Association of Missouri Geologists Field Trip Guidebook

72nd Annual Meeting

St. Francois Mountains

October 3 and 4, 2025

Association of Missouri Geologists
72nd Annual Meeting
October 3 and 4, 2025

GUIDEBOOK TO FIELD TRIPS:

Precambrian Geology
St. Francois Mountains Terrane
Missouri

2025

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Association of Missouri Geologists
2025

INTRODUCTION

The geological units that will be visited today are of primarily Precambrian age and are located at the structural apex of the Ozark Uplift. These exposures are primarily Precambrian silicic volcanic rocks and their granitic plutons. The outcrops in this area represent a very important window on a much larger terrane of similar rocks, located primarily in the subsurface, which extends from northern Ohio to the Texas Panhandle.

There have been a large number of investigations conducted in the St. Francois Mountain area (SFM) and there have been many field trips previously taken to this area, hence there were a number of field guides already available for me to draw from on from this field guide. That said, the information in this field guide comes from many sources. I would like to take this opportunity to acknowledge and thank the authors of these publications for their contributions, many of which are listed in the references cited section of this guidebook.

PRECAMBRIAN CONCEPTUAL MODEL:

Most of the SFM can be thought of as formed in association with two large calderas, the Taum Sauk Caldera and the Butler Hill Caldera [Sides et al, 1981].

Butler Hill Caldera:
The Butler Hill Caldera is located east of Ironton. The major eruptive unit is named Grassy Mountain Ignimbrite. Unlike the Taum Sauk Caldera, the central pluton of this caldera is exposed and is named the Butler Hill Granite, along with its roof facies, the Breadtray Granite. The Grassy Mountain Ignimbrite has a thickness of greater than one kilometer as demonstrated on the southern portion of the mapped area [Sides,1981]. However, the unit is absent in the central portion of the caldera due to the resurgent doming, as discussed below. It appears to have been truncated on the west side, indicating that the Taum Sauk Caldera was somewhat younger than the Butler Hill Caldera [Sides, 1981].

Butler Hill Caldera - Low Silica Granites (Ring Plutons)
The Butler Hill Caldera is associated with the occurrence of four “ring plutons” consisting of relatively low silica granites which are significantly more mafic compared to the Butler Hill Granite. These ring plutons include The Knoblick Granite (northeast), Slabtown Granite (southeast), Silvermine Granite (south) and the Stono Granite (north). These were interpreted to represent the original magmas emplaced in the area. The more silica-rich volcanic and intrusive rocks are thought to have differentiated from these lower silica magmas.

Taum Sauk Caldera:
The Taum Sauk Caldera is the westernmost of the two calderas, located west of Ironton, Missouri. It is comprised of a thick sequence of volcanic units, with no exposed central pluton. The major eruptive unit of this caldera is named the Taum Sauk Rhyolite. The thickness of the Taum Sauk Rhyolite is reported to be greater than one kilometer [Kisvarsanyi, 1961]. Structurally, the overall configuration of the Taum Sauk Caldera is that of a large depression. Past mapping does not support resurgent doming of this caldera. Some authors interpret the caldera as a trap door structure, with a hinge area on the western side of the caldera. This hinge area corresponds to the Johnson’s Shut-Ins area. Stops on Day 1 will include views primarily of the western portion of the Taum Sauk Caldera.

Late-Stage Mafic Rocks:

The final stage of igneous activity was the emplacement of basaltic magma in the form of diabase dikes and gabbroic sills. The age of the basaltic rocks is not known, but clearly post-date the granitic rocks. Speculatively, the basaltic rocks may have acted as the “heating fluid” which melted the lower crust to form the more silicic units.

AGE-RELATED INFORMATION:

A number of the units were age-dated, as part of a regional study of crustal rocks in the mid-continent. Much of this work was conducted beginning in the late 1970’s, utilizing U-Pb techniques on zircon crystals. A comprehensive summary of this age dating work was published in 2014 [Bickford and Others, 2014]. Based on this information, the ages of most of the volcanic and intrusive units are slightly younger than ~1.5 billion years. However, there are two conspicuous exceptions, including the Graniteville Granite (Elephant Rocks State Park) and the Munger Granite Porphyry (near Johnson’ Shut-Ins State Park). These two units area are ~1.4 billion years old, demonstrating that there were two thermal/tectonic events in the SFM.

PALEOZOIC UNITS:

During early Paleozoic time, the SFM was the location of a shallow sea. At that time, the Precambrian units were thought to be islands exposed above water depth, with sedimentary units deposited around the exposed igneous rocks. Therefore, onlapping sedimentary rocks are observed at a number of locations. The two primary formations noted include the basal Lamotte Sandstone and the Bonneterre Formation. The Lamotte Sandstone is predominantly a quartzose sandstone that in many places, grades into arkose and conglomerate. The Bonneterre Formation is typically a light-gray medium- to finely crystalline, medium bedded dolomite-grained. It may contain pebbles and cobbles of igneous rock if it is located near the Precambrian rock.

PRECAMBRIAN CONCEPTUAL MODEL:

Volcanic stratigraphic evidence demonstrates that the Taum Sauk Rhyolite is younger than the Grassy Mountain Ignimbrite, indicating that the Butler Hill Caldera is older. However, their chemical composition is similar. <u>Flow direction studies of the Grassy Mountain Ignimbrite demonstrate that the source of this unit was the Butler Hill Granite.</u> The conceptional model for development of the two calderas follows [Sides and Others, 1981].

A) A large area of relatively low silica granite magma is emplaced into the shallow crust. However, upper portions of the magma fractionate into magma composed of higher silica content.

B) The crust above the eastern part of the low silica magma collapses into the magma chamber accompanied by eruption of the major eruptive unit, Grassy Mountain Ignimbrite. This unit crops out primarily on the west side of the caldera. However, that unit also occurs on the eastern side of the caldera (Knob Lick area), presumably down dropped into that location along a caldera ring fault.

C) The Butler Hill Caldera is resurgently domed. Low silica granites intrude into ring faults to form ring plutons around the periphery of the caldera, including the Silvermine Granite, Slabtown Granite, Knoblick Granite and Stono Granite.

D) A new caldera is formed to the west of the Butler Hill Caldera in what is now the Taum Sauk area (Taum Sauk Caldera). The eastern ring fault area of this caldera truncates the western margin of the older Butler Hill Caldera.

E) Extrusion of the thick Taum Sauk Rhyolite occurs, presumably along ring faults of that caldera. In this case, the structure is that of a large basinal or synclinal structure with the greatest thickness of Taum Sauk Rhyolite near the center of the caldera. Some authors have speculated that it is a "trap-door" structure with a hinge area on the west side, based on structural data.

F) After the formation of both calderas, a thermal/tectonic event occurred at roughly ~1.4 billion years, consisting of the emplacement of the Munger Granite Porphyry (Johnson's Shut-ins area) and the Graniteville Granite. Munger Granite Porphyry is thought to have been emplaced along arcuate ring faults of the Taum Sauk Caldera, based largely on the arcuate outcrop areas of the Munger Granite Porphyry.

DAY 1 AND DAY 2

On Day 1 of the field trip, we will explore portions of the Taum Sauk Caldera volcanic sequence and on Day 2, we will explore portions of the Butler Hill Caldera.

The volcanic units produced by these calderas were primarily pyroclastic in nature and a large majority of the units were originally welded ash flow tuffs. These units have completely devitrified over time, but the outlines of the original glass shards are still preserved in many units and are visible in thin section. There are also a number of units which were produced as volcanic flows, but these are volumetrically much less abundant.

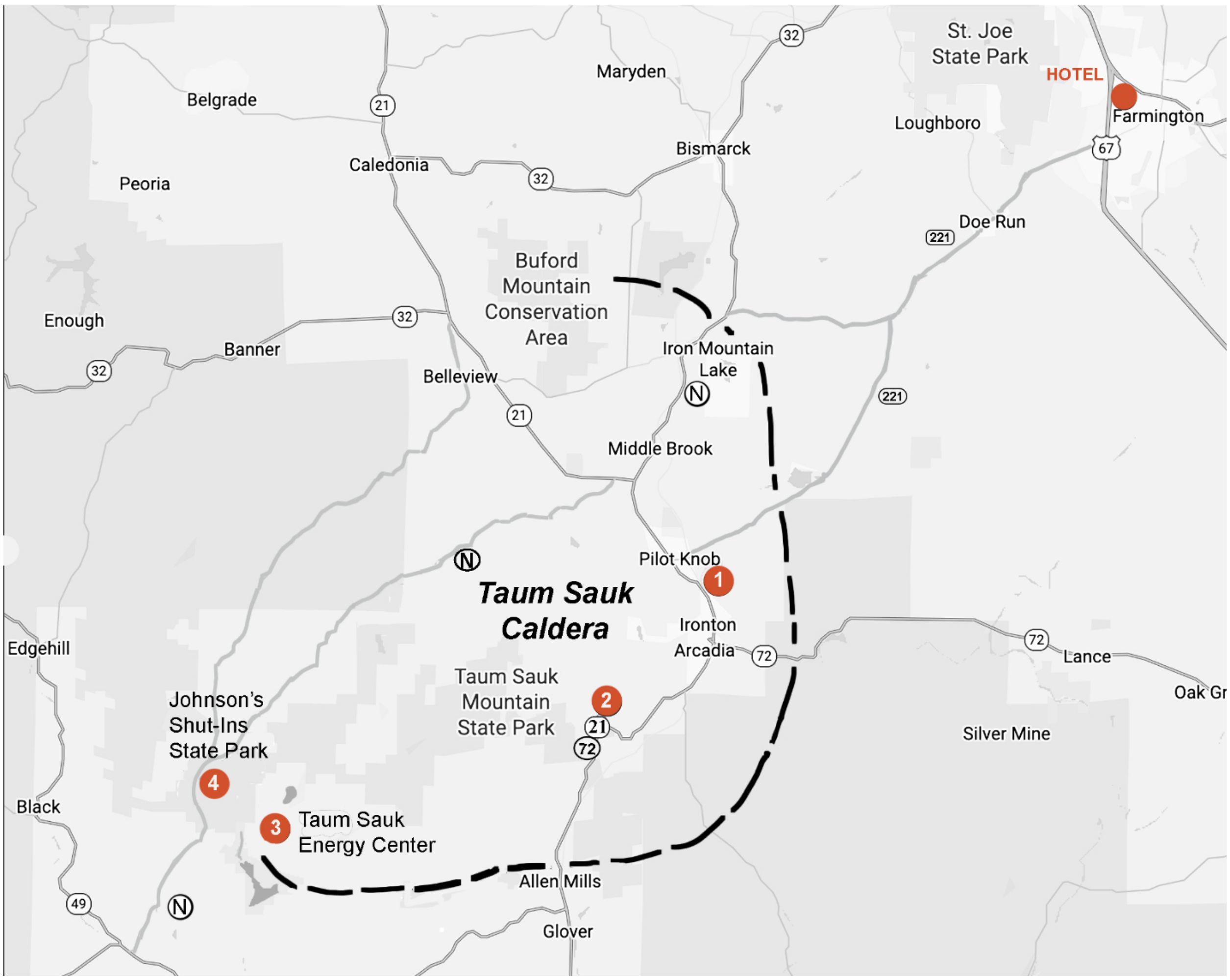
Field Trip Day 1

Friday, October 3, 2025

Igneous Geology of the St. Francois Mountains Precambrian Terrane Missouri

Volcanic and Intrusive Units Associated with the Taum Sauk Caldera

DAY 1 STOPS


St. Joe
State Park
HOTEL
Farmington
Loughboro
Maryden
Belgrade
Caledonia
Bismarck
Peoria
Doe Run
Buford
Mountain
Conservation
Area
Enough
Banner
Belleview
Iron Mountain
Lake
Middle Brook
Pilot Knob
Taum Sauk
Caldera
Ironton
Arcadia
Lance
Oak Gr
Edgehill
Johnson's
Shut-Ins
State Park
Taum Sauk
Mountain
State Park
Silver Mine
Black
Taum Sauk
Energy Center
Allen Mills
Glover
1
2
3
4

Association of Missouri Geologists
FIELD TRIP – DAY 1
October 3, 2025

Mileage 0.0: Starting point for the field trip, located at the intersection of Highway 67 and County Route 221 (CR 221).

From this point proceed to the southwest on County Road 221 (CR 221) (Missouri Route W) to Ironton.
Once in Ironton, turn left and continue on CR 221 for a short distance to **Stop #1,** Fort Davidson, the location of an important Civil War battle will be visible on your left, along with the Pilot Knob Iron Mine **(0.2 mile.)**

Mileage ~16.3 STOP# 1 Fort Davidson and the former Pilot Knob Mine (DRIVE-BY ONLY)

This vantage point affords a good view of the former Pilot Knob mine, a former iron mine. Mining at this location began in the mid-1800s at a hematite deposit located near the top of Pilot Knob. Hematite here included deposits of banded iron formation (alternating bands of hematite and iron-rich jasper) located at the top of the mountain, in an open pit area.

Based on test drilling in the 1950s along a magnetic anomaly, it was determined that a large magnetite ore body was located in the subsurface, and a subsurface mine was opened beginning in 1968. The Piot Knob magnetite ore is considered to be conformable with westward-dipping ash-flow tuffs and rhyolitic flows of the Tam Sauk Caldera. The hanging wall is thought to be Shepard Mountain Rhyolite / Unit 700 and the footwall may correspond to the Ironton Hollow Rhyolite. There were two predominant magnetite ore types, magnetite disseminated in the volcanic rock (30% to 40% magnetite) and matrix ore near the footwall (40% to 60% magnetite). An excellent description of this former mine was provided by David Wracher, mine geologist at the Pilot Knob Pellet Company [Kisvarsanyi, 1976]. I was privileged to take a mine tour with Mr. Wracher while the mine was still active in the mid-1970s. The magnetite mining operation was closed in 1987.

The earthworks you see in the foreground are associated with historic Fort Davidson. Fort Davidson was a civil war artillery post of great strategic importance due to the presence of the nearby iron mine, which was one of the few iron producing mines in the area. This was the site of an important battle between Union and Rebel forces in on September 27, 1864; for control of the iron mine. Ultimately, this battle was lost, but the Confederate forces were so decimated that they could not attack the next intended target, which was St. Louis! The readers of this Guidebook are strongly encouraged to visit the nearby museum in Pilot Knob, to learn more about this historical strategic location.

Former Pilot Knob Mine showing the historical open pit mining area on the crest of the mountain

From Stop Number1, proceed a short distance to the intersection with State Highway 21 (Highway 21). Then turn left onto Highway 21 and proceed generally southward to County Road CC **(6.6 Miles)**. Turn left onto County Road CC and proceed to the Location of Stop #2 **(1.6 miles)**

Mileage ~24.7 STOP #2, Royal Gorge Rhyolite / Unit 810b

The Royal Gorge Rhyolite / Unit 810 is located stratigraphically near the top of the Taum Sauk Caldera volcanic sequence. Generally speaking, it forms massive outcrops and is a red to maroon lava flow, containing about 5 percent phenocrysts of quartz and alkali feldspar. At this locality, the lava flow is prominently banded, and the banding is nearly vertical and strikes N 5° E. Individual flow bands may be followed on strike for several hundred feet [Berry, 1970]. Individual maroon bands are devitrified glass having a well-developed snowflake texture whereas the white bands are recrystallized pomaceous material with pronounced secondary crystallization. The banding was presumably caused by concentration of gases along shear planes created by the "glacier-like" flowing of the upper part of the highly gaseous and viscous basal flow.

The reason for the vertical attitude of the flow banding at this location is not known. According to [Berry, 1970], the lower part of the rhyolite is massive and not banded. The upper part of the unit has irregular banding and dips in different directions at various angles, sometimes approaching the horizontal. Three possibilities include:

- The vertically banded outcrop is simply a fault block of the rhyolite turned up on edge;
- The unit flowed down over a nearly vertical cliff just before it solidified;
- We may be looking just above the fissure or vent which the lava squeezed through before it solidified.

Flow banding in the royal Gorge Rhyolite / Unit 810

Proceed back eastward on County Road CC to the intersection with Highway 21 and turn right onto Highway 21 **(1.6 Miles)**. Proceed southward on Highway 21 to the intersection with County Road AA **(3.4 Miles)**. (County Road AA becomes CR 204.) Turn right onto County Road AA/204 and continue on CR204 until the entry road to the Taum Sauk Energy Center (Stop #3) is reached **(9.6 miles)**.

Mileage ~ 39.3 STOP #3, Ameren Energy Center-Taum Sauk Rhyolite and Munger Granite Porphyry

The Taum Sauk Energy Center is a pumped storage hydroelectric power plant, which is located on Proffit Mountain near Lesterville, Missouri. The original hydroelectric plant was constructed at this location in 1960-1962 and began operation in 1963. The facility includes two water reservoirs; the Lower Reservoir and an Upper Reservoir located at the top of Proffit Mountain. Electrical generators are powered by water flowing from the upper to the lower reservoir in the daytime at time of peak demand. At times of lower demand (nighttime), the generators are reversed, and water is pumped back into the Upper Reservoir.

The original Upper Reservoir was constructed of loose material which had been covered by a lining. On December 14, 2005, a catastrophic failure of the Upper Reservoir occurred. **This failure resulted in the release of roughly 1 billion gallons of water in only about 12 minutes.** The massive release of water caused removal of rock and soil, creating a **Scour Zone** on the north flank of Proffit Mountain. A new Upper Reservoir of roller-compacted concrete was completed in 2010. It is the largest Pump Storage facility in North America.

<u>**Stop 3A Energy Center Geology**</u>

There are two primary areas of geologic interest near the Energy Center. One of these is located near the generators at the upstream area of the Lower Reservoir (Stop 3A). At this location, the Grand Unconformity is exposed, with Cambrian sedimentary rock (thought to be Bonneterre Dolomite) onlapping Precambrian Taum Sauk Rhyolite. In Cambrian time, the SFM are thought to have been exposed as islands, in a shallow sea. The dip of the carbonate units at this location is considered to be depositional primary dip rather than tectonic.

Stop 3B Upper Reservoir-Scour Zone Geology

The Upper Reservoir is located on the western side of the **Taum Sauk Caldera**, and the primary geologic unit in this area is the **Taum Sauk Rhyolite (Unit 810a)**. The Taum Sauk Rhyolite was the major eruptive unit of the Taum Sauk Caldera. The unit is described as a red to dark maroon ash-flow tuff, containing up to 30% phenocrysts of alkali feldspar and quartz [Kisvarsanyi, 1976]. Fiamme may be present, but is not commonly observed. The **Munger Granite Porphyry** is also located on Proffit Mountain near the Upper Reservoir. Boulders of this unit can be seen along the roadway to the Upper reservoir. This unit is described further at the Stop 4 discussion.

The sudden massive flood of water flowed downhill to the north, eventually reaching the base of Proffit Mountain near State Route N. The flood turned westward and then flowed southward into the East Fork of the Black River through Johnson's Shut-Ins. (see Stop 4). The rapid discharge of water was violent enough to remove soil and regolith materials from the bedrock, creating the Scour Zone. The sudden massive flood of water flowed downhill to the north, eventually reaching the base of Proffit Mountain. The flood turned westward and then flowed southward through the East Fork of the Black River (Stop 4). At lower elevations exposed in the Scor Zone, bedrock included **Munger Granite Porphyry** in some locations and Bonneterre Dolomite at lower elevations.

Stop 3B will also include a look at the new Upper Reservoir, which was constructed of roller-compacted concrete.

Stop 3C Taum Sauk Lower Reservoir – (DRIVE-BY ONLY),

The shortest way to the final stop (Stop #4 – Johnson's Shut-Ins) passes through the Taum Sauk Lower reservoir dam area of the Taum Sauk Energy Center.

Proceed southward and eastward on the Taum Sauk Energy Center entrance road to the intersection until the intersection with Couty Road 204 is reached **(1.6 Miles)**. Turn right on County Road 204 and proceed to the Lower Reservoir **(2.2 Miles)**. This stop includes a nice view of the dam on the Lower Reservoir. Based on historic mapping [Kisvarsanyi, 1976], the units exposed at this location include (from higher to lower elevation):

- Taum Sauk Rhyolite (Unit 810a)
- Bell Mountain Rhyolite (Unit 790) and
- Wildcat Mountain Rhyolite (Unit 780), [Kisvarsanyi, 1976]

Depending on the timing, we may stop briefly at this location.

Mileage ~57.0 STOP# 4, Johnson's Shut-Ins State Park

Continue southward onto County Road 204, which becomes County Road U, to the intersection with State Highway 72-49 near Lesterville, Missouri **(3.5 Miles)**. Turn Right and proceed westward on State Highway 72-49 to the intersection with County Road N **(6.0 Miles).** Turn right onto State Highway N and proceed to the entrance to the Johnson's Shut-in State Park State Park **(6.0 Miles)**.

Rock sampling is not allowed in this State Park. Rock hammers stay in the bus.

The Precambrian geology of the Johnson's Shut-Ins area has been mapped by Anderson (1970) and was mapped in great detail by Elizabeth (Betsy) Blades as part of the work toward her Master's degree [Blades-Zeller 1976]. The mile-long shut-ins exposes a 650 m (2,100 feet) thick sequence of ash flow tuffs (ignimbrites) and intercalated volcaniclastic sedimentary rocks that dips about 15 degrees to the northeast. (This dip is compatible with the interpretation of the Taum Sauk Caldera as a structural sag.) Stratigraphically, these units are interpreted to be located above the Taum Sauk Rhyolite and are therefore some of the highest units in the Taum Sauk "sequence."

This sequence consists overall of two separate welded ash flow tuff units. One of these is located at the park overlook, and one is located just to the south. These were separate cooling units with some time passing between eruptions, so that volcaniclastic sediments developed between these two ash-flow tuff units.

Upper Ash-Flow Tuff:
The Shut-ins overlook provides an excellent exposure of the highest of the two eruptive units, the Upper Ash-Flow Tuff. This unit is described as a gray ash-flow tuff with phenocrysts of alkali feldspar (4 to 12%) and plagioclase (~3%), with abundant lithophysae. The Upper Ash-Flow Tuff is considered to be a single cooling unit. The lower portion of this unit includes a prominent zone of **pisolites** (most easily recognized in float). These are interpreted as forming in ash-impacted raindrops. **Lithophysae** are abundant in the middle and upper portion of this unit. **Lithophysae** are interpreted to have formed as "gas bubbles" in volatile-rich volcanic units. Some features suggesting active **fumarolic** activity are noted, based on color changes in the Upper Ash Flow tuff.

A prominently exposed bed of water-laid tuff is located at the beginning of the upper shut-in, directly across the river from the observation platform. This is described as a uniform, gray, fine-grained, water-laid tuffaceous volcaniclastic siltstone with ripple marks, cross-bedding, and finely graded bedding [Blades-Zeller, 1980]. The unit is also described as a tuffaceous volcaniclastic siltstone.

This stop will also include a view of the Munger Granite Porphyry. Boulders of this unit were transported to the park location by the catastrophic failure of the older Upper Reservoir. The Munger Granite Porphyry is one of the two geologic units which are notably younger (1.4 billion years old) than most of the igneous geologic units (1.5 billion years old). The Munger Granite Porphyry is exposed in an arcuate pattern on the western side of the Taum Sauk Caldera. It has been suggested that the Munger Granite Porphyry was emplaced along ring faults of the Taum Sauk Caldera.

Prominent lithophysae (right) and potential fumarolic zone (left) in the Upper Ash-Flow Tuff, located near the main overlook.

Pisolites in float located just below the cliff-forming Upper Ash-Flow Tuff (right) and water laid tuff (volcaniclastic siltstone) just above the main shut-ins area (left)

STOP #4A Johnson's Shut-ins Visitor Center & Boulder Field Area.
The torrent of water from the dam failure was primarily along the outcrop area of an intrusive unit called the Munger Granite Porphyry. This unit includes conspicuous orthoclase phenocrysts up to 8 mm in length and quartz phenocrysts up to 4 mm in length. The rock is reddish brown with greenish mottling due to fine-grained mafic minerals [Tolman and Robertson, 1969]. The porphyritic nature of the intrusive unit suggests that it was emplaced at a relatively high crustal level, perhaps a feeder for volcanic units. Because the torrent of water preferentially flowed across this unit, many of the boulders in the boulder field are comprised of this unit.

It has been suggested that the Munger Granite Porphyry was emplaced along ring faults of the Taum Sauk Caldera. Structurally, this may be possible. However, the Munger Granite

Porphyry has been age dated at ~1.4 billion years (U-PB age with zircons) along with one other significant igneous unit in the St. Francois Mountains, the Graniteville Granite, and units in the subsurface [Bickford and others, 2014]. While the emplacement of the Munger Granite Porphyry may have been fault controlled, it does not appear otherwise related to development of the Taum Sauk Caldera, with units age dated at ~1.5 billion years.

Munger Granite Porphyry:

Association of Missouri Geologists 2025

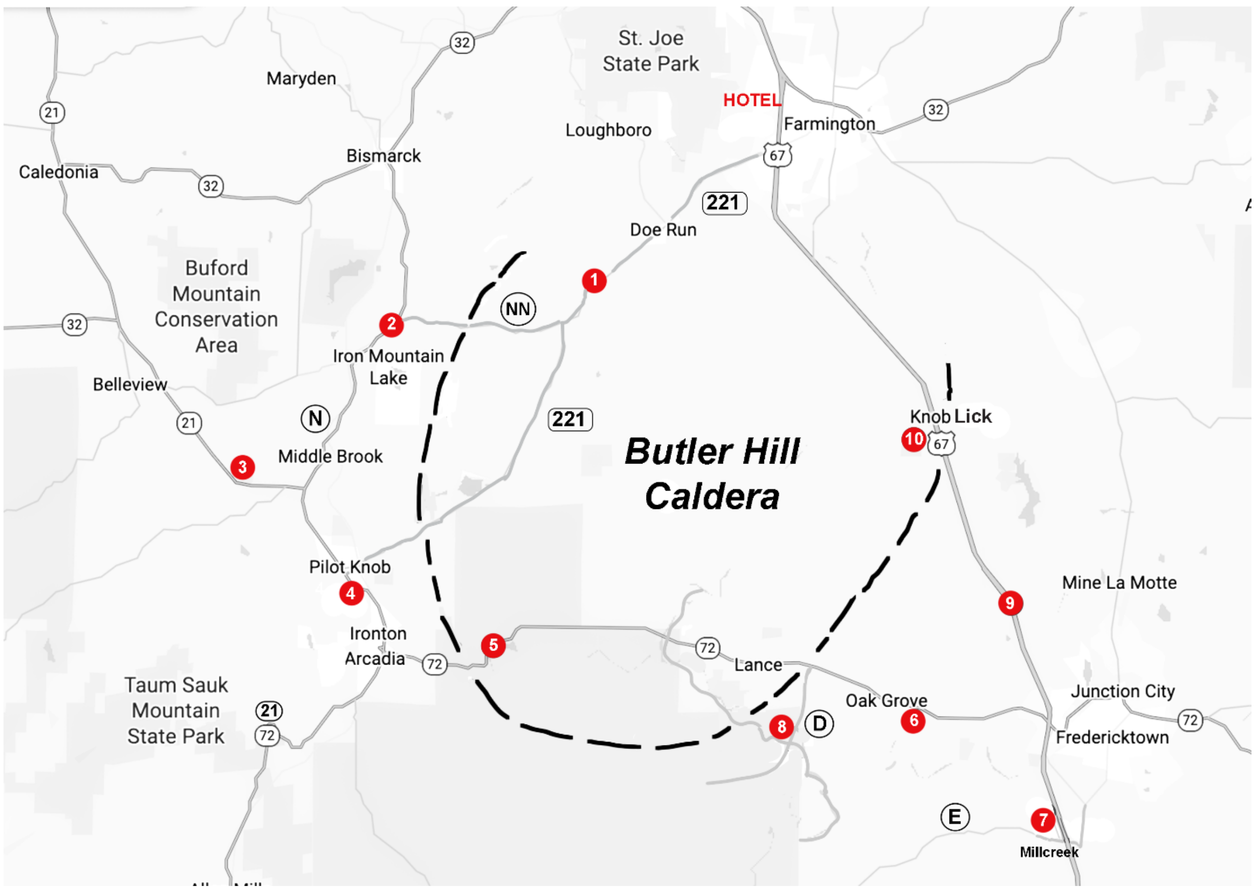
Field Trip Day 2

Saturday, October 4, 2025

Igneous Geology of the St. Francois Mountains Precambrian Terrane Missouri

Volcanic and Intrusive Units Associated with the Butler Hill Caldera

DAY 2 STOPS


St. Joe State Park
HOTEL
Farmington
Maryden
Loughboro
Bismarck
Caledonia
Doe Run
221
NN
Buford Mountain Conservation Area
Iron Mountain Lake
Belleview
N
Middle Brook
221
Butler Hill Caldera
Knob Lick
Pilot Knob
Mine La Motte
Ironton
Arcadia
Lance
Taum Sauk Mountain State Park
Oak Grove
D
Junction City
Fredericktown
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Millcreek
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Association of Missouri Geologists
FIELD TRIP – DAY 2
October 4, 2025

Introduction:

The geological units that will be visited today are intrusive and volcanic rocks associated with the Butler Hill Caldera, which is the older of the of two calderas in the St. Francois Mountains. This name derives from the central pluton beneath the caldera, called the **Butler Hill Granite, (**along with its finer-grained roof facies, referred to as the **Breadtray Granite),** which intruded a roof of its own volcanic ejecta. For the Butler Hill Caldera, the majority of the volcanic ejecta was eroded away, exposing the granite which originally underlay the volcanic rocks.

Low-Silica Ring Plutons:

The boundaries of the Butler Hill Caldera correspond to the location of four "ring plutons." The ring plutons were emplaced after the Butler Hill Granite and are different (more mafic, lower silica) in composition. The boundaries of the Butler Hill Caldera correspond to the location of four relatively low-silica granites. These are thought to have been emplaced along the ring faults of the Butler Hill Caldera. They are (clockwise from the north):

- Stono Granite (north)
- Knob Lick Granite (northeast)
- Slabtown Granite (east)
- Silvermine granite (south)

It is considered likely that differentiation of the low silica granites resulted in the formation of the high silica granite (e.g., Butler Hill - Breadtray Granite)

Mileage 0.0: Starting point for the field trip, located at the intersection of Highway 67 and County Route 221 (CR 221).

From this point proceed to the southwest on CR 221 (Missouri W) 5.8 miles to Stop # 1.

Mileage ~5.8 miles: STOP #1 Butler Hill / Breadtray Granite

Older literature relative to the Butler Hill Caldera referred to the Butler Hill Granite and the Breadtray Granite as two separate bodies with a gradational contact between them. However, more recent publications [Sides et al, 1981] refer to the Breadtray Granite as the "roof facies" of the Butler Hill Granite. The Butler Hill Granite is relatively coarse-grained as observed in east and central exposures. However, western exposures of the granite (Breadtray roof facies), become finer-grained, redder in color, and more granophyric. Stop #1 is a relatively new road cut exposure of the Breadtray roof facies of the Butler Hill Granite. The unit is relatively fine grained, and consists predominantly of perthitic alkali feldspar, quartz, and biotite; with minor amounts of plagioclase and alkali amphibole.

Mileage ~9.3 miles: STOP #2 (DRIVE-BY ONLY), Iron Mountain Trap Rock Property (former Iron Mountain Mine.

From **Stop #1**, continue southwest on SR 221 (Missouri W) miles to the intersection of County Road NN **(1.4 miles)**. Turn onto County Road NN and proceeded westward to the intersection with County Road N **(1.3 miles**). Continue westward on County Road N to **Stop #2**, the Black Trap Rock operation (Former Iron Mountain Mine.)

Iron mining began at this location in the early 1800s. Hematite and magnetite were almost continuously mined from 1844 to 1966 with production of 9 million tons of iron ore concentrates [Berri, 2009]. The ore minerals occurred primarily as open space filling in fractured and brecciated andesite porphyry with minor wall rock replacement. Country rock includes Precambrian dacite, rhyolite, and andesite. The ore consisted primarily of hematite, with magnetite less common. There were two dome-shaped ore bodies, which were aligned northwest. Although the iron ore has been mined out, the property continues to produce dense volcanic rock, which is crushed for used for road construction, railroad beds, and landscaping (Trap Rock).

Mileage ~14.5 STOP #3 Elephant Rocks State Park

From **STOP #2** Continue westward on Couty Road N to the Intersection with Highway 21 **(3.6 Miles)**. At this intersection, turn right onto Highway 21 and proceed 1.6 miles to **Stop #3**, Elephant Rocks State Park.

Rock sampling is not allowed in this State Park. **Rock hammers stay in the bus.**

Elephant Rocks State Park was opened in the Spring of 1969. It features the first self-guiding Braille trail for the visually handicapped among Missouri State Parks. It was opened as a result of a donation of land in 1966 by Dr. John S. Brown, former Chief Geologist of the St. Joseph Lead Company.

The dark·red color of the rock is due to finely disseminated iron oxide particles in the feldspars, which makes it unsuitable for ceramic uses. The last commercial production of the Graniteville Granite was from the Heyward Granite Company about (0.5 miles) northeast of Elephant Rocks State Park. Its last reported production in 1979 was less than 300 tons.

The prime scenic attractions of the park are the large residual boulders ("elephant rocks") of Graniteville Granite, the result of **spheroidal weathering** along joint planes. Graniteville Granite, commercially known as "Missouri Red," has been quarried commercially in the area since 1869. Blocks of Graniteville Granite were being used as paving and curbing stone in St. Louis city streets and other cities by the turn of the century. It was also used as a building stone in many of the local buildings.

The Graniteville Granite is a medium- to coarse-grained, muscovite-biotite alkali granite averaging 55 % alkali feldspar,40 % quartz, and less than 5 % mafic minerals. The alkali feldspar is typically microcline·microperthite, but albite and orthoclase·microperthite are also present. Both primary and secondary muscovite (sericite) can be recognized in thin sections.

Drill holes indicate that Graniteville Granite underlies the sedimentary rocks within Belleview Valley to the north at depths ranging from ~90 m to ~180 m (~300 to ~600 feet). Aeromagnetic evidence suggests that the areal extent of the pluton is an oval.

<u>So how does the Graniteville Granite fit into the genesis of the St. Francois Mountain terrane?</u>
The answer is “not very well”. The Graniteville Granite is one of only two igneous units which crop out in the SFM, which are younger compared to the other units, with U-Pb age dates of ~1.4 billion years (the other being Munger Granite Porphyry). The presence of these younger

plutons document a subsequent thermal/tectonic event about which little is known. Early age dating by rubidium/strontium methods indicated most of the igneous rocks to be ~1.3 - ~1.4 billion years. It is possible that the younger apparent age was the result of a thermal event, which caused loss of strontium [Bickford & Mose, 1975].

Mileage ~20.0 STOP #4, (DRIVE-BY OR BRIEF STOP-TIME PERMITTING) Lower Units of the Taum Sauk Caldera

From Stop #3, turn eastward onto Highway 21 and follow the highway into the Ironton Missouri area for a distance of 5.5 miles. The volcanic unit exposed on the right is described as the Shepard Mountain Rhyolite as designated by [R.E. Anderson, 1970] and Unit 700 as designated by [Berry, 1970]. This is one of the lowest units associated with the Taum Sauk Caldera. The Shepard Mountain Rhyolite is described as a brick-red to dark maroon ash-flow tuff containing white to slightly pink plagioclase phenocrysts and many fiamme. It generally has well-developed snowflake texture and has neither quartz nor perthitic potassium feldspar. Structurally, the unit at this outcrop dips approximately 20 to 35 degrees to the southwest, supporting the interpretation of the Taum Sauk Caldera as a structural sag.

Shephard Mountain Rhyolite / Unit 700 along Highway 21

Mileage 24.3 STOP #5 Stouts Creek Shut-ins

From Stop #4, proceed further south on Highway 21 for 1.4 miles to the intersection with Highway 72. From this intersection, proceed eastward 2.9 miles to a parking area at Camp Penuel.

The author wished to express his thanks to the owner of Camp Penuel for allowing AMG to park a bus at this location.

Stouts Creek Shut-ins presents an excellent exposure of two of the primary units associated with the Butler Hill Caldera, the **Grassy Mountain Ignimbrite (GMI)** and **Lake Killarney Formation (LKF)**. This is one of the very few locations where these two units can be seen together, along with the contact between them.

This stop will involve a hike along an active highway. High Visibility Vests are mandatory and caution will be important when crossing or walking along Highway 72.

Lake Killarney Formation

The lowermost unit at this location is the **LKF**. This formation is the oldest known rock mass exposed in the SFM (Sides et al 1981). It is at least 1,200 feet thick, and consists of at least two ash flow sheets and one or two rhyolitic lava flows, with some intercalated volcaniclastic sedimentary units. Most of the **LKF** is porphyritic dark-maroon ash flow tuff. Phenocrysts occur in relatively low abundance, including quartz (~3%) and pink alkali feldspar (~4.6%), (Sides 1978). The upper portion of the formation has a persistent unit consisting primarily of coarse fragmental tuff, coarse breccia, or both; called the Anderson Mountain Member, which is exposed at this location near the contact with the overlying **GMI**.

Grassy Mountain Ignimbrite

The **GMI** is a very thick and widespread welded ash-flow tuff, which is distinguished by its black to dark maroon cryptocrystalline matrix, and a relatively high abundance of quartz (~9%) and salmon colored orthoclase feldspar (~12%). Pyroclastic features such as fiamme and other features occur, which allow structural interpretation, but are not common. This was a major and massive eruptive pyroclastic unit with an original estimated thickness of ~1.0 km. To date, no one has identified any individual cooling units within this thick formation. At this location, the fiamme texture which is common in some welded ash-flow tuffs exists. However, the orientation of the fiamme at this location is vertical indicating that the GMI unit here is vertical (see below).

As part of a Master's thesis, Robert (Bob) Shuster studied two geologic sections of the **GMI**, one here and one on nearby Kelly Mountain and found no physical, textural, chemical or mineralogical breaks in the unit, which has a minimum thickness of at least 1 km [Schuster, 1978].

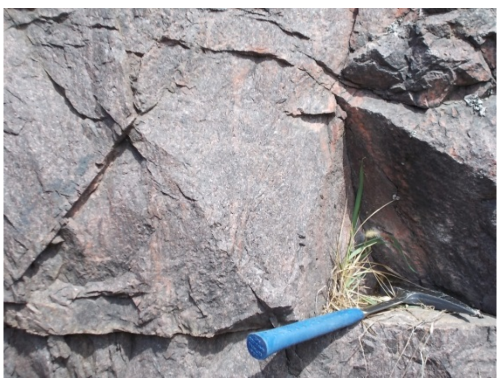
The **GMI** is known to exist as far as 12 miles to the northeast and 14 miles to the east of this location (Sides 1981). **However, the GMI is not known to exist to the west of this location.** This demonstrates a major change of volcanic stratigraphy to the west, consistent with the presence of the Taum Sauk Caldera to the west.

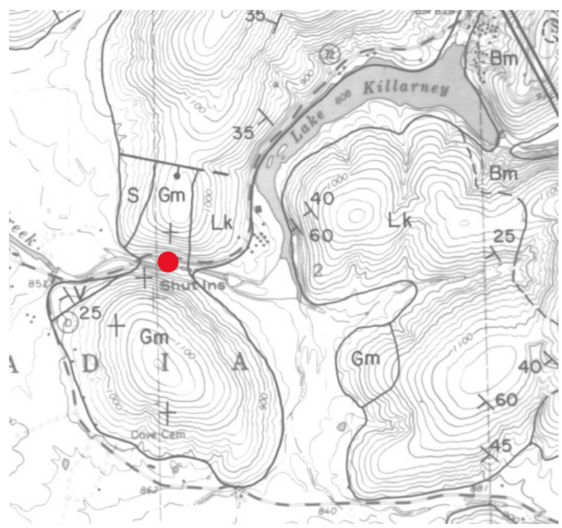
So why is it vertical here? The vertical nature of the **GMI** remains an open question. The **GMI** also occurs approximately 2.5 miles to the northeast of this location, where it dips to the northeast at a relatively low angle (approximately 20 degrees). Therefore, the overall structure here is interpreted as a breached anticline with one steep limb (this location), one relatively gentile limb, and with older **LKF** exposed in between.

From this location, exposures of essentially vertical or steeply dipping **GMI** are observed as far as 3 miles to the north-northwest, which appear to be fault bounded blocks. To the south, large areas of relatively flat lying **GMI**, are exposed on Grassy Mountain (type locality) and Kelly Mountain, extending for at least 6 miles to the south of this location.

One potentially important intrusive unit is exposed approximately 1.3 miles to the east, of this location, called the Brown Mountain Rhyolite Porphyry. This fine-grained shallow intrusive unit, occurs in a northwest-southeast orientation, and is exposed for a length of approximately 2.5 miles. The volcanic units to the west of this pluton tend to be steep to vertical. It is possible that emplacement of this shallow pluton caused or augmented the steep dips in the overlying volcanic units at this stop and elsewhere.

Additional structural controls may be important in this area. The vertical orientation of the Grassy Mountain Ignimbrite here is also consistent with resurgent doming of the Butler Hill Caldera.





Vertical fiamme in Grassy Mountain Ignimbrite (upper) and the autobreccia near the top of the Lake Killarney Formation (Anderson Mountain Member). Also shown is the outcrop pattern for this stop.

Mileage 38.0 STOP #6 Diabase Dike and Grassy Mountain Ignimbrite

From Stop #5, proceed further east on Highway 72 for 13.7 miles to the west at Stop #6

This stop serves to illustrate important time relationships of the Precambrian units. Based on the relationships illustrated on both the north and south sides of the roadcut, the volcanic unit originated first, with the diabase dike occurring obviously later than the volcanic rocks. The dike is terminated at the Precambrian surface. On the south side of the exposure, the dike is truncated by a basal boulder conglomerate. Paleozoic strata lap onto the Precambrian erosional surface from the east. The boulder conglomerate consists mostly of weathered Precambrian rhyolitic porphyry. Coarse sandy dolomite and dolomite of the Bonneterre Formation overlie the boulder bed. Since the Precambrian units are ~1.5 billion years old, the exposed unconformity represents a time interval of roughly 1 billion years (give or take some).

Everywhere they are observed, the mafic bodies are known to have been emplaced after the silicic rocks. However, they have not yet been age-dated. It is thought that these mafic units may have been the “heating fluid,” which facilitated the development and subsequent emplacement of the silicic magma and then intruded the silicic rocks at a late stage after emplacement.

The volcanic unit exposed here is mapped as the **GMI**, the same unit visited 13.7 miles to the west at Stop #5, and will be seen ~ 6 miles to the north at Stop #10; documenting its original widespread nature.

The dike contacts are sharp, but fractured and sheared, with calcite and quartz filling narrow fractures along the sheared contact with the rhyolite. Mafic intrusions, while volumetrically small, are an important part of the SFM volcanic terrane. Small bodies of gabbro and diabase are exposed at various locations in the SFM, predominantly dikes and sills which are known to be up to 900 feet thick. These bodies tend to occur in elongated broad flat lowlands created by relatively rapid and deep weathering. This results in sparse and scattered outcrops, partially masking their true extent. Many of the sills display mineralogical layering. A large body of intrusive mafic rock called the Skrainka Diabase, is located approximately 1.2 miles to the north-northeast of this location.

Mileage 42.3 STOP #7 Mill Creek Igneous Geology at Route E.

From Stop #6, proceed further east on Highway 72 for 1.3 miles to the intersection with Highway 67. Turn south on Highway 67 for a distance of 3.0 miles to the intersection with Highway E.

Introduction:

This outcrop and other nearby areas were investigated by John Leonard Dolde in the early 2000’s and the information was summarized in a Master’s Degree Thesis which was published in 2004 [Dolde 2024]. Most of the information provided below was derived from that thesis. Casual inspection of the outcrop at this location indicates the presence of two primary units, based largely on a notable color difference. The northernmost of the two units is a dark purple-black in color and is called the Priday Rhyolite. The southernmost of these units is salmon pink in color and is called Millcreek Microgranite. The outcrop will be discussed in two parts, the Northern Portion and the Southern Portion.

Northern Portion of the Outcrop: Priday Rhyolite
The Priday Rhyolite is prominently displayed in the northern portion of the outcrop as a purplish-black unit. Dolde's interpretation is that the unit is not an ash-flow tuff, but consists of at least three lava flows, separated by maroon epiclastic beds. Phenocrysts include plagioclase (6%), alkali feldspar (3%), and quartz (1%). Compaction/flow lineations are visible as faint white stringers filled with alteration products. These lavas are dark purple, crystal-poor rhyolites. Hydrothermal products pervasively fracture and vein this unit at microscopic scale. No devitrified pumice or fiamme were reported. The unit thickness is reported to be at least 1,000 feet. A prominent rhyolite dike is located at the northern end of the exposure. The dike ranges in thickness from approximately three feet at the base, tapering upward and appears to terminate upward. Based on color, this is considered to be due to intrusion of the Millcreek Microgranite unit in the southern portion of the outcrop, as discussed below.

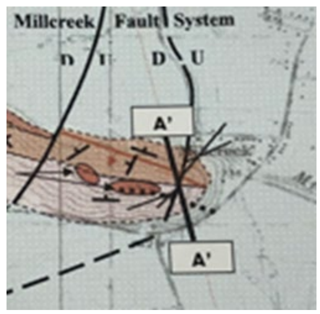
Southern Portion of the Outcrop: Millcreek Microgranite
The Millcreek Microgranite is exposed at the southern end of the outcrop, and is distinguished by its salmon pink color. The Millcreek Microgranite contains phenocrysts of quartz (15%) and alkali feldspar (5%) set in an aphanitic matrix. The matrix material consists of quartz, along with feldspar. The microgranite appears to be intrusive into the Priday Rhyolite. In some areas of the microgranite, inclusions of what appears to be Priday Rhyolite are noted "floating" within the microgranite. In other areas, small tongues of the microgranite appear to intrude the Priday Rhyolite.

Structural Considerations
Dolde discussed evidence of faulting in the area of the Route E outcrop. This outcrop is located in the vicinity of the what is designated as the **Millcreek Fault System.** A map in his thesis indicates a roughly north-south trending fault cutting through the area of the outcrop, which is shown as **downthrown to the west**. Based on that information, the fault **roughly parallels Highway 67**. This seems consistent with the relatively shattered nature of the outcrop. Some evidence of faulting is noted in the outcrop area of the microgranite about 300 feet north of the southern end of the outcrop. Displacements are difficult to determine, but may be in the range of 3 to 6 feet. A structural "flower structure" is described at this location (Dolde 2004). At this location, fractures are noted sloping downward both to the east and to the west.

Stratigraphy – Source Area
The Dolde thesis does not discuss the origin and stratigraphic position of the Priday Rhyolite. Based on conversations with the Missouri Geological Survey, the Priday Rhyolite is considered to be stratigraphically above and therefore younger than the Grassy Mountain Ignimbrite. I am not aware of any flow direction studies conducted to determine the source for this unit.

Additional Information:

Dolde also describes the presence of a unit called Tridymite Rhyolite Dike. This is described as a roughly 60 foot thick dike located to the west of the outcrop area, which is oriented east-west. It does not appear to crop out along Highway 67. Based on its proximity, it may have had an effect on the thermal history of the outcrop area.



Mileage 52.6 STOP #8 Silvermine Recreation Area – LUNCH STOP

From The intersection of Highway E and Highway 67, proceed back to the north 3.0 miles to the intersection with Highway 72. Proceed westward 4.1 miles to County Road D. Turn left onto County Road D and proceed southward 3.2 miles to Silvermine Recreation Area. Turn right into the picnic area.

Silvermine Granite is the host rock for most of the ore veins comprising the mining district. Silvermine Granite varies from pinkish gray to gray and is medium to coarse grained. Minerology includes quartz (29%), perthitic alkali feldspar (27%), plagioclase (36%) and several mafic minerals, including hornblende, magnetite, and chlorite/epidote [Lowell, 1975]. As such, it is distinctly more mafic compared to the Butler Hill Granite.

The Silvermines area has a number of intermediate and mafic dikes, quartz veins, and at least two recognized shear zones, nearly all of which trend northeast-southwest. Mining occurred primarily at two locations, including:

(1) The Einstein Mine located along a quartz vein at the edge of the St. Francis River.
(2) The Apex Mine located along a shear zone near the top of the nearby hill. These locations are shown on a map in Appendix B [Berri 2009].

<u>Mining History:</u>
The Einstein Mining Company began mining argentiferous (silver bearing) galena from the "Einstein Mine" in 1879, which included a main portal located about 50 feet above the river level.

Mining occurred on three levels [Lowell, 1975]. A dam was constructed in 1879 to provide power for the milling and mining operations . Mining ceased after a few years, but the dam is mostly still intact. The Apex mine was operated at about the same time. Records indicate production of 3,000 ounces (~188 pounds) of silver and 50 tons of lead. So the actual amount of silver produced was not large.

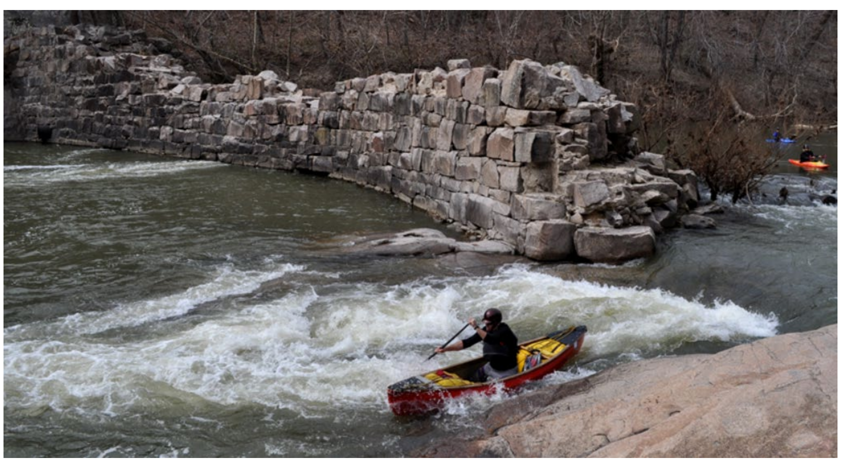
The mine was reopened on at least two occasions, for production of tungsten. One of these was in 1916 and one was in 1927. In addition, the mine was reopened in 1948, but all mining activity ceased by 1958. Although mining activity ceased, a portion of the original dam remains intact.

The minerology of the veins suggests that the mineralization was due to a hypothermal deposit, and that the existing veins and fracture zone served as conduits for movement of the hydrothermal deposits. [Lowell, 1975]

Potential Lunch Hike – Time Permitting:

A large portion of the dam discussed above remains intact. The main entrance to the Einstein Mine was located approximately 300 feet to the south of the dam, close to the river level. Through at least the 1970s, the entrance to the mine was visible but was barricaded off in order to try to prevent entry (apparently without success). However, the entrance was subsequently permanently closed and covered with rock rubble to prevent further access.

The hiking trail on the north side of the St. Francis River is very scenic with nice views of the river and leads to an overlook of the dam remnant. The distance to the dam is about 0.4 miles. The trail crosses several geologic features of interest including several aplite dikes and a fine-grained diabase dike up to two feet wide. This optional hike <u>may be possible</u> depending on timing and group interest.



Mileage 62.8 STOP #9 - Exposures of the Slabtown Granite (Time Permitting)

The Slabtown Granite represents the southeastern ring intrusion of the Butler Hill Caldera. The appearance of the Slabtown Granite is much different compared to the Knoblick and Silvermine granites due to its fine-grained texture, which is locally granophyric. The Slabtown is a fine-grained amphibole granite consisting of about 55% orthoclase microperthite, 20% quartz, 12%

plagioclase, and 10% biotite/chlorite. In this roadcut, the Slabtown is intruded by small mafic dikes, consisting of a large number of nearly vertical diabase dikes. These are located within a shear zone about 25 feet wide. This shear zone is thought to be associated with a regional Precambrian structure called the Annapolis Lineament [Kisvarsanyi and others, 1981].

The small dikes may be related to the Skrainka Diabase, which is located approximately 6 miles west of this location. The Skrainka Diabase is characterized as a large diabase “dike or sill” with a length of nearly two miles, which has intruded the Butler Hill Granite, reportedly along a granite-rhyolite contact [Hayes, 1961]. The Skrainka has been actively quarried in the past.

Mileage 67.3 STOP #10 Knob Lick Mountain Lookout Tower

Regional Overview:
Knob Lick offers a beautiful vantage point to begin an overview of what has been named the Butler Hill Caldera. The ridge you are standing on consists of volcanic units which overly the Knob Lick Granite. Looking generally to the southwest, we see a large expanse of relatively low-lying rolling hills with the Ozark mountains located approximately (10 miles) to the southwest and approximately 6 miles to the south. This large expanse of low-lying topography (called the Flatwoods on topographic maps) corresponds to a large outcrop area of the Butler Hill Granite, and its associated finer-grained roof facies, the Breadtray Granite.

The Butler Hill Granite is thought to have underlain what is called the Butler Hill Caldera. The Butler Hill Caldera originated as the Butler Hill Granite magma intruded a roof of its own volcanic ejecta. That said, the Butler Hill Caldera has been largely eroded away, but the location of the former ring faults correspond to smaller and younger intrusions. These include Knob Lick Granite (present here), the Slabtown Granite to the south, the Silvermine Granite to the southwest, and the Stono Granite to the west. These granites occur in a roughly circular pattern surrounding the Butler Hill Granite and are sometimes referred to as “low silica granites.”

Primary Units Exposed at this Location and Regional Relationships:
This location includes exposures of several key units associated with the Butler Hill Caldera. These include the Knoblick Granite, and two volcanic units associated with the Butler Hill Caldera, the Grassy Mountain Ignimbrite (**GMI**) and the Lake Killarney Formation (**LKF**) [Bickford and Sides, 1983].

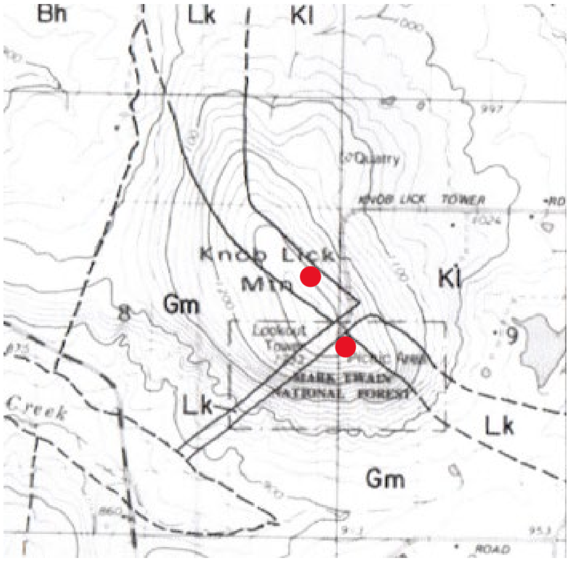
Knob Lick Mountain primarily consists of the Knoblick Granite, which is not exposed at the crest of this mountain, but underlies the mountain (hence the name). The Knoblick Granite is assumed to be emplaced along a caldera ring fault associated with the Butler Hill caldera and is hypothesized to be near the eastern boundary of the Butler Hill Caldera. The Knoblick Granite consists of approximately 24% quartz, 43% orthoclase, 26% plagioclase and more than 6% mafic minerals including hornblende and biotite/chlorite.

The volcanic unit seen at this location has been mapped as the **GMI**. The **GMI** is very thick and widespread welded ash-flow tuff, as described at Stop # 5. The **GMI** is relatively devoid of pyroclastic features such as fiamme and other features which allow structural interpretation. This was a major and massive eruptive pyroclastic unit with an original estimated thickness of ~1.0 km regionally. To date, no one has identified any individual cooling units within this thick formation.

Another volcanic unit is exposed on this hill, interpreted to be the **LKF**. The **LKF** is not exposed at this outcrop but is easily visible as float on the north side of Knoblick Mountain and at the quarry associated with Stop 10A.

A granitic dike is also exposed on Knob Lick, which is considered equivalent to the Knoblick Granite. This dike is reported to be up to 20 feet wide and runs northeast to southwest from near the crest of Knob Lick. The dike material is not well exposed potentially due to more rapid weathering compared to the volcanic rocks. However, we will make a brief stop to look at the lithology of the dike material, if possible.

Geologic mapping in this area demonstrates the timing of the units exposed on Knob Lick. The **LKF** underlies the **GMI** demonstrating that it is the oldest unit exposed here. The cross-cutting dike, essentially equivalent to the Knoblick Granite, demonstrates that the Knoblick Granite is younger that either of the volcanic units. As discussed in the next section, there is clear evidence of the intrusion of the Knoblick Granite into the volcanic sequence.



STOP #10A Unnamed Quarry near Knob Lick Mountain Lookout Tower (time permitting).

From Stop #2, proceed northwestward to an unnamed quarry located approximate 2,000 feet to the southwest of the lookout tower. This quarry presents an exposure of the Knoblick Granite. The Knoblick Granite has a large number of mafic clots of variable size. Some of them are partially assimilated basaltic xenoliths and some are basic segregations in the granite.

This quarry clearly demonstrates the intrusive relationship of Knoblick Granite into the volcanic rocks. The intrusive contact of the Knoblick Granite with the overlying volcanic unit is well exposed along the west face of the quarry. The volcanic unit here is interpreted as a facies of the Lake Killarney Formation. At this location, the **LKF** is almost aphanitic, with relatively few phenocrysts. The **LKF** is more variable compared to the **GMI**, with fewer phenocrysts. It is generally characterized as a dark maroon ash-flow tuff with phenocrysts of quartz (~3%) and alkali feldspar (~5 %). The unit is relatively devoid of pyroclastic features such as fiamme and other which allow structural interpretation so thickness estimates are difficult to make, but a minimum thickness of 390 m has been estimated [Sides and others, 1981].

The intrusive contact is sharp and gently undulating with granite clearly extending into the volcanic rock and xenoliths of the rhyolite are included in the granite, indicating active stoping at the time. Thin seams of epidote are common along the contact, likely secondary mineralization. The rhyolite above the contact appears recrystallized to a fine aggregate of quartz and alkali feldspar. The outcrop presents a picture of the active upward stoping and assimilation of the Lake Killarney Formation by the underlying granite now frozen into the outcrop.

Examples of the original stoping and assimilation process as the Knoblick Granite was advancing into the Lake Killarney Formation (upper) and the igneous dike near the crest of Knob Lick (lower)

Closing and Acknowledgements:

There have been a large number of investigations conducted in the SFM and there have been many field trips previously taken to this area, hence there were a number of field documents already available for me to draw from on for this field guide. That said, the information in this field guide comes from many sources. I would like to take this opportunity to acknowledge and thank the authors of these publications for their contributions, many of which are listed in the references cited section of this guidebook. I would also like to acknowledge the support of the Field Trip Committee of the **Association of Missouri Geologists**, for facilitating this Field Trip and conference. In addition, I would like to convey special thanks to the following individuals for their contributions:”

- Jo Schaper for her help with Field Guide illustrations
- Bart Maybry of Ameren who, facilitated the Taum Sauk Energy Center Visit,
- Larry Booth for allowing us to park a bus on Camp Penuel property
- Duncan Noack for providing the Business Meeting presentation

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APPENDIX A
Primary geologic units of the Taum Sauk Caldera.

Taum Sauk Caldera
Abbreviated Table of Stratigraphic Units

Formation	Thickness	Description
Cope Hollow formation	~42 m	Sequence of maroon to dark gray ash-flow tuffs with a basal air fall tuff, 5-10% quartz and feldspar phenocrysts
Johnson's Shut-ins Rhyolite	~55 m	Sequence of two ash-flow tuffs and volcaniclastic sediments, 15-20% quartz and feldspar phenocrysts
Proffit Mountain Formation	~138 m	Sequence of rose-gray to maroon ash flow tuffs, and air-fall tuffs, 20-30% quartz and feldspar phenocrysts
Taum Sauk Rhyolite / Unit 810a	>1,000 m	Red to dark maroon ash flow tuff, up to 30 % quartz and feldspar phenocrysts
Royal Gorge Rhyolite / Unit 810b	0 to 700 m	Red to maroon lava flows, with vivid flow banding, ~5% quartz and feldspar phenocrysts
Bell Mountain Rhyolite / Unit 790	25 m	Maroon to dark maroon air-fall tuff, with ~1 percent quartz and alkali feldspar and a prominent lithophysal zone
Wildcat Mountain Rhyolite / Unit 780	90 m	Deep maroon ash-flow tuff with 5-10% quartz and feldspar phenocrysts
Russell Mountain Rhyolite / Unit 770	300 m	Brick red to dark maroon ash-flow tuff with 2-5 percent feldspar phenocrysts
Lindsey Mountain Rhyolite / Unit 760	500-700 m	Gray to black to dark maroon ash-flow tuff with 5-20 % quartz and feldspar phenocrysts
Ironton Rhyolite / Unit 740	340 m	Dark maroon to black ash-flow tuff with 5-15%quartz and alkali feldspar.
Buck Mountain Shut-ins Formation / Unit 720	80-1,000 m	Sequent of black andesitic ash-flow tuff with white plagioclase phenocrysts; includes air fall tuffs
Pond Ridge Rhyolite / Unit 715	130 m	Dark maroon to gray ash flow tuff with up to 20% pink feldspar with minor quartz and many fiamme
Cedar Bluff Rhyolite / Unit 710	580 m	Brown-marron to gray ash-flow tuff with 25-50% white plagioclase phenocrysts
Shephard Mountain Rhyolite / Unit 700	600 m	Brick-red to dark maroon ash-flow tuff with white to pink plagioclase phenocrysts and many fiamme

Source: Kisvarsanyi, E. B., Studies in Precambrian Geology, Missouri Department of Natural Resources, Division of Land Survey, Report of Investigations 61, 1976.