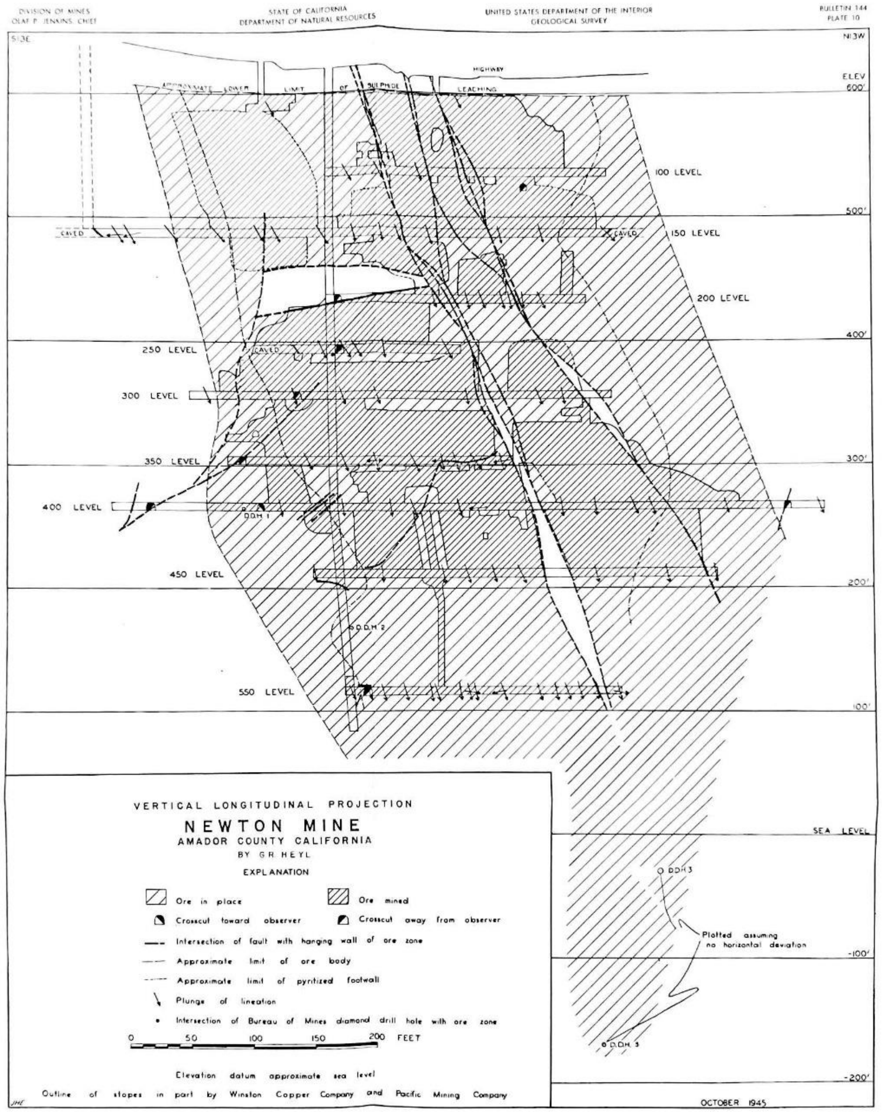

Figure 9 - Cross-section of ore body and mining levels at the Newton Copper Mine as of 1948. (Modified from Plate 10, Heyl and Eric, 1948).

Legacy Water Quality Impacts

Ore processing activities created acid mine drainage and heavy metals contamination of the adjacent creek drainage. In the 1950's, the Central Valley Regional Water Quality Control Board (Central Valley Water Board) identified mining waste discharge was occurring from the Site. Central Valley Water Board staff conducted research to identify a potential responsible party, but no viable party was discovered. The discharge of mining waste from the Mine to Copper Creek has degraded water quality downstream as evidenced by low pH (2 to 3), elevated copper, iron, and sulfate concentrations. The current property owners are under a Cleanup and

Abatement Order (Water Code 13304) requiring water quality monitoring, waste characterization, cleanup, and post closure monitoring. The Central Valley Water Board is working with the property owners to potentially secure grant funding to complete the required cleanup. A full Site regulatory history can be found on the State Water Resource Control Boards webpage here: https://geotracker.waterboards.ca.gov/profile_report.asp?global_id=L10005756707

Stop 3: Bear Mountains Fault and Mélange Complex (milepost 5.2)

The Bear Mountains Fault is crossed by the railroad just east of the Sunnybrook CA-88 road crossing. The trace of the fault line here is mapped as approximate due to vegetation cover. However, the appearance of mélange complex rock units in railroad outcrops beyond the highway crossing are an indicator that the tracks have crossed the fault separating the Copper Hill volcanics from mélange lithologies. At Stop 3, a few hundred feet northeast of the highway, interbedded and perhaps tectonically juxtaposed metavolcanic rock and siliceous slate in the mélange complex are exposed on either side of the tracks.

The mélange along the Amador Central Railroad is roughly 5 km (3 miles) thick delineated by the Bear Mountains Fault on the west and the Sharpfield Fault on the east. The mélange belt, or Bear Mountains Fault Zone as some have mapped it (e.g. Clark, 1964), is a controversial crustal-scale fault or shear zone that separates the Gopher Ridge Belt from the Mother Load Belt. It was active from 151 to 123 Ma (Late Jurassic to Early Cretaceous) based on deformation in and around the Guadalupe Igneous Complex, exposed about 110 km to the south of here (Tobisch et al., 1989). It has been hypothesized to be a suture zone/paleo-subduction zone, based on the presence of ophiolitic material and blocks of high-grade metamorphic rocks (Miller and Paterson, 1991), or an intra-arc reverse fault (Miller and Paterson, 1991; Day and Bickford, 2004).

There are two mechanisms proposed to explain the diverse lithologies and ages along with the discontinuous outcrop of the mélange belt. One is that unit is a tectonic mélange formed by deformation within the mélange belt (Sharp and Duffield, 1975; Behrman, 1978; Miller and Paterson, 1991). The other is that the mélange is a sedimentary unit that underlies the Logtown Ridge volcanics, forming part of the tectonostratigraphy of the Mother Lode Belt (Schweickert, 2015). In this case, the mélange may have been formed by input of olistostromal (submarine landslide) blocks into a sedimentary basin followed by some amount of deformation (Wakabayashi, 2015).

Stop 4: Serpentinite in the Mélange Complex (milepost 6.4)

Serpentinite, exposed abundantly at Stop 4, is the official State Rock of California. Slick, reflective (often green or gray) surfaces that resemble a serpent's skin is the typical appearance of serpentinite. The surfaces of the rock have a shiny or wax-like appearance and a slightly soapy feel. Serpentine is a phyllosilicate—the clay minerals group. The platy, tiny crystallites of this mineral align parallel to the direction of the shearing forces during metamorphism to create the slickenside-like smooth surfaces. Serpentinite is usually fine-grained and compact but may display other morphologies including granular, platy, bladed or fibrous.

Serpentinite is the hydrated metamorphic product of magnesium-rich or ultramafic (low silica, high magnesium and iron) rock—most commonly derived from the rock peridotite, occurring deep in the Earth's upper mantle. Serpentinite is commonly found in convergent plate boundaries where ultramafic mantle rocks are exposed to seawater while being subducted, resulting in the mineralogic transformation to serpentinite. Thus, anhydrous ultramafic minerals such as pyroxene and olivine are transformed to the hydrous mineral serpentine. Serpentinites are usually brought to the earth's surface by complex tectonic faulting processes. The serpentinite exposed at this outcrop has been entrained in the extremely deformed mélange complex rocks.

Figure 10 – Serpentinite at MP 6.4: this sample of serpentinite from MP 6.4 exhibits a rhombohedral shape defined by sheared surfaces and veins of asbestiform minerals. The mineral composition of serpentinite is usually dominated by antigorite, lizardite, chrysotile, and magnetite.

While the serpentinite at this stop is mapped as part of the mélange unit on the CGS maps (Figure 2), it is along strike with the Tuolumne ultramafic complex exposed along Lake Don

Pedro about 60 km to the south (Morgan, 1976; Schweickert and Bogen, 1983). This, plus the location of the serpentinite just east of the Bear Mountains Fault Zone, suggests an alternative view in which this serpentinite may represent the ophiolitic basement of the Mother Lode Belt (Schweickert, 2015). After crossing CA-88 for the second time at Mountain Springs, the railroad grade traverses through the mélange complex for the next 3 miles along the tracks.

Optional Stop – Serpentinite, Slate and other Mélange Rocks (milepost 7.3)

East of the Serpentinite observed at Stop 4, the mélange rocks take on the block-in-matrix (BIM rocks) texture often associated with mélange. At MP 7.3 and extending east for approximately a tenth of a mile (~0.17 km) highly sheared serpentinite and siliceous clay slate form matrix rocks surrounding hard blocks of meta-conglomerate. Isolated blocks of resistant conglomerate near MP 7.3 ranging in thickness from 5 to 10 m are encased in sheared serpentinite and slate. Farther east, a much thicker outcrop of conglomerate is exposed and contains many large clasts of limestone.

The conglomerate is typically silica-cemented pebble to cobble size clasts of intermediate to basaltic volcanic rocks, black clay slate, chert, quartzite, limestone, and milky quartz (Duffield and Sharp, 1975). Lithologic similarities to the Paleozoic Calaveras Formation and the presence of limestone clasts, which in other areas have yielded Permian ages, led earlier mappers to map this part of the mélange as the western Calaveras Formation (e.g. Clark, 1964). Duffield and Sharp (1975) were the first to recognize the presence of the mélange complex and postulate that the slates and conglomerates outcropping here may be Calaveras Formation rocks caught up in the mélange.

Enroute Point of Interest - Sharpfield Fault (milepost 9.3)

This generally north-south trending fault separates the mélange complex rocks to the west from the Logtown Ridge Formation further east. The trace of the fault line is discerned on the slopes of the valley by the abrupt appearance of resistant, large blocky outcrops of Logtown Ridge rocks sitting prominently on the ground surface. Time permitting, the inferred trace of the Sharpfield fault will be viewed at Stop 6 after lunch.

Figure 11 - Approximate trace of the Sharpfield Fault at MP 9.3. North is to the left.

Stop 5: Logtown Ridge Formation —End of track (milepost 9.6)

Dark green resistant rocks of this unit are exposed at the end of the railroad tracks just before the intersection of Highway 88 at the town of Martell. These metamorphosed rocks are the Rabbit Flat member of the Late Jurassic Logtown Ridge Formation (Duffield and Sharp, 1975) and have been interpreted as equivalents of the Gopher Ridge volcanics of the Gopher Ridge Belt (Schweickert, 2015). In addition to the notably distinctive resistant outcrop pattern, these andesitic to basaltic rocks contain abundant dark euhedral augite phenocrysts between 2 and 5 mm in diameter. Deformed subrounded breccia clasts are visible in the rock outcrops indicating that most of these rocks were originally deposited in some form of pyroclastic eruptions that incorporated other volcanic rock fragments as they erupted and flowed over the ground surface.

Figure 12 - Logtown Ridge Formation outcrops at MP 9.6 and end of tracks.

RETURN TRIP - MARTELL TO IONE
TERTIARY SEDIMENTARY ROCK UNITS

While the Mesozoic rocks tell a story of tectonic and environmental conditions on a regional scale, the Tertiary sedimentary section of rocks provides an equally important record of the many and diverse geologic processes that occurred during the last 60 million years. This complex geologic history is reflected in the mineralogy and composition of the sediment at both the microscopic, clay-size scale and coarse-grained macro scale. These factors collectively define the sedimentary facies that can give clues to things such as channel configuration or architecture, geologic processes such as regional uplift and erosion or, conversely, the absence thereof, as well as paleoclimatic changes and episodes of volcanism. To assist in the interpretation of this sedimentary record we include data of analytical methods including thin section petrography and X-ray diffraction mineral analyses (XRD) techniques in the guidebook text and appendix.

Stop 6: Mehrten Formation and Mehrten Sandstone (milepost 9.3)

The cobbly river gravel of the Mehrten Formation (PMm) caps the basement rocks at numerous areas along the eastern portions of the railroad route between milepost 7 to 9. The Mehrten Formation is a sequence of volcaniclastic sedimentary rocks that includes sandy conglomerate, sandstone, fluvially reworked tuff, and well cemented mudstone breccia — rocks formed from muddy debris flows called lahars. These fluvial sedimentary rocks formed in Miocene-Pliocene times ~12 to 4 million years ago when the active ancestral Cascade volcanic arc was located approximately at, and east of, the modern Sierra Nevada crest (Busby et al, 2008). Because these paleo rivers were eroding an andesitic volcanic terrain, the river cobble clasts are predominantly andesitic composition. Since that time, the Cascade volcanic arc has migrated north and west. Its southern end is now the Shasta and Lassen volcanic centers.

The Mehrten rock units exhibit inverted topography in many regions of the Sierra, meaning that a portion of the river channel that was originally the topographic low point on the landscape when it was active, now forms the resistant higher ridge top or topographic high spot relative to the current surrounding countryside (Wakabayashi, 2013). The Mehrten rock units similarly cap ridgetops and knolls in this fashion in this region of the Sierra foothills. Two principal factors can contribute to this occurrence. As the Miocene rivers continued to fill the paleo-river valleys, they eventually spilled over onto the bedrock interfluves. Post Sierran uplift led to the renewal of fluvial channel incision and erosion leaving only the margins of the Mehrten interfluve deposits as remnants of the preserved upland surface. Note that the Mehrten capping deposits occur on opposing sides of the modern river valley at milepost 8.5 to 9.5. Secondly, the

Mehrten fluvial sediments contained considerable volumes of volcanic ash. Upon consolidation and alteration, the ash constituent became an effective cementing agent to these sediments which retarded the weathering and erosion the Mehrten capping rock favoring its preservation on the ridge tops.

While coarse conglomeratic gravel is the dominant lithology seen along the tracks, other minor Mehrten sedimentary rocks along this stretch of track are important to note. At mileposts 9.3 and 8.8, a moderately well sorted sandstone is seen at the base of Mehrten fluvial gravel. Subtle horizontal flow laminae are visible in the sandstone and inclined cross bedding is not apparent. These deposits of finer grained sediment could signify an episode of lower energy of the river system or perhaps a part of the river channel that received lower water flow velocity such as an overbank/levee deposit. Notice a few andesitic pebbles embedded in the sand. This shows that coarser cobbly river sediment was somewhere close by.

Figure 13 - Mehrten Formation at MP 9.3: Mehrten Sandstone with random entrained pebbles and overlying cobble conglomerate.

XRD mineral analysis of clay size fraction of this sand (<2 μm) indicates that the matrix is rich in smectite, halloysite, and kaolinite clay (See XRD scan pattern for Milepost 9.3 in Appendix). The smectite and halloysite in this mineral assemblage are typical of the clay mineral suite derived from the alteration of volcanic ash. As these Mehrten fluvial sediments were part of the basal fluvial sequence over the altered bedrock surface, a possible source of the kaolinite component could have been the scouring and amalgamation of clay from the older Tertiary landscape across which the Mehrten river systems flowed.

This clay assemblage alone would not definitively distinguish this sandstone from others with similar appearance that occur in older rock units such as the Valley Springs Formation (Oligocene), which are derived from rhyolitic volcanic rocks. However, XRD analysis of the coarser silt sized fraction (<15 μm) of this sandstone shows the prominent occurrence of plagioclase feldspar with no sanidine feldspar or substantial quartz minerals present. The occurrence of plagioclase feldspar identifies the likely source of this sediment as the Miocene age andesitic volcanics. The absence of sanidine and quartz rules out the possibility of this sandstone being attributed the Valley Springs rhyolitic sediments or the earlier quartz rich Eocene Ione Formation, respectively.

Another notable mineral constituent detected in the XRD analysis of the clay size fraction is the appearance of an amorphous silica peak (opal). The occurrence of an amorphous mineraloid silica in an x-ray analysis that largely detects crystalline minerals is an indication that a substantial content of amorphous silica occurs in the clay fraction. Amorphous silica is similarly a byproduct of the alteration of volcanic ash. In other studies of Sierran fluvial sandy sediments containing copious quantities of altered ash constituents, amorphous silica occurs as an effective cement that binds sand-sized altered ash clasts (Wood, 1994). Here, as in other Tertiary fluvial sediments, the smectite and halloysite clay constituents likely occur in this sandstone in the form of sand-sized clay clasts (peds) cemented with amorphous silica and transported as bedload sediment.

Contact Relationship with Basement Rocks

The basement rocks exposed below the contact with the Mehrten Fm gravels from MP 7 to 9.3 occur in various stages of alteration. Because these rocks were near the paleosurface at the time of Miocene river scouring and deposition, this alteration was likely due to the surface weathering of the rocks in the earlier Tertiary climatic regimen. The climatic regimens in the Eocene and early Oligocene epochs were warm and humid leading to severe chemical alteration of rocks exposed at the paleosurface. Consequently, deep and well developed paleosols formed on the bedrock. An example of one of these will be viewed at Stop 9.

Recent X-Ray diffraction analysis of clays obtained from altered slate at Milepost 9.0 (See XRD scan pattern for Milepost 9.0 in Appendix) indicates that transformation of mica and other parent minerals to vermiculite and smectite (montmorillonite) has occurred. This degree of mineral alteration is consistent with these rocks being classified as saprolite or, at the least, represent the weathering front of a paleosol developed on the parent bedrock. Rocks in the saprolite horizon of a soil profile are altered to clay minerals but retain the structure of the original rock. These initial mineral weathering products identified in XRD may be limited to the rock weathering interface (weathering front) and may be ephemeral. As such, they are typically replaced by kaolinite as soil development progresses, particularly in warm and humid tropical environments where extensive chemical leaching occurs.

Stop 7: Mehrten Tuff and Tuffaceous Sandstone (milepost 8.8)

Along this stretch of track, a layer of tuff and tuffaceous sandstone is exposed at the base of a Mehrten gravel. These graded tuffaceous beds are reworked ash materials deposited in the river channel as opposed to a primary hot ash flow tuff. The lower coarser grained layer contains pumice fragments and interbedded laminae of pebbles. The ash and pumice particles in these beds were reworked from either an air fall deposit or a hot pyroclastic ash flow deposited upstream. These sources of ashy sediment would have originated from the volcanic centers near the current Sierran crest to the east.

Recent XRD analysis of this sediment shows that the ash has altered to halloysite and smectite clays with opal and anorthite also appearing in the clay size fraction (See XRD scan pattern for Milepost 8.8 in Appendix). Kaolinite clay is absent in this finer grained sediment indicative of a lower velocity flow regime.

The undulating contact of the overlying cobbly river gravel indicates that the river was scouring into the consolidated tuff bed below. The base of the overlying Mehrten cobble layer contains cobbles and boulders of the tuff that were ripped up from the underlying tuff bed.

Figure 14 - Mehrten Formation at MP 8.8: Mehrten Tuff bed below Mehrten fluvial gravel.

Stop 8: Mehrten Formation at Pete's Hole (milepost 8.2)

The rocks exposed in this railroad cut show unique sedimentary features of Mehrten river channels that are not seen in any other outcrops in the foothills. The coarse river gravel composed of large cobbles illustrate the high energy involved with the transport and deposition of the sediment that was moved such long distances in these ancient fluvial systems. Plus, large clasts—in this case, sandstone boulders the size of household appliances—are prevalent in the exposure.

The well-rounded cobbles are largely of andesite composition. Their modal grain size is strikingly different from the sandstone boulders. These two constituents are certainly not hydrodynamically equivalent. Recent XRD analysis of the sandstone matrix of these boulders identified clay minerals including smectite, halloysite and kaolinite (See XRD scan pattern for Sandstone Boulder at Milepost 8.2 in Appendix). The smectite and halloysite clay mineral assemblage is indicative of a high content of altered volcanic ash. In addition, analysis of the silt size fraction shows the presence of plagioclase feldspar. The XRD results show that the mineral assemblage of these boulders is identical to the mineral assemblage of the intact sandstone layer encountered at MP 9.3 further up the track kaolinite (See XRD scan pattern for Sandstone Boulder Silt Fraction at Milepost 8.2 in Appendix).

Figure 15 - Mehrten Formation at MP 8.2: Large boulder-sized clasts of sandstone in a cobble matrix.

The bimodal grain size distribution of this river cobble with entrained boulders could be caused by a number of conceivable scenarios including debris flows, but the concentration of numerous similarly sized boulders of the same sandstone lithology as the sandstone beds seen upstream suggests a more likely scenario. If the river channel was laterally undercutting a previously deposited bed of sandstone, large chunks of rock could have collapsed into the river and become lodged in the river gravel as boulders. In essence, these could have been fluvial drop stones.

There are no indications that these boulders rolled very far after they became entrained in the sediment. The boulders are not particularly rounded nor do smaller sized sandstone cobbles occur in the gravel that would indicate that the larger boulders were breaking up into smaller fragments as they rolled along in the strong river current.

Notice that the bottom surfaces of the boulders are deformed and mold to the bumpy surfaces of the underlying river cobbles. This feature is likely due to the high concentration of plastic clay constituents in the sandstone that caused the boulders to deform and mold to the underlying gravelly surface when the sediment later consolidated and compacted caused by the weight of the thick sediment overburden.

Enroute Point of Interest - Mehrten Mudstone Breccia (milepost 8.0)

A common Mehrten Formation rock type that occurs in many other Sierra foothill locations but does not occur in place (in situ) on this AMC route is mudstone breccia. This is a hard resistant rock that formed from the solidification of viscous mud flow (lahar) sediment originating near the Sierra crest when eruptions of volcanic ash fell onto snow covered volcanic terrain. The ensuing mudflows coursed down the river valleys and entrained rock fragments and cobbles along the way. The resulting rock is a conglomerate or breccia depending on the prevailing angular nature of the cobble that is cemented with the altered ash matrix material.

On the slope above the tracks at MP 8.0 are some boulders of this rock type in the cobbly sediments. The solidified ash in the mud matrix imparts unusually high induration to the rock making it very hard and resistant to abrasion—a natural concrete. As can be seen here, these boulders composed of cemented ash and clastic sediment withstood stream transport from a distant location upstream. This is a common Mehrten rock type seen throughout the Sierra foothills such as in the Rocklin and Roseville highland areas where it forms resistant hilltop caps throughout the developed suburban areas and poses difficulties for grading and excavation construction work.

Figure 16 - Mehrten Mudstone Breccia (lahar) boulder in cobbly gravel deposit at MP 8.0.

Stop 9: Eocene Weathering Profile—Altered Slate Saprolite (milepost 6.7)

Subsequent to the convergent plate boundary collision and the ensuing mountain building episode during the Jurassic period, a long period continental tectonic quiescence in the Sierra region led to prolonged erosion and denudation of the landscape. This period of landscape denudation, weathering, and soil development continued through the Cretaceous period and into the Early Tertiary period. The landscape was gradually transformed into one of low relief during a prolonged tropical climatic regimen that culminated in the Middle Eocene. This climatic peak is called the Early Eocene Climatic Optimum (EECO) (Zachos et al., 2001).

The railroad cut at Stop 9 exposes a thick section of severely altered slate within the mélange complex. XRD clay mineral analysis indicates that the original micaceous slate mineralogy is largely altered to kaolinite, hence the white coloration (See XRD scan pattern for Slate Saprolite at Milepost 6.7 in Appendix). This thick altered zone is typical of the saprolite horizon of a paleo-Oxisol—a chemically weathered soil profile that develops with intense chemical leaching associated with tropical climatic conditions over a long period of time. A saprolite horizon retains the original rock structure but severe chemical weathering has altered most of the weatherable minerals to clay. Oxisols may be very thick (5-30 meters and sometimes greater) and often exhibit mineral zonation with kaolinite and gibbsite in the upper soil and halloysite and goethite in deeper, wetter parts of the weathering profile.

This thick pallid saprolite zone would have occurred below the oxic horizon, commonly known as the laterite horizon. This latter surface horizon that undergoes repetitive wetting and drying cycles often exhibits redoximorphic iron oxide morphologies (mottling). In addition, remnants of the original rock structure are obliterated by intense soil processes including bioturbation. Very few, if any, remnants of weatherable minerals remain.

A thick well developed Oxisol profile requires a minimum of 0.75 to 1.0 million years to achieve its characteristic evolved clay mineral zonation and morphology. Thus, Oxisols only develop on tectonically stable continental landscapes where erosion is minimal and when tropical climatic conditions exist. In tectonically active terrains, erosion occurs faster than an Oxisol profile can develop. Remnants of these soil types exist throughout the Sierra foothills and are indicative of the tectonic quiescence of Cretaceous through Eocene times combined with the tropical climatic conditions that culminated at the EECO at approximately 50 Ma.

In the XRD analysis of this altered rock at milepost 6.7, kaolinite is the dominant clay with smectite and mica as minor constituents (See XRD scan pattern for Iron Oxide Cement at Milepost 6.7 in Appendix). The smectite clay is a transitory or intermediate clay that initially alters from parent minerals such as plagioclase feldspar or ferromagnesium minerals in the weathering front but eventually alters to kaolinite later in the weathering sequence. Quartz with minor mica are the only residual minerals from the original mineral suite.

The upper half of Oxisols is primarily composed of kaolinite, quartz, and other minor resistant minerals such as rutile and gold (if originally present in the parent rock). Another paleo Oxisol preserved in the Ione valley contains the clay mineral gibbsite—the ultimate alteration clay mineral of extreme chemical weathering. A rock mostly composed of gibbsite is called bauxite (aluminum ore) and often has a pisolitic texture.

Figure 17 - Weathered Mélange at MP 6.7: Altered slate saprolite outcrop in a thick paleo Oxisol.

In this outcrop, notice the iron oxide cement that precipitated along the fractures in the original rock structure. Some fragments of these iron oxide fracture fills display botryoidal growth habit as the mineralization front progressed into the clay fabric of the saprolite. XRD analysis shows the presence of goethite with kaolinite which indicates that the iron oxide cement precipitated in the matrix of the pre-existing kaolinite fabric. Complete dissolution of iron bearing minerals in the upper portions of these intensely leached soils occurring throughout the landscape would have enriched dissolved iron in the groundwater and led to precipitation of iron oxide cement in the fractures of the soil column. This is analogous to the supergene enrichment of metals that can occur from the chemical weathering of rock in Oxisols. Gold nuggets can similarly form in Oxisols developed on rock with disseminated gold by this process. Some gold deposits mined in tropical regions of the world are of this type of occurrence.

Figure 18 - Weathered Mélange at MP 6.7: Botryoidal growth habit of iron oxide cement in altered slate saprolite outcrop.

Loose Mehrten fluvial cobbles are visible on this slope. They are derived from an in-situ Mehrten gravel deposit capping the hill top. Therefore, the paleo surface that once existed before the overlying fluvial sediment was deposited is somewhere upslope of this altered slate outcrop. This rock sequence is a rare preserved example of a river channel rolling over a paleo landscape mantled by a thick tropical soil typical of those that once covered much of the entire Sierra landscape in Early Tertiary times.

Stop 10: Ione Formation and Angular Unconformity (milepost 2.2)

This outcrop displays an important contact between the Salt Spring Slate bedrock (first seen at Stop 1) and the overlying Ione Formation sediments (Creely and Force, 2007). The contact is an angular unconformity between the vertical foliation of underlying Salt Springs Slate with the overlying Ione sandstone basal conglomerate. This unconformity represents an impressive age gap and difference of about 100 million years between the Late Jurassic deposition of the original sediments comprising the slate (150 Ma) and the approximate age of the Eocene Ione Formation sediments (50 Ma).

Previous mappers working in this vicinity of heavy brush cover believed that the Ione sediments could be in fault contact with the Salt Springs slate. The contact between the two units illustrated in this outcrop here is clearly depositional in nature.

The Ione sediments at this location consist of interbedded sandstone and conglomeratic sandstone. The basal conglomerate includes slate rip up clasts and pebbles of white vein quartz. The quartz gravel clasts vary from angular to subrounded reflecting varying distances of transport. Many are tabular in shape reminiscent of the white quartz veins in the adjacent Salt Springs Slate unit over which the rivers were traversing immediately prior to deposition.

XRD analysis on this slate outcrop indicates that the slate below this unconformity is only partially weathered to kaolinite clay with mica dominating the mineralogy (See XRD scan pattern for Weathered Salt Spring Slate at Milepost 2.2 in Appendix). This mineral assemblage is what would be expected in the weathering front at the base of a well-developed thick residual soil formed in the Early Eocene. Here, the fluvial channel eroded down to the partially altered resistant bedrock. In other locations in the Sierra foothills, more energetic fluvial scouring by major paleo rivers eroded entirely down to fresh bedrock. The inclined contact here may represent the slope of the paleo channel margin.

Figure 19 - Angular Unconformity at MP2.2: Contact between the underlying upended Salt Spring Slate with the overlying Ione basal conglomerate.

Optional Stop - Lanes Station and Ione Sandstone (milepost 2.1)

Tertiary globally warm and humid climatic conditions peaked in the middle Eocene period at about 50 Ma (EECO). Rivers flowing from as far east as central Nevada were eroding a mature landscape of low relief (Henry and John, 2013). The entire landscape was generally mantled by thick kaolinitic tropical soils (Oxisols) similarly to tropical regions today (Cassel and Graham, 2011). Remnants of many of these paleosols can be found throughout the Sierra foothills similar to the one visible at Stop 9 (MP 6.7). Erosion of these well-developed profiles of residual mineral components sent copious volumes of kaolinitic detritus down the Tertiary rivers. XRD analysis of an Ione sandstone that crops out on Hwy 104 directly west of the outcrop at Stop 10 shows that kaolinite is the dominant clay mineral constituent with mica and smectite occurring in only in trace amounts (See XRD scan pattern for Ione Sandstone at Milepost 2.1 in Appendix).

The outcrop of sandstone on the opposite side of Hwy 104 is typical of much of the Ione sandstone in the Ione basin to the west. Here, it is medium to coarse grained. Sandstones in this Ione basin become finer grained as the rivers flowed westward. Clay mineral XRD analysis shows that Ione sandstone in much of this basin is primarily composed of kaolinite and quartz. Other minerals such as feldspar and ferromagnesium minerals also occur but in trace amounts and quite commonly visible in thin section.

The cut faces of nearby mining pits and the adjacent road cuts on Hwy 104 to the south are indurated by iron oxide cement. A misconception is that the strong iron oxide appearance of these cemented cut faces of sandstone were created by severe chemical weathering of iron bearing minerals in the ancient Eocene tropical climate following sediment deposition. However, if one digs back into the outcrops a few inches, the sands appear white with no significant indications of alteration.

A good illustration of this phenomenon is the relatively unweathered outcrop of the recent road widening of Hwy 104 across the road to the northwest of this location. The outcrop face was laid back from its original nearly vertical face to a 1:1 slope. The sandstone in the outcrop displays very little signs of weathering compared to older road outcrops to the south of this recent cut.

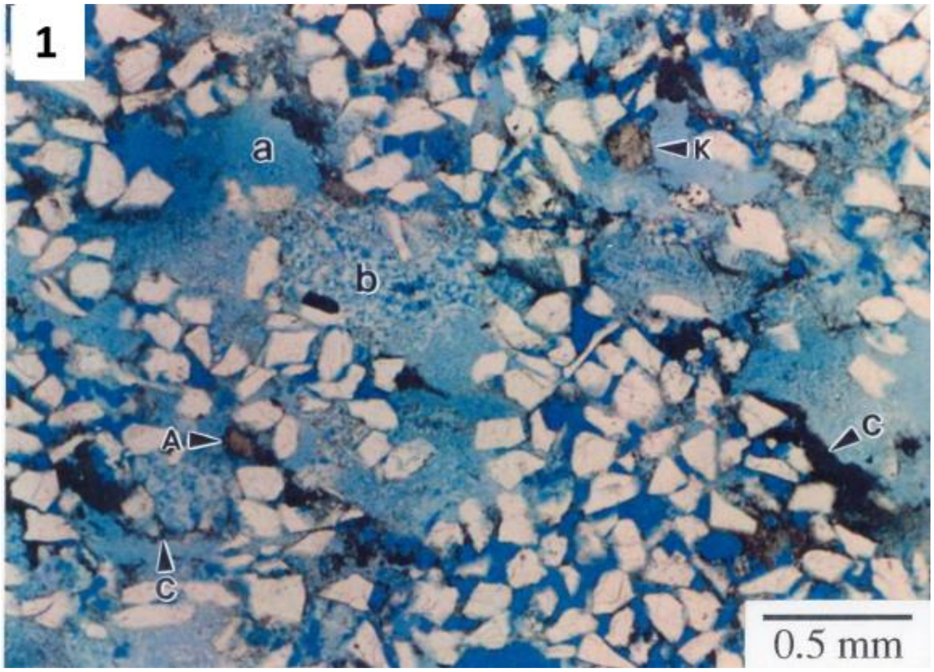

Figure 20 – Thin section Photo 1, plane polarized light: Typical Ione sandstone fabric. Large patches of milky blue zones are squashed kaolinite clasts ('a' and 'b'). Feldspar (K) and amphibole (A) appear unaltered. In the discussion, c = unoxidized iron in silica cement. Dark blue areas are formerly porous areas filled with epoxy used in preparing the thin section (Wood 1994).

Figure 20 is a thin section photo in plane polarized light (ppl) of a sandstone from a nearby mining pit that illustrates the fabric of a typical Ione sandstone in the Ione basin. These Ione sands are primarily composed of kaolinite and quartz grains. Quartz sand grains appear white in this view. However, the sands commonly possess trace to minor grains of ferro-magnesium minerals such as amphibole (A) and feldspar (K). Notice that these latter minerals that are susceptible to weathering in a tropical climate show little or no apparent effects of post depositional weathering. Plus, other pedogenic features that would be indicative of post depositional weathering are absent.

Kaolinite clay with microporosity (blue dye milky areas) is a major constituent of Ione sands in the form of silica cemented clay clasts ('a' and 'b') that were eroded from Oxisols in upstream source areas and transported in ancestral rivers as sand-sized bedload clasts. Subsequent sediment consolidation led to the compression of the clay clasts to form pseudo-matrix. In these well sorted sands, the clay clasts with microporosity (lower density) are much larger than hydrodynamically equivalent quartz grains (white) which resulted in a bimodal sand size distribution. Primary porosity appears clear dark blue.

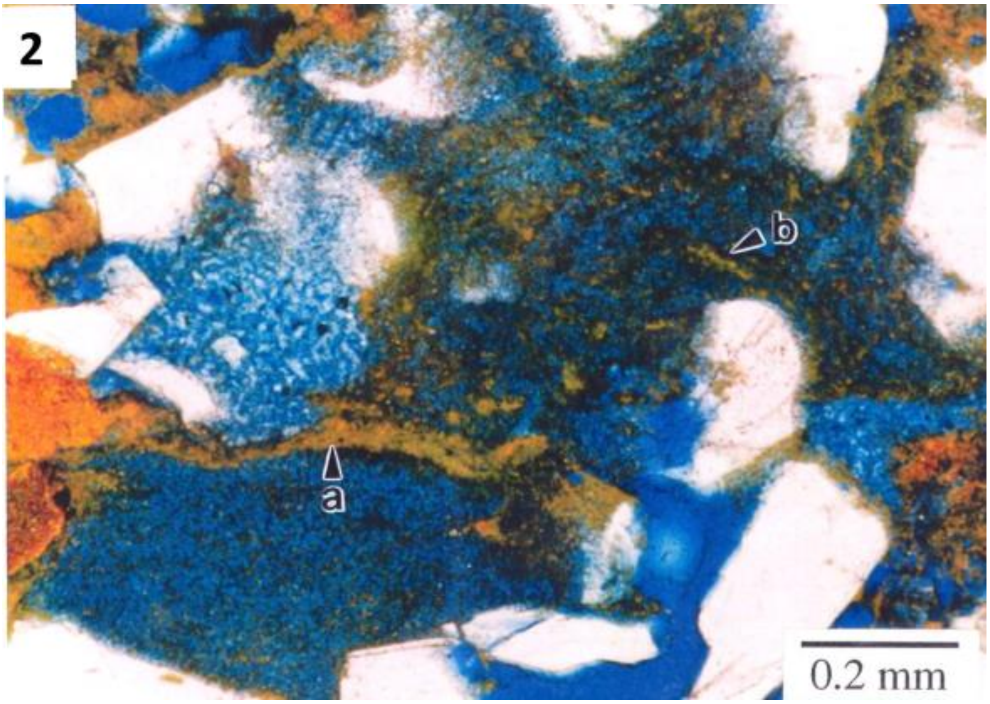

Figure 21 - Thin section Photo 2, plane polarized light: Ione sandstone in road outcrops on Hwy 104. In the discussion, a and b = oxidized iron in siliceous cement. Dark blue areas are formerly porous areas filled with epoxy used in preparing the thin section.

Petrographic inspection of the sandstone in the iron cemented outcrops (Figure 21, thin section Photo 2) reveals that the source of the iron cementation is largely caused by oxidation of trace iron inherent in the pedogenic amorphous silica cement (cement originating in source soils) that binds the clay clasts. Thus, iron associated with this amorphous cement is more susceptible and sensitive to atmospheric exposure compared with structurally bound iron that occurs in various silicate mineral structures such as amphibole or pyroxene. Oxidation at the outcrop caused the precipitation of goethite and hematite cements. Iron rich groundwater evaporating at the outcrop increases the iron cement concentration. Compare the morphology of the oxidation of iron in the silicious cements ‘a’ and ‘b’ in thin section Photo 2 (Figure 21) with the unoxidized cements ‘c’ (opaque appearance) in thin section Photo 1 (Figure 20).

Ferricrete Layers

A spur track once branched off the mainline track to an adjacent loading platform where clay products from a nearby mining pit were loaded into railroad cars for transport. Traces of railroad ties of this spur track can be seen embedded in the ground surface alongside the loading dock. A remnant pile of raw clay material was left on top of the loading dock. The loading dock is constructed of dry stacked tabular blocks of Ione sandstone cemented with iron oxide minerals (hematite and goethite). These are fragments of ferricrete layers that sporadically occur in the Ione sandstone stratigraphy. Ferricrete layers form by way of iron oxide cement precipitating in more porous sandstone or conglomerate layers above a permeability barrier such as a tight claystone bed or bedrock surface. These ferricrete blocks provided convenient building material where the use of concrete was either uneconomical or non-existent. Plus, the ferricrete blocks are more resilient and long lived compared to concrete that would have degraded in the 100 years or so since this structure was built.

Note: if this Optional Stop is not available at the time of your field trip, interested participants are encouraged to visit the road cut on Highway 104 west of Lanes Station later.

Stop 11: Firebrick Pit (milepost 1.3)

Kaolinite clay dominates the clay composition of the Ione sandstones and claystones quarried from this mining pit and were used to manufacture fire brick products in an adjacent brick plant. High purity kaolin clay is called refractory clay due to its high heat resistance when made into firebrick. Firebricks are commonly used to line steam boilers, blast furnaces, and ceramic furnaces.

The sediments exposed in the floor and walls of this mining pit include a lower layer comprised largely of claystone and sandy claystone. This lower claystone unit is overlain by cross bedded channel deposits of medium sandstone with interbedded pebbly sandstone. This sedimentary sequence represents a coarsening upward sequence as coarser gravelly sands typical of upstream river channels prograded westward into the Ione sedimentary basin and overrode fine grained swamp mud deposits.

The contact between the lower claystone beds and overlying cross bedded sandstones undulates with cut and fill structures indicative of laterally migrating river channels scouring the softer clay beds below. The trace amounts of iron bound in the clay has oxidized due to atmospheric exposure in the years that this mining pit sat idle.

Figure 22 - Ione Formation exposed in the Firebrick Pit at MP 1.3: This mining pit was the source of kaolinitic claystone (floor) and overlying kaolinitic sandstone (pit wall) to supply feedstock to the nearby brick plant.

Summary

This geological field outing by way of railroad speeder cars on the historic Amador Central Railroad track provides a unique mode of transportation to view the varied geology of the Sierra foothills. The rock units observed on this trip convey the complexity of the geologic processes that occurred over a wide time frame to create the scenic landscapes that typify the Sierra Foothills of Central California. The exploitation of the rich mineral wealth occurring in these diverse rock units by enterprising settlers following the Gold Rush led to the rapid development of the California economy in the late 19th and early 20th centuries. The historic Amador Central Railroad played a crucial role in that story.

Some of the outcrop exposures along this route are unparalleled in displaying the varied geology that underlies the densely vegetated landscape typical of this region. The opportunity to view some of the best outcrops that display these geologic units is only due to the preservation of this historic railroad corridor whose right-of-way traverses private lands that otherwise would be difficult or impossible to access. We hope to share and offer this exceptional field trip opportunity to other geology groups and the general public in the future. Thanks for coming aboard!

Acknowledgements

We’d like to express our gratitude to the Amador Central Railroad organization and the generous time of its volunteers for hosting our unique group fieldtrip on the rails. We also appreciate the time and contribution of the private motorcar owners who provided additional seats for our fieldtrip attendees. Without the collaboration of all these people and the continued preservation of this railroad, this unique and extraordinary geology fieldtrip would not be possible. This guidebook benefitted greatly from many thoughtful comments from David Shimabukuro and John Wakabayashi.

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Appendix of X-ray Diffraction Data

The character and geologic history of many of the rock units in the Sierra foothill province are determined by their mineralogy, both original parent mineralogy as well as the result of the climatic influences on weathering products that contributed to later sedimentary detritus. Therefore, we feel that X-ray diffraction (XRD) analysis to determine the clay mineralogy of selected rock units is crucial to provide a more informed interpretation of the geologic history of the rock units that are encountered on this fieldtrip transect.

The following X-ray Diffraction scan patterns (diffractograms) included here were performed over different time periods. XRD analyses of Ione sandstone materials were conducted during the course of research at the Union Oil Company (UNOCAL) Science and Technology Center in Southern California. Other recent XRD analyses of rocks along the railroad route were performed by J. Reed Glasmann of Willamette Geological Services in Oregon.

These data report the results of XRD analysis of the <2um size fraction (clay size) and in some cases the <15um size fraction (silt size) using the recommended methods of Theisen and Harward, 1962 and Glasmann and Simonson, 1985. Clay mineral identification and characterization were determined using oriented clay mounts with controlled solvation and hydration—ethylene glycol and 54% RH (air dry, AD)—and cation saturations (Mg or K).

Key to Mineral Labels on XRD Patterns

A—Anorthite (intermediate composition plagioclase feldspar)

G—Goethite

H—Halloysite

K—Kaolinite

M—Mica

O—Opal (amorphous silica)

Q—Quartz

R—Rutile

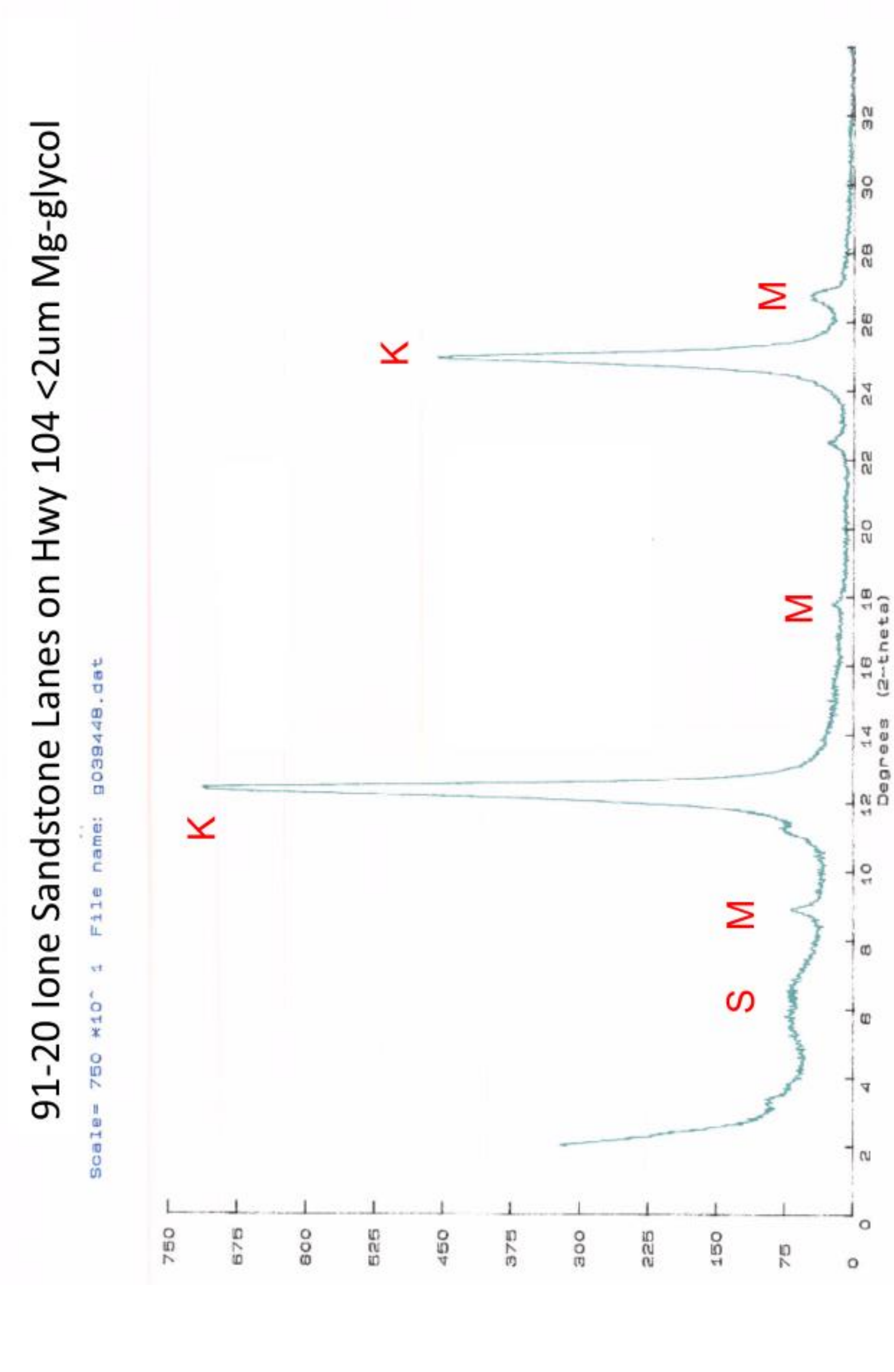
S—Smectite (e.g., montmorillonite)

V—Vermiculite

Milepost 2.1 Ione Sandstone—Lanes Station on Hwy 104

Sample ID 91-20 <2um Mg-Glycol

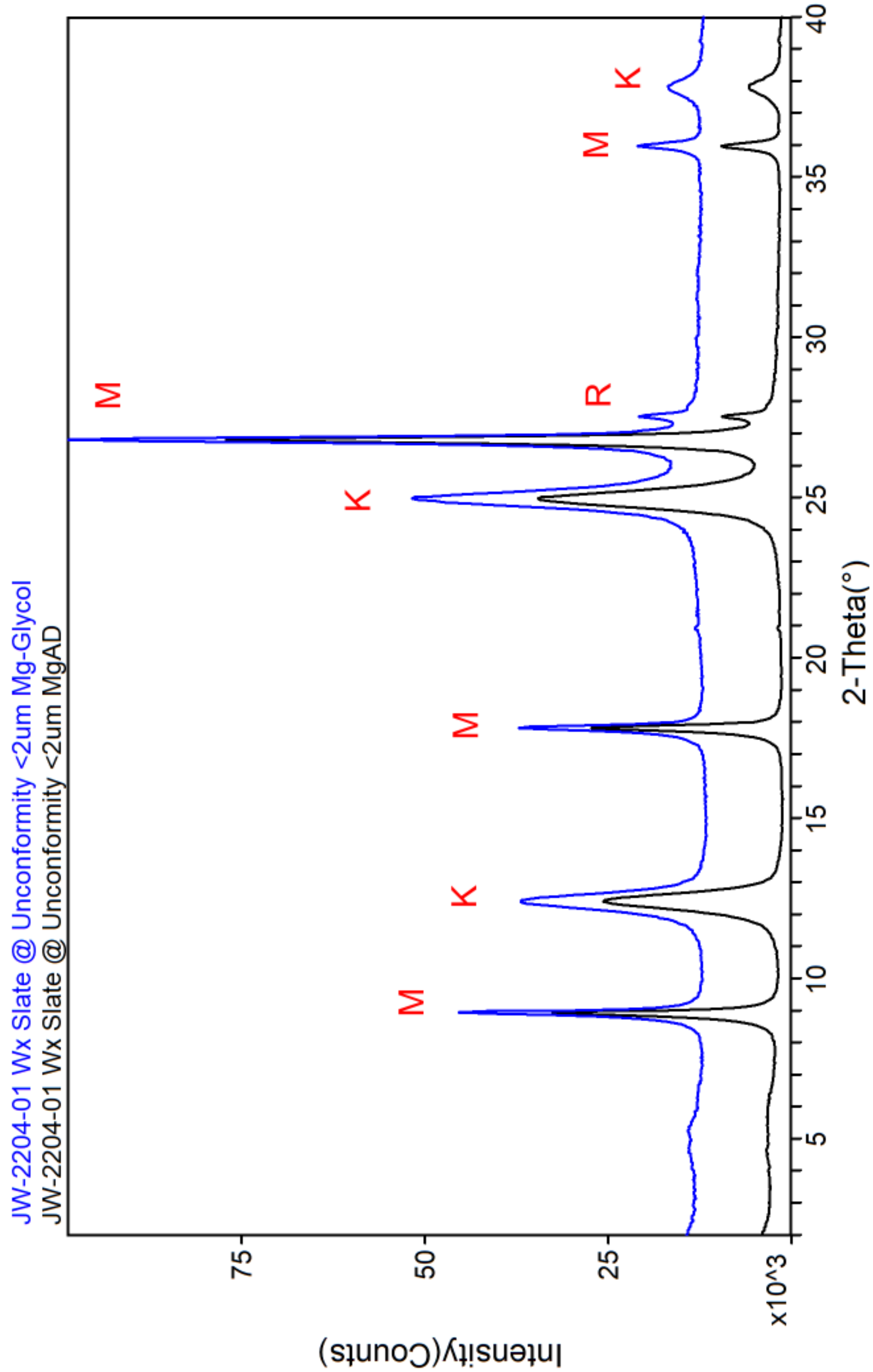
Kaolinite dominant; mica minor; smectite trace



Milepost 2.2 Weathered Salt Spring Slate at Unconformity

Sample ID JW 2204-01 <2um Mg-Glycol and Mg-AD

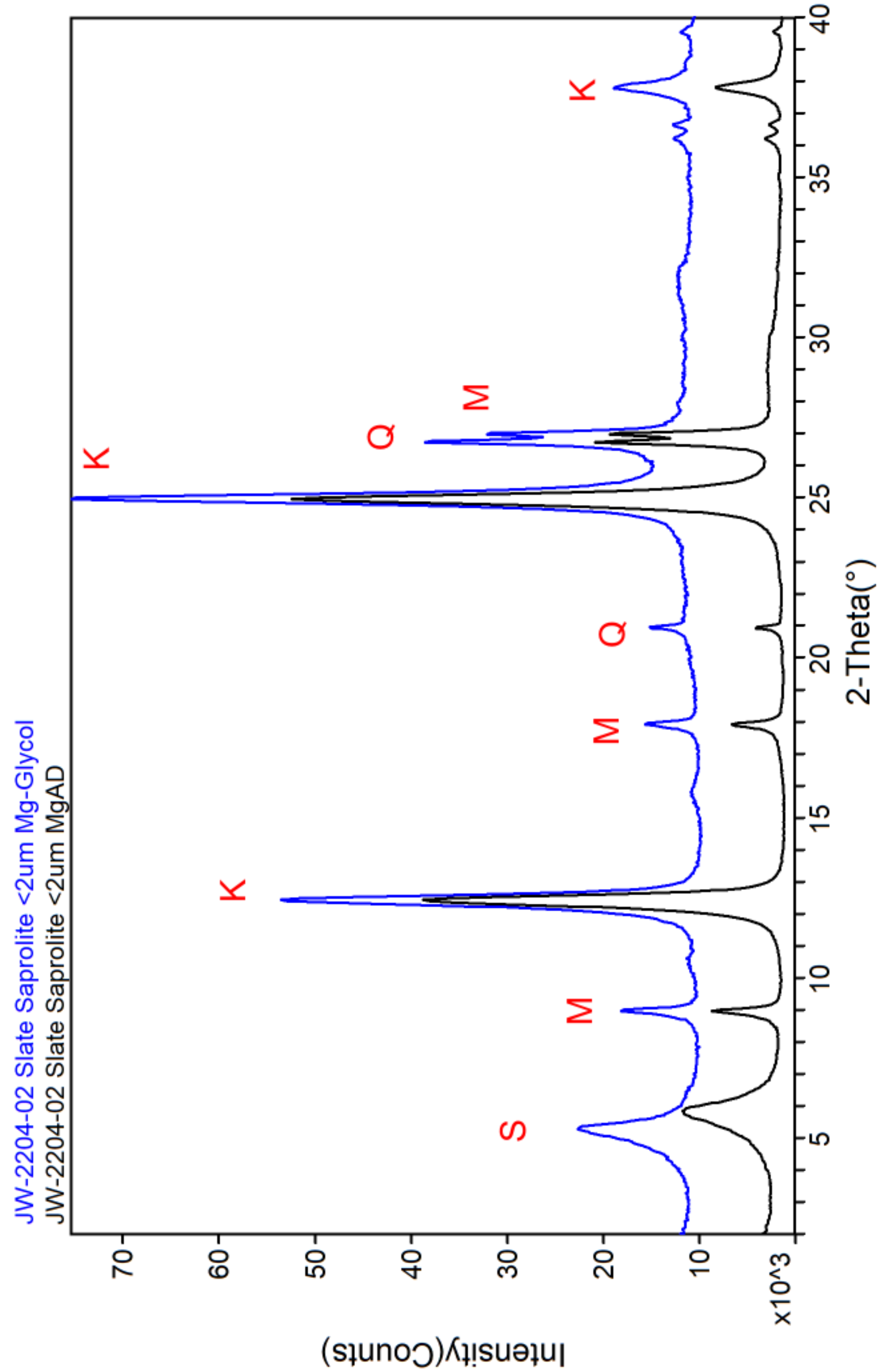
Kaolinite and mica major; rutile accessory



Milepost 6.7 Slate Saprolite in Weathering Profile

Sample ID JW 2204-02 <2um Mg-Glycol and Mg-AD

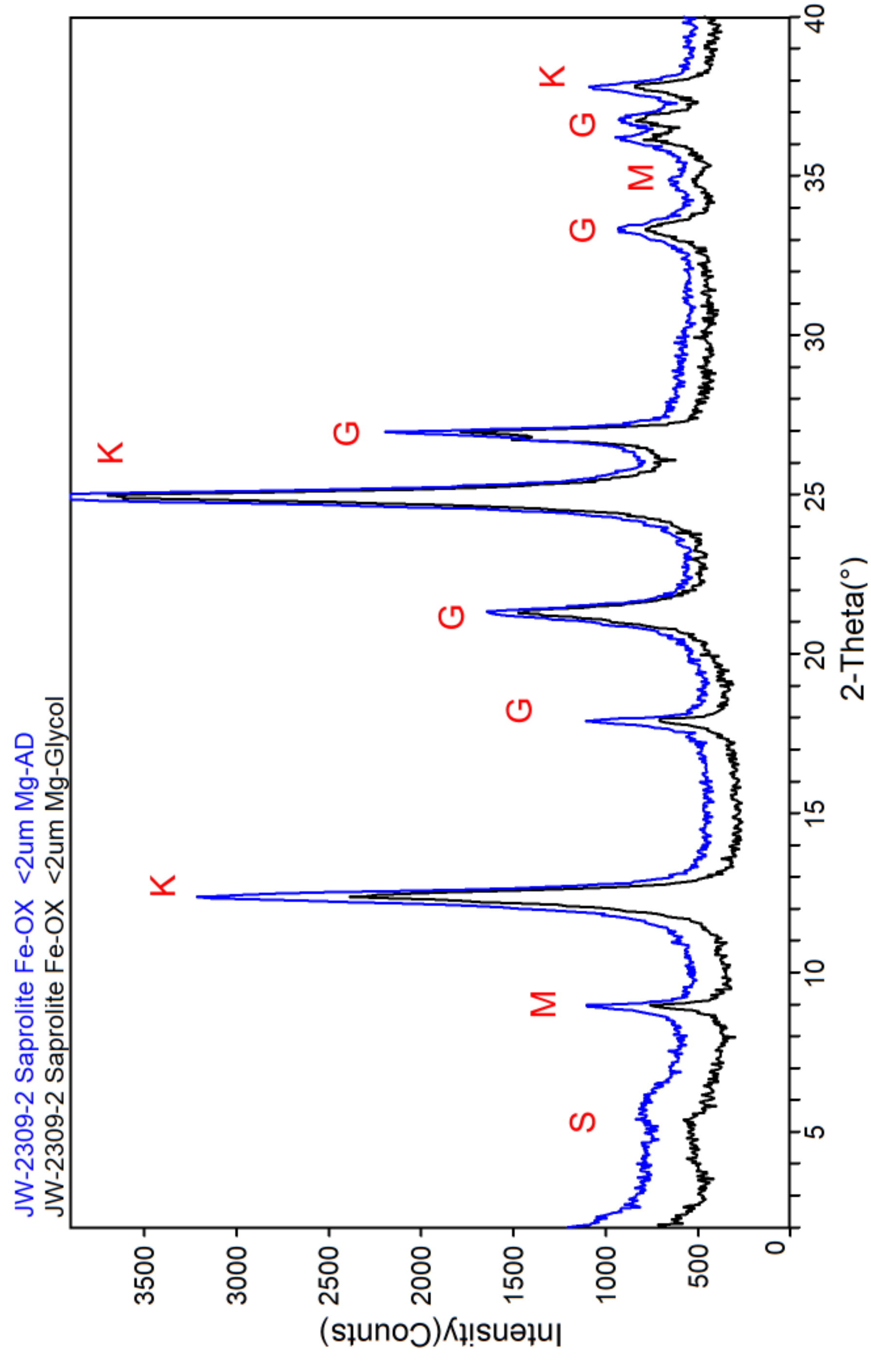
Kaolinite dominant; smectite and mica moderate to minor; quartz moderate



Milepost 6.7 Iron Oxide Cement in Slate Saprolite

Sample ID JW 2309-2 <2um Mg-Glycol and Mg-AD

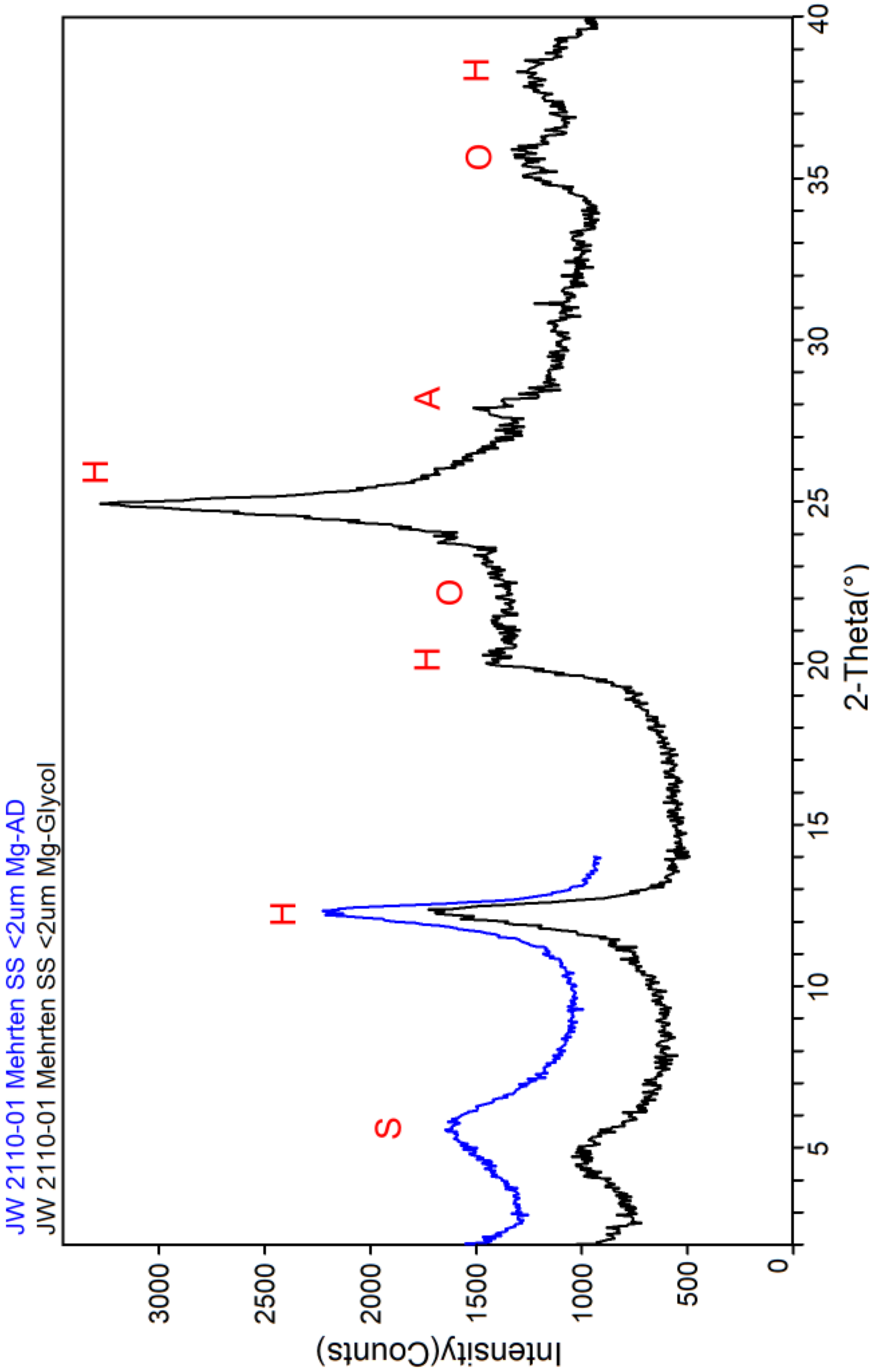
Kaolinite and goethite dominant; smectite and mica minor.



Milepost 8.2 Sandstone Boulder in Mehrten Gravel

Sample ID JW 2110-01 Mehrten SS <2um Mg-Glycol and Mg-AD

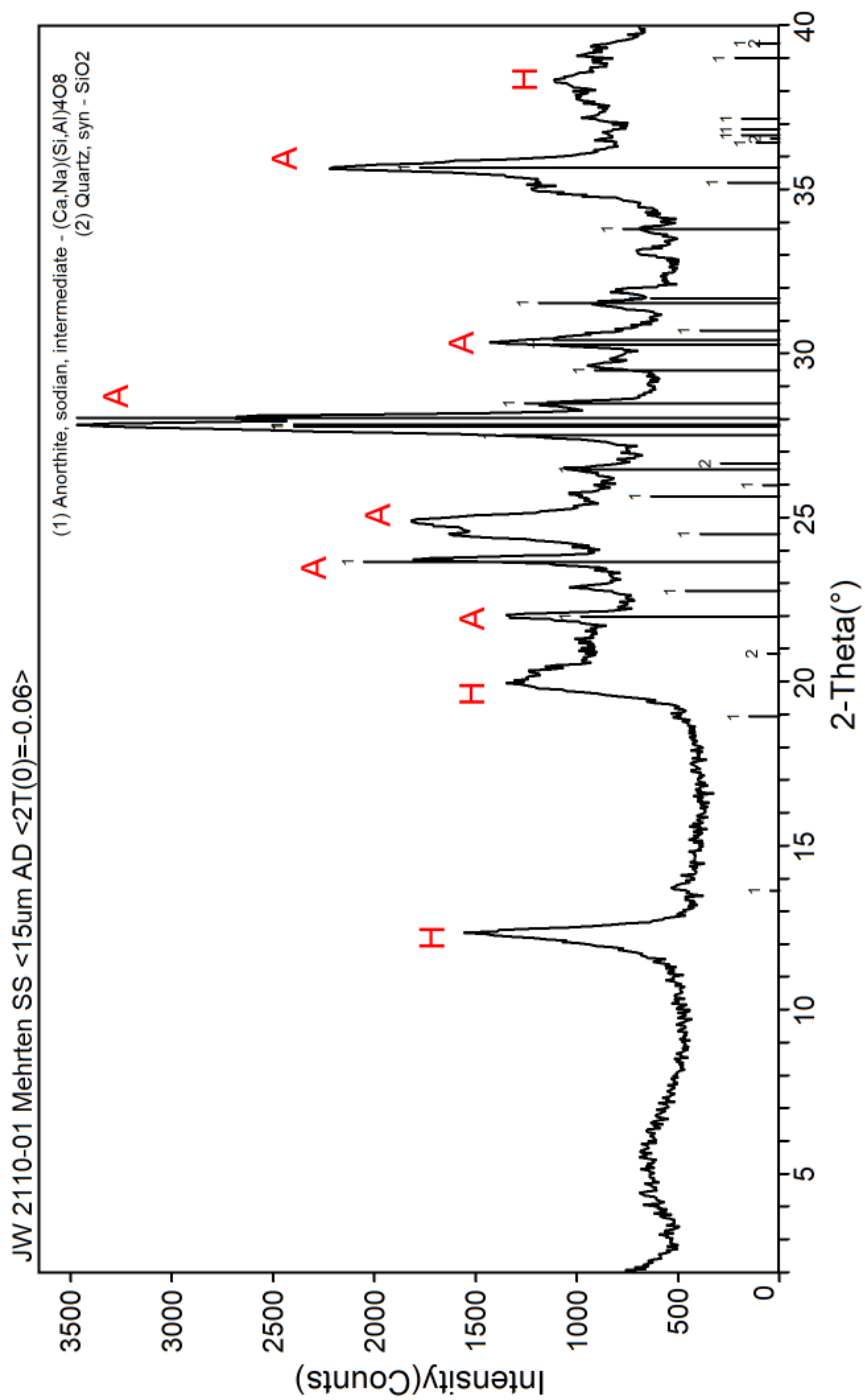
Halloysite and smectite dominant; opal moderate; anorthite accessory.



Milepost 8.2 Sandstone Boulder in Mehrten Gravel (Silt Fraction)

Sample ID JW 2110-01 Mehrten SS <15um AD

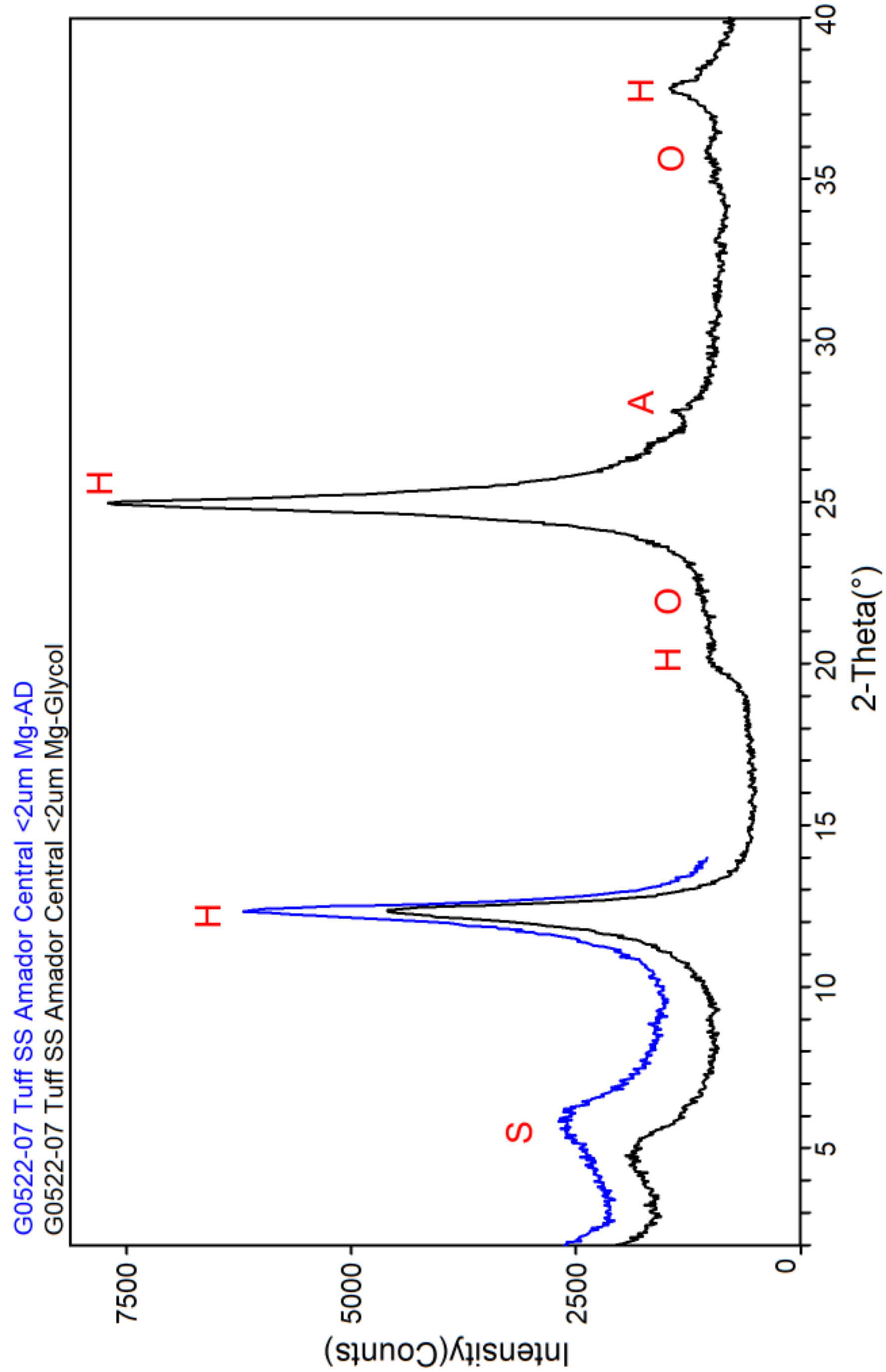
Anorthite dominant



Milepost 8.8 Tuffaceous Sandstone (reworked tuff)

Sample G0522-07 Stratified pumaceous tuff <2um Mg-Glycol & Mg-AD

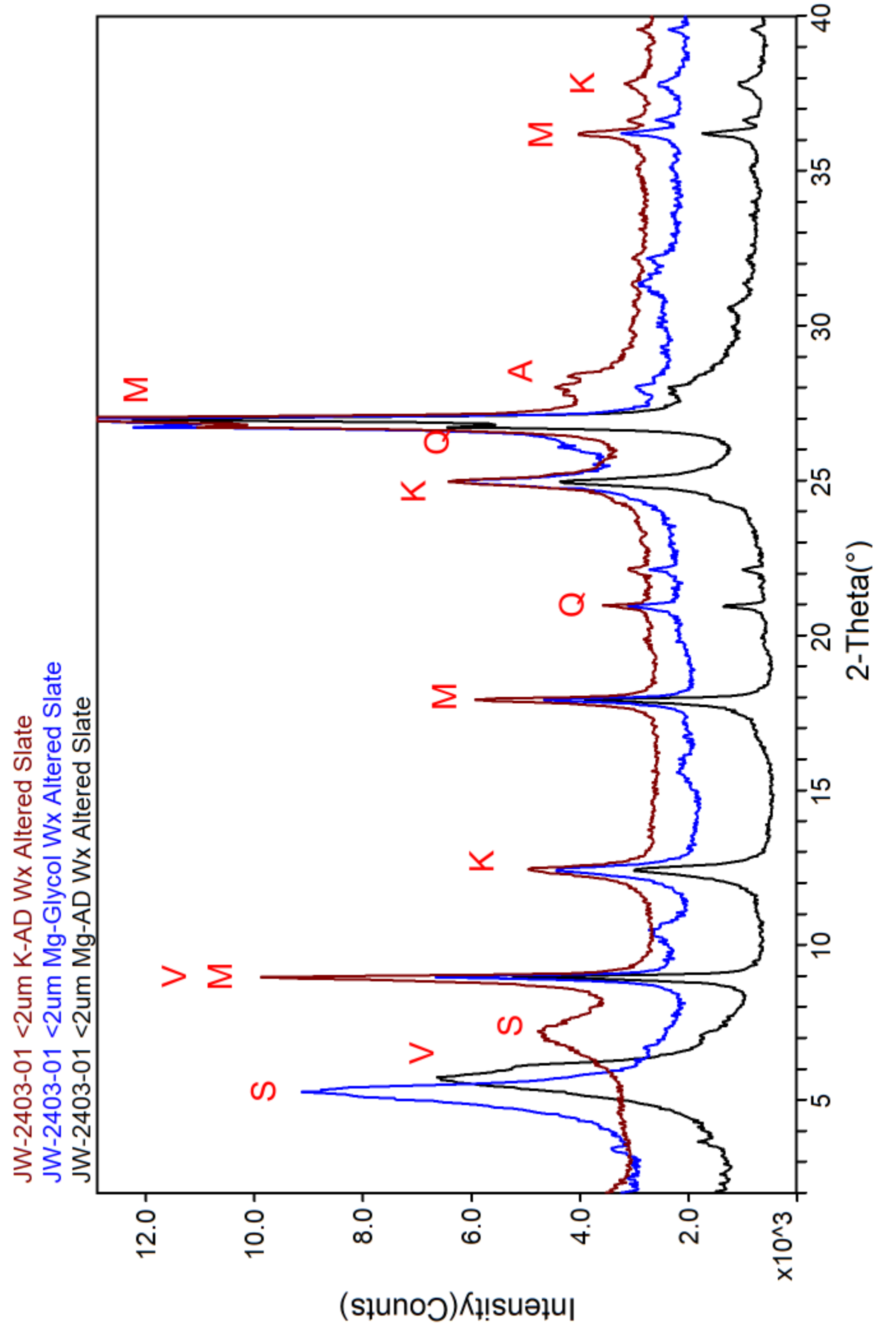
Halloysite & smectite dominant; anorthite and opal (amorphous silica) accessory



Milepost 9.0 Slate Saprolite in Mélange Sequence

Sample ID JW 2403-01 <2um Mg-Glycol, Mg-AD, K-AD

Mica dominant; smectite, kaolinite & vermiculite moderate; anorthite & quartz accessory



Milepost 9.3 Sandstone Layer Below Mehrten Gravel

Sample ID JW 2309-1 <2um Mg-Glycol and Mg-AD

Smectite and halloysite dominant; opal moderate; anorthite accessory