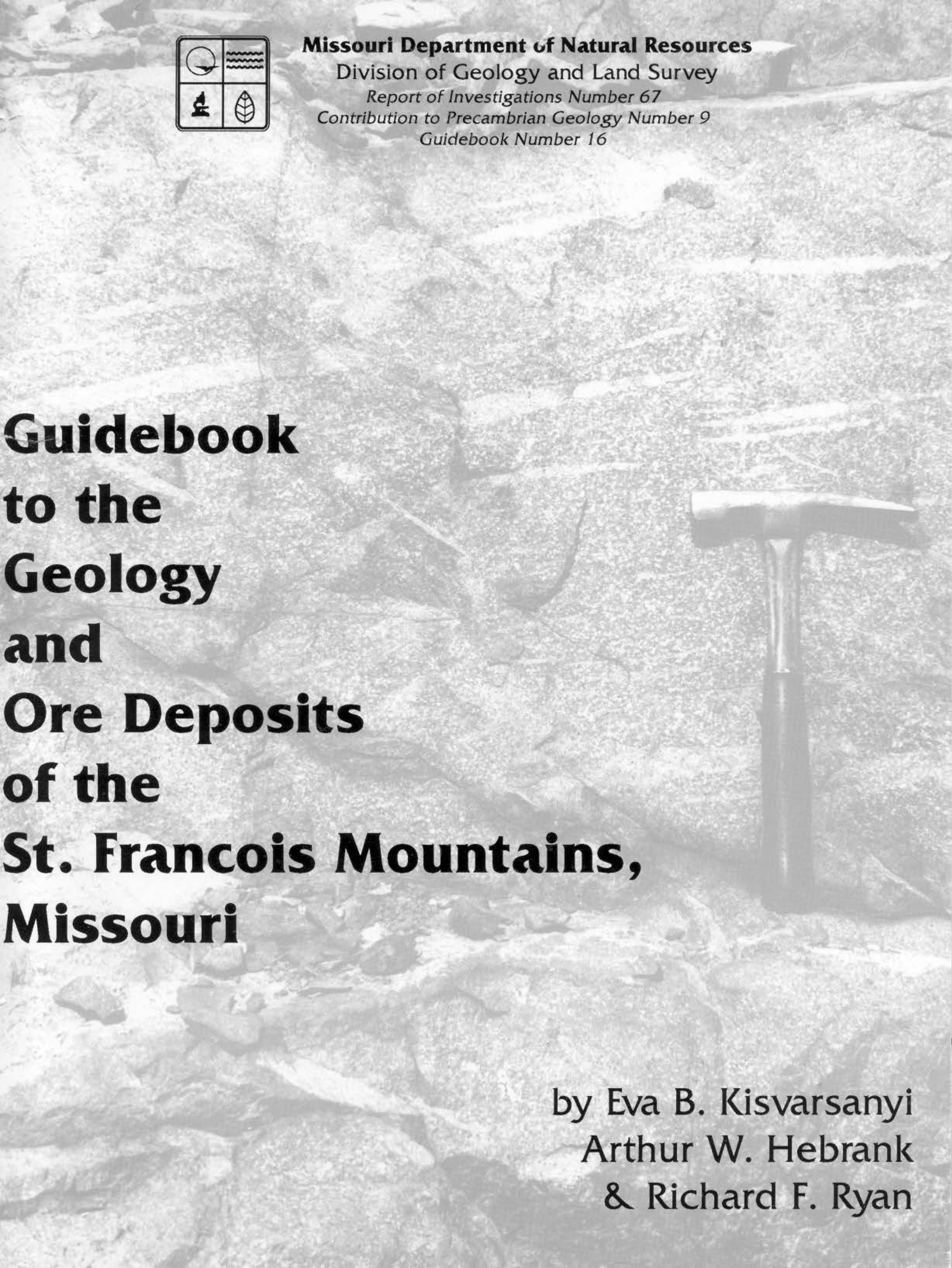

Missouri Department of Natural Resources
Division of Geology and Land Survey
Report of Investigations Number 67
Contribution to Precambrian Geology Number 9
Guidebook Number 16

Guidebook to the Geology and Ore Deposits of the St. Francois Mountains, Missouri

by Eva B. Kisvarsanyi
Arthur W. Hebrank
& Richard F. Ryan

Spectacular eutaxitic structure in Taum Sauk Rhyolite. This exposure is described at mileage point 34.5, in Road Log No. 2, page 71. Photo by Art Hebrank. Cover design by Sue Dunn.

Contribution to Precambrian Geology Number 9

REPORT OF
INVESTIGATIONS
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1981

GUIDEBOOK TO THE GEOLOGY AND ORE DEPOSITS OF THE ST. FRANCOIS MOUNTAINS, MISSOURI

by

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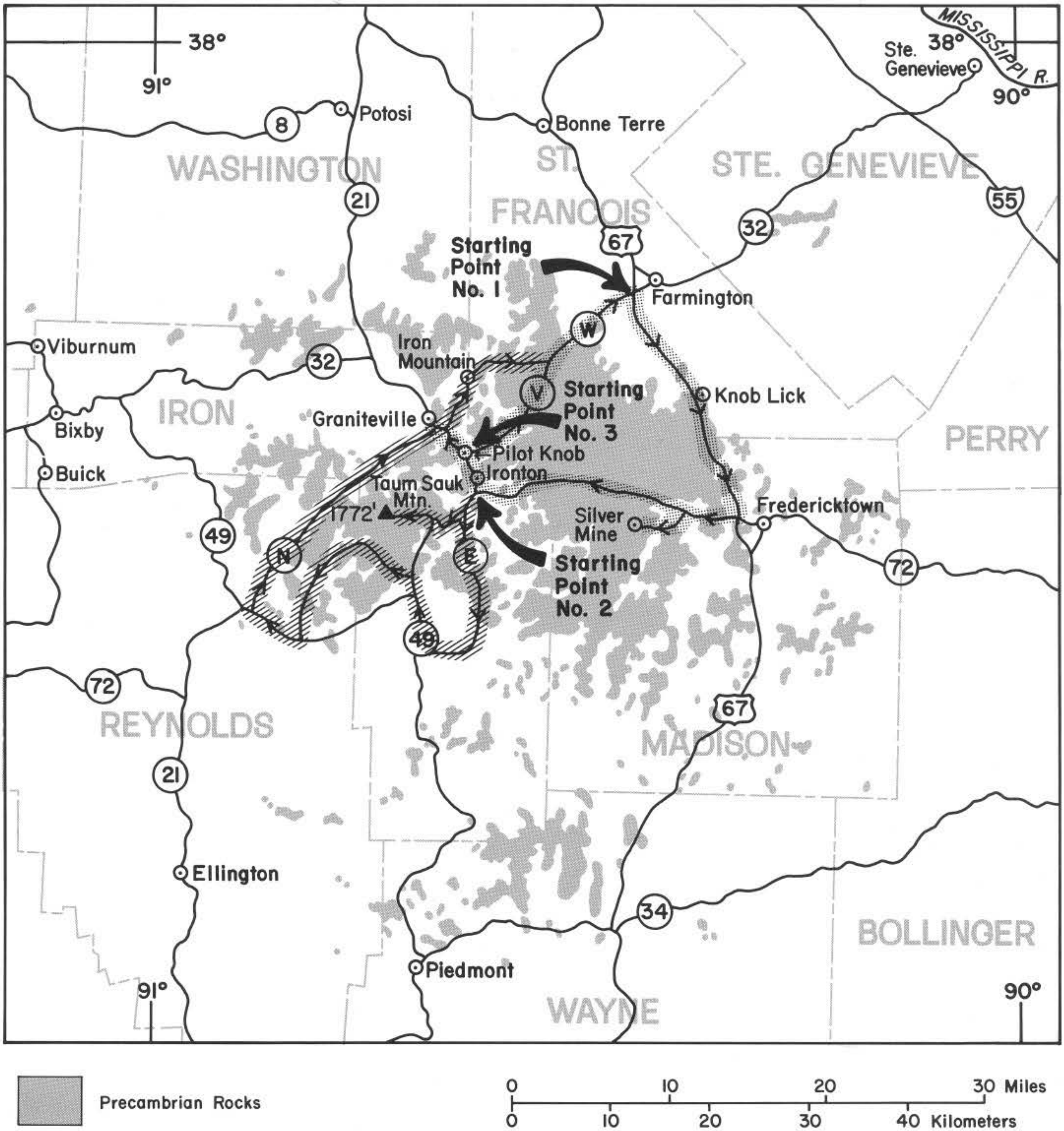


Figure 1. *Precambrian outcrop map of the St. Francois Mountains. Road log routes are highlighted: No. 1 is dotted, No. 2 is hachured, No. 3 is a walking tour of Pilot Knob.*

INTRODUCTION

This Guidebook was prepared for a field trip held in conjunction with the 1981 Annual Meeting of the Geological Society of America. However, it is intended for use by all those interested in the unique opportunity to study the only extensive outcrops of Precambrian rocks in the continental interior of the United States.

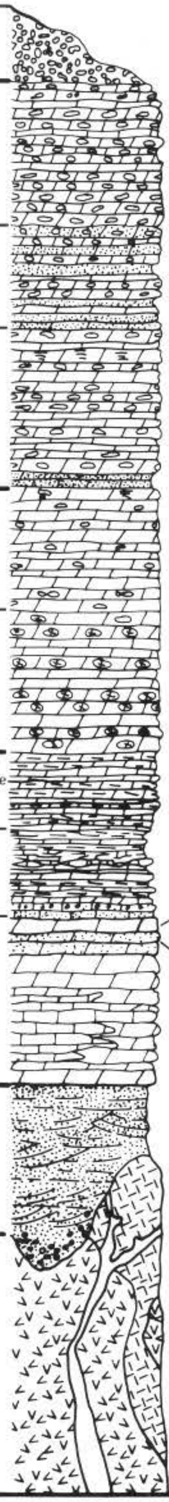
A previous guidebook to the region is out of print and obsolete (Hayes, 1961). Another volume (Kisvarsanyi, 1976) contains a guide to selected parts of the St. Francois Mountains, but its primary function is to present investigations pertaining to the Precambrian of southeastern Missouri. The present Guidebook was prepared following several recent studies that contributed significant new data on the Precambrian geology of the region (Pratt and others, 1979; Kisvarsanyi, 1981). The routes (fig. 1) were chosen to feature the principal granite types (Road Log No. 1), diverse volcanic rocks (Road Log No. 2), and one of several iron-ore deposits (Road Log No. 3).

REGIONAL GEOLOGIC SETTING

The St. Francois Mountains constitute the exposed portion of an extensive Precambrian terrane of anorogenic, granitic ring complexes identified on the basis of drillhole data and aeromagnetic maps (Kisvarsanyi, 1981). This igneous terrane is of regional interest because similar rocks, between 1.3 and 1.5 b.y. old, are widely distributed in the Precambrian craton (Silver and others, 1977) and represent significant additions of sialic material to the continental crust. The terrane is characterized by the predominance of alkaline-silicic over mafic rocks, and trachytic intermediate rocks. The oldest rocks recognized in the terrane are rhyolites (ash-flow tuffs and lava flows) intruded by comagmatic granite plutons of an epizonal batholith (Tolman and Robertson, 1969; Hamilton and Myers, 1967). The age of the rocks is about 1.5 b.y. (Bickford and Mose, 1975).

The distinctive ore deposits of the St. Francois terrane are (1) magmatic and hydrothermal iron-apatite deposits (Kiruna-type); (2) hypo-xenothermal vein deposits of tungsten, silver, and lead; and (3) vein and replacement deposits of manganese. The terrane also has a potential for granitic uranium deposits of the Bokan Mountain type and for tin-niobium deposits of the Nigerian type (Kisvarsanyi, 1981).

The Precambrian terrane has been deeply eroded and dissected, resulting in a rugged topography and the unroofing of granite, but it has not been regionally metamorphosed. Upper Cambrian marine sedimentary rocks are in nonconformable contact with the underlying igneous rocks. Near the crest of the Ozark dome, the prominent structure of the region, the Precambrian outcrops represent a



Era	System	Series	Formation	Lithologic Description	Mineral Resources and Products
PALEOZOIC ERA	ORDOVICIAN SYSTEM	LOWER CANADIAN SERIES	Chert residuum		
			Jefferson City Dolomite (200'-300')	Dolomite, fine- to medium-grained, argillaceous, cherty, "cotton rock" variety locally abundant.	Crushed stone
			Roubidoux Formation (125'-200')	Dolomite, light-gray to brown, fine-grained, cherty. Sandstone, quartzose.	Building stone Ground water
			Gasconade Dolomite (250'-300')	Dolomite, light-gray to buff, fine- to coarse-grained, cherty, contains beds and lenses of cryptozoon.	Crushed stone
			Gunter Ss. Mbr. (20'-40')	Dolomite, arenaceous, rounded-frosted quartz grains.	Ground water
	CAMBRIAN SYSTEM	UPPER CAMBRIAN SERIES	Eminence Dolomite (150'-300')	Dolomite, light-gray, medium- to coarse-grained, medium- to massively bedded, cherty.	Crushed stone
			Potosi Dolomite (250'-300')	Dolomite, brown to gray, fine- to medium-grained, massively bedded, contains abundant quartz druse and cherty digitate algal forms.	Barite Lead Zinc Ground water
			Elvins Group: Derby-Doerun Dolomite (100'-200')	Dolomite, tan to buff, fine- to medium-grained, argillaceous, silty, oolitic.	
			Elvins Group: Davis Formation (125'-225')	Shale, dolomitic, thin-bedded; contains edgewise conglomerate; *Eoorthis* zone 30 to 35 feet below top. "Marble boulder bed" 60 to 70 feet below top. Interbedded limestone in some areas.	
			Whetstone Creek Mbr.	Dolomite, fossiliferous, glauconitic, locally shaly, silty or sandy, micritic.	
			Sullivan Siltstone Mbr.	Laminated siltstone, calcarenitic, may contain mud-chip conglomerate; glauconite.	
			Bonneterre Formation (200'-450')	Dolomite, light-gray to dark-brown, fine- to medium-grained, glauconitic in places, contains some dark-green to black, thin shale beds. Lenses of gray to pink limestone are referred to as "Taum Sauk marble".	Lead, Silver Zinc, Cobalt Copper, Nickel Crushed stone Dolomitic quicklime Dead-burned dolomite
			Lamotte Sandstone (0-500')	Sandstone and conglomerate, quartzose, arkosic; contains interbedded red-brown shale.	Building stone Ground water
PRECAMBRIAN	PRECAMBRIAN Y*		St. Francois Mountains Intrusive Suite	Diabase and gabbro dikes and sills. Alkali-granite central plutons; granite, granite porphyry, syenite, and trachyte ring intrusions; granophyre and alkali-granite subvolcanic massifs.	Iron Manganese Copper Tungsten Silver Lead Phosphates Feldspar Dimension stone Crushed stone Roofing granules
			St. Francois Mountains Volcanic Supergroup	Rhyolitic ash-flow tuffs, lava flows, and bedded tuffs, minor trachytes.	

*James, H.L., 1972, Subdivision of Precambrian: an interim scheme to be used by U.S. Geological Survey: Stratigraphic Commission Note 40, Amer. Assoc. Petroleum Geologists Bull., v. 56, n. 6, p. 1128-1133.
The subdivisions are purely temporal; the geochronologic boundaries of Precambrian Y are 800 m.y. and 1,600 m.y., B.P.

Figure 2. *Generalized stratigraphic column of the St. Francois Mountains area.*

structural and topographic high. The highest point in the State, 1772-ft Taum Sauk Mountain, is within the most extensive outcrop of volcanic rocks in the area.

The first detailed account of the Precambrian rocks is by Haworth (1895). Mapping at a scale of 1:62,500 began in the 1930's, continued in the 1940's, and resulted in the publication of a 1:125,000-scale map and report by Tolman and Robertson (1969). Recognition of ash-flow tuffs in the St. Francois Mountains by R.E. Anderson (1962, 1970) gave impetus to the renewal of geologic mapping, by applying modern concepts of ash-flow magmatism. Mapping at a scale of 1:24,000 continued through the 1970's and resulted in a new geologic map at 1:125,000 scale, by Pratt and others (1979), showing the outlines of three proposed calderas: the Taum Sauk, the Butler Hill, and the Hawn Park. The granitic ring complexes in the buried part of the terrane represent the deeply eroded root region of a formerly extensive volcanic terrane comprising several calderas, cauldron subsidence structures, ring intrusions, and resurgent cauldrons. The stratigraphic section of the Precambrian and overlying Paleozoic rocks is shown in figure 2, and the formal nomenclature of the Precambrian rocks is shown in table 1.

Table 1

PRECAMBRIAN ROCK UNITS IN THE ST. FRANCOIS MOUNTAINS

ST. FRANCOIS MOUNTAINS VOLCANIC SUPERGROUP	ST. FRANCOIS MOUNTAINS INTRUSIVE SUITE	
	HYPABYSSAL ROCKS***	PLUTONIC ROCKS***
Taum Sauk Group*		
Johnson Shut-ins Rhyolite		Graniteville Granite
Taum Sauk Rhyolite		
Royal Gorge Rhyolite		
Bell Mountain Rhyolite	Buford Granite Porphyry	
Wildcat Mountain Rhyolite	Munger Granite Porphyry	
Russell Mountain Rhyolite	Carver Creek Granite Porphyry	
Lindsey Mountain Rhyolite		
Ironton Rhyolite		
Buck Mountain Shut-ins Formation		
Pond Ridge Rhyolite		
Cedar Bluff Rhyolite		
Shepherd Mountain Rhyolite		
Butler Hill Group**		
Pilot Knob Felsite		Silvermine-Knoblick Granites
Grassy Mountain Ignimbrite	Brown Mountain Rhyolite Porphyry	Slabtown-Stono Granites
Lake Killarney Formation		Butler Hill-Breadtray Granites

* Volcanic units defined by Berry (1976).
** Volcanic units defined by Sides (1976).
*** Formal names from Tolman and Robertson (1969).

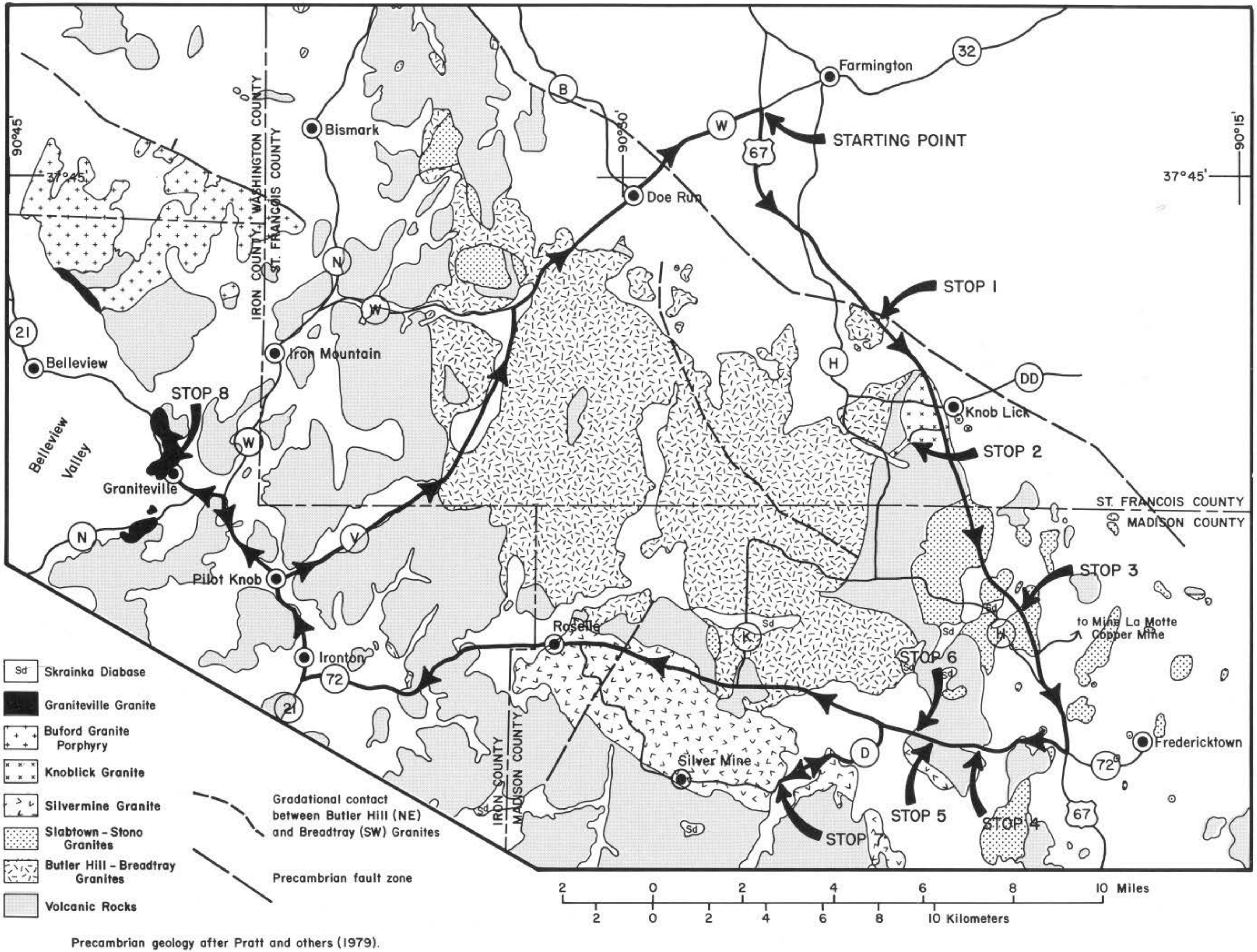


Figure 3. *Route map of Road Log No. 1. Total logged distance is 68.7 miles.*

ROAD LOG NO. 1 – THE INTRUSIVE SUITE

This route through the eastern part of the St. Francois Mountains (fig. 1) transects the principal granite types exposed in the area: a subvolcanic massif (Butler Hill and Breadtray Granites), a differentiated, multiple ring intrusion (Knoblick, Slabtown, and Silvermine Granites), and a central pluton (Graniteville Granite). Several short stops are scheduled along the road as well as three extended stops: on Knob Lick Mountain (1- to 1.5-hour hike), at Silver Mine (2-hour hike), and at the Elephant Rocks State Park (1.5-hour hike). Note that rock collecting within State Park boundaries is prohibited by law.

STARTING POINT (fig. 3):

Junction of U.S. Highway 67 and State Road W, west of Farmington, St. Francois County, Missouri (SW¼ NE¼ sec. 2, T. 35 N., R. 5 E.).

Cum.	Diff.	
0.0		State Road W overpass above U.S. Highway 67. **Proceed south on Highway 67 from starting point.**
	1.3	
1.3		Bridge over St. Francis River.
	0.7	
2.0		Cuts on both sides of road expose shaly, silty Davis dolomite.
	0.7	
2.7		Davis dolomite on both sides of road; same lithology as in previous cut.
	0.4	
3.1		Junction with State Road H. The small cut at the southwest corner of the intersection exposes thin-bedded Davis shale and dolomite; cuts at all other corners expose massive Derby-Doerun(?) Dolomite. Relationships indicate a fault striking approximately northwest-southeast, and cutting across the southwest corner of the road junction. This area is part of the 3-mi-wide Libertyville graben, bounded on the northeast by the Wolf Creek-Greasy Creek fault zone, and on the southwest by the Simms Mountain fault system.
	0.5	

3.6 Davis dolomite exposed in cuts on both sides of road.

0.5

4.1 Shaly Davis dolomite exposed in roadcuts. Within the next mile, a segment of the Simms Mountain fault system strikes N 74° W across the highway. The upthrown side is on the south; Precambrian granite, 1.2 mi ahead on the hilltop, is topographically at the same elevation as this dolomite outcrop.

1.0

5.1 Bridge over St. Francis River.

0.2

5.3 **STOP 1.** Roadcuts in Butler Hill Granite (SE¼ NW¼ SW¼ sec. 29, T. 35 N., R. 6 E.). The Precambrian Butler Hill Granite is exposed on both sides of the road. Lamotte Sandstone overlaps the Precambrian erosional surface from the south.

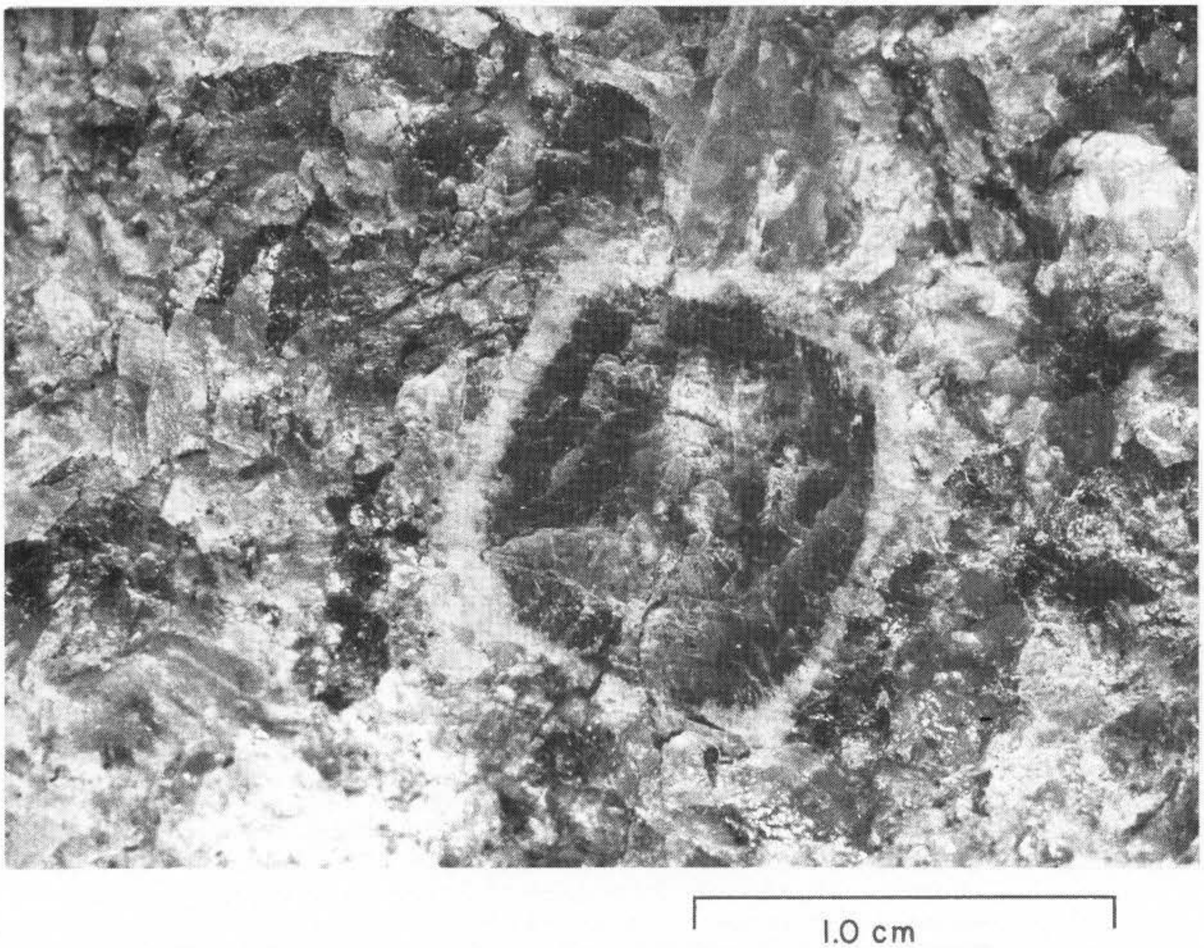


Figure 4. *Alkali feldspar phenocryst mantled by a rim of oligoclase (rapakivi texture) in Butler Hill Granite. From roadcut, now obliterated by widening of Highway 67, STOP 1. Photo by Art Hebrank.*

The Butler Hill Granite and its granophyric roof facies, the Breadtray Granite, are the most extensively exposed granites in the St. Francois Mountains (fig. 3). They constitute an epizonal, subvolcanic massif that produced a comagmatic suite of rhyolitic ash-flow tuffs now largely removed by erosion. Roof pendants of rhyolite are locally preserved within the massif and along its southwestern periphery.

The Butler Hill Granite at this locality has well-developed rapakivi texture: ovoidal, pink alkali feldspars (orthoclase-microperthite) up to 3 cm in diameter are mantled by a thin white rim of oligoclase (fig. 4). The granite has prominent joint sets; it is intruded by an aplite dike that follows the major joint directions and branches out into fractures. The dike is exposed in the west roadcut.

To the north, downhill to the St. Francis River, Butler Hill Granite is exposed at the surface. Small quartz veins and a mafic dike cut the granite at an outcrop on the graded slope; the dike strikes N 10° E.

The erosional contact between Butler Hill Granite and the basal Paleozoic strata is well exposed in the cuts on both sides of the road. The granite is weathered on top and is overlain by dark-maroon, shaly regolith derived from the weathering of the granite. Buff-colored shale and arkosic Lamotte Sandstone rest on top, lapping onto the Precambrian surface (fig. 5).

0.3

5.6 Cross-bedded Lamotte Sandstone is exposed in cuts on both sides of the road. Beds of arkosic sandstone and fine pebble conglomerate alternate.

0.4

6.0 Cuts on both sides of the road expose more-massive Lamotte Sandstone with prominent cross-bedding.

0.4

6.4 Lamotte Sandstone exposed in roadcut.

0.4

6.8 Contact between Lamotte Sandstone and Knoblick Granite is exposed on the west side of the road. The granite-rhyolite contact is mapped just west of the small point exposing a fine-grained, porphyritic facies of Knoblick Granite. Float along the road to the southwest is Knoblick Granite.

0.6

7.4 Cuts on both sides of the road expose Knoblick Granite. The granite is gray, porphyritic, and contains partially assimilated xenoliths. Epidote lines fractures and joint surfaces; a small hematite vein fills one of the joints.

0.3

7.7 Junction with State Road DD. To the east is the village of Knob Lick. Knob Lick Mountain, topped by a lookout tower, is visible to the southwest.

0.5

8.2 Knoblick Granite exposed in cut on west side of highway.

0.1

8.3 Junction of Highway 67 and Knob Lick Tower Road. **Turn west on Knob Lick Tower Road.** Proceed 60 ft west and turn north. Follow the Tower Road to the top of Knob Lick Mountain. Boulders and outcrops adjacent to the road are Knoblick Granite.

1.1

Figure 5. *Nonconformable contact between Butler Hill Granite (below) and basal Paleozoic strata (above). Arkosic Lamotte Sandstone overlaps the deeply weathered Precambrian rock. East side of Highway 67, STOP 1. Photo by Art Hebrank.*

9.4 **STOP 2.** Knob Lick Mountain (NE¼ NE¼ SE¼ sec. 8, T. 34 N., R. 6 E.). Park by the lookout tower atop Knob Lick Mountain (elevation 1333 ft above sea level). This stop involves about a 1.5-hour hike.

Rhyolitic ash-flow tuffs are exposed at the top of Knob Lick Mountain, along its southern slope, and in a narrow belt for about 10 mi southward (fig. 3). This area of rhyolite, mapped as Grassy Mountain Ignimbrite, is a roof pendant in Butler Hill-Breadtray Granites which are exposed to the west of it. East of the rhyolite outcrop, the Knoblick and Slabtown Granites are exposed.

The Knoblick Granite is exposed on the northeastern part of Knob Lick Mountain. It is a small pluton emplaced along the eastern boundary of the proposed Butler Hill caldera and is part of the multiple ring intrusion comprising the Silvermine, Slabtown, and Knoblick Granites.

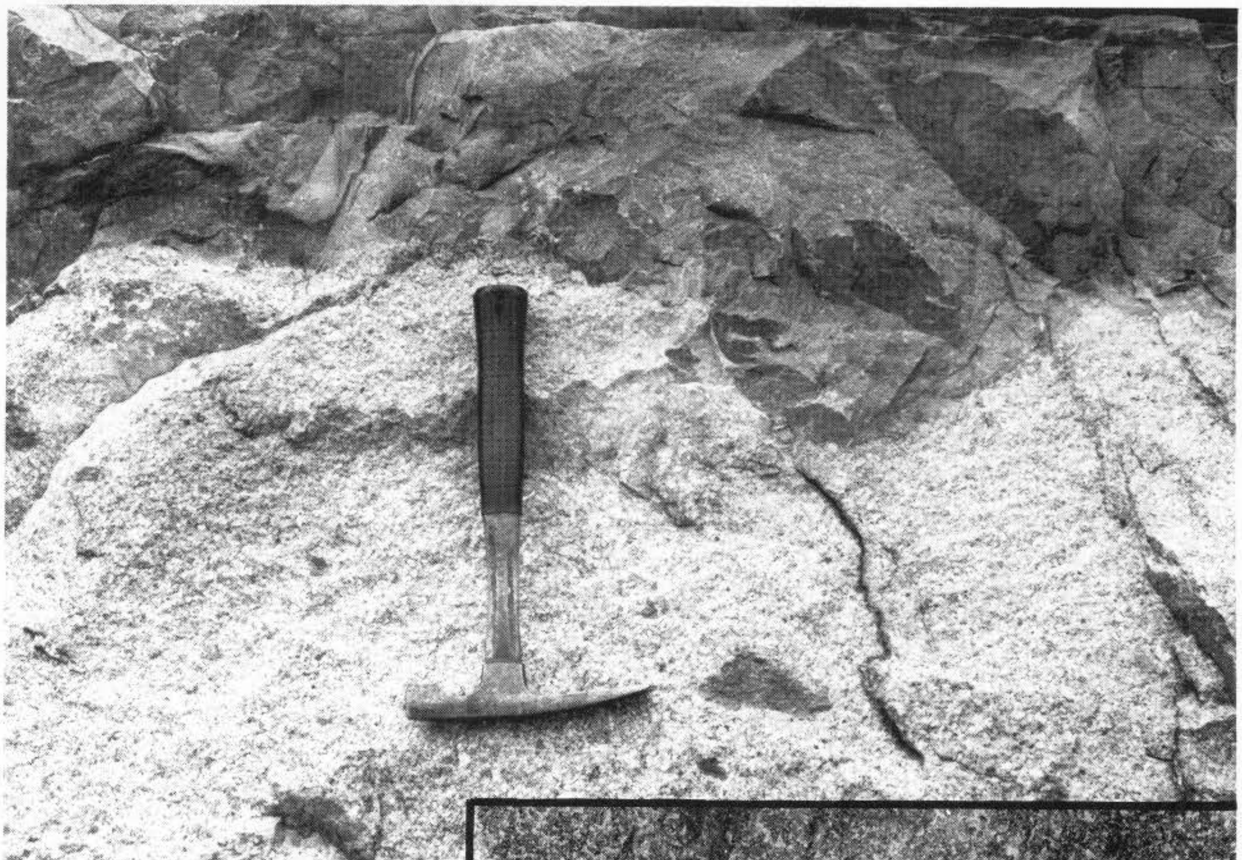
From the lookout tower walk 2000 ft northwest down the old ridge road, then through the woods to the right to the abandoned granite quarry.

STOP 2A. Abandoned quarry (SW¼ NE¼ NE¼ sec. 8, T. 34 N., R. 6 E.).

In the entire igneous-outcrop area, this quarry affords one of the best exposures illustrating the intrusive relationship of granite into the volcanic rocks. The intrusive contact of Knoblick Granite with alkali rhyolitic ash-flow tuff is exposed for about 20 ft along the west face of the quarry (fig. 6). The contact is sharp and gently undulating; apophyses of granite extend into the rhyolite and xenoliths of rhyolite are included in the granite. Thin seams of epidote are common along the contact. The rhyolite above the contact, however, is recrystallized to a fine hornfelsic aggregate of quartz and alkali feldspar; only occasional relict pumice fragments indicate the ash-flow origin of this rock. The near-vertical orientation of these flattened fragments suggests the steep dip of the rhyolite above the granite contact. According to Davis (1969), the volcanic rocks exposed southwest of the quarry have a steep southwesterly dip. He suggested that the steep dips are the result of structural deformation caused by the forceful intrusion of the Knoblick pluton. The east-west section across the quarry shows the volcanic roof pendant "wedged" between the pluton and Butler Hill Granite (fig. 7b).

The northeastern contact of the Knoblick pluton is overlapped by the Lamotte Sandstone but can be inferred from the aeromagnetic map of the area (U.S. Geological Survey and Missouri Geological Survey, 1949), which shows a broad, low-amplitude magnetic high roughly corresponding to the mapped boundaries of the pluton.

The Knoblick Granite is a medium-grained amphibole-biotite adamellite containing an average of 30 percent orthoclase-microperthite, 35 percent plagioclase, 23 percent quartz, and 10 percent mafic minerals; a chemical analysis of the rock from the quarry is comparable to Nockolds' (1954) average of 41 samples of hornblende-biotite adamellites (table 2). The early-crystallized, euhedral, zoned plagioclase in Knoblick Granite tends to impart a porphyritic aspect to the rock, especially on weathered surfaces. Another conspicuous characteristic of Knoblick Granite is the presence of a large number of mafic clots of variable size. Some of them are partially assimilated basaltic xenoliths; some are basic segregations in the granite. Davis (1969) also reported xenoliths of mica schist believed to have been brought up from the metamorphic basement by the intrusion of the pluton.



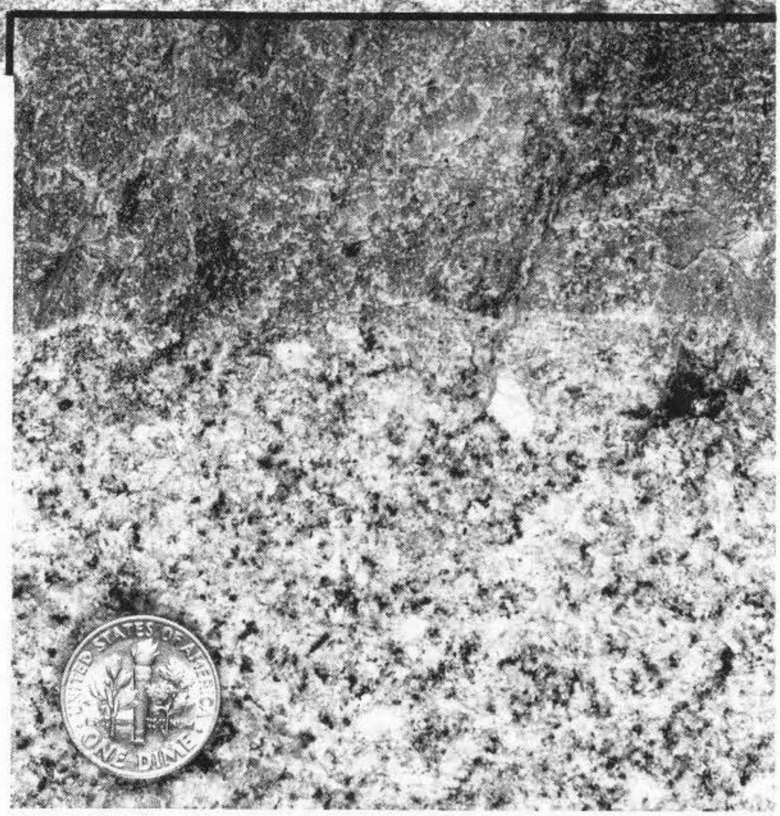


Figure 6

Distant and close-up views of intrusive contact between Knoblick Granite (below) and rhyolite (above). Note prominent rhyolite zenolith near point of hammer in distant view. West face of abandoned quarry, STOP 2A. Photos by Art Hebrank.

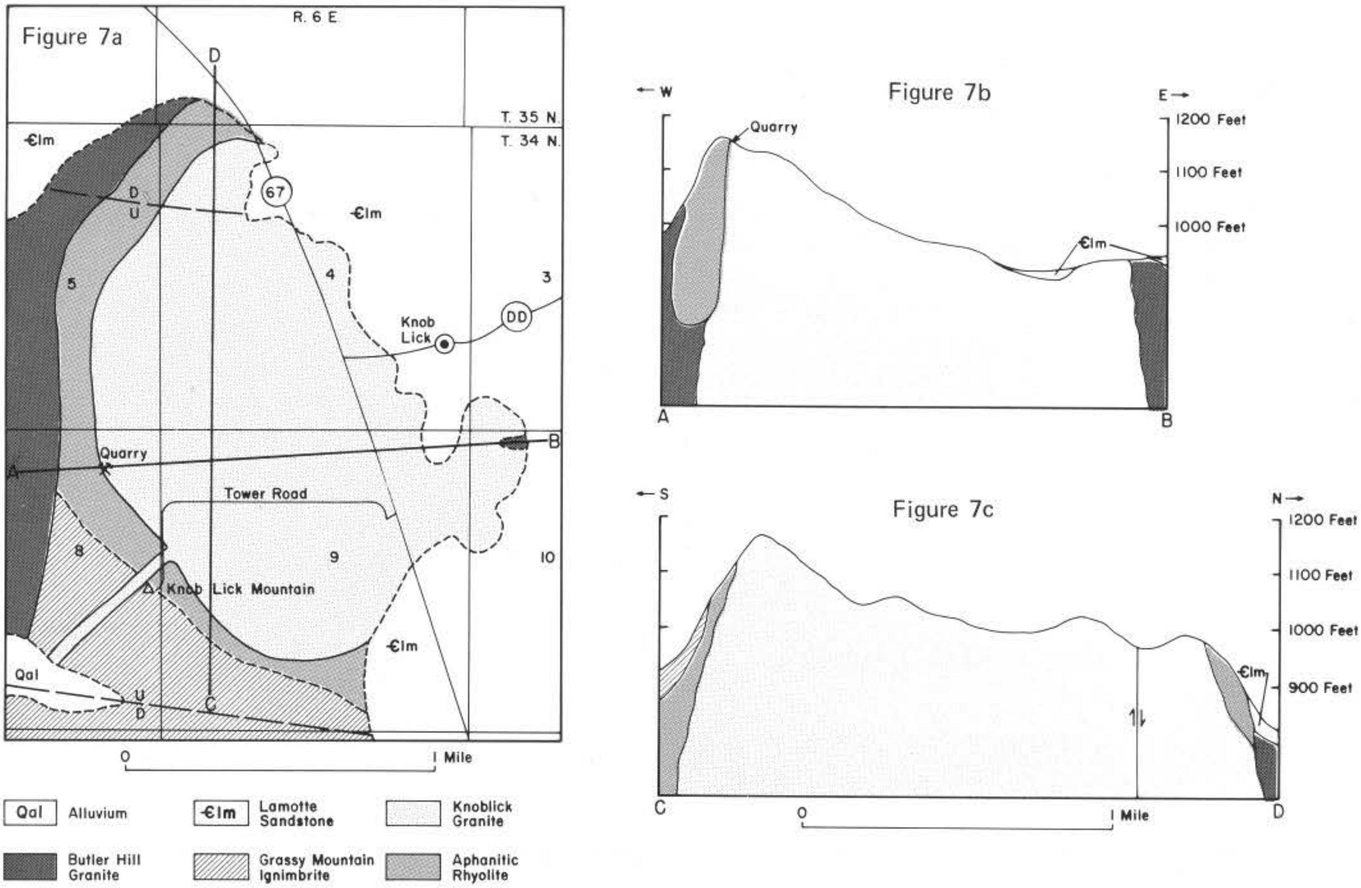


Figure 7. *Geologic map and cross sections of the Knob Lick Mountain area, STOP 2. Map (fig. 7a) is modified from Davis (1969), and Bickford and Sides (1976). East-west (fig. 7b) and north-south (fig. 7c) cross sections are from Davis (1969).*

Return to parking lot by retracing the route along the ridgetop road. From the parking lot, walk south to the "bald," then about 200 yards west along the barren southern slope of Knob Lick Mountain.

STOP 2B. Outcrops of rhyolitic ash-flow tuffs intruded by dike of Knoblick Granite (NE¼ SE¼ sec. 8, T. 34 N., R. 6 E.).

The dense, aphanitic rhyolite we have seen intruded by Knoblick Granite in the quarry is overlain by a porphyritic unit, the Grassy Mountain Ignimbrite, forming most of the prominent outcrops on the southern slope of Knob Lick Mountain. The ignimbrite is somewhat bleached and recrystallized, suggesting that the intrusive contact of Knoblick Granite may not be far below. A north-south section across Knob Lick Mountain shows the relationship of these volcanic units and the granite (fig. 7c).

Both the aphanitic and porphyritic rhyolites are intruded by a 10- to 20-ft-wide dike of porphyritic Knoblick Granite (fig. 7a), well exposed in small prospect pits at this stop. The dike strikes N 40° E and has been mapped for 3000 ft down the mountain slope by Bickford and Sides (1976).

Table 2

CHEMICAL ANALYSIS OF KNOBLICK GRANITE

	Knoblick Granite*	Average hornblende-biotite adamellite**
SiO_2	66.55	65.88
Al_2O_3	15.52	15.07
Fe_2O_3	1.57	1.74
FeO	2.88	2.73
MgO	1.28	1.38
CaO	3.04	3.36
Na_2O	4.34	3.53
K_2O	3.18	4.64
H_2O^+	0.74	0.52
H_2O^-	0.11	––
TiO_2	0.48	0.81
P_2O_5	0.16	0.26
MnO	0.08	0.08
F	0.07	––
Total	**100.00**	**100.00**

* Analysis no. 50 *in* Kisvarsanyi, 1972.
** From Nockolds, 1954.

From our position on the "bald," a large area of relatively low topographic relief is seen to the southwest (fig. 8). This area, called The Flatwoods, and the distant surrounding knobs, illustrate the strikingly different topographic expressions of granite and volcanic terrains in the St. Francois Mountains. Granite areas tend to be gently rolling, whereas the more resistant rhyolites are commonly expressed as knobs or areas of dramatic high relief. The Flatwoods is underlain by Butler Hill and Breadtray Granites, and all of the prominent knobs in the distance are "held-up" by volcanic rocks.

Return to parking lot and continue by car. Descend Knob Lick Mountain by retracing Knob Lick Tower Road to Highway 67.

	1.1	
10.5		Junction of Highway 67 and Knob Lick Tower Road. **Turn right and proceed south on Highway 67.**
	1.0	
11.5		Small outcrops of rhyolite on both sides of road.
	0.4	
11.9		Slabtown Granite exposed in ditches on both sides of road.
	0.3	
12.2		Enter Madison County.
	0.7	

Figure 8. *View of the Flatwoods, an area of relatively low topographic relief, looking southwest from the top of Knob Lick Mountain, STOP 2. The Flatwoods is underlain by Butler Hill-Breadtray Granite; hills along the distant horizon are volcanic rocks more resistant to weathering. Outcrops in the foreground are Grassy Mountain Ignimbrite. Photo by Jerry Vineyard.*

12.9		Slabtown Granite exposed on west side of road.
	0.3	
13.2		Roadcuts in deeply weathered Slabtown Granite.
	0.6	
13.8		Slabtown Granite exposed in cuts on both sides of road. Veinlets of epidote traverse the rock and line open joints.
	0.2	
14.0		Slabtown Granite on both sides of road.
	0.4	
14.4		Lamotte Sandstone is exposed in the cuts on both sides of the road. The sandstone beds on the east side are fractured into large blocks and appear to be somewhat displaced. Lamotte Sandstone and basal boulder conglomerate overlap weathered granite on the west side of the road, at the south end of the cut.
	0.4	
14.8		**STOP 3.** Roadcuts in Slabtown Granite cut by mafic dikes (NW¼ SW¼ NE¼ sec. 35, T. 34 N., R. 6 E.). Slabtown Granite is exposed in the large cuts on both sides of the road.

The Slabtown Granite forms numerous small outcrops overlapped by Lamotte Sandstone, within an area of six by eight miles in the southeastern part of the igneous outcrop area (fig. 3). Drillholes between the isolated outcrops encountered Slabtown Granite at depths of less than 100 ft to over 300 ft, suggesting moderate topographic relief on its erosional surface.

The Slabtown Granite is inferred to be part of a multiple ring intrusion because of its marginal position along the southeastern boundary of the proposed Butler Hill caldera and because of its mineralogical and chemical similarity to ring intrusions identified elsewhere in the St. Francois terrane (Kisvarsanyi, 1980). It is considered to be an older pluton in the partial ring formed by the Knoblick, Slabtown, and Silvermine Granites, because Silvermine Granite contains large xenoliths of Slabtown Granite about 6 mi southwest of here (Tolman and Robertson, 1969).

The roadcuts at this locality expose typical Slabtown Granite: fine-grained amphibole granite consisting of about 55 percent orthoclase-microperthite, 12 percent albite-oligoclase, 20 percent quartz, 10 percent fibrous, blue-green amphibole mostly altered to chlorite, and 3 percent magnetite. Although granophyric texture

Table 3

CHEMICAL ANALYSIS OF SLABTOWN GRANITE

	Slabtown Granite*	Average amphibole granite**
SiO_2	72.55	70.46
Al_2O_3	13.09	14.37
Fe_2O_3	1.80	1.09
FeO	1.47	2.48
MgO	0.39	0.22
CaO	0.80	1.19
Na_2O	4.18	4.19
K_2O	4.51	5.18
H_2O^+	0.51	0.37
H_2O^-	0.11	—
TiO_2	0.40	0.34
P_2O_5	0.06	0.06
MnO	0.04	0.05
Total	**99.91**	**100.00**

* Analysis no. 32 *in* Kisvarsanyi, 1972.
** From Nockolds, 1954.

is locally common in Slabtown Granite, it is not well developed here. In table 3, a chemical analysis of Slabtown Granite from sec. 6, T. 33 N., R. 7 E., about 2.5 mi southeast of here, is compared with Nockolds' (1954) average of 8 amphibole (ferrohastingsite) granites.

In this roadcut, Slabtown Granite is intruded by small mafic dikes. Near the north end of the cut, a dike swarm is exposed on both sides of the road. Thirty or more nearly vertical basalt dikes, most of them less than 3 in. wide, have intruded joints and fractures of a 25-ft-wide, sheared interval of granite (fig. 9). This shear zone and dike swarm are believed to be part of a regional Precambrian structural feature defined as the Annapolis lineament by Kisvarsanyi and Kisvarsanyi (1976). The Annapolis lineament is briefly described in the discussion relating to STOP 5 of this road log. Skrainka Hill, the type locality of the Skrainka Diabase (Tolman and Robertson, 1969), is just 1.5 mi southwest beyond this roadcut, and the dike swarm is believed to be an offshoot of the large gabbro sill exposed there.

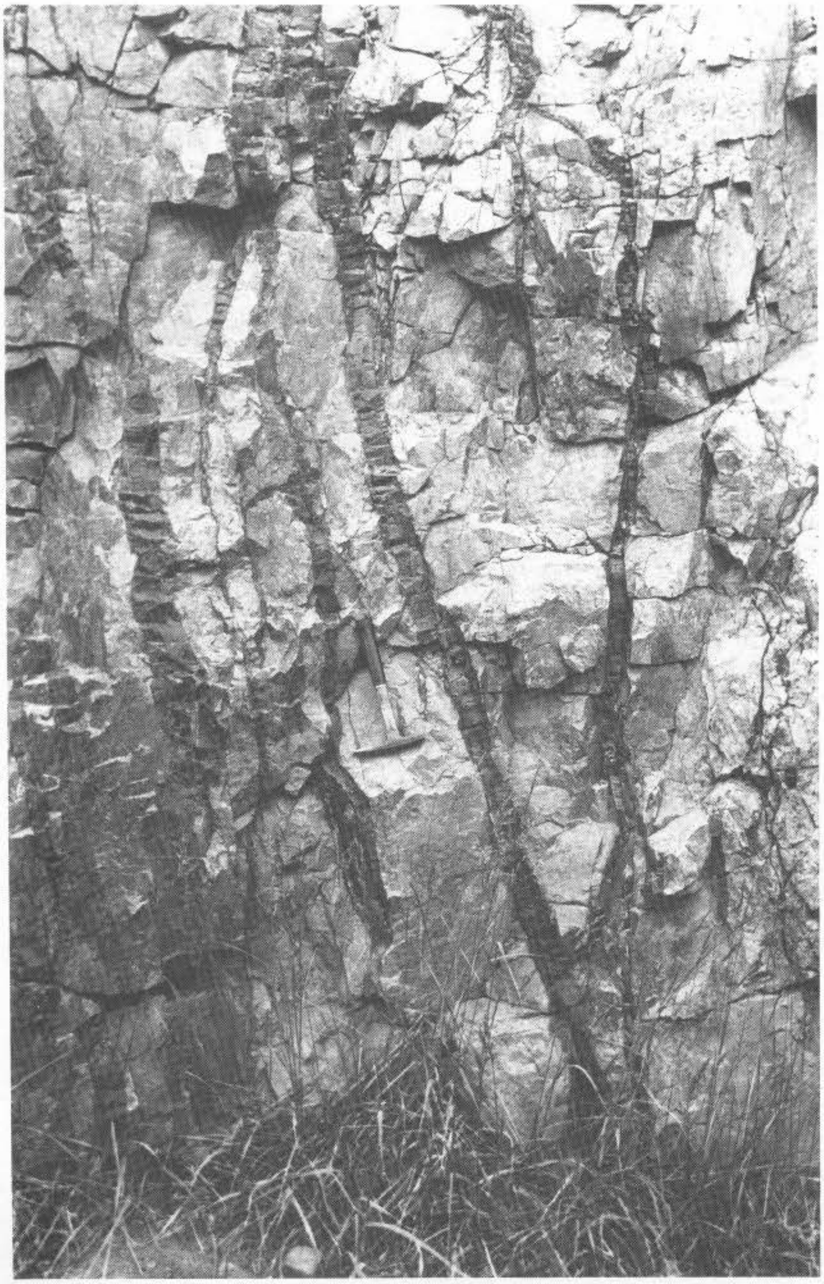


Figure 9

Part of a basalt-dike swarm intruded along joints and fractures in Slabtown Granite. East side of Highway 67, STOP 3. Photo by Art Hebrank.

0.8

15.6 The road to the east leads to the Mine La Motte Copper Mine, about 0.5 mi distant. This property was first worked for copper in 1838. By 1844 cobalt and nickel were also being recovered, and reported production of lead commenced in 1905. Mining was conducted intermittently on a relatively small scale until activity ceased in the early 1950's; total production was not large. The ore-grade deposits of galena, chalcopyrite, and siegenite occurred in the lower several feet of the Bonneterre Formation.

About 3 mi to the northeast is historic Mine La Motte, one of the oldest lead-mining areas in Missouri. Surface lead was discovered here in 1720 and first mined in 1723 under the supervision of M. de la Motte Cadillac, a subordinate of Philip Francois Renault, director of mines for the Company of the West. The Mine La Motte tract was active almost continuously from 1723 to the late 1950's, with total production of lead estimated at 475,000 tons. Galena, chalcopyrite, and siegenite, as disseminations and open-space fillings, occur in the lower 50 ft of the Bonneterre Formation and upper several feet of the Lamotte Sandstone.

At this writing, plans are under way to develop copper-cobalt-nickel ore reserves in the old Madison Mine, inactive since the early 1960's, near Fredericktown, about 4 mi southeast of this point. The Anschutz Mining Corporation plans to produce 2 million pounds per year of cobalt and a similar quantity of nickel, either as a mixed cobalt-nickel carbonate, as cobalt and nickel salts, or as metal. Significant amounts of copper, silver, and sulfuric acid will be recovered as by-products. Production start is planned for 1983.

0.1

15.7 This cut and the next cut to the south are in residuum derived mostly from Upper Cambrian sediments. Characteristic cherts from at least as high in the section as the Potosi Dolomite can be recognized.

0.3

16.0 Junction with State Road H to the west.

About 300 to 400 yd to the west and northwest are the Catherine Mines. Opened in the late 1860's, this group of mines operated intermittently for nearly 90 years, producing an estimated 55,000 tons of lead from the sandy dolomites in the lower part of the Bonneterre Formation.

1.0

17.0 Village of Catherine Place.

0.3

17.3 Divided highway begins. Low ledges of Bonneterre dolomite are exposed on the east side of the northbound lane.

0.2

17.5 Exit ramp to Missouri Highway 72; **turn right onto exit ramp.** Low ledges of Bonneterre dolomite are exposed along the west side of the ramp.

0.2

17.7 Junction with Missouri Highway 72. The town of Fredericktown is to the east. **Turn right and proceed west on Highway 72.**

0.7

18.4 The Hickory Nut Mine is a few hundred feet north of the road. Lead was first mined on this property in 1870; early production was insignificant. In the late 1940's and early 1950's a moderate tonnage of lead was produced from a second shaft 0.5 mi to the northeast.

0.5

18.9 Thick to medium beds of Bonneterre dolomite are exposed in the new cuts on both sides of the road.

0.2

19.1 Highway crosses Plum Creek; Mount Devon is visible about 2 mi to the south. An unusual diabase porphyry dike occurs on Mount Devon (Tolman and Robertson, 1969, p. 64).

0.2

19.3 **STOP 4.** Roadcuts along Highway 72 (NE¼ SE¼ NW¼ sec. 11, T. 33 N., R. 6 E.).

The new roadcuts at this locality expose some fundamental geologic relationships of the St. Francois Mountains remarkably well. Massive Precambrian rhyolite porphyry, the Grassy Mountain Ignimbrite, with well-developed joint sets is exposed on both sides of the road. A 4- to 5-ft-wide diabase dike has intruded the rhyolite along one of the prominent northeast-trending (N 15° E) joints and is exposed on both sides of the road. On the south side the dike is terminated

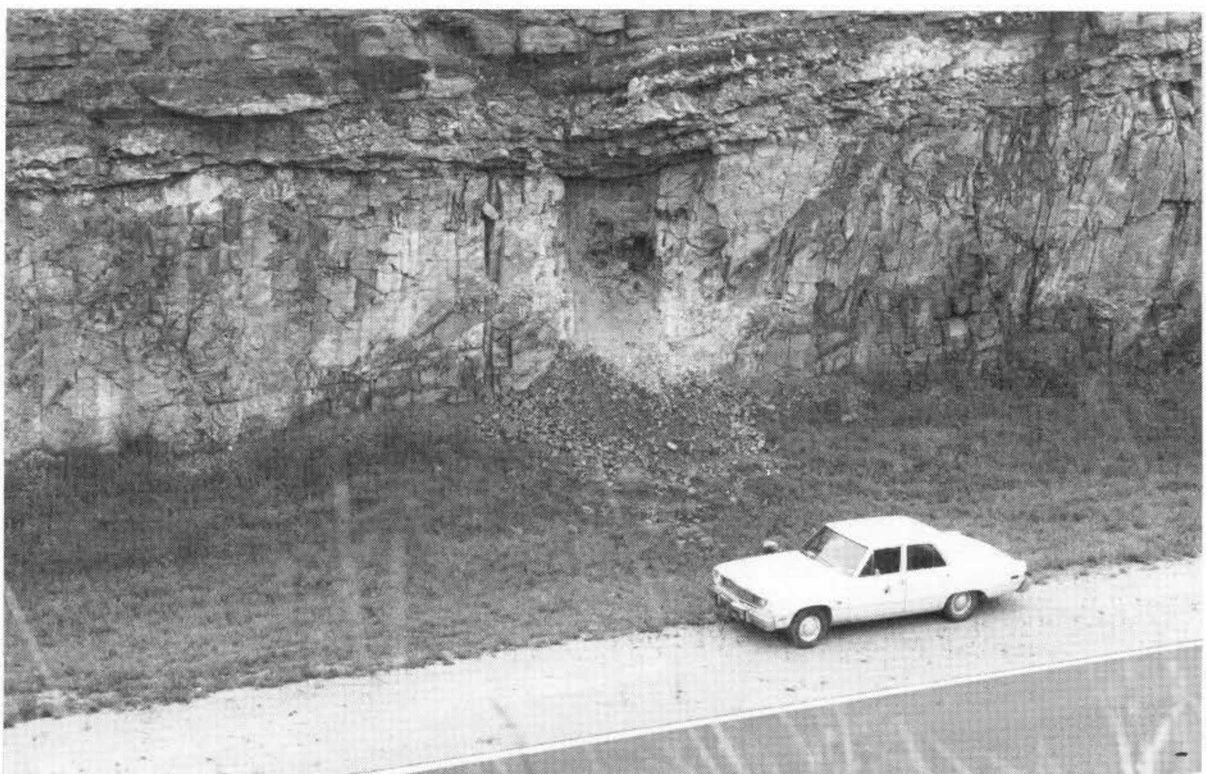


Figure 10. *Mafic dike in Grassy Mountain Ignimbrite truncated by overlying basal boulder conglomerate. The conglomerate is overlain by sandy Bonneterre dolomite. South side of Highway 72, STOP 4. Photo by Art Hebrank.*

at the Precambrian surface and is truncated by the overlying basal boulder conglomerate (fig. 10); on the north side of the road the boulder bed is absent and the dike (fig. 11) is exposed at the surface, on the top of the roadcut. The dike is deeply weathered in the southern cut and in the upper portion of the northern cut, but is relatively fresh near the road level in the northern cut. The contacts of the dike are sharp, but fractured and sheared, with calcite and quartz filling narrow fractures along its sheared contact with the rhyolite (fig. 12). Near the west end of the cut, on the south side, a similar but much smaller dike, about 1 ft wide, has intruded the rhyolite.

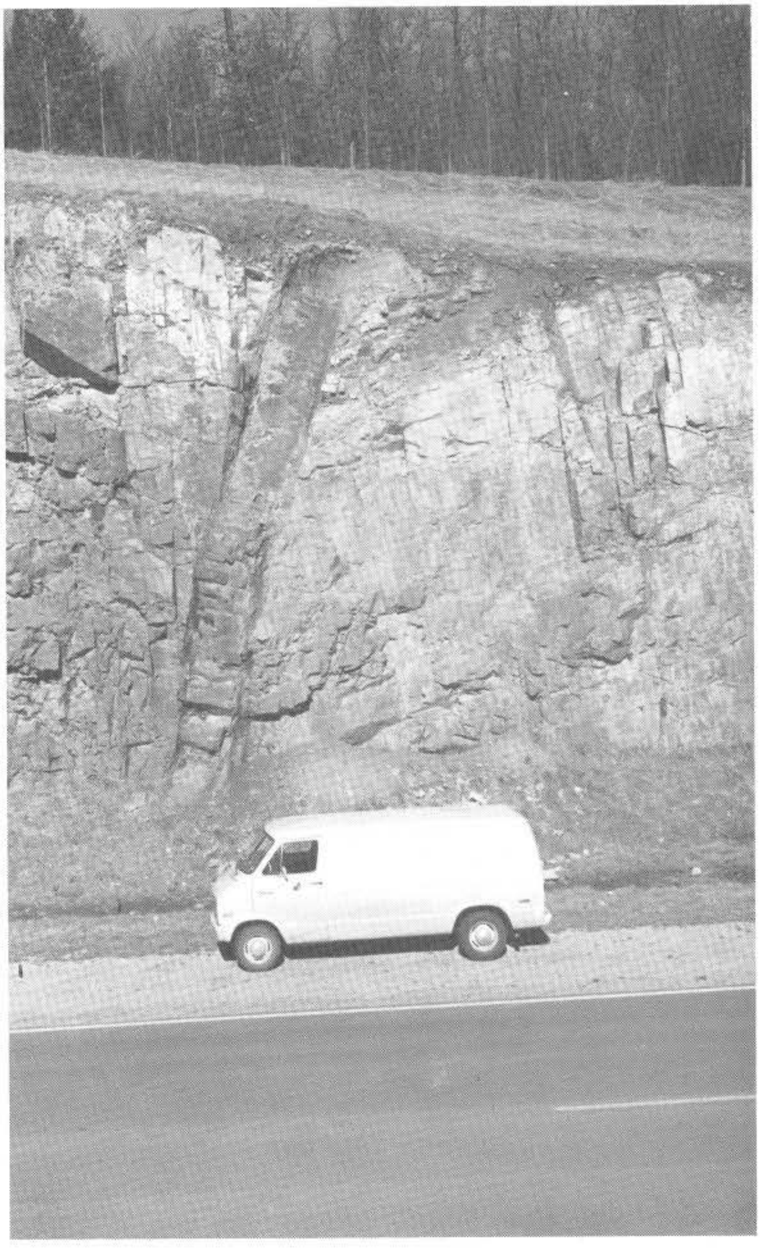


Figure 11

Mafic dike in Grassy Mountain Ignimbrite. North side of Highway 72, STOP 4. This is the same dike shown in figure 10, but here the overlying boulder conglomerate has been removed by erosion, and the dike is exposed at the top of the cut. Photo by Art Hebrank.

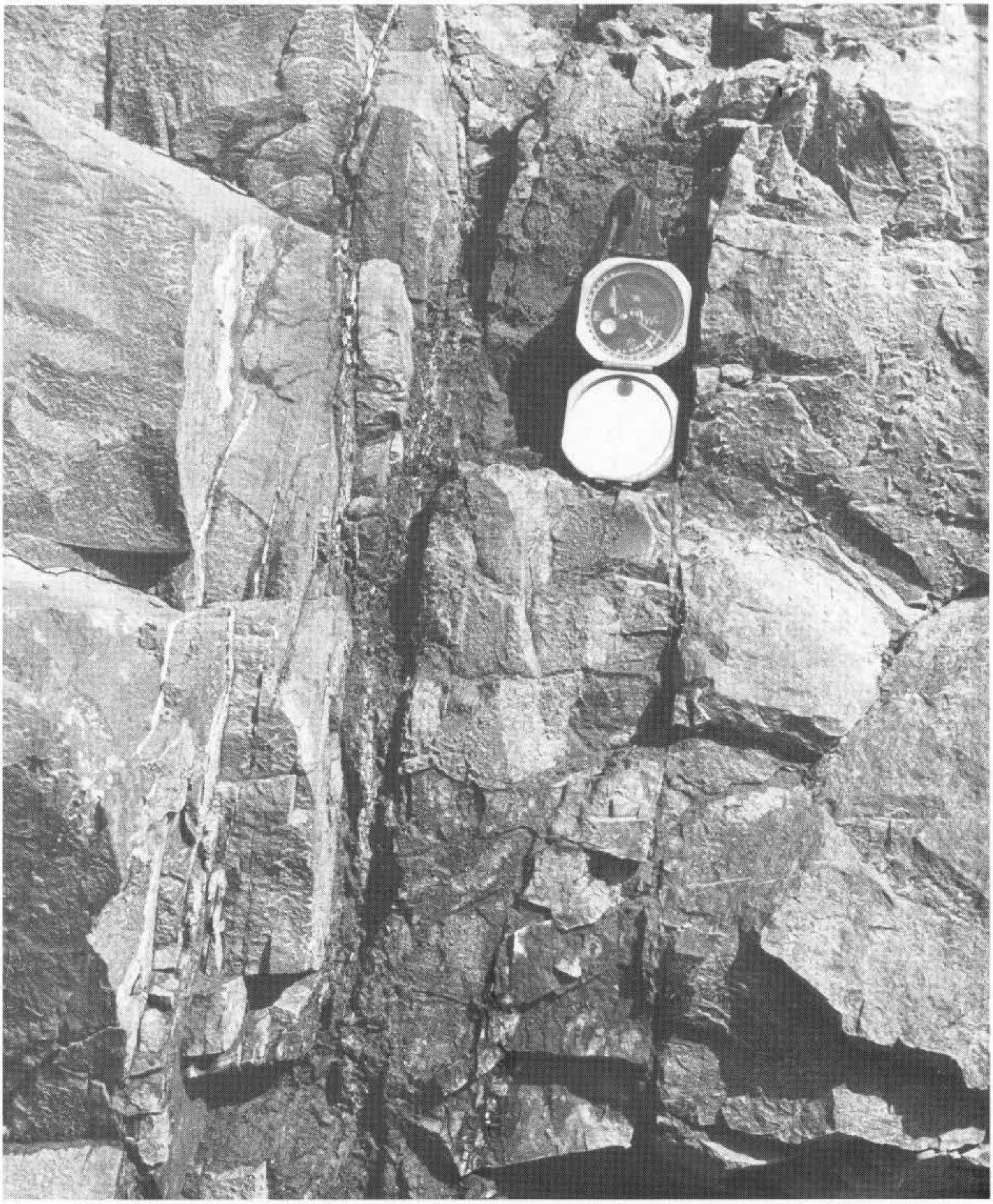


Figure 12. *Calcite- and quartz-filled fractures along the near-vertical contact of the mafic dike (left) and Grassy Mountain Ignimbrite (right). This is a close-up view of the dike shown in figure 11. Photo by Art Hebrank.*

On the south side of the road, the basal Paleozoic strata lap onto the Precambrian erosional surface from the east (fig. 13). The Precambrian rocks are overlain by a 6-ft-thick section of coarse boulder conglomerate: most of the boulders are weathered Precambrian rhyolite porphyry. The boulder bed is overlain by coarse, sandy dolomite and dolomite of the Bonneterre Formation.

Figure 13. *Sandy Bonneterre dolomite overlapping basal boulder conglomerate which mantles Grassy Mountain Ignimbrite. South side of Highway 72, STOP 4. Photo by Art Hebrank.*

	0.2	
19.5		Outcrops of Grassy Mountain Ignimbrite on the north side of the road.
	0.3	
19.8		Roadcuts expose Grassy Mountain Ignimbrite on both sides. The rock has several well-developed joint sets. Fracture-filling hematite veinlets are exposed on the south.
	0.9	
20.7		**STOP 5.** Roadcuts along Highway 72 (SW¼ NW¼ NW¼ sec. 10, T. 33 N., R. 6 E.).

Large cuts on both sides of the road are in massive Grassy Mountain Ignimbrite (fig. 3), which contains quartz and alkali-feldspar phenocrysts in a microcrystalline matrix of quartz and alkali feldspar. Quartz phenocrysts are euhedral and partially resorbed; feldspar phenocrysts are euhedral and broken orthoclase-microperthite. Shredded flakes of chlorite occur sparingly. Small, euhedral grains of magnetite are distributed evenly in the groundmass. Zircon, sphene, and fluorite are accessory minerals. Devitrification and recrystallization of the groundmass have all but completely obliterated textural features characteristic of welded ash-flow tuffs, but relicts of collapsed pumice indicate an ash-flow origin for the massive rhyolite.

Spectacular joint sets and shear planes may be observed in these roadcuts (fig. 14). Two prominent shear planes on the north side of the highway are parallel with a northeasterly striking, nearly vertical joint set; some displacement along these planes is indicated. Near the west end of the roadcut, on the north side, two nearly vertical, weathered diabase dikes parallel the major joint set, while a third intrusive body of diabase is in nearly horizontal contact with the rhyolite above. The lower contact of the third intrusive is obscured, but the diabase may be part of a sill or stock. This roadcut is directly south of Skrainka Hill.

The emplacement of diabase dikes and sills and attendant shearing and tectonic adjustments here are believed to be associated with a regional Precambrian structural feature defined as the Annapolis lineament by Kisvarsanyi and Kisvarsanyi (1976). The lineament is defined as a 1- to 2-mi-wide tectonic zone that strikes N 40° E and extends approximately 75 mi, from the southwest near Eminence, in Shannon County, to the northeast near Avon, in Ste. Genevieve County. Faulting, igneous intrusions, and mineralization are associated with the lineament along its strike. Remote-sensing imagery of southeast Missouri confirms the assumption that the Annapolis lineament is a major Precambrian crustal feature.

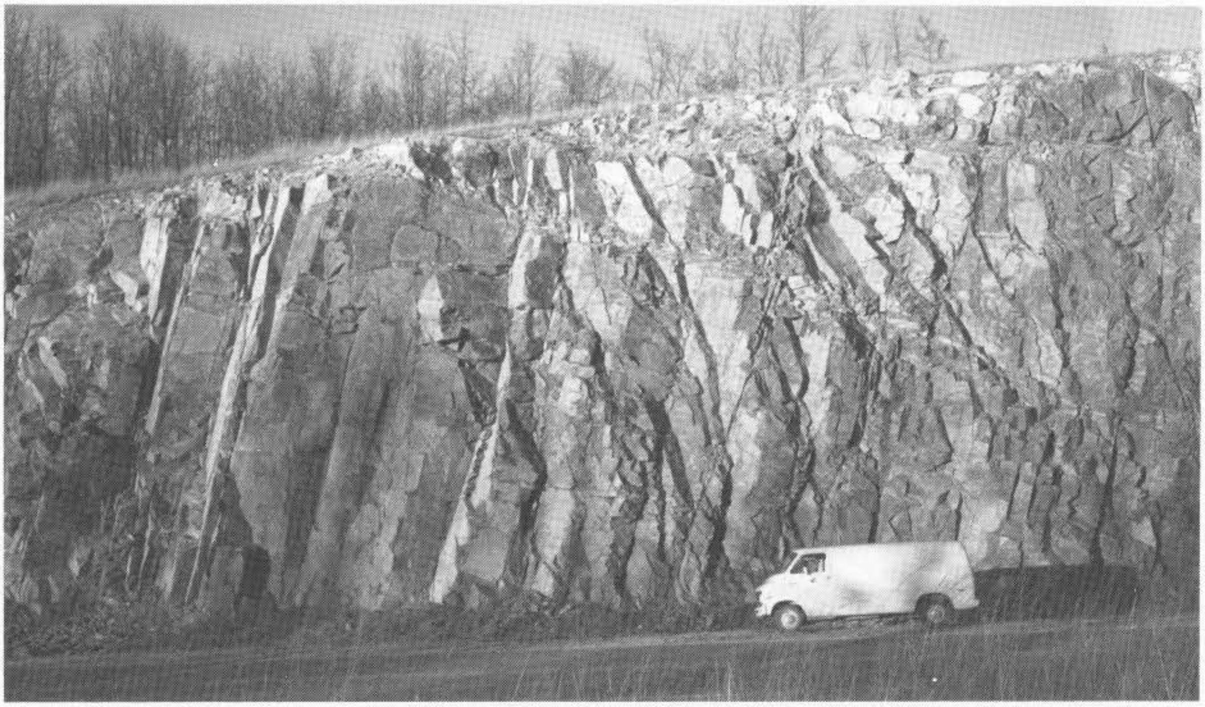


Figure 14. *Prominent joint sets and shear planes in Grassy Mountain Ignimbrite. North side of Highway 72, STOP 5. Photo by Art Hebrank.*

	0.2	
20.9		The small cut on the south side of the road exposes inconspicuously porphyritic Breadtray(?) Granite.
	0.1	
21.0		**STOP 6.** Roadcuts along Highway 72 (NE¼ NE¼ NE¼ sec. 9, T. 33 N., R. 6 E.).

Roadcuts expose a thick section of coarse boulder conglomerate that mantles a Precambrian diabase knob. A large intrusive body (possibly a small stock) of Precambrian diabase is exposed at the east end of the cut, on the south side of the road. The diabase is deeply weathered: large exfoliated masses (in situ) are surrounded by disintegrated diabase. The largest of the boulders of exfoliation is 10 ft in diameter (fig. 15). Thin sections from its interior indicate fresh olivine diabase with ophitic texture (fig. 16).

Figure 15. Exfoliated mass of diabase. This 10-ft-diameter boulder of exfoliation is in situ, surrounded by disintegrated diabase. South side of Highway 72, STOP 6. Photo by Art Hebrank.

Figure 16. *Photomicrograph showing ophitic texture in fresh olivine diabase from the center of the "boulder" shown in figure 15. Twinned crystals are plagioclase, augite shows parallel cleavage traces, and olivine exhibits characteristic cross fractures. Crossed polars. Photo by Art Hebrank.*

A thick boulder bed overlies the Precambrian (diabase) erosion surface. Many of the boulders are weathered red granite; some are exfoliated (fig. 17). The center of the cut is dominated by a large angular block (20 ft wide by 5 ft high) of pale pink, partly recrystallized, porphyritic amphibole granite. This block lies on the west flank of the diabase knob and is a part of the boulder bed (fig. 18).

Thin sections of the recrystallized granite from the central block on the south side of the cut indicate that the rock is composed of perthitic alkali feldspar, quartz, and a blue-green, sodic amphibole. Feldspar grains are equant and up to 3 mm in diameter; quartz is both euhedral and anhedral, and is frequently fractured; small, fibrous grains of amphibole are commonly less than 0.5 mm long, and poikilitically enclose smaller feldspar, quartz, and magnetite grains. The groundmass is completely recrystallized to a fine-grained mosaic of feldspar and quartz.

This block and similar, smaller blocks exposed on the north side of the road, appear to be wall-rock remnants of the country rock that was intruded by the diabase. The recrystallization of the granite is believed to have been thermally induced by the diabase intrusion.

On the north side of the highway, 10 to 12 ft of coarse boulder conglomerate are exposed in the upper face of the graded roadcut. Near the western end of the lower cut, a part of the boulder bed is underlain by a water-deposited sedimentary sequence 4 ft in maximum exposed

Figure 17. *Exfoliated boulder of granite in coarse boulder conglomerate. South side of Highway 72, STOP 6. Photo by Art Hebrank.*

thickness and consisting of very thin-bedded siltstone and silty shale (fig. 19). Its irregular contacts with the boulder bed suggest that this material is a channel fill. Similar lithologies occur in the Lamotte Sandstone exposed in the drainage ditch immediately northwest of and below this roadcut, and in better exposed Lamotte sequences to the west.

	0.3	
21.3		Outcrops of massive Lamotte Sandstone and fine pebble conglomerate on north side of road.
	0.2	
21.5		Cut on north side of road exposes Lamotte-Bonneterre transition beds. Sequence consists of dolomite, sandy dolomite, siltstone, and sandstone.
	0.2	
21.7		Junction of Highway 72 with State Road D to the south. **Turn south and follow State Road D to the historic Silver Mine area.**
	1.2	

22.9 Lamotte Sandstone exposed in roadbank and ditch along north side of road.

0.5

23.4 Road crosses Piney Creek. Silvermine Granite crops out in the creek bed and on the hillslope to the northwest. The granite exposure in the creek bed immediately north of the road is prominently fractured; a network of narrow (up to one-inch-wide), nearly vertical aplite dikes and quartz veins strike approximately N 5° E.

0.2

23.6 Lamotte Sandstone in roadbank to the south.

0.1

23.7 Road crosses creek branch. Lamotte sandstone, siltstone, and cobble conglomerate is exposed in banks on both sides of road.

0.4

Figure 18. *Large shattered block of partly recrystallized granite (top center). This block is part of a coarse boulder conglomerate (top right) mantling a deeply weathered diabase knob (left and bottom). South side of Highway 72, STOP 6. Photo by Art Hebrank.*

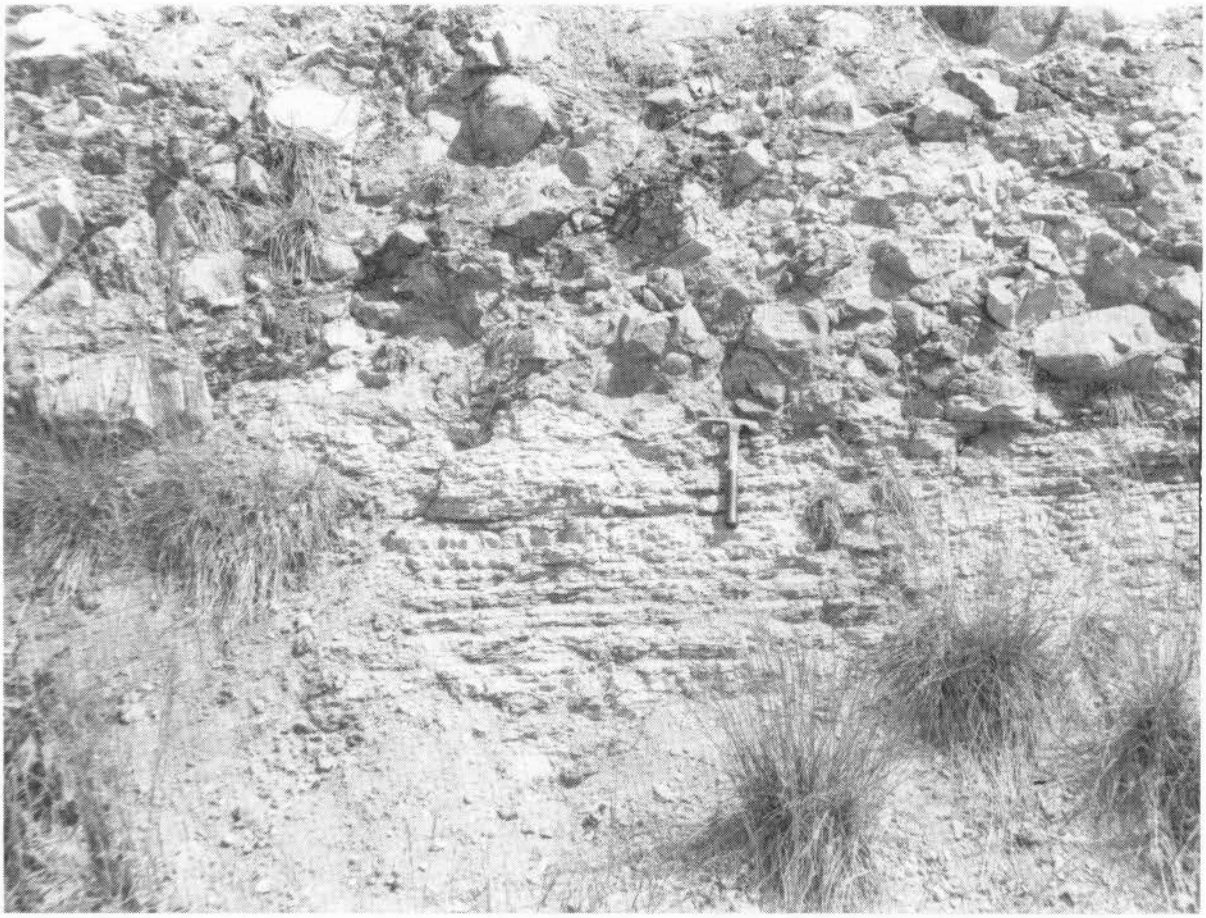


Figure 19. *Thin-bedded siltstone and silty shale filling a channel in coarse boulder conglomerate. North side of Highway 72, STOP 6. Photo by Art Hebrank.*

24.1		Cobble conglomerate exposed in bank along north side of road.
	0.6	
24.7		Enter Silver Mine Recreation Area. Road to north leads to Turkey Creek Camp and Picnic Grounds; St. Francis River to the south. Silvermine Granite exposed on both sides of road.
	0.2	
24.9		Sharp turn to left; one-lane bridge over St. Francis River.
	0.1	
25.0		**STOP 7.** Parking lot adjacent to picnic area on east side of road about 200 ft south of St. Francis River. (NE¼ NE¼ sec. 13, T. 33 N., R. 5 E.). Park and lock cars; this stop involves about a 2-hour hike.

Silvermine Granite is exposed in the bluffs along the St. Francis River. Upstream from the one-lane bridge, for a distance of about 0.5 mi, river erosion has developed a scenic, canyon-like gorge in the granite, referred to as a "shut-in" or "narrows" (fig. 20). Shut-ins are regionally unique physiographic features in the St. Francois Mountains but are more commonly developed where streams flow over volcanic rocks. This is one of the best known granite shut-ins of the region.

The Silvermine Granite is considered to be part of the multiple ring intrusion formed by the Knoblick, Slabtown, and Silvermine Granites. Emplaced along the southern boundary of the proposed Butler Hill caldera, it has steeply dipping contacts with the intruded volcanic rocks (Sides, 1978). It is a medium-grained amphibole-biotite granite composed of an average of 40 percent orthoclase-microperthite, 30 percent sodic oligoclase, 20 percent quartz, and 10 percent mafic minerals. A chemical analysis of Silvermine Granite is compared with Nockolds' (1954) average of six biotite-hornblende granites in table 4. Chemically, Silvermine Granite is intermediate between less silicic Knoblick Granite and more silicic Slabtown Granite (compare with tables 2 and 3). The chief mineralogical difference between Silvermine and Knoblick Granites is in the composition of their plagioclase: the former has Ab_{86-90} and the latter Ab_{76-80}.

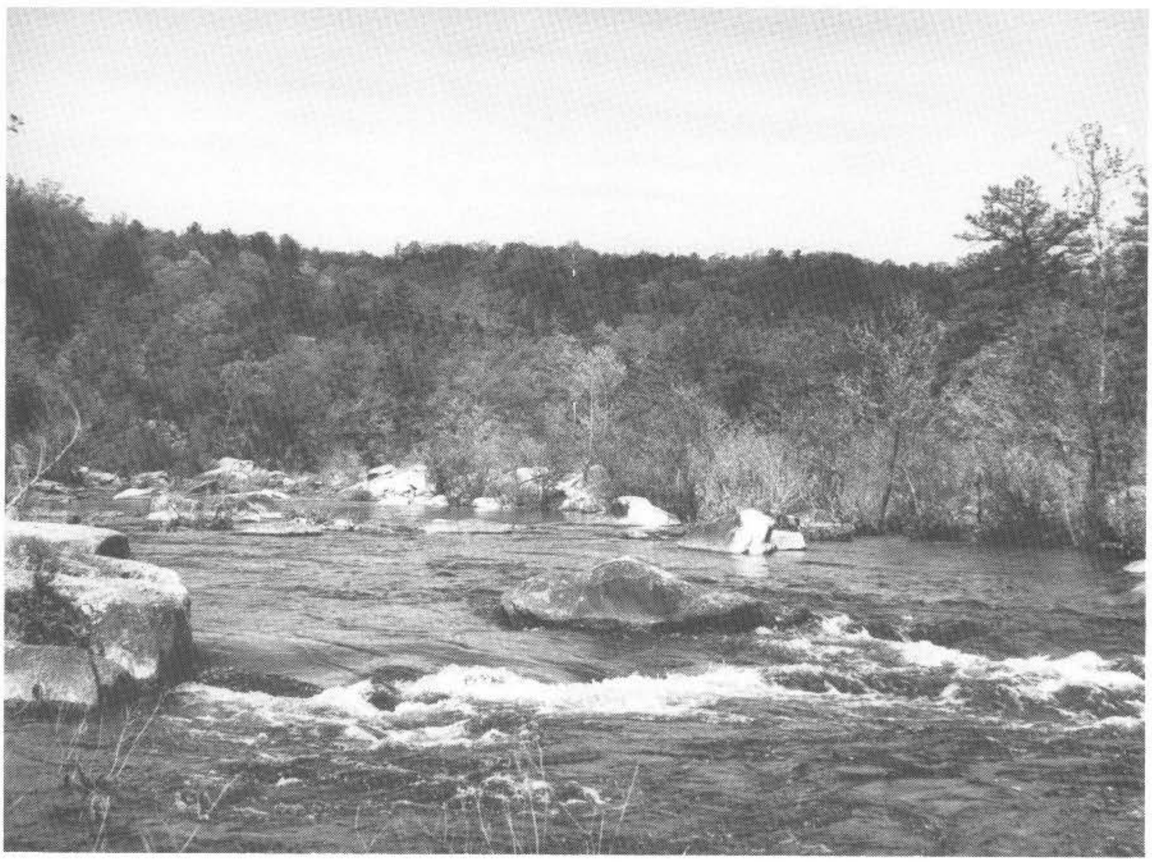


Figure 20. *The downstream end of the St. Francis River Shut-in near Silver Mine; the channel here is carved in Silvermine Granite. View west from Highway D bridge, about 200 ft north of STOP 7. Photo by Art Hebrank.*

Cross the road and walk uphill west then north on the prominently marked foot trail leading to the historic Einstein Silver Mine (fig. 21). The trail roughly parallels the river for about 2000 ft to the mine. Float and outcrops along the trail are of Silvermine Granite. About 1500 ft from State Road D, the trail joins an old wagon road carved into bedrock; bear right and follow the old wagon road downhill to the mine.

STOP 7A. Einstein Silver Mine (NW¼ SW¼ SE¼ sec. 12, T. 33 N., R. 5 E.).

The Einstein Mine is but one of several mines and prospects that began operations in the 1870's to produce silver from argentiferous galena in quartz veins cutting Silvermine Granite. These high-temperature pneumatolytic ore deposits have been described in detail by Tolman (1933) and Lowell (1975).

Table 4

CHEMICAL ANALYSIS OF SILVERMINE GRANITE

	Silvermine Granite*	Average biotite-hornblende granite**
SiO_2	69.70	70.56
Al_2O_3	14.80	14.00
Fe_2O_3	1.26	0.91
FeO	1.80	2.41
MgO	0.76	0.48
CaO	1.75	1.63
Na_2O	4.18	3.56
K_2O	3.92	5.39
H_2O^+	0.76	0.50
H_2O^-	0.13	—
TiO_2	0.40	0.40
P_2O_5	0.14	0.10
MnO	0.07	0.06
F	0.07	—
Total	**99.74**	**100.00**

* Analysis no. 52 *in* Kisvarsanyi, 1972.
** From Nockolds, 1954.

There were two distinct periods of mining in the Silver Mine area: 1877 to 1894 and 1916 to 1946. During the earlier period, an estimated 50 tons of lead and 3000 ounces of silver were produced; during the latter, an estimated 120 short tons of tungsten concentrates were produced, largely by high-grading the old dumps, and from shallow surface diggings.

The earlier period of mining saw a short-lived boom in the area: a town with a post office, school, bank, and businesses was established about 0.5 mi west of the Einstein Mine. At the height of the mining activity, when some 200 or 300 miners were employed by the Einstein Silver Mining Company, the population of the town was between 800 and 900. From our vantage point about 50 ft above the river, the remains of the dam constructed in 1879 can be seen (fig. 22). Foundation remnants on the west hillslope south of the dam are all that remain of the large mill constructed during the silver- and tungsten-mining periods (fig. 23).

Of the several quartz veins mined and prospected in the area, vein no. 1, the Einstein, was the most productive; it accounted for the bulk of the early lead and silver production. It was entered by the River Tunnel, the entrance to which is about 50 ft above the river (fig. 24).

(CAUTION: ENTRY THROUGH THIS OLD ADIT IS DANGEROUS AND SHOULD NOT BE ATTEMPTED!!!)

The vein strikes N 80° E and dips 35° S. The adit followed the vein along its strike for a distance of 548 ft, and a 180-ft-deep incline was sunk near the entrance. Two other levels in the mine were also opened above the River Tunnel and it was formerly possible to ascend to the top of the hill

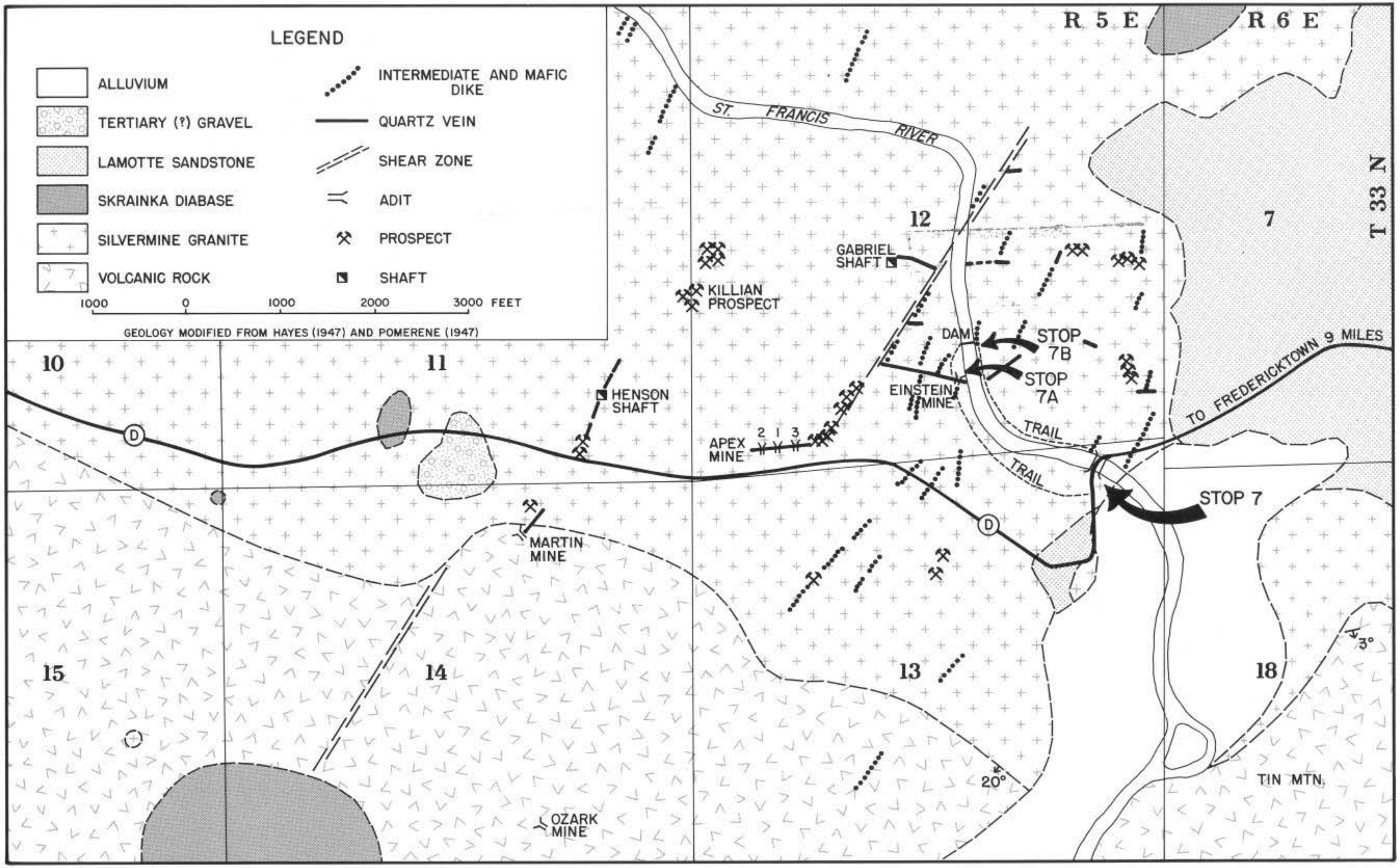


Figure 21. *Geologic map of the Silver Mine area, STOP 7.*

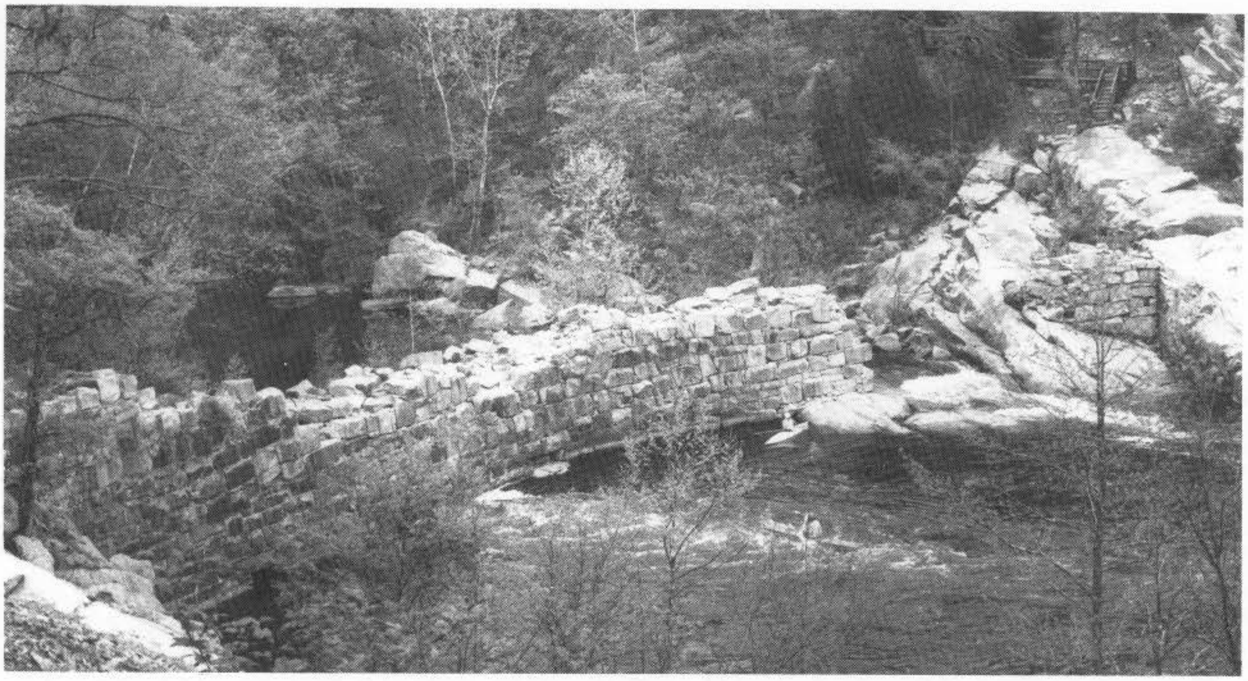


Figure 22. *Remains of the stone dam constructed in 1879 on the St. Francis River, near Einstein Silver Mine. View to the northeast from near STOP 7A. Photo by Art Hebrank.*

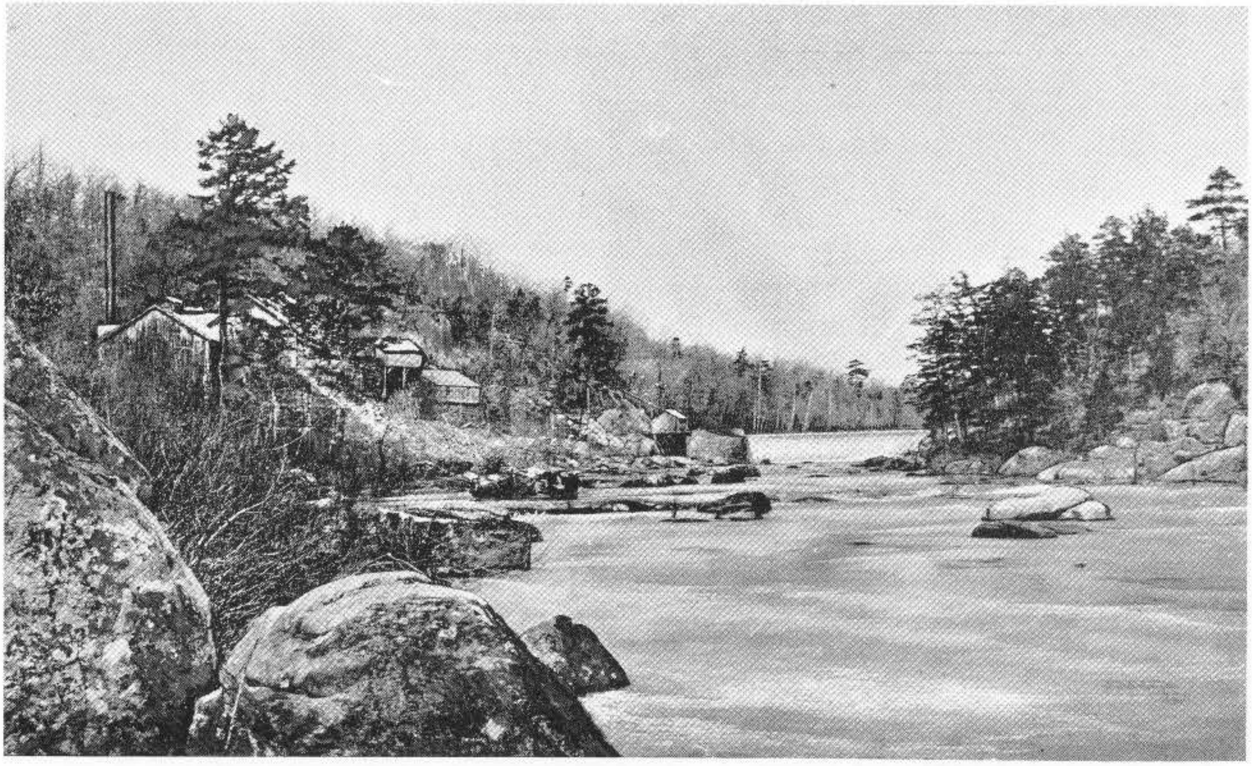


Figure 23. *Historic photograph of the Einstein Silver Mine area, ca. 1895. The view is to the north; buildings on the west bank of the river were constructed for milling and processing the ore. Note the dam and compare with its present condition shown in figure 22. Division of Geology and Land Survey archives.*

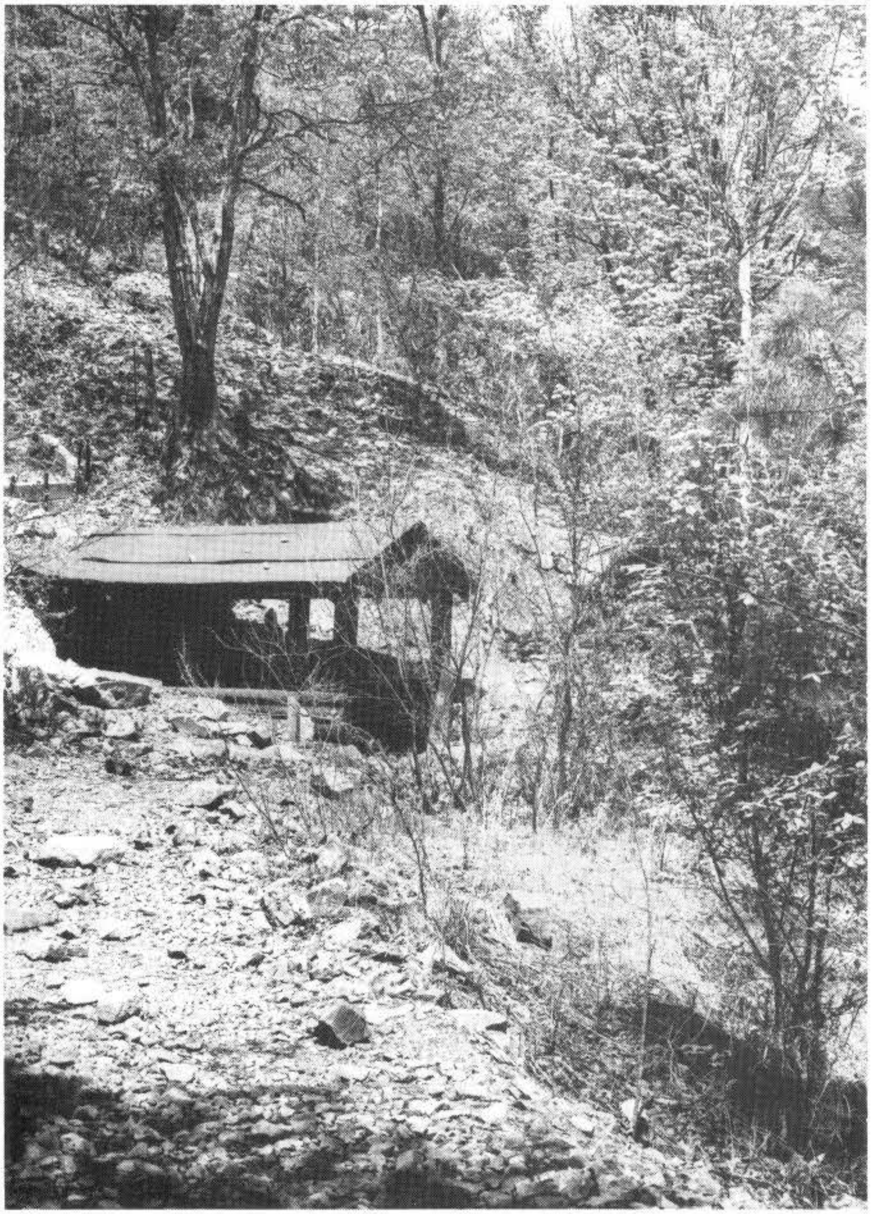


Figure 24

Entrance to the underground workings at the Einstein Silver Mine; this adit was known as the "River Tunnel" (see fig. 25). West bank of St. Francis River, STOP 7A. Photo by Art Hebrank.

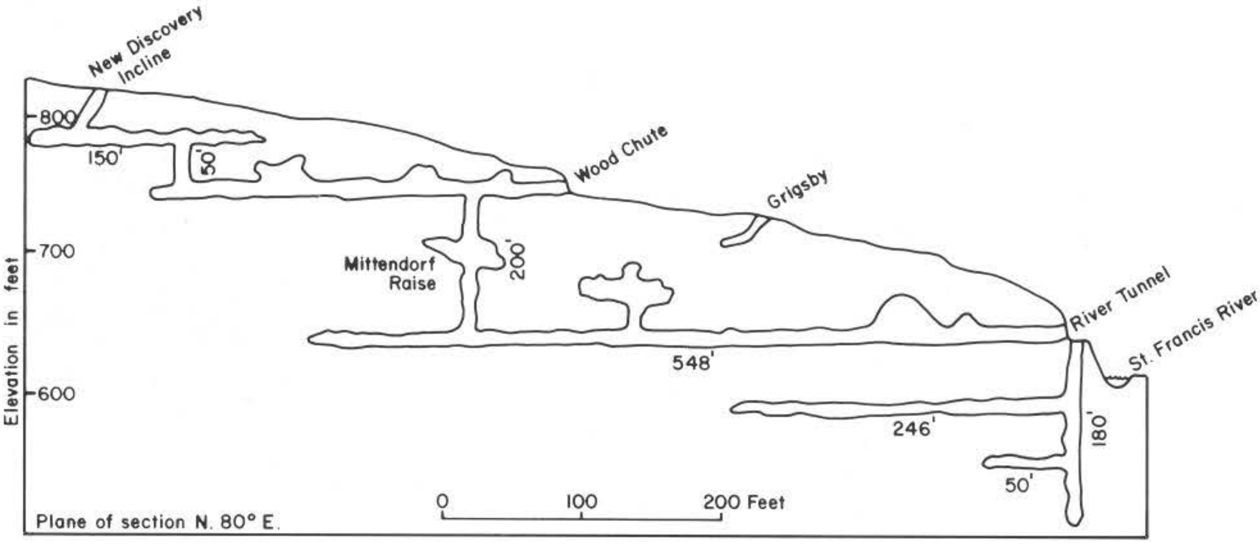


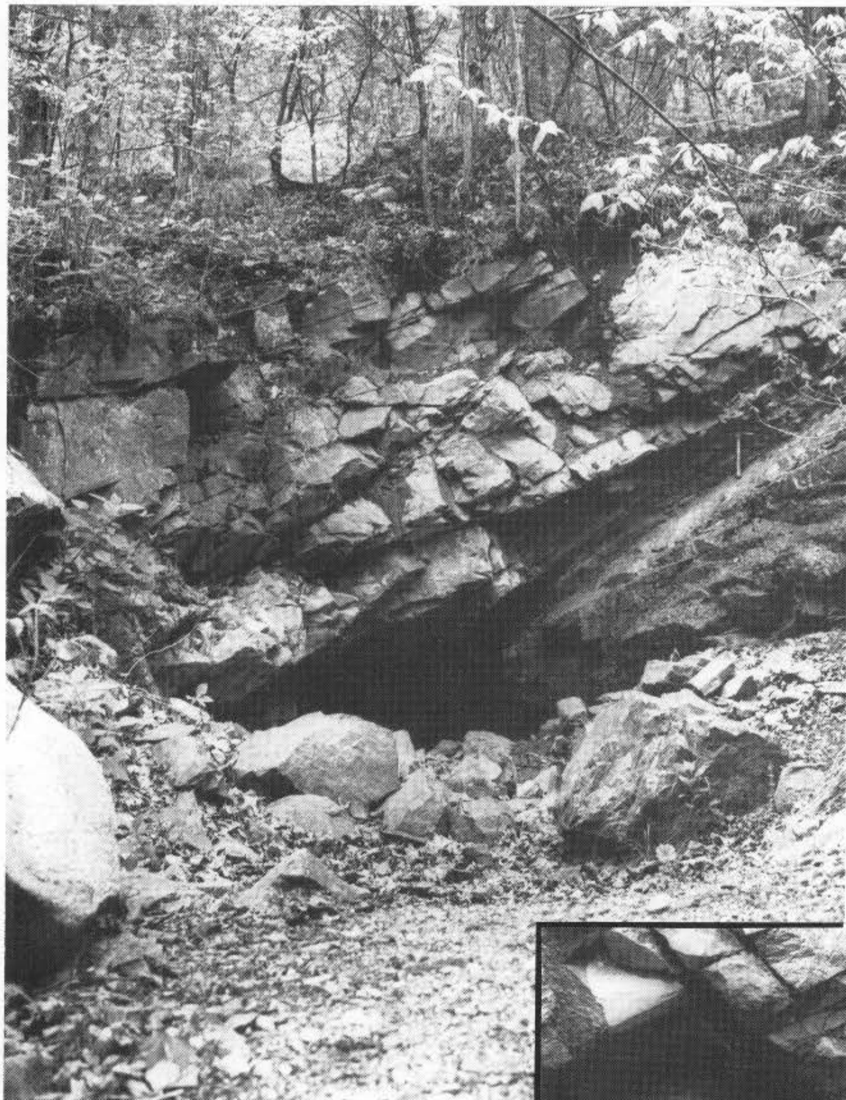
Figure 25. *Diagrammatic longitudinal cross section of the Einstein Silver Mine, interpreted by W.C. Hayes from unpublished field notes by G.A. Muilenburg, ca. 1941. Division of Geology and Land Survey, Mineral Resources Section files.*

through the underground workings and exit through the New Discovery Incline (fig. 25). The width of the vein was variable because of pinches and swells; its maximum width was probably not over 7 ft, with an ore zone of up to 2 ft (Tolman, 1933, p. 35). A pinched outcrop of the vein is visible above a small mine opening in the hillside, about 50 ft uphill from the River Tunnel, where the vein is less than 2 inches wide (fig. 26). The intruded granite is intensely altered to greisen, a fine-grained quartz-topaz-sericite rock, near the contacts.

The deposits at Silver Mine are of particular geologic interest because they represent the only known pneumatolytic ore-mineral association in the region. The mineral suite includes argentiferous galena, wolframite, arsenopyrite, sphalerite, cassiterite, chalcopyrite, covellite, hematite, stolzite, and scheelite. Quartz, topaz, sericite, fluorite, zinnwaldite, chlorite, and garnet are among the gangue minerals. Persistent search on the dump downhill from the mine may turn up good specimens.

Numerous intermediate to mafic dikes, older than the quartz veins, have been mapped in the Silver Mine area (fig. 21). One of these is well exposed in the eastern bank of the St. Francis River just below the dam. During the dry season, when the water level is low, it is possible to cross the river at the dam. This should not be attempted after heavy rains. During high-water periods the dike outcrop should be approached by way of a trail originating at the northwest end of the Highway D bridge and paralleling the river on the east side.

STOP 7B. Large mafic dike on east side of St. Francis River, just below Silver Mine dam (NW¼ SW¼ SE¼ sec. 12, T. 33 N., R. 5 E.).



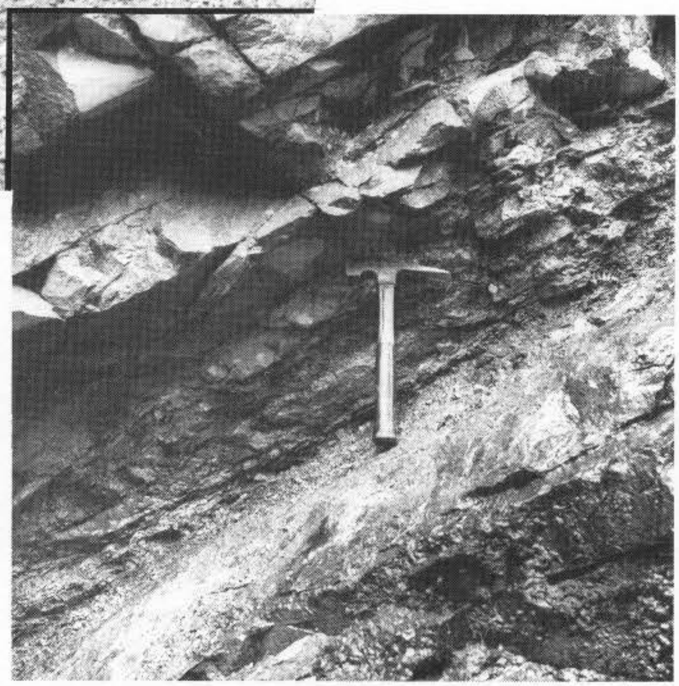


Figure 26

Distant and close-up views of a 2-in-wide "pinched" quartz vein in Silvermine Granite altered to greisen. This offshoot of the Einstein vein is above a small mine opening on the west bank of the St. Francis River, about 50 ft uphill (northwest) from the River Tunnel, STOP 7A. Photos by Art Hebrank.

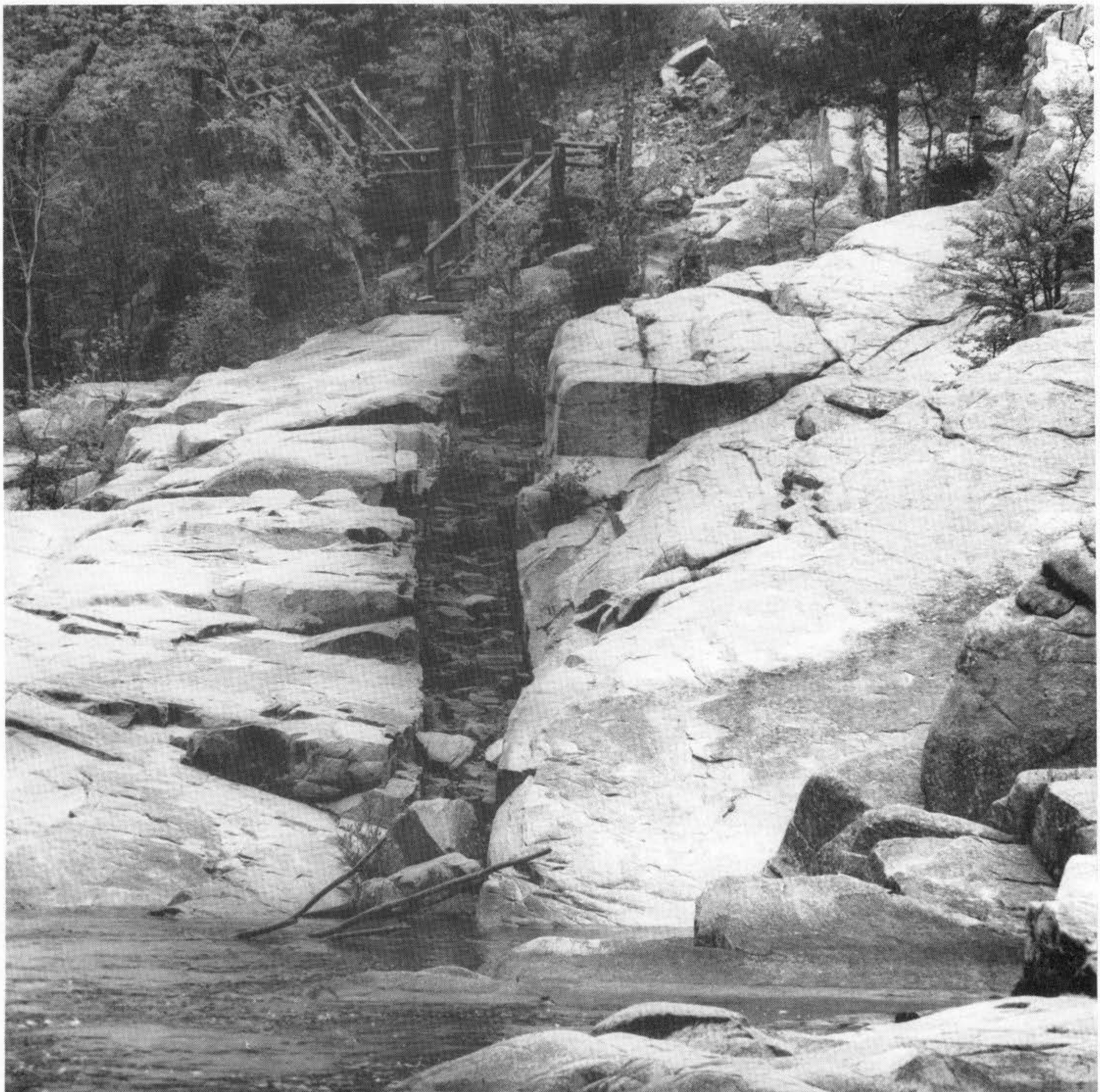


Figure 27. *Outcrop of the "Big Dike," on the east bank of the St. Francis River, just downstream from the Silver Mine dam. This near-vertical, 4-ft-wide basalt dike intrudes Silvermine Granite. STOP 7B. Photo by Art Hebrank.*

The dike is about 4 ft wide, strikes N 65° E, and is nearly vertical (fig. 27). It has chilled borders against Silvermine Granite but is coarser grained in the central part. The rock contains a few small plagioclase phenocrysts in a groundmass of andesine and augite with intergranular texture. Euhedral magnetite and pyrite are abundantly disseminated through the groundmass and there is a small amount of interstitial quartz. The phenocrysts and the mafic minerals are considerably altered and replaced to various degrees by calcite, uralite, epidote, and chlorite. On the basis of its mineralogical composition, the rock is a tholeitic augite-basalt porphyry; its chemical composition is not known.

Another type of dike rock is not observed in place at the Einstein Mine, but is found as float on the hillside and as boulders among the rocks used in the construction of the dam. This interesting rock, containing abundant quartz phenocrysts and sparse alkali-feldspar phenocrysts in a very fine-grained, dark-gray groundmass, was described as quartz-basalt porphyry by Tolman and Robertson (1969, p. 61-62). Our examination of thin sections indicates, however, that it is an alkalic-intermediate rock, apparently much less basic in chemical composition than a basalt.

Return to parking lot (STOP 7) either by retracing the trail followed to the mine or, if conditions permit, by crossing the St. Francis River at the dam and following the trail along the eastern bluffs of the river (fig. 21). Along the latter route the continuation of the Einstein vein is indicated by quartz float on the hillside; also, from along this route there are good views of the mine and dump across the river.

From the parking lot, retrace the 3.3-mi segment of State Road D back to its junction with Highway 72.

	3.3	
28.3		Junction of State Road D and Missouri Highway 72. Turn left and continue west on Highway 72.
	0.1	
28.4		Lamotte-Bonneterre transition beds exposed in cut on north side of road. Lamotte Sandstone and silty shale are exposed in the drainage ditch leading northwest.
	0.3	
28.7		The large cuts on both sides of the road, and the steep ditches draining to the east expose a thick sequence of Lamotte, consisting of arkosic sandstone, maroon and green silty shale, and pebble conglomerate. Cross-bedding is apparent in some beds. For the next mile, ledges and beds of similar Lamotte clastic rocks are exposed in the roadbanks and ditches.
	0.9	
29.6		Pebble conglomerate in the roadbank to the north.
	1.4	
31.0		Prominent outcrop of Breadtray Granite on south side of road.
	0.6	
31.6		Junction with State Road K to the north. Arkosic sandstone and pebble conglomerate of the Lamotte Sandstone are exposed in the ditches on both sides of the road.

Evans Mountain is seen to the northwest. This rhyolite knob stands prominently above the surrounding, less-resistant granite terrane.

0.2

31.8 Fresh exposures of Breadtray Granite in the ditches on both sides of the road. The rock is typical of the Breadtray Granite: medium grained, inconspicuously porphyritic, and dull salmon red. It is made up predominantly of alkali feldspar and quartz, with a paucity of mafic minerals.

0.3

32.1 Low cuts on both sides of the road (best on north) expose Grassy Mountain Ignimbrite. This outcrop is near the southernmost tip of a large body of exposed rhyolite, which forms a roof pendant in Breadtray Granite and constitutes the bulk of Evans Mountain. Contact with the adjacent granite is not well exposed, but isolated boulders and weathered outcrops of granite can be seen at either end of the small roadcut in rhyolite.

0.7

32.8 Boulders and weathered outcrops of Silvermine Granite cover hillslopes on both sides of road.

0.4

33.2 The outcrop on the north side of the road exposes typical Silvermine Granite. Some samples from this outcrop contain visible grains of pyrite.

0.5

33.7 Begin descent of hill to St. Francis River. Boulders and weathered outcrops of Silvermine Granite along both sides of road.

0.2

33.9 Low cuts on both sides of road near base of hill expose Silvermine Granite.

0.1

34.0 Bridge over St. Francis River. Hilltop ahead is covered by granite boulders.

The Roselle lineament (Gillerman, 1970) strikes approximately perpendicularly across the highway between here and the village of Roselle, 1.3 mi ahead.

0.5

34.5 Junction with State Road MM to the north. Weathered Silvermine Granite is exposed.

0.8

35.3 Enter village of Roselle. Silvermine Granite is exposed in several front yards.

0.4

35.7 Leave Roselle. Ledges of silty Bonneterre dolomite exposed in ditches on both sides of road.

0.3

36.0 Enter Iron County. We are leaving the area of the best-exposed granitic ring complex in the St. Francois Mountains and entering more mountainous terrain underlain by thick sequences of rhyolitic ash-flow tuffs. Between here and Ironton, about 5.5 mi ahead, the exposed volcanic rocks have been mapped most recently by Sides (1978).

Figure 28. *Vertical compaction foliation in Grassy Mountain Ignimbrite. North side of Highway 72, near mileage point 39.0 (SE¼ SE¼ SE¼ N½ sec. 3, T. 33 N., R. 4 E.). Photo by Art Hebrank.*

	0.5	
36.5		Small cut on north side of road exposes Bonneterre dolomite.
	0.3	
36.8		Bonneterre dolomite containing abundant angular rhyolite fragments is exposed in the small creek and ditch along the north side of the road.
	0.5	
37.3		Reddish-brown, slightly porphyritic rhyolite is exposed in the old cut on the south side of the road. Bonneterre dolomite containing abundant angular rhyolite fragments laps onto the rhyolite from the east. Similar basal-conglomeratic dolomite crops out along the small creek paralleling the road on the north side.
	0.2	
37.5		In the south roadbank and extending to the base of the hill, basal arkosic grits and conglomerates are exposed.
	0.1	
37.6		Enter Lake Killarney village.

Figure 29. *Coarse lithic clasts in brecciated Lake Killarney Formation. South side of Highway 72, near mileage point 38.8 (SE¼ SW¼ SW¼ N½ sec. 2, T. 33 N., R. 4 E.). Photo by Art Hebrank.*

0.3

37.9 Lake Killarney to the south. This reservoir, constructed in 1909, is one of Missouri's older sizeable impoundments.

For the next 1.1 mi, rhyolitic ash-flow tuffs are exposed more or less continuously along the north side of the road. They have been mapped as the Lake Killarney composite ash-flow tuff by Sides (1978).

1.1

39.0 Roadcuts and massive cliffs on the north side of the road expose Grassy Mountain Ignimbrite, a widespread and uniform volcanic unit, believed by Sides (1978) to be the major ash-flow sheet produced by caldera-collapse eruptions of the proposed Butler Hill caldera. The chemical similarity between this alkali rhyolitic ash-flow tuff and Butler Hill-Breadtray Granites supports the idea that they are comagmatic (compare analyses nos. 12, 13, and 14 with nos. 41 through 49 *in* Kisvarsanyi, 1972).

The Grassy Mountain Ignimbrite is characterized by abundant quartz phenocrysts and collapsed pumice fragments. The collapsed pumice fragments produce striking compaction foliation, manifested as prominent, discontinuous banding (fig. 28). In these cuts, compaction foliation is nearly vertical, with steep west-southwest dips.

The contact between Grassy Mountain Ignimbrite and the older Lake Killarney unit is about 550 ft east of this mileage point but is not exposed. A coarse breccia of the Lake Killarney unit, exposed about 1000 ft east, is shown in figure 29.

0.1

39.1 Bridge over Stouts Creek.

Stouts Creek Shut-ins, seen to the southeast (fig. 30), is one of the better known of these regionally unique canyon-like gorges.

At the upper end of the shut-ins and immediately northwest of the bridge is the site of the Tong-Ashebran furnace. Built in 1816, this was the first iron furnace in Missouri and produced charcoal iron from hematite ore mined nearby and on Shepherd Mountain, 3.5 mi to the northwest. Production ceased about 1819 (see description of the history of this furnace *in* Hayes, 1961, p. 11-13).

0.2

39.3 Junction with State Road D to the south.

0.7

40.0 Junction with State Road JJ to the south. Bonneterre dolomite exposed in small cut about 200 ft south on JJ.

0.2

40.2 Home for Aged Baptists on the south is built of Graniteville Granite, quarried near Graniteville, about 5 mi to the north.

0.6

40.8 City limits of Arcadia.

0.4

Figure 30. *Stouts Creek Shut-in. View southeast from the Highway 72 bridge, at mileage point 39.1 (SE¼ SE¼ SE¼ N½ sec. 3, T. 33 N., R. 4 E.). Photo by Art Hebrank.*

41.2		Overpass above Missouri Pacific Railroad tracks and Missouri Highway 21. Rhyolite exposed in small cut ahead, on the south. Down-ramp from overpass veers right.
	0.2	
41.4		**Turn right** and continue on Highway 72.
	0.1	
41.5		Junction with Missouri Highway 21. **Turn left and proceed north on Highway 21.**
	0.3	
41.8		Bridge over Stouts Creek; Ironton city limits. Highway 21 bypasses Ironton and parallels the Missouri Pacific Railroad tracks to the east.
	0.1	
41.9		Junction with State Road M; downtown Ironton is to the west.
	0.8	
42.7		Road to west leads to Ironton business district; good view of Pilot Knob (elevation 1500 ft above sea level) to the northeast.

0.3

43.0 The large roadcut (west side of highway) exposes Shepherd Mountain Rhyolite (Berry, 1976), a rhyolitic ash-flow tuff containing abundant crushed pumice fragments that impart a characteristic layering to the rock.

Shepherd Mountain (elevation 1608 ft above sea level) rises more than 600 ft above Arcadia Valley on the west side of the road. Shepherd Mountain was the site of the first recorded iron-ore mining in Missouri (Crane, 1912). Between 1815 and 1860, vein deposits of hematite, mixed with variable amounts of magnetite, were worked from open cuts near the crest of the mountain. The deposits are credited with a total production of 75,000 tons of ore. The veins struck about N$\cdot$50° E and dipped between 2 and 5 degrees northwest. They varied in width from about 2 to 30 ft. Near the north base of the mountain, across the valley from Pilot Knob, another deposit was discovered in 1888 by diamond drilling. Seams of iron ore up to 17 ft in thickness have been encountered in fresh rhyolite at depths ranging from 546 to 775 ft. Although subsequent exploratory drilling has been done, the subsurface deposit was not developed, possibly because of the high sulfur content of the ore.

0.6

43.6 Junction of Missouri Highway 21 and State Road V. Continue northwestward on Highway 21.

0.1

43.7 City limits of Pilot Knob.

0.5

44.2 Good view of Cedar Hill to the northeast. This Precambrian rhyolite knob rises about 400 ft above the valley floor. Another of the numerous Precambrian iron ore deposits of the region was mined near the crest of this hill. Mining began in 1872 and 25,000 tons of ore, consisting entirely of hematite, were produced (Crane, 1912).

1.1

45.3 Precambrian rhyolite exposed in cut on west side of road.

0.4

45.7 Precambrian rhyolite exposed in cuts on both sides of road. The rhyolite is overlain by a coarse basal conglomerate at the north end of the cut on the west side of the road.

0.4

46.1 Precambrian rhyolite exposed in cuts on both sides of road.

0.2

46.3 Junction of Missouri Highway 21 and State Road W. **Turn left and continue west on Highway 21.**

0.5

46.8 Junction with State Road N to the south. The valleys between the Precambrian hills in this area are underlain by dolomite of the Bonneterre Formation. North of the highway, Middlebrook Hill, a Precambrian rhyolite knob (elevation 1568 ft above sea level), rises some 400 ft above the valley floor.

	0.3	
47.1		City limits of Graniteville.
	0.2	
47.3		Junction of Missouri Highway 21 and State Road RA. **Turn left and proceed west on State Road RA.**
	0.6	
47.9		Abandoned quarry in Graniteville Granite on north side of road. We are now entering an area where the third principal granite type, a central pluton of the ring complexes, is exposed.
	0.1	
48.0		Entrance to Elephant Rocks State Park. Turn right into parking lot.

STOP 8. Elephant Rocks State Park (SE¼ SE¼ NE¼ sec. 15, T. 34 N., R. 3 E.). Park and lock cars. This stop involves approximately a 1.5-hour hike.

NOTE: ROCK COLLECTING AND HAMMERING IS PROHIBITED WITHIN THE BOUNDARIES OF THE PARK!

One-hundred-and-twenty acres of this 129-acre park were donated in 1966 to the State of Missouri by Dr. John S. Brown, former Chief Geologist of the St. Joseph Lead Company, as a Thanksgiving gift. Dr. Brown purchased the property shortly before that from the Heyward Granite Company, operator of a quarry just northeast of the park, across Highway 21. His intention was to preserve and protect the property as a geologically unique natural area and to place it under the stewardship of the people of Missouri. The area was opened as a State Park in the spring of 1969. It features the first self-guiding Braille trail for the visually handicapped among Missouri State Parks.

Follow marked trail to the lookout point near the top of the hill. The prime scenic attraction of the park are the giant, picturesque residual boulders ("elephant rocks") of Graniteville Granite, the result of spheroidal weathering along joint planes (fig. 31).

Graniteville Granite, commercially known as "Missouri Red," has been quarried in the area since 1869. By the turn of the century, building-, paving-, and monumental-stone were being produced from several quarries. Blocks of Graniteville Granite were being used as paving and curbing stone in St. Louis city streets. Buildings and monuments from San Francisco, California to Pittsfield, Massachusetts bear witness to the popularity and widespread use of this beautiful rock as a construction and monumental stone. Many of the older homes and commercial buildings in the area were also constructed from Graniteville Granite (fig. 32).

With the modernization of construction methods and the use of different materials for building and paving, granite production from the area has declined significantly. The dark-red color of the rock, due to finely disseminated iron oxide "dust" in the feldspars, makes it unsuitable for ceramic uses. Only the Heyward Granite Company quarry, 0.5 mi northeast of Elephant Rocks State Park, survives as an intermittent producer of monumental stone. Its last reported production in 1979 was less than 300 tons.

The Graniteville Granite is a medium- to coarse-grained, muscovite-biotite alkali granite averaging 55 percent alkali feldspar, 40 percent quartz, and less than 5 percent 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. The rock contains a varied suite of accessory minerals, including abundant fluorite, zircon, and magnetite;

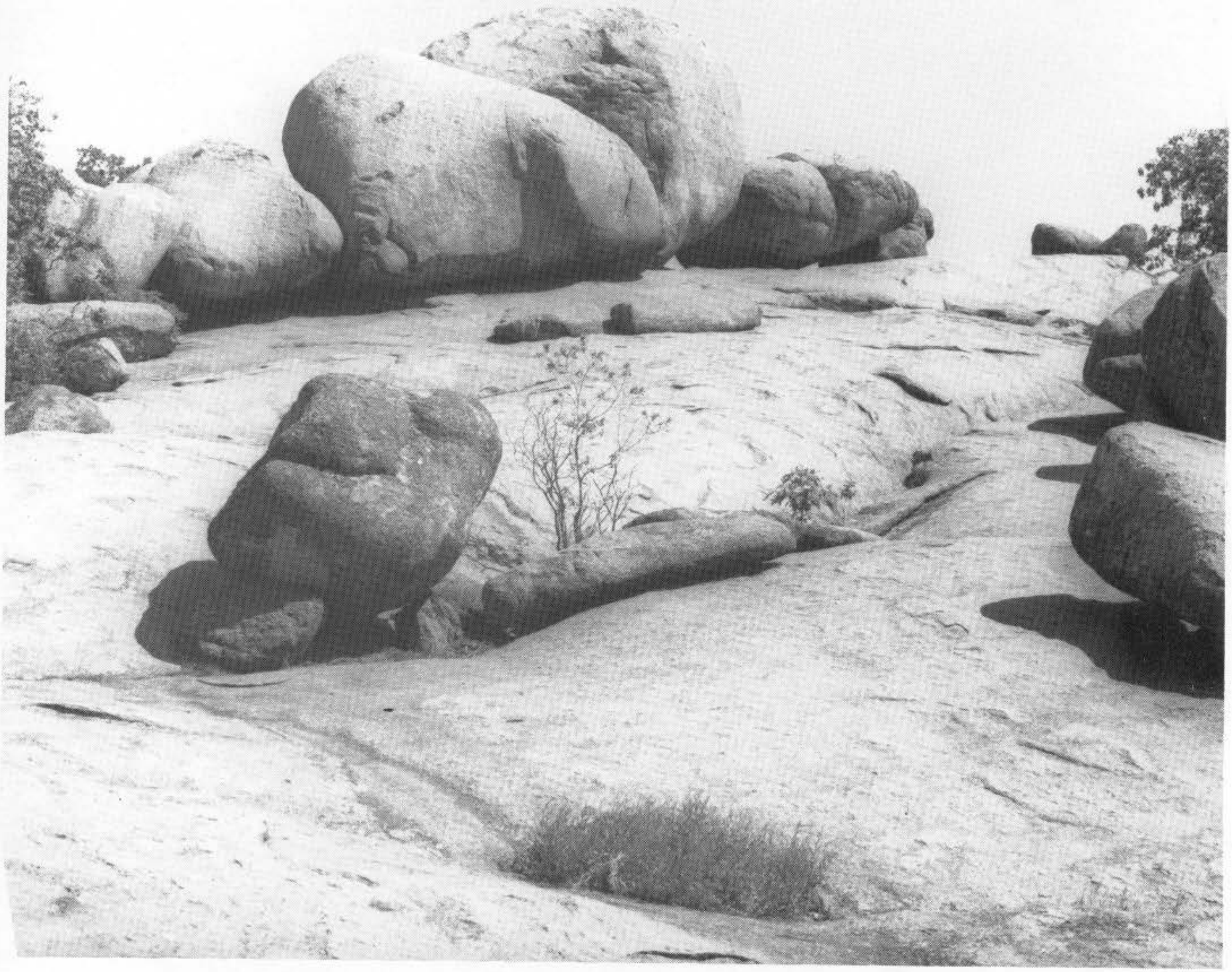


Figure 31. *"Elephant Rocks": spheroidally weathered giant boulders of Graniteville Granite in Elephant Rocks State Park, STOP 8. In this view to the northeast, the largest "elephant" atop the granite bald is 25 ft high. Photo by Art Hebrank.*

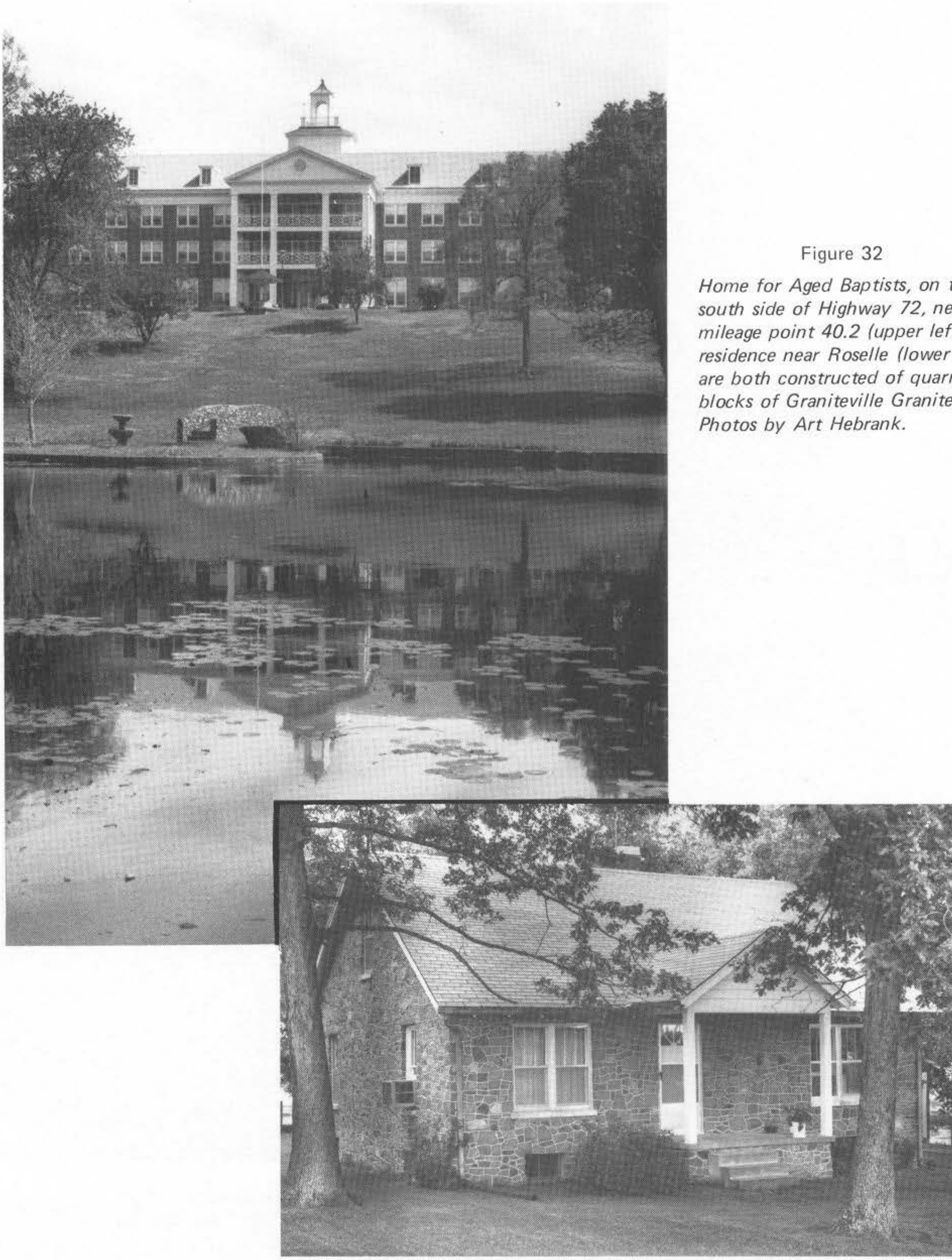


Figure 32

Home for Aged Baptists, on the south side of Highway 72, near mileage point 40.2 (upper left), and residence near Roselle (lower right) are both constructed of quarried blocks of Graniteville Granite. Photos by Art Hebrank.

Tolman and Koch (1936) also reported cassiterite and molybdenite. In table 5, a chemical analysis of Graniteville Granite from the Heyward Quarry is compared with Nockolds' (1954) average of 17 muscovite-biotite alkali granites. Anomalously high Sn, Be, Y, Nb, F, and U contents in Graniteville Granite led to its identification as one of the tin-granite central plutons of the St. Francois terrane (Kisvarsanyi, 1980). Locally, the granite contains complex pegmatites with topaz, beryl, muscovite, fluorite, rutile, cassiterite, and sulfide minerals (Tolman and Goldich, 1935).

The outcrop of Graniteville Granite is restricted to three small areas along the eastern and southeastern boundaries of a sediment-filled depression known as the Belleview Valley (fig. 3). Morphologically the valley is square, bounded by straight topographic escarpments, especially pronounced along its northwestern and northeastern sides. It was suggested by Graves (1938) that the valley is a fault-bounded, down-dropped Precambrian structural block and that the topographic escarpments resulted from erosion along nearly vertical faults. The square-shaped Belleview Valley is a prominent feature on satellite imagery of the region (Kisvarsanyi and Kisvarsanyi, 1976).

Looking northwest from the look-out point in the park, Belleview Valley appears to be a gently rolling, bowl-shaped depression surrounded on the far horizon by higher hills of rhyolite. The distance between here and the farthest visible hill across the valley, Logan Mountain, is approximately 8 mi. The difference in elevation between the dissected hills of sedimentary rocks within the valley and the rhyolite hills surrounding it varies between 300 and 700 ft; the greatest being on the northeast side, where Buford Mountain (elevation 1740 ft above sea level) rises some 700 ft above the valley floor.

Drillholes indicate that Graniteville Granite underlies the sedimentary rocks within Belleview Valley. In a drillhole 1 mi northwest of here (sec. 9, T. 34 N., R. 3 E.) the granite was encountered below Bonneterre dolomite, at a depth of 305 ft.

Table 5

CHEMICAL ANALYSIS OF GRANITEVILLE GRANITE

	Graniteville Granite*	Average muscovite-biotite alkali granite**
SiO_2	76.44	74.63
Al_2O_3	12.48	13.86
Fe_2O_3	0.44	0.52
FeO	0.45	0.89
MgO	0.05	0.33
CaO	0.95	0.57
Na_2O	3.67	3.05
K_2O	4.84	5.16
H_2O^+	0.13	0.63
H_2O^-	0.05	—
TiO_2	0.07	0.14
P_2O_5	0.00	0.18
MnO	0.00	0.04
F	0.41	—
S	0.02	—
BaO	0.01	—
Total	**100.01**	**100.00**

* Analysis no. 57 *in* Kisvarsanyi, 1972.
** From Nockolds, 1954.

Farther west, several drillholes cut the granite at depths between 400 and 600 ft. Aeromagnetic maps also indicate the extent of the pluton as an oval magnetic low coincident with Belleview Valley (Cordell, 1979). The theory that the Graniteville Granite is a central pluton emplaced during a resurgent cauldron cycle was developed by Kisvarsanyi (1980, 1981).

Return to parking lot by following the trail through Elephant Rocks State Park.

Resume trip by car. Retrace 4.4-mi segment of road via State Road RA and Missouri Highway 21, southward to State Road V and the town of Pilot Knob.

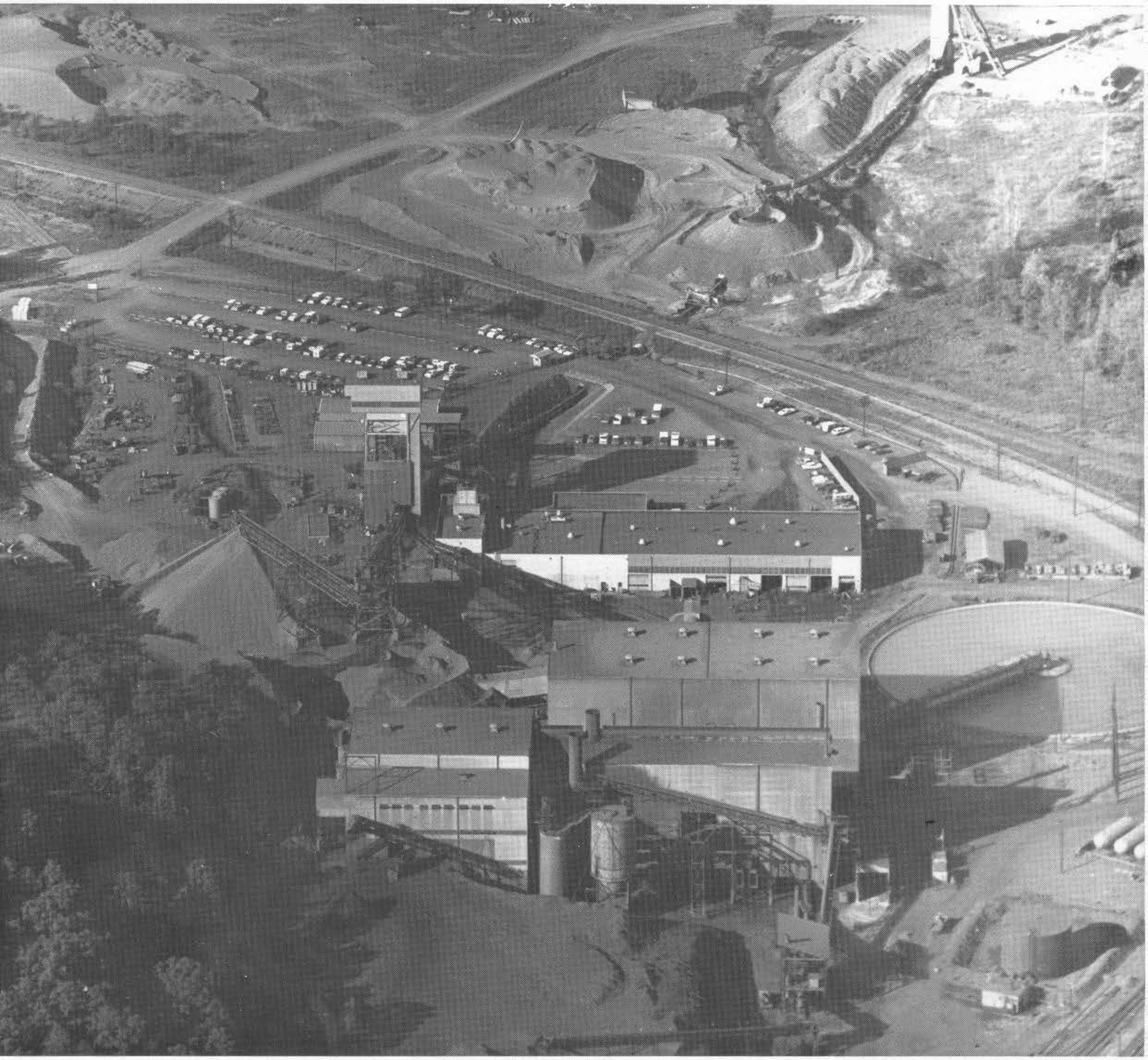


Figure 33. *Panoramic view southwest of the Pilot Knob Pellet Company's mine and pelletizing plant (SE¼ NE¼ and N½ SE¼ sec. 30, T. 34 N., R. 4 E.). Production shaft is near the left center of the picture; building in foreground is the pelletizing plant. This mine-mill complex is 1800 ft east of mileage point 52.6. Photo by Jerry Vineyard.*

4.4

52.4 Junction of Missouri Highway 21 and State Road V. **Turn left on V and proceed northeast into town of Pilot Knob.**

0.1

52.5 Bridge over West Branch of Knob Creek; entrance road to Pilot Knob Pellet Company to the east.

0.1

52.6 Roadside park on east side of road offers a good view of the Pilot Knob Pellet Company headframe and surface plant, and the Battle of Pilot Knob State Historic Site.

The surface plant of the Pilot Knob Pellet Company is seen to the east (fig. 33). This integrated mine, mill, and pellet plant went into production in 1968 and produced more than 19 million tons of iron ore during its 12 years of operation. It was closed down permanently in November 1980. The 1360-ft production shaft penetrated a Precambrian magnetite orebody emplaced in volcanic host rocks. Ore depth ranged from about 400 ft to 1500 ft from the surface. The deposit is described by Wracher (1976). Surface iron deposits near the top of the mountain are described in Road Log No. 3 of this Guidebook.

The historical marker (fig. 34) commemorates the Battle of Pilot Knob. Earthwork remnants of Fort Davidson, occupied by Union forces during the Battle of Pilot Knob, are still visible at this State Historic Site. This Civil War battle, September 27, 1864, lasted less than an hour but claimed more than 1200 casualties. With a force of approximately 1000 men, General Thomas Ewing repulsed an attack of between 12,000 and 20,000 poorly equipped Confederates under the command of General Sterling Price. The "fort" (really little more than an earthwork surrounded by a dry moat) was built by Union troops to protect the terminus of the St. Louis and Iron Mountain Railroad, and the iron mines on Pilot Knob and at Iron Mountain. The demoralizing and delaying effects of this bloody battle forced Price to abandon plans for what might have been a successful Confederate takeover (at least temporarily) of the city of St. Louis, defended at the time by a garrison of around 6000 men.

0.1

52.7 **Turn right and continue east on State Road V.**

0.3

53.0 State Road V passes under the trestle of the Missouri Pacific Railroad and swerves left. Oak Mountain is to the north and Pilot Knob to the south. These Precambrian rhyolite hills rise 400 to 500 ft above the valley floor.

0.4

53.4 Rhyolite exposed on north side of road. It was mapped by Nusbaum (1980) as part of the series of lava flows exposed on the southern flank of Oak Mountain. The rock typically has sparse phenocrysts of albite and, rarely, of quartz in a microcrystalline groundmass of quartz and alkali feldspar with disseminated iron oxide.

1.9

55.3 The tailings pond of Pilot Knob Pellet Company is visible to the north. Tribby Mountain (elevation 1377 ft above sea level) is visible immediately north of the tailings pond. It is the type locality of a widespread heterolithic breccia believed to have formed during caldera collapse (Nusbaum, 1980).

	0.6	
55.9		Enter St. Francois County.
	0.6	
56.5		Precambrian volcanic rocks exposed on south side of road. This outcrop is immediately east of a major angular unconformity mapped by Nusbaum (1980), which he infers to be a caldera boundary. The unconformity is not exposed along the road but its mapped strike is nearly N-S. About 2.5 mi north of here, on Brown and Wolf Mountains, Nusbaum (1980) mapped a "zone of chaotic structures" marking the boundary of the proposed collapse caldera.
	0.1	
56.6		Tailings pond dam to the north.
	0.6	
57.2		Deeply weathered Breadtray Granite exposed on both sides of the road. The contact of Breadtray Granite and the overlying Grassy Mountain Ignimbrite is not exposed along the road but is mapped just west of these outcrops.

Figure 34. *Fort Davidson historical marker. Remnants of the old fort's earthwork embankment and moat, now overgrown with trees, are visible directly behind the sign. Battle of Pilot Knob State Historic Site (NW¼ NW¼ SE¼ sec. 30, T. 34 N., R. 4 E.), at mileage point 52.6. Photo by Art Hebrank.*

Table 6

CHEMICAL ANALYSES OF BUTLER HILL AND BREADTRAY GRANITES

	Butler Hill Granite[1]	Breadtray Granite[2]	Grassy Mountain Ignimbrite[3]	Average biotite alkali granite[4]	Average alkali rhyolite[5]
SiO_2	75.50	76.59	76.35	75.01	74.57
Al_2O_3	12.74	12.10	11.63	13.16	12.58
Fe_2O_3	0.46	0.64	1.24	0.94	1.30
FeO	1.12	0.51	1.27	0.88	1.02
MgO	0.19	0.14	0.12	0.24	0.11
CaO	0.63	0.53	0.39	0.56	0.61
Na_2O	3.43	3.25	3.53	3.48	4.13
K_2O	4.66	5.38	4.50	5.01	4.73
H_2O^+	0.68	0.37	0.35	0.37	0.66
H_2O^-	0.13	0.13	0.04	––	––
TiO_2	0.14	0.11	0.16	0.17	0.17
P_2O_5	0.04	0.02	0.00	0.11	0.07
MnO	0.05	0.02	0.08	0.07	0.05
F	0.13	0.26	0.10	––	––
Total	**99.90**	**100.05**	**99.76**	**100.00**	**100.00**

[1] Analysis no. 47 *in* Kisvarsanyi, 1972.
[2] Analysis no. 41 *in* Kisvarsanyi, 1972
[3] Analysis no. 12 *in* Kisvarsanyi, 1972
[4] and [5] are from Nockolds, 1954.

We are now re-entering the outcrop area of the largest exposed granite massif of the St. Francois terrane, the Butler Hill-Breadtray Granite (fig. 3). At several places along its 10-mi-long, arcuate contact with rhyolite, Tolman and Robertson (1969) reported very low dip angles, implying a sill-like body. To the east, they indicated a gradational contact of Breadtray Granite with coarser grained Butler Hill Granite, suggesting that the Breadtray is a marginal roof facies of the Butler Hill. The exposure of gradually coarser grained, deeper portions of the massif in the northeast direction was explained by regional tilting of the entire granite-rhyolite complex to the southwest, and erosion of the volcanic roof before deposition of Upper Cambrian sedimentary rocks (Snyder and Wagner, 1961; G. Kisvarsanyi, 1977; Sides, 1978).

The Breadtray Granite is typically a fine- to medium-grained alkali-feldspar granophyre composed of 60 to 70 percent orthoclase-microperthite and 30 to 40 percent quartz. The mafic mineral, if present at all, is sparse biotite. Magnetite and fluorite are the most common accessory minerals. Chemical analyses of Breadtray Granite, Butler Hill Granite, and their comagmatic volcanic product, the Grassy Mountain Ignimbrite, are compared with Nockolds' (1954) averages of 12 biotite alkali granites and 21 alkali rhyolites in table 6.

	0.3	
57.5		Breadtray Granite exposed on east side of road.
	0.5	
58.0		Breadtray Granite exposed on east side of road.
	0.3	
58.3		Breadtray Granite exposed on east side of road.
	0.4	
58.7		Junction with King School Road and Buck Mountain Road.
		Bread Tray Mountain is visible to the northeast. A Precambrian knob rising about 300 ft above road level, it is the type locality of the Breadtray Granite.
	1.3	
60.0		Boulders and outcrops of Breadtray Granite for the next 1.1 mi.
	1.5	
61.5		Junction of State Roads V and W. **Turn right and proceed east on State Road W.** The road west leads to Iron Mountain, approximately 5 mi to the west, where Precambrian iron ore was mined from the early 1800's until 1966. The iron deposit is described briefly in Road Log No. 2 of this Guidebook.

Stono Mountain, topped by a lookout tower, is visible just northwest of the junction. The granite-rhyolite contact is exposed north of State Road W along the southern slope of Stono Mountain. Numerous xenoliths and small roof pendants of rhyolite are enclosed in Breadtray Granite along the contact.

A small granite outcrop on the top and north slopes of Stono Mountain was named the Stono Granite by Tolman and Robertson (1969). Stono Granite is quite similar in mineralogy and chemistry to the Slabtown Granite and is believed to be related to the ring intrusions of the St. Francois terrane; however, roof pendants of Grassy Mountain Ignimbrite in Stono Granite are truncated by Breadtray Granite (fig. 3), and if related to the multiple ring intrusion around the proposed Butler Hill caldera, Stono Granite is apparently older than the caldera.

	0.2	
61.7		Boulders in the road ditch are of Breadtray Granite.
	0.2	
61.9		Village of Mineral City. Scattered outcrops of Breadtray Granite occur along the road for the next mile.
	1.0	
62.9		Last granite outcrop. Northwest-trending faults of the Simms Mountain fault system displace the Precambrian rocks north of the fault zone. Breadtray Granite was encountered at a depth of 320 ft in a drillhole near Doe Run. The sediments of the valley ahead are dolomites of the Upper Cambrian Bonneterre Formation and Elvins Group.
	1.7	
64.6		West city limit of Doe Run.
	0.6	

65.2		Junction with State Road B to the north.
	0.4	
65.6		East city limit of Doe Run.
	1.0	
66.6		Outcrop of Cambrian dolomite.
	0.9	
67.5		Bridge across St. Francis River.
	0.1	
67.6		Outcrop of Cambrian dolomite.
	1.1	
68.7		Overpass of State Road W above U.S. Highway 67. The starting point for this road log was below this overpass. Highway 67 north leads to the cities of Flat River and Bonne Terre; the city of Farmington is about one mile ahead along State Road W.

We have now completed our tour of nearly all the exposed granite types of the St. Francois Mountains region. About 10 mi east of Farmington, in Ste. Genevieve County, more granite is exposed on the crest of the Farmington anticline, a Paleozoic structure. The granite outcrops are mostly along the channels of Jonca and Pickle Creeks and are partly within the boundaries of Hawn State Park. The Precambrian geology of that area is described in detail by Lowell and Hebrank *in* Kisvarsanyi (1976, p. 4-16). The outcrops are mainly coarse-grained biotite granite, probably correlative with the Butler Hill (Lowell, 1976). It is interesting to note that the granite outcrops in Ste. Genevieve County are near the center of another proposed caldera, the Hawn Park caldera, inferred by Cordell (1979) from geophysical data. As shown by drillholes, the area between the proposed Butler Hill and the Hawn Park calderas is underlain by Butler Hill-Breadtray-type granites. These alkali feldspar-biotite granites and granophyres appear to be the most widely distributed rocks forming the largest granite massifs in the St. Francois terrane (Kisvarsanyi, 1981).

Sources referred to in this road log are listed in the combined bibliography at the end of this Guidebook.

TRAVEL ON SAFELY!

END OF ROAD LOG NO. 1

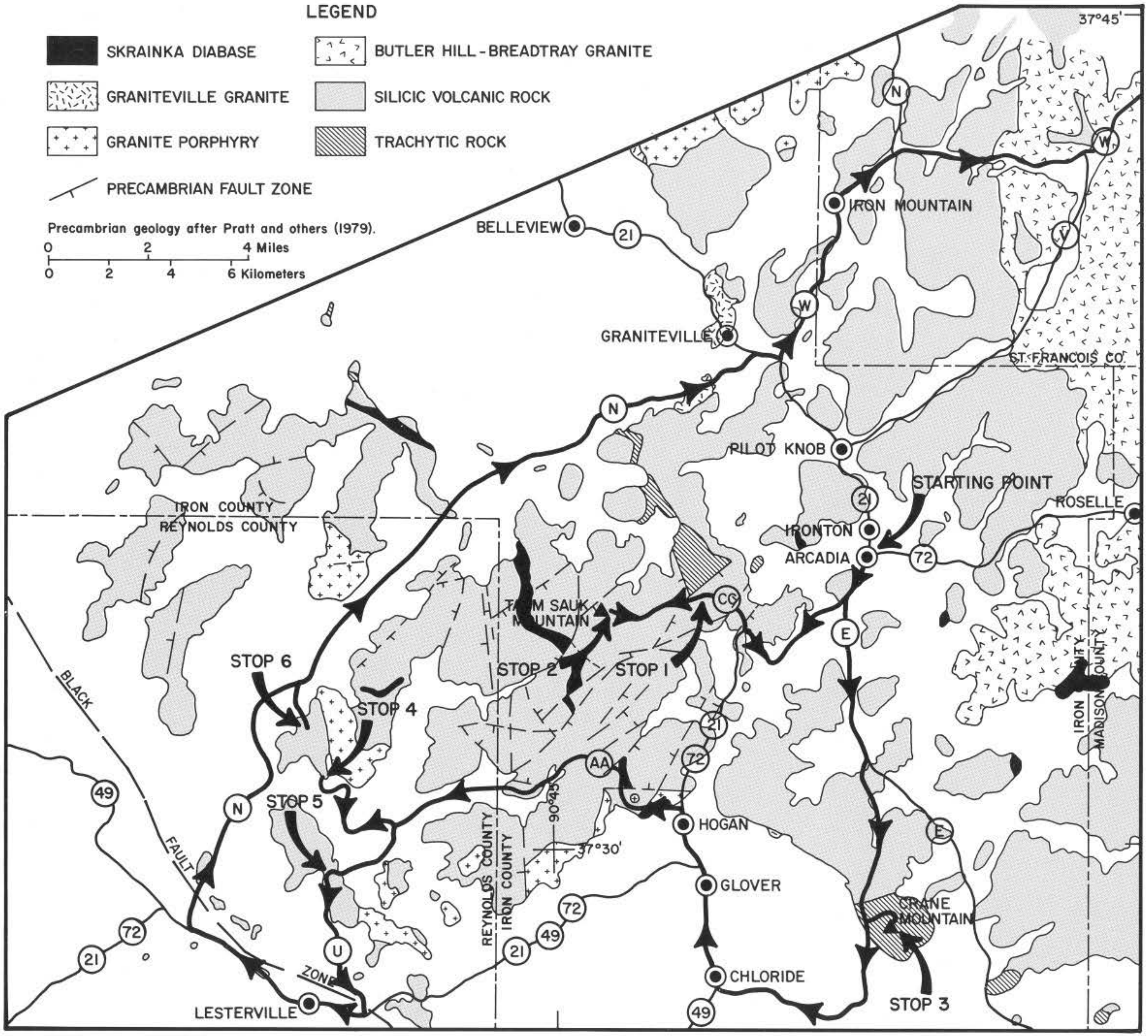


Figure 35. *Route map of Road Log No. 2. Total logged distance is 87.6 miles.*

ROAD LOG NO. 2 – THE VOLCANIC TERRANE

This route winds through the western part of the St. Francois Mountains (fig. 1) focusing on the volcanic rocks. Stops are scheduled on Russell Mountain (2- to 2.5-hour hike), on Taum Sauk Mountain (elevation 1772 ft above sea level, highest point in Missouri), on Crane Mountain, at Union Electric Company's Taum Sauk Pumped Storage Power Plant on Proffit Mountain, and at Johnson Shut-ins State Park (2-hour hike).

STARTING POINT (fig. 35):

Junction of Missouri Highways 21 and 72, Arcadia, Iron County, Missouri (NW¼ SE¼ N½ sec. 5, T. 33 N., R. 4 E).

Mileage Cum.	Diff.	
0.0		Proceed south from starting point on combined Missouri Highway 21-72.
	0.1	
0.1		Precambrian rhyolitic ash-flow tuff in roadcut on west side of road.
	0.5	
0.6		On the west side of the road, College Hill, a Precambrian knob, rises 240 ft above the sediment-filled valley to the north. Between the top of the hill and the Arcadia city water well, a distance of about 3000 ft, the relief on the Precambrian surface is 560 ft.
	0.6	
1.2		Outcrops of Bonneterre dolomite in the roadbank to the east.
	0.2	
1.4		Junction of Missouri Highway 21-72 with State Road E. Continue straight ahead (south) on Highway 21-72.
	0.2	
1.6		A quarry in Bonneterre dolomite is visible about 500 yd west of the road. This quarry was opened by the Porter-DeWitt Company in 1969 to produce concrete aggregate for the construction of Highways 21 and 72. Since then it has been operated intermittently by several small producers as a source of aggregate for local use. For the next 2.7 mi, Highway 21-72 skirts Vail Mountain and turns temporarily northward. Vail Mountain consists dominantly of rhyolitic ash-flow tuffs.
	0.2	

1.8		Bonneterre dolomite exposed on both sides of road.
	0.1	
1.9		Bonneterre dolomite exposed in east roadbank.
	0.4	
2.3		Residual chert boulders are scattered along the ridgetop for the next 2 mi. These boulders are derived from the Ordovician Gasconade Dolomite.
	1.8	
4.1		Tip Top Roadside Park and picnic area on the north side of the road. Large boulders are chert derived from the Gasconade Dolomite(?). An old railroad cut to the south exposes Paleozoic residuum.
	0.4	
4.5		Junction of Missouri Highway 21-72 with State Road CC. **Turn right (north) and follow State Road CC up Vail Mountain (elevation 1440 ft above sea level) and on to Russell Mountain (elevation 1726 ft above sea level).** Boulders and outcrops along road are volcanic rocks of rhyolitic composition.
	1.6	
6.1		**STOP 1.** Russell Mountain volcanic section (SE¼ SE¼ sec. 3 and SW¼ SW¼ sec. 2, T. 33 N., R. 3 E.).

Stop in the small parking area on the left (south) side of the road by the massive rhyolite outcrop; park and lock cars. This stop involves approximately a 2-hour hike.

The thick section of Precambrian rhyolitic volcanic rocks exposed on Russell, Vail, and Taum Sauk Mountains has been mapped in detail by R.E. Anderson (1962, 1970), by J.E. Anderson and others (1969), and by Berry (1970). The nomenclature of the different volcanic units is adapted from Berry (1976). The combined thickness of the volcanic units in the region is estimated to exceed 5000 ft. R.E. Anderson (1970) inferred that the volcanic rocks accumulated in an extra-caldera depression. J.E. Anderson and others (1969) proposed that the rocks are within the caldera, which they named the Taum Sauk caldera. Cordell (1979) found no geophysical expression of the Taum Sauk caldera as proposed by J.E. Anderson and others (1969). However, from subsurface data, Kisvarsanyi (1980) identified several circular, caldera-like structures (ring complexes) north and south of the exposed volcanic rocks.

Most of the rocks exposed in the area are ash-flow tuffs of alkali rhyolite composition. The most widespread unit, the Taum Sauk Rhyolite, locally more than 3000 ft thick, is believed by Sides (1978) to have been produced as the major collapse ash flow of the proposed Taum Sauk caldera, just as the Grassy Mountain Ignimbrite is considered to be the major collapse ash flow of the proposed Butler Hill caldera. In any case, the Taum Sauk and the Grassy Mountain are very similar in chemistry and mineralogy, and are the most voluminous ash flows in the western and eastern St. Francois Mountains, respectively.

The Buck Mountain Shut-ins Formation, shown in the northern part of figure 36, was defined by Berry (1976, p. 87) as a "sequence of black, andesitic lava flows containing white plagioclase phenocrysts; interbedded with bedded air-fall tuffs and at least one rhyolitic ash-flow tuff."

During our northeasterly traverse of Russell Mountain, along the Taum Sauk Trail, we shall encounter outcrops and float of four of the volcanic units shown in figure 36. In descending stratigraphic order, these are the Royal Gorge Rhyolite, a lava flow (STOPS 1A and 1B); the Bell Mountain Rhyolite, an air-fall tuff with a distinctive lithophysal zone (STOP 1C); a basal brecciated zone of the Wildcat Mountain Rhyolite, an ash-flow tuff (STOP 1D); and the Russell Mountain Rhyolite, an ash-flow tuff (STOP 1E).

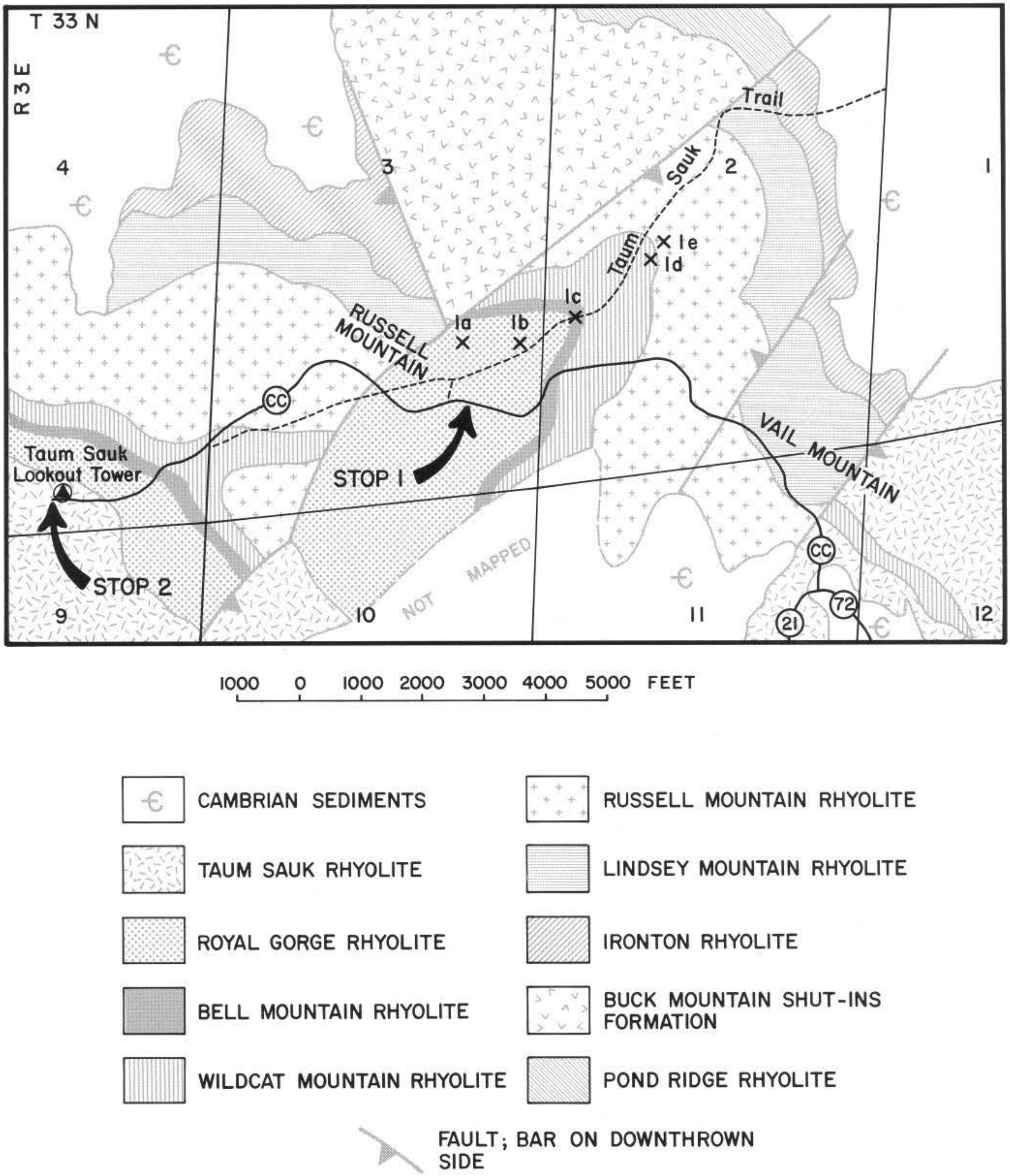


Figure 36. *Geologic map of Russell, Vail, and Taum Sauk Mountains, STOPS 1 and 2. Geology after Berry (1970, 1976).*

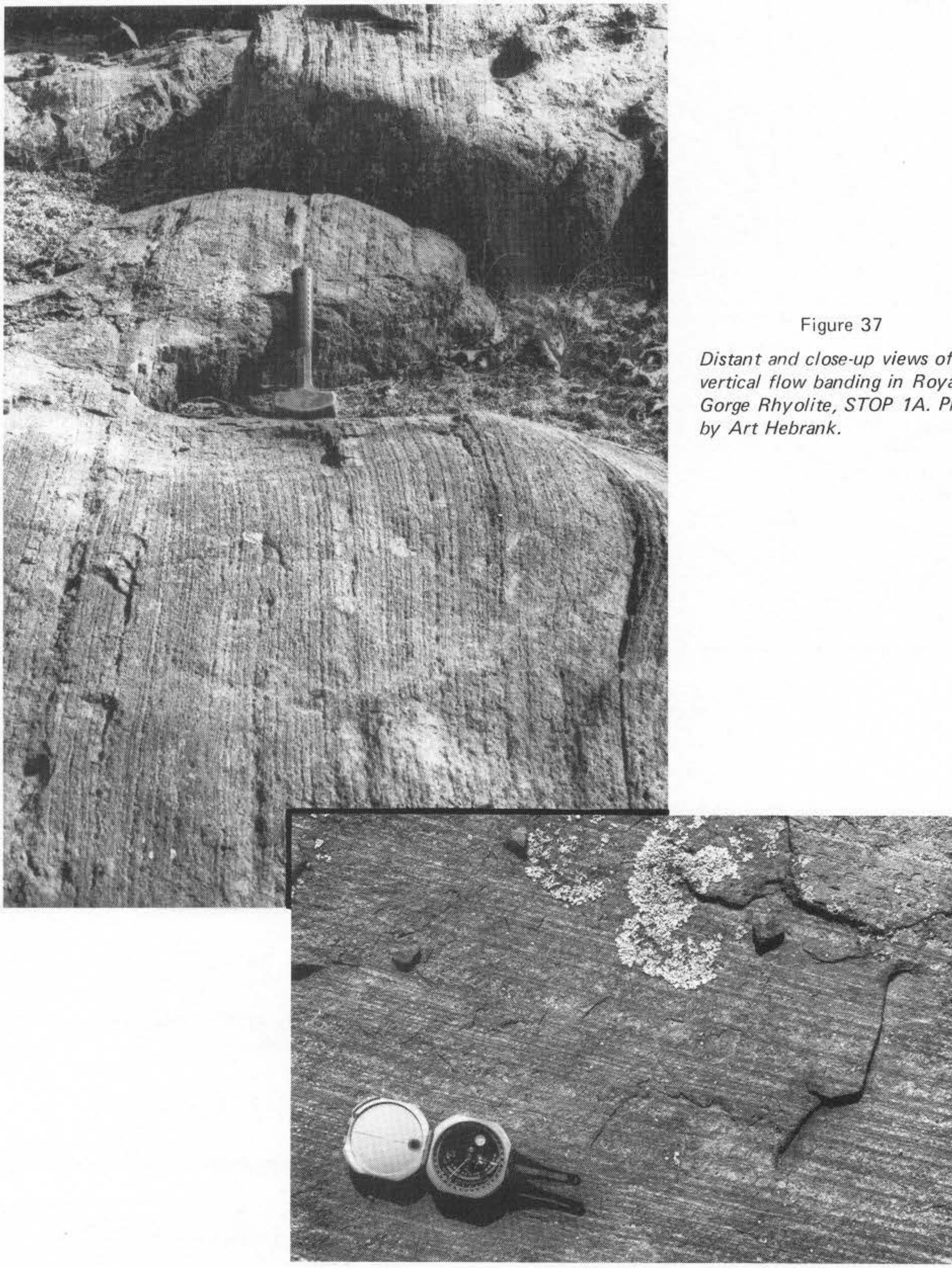


Figure 37

Distant and close-up views of vertical flow banding in Royal Gorge Rhyolite, STOP 1A. Photos by Art Hebrank.

Walk west 300 ft along the paved road, then turn north along a prominent logging road. Walk 300 ft along the logging road to its intersection with the Taum Sauk Trail, a jeep road at this point. Continue straight ahead through the woods another 100 ft to STOP 1A (fig. 36).

STOP 1A. Vertical flow banding in Royal Gorge Rhyolite (SE¼ SE¼ sec. 3, T. 33 N., R. 3 E.).

Approximately 100 ft north of the intersection of the logging road and the Taum Sauk Trail, the Royal Gorge Rhyolite forms massive outcrops. The rock, a red to maroon lava flow, contains 5 percent phenocrysts of quartz and alkali feldspar. At this locality, the lava flow is prominently banded, and the banding is nearly vertical (fig. 37). Berry (1970) measured dips of 85° E for the flow banding, and a strike of N 5° E. Individual flow bands may be followed on strike for several hundred feet. The following microscopic description of the banded lava flow is from Berry (1970, p. 139):

" . . . the maroon bands are devitrified glass having a well developed snowflake texture whereas the white bands are recrystallized pumiceous material with pronounced secondary crystallization. The outer edges of the white bands consist of a spherulitic intergrowth of quartz and feldspar from which tabular crystals of feldspar terminate in deformed amygdules. Secondary crystallization of quartz, feldspar, fluorite, calcite, and iron oxide have subsequently filled these cavities. 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 understood. According to Berry (1970), the lower part of the rhyolite is massive and not banded. Contorted, irregular banding and dips in different directions at various angles, sometimes approaching the horizontal, characterize the rhyolite elsewhere, as we shall see at STOP 1B. Perhaps the vertically banded outcrop is simply a fault block of the rhyolite turned up on edge. Possibly, it is part of a megabreccia, as described by Lipman (1976) from the San Juan Mountains, and we are looking at a huge breccia clast that has been rotated from its original position. Alternatively, the viscous flow either piled up against or flowed down over a near-vertical cliff just before it solidified. Then again, we may be looking at the fissure which the lava squeezed through before it froze in place.

Table 7

CHEMICAL ANALYSIS OF ROYAL GORGE RHYOLITE*

SiO_2	76.26
Al_2O_3	11.53
Fe_2O_3	2.22
FeO	0.31
MgO	0.03
CaO	0.00
Na_2O	0.13
K_2O	8.52
H_2O^+	0.46
H_2O^-	0.03
TiO_2	0.13
P_2O_5	0.01
MnO	0.03
F	0.02
Total	**99.68**

* Analysis no. 1 *in* Kisvarsanyi, 1972.

Return to Taum Sauk Trail and follow it 1200 ft northeastward along the ridgetop to STOP 1B (fig. 36).

STOP 1B. Irregular flow banding in Royal Gorge Rhyolite (SE¼ SE¼ sec. 3, T. 33 N., R. 3 E.).

In the large clearing with the rockpile near its center, just north of the Taum Sauk Trail, numerous outcrops of Royal Gorge Rhyolite can be seen. The flow banding is irregular, contorted, and dips in different directions at various angles (fig. 38). A chemical analysis of the rhyolite from its type locality in the Royal Gorge about 2.5 mi south of here along Highway 21-72 (SW¼ SE¼ sec. 14, T. 33 N., R. 3 E.) shows anomalously high K_2O content and low Na_2O content (table 7) for alkali rhyolite. R.E. Anderson (1970) suggested that the rock had been subject to a high degree of sodium leaching and potassium enrichment through post-cooling hydrothermal alteration. However, there is scant mineralogical evidence for large-scale hydrothermal alteration of the rhyolite.

Figure 38. *Contorted flow banding in Royal Gorge Rhyolite, STOP 1B. Photo by Art Hebrank.*

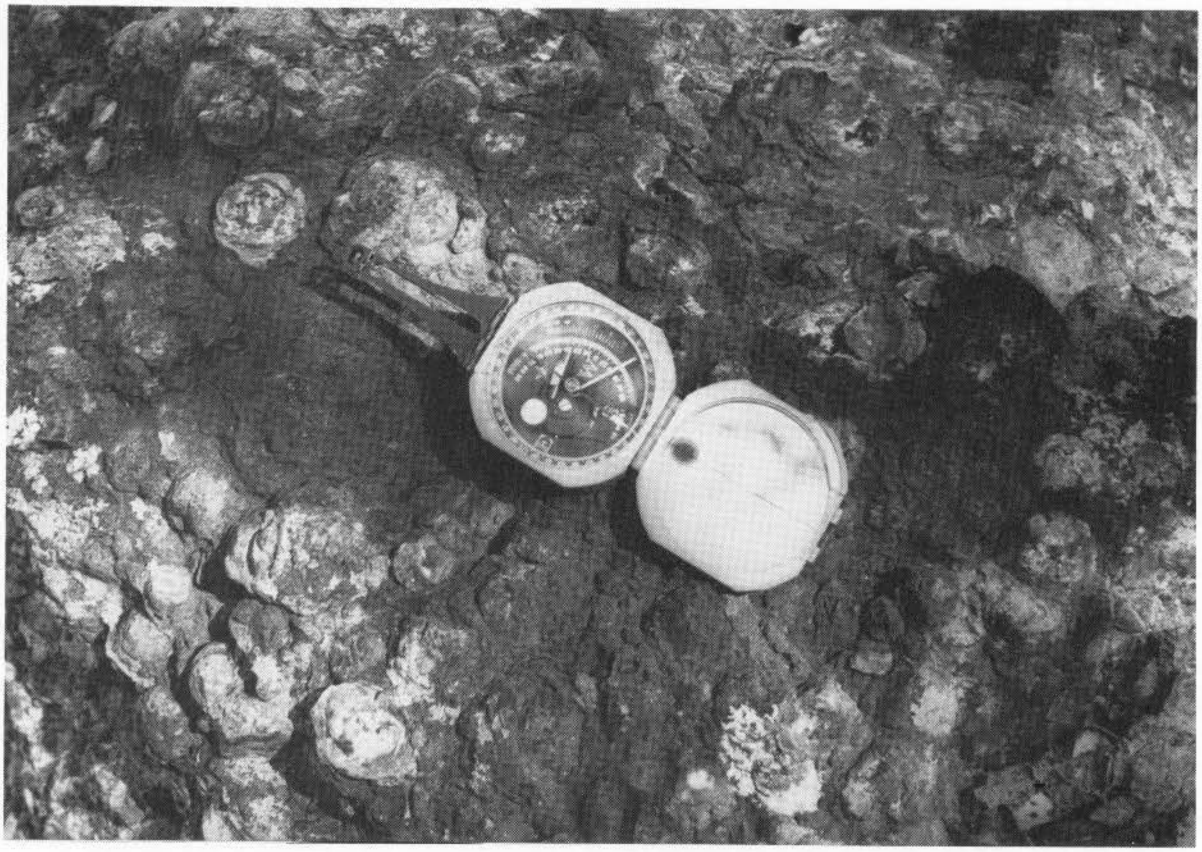


Figure 39. *Float of Bell Mountain Rhyolite showing weathered lithophysae ("thunder eggs"), STOP 1C. Photo by Art Hebrank.*

Return to Taum Sauk Trail and follow it about 1000 ft northeastward to STOP 1C (fig. 36).

STOP 1C. Bell Mountain Rhyolite float (SW¼ SW¼ sec. 2, T. 33 N., R. 3 E.).

Boulders and float of the Bell Mountain Rhyolite occur on both sides of the trail for a distance of about 100 ft. This widely exposed volcanic unit, an excellent stratigraphic marker in the western St. Francois Mountains, is described by Berry (1976) as a fine-grained, cross-bedded air-fall tuff, about 75 ft thick, containing a distinctive lithophysal ("thunder-egg") zone up to 15 ft thick, near the center of the unit.

The lithophysae (fig. 39) vary from a few millimeters to about 25 cm in diameter. They are more resistant to weathering than the tuff that contains them and may weather out. Their resistant outer rims consist of recrystallized tuff; their interiors are filled with fluorite, quartz, feldspar, or hematite.

Return to Taum Sauk Trail and follow it 1500 ft downhill to its intersection with the wide linear clearing, which spans a buried utilities line. Walk downhill (south) through the clearing approximately 200 ft to STOP 1D (fig. 36).

Figure 40. *Heterolithic breccia in basal portion of Wildcat Mountain Rhyolite, STOP 1E. Photo by Art Hebrank.*

STOP 1D. Brecciated zone in Wildcat Mountain Rhyolite (SW¼ SW¼ sec. 2, T. 33 N., R. 3 E.).

Massive outcrops on the slope are of a very coarse, heterolithic breccia, believed to be equivalent to the basal part of the Wildcat Mountain Rhyolite. The unit is defined by Berry (1976) as a 270-ft-thick ash-flow tuff containing 5 to 10 percent quartz and feldspar phenocrysts, and characteristic "white stringers" (crushed pumice?) of microcrystalline quartz and feldspar. According to Berry (1970), in many places there is a basal brecciated zone that includes fragments of the underlying Russell Mountain Rhyolite. The breccia at STOP 1D consists of diverse rock clasts of assorted sizes in a rhyolitic matrix (fig. 40). Dimensions of some clasts are measured in inches; others, in feet. Such an unsorted assemblage of heterogeneous rocks may have formed as a talus near the base of a steep slope before engulfment and possible remobilization by a subsequent ash flow, i.e., the Wildcat Mountain.

Walk northeast 200 ft uphill and cross utilities clearing to rocky clearing and STOP 1E (fig. 36).

STOP 1E. Eutaxitic structure and devitrification dikes in Russell Mountain Rhyolite (SW¼ SW¼ sec. 2, T. 33 N., R. 3 E.).

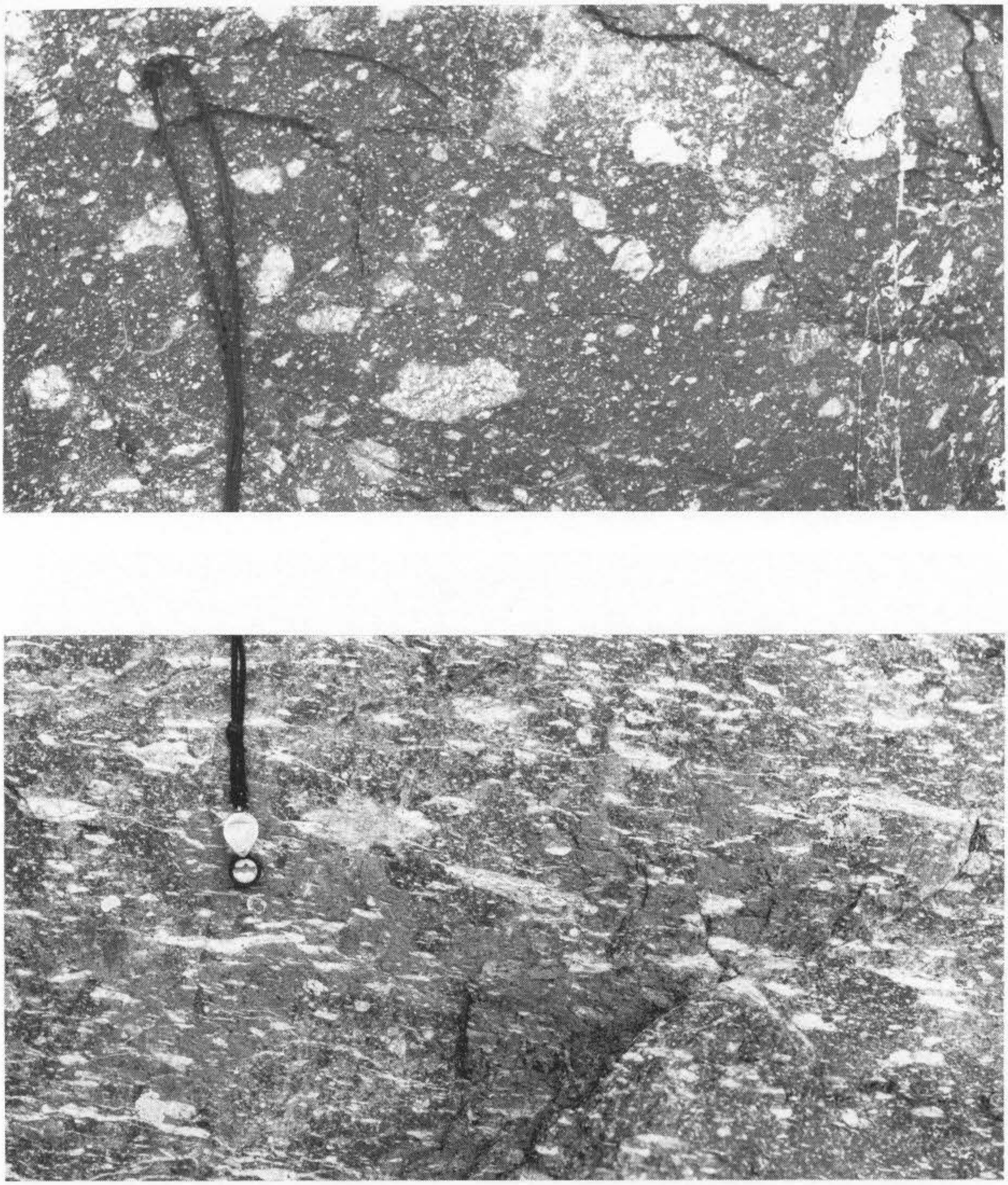


Figure 41. *Eutaxitic structure in Russell Mountain Rhyolite, STOP 1E. Top view (upper photo) and side view (lower photo) of this ash-flow tuff illustrate the characteristic shape of the crushed pumice fragments. Photos by Art Hebrank.*

Massive outcrops are of Russell Mountain Rhyolite. The unit is defined by Berry (1976) as a brick-red to dark-maroon ash-flow tuff with abundant, large fiamme and 2 to 5 percent white feldspar phenocrysts; it is 900 ft thick.

In these outcrops, the rock displays excellent compaction foliation; the compacted pumice fragments impart a distinctive eutaxitic structure to the tuff (fig. 41). Devitrification dikes, probably forming along tension cracks induced by slow creep of the still hot ash flow shortly after emplacement, form vivid pink parallel bands (fig. 42), and are believed to be perpendicular to the direction of creep.

Return to Taum Sauk Trail by walking about 200 ft north of the clearing. Retrace route by following the trail southwestward until the logging road is reached, then turn south to reach cars parked along State Road CC.

Continue by car, westward along State Road CC. The road winds along the ridgetop of Russell Mountain for about 0.5 mi, descends into the saddle between Russell and Taum Sauk Mountains for the next 0.5 mi, then climbs to Taum Sauk Mountain. Boulders and outcrops along the road are of the volcanic units shown in figure 36.

Figure 42. *Vertical view of devitrification dikes in Russell Mountain Rhyolite, STOP 1E. Photo by Art Hebrank.*

1.5

7.6 **STOP 2.** Taum Sauk Mountain Lookout Tower and Picnic Area (S½ sec. 4, T. 33 N., R. 3 E.).

Pull into parking lot by the picnic grounds; park and lock cars. This stop may include an **optional** hike to the top of Taum Sauk Mountain, or down the Taum Sauk Trail to Mina Sauk Falls and Devils Toll Gate (fig. 43). The hike requires several hours and the remainder of this road log should be planned accordingly.

The top of Taum Sauk Mountain, at 1772 ft above sea level the highest point in Missouri, is approximately 0.5 mi west of the lookout tower and may be reached via the northern trace of the Taum Sauk Trail (fig. 43). The "climb" to the top is almost level, as the difference in ground elevation between the "peak" and the lookout tower is only 13 ft. The southern trace of the trail descends steeply to Mina Sauk Falls, about 1.5 mi southwest of the picnic grounds. Mina Sauk Falls is the highest (132 ft) waterfall in Missouri; the Indian legend of its origin is recounted by Beveridge (1978). Devils Toll Gate, an additional 1 mi southwest of the falls, is an 8-ft-wide gap in rhyolite with steep, 30-ft-high walls. Both these scenic features are within the extensive outcrop area of the Taum Sauk Rhyolite, which forms the bulk of Taum Sauk Mountain and the surrounding hills.

The Taum Sauk Rhyolite is found only as float in the immediate vicinity of the picnic grounds.

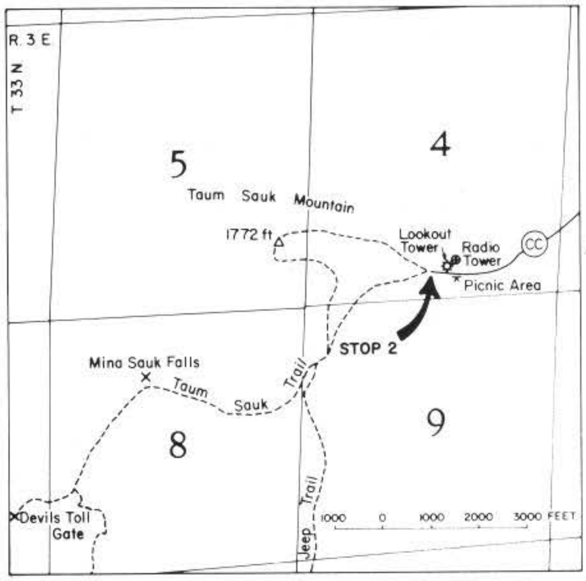


Figure 43

Trail map of Taum Sauk Mountain area, STOP 2.

Return to cars and retrace 3.1-mi segment of route along State Road CC to its junction with Missouri Highway 21-72.

3.1

10.7 Junction of State Road CC and Missouri Highway 21-72.

Turn left (east) and retrace 3.1-mi segment of route along Missouri Highway 21-72 to junction with State Road E.

3.1

13.8 Junction of Missouri Highway 21-72 with State Road E. **Turn right and proceed south on State Road E.**

0.5

14.3 Missouri Pacific Railroad overpass. Bonneterre dolomite is exposed in the deep railroad cut. The low rhyolite knob in the distance to the east is Crane Mountain (not to be confused with Crane Lookout Tower atop the mountain 6 mi to the south at STOP 3).

	0.8	
15.1		Cross over upper reaches of Marble Creek. Cuthbertson Mountain is immediately to the west.
	0.5	
15.6		Rhyolitic ash-flow tuff exposed in bank on west side of road.
	0.5	
16.1		Gravel road west leads to Cuthbertson Mountain manganese mine and outcrops of Precambrian stromatolitic limestone described in Kisvarsanyi, 1976, p. 46-50.
	0.9	
17.0		Cross over unnamed branch of Marble Creek. Bonneterre dolomite crops out on hillside to the southwest.
	0.2	
17.2		Cross over unnamed branch of Marble Creek. Junction with unmarked blacktop road (FH-69) to the south. **Turn right and proceed south on FH-69.** Bonneterre dolomite is exposed on the east side of State Road E at the junction.
	0.2	
17.4		Ledges of Bonneterre dolomite exposed in both roadbanks.
	0.8	
18.2		Cross over small creek branch; Bonneterre dolomite exposed on hillslope southeast of crossing. This coarsely crystalline dolomite is commonly referred to by area geologists as "white-rock" or "netted-rock" dolomite. It is an extensively recrystallized dolomite – originally a burrowed lime mud – that developed in shallow water on the flanks of the Precambrian high represented by the St. Francois Mountains. "White-rock" lithology is a prominent facies of Cambrian formations from the Bonneterre through the Potosi.
	0.1	
18.3		Bonneterre limestone exposed in small glade on east side of road. This pinkish-gray mottled limestone is informally referred to as the "Taum Sauk marble." It has been quarried intermittently on a small scale for use as dimension stone or, where more dense, terrazzo chips.
	0.4	
18.7		Cross over unnamed creek branch.
	0.3	
19.0		Road curves to left; boulders of rhyolite on east hillslope.
		About 100 ft farther south, Precambrian bedded tuff is exposed along the east side of the road. The tuff is dark gray, fine grained, and is traversed by micro-veinlets of quartz.
	0.2	
19.2		Small outcrop(?) of Grassy Mountain Ignimbrite about halfway up the hill on east side of road. In this outcrop, the rock is somewhat brecciated.
	0.3	

19.5		Large boulders of Grassy Mountain Ignimbrite along ridgetop.
	0.4	
19.9		Small outcrop(?) of Grassy Mountain Ignimbrite in east roadbank.
	0.2	
20.1		Outcrops of trachyte porphyry on west side of road.
	0.4	
20.5		Begin short, steep descent; small outcrop of trachyte porphyry on east side of road.
	0.4	
20.9		Junction with Forest Service Road 2192. **Turn left and proceed east on Forest Service Road 2192.** This road leads up to a mountaintop where a recently dismantled lookout tower stood. The U.S.G.S. Des Arc NE 7½-minute quadrangle map (1968) still indicates the landmark as Crane Lookout Tower. The local name for the 1500-ft-high mountain is Crane Mountain, but it is not to be confused with Crane Mountain proper, 6 mi to the north and shown on both the Ironton and Lake Killarney 7½-minute topographic maps (1968). Outcrops and boulders on upper slopes of mountain are trachyte porphyry.
	0.9	
21.8		**STOP 3.** Crane Lookout Tower (SE¼ SE¼ NE¼ sec. 8, T. 32 N., R. 4 E.).

Park cars in clearing near the summit of the mountain. This stop involves a short, approximately one-half-hour hike.

Walk about 50 ft west, downhill from the summit to massive outcrops along the western slope of the mountain.

The southeast rim of Crane Mountain affords an excellent view across the Sabula basin to the southwest, and of the surrounding mountain range of which Crane Mountain is a part. Looking northwest, Ketcherside and Hogan Mountains are visible, and on a clear day the top of Taum Sauk Mountain, some 7 mi distant, may be seen. In good weather the sweeping vista to the southwest is broken only by the highest peaks of the mountains in the Eminence area on the far horizon, some 40 mi distant.

The Sabula basin is a down-dropped block, similar to the Belleview basin, filled with Cambrian sediments and bounded by northeast- and northwest-trending lineaments. The northeast boundary is a steep scarp consisting of a narrow, northwest-trending mountain range which is coincident with the West Belleview-East Sabula lineament as defined by Kisvarsanyi and Kisvarsanyi (1976). Crane Mountain forms the southeastern abutment of this range, and Ketcherside Mountain its northwestern part. The northwestern boundary of the Sabula basin is defined by a northeast-trending mountain front consisting of Hogan and Vickery Mountains, and corresponds to the Hogan lineament of Kisvarsanyi and Kisvarsanyi (1976). The southeast and southwest boundaries of the basin are less well defined, but remote-sensing imagery indicates that the southeast boundary is coincident with the Annapolis lineament.

The sediments of the basin have been dissected by stream erosion into a relatively rugged topography; however, the bordering mountain ranges average about 500 ft higher than the ridgetops of the basin (fig. 44). Drillholes indicate that the Precambrian surface at Glover is approximately 250 ft above sea level. On Ketcherside Mountain, Precambrian rocks are exposed at 1700 ft above sea level. In a distance of a little over 2 mi, the Precambrian surface has a relief of 1450 ft. The Sabula basin is inferred to be underlain by one of the central plutons of the St. Francois terrane (Kisvarsanyi, 1980).

Along the southwest face of Crane Mountain, massive outcrops of Precambrian trachyte porphyry form step-like cliffs. The rock is dark-reddish-brown,

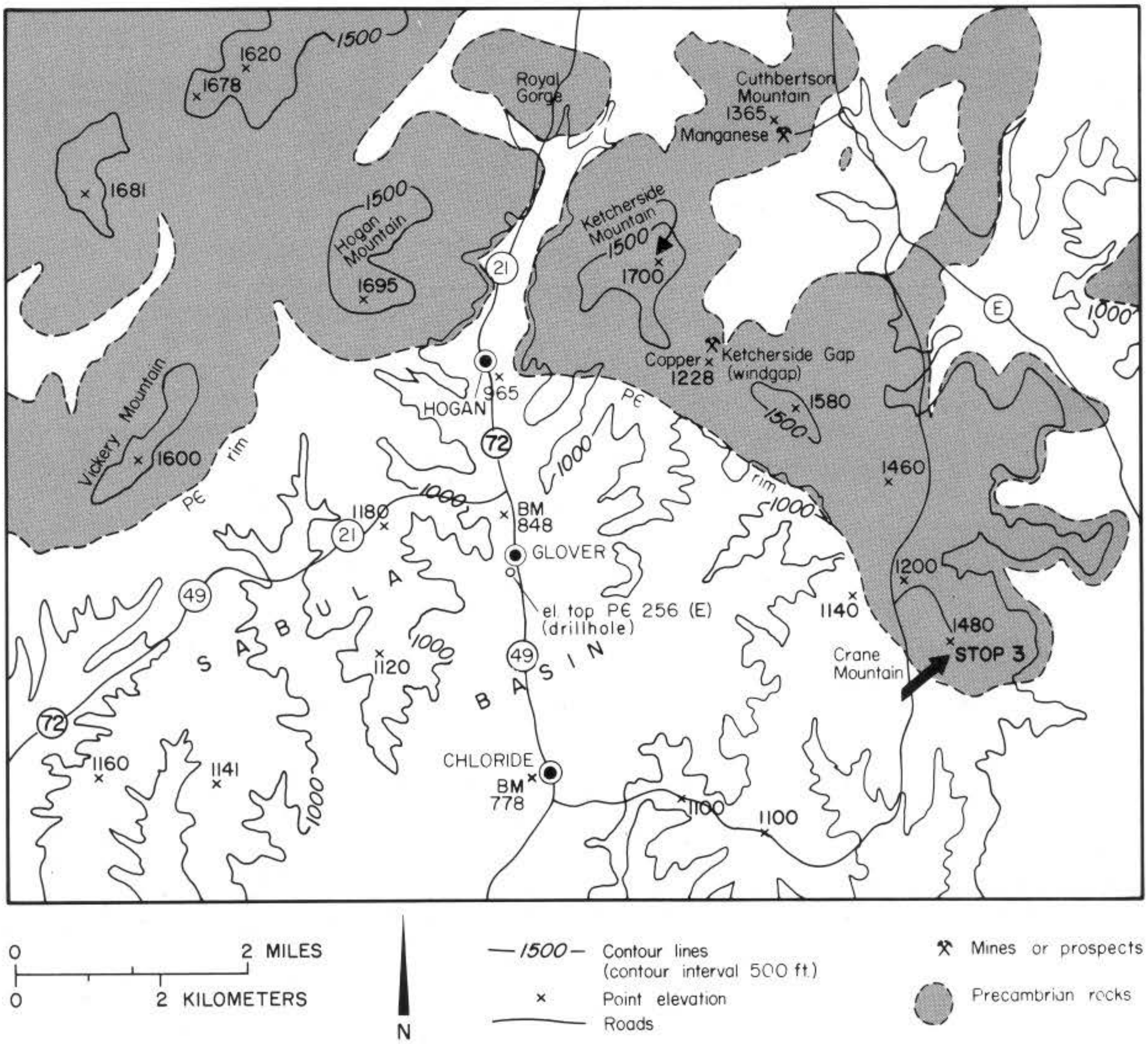


Figure 44. *Generalized topographic and geologic map of the Sabula basin and surrounding mountains, STOP 3.*

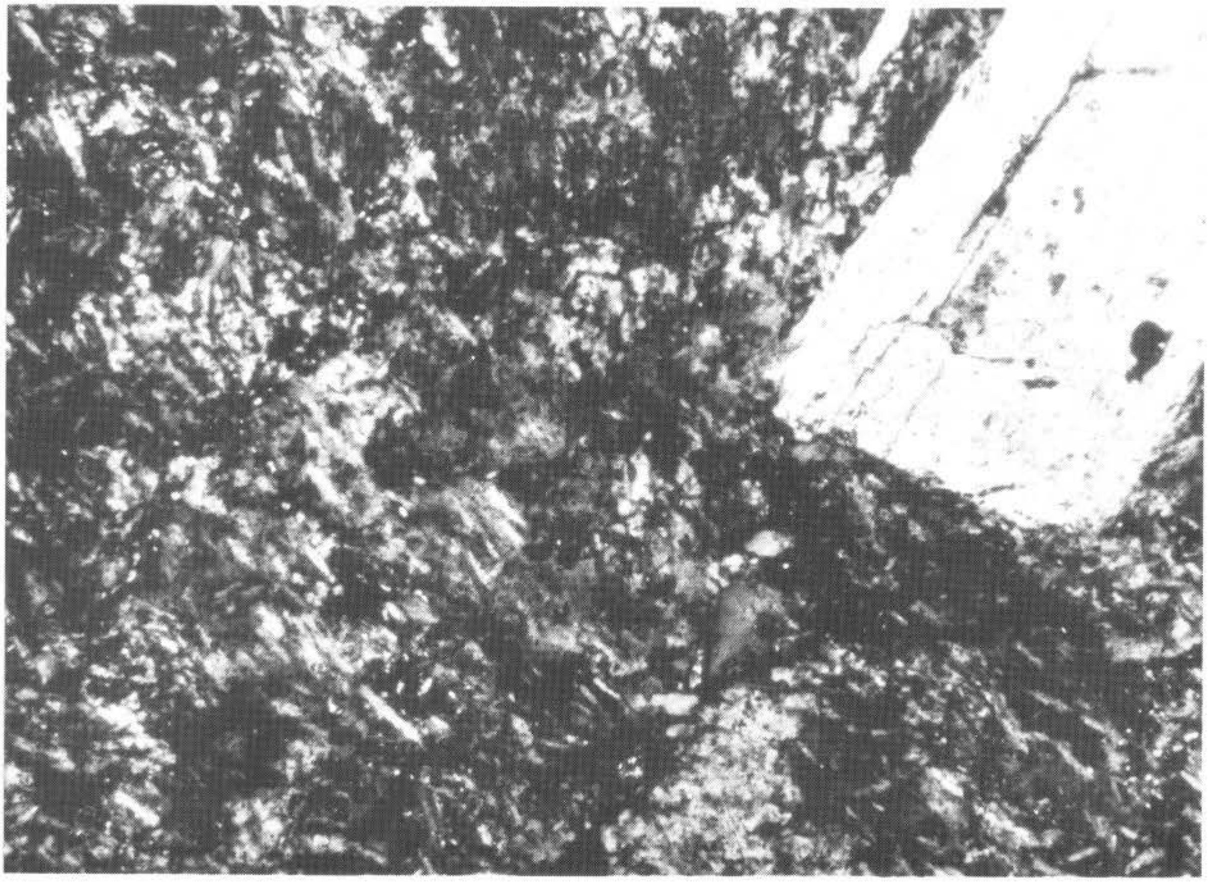
with abundant phenocrysts of sodic plagioclase and orthoclase in a holocrystalline groundmass. The groundmass has fine-grained trachytic texture characterized by fluidal arrangement of tabular feldspar microlites, and contains abundant magnetite grains (fig. 45).

The rock has been fractured and sheared and is locally mildly propylitized. Quartz, epidote, and clinozoisite fill microfractures that traverse the rock, and completely replace former ferromagnesian minerals. Development of calcite, chlorite, iron oxide, and sericite accompanies the alteration. Veins of epidote and hematite, 1 to 2 inches thick, occur in highly fractured zones near the base of the outcrop.

Near the top of the cliff-forming outcrops, the trachyte porphyry contains conspicuous xenolithic masses of a dense, dark-gray rock. The inclusions range in size from a few inches to several feet and are frequently twisted and contorted. They have sharp contacts with the enclosing rock. Traces of relict bedding are faintly discernible on slabbed surfaces, and microscopic observations indicate that the inclusions represent fragmented and recrystallized vitric-tuff beds that were caught up in the trachyte-porphyry flow.

The major fracture traces on Crane Mountain strike northwest and are subparallel to the West Belleview-East Sabula lineament. The combination of fracturing, straight-line relationship of the mountain scarp and the Sabula basin, difference in elevation of the Precambrian surface across the mountain-basin boundary, and configuration of the total magnetic-intensity map of the area (fig. 46) suggests that the northeast boundary of the Sabula basin is a normal fault and that Crane Mountain forms part of the relatively uplifted northeast block.

Return to cars. **Descend from Crane Mountain by retracing 0.9-mi segment of Forest Service Road 2192 to its junction with road FH-69.**



0.5 mm

Figure 45. *Photomicrograph showing trachytic texture in trachyte porphyry from Crane Mountain, STOP 3. Large phenocryst in upper right is alkali feldspar. Crossed polars. Photo by Art Hebrank.*

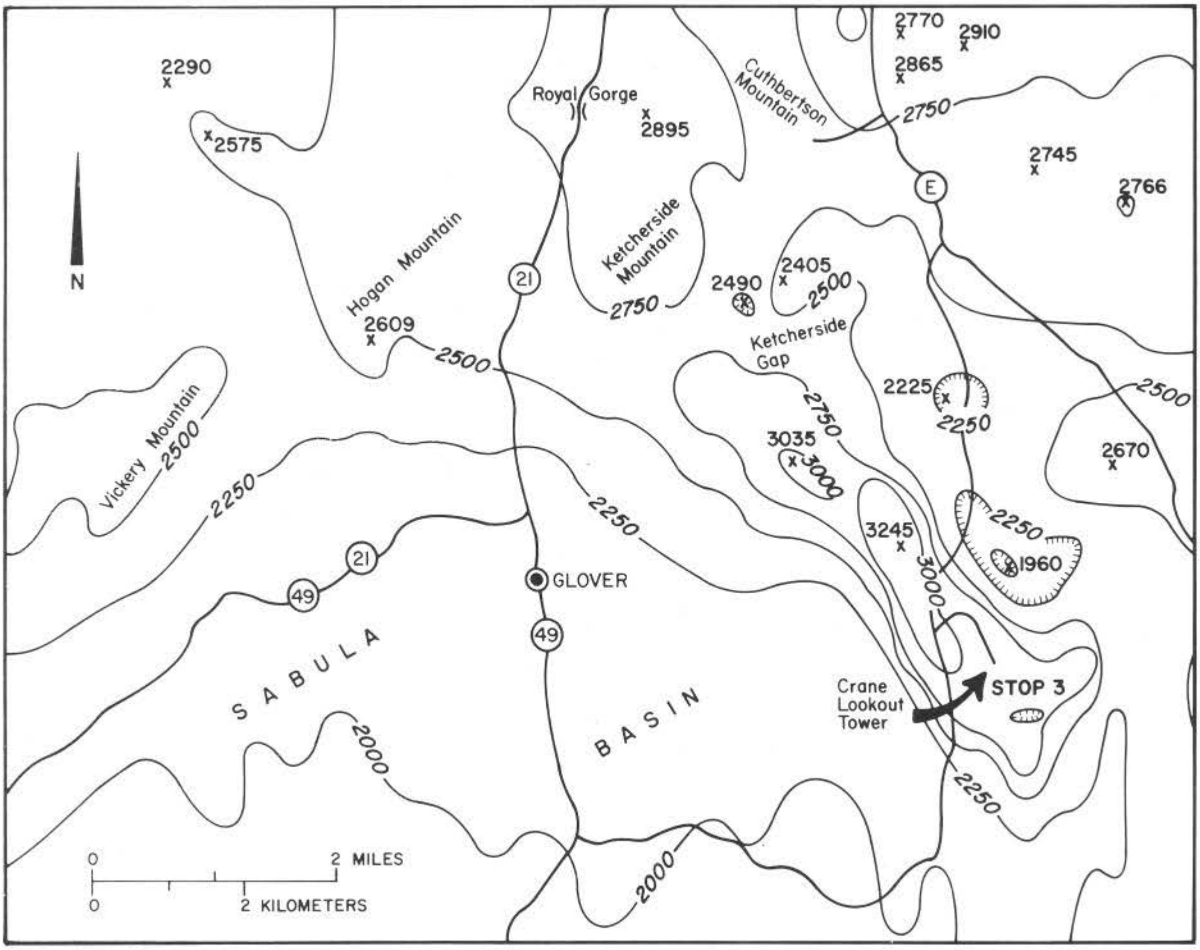


Figure 46. *Total-intensity aeromagnetic map of parts of the Ironton and Des Arc 15-minute quadrangles. Map covers the same area as figure 44. Adapted from U.S. Geological Survey and Missouri Geological Survey, 1949. Contour interval 250 gammas.*

	0.9	
22.7		Junction with road FH-69. **Turn left and proceed south on FH-69.** The road passes southward through a thickly forested area in the Sabula basin.
	0.9	
23.6		Residual blocks of sandstone along both sides of road.
	0.3	
23.9		Chert and sandstone residuum in road ditches and banks.
	0.7	
24.6		Intersection of unmarked north-south and east-west gravel roads. **Turn right and proceed west on east-west road.**
	0.2	

24.8		Cross over Crane Pond Creek; ascend hill. Chert and sandstone residuum in roadbanks and ditches along ridgetop for next 2.5 mi.
	2.7	
27.5		Begin steep descent into Big Creek valley.
	0.2	
27.7		Bonneterre dolomite outcrop along north side of road for next 0.1 mi.
	0.3	
28.0		Cross unnamed branch of Big Creek.
	0.1	
28.1		Bonneterre dolomite on north side of road.
	0.1	
28.2		Cross low-water bridge on Big Creek. **CAUTION**: Bridge is impassable after heavy rains.
	0.1	
28.3		Missouri Pacific Railroad crossing, and junction with Missouri Highway 49. **Turn right and proceed north on Highway 49.** Proceed through Sabula basin toward Precambrian rim about 3 mi ahead. Low hills within the basin consist of Cambrian sediments.
	0.3	
28.6		Passing through the "one-house" village of Chloride.
	0.3	
28.9		Small outcrops of Cambrian (Bonneterre?) dolomite on west side of road.
	0.1	
29.0		Cambrian (Bonneterre?) dolomite exposed discontinuously (best along west side of road) for next 0.5 mi. Solution weathering has produced a well-developed, pinnacled surface.
	0.6	
29.6		Cross Missouri Pacific Railroad spur to lead smelter.
	0.4	
30.0		Bridge over Scroggins Branch. ASARCO Incorporated's Glover lead smelter is to the west. The multimillion-dollar facility started production in 1968 and has an annual capacity of 110,000 tons of refined lead. The plant processes lead-ore concentrates from mines in the Viburnum Trend lead-zinc-copper deposits about 20 mi to the west. Cleaned gas, cooled and filtered to remove particulates, is emitted through the 610-ft concrete stack (fig. 47).
	0.7	
30.7		Outcrops of Cambrian (Bonneterre?) dolomite on west side of road.
	0.2	
30.9		Bridge over Goff Creek.
	0.1	
31.0		Junction of Missouri Highway 49 with Missouri Highway 21-72. Continue straight ahead (north) on Highway 21-72.
	1.3	

Figure 47. *ASARCO Incorporated lead smelter and refinery (SW¼ SW¼ sec. 2, T. 32 N., R. 3 E.), 800 ft west of mileage point 30.0, Glover, Missouri. Photo by Jerry Vineyard.*

32.3 Village of Hogan, and junction of Missouri Highway 21-72 with State Road AA to the west. **Turn left and proceed west on State Road AA.**

Hogan Mountain, rising to an elevation of 1639 ft above sea level, is immediately north of the road. Royal Gorge, another of the picturesque shut-ins of the St. Francois Mountains, is about 2 mi north of this junction on Highway 21-72.

We are now re-entering the area of the proposed Taum Sauk caldera. The bulk of Hogan Mountain is formed of thick ash-flow tuff of the Taum Sauk Rhyolite discussed at STOP 1 of this road log.

0.6

32.9 Bonneterre dolomite exposed for 0.1 mi along south side of road.

0.2

33.1 Low cuts on south side expose Bonneterre dolomite.

0.1

33.2 Cuts on both sides of road expose a coarse boulder conglomerate. Most boulders are Taum Sauk Rhyolite and are extensively weathered. From the east, beds of Lamotte sandstone and siltstone interfinger with the boulders.

0.1

33.3 Carver Creek Granite Porphyry, exposed in low cuts on both sides of the road, is interpreted as a ring dike along the southeastern margin of the proposed Taum Sauk caldera (J.E. Anderson and others, 1969). The rock contains alkali feldspar and amphibole phenocrysts in an ultrafine granophyric groundmass. Biotite, magnetite, zircon, and apatite are present in small amounts.

The granite porphyry is intruded by a diabase dike near the western end of these cuts. The dike is deeply weathered; its existence is indicated by a yellow-green soil zone, and scattered exfoliated boulders.

0.4

33.7 Victory Baptist Church on south side of road. Low cuts on north side of road expose Taum Sauk Rhyolite.

0.2

33.9 Carver Creek Granite Porphyry forms massive outcrops on east side of road.

0.4

34.3 Cut on east side of road exposes deeply weathered Taum Sauk Rhyolite.

0.1

34.4 Small shut-ins on west side of road in Taum Sauk Rhyolite.

0.1

34.5 Cut on east side of road exposes Taum Sauk Rhyolite. This ash-flow tuff exhibits excellent compaction foliation; large, angular, crushed pumice fragments, some as large as one meter long, impart a distinctive eutaxitic structure (fig. 48).

Road crosses over Carver Creek.

0.4

34.9 Low cuts along west side of road expose Taum Sauk Rhyolite.

0.3

35.2 State maintenance ends. Unmarked paved road makes a sharp turn to the southwest. The road straight ahead leads to Devils Toll Gate scenic feature (mentioned at STOP 2), but becomes rough and impassable for passenger cars.

Follow the unmarked paved road to the left, proceeding southwestward from the end of State Road AA.

0.2

35.4 Deep road cut in Paleozoic residuum.

0.3

35.7 Outcrop of Taum Sauk Rhyolite on south side of road. Crushed pumice fragments define a prominent eutaxitic structure; compaction foliation is nearly vertical and strikes about N 20° W.

0.2

35.9 Very coarse, basal boulder conglomerate exposed in cut on south side of road. Most boulders are Taum Sauk Rhyolite.

0.5

36.4 Cross over Little Taum Sauk Creek.

For the next 3 mi the road parallels Little Taum Sauk Creek, which has cut a narrow valley into the Precambrian rocks exposed on both the north and south upper hillslopes. Cambrian sedimentary rock is locally exposed throughout the valley floor.

0.1

36.5 Low cuts on north side of road expose Bonneterre Formation: dark gray, fine-grained, medium-bedded dolomite intercalated with siltstone and shale. The section is increasingly shaly near the top.

0.2

36.7 Bonneterre dolomite in north road ditch.

0.7

37.4 Small outcrop of Bonneterre dolomite in gully on north side of road.

0.1

37.5 Along the south bluff of Little Taum Sauk Creek, just south of the road, the type section of Brightman's (1938) "Taum Sauk member of the Bonneterre Formation" is exposed. This 150-ft-thick section of finely crystalline limestone, dolomitic limestone, and coarse crystalline dolomite was described by Howe (1968) as an atypical, progressively dolomitized, time-transgressive carbonate facies in the Bonneterre and younger Cambrian formations. The facies consists of alternating planar stromatolites and burrowed carbonate mud; its distribution near Precambrian highland areas throughout southeastern Missouri was considered by Howe (1968) to be supportive evidence for sedimentation in a protected environment, with minimal wave and current activity. The section exposed here is described in detail by Howe (1968, p. 75-77).

0.1

Figure 48. *Spectacular eutaxitic structure in Taum Sauk Rhyolite. East side of State Road AA, at mileage point 34.5 (NW¼ NE¼ NW¼ sec. 28, T. 33 N., R. 3 E.). Photo by Art Hebrank.*

37.6 Enter Reynolds County. For the next 2 mi, road passes between Church Mountain on the north and Vickery Mountain on the south. Both are Precambrian hills rising about 1600 ft and 1400 ft above sea level, respectively. The Taum Sauk Rhyolite is the dominant rock exposed on both hills.

0.9

38.5 Very small outcrop of Bonneterre dolomite on north side of road where it intersects nose of hill.

1.5

Figure 49

The Upper Reservoir of Union Electric Company's Taum Sauk Power Plant as seen from the valley of Little Taum Sauk Creek. View is north from mileage point 40.1 (NW¼ NE¼ SE¼ sec. 27, T. 33 N., R. 2 E.). Photo by Art Hebrank.

Figure 50. *The Lower Reservoir of Union Electric Company's Taum Sauk Power Plant. View is south from mileage point 41.0 (NW¼ SW¼ SW¼ sec. 27, T. 33 N., R. 2 E.). Photo by Art Hebrank.*

40.0		Junction with extension of State Road U from the south. **Continue straight ahead to Taum Sauk Hydroelectric Power Plant.**
	0.1	
40.1		The Upper Reservoir of Union Electric Company's Taum Sauk facility is visible in the distance to the north (fig. 49).
	0.1	
40.2		Low-water bridge across Taum Sauk Creek.
		CAUTION: impassable during high water.
	0.6	
40.8		Small barrow pit in Paleozoic residuum on north side of road.
	0.2	
41.0		The Lower Reservoir of the Taum Sauk Power Plant is visible to the south, at the junction with the lake access road (fig. 50). A 75-ft-high concrete dam was constructed in 1963 to impound the East Fork of the Black River for pumped-storage electric power generation. Covering an area of approximately 200 acres, the average volume of water in the reservoir

is about 2 billion gallons, but the maximum capacity of the reservoir is nearly twice that much (oral communication, David Hoffman, Missouri Department of Natural Resources, Dam Safety Program).

Road turns sharply north towards Proffit Mountain.

0.2

41.2 Roadcuts for the next 0.8 mi expose residuum containing predominantly chert of the Gasconade Dolomite and Roubidoux sandstone boulders.

0.4

41.6 Cut on east side of road exposes a residual bed of Roubidoux sandstone.

0.3

41.9 Large pit on east side of road is in Gasconade and Roubidoux residuum; prominent bedding is exhibited in this clay, chert, and sandstone regolith. Material from the pit was used for road metal during construction of the power plant.

0.1

42.0 Entrance gate to Union Electric Company's Taum Sauk Pumped Storage Hydroelectric Power Plant. The Taum Sauk Nature Museum and Visitor Center is immediately beyond the gate on the east side of the road. A parking area, picnic tables, refreshment- and rest-facilities are available, and visitors are welcome. A scaled-down model of the power plant is displayed on the outside wall of the Visitor Center. An optional stop is recommended to view the exhibits.

0.1

42.1 Massive outcrops and boulders high on the hillslope to the north are of Munger Granite Porphyry.

The Munger Granite Porphyry is believed to be part of the ring intrusion around the proposed Taum Sauk caldera (see fig. 35). It is very similar in chemistry and mineralogy to the Carver Creek Granite Porphyry.

0.1

42.2 Road bifurcates. **Turn left and proceed downhill (west) toward power plant.** Road to right leads uphill to the Upper Reservoir about 1.5 mi north.

Large boulders of Munger Granite Porphyry are float over Paleozoic residuum along north side of road.

Paleozoic residuum is exposed in cuts for next 0.5 mi to base of hill. Some sandstone and massive chert beds retain a crude bedding.

0.9

43.1 Sharp turn to right (east). **Turn again immediately into large open area to the east (outside of gate).**

STOP 4. Union Electric's Taum Sauk Power Plant and Precambrian-Paleozoic erosional unconformity (NE¼ SE¼ SW¼ sec. 21, T. 33 N., R. 2 E.).

Park and lock cars. Walk through the gate and down the road into the cut, about 300 ft in an easterly direction. (Passenger cars could proceed an additional 0.1 mi through the gate to the parking lot by the power station, but busses could not turn around in the cul-de-sac at the foot of the steep rock cuts.)

Constructed at a cost of 50 million dollars, the power plant and reservoirs were completed in 1963. It was one of the first and, at the time, the largest pumped-storage plant in the United States. It has the capacity to generate 350,000 kilowatts of electricity. During periods of low demand, excess electricity from distant steam-turbine generating plants is used to pump water uphill through a 6600-ft-long tunnel into the Upper Reservoir for storage; at times of peak demand for electricity, the water runs back down through the turbines, generating power. Pumping is performed by reversing rotation of the generating units. The operation of the plant is automatic, remotely controlled from the Company's Osage plant and from the dispatcher's office in St. Louis.

At the time of its construction, the Upper Reservoir was hailed as an engineering marvel. It is carved out of the top of Proffit Mountain 1579 ft above sea level; its surface covers approximately 55 acres (fig. 51). Its concrete-lined walls are 94 ft high and will hold 1.5 billion gallons of water (oral communication, David Hoffman, Missouri Department of Natural Resources, Dam Safety Program).

Figure 51. *Aerial view of the Upper Reservoir atop Proffit Mountain (SW¼ sec. 15, T. 33 N., R. 2 E.). Photo by Jerry Vineyard.*

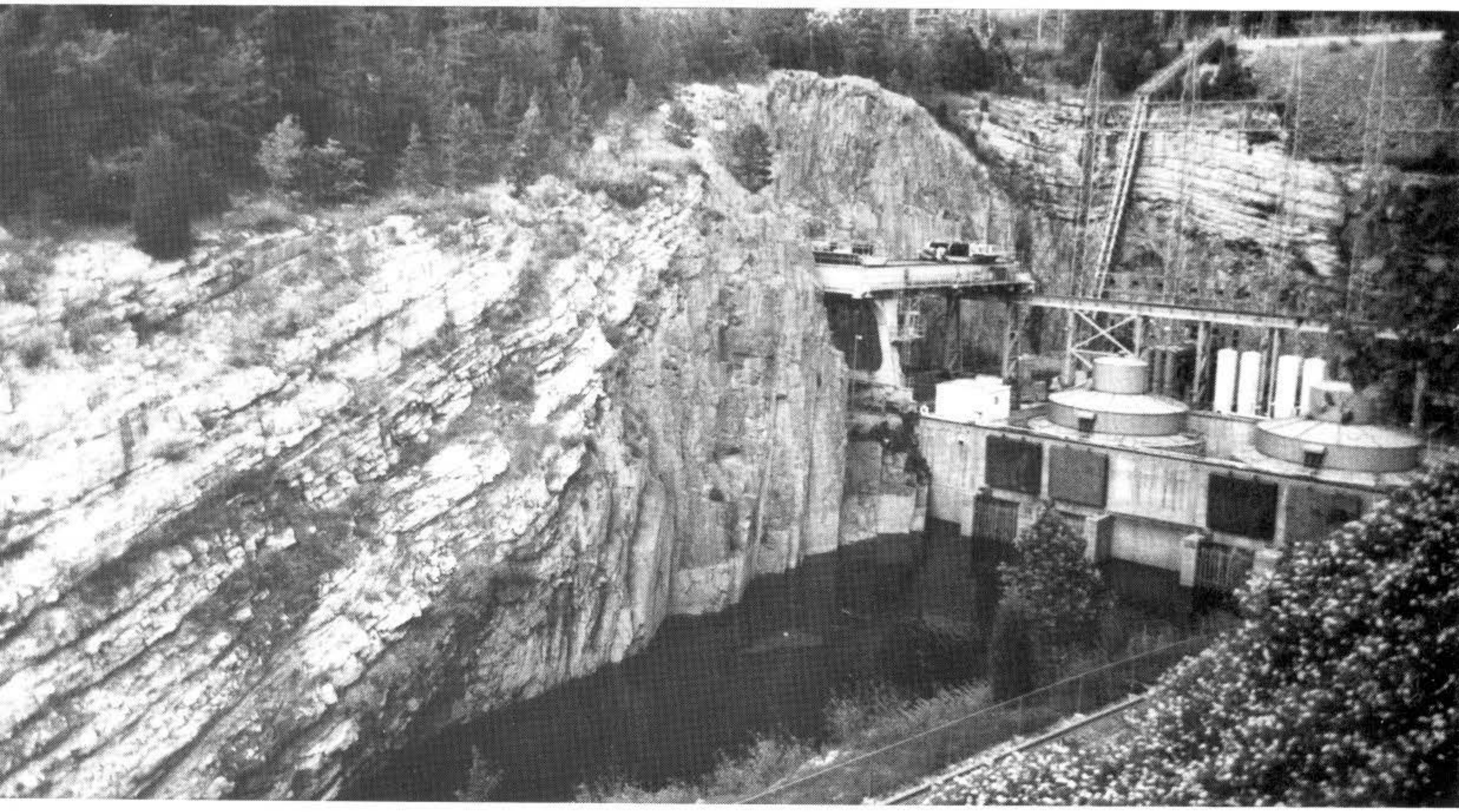


Figure 52. *Power station of the Taum Sauk Hydroelectric Plant at the base of Proffit Mountain. The U-shaped cut exposes a Precambrian knob of Taum Sauk Rhyolite overlapped from the west by Davis and Derby-Doerun sedimentary beds. View to the northeast, STOP 4. Photo by Art Hebrank.*

The U-shaped cut at the power station exposes massive Precambrian ash-flow tuff (Taum Sauk Rhyolite) overlain by Upper Cambrian sedimentary rocks. It stands some 100 ft above the tailrace and reveals a spectacular three-dimensional cross section of the Precambrian-Paleozoic erosional unconformity (fig. 52). Weathering has produced a few tens of feet of relief on the rhyolite surface. In the north face of the cut, the rhyolite knob is exposed at the ground surface, the overlying sediments having been removed by erosion. In the east and south faces of the cut, the knob is still buried by sediments (fig. 53).

The rhyolite is overlain by beds of shaly and arkosic dolomite, a sequence of alternating stromatolitic and burrowed carbonate muds assigned by Howe (1968) to the upper Davis Formation and the Derby-Doe Run Dolomite. The dolomite laps on to the Precambrian surface from the west and has a maximum dip of 25 degrees (fig. 54). The steep dips are attributed to differential compaction of unconsolidated sediments deposited over the uneven rhyolite surface. Howe (1968) believes that the combined effects of carbonate solution, dolomitization, and compaction of argillaceous layers caused a loss of volume in the sedimentary beds, and that

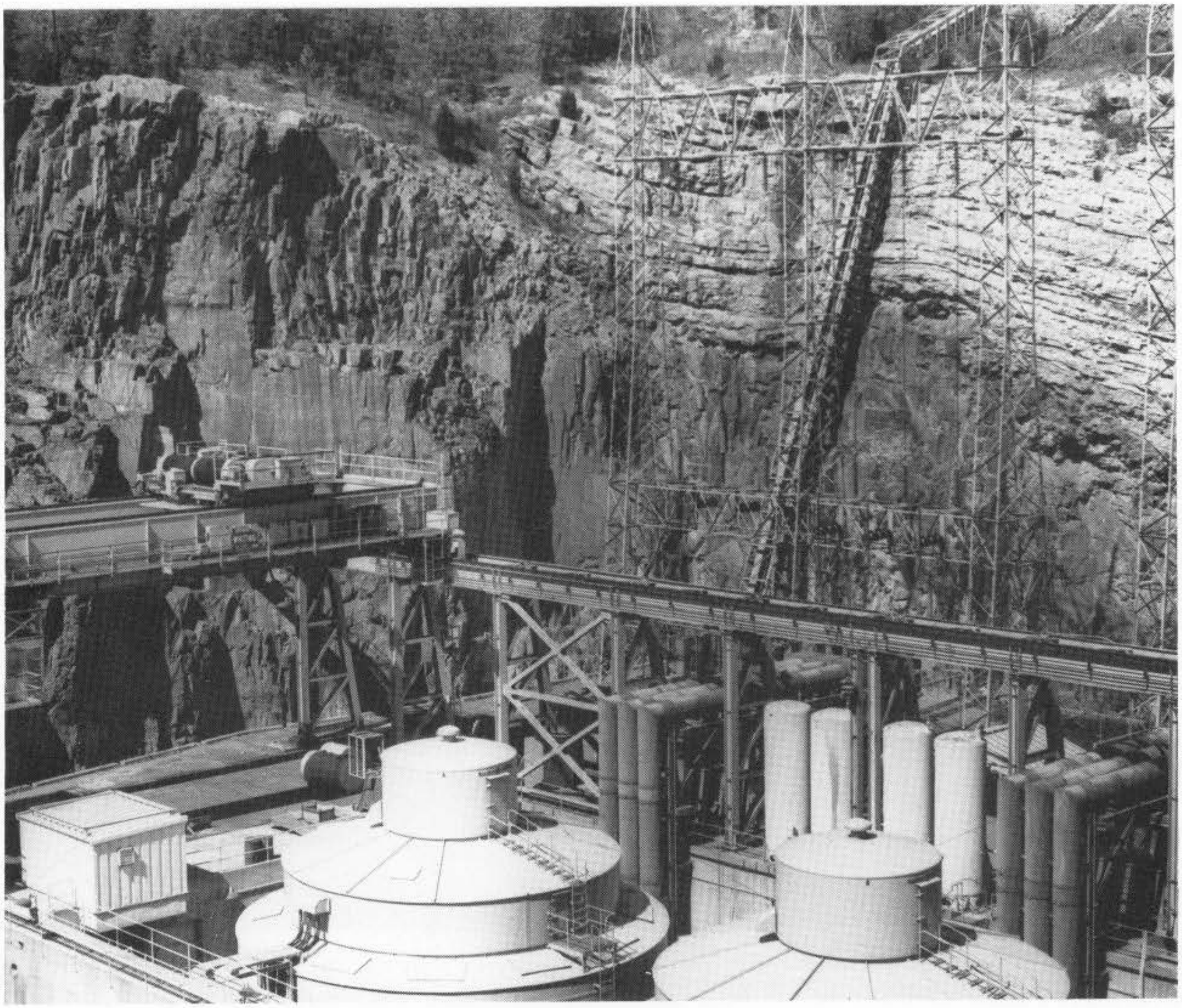


Figure 53. *Rhyolite knob is exhumed in the north face of the power station cut (left), but still buried beneath sedimentary beds in the east face (right). Note the prominent columnar jointing exhibited by the rhyolite. STOP 4. Photo by Art Hebrank.*

some relative movement of the sediments with respect to the rhyolite knob has occurred. The stratigraphic section here is described in detail by Howe (1968, p. 81-86).

Return to cars. **Retrace 3.1-mi segment of road to its junction with State Road U, about 0.2 mi east of the low-water bridge across Taum Sauk Creek.**

3.1

46.2 Junction with State Road U to the south. **Turn right and proceed south on State Road U.**

0.1

46.3 Low-water bridge across Little Taum Sauk Creek. **CAUTION:** Impassable during high water.

Figure 54. *Steep initial dip exhibited by Davis and Derby-Doerun shaly dolomite beds resting nonconformably on the flank of a buried Precambrian knob of Taum Sauk Rhyolite. North face of power station cut, STOP 4. Photo by Art Hebrank.*

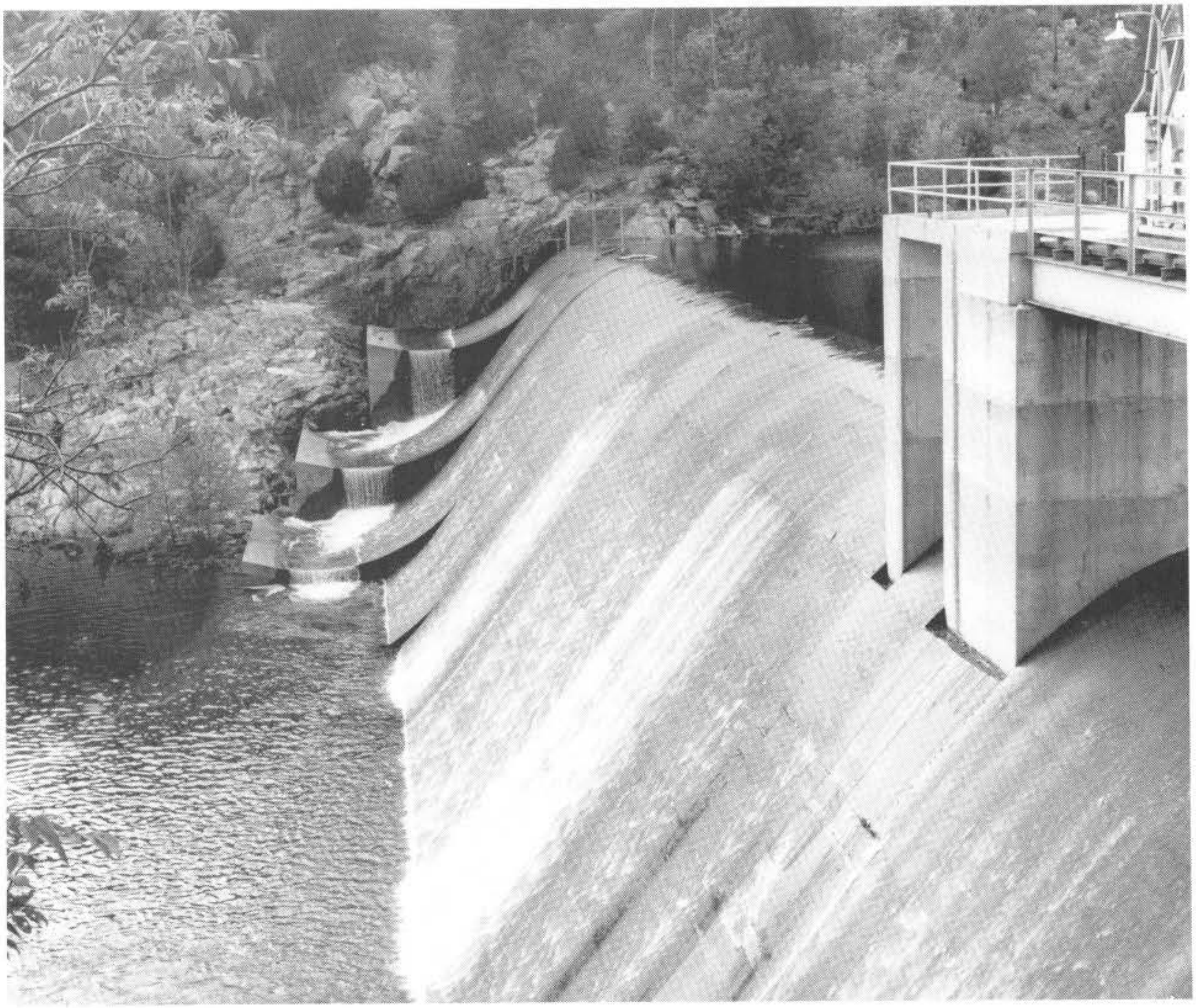


Figure 55. *The dam of the Taum Sauk Lower Reservoir. View is north from hillslope, just below STOP 5. Photo by Art Hebrank.*

		In the course of the next 2 mi the road gradually turns southwest and approaches the south end of the Taum Sauk Lower Reservoir. Float and boulders in roadcuts and mantling hillslopes along this 2-mi segment are sandstone and chert from the Roubidoux Formation and Gasconade Dolomite.
	0.8	
47.1		Residual beds of Roubidoux sandstone in roadcut on south side of road.
	0.2	
47.3		Residual beds of Roubidoux sandstone on north side of road.
	0.9	
48.2		Begin steep descent of hill; Taum Sauk Rhyolite exposed in small cut on south side of road.

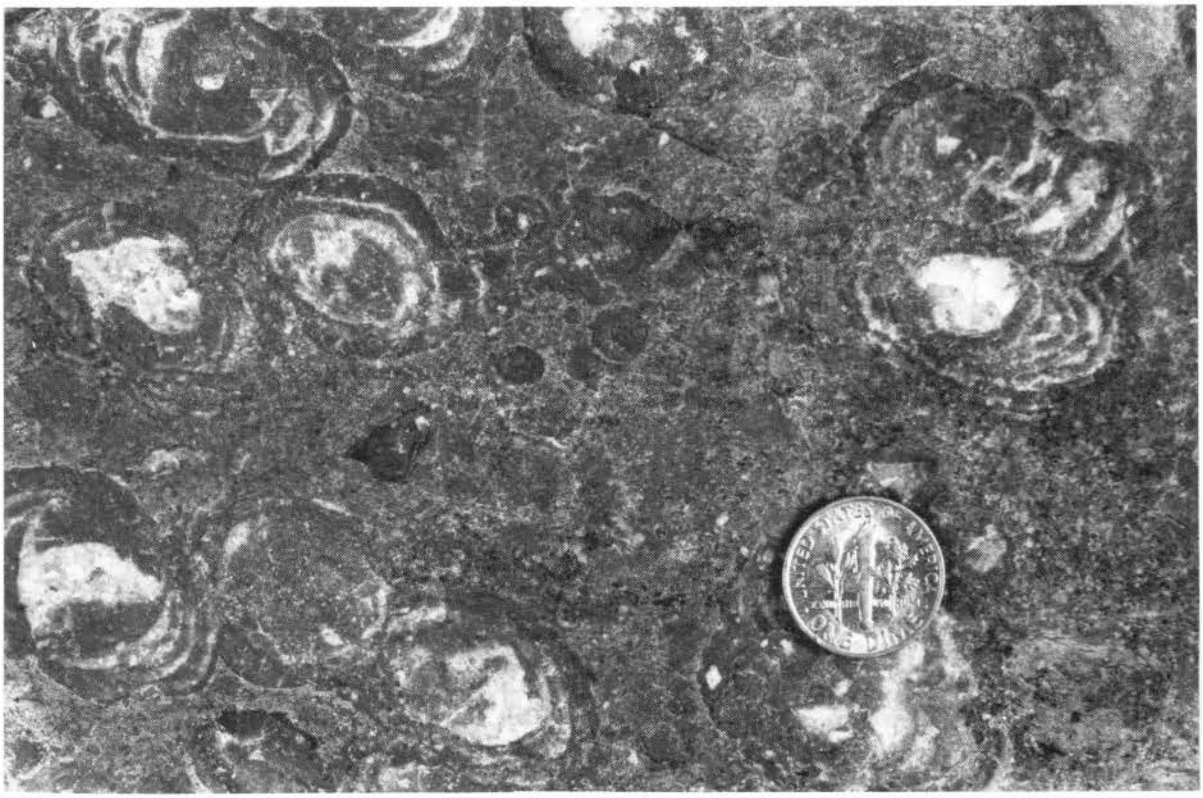


Figure 56. *Lithophysal ("thunder-egg") zone in Bell Mountain Rhyolite. The lithophysae are exposed in cross-section; note the concentric structure and vapor-phase quartz filling. South side of road, STOP 5. Photo by Art Hebrank.*

	0.1	
48.3		Long cut on south side of road exposes Taum Sauk Rhyolite.
	0.1	
48.4		Bell Mountain Rhyolite exposed in cuts along south side of road next 0.2 mi.
	0.1	
48.5		**STOP 5.** Road cuts in lithophysal zone of Bell Mountain Rhyolite (NW¼ NW¼ SE¼ sec. 33, T. 33 N., R. 2 E.).

Pull off and park at the Lower Reservoir scenic overlook on the north side of the road, just before a sharp curve to the south. The dam of the Taum Sauk Lower Reservoir is visible about 500 ft north of the road (fig. 55).

Cuts along the south side of the road expose a lithophysal ("thunder-egg") zone in the Bell Mountain Rhyolite. This distinctive volcanic unit has also been mapped on Lee Mountain, just north of the Lower Reservoir (Anderson, 1970). These outcrops are near the southwestern boundary of the proposed Taum Sauk caldera, opposite where we saw the lithophysal unit on Russell Mountain at STOP 1 of this road log, about 10 mi northeast of here. Recognition of the identical stratigraphic succession of the volcanic units on Lee and Russell Mountains, with units dipping northeast and southwest, respectively, led Anderson (1970) to conclude that the volcanic rocks of the area accumulated in a broad depression or sag in the roof of an epizonal batholith.

The lithophysal ("thunder-egg") zone is especially well exposed on the south side of the road, about 325 ft east (uphill) from the scenic overlook. Spheroidal and somewhat flattened lithophysae (fig. 56) are up to 2 inches in diameter and are commonly filled with vapor-phase minerals among which quartz and deep-purple fluorite are predominant. The lithophysae occur in very fine-grained, crystal-poor vitric tuff composed of devitrified glass shards that show extreme compaction. A large clast of the lithophysal tuff, about 2 ft by 3 ft (fig. 57), is visible in the middle part of the cut, about 250 ft east of the scenic overlook. This clast indicates the fragmental nature of the unit.

Return to cars. **Continue south on State Road U.** The road turns south a short distance beyond this stop and parallels the East Fork of the Black River.

0.1

48.6 Bell Mountain Rhyolite exposed along upland creek just east of road.

0.5

49.1 Bell Mountain Rhyolite exposed in cut on east side of road.

Figure 57. *Large clast of lithophysal tuff in Bell Mountain Rhyolite. South side of road, STOP 5. Photo by Art Hebrank.*

	0.3	
49.4		State maintenance of State Road U begins.
	0.1	
49.5		Rhyolite boulders mantle lower hillslopes of Precambrian knob on east side of road.
	0.2	
49.7		Cambrian (Davis?) dolomite exposed in east roadcut and west hillslope.
	0.6	
50.3		Roadcut through Paleozoic residuum.
	0.4	
50.7		Cambrian dolomite ("white rock"; "netted rock") exposed almost continuously along east side of road for next 0.7 mi.
	1.3	
52.0		Junction of State Road U and Missouri Highway 21-49-72. **Turn right and proceed west on Highway 21-49-72.**
	0.2	
52.2		Low cuts along north side of road expose Derby-Doerun and Potosi Dolomites.
	0.2	
52.4		Bridge over East Fork of Black River. Note bluff of Derby-Doerun and Potosi Dolomites northeast of bridge.
	0.2	
52.6		East city limits of Lesterville.
	1.5	
54.1		Outcrops of Derby-Doerun Dolomite on north side of road. West city limits of Lesterville.
	0.1	
54.2		Outcrops of Derby-Doerun Dolomite on north side of road.
	0.5	
54.7		Precambrian crystal-lithic flow breccia exposed on north side of road. Lithic clasts are trachyte and rhyolite. Crystals are albite and relict Fe-rich pyroxene(?). Small ovoidal lithophysae are filled by coarse crystalline quartz and calcite. Under the microscope, the groundmass exhibits prominent flow banding. A partial chemical analysis of this rock is shown in table 8. This small Precambrian knob is one of many along the southwestern perimeter of the proposed Taum Sauk caldera.
	0.4	
55.1		On north side of road, outcrop of massive, coarsely brecciated, locally conglomeratic Derby-Doerun Dolomite displays cross-bedding and oolitic texture.
	0.4	
55.5		Road crosses Adams Hollow.
	1.0	
56.5		Junction of Missouri Highway 21-49-72 and State Road N. **Turn right and proceed north on State Road N.** This area is blanketed by relatively thick residuum and there are few outcrops of bedrock.

1.1

57.6 Cuts on west side of road expose Precambrian rhyolite porphyry ash-flow tuff. (There is a pull-off on the east side of the road, across from the upper cut.) The rock contains abundant small phenocrysts of orthoclase, quartz, and relict mafic minerals. The latter amount up to 10 percent of the rock by volume and are believed to be relict, Fe-rich pyroxenes. Their interiors are completely replaced by secondary minerals, but their original euhedral crystal form is outlined by a rim of iron oxide. The groundmass consists of quartz, alkali feldspar, and minute grains of iron oxide. It has a distinctive snowflake texture, the quartz showing an acicular habit and forming a "network" in optical continuity around the phenocrysts. Lenticular patches of granophyre are interpreted as replacements of pumiceous material in this ash-flow tuff.

Table 8

CHEMICAL ANALYSES OF VOLCANIC ROCKS NEAR LESTERVILLE, REYNOLDS COUNTY

	1	2
SiO_2	65.50	69.20
Al_2O_3	13.40	11.80
Fe_2O_3	4.50	3.90
MgO	0.63	0.20
CaO	2.42	0.36
Na_2O	2.60	0.95
K_2O	3.13	7.62
TiO_2	0.66	0.55
P_2O_5	0.14	0.14

Data from Pratt and others, 1980. Sample 1 is from mileage point 54.7; sample 2 is from mileage point 57.6.

A partial chemical analysis of this rock is shown in table 8. Note that the contents are relatively low in silica and alumina, very low in calcium and magnesium, and high in iron; also note the exceptionally low Na:K ratio. Rhyolites of similar composition and mineralogy are common among the Eminence area Precambrian outcrops, about 35 mi southwest of here.

0.3

57.9 Bridge over Baker Branch, a tributary of the Middle Fork of the Black River.

0.6

58.5 Potosi residuum along east side of road is characterized by moderately large masses of drusy quartz and red soil.

0.2

58.7		Potosi residuum.
	0.2	
58.9		Cuts on west side of road expose thick residuum.
	0.8	
59.7		Arkosic dolomite of Davis Formation is exposed for 0.3 mi along south side of road.
	0.3	
60.0		Walker Branch Church to the north.
	0.1	
60.1		Bridge over Walker Branch, a tributary of the East Fork of the Black River.
	0.2	
60.3		Davis Formation exposed on west side of road. The rock is massively bedded arkosic dolomite, which is locally crossbedded.
	1.1	
61.4		Roadcut in residuum characterized by large sandstone blocks and chert masses. Cuts for next 0.5 mi expose similar residuum.
	1.1	
62.5		Junction with State Road MM to the north.
	0.1	
62.6		Coarse, arkosic, fossiliferous Davis dolomite exposed on south side of road.
	0.1	
62.7		Junction of State Road N and Johnson Shut-ins State Park road. **Turn right and proceed south into Johnson Shut-ins State Park.**
	0.2	
62.9		Entrance gate to Johnson Shut-ins State Park. Proceed along main road, past picnic areas. Outcrops along the road are dolomite of the Davis Formation and the Derby-Doerun Dolomite.
	0.5	
63.4		Road turns sharply left into Visitors Parking Lot.
	0.1	
63.5		**STOP 6.** Johnson Shut-ins State Park (N½ SW¼ sec. 16, T. 33 N., R. 2 E.).

Park in Visitors Parking Lot and lock cars. This stop involves approximately a 2-hour hike.

NOTE: ROCK COLLECTING AND HAMMERING IS PROHIBITED WITHIN THE BOUNDARIES OF THE PARK!

Walk east from parking lot, on well-marked trail, about 1800 ft to shut-ins overlook (fig. 58).

Johnson Shut-ins is one of the most picturesque Precambrian-rock "canyons" in Missouri and unquestionably one of the Show-Me-State's most popular natural tourist attractions. The important

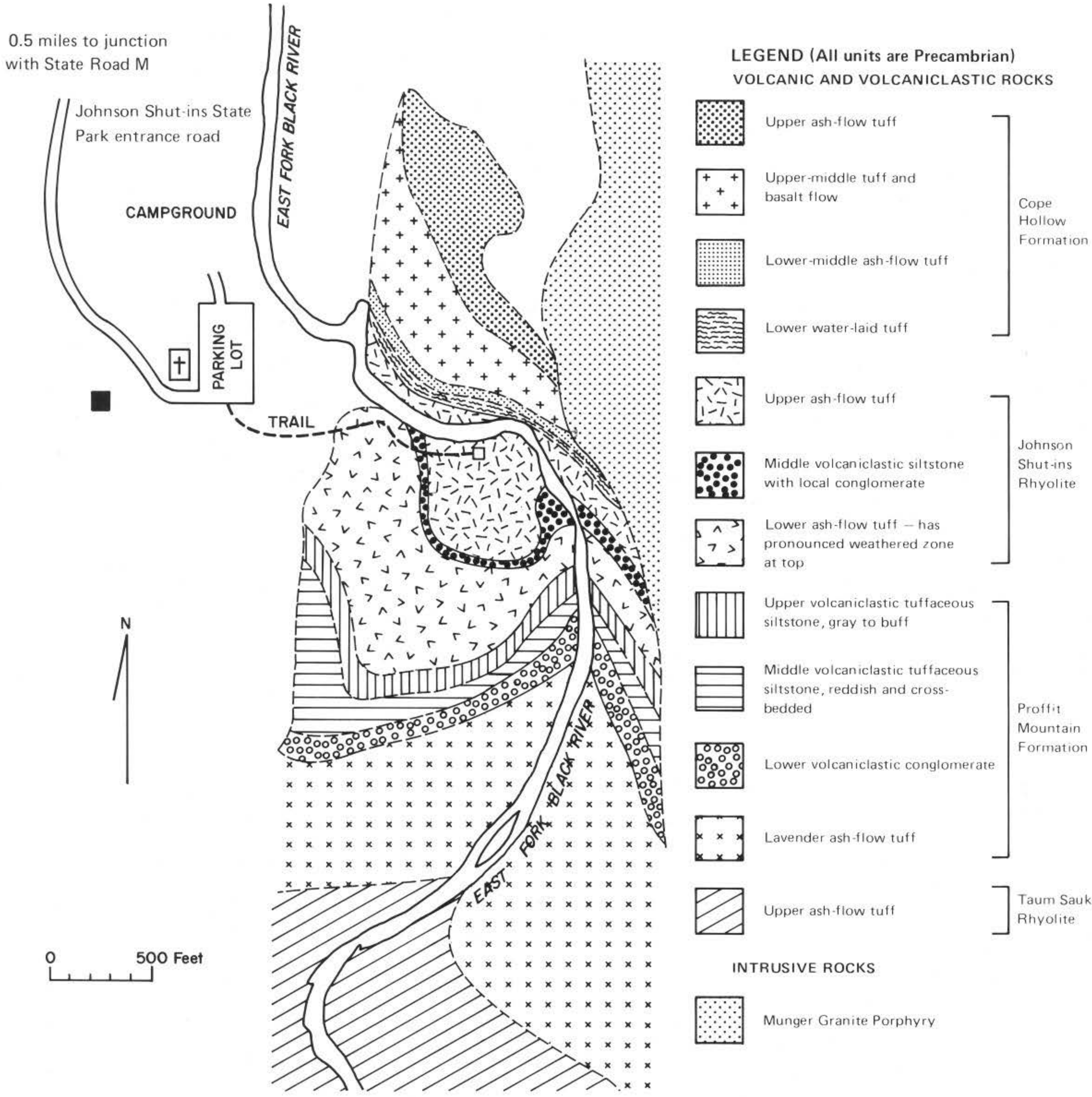


Figure 58. *Geologic map of the Johnson Shut-ins area, STOP 6. Modified from Blades and Bickford (1976); formal nomenclature after Berry (1976).*

Figure 59. *Johnson Shut-ins. View east from the head of the upper shut-in, STOP 6. Resistant, rounded, potholed rock in the foreground is Johnson Shut-ins Rhyolite. Photo by Art Hebrank.*

morphologic features of the shut-ins are described by Beveridge (1978). A one-mile-long segment of the East Fork of the Black River is confined within a narrow, steep-walled canyon, where it cuts through a thick sequence of erosion-resistant volcanic rocks (fig. 59). The same river has formed an alluvial flood plain more than 0.25 mi wide in sedimentary rocks upstream and downstream from the shut-ins.

Within the confines of the shut-ins, stream erosion is controlled by vertical jointing in the rhyolite. Beveridge (1978) describes three important joint sets. The major joints trend northeast, at right angles to the valley; the valley drains to the southeast, parallel to secondary joints; and a third set of joints trending due east has been enlarged by erosion, making the channelways all the more complex.

While technically a single geomorphic feature, Johnson Shut-ins is popularly thought of as two tandem shut-ins: an upper and lower cascade, each with its own distinctive character. The upper shut-in is characterized by a maze of potholes, plunge pools, and tortuous narrow channelways (fig. 60); the lower is dominated by a single, long, deep chute developed along a joint which parallels the direction of flow of the river.

The Precambrian geology of the Johnson Shut-ins area has been mapped by Anderson (1970) and by Blades and Bickford (1976). The mile-long shut-ins expose a 650-m-thick sequence of ignimbrites and intercalated volcaniclastic sedimentary rocks (fig. 61) that dip about 15 degrees to the northeast.

The upper (potholed) cascade, immediately east of the overlook platform, is developed in ash-flow tuffs of the Johnson Shut-ins Rhyolite (fig. 58). This unit is described in detail by Blades and Bickford (1976). It is predominantly a series of ash-flow tuffs, dark gray to red in color, which exhibit well-preserved textures and features indicative of pyroclastic origin. Readily observable are fiamme (flame-shaped, compacted pumice fragments), lithic fragments, and pisolites (fig. 62). In thin section, the pisolites are seen to be accretionary lapilli composed of fine ash and shards (fig. 63). Lithophysal units are also present in the sequence; the products of vapor-phase crystallization within the individual lithophysae are anhedral quartz, feldspar, and muscovite.

Interbedded with the several ash-flow tuffs are a series of volcaniclastic sedimentary rock units. Easily examined – at the head of the upper shut-in, directly across the river from the observation platform – is a prominently exposed bed of water-laid tuff (fig. 58), a unit described by Blades and Bickford (1976) as a uniform, gray, fine-grained, water-laid tuff with ripple marks, cross-bedding (fig. 64), and finely graded bedding.

It is suggested that interested groups with sufficient time examine the entire sequence of zoned ash-flow tuffs and volcaniclastic sediments exposed at the shut-ins. Possibly the most meaningful procedure would be to walk up through the exposed section starting at the lower end of the constriction. Plan this adventure for a nice warm day and expect to get wet!

		Return to parking lot and cars. **Retrace 0.8-mi segment of Johnson Shut-ins State Park road to its junction with State Road N.**
	0.8	
64.3		Junction of Johnson Shut-ins State Park road and State Road N. **Turn right and proceed north on State Road N.**
	0.2	
64.5		Bridge over Cope Hollow.
	0.2	
64.7		Bridge over East Fork of the Black River. Roadcuts at northeast corner of bridge expose dolomites of the Davis Formation.

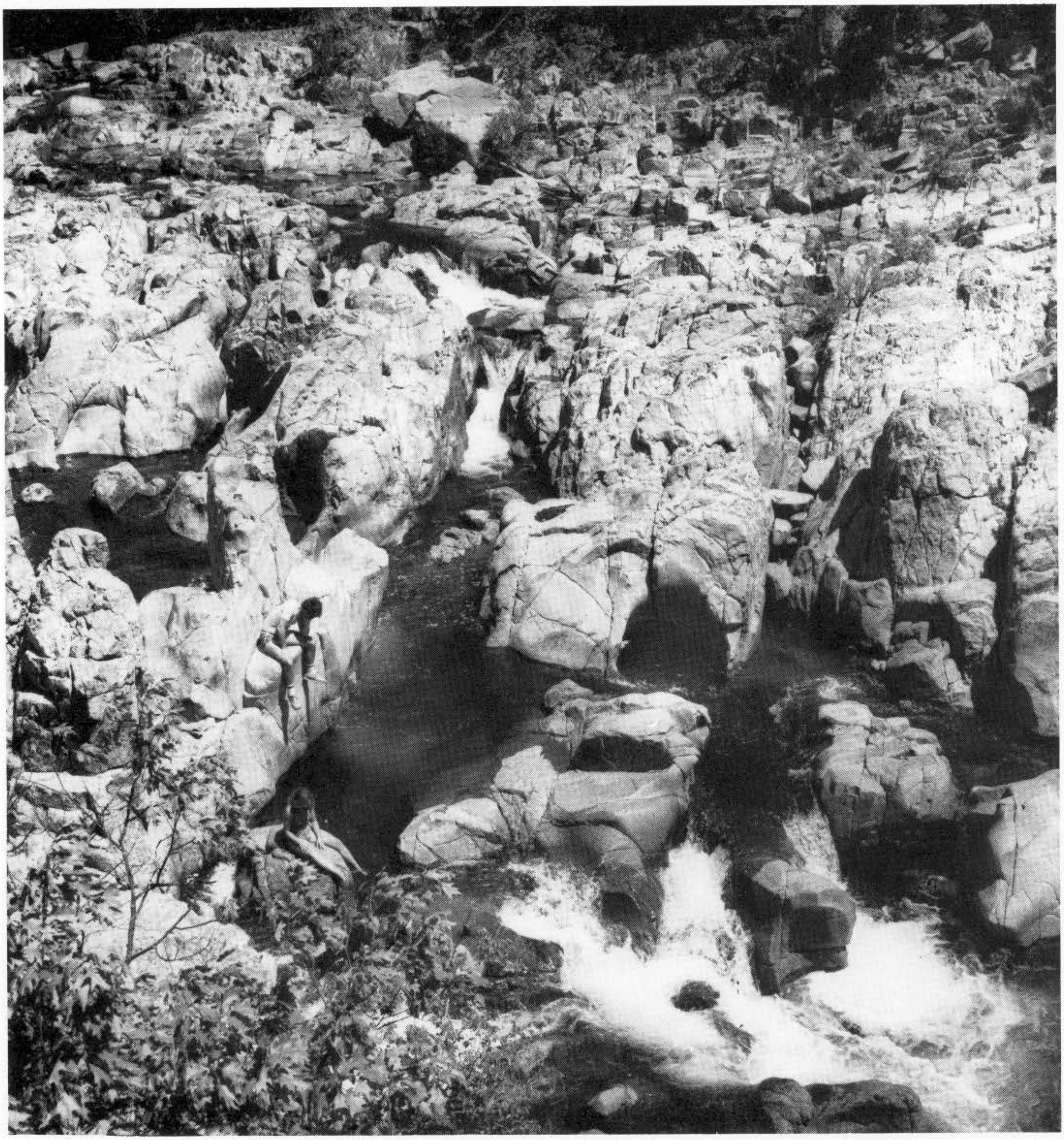


Figure 60. *The upper shut-in, developed in Johnson Shut-ins Rhyolite. Note the prominent jointing and its effect on stream erosion. View to the northeast from near the overlook, STOP 6. Photo by Art Hebrank.*

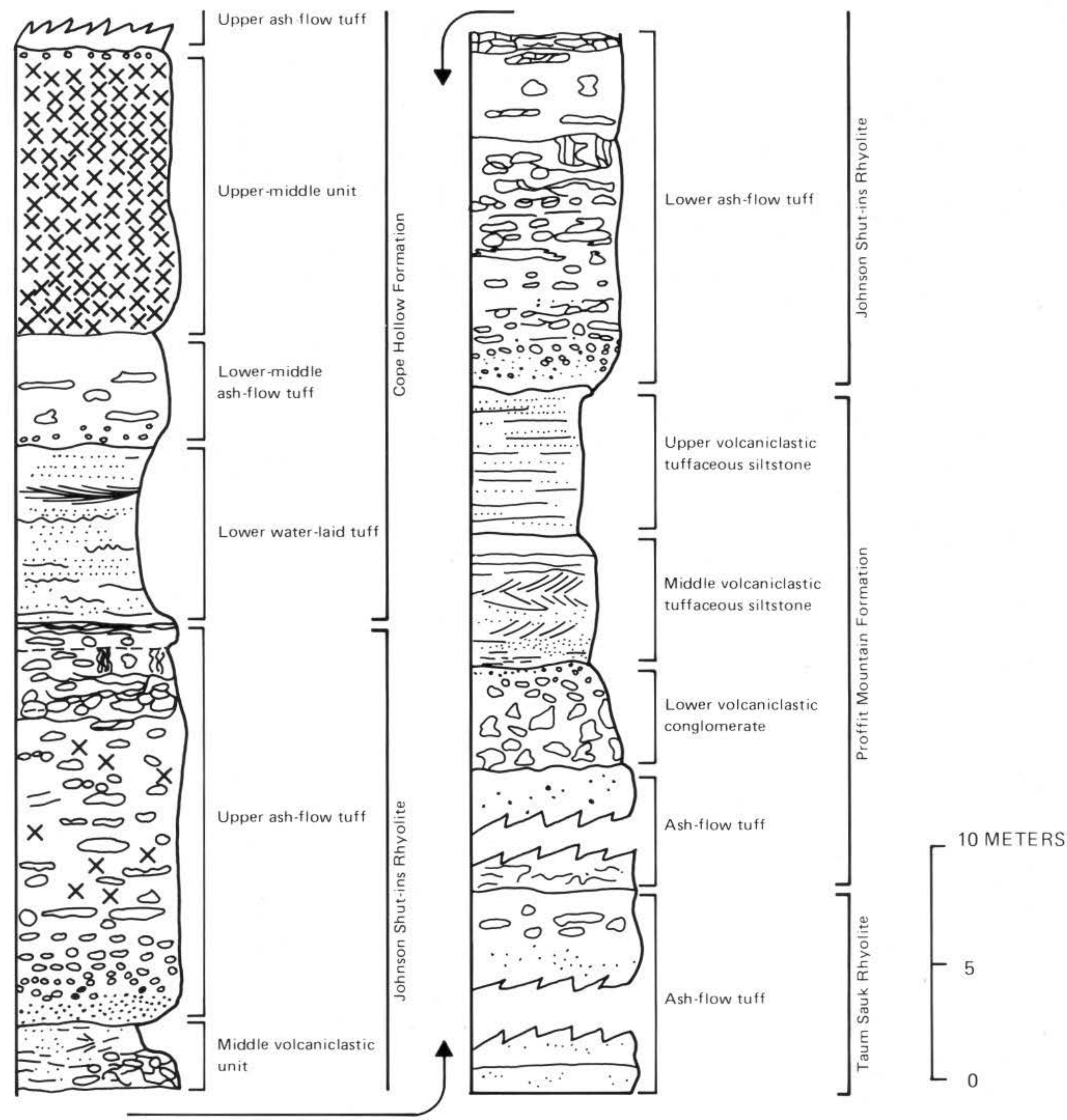


Figure 61. *Measured stratigraphic section of Precambrian volcanic-rock units exposed in the Johnson Shut-ins area, STOP 6. Modified from Blades and Bickford (1976); formal nomenclature after Berry (1976).*

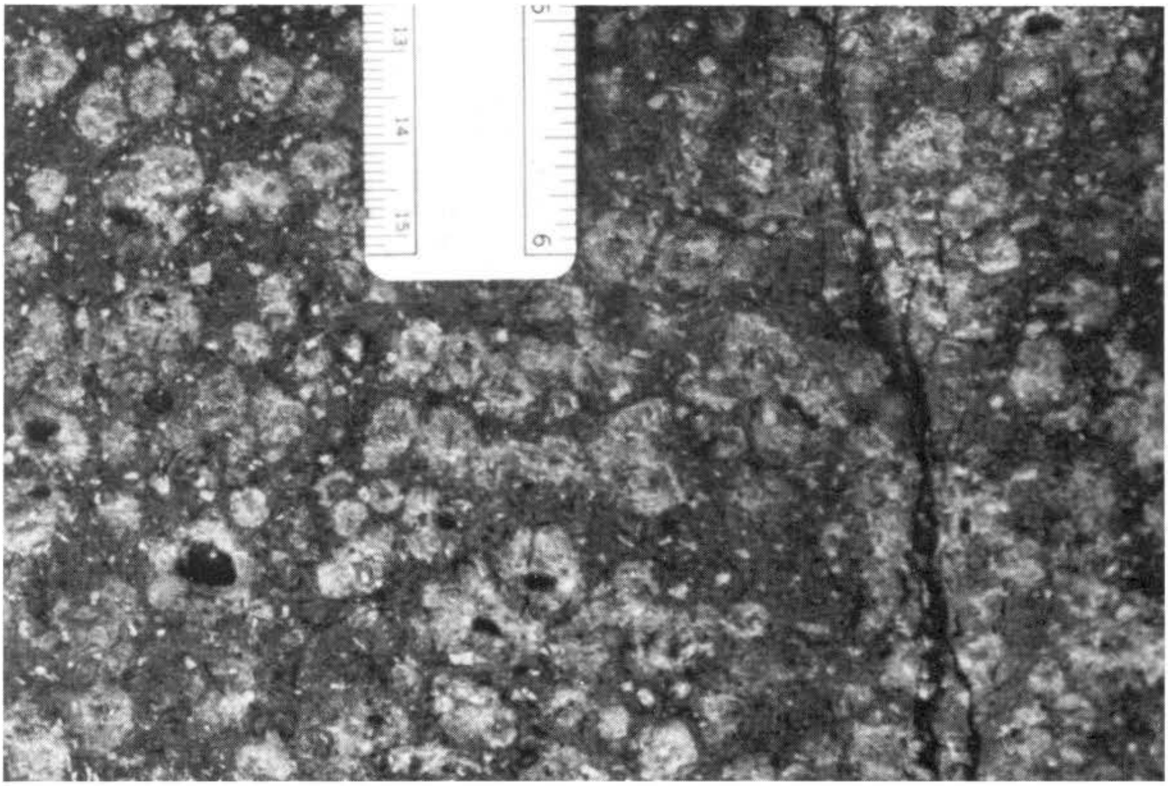


Figure 62. *Pisolites in Johnson Shut-ins Rhyolite, STOP 6. Scale in centimenters (left) and inches (right). Photo from Blades and Bickford (1976).*

State Road N follows the course of the East Fork of the Black River for the next 9 mi. The valley floor and lower hillslopes are covered with river alluvium and expose Upper Cambrian sedimentary rocks, but the hilltops along both sides of the valley for the next 5 mi expose Precambrian rocks.

0.1

64.8 Davis dolomite exposed in cuts along east side of road.

0.2

65.0 Low cuts on both sides of road expose Davis dolomite.

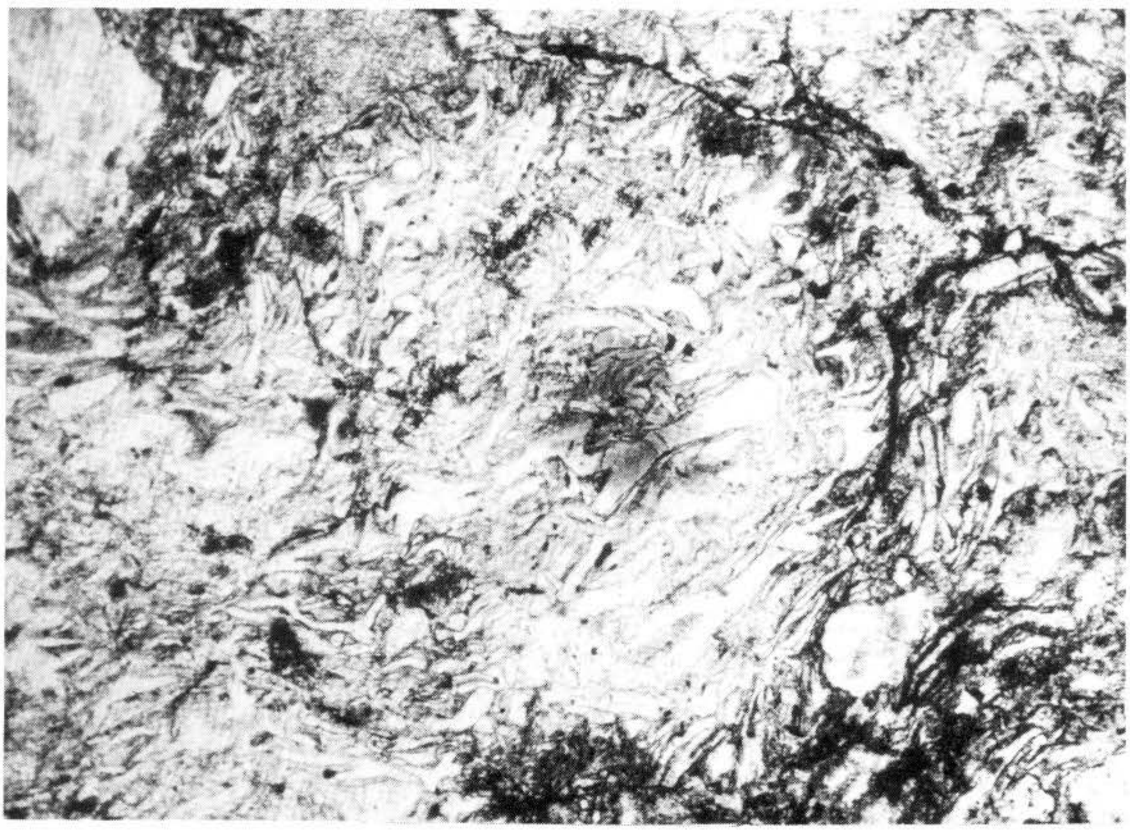
0.2

65.2 Davis dolomite crops out on east hillslope.

0.2

65.4 Good view of High Top Mountain to the north. The prominent Precambrian peak rises to an elevation of 1590 ft above sea level (about 600 ft above the valley floor) and consists mostly of Munger Granite Porphyry. The north end of Proffit Mountain, to the east, exposes Precambrian rhyolites.

	1.7	
67.1		High cut on east side of road exposes medium-crystalline Cambrian (Bonneterre?) dolomite and chert-free, red clay residuum.
	0.9	
68.0		Prominent outcrops of Cambrian (Davis?) dolomite on distant slope to the east.
	0.3	
68.3		Davis dolomite exposed on both sides of road.
	0.1	
68.4		Cross unnamed branch of East Fork of Black River; Davis dolomite exposed along south bank of creek.
	0.7	



1 mm

Figure 63. *Photomicrograph of a spherical pisolite, an accretionary mass of fine ash and shards, in Johnson Shut-ins Rhyolite, STOP 6. Photo from Blades and Bickford (1976).*

69.1 Village of Munger (no sign).

0.4

69.5 Enter Iron County.

The East Fork of the Black River and State Road N pass through a small shut-in; much of the east canyon wall has been cut away to make the highway right-of-way wider. The shut-in is developed in the Lindsey Mountain Rhyolite of Berry (1976),

Figure 64. *Prominent cross-bedding in water-laid tuff of the Cope Hollow Formation. On north hill-slope above upper shut-in, STOP 6. Photo by Art Hebrank.*

a dense, violet-gray, blackish, or maroon ash-flow tuff with 5 to 20 percent quartz and alkali-feldspar phenocrysts.

0.1

69.6 Bridge over East Fork of the Black River.

1.0

70.6 Bridge over Womble Hollow, Indian Point area.

1.2

71.8 Bridge over East Fork of the Black River.

Outcrops on the north hillslope, and the impressive bluff to the south expose a thick sequence of basal conglomerate, sandstone, and siltstone. Clastic constituents include angular-to-subrounded quartz sand and silt, small weathered K-feldspar grains, and igneous-rock fragments up to about one inch in diameter. A very few thin beds contain minor dolomite cement. Beds dip about 10 degrees to the southwest.

While distinctly a Lamotte Sandstone lithology, Dake (1930) considered this particular occurrence to be a conglomeratic, sandy, near-shore facies of the Bonneterre Formation, accumulated on the steep slopes of a Precambrian knob. A small isolated rhyolite knob crops out about 500 ft east of the bluff.

0.9

72.7 Giant residual chert boulders on both sides of road. Similar boulders are exposed in roadbanks, and mantle the hillslopes for the next two miles. Casual examination of numerous boulders disclosed chalky white, translucent-gray, and gray-quartzose "rusty" cherts with virtually no relict sedimentary textures. An occasional boulder is conglomeratic(?) or autoclastic.

Dake (1930) described this chert as Gasconade residuum, but advanced the theory that much of it was secondary, a product of massive silicification of dolomite, possibly related to chemical weathering. The enormous volume of chert, the abnormal size of the blocks (some exceed 20 ft in diameter), and the lack of primary sedimentary textures (oolites, pellets, cryptozoon structures, etc.) typical of diagenetic(?) Gasconade cherts, certainly support the theory of a late secondary origin.

1.0

73.7 Cambrian (Bonneterre?) dolomite crops out in woods on south side of road.

0.2

73.9 Pass under high-voltage electric line. This is the main transmission line from Union Electric's Taum Sauk Pumped Storage Power Plant into the St. Louis area power net.

1.2

75.1 Road tops small rise; arkosic Davis dolomite exposed in north roadbank.

0.6

75.7 Graniteville Granite boulders and outcrops on both sides of road. We have now returned to the southeastern part of the Belleview Valley area; the granite exposed here is part of the Graniteville central pluton described at STOP 8 in Road Log No. 1.

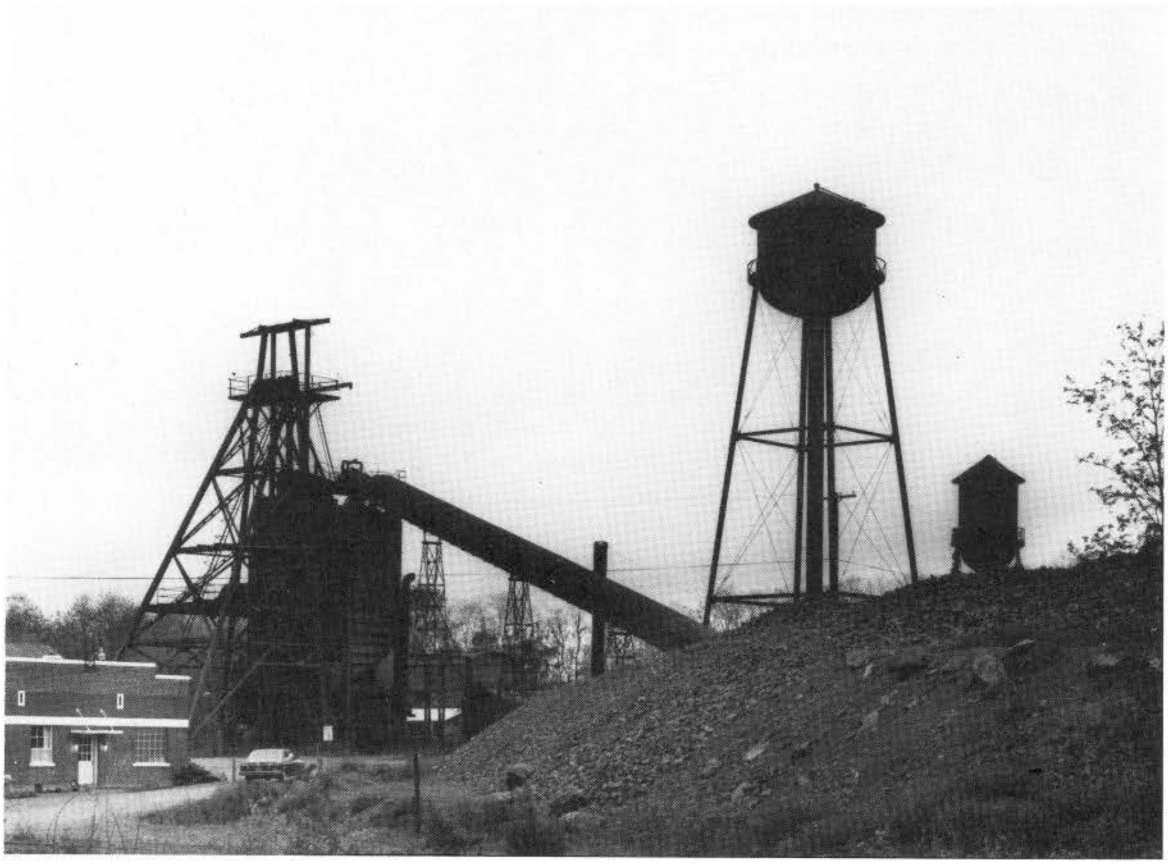


Figure 65. *Entrance to Iron Mountain Trap Rock Company. Headframe, water tanks, and buildings are remnants of the old Iron Mountain iron-mine facilities. North side of Highway W, at mileage point 81.9 (S½ SE¼ NW¼ sec. 31, T. 35 N., R. 4 E.). Photo by Art Hebrank.*

	0.1	
75.8		Old road to south (by small granite building) leads to abandoned quarries in the Graniteville Granite.
	0.1	
75.9		Small "elephants" of Graniteville Granite crop out prominently on the near-distant hillslope to the north.
	0.9	
76.8		Road to the south leads to Snow Hollow Lake.
	0.7	
77.5		Junction of State Road N with Missouri Highway 21. **Turn right and proceed east on Highway 21.**
	0.5	
78.0		Junction of Missouri Highway 21 with State Road W. **Turn left and proceed north on State Road W.**

		Good view to the north of Middlebrook Hill, a rhyolite knob (elevation 1568 ft above sea level).
	0.2	
78.2		Railroad crossing: seldom-used spur of Missouri Pacific Railroad leads west to Graniteville.
	0.1	
78.3		Road crosses Middlebrook Creek.
	0.3	
78.6		Road to northeast leads to village of Middlebrook.
	0.9	
79.5		Railroad overpass above Missouri Pacific tracks.
	0.3	
79.8		Road to southeast leads to village of Middlebrook. Enter St. Francois County.
	0.4	
80.2		King School Road to the east.
	0.5	
80.7		Good view of Reservoir Hill to the northeast. Prominent outcrops near top of hill are Precambrian rhyolite.
	0.7	
81.4		South city limits of Iron Mountain.
	0.5	
81.9		Iron Mountain Trap Rock Company facilities on north side of road (fig. 65).

The Iron Mountain Trap Rock Company crushes, screens, and markets dense Precambrian volcanic rock (mostly rhyolite) for use as a hard, wear-resistant, non-skid paving aggregate, and for other high-quality aggregate uses. Production is from iron-mine wasterock stockpiled on the property, or transported from the nearby Pilot Knob Pellet Company. The property is leased from the Hanna Mining Company, which, until 1966, operated the historic Iron Mountain mine and mill on this site.

The town of Iron Mountain is at the foot of the Precambrian knob of the same name. Specular hematite admixed with minor magnetite was discovered here in the early 1800's, and the site soon achieved wide acclaim as "a mountain of nearly pure iron"! The Missouri Iron Company was incorporated in 1836 (fig. 66) to mine the rich ore, but failed a few years later, due to litigation over property ownership. The American Iron Mountain Mining Company commenced operations in 1843, and ore production by a succession of companies was almost continuous until 1966. During its 123 years of operation, the property yielded nearly 9 million long tons of concentrates, and was the largest and most productive of the Precambrian iron-ore deposits of the region.

According to Crane (1912), three types of ore occurred at Iron Mountain: boulder ore, vein ore, and conglomerate ore. The boulder ore, the first type to be discovered and mined, consisted of hematite boulders embedded in surface residual clays. The vein ore occurred as several massive veins in Precambrian volcanic rocks, and was mined at first by open-pit methods from the Big Cut (fig. 67) and Hayes Cut. Later, when magnetic surveys and exploratory drilling disclosed the deeper, vein-type ore bodies (Main Ore Body, Northwest Ore Body), underground methods were also employed. The conglomerate ore, worked mostly by underground methods, occurred in the basal conglomerate

Figure 66. *Historic document: certificate for 1000 shares ($100,000) of capital stock in the Missouri Iron Company, incorporated in 1836 to mine the rich ores of Iron Mountain and Pilot Knob. Property of Art Hebrank.*

between the Precambrian rocks and the overlying Upper Cambrian sediments. By far the greatest production was from the vein deposits. Both the boulder ore and the conglomerate ore were derived from erosion of a primary, vein-type ore body.

The geology of the Iron Mountain deposit is discussed in detail by Murphy and Ohle (1968). They contend that the deposit received an inordinately large amount of scholarly investigation for its size. This is understandable, however, as the vein deposits display some features which can be interpreted as the result of ore-magma injections, whereas other features favor a hydrothermal origin. Kisvarsanyi and Proctor (1967) concluded, on the basis of trace element data, that the deposit was formed by ore-magma injections that developed pegmatitic and hydrothermal end phases.

It is interesting to note that both the Iron Mountain and the Pilot Knob (surface) deposits were visited by participants of the 16th International Geological Congress and that both deposits are featured in I.G.C. Guidebook No. 2 (Lake, 1933; Steidtmann, 1933).

At the time of this writing, not much can be seen of the famous deposit. The underground workings are inaccessible and the lower levels of the open cuts are intermittently flooded by water. In the face of the open cuts, however, hematite seams are still exposed and can be seen in association with the high-temperature mineral assemblage (actinolite, apatite, garnet) which characterized the deposit. If an **optional stop** is planned at the Iron Mountain mine, prospective visitors are advised to make advance arrangements with Mr. John Malloy, Iron Mountain Trap Rock Company, P.O. Box 35, Iron Mountain, Missouri 63649.

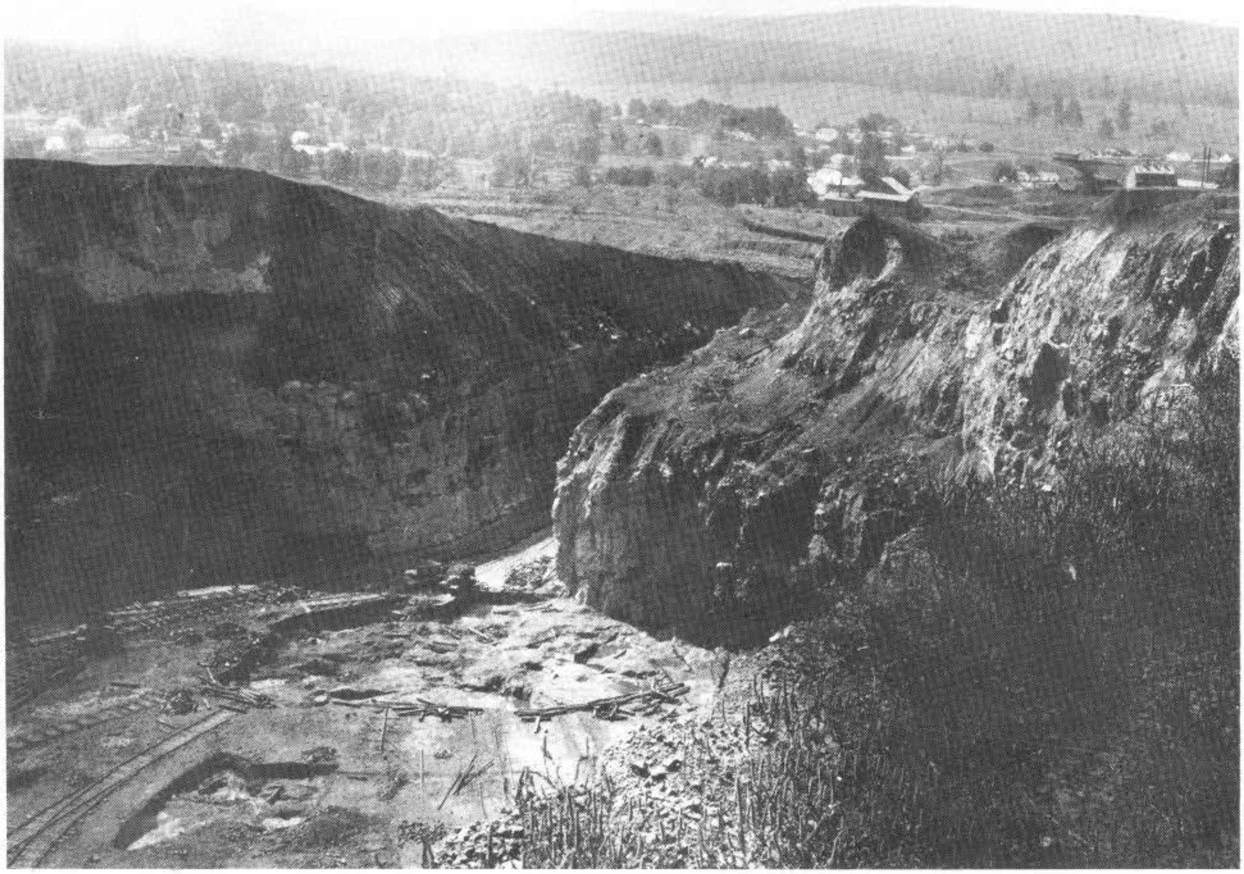


Figure 67. *Big Cut of the Iron Mountain mine, early 1900's. The large abandoned open pit (NE¼ NW¼ and NW¼ NE¼ sec. 31, T. 35 N., R. 4 E.) is located 1800 ft northeast of mileage point 81.9. Division of Geology and Land Survey archives.*

0.5

82.4 North city limits of Iron Mountain.

0.4

82.8 Road south leads to Iron Mountain Lake. The 70-acre lake, about 0.75 mi distant from State Road W, is the oldest of Missouri's numerous man-made lakes. Reportedly using prison labor, the 1200-ft-long, 22-ft-high, earth and rock-fill dam was constructed in 1869 to impound Indian Creek. The lake is owned by the Iron Mountain Lake Association and is for recreational use (oral communication, David Hoffman, Missouri Department of Natural Resources, Dam Safety Program).

0.3

83.1 Junction with State Road N to the north.

0.7

83.8 Road descends through narrow valley between Pine Mountain on the north and an unnamed hill on the south. Thick ledges of Lamotte Sandstone crop out on both sides of the road along the valley bottom. The upper slopes of both hills expose Grassy Mountain Ignimbrite.

0.5

84.3 Bridge over Indian Creek. Pale-pinkish-gray (bleached?) Grassy Mountain Ignimbrite crops out on southeast hillslope.

0.4

84.7 Boulders and outcrops of Grassy Mountain Ignimbrite on south hillslope.

0.3

85.0 Bridge over White Creek. Scattered small outcrops and boulders of Grassy Mountain Ignimbrite.

0.8

85.8 Low cuts along north side of road expose Lamotte Sandstone; Breadtray Granite boulders mantle the gentle hillslope immediately above the sandstone.

The contact of the Breadtray Granite and overlying Grassy Mountain Ignimbrite is not exposed along the road, but is mapped just west of these outcrops. A detailed description of the Butler Hill-Breadtray Granite massif is presented at mileage point 57.2 in Road Log No. 1 of this Guidebook.

0.2

86.0 Breadtray Granite on north hillslope.

0.2

86.2 Breadtray Granite along north side of road.

0.1

86.3 Road curves sharply left (to the east) around massive outcrop of Breadtray Granite on north side of road. Coarse-grained, ferruginous Lamotte Sandstone is almost in contact with the granite in the north roadbank at the east end of the curve.

0.3

86.6 Breadtray Granite exposed on hillslope and in bank along south side of road.

	0.3	
86.9		Lighthouse Tabernacle Church on south side of road; outcrops and boulders of Breadtray Granite on both sides of road for next 0.3 mi.
	0.5	
87.4		Stono Mountain (elevation 1644 ft above sea level) and lookout-tower access road (barred by gate) to the north. Relationships between the Stono Granite, Breadtray Granite, and Grassy Mountain Ignimbrite – all exposed on Stono Mountain – are discussed briefly at mileage point 61.5 in Road Log No. 1 of this Guidebook.
	0.2	
87.6		Junction of State Road W with State Road V to the south.

This junction is at mileage point 61.5 in Road Log No. 1 of this Guidebook. To return to Flat River, follow Road Log No. 1 from mileage point 61.5 and proceed northeastward on State Road W for 7.2 mi to the U.S. Highway 67 overpass, then go north on Highway 67 for about 5 more mi to Flat River (refer to figure 1).

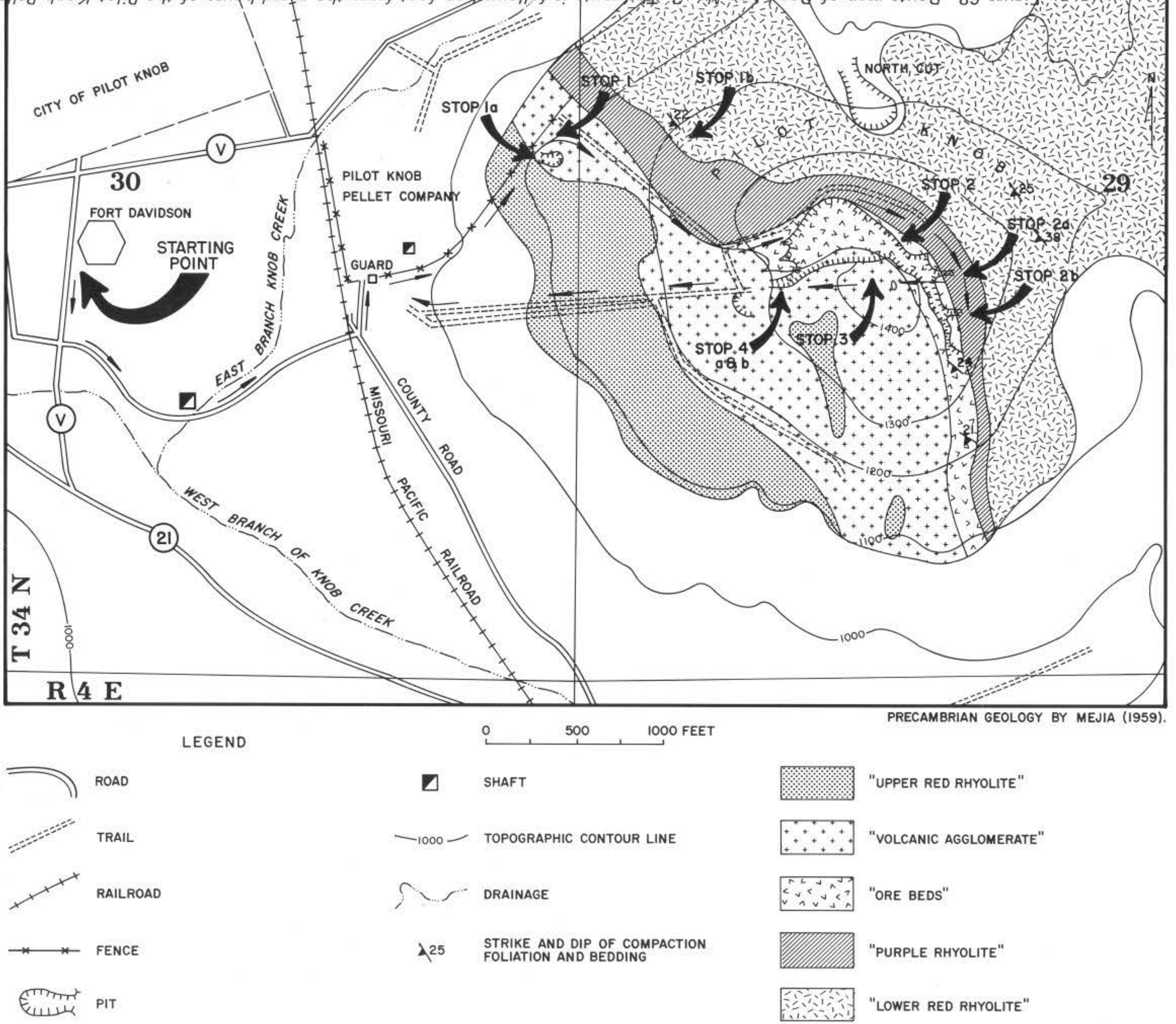
To reach the starting point for Road Log No. 2, in Arcadia, about 11 mi southwest of the junction of State Roads V and W, turn right and proceed southwest on State Road V to Pilot Knob, then go south on Missouri Highway 21 to Ironton and Arcadia.

Sources referred to in this road log are listed in the combined bibliography at the end of this Guidebook.

TRAVEL ON SAFELY!

END OF ROAD LOG NO. 2

Figure 68. Route map of Road Log No. 3. The route is followed on foot from the guard house of the Pilot Knob Pellet Company. Total distance logged is 6000 ft.



ROAD LOG NO. 3 – AN IRON-ORE DEPOSIT

This route features one of the historic Precambrian iron-ore deposits, the Pilot Knob Mine (surface). It involves approximately a 3-hour hike, consisting of a moderately steep climb from the base of Pilot Knob to its top, a difference in elevation of about 500 ft. Because the property is privately owned, individuals, schools, or other groups desiring to use this road log are advised to obtain permission and make advance arrangements by contacting Mrs. Merly Friedland, Pilot Knob Ore Company, c/o St. Louis Union Trust Company, 510 Locust St., St. Louis, Missouri 63101 (phone: 314-231-9300).

To reach the starting point with reference to this Guidebook, proceed south on U.S. Highway 67 to its intersection with State Road W. Turn west on State Road W and follow it until its junction with State Road V. Turn south on State Road V and follow it until the town of Pilot Knob is reached. This 16-mi segment of road on State Roads W and V constitutes the latter part of Road Log No. 1 followed backwards (see fig. 3). From other directions the town of Pilot Knob may be reached via Missouri Highway 21.

Distances given in this road log are measured in feet, because it is essentially a walking tour. The different Precambrian rock units encountered along the way have been defined by Mejia (1959) and the informal names applied to them conform to the nomenclature used by Pilot Knob Pellet Company geologists. Following this road log is a description of the history and geology of the Pilot Knob hematite deposit, by Richard F. Ryan, former mine geologist of the Pilot Knob Pellet Company.

STARTING POINT (fig. 68):

Ford Davidson State Historical Site on State Road V (NW¼ NW¼ SE¼ sec. 30, T. 34 N., R. 4 E.). To the west, Pilot Knob looms prominently 500 ft above the valley of Knob Creek. Figure 69 is a chronologic sequence of Pilot Knob views, including one from this point.

From the starting point, drive south on State Road V for 0.1 mi, turn left and proceed 2000 ft east along mine road. Cross Missouri Pacific Railroad tracks and turn north immediately after the tracks. Follow road for about 250 ft to the guard house (N½ SW¼ NE¼ SE¼ sec. 30, T. 34 N., R. 4 E.) by the fence at the entrance of the Pilot Knob Pellet Company parking lot. Park and lock cars.

Distance in feet Cum.	Diff.	
0.0		Walk northeast along the fence to the old pit by the old tramway leading to the top of Pilot Knob.
	1600	

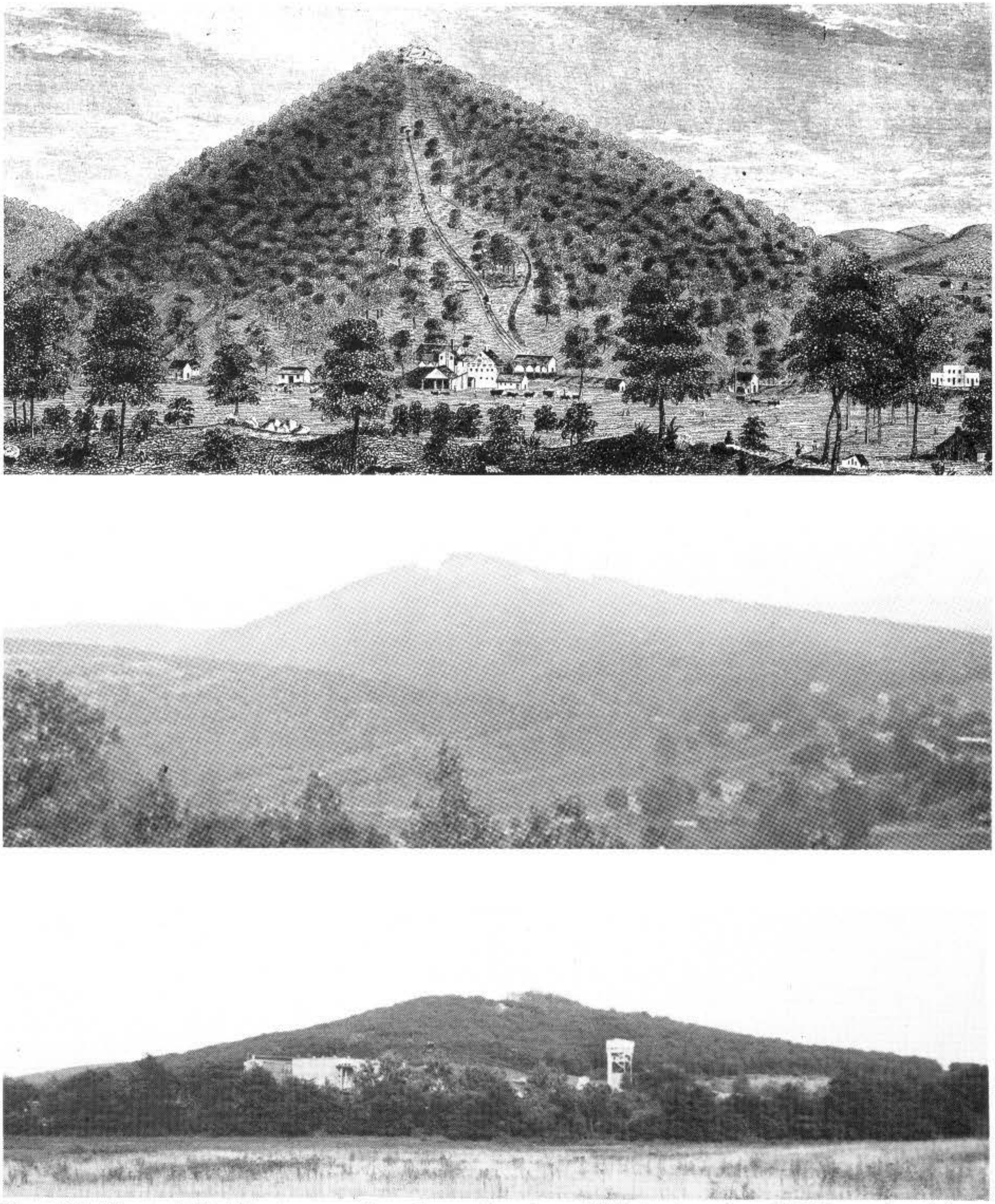


Figure 69. *Views of Pilot Knob as seen from the northwest, ca. 1855 (top), and ca. 1890 (center), and from the west in 1981 (bottom). Visible in both photographs is the large open cut (STOP 2, Road Log No. 3) "notching" the mountain top and indicating the extent of ore removed by open-pit mining. Note also the artistic exaggeration in the old illustration. Engraving from Swallow (1855); photos from Crane (1912) and by Art Hebrank.*

1600 **STOP 1.** Old pit (NE¼ NE¼ SE¼ sec. 30, T. 34 N., R. 4 E.).

The "Lower Red Rhyolite," a fine-grained, red to reddish-brown ash-flow tuff, is exposed on the northwest slope of Pilot Knob. It may be observed in contact with a purple mineralized rhyolite mapped by company geologists and shown in figure 68 as the "Volcanic Agglomerate." However, we believe the purple rhyolite to be part of the "Lower Red Rhyolite" unit, and its darker color is due to its higher iron content.

In this old pit, northeast-striking ore veins and breccia were prospected and there was an attempt to mine them in the past (STOP 1A, fig. 68).

Three hundred feet east of the old cut (STOP 1B, fig. 68), is a large outcrop of the "Lower Red Rhyolite." It displays abundant lithic clasts, collapsed pumice, and spherulitic structures.

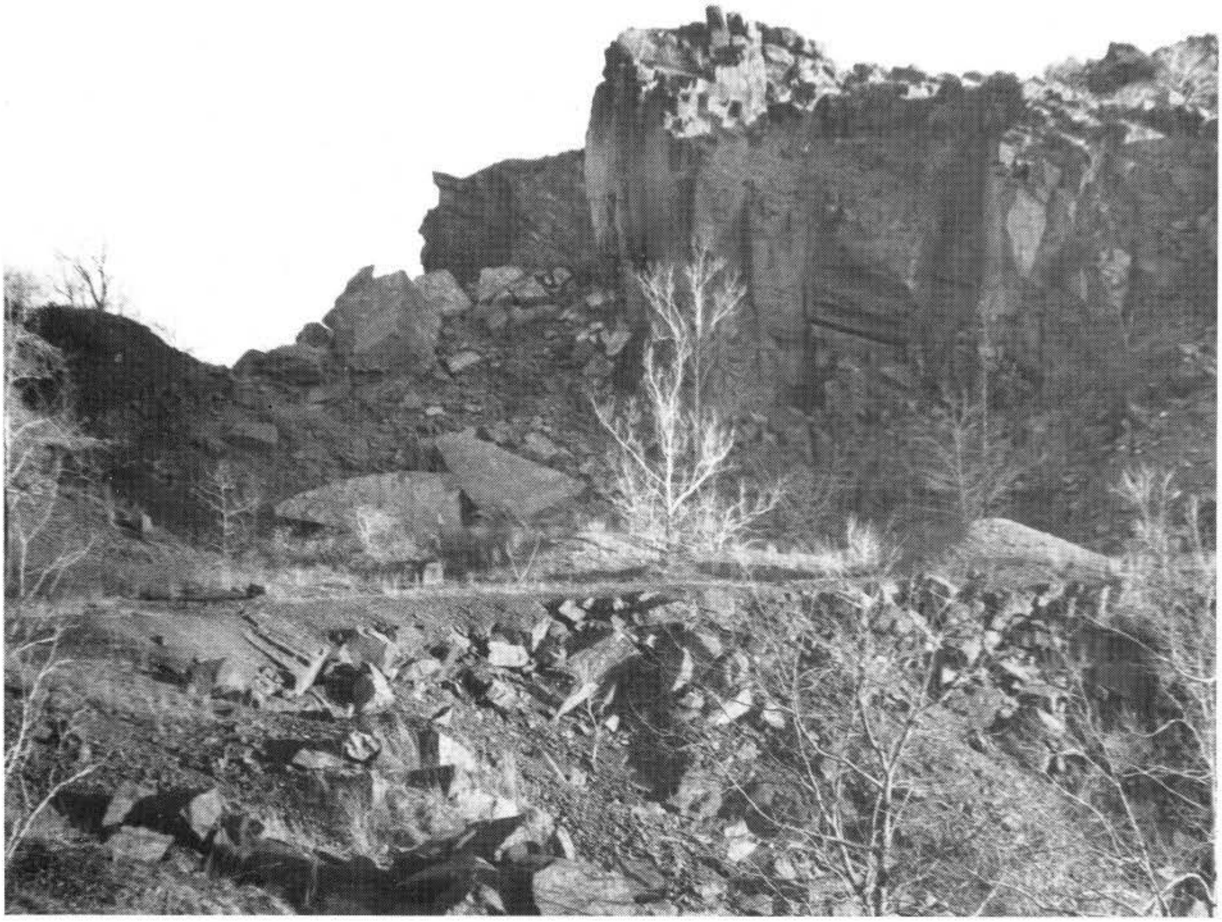


Figure 70. *The old cut at the top of Pilot Knob, as seen from STOP 2. Photo by Dick Ryan.*

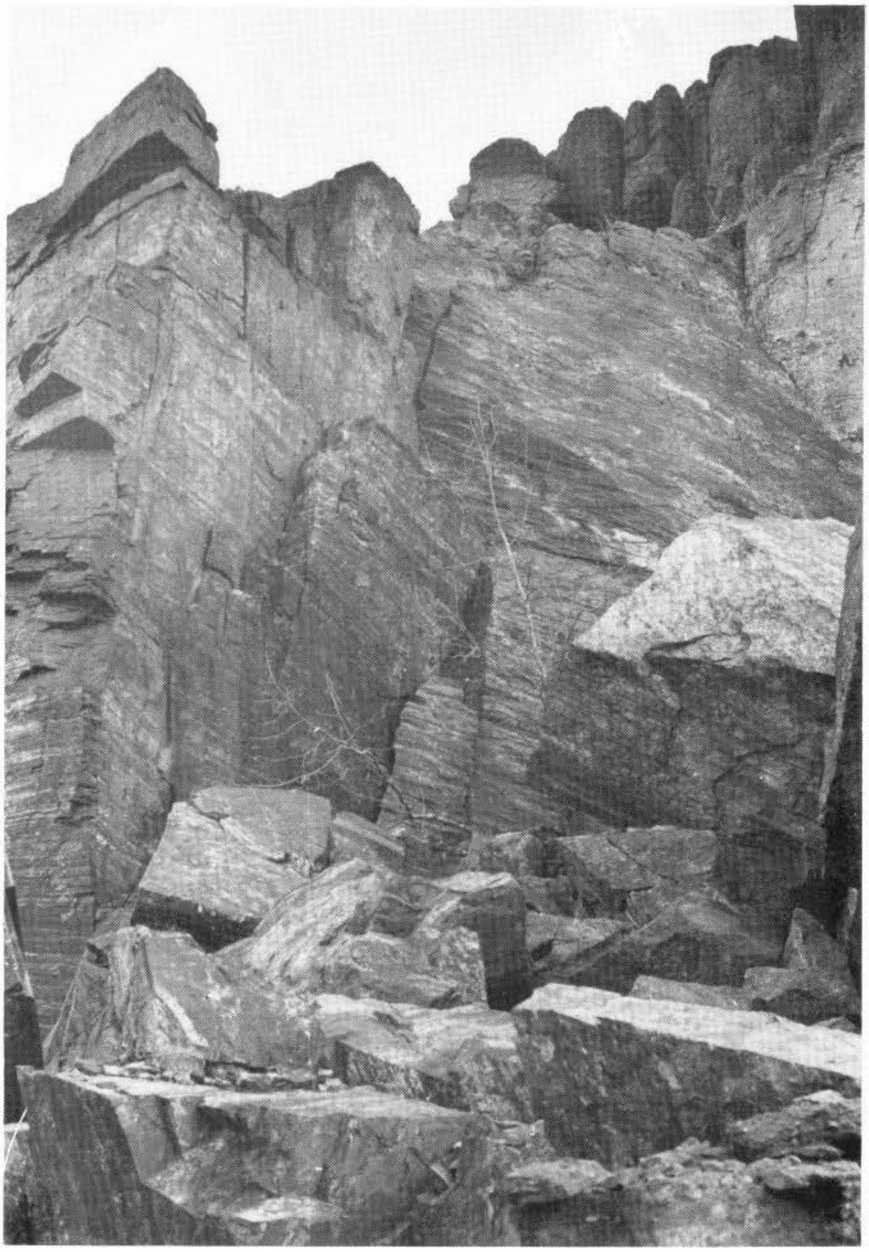


Figure 71

The "Upper Ore Bed," a mineralized bedded tuff, in the face of the old cut at the top of Pilot Knob, STOP 2. Photo by Dick Ryan.

Proceed uphill southeast along the old tramway to the old cut on the top of Pilot Knob. Walk along the edge of the cut to STOP 2 (fig. 68).

2200

3800 **STOP 2.** Old cut on top of Pilot Knob (NE¼ SW¼ sec. 29, T. 34 N., R. 4 E.).

This old cut was the site of the open-pit mining operations and the source of most iron-ore production from this hematite deposit (fig. 70). The face of the cut and the large blocks within it are assigned to the "Upper Ore Bed," a mineralized, bedded tuff. This unit displays many sedimentary features: bedding (fig. 71), ripple marks (fig. 72), mud cracks (fig. 73), and raindrop prints(?).

The "Upper Ore Bed" is underlain by the "Clay Seam," which separates it from the "Lower Ore Bed." This contact is obscured by talus in these cuts. The sharp footwall contact of the ore beds is exposed about 250 ft and 500 ft south of here, at STOP 2A and STOP 2B, respectively (fig. 68).

From STOP 2A climb westward up to the peak of Pilot Knob.

300

Figure 72. *Ripple marks on the surface of a large block of the bedded tuff on Pilot Knob, STOP 2. Photo by Dick Ryan.*

Figure 73. *Mud cracks on the surface of a block of the bedded tuff on Pilot Knob, STOP 2. Photo by Dick Ryan.*

4100 **STOP 3.** Top of Pilot Knob (NE¼ SW¼ sec. 29, T. 34 N., R. 4 E.).

The "Volcanic Agglomerate" unit is exposed at the crest of the hill. Large cracks in the rock are due to caving in of old underground workings.

Begin descent down the western slope of Pilot Knob.

800

4900 **STOP 4.** "Ice Cave" (NW¼ SW¼ sec. 29, T. 34 N., R. 4 E.).

CAUTION: LOOSE ROCK!

There were two adits here, now blocked by rock slumped from the walls of the upper cut. Cold air used to blow from the adits, giving rise to the early miners' name for this locality, the "Ice Cave." Large blocks of the "Volcanic Agglomerate" (fig. 74) are not in place, but are scaled off the southern wall of the upper cut.

At STOP 4A and STOP 4B (fig. 68), the "Lower Ore Bed" is seen in gradational contact with the foot-wall rhyolite.

Proceed downhill on the western slope of Pilot Knob along the trail leading from the "Ice Cave" to the starting point.

1500

6400 End of trail by the entrance to Pilot Knob Pellet Company. Resume trip by car.

Sources referred to in this road log are listed in the combined bibliography at the end of this Guidebook.

TRAVEL ON SAFELY!

END OF ROAD LOG NO. 3

Figure 74. *"Volcanic Agglomerate," consisting of angular to subangular fragments of rhyolite porphyry cemented by fine-grained siliceous hematite, STOP 4. This large block is not in place, but scaled off the south wall of the old cut atop Pilot Knob. Photo by Dick Ryan.*

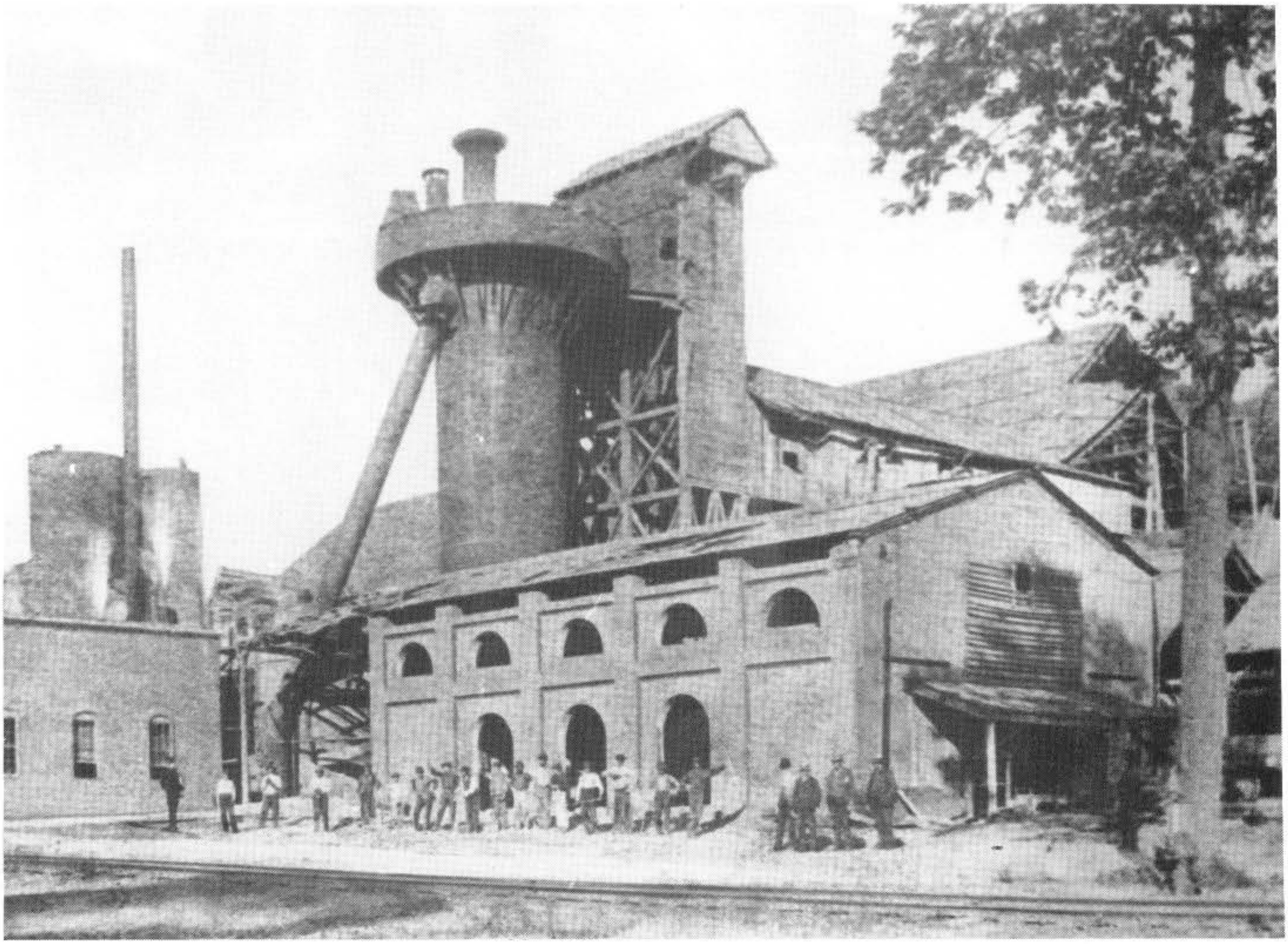


Figure 75. *Historic photograph of the iron works at the northwest base of Pilot Knob, ca. 1880. Source: The Hanna Mining Company.*

THE PILOT KNOB HEMATITE DEPOSIT

Richard F. Ryan

INTRODUCTION

The Pilot Knob hematite deposit, at the top of Pilot Knob, SW¼ sec. 29, T. 34 N., R. 4 E., Iron County, is part of the southeast Missouri iron metallogenic province, a major Precambrian iron-ore district, approximately 70 mi by 40 mi, containing six major and numerous smaller deposits (Kisvarsanyi and Proctor, 1967). A subsurface magnetite-hematite deposit near the western base of the mountain was mined between 1968 and 1980 by the Pilot Knob Pellet Company, a joint venture of The Hanna Mining Company and Granite City Steel Company. Both historically and currently, iron ore is by far the most important mineral resource of the Precambrian of southeastern Missouri.

HISTORY

Precambrian iron ore in Missouri was first mined in 1815, from vein deposits on Shepherd Mountain, one mile southwest of Pilot Knob. A total of 75,000 tons of ore were produced and smelted at the Tong-Ashebran furnace near Stouts Creek Shut-ins, about 4 mi southeast of Pilot Knob (Crane, 1912). With development of the Iron Mountain and Pilot Knob deposits, Missouri became a major iron-ore producer by the 1840's. By the time of the discovery of the large deposits of the Lake Superior region in the late 1880's, Missouri's higher grade deposits were nearly depleted and could not compete with the lower mining costs of the high-grade Lake Superior deposits.

The Iron Mountain deposit, 7 mi north of Pilot Knob, became an active pit in 1843. Production declined after 1892 and was intermittent until the discovery, in the late 1940's, of subsurface ore-bodies, which were depleted in 1966. Total production from the Iron Mountain deposit amounted to about 14 million tons of hematite and magnetite ore. Until 1858, when the St. Louis-Iron Mountain Railroad was completed, the ore was hauled to Ste. Genevieve on the Mississippi River by wagons via a plank road.

The Pilot Knob (surface) hematite deposit was first mined in 1835. Large scale production started in 1848, when a furnace was built at the base of the mountain by the Madison Mining Company (Crane, 1912). Remnants of a furnace built in 1880 (fig. 75) still stand near the pellet-loading depot of the Pilot Knob Pellet Company. The mine was operated by several companies until about 1890, when the St. Louis Ore and Steel Company discontinued underground operations. Around 1910 the Puxico Iron Company mined conglomerate ore from the northern slope of Pilot Knob. The Big Muddy Coal and Iron Company mined the deposit in the early 1920's. The rhyolite host rock was quarried for road metal. Total production from the Pilot Knob hematite deposit was more than 1.6 million tons of ore (Hayes, 1951).

A small deposit near the crest of Cedar Hill, one mile northwest of Pilot Knob, was opened in 1872 and produced about 25,000 tons of hematite from vein and breccia ore.

Aeromagnetic surveys in the 1950's led to subsequent discoveries of several major magnetite deposits at depth. One of these, the Pilot Knob (subsurface) magnetite orebody in the valley just west of Pilot Knob, was discovered in 1957 by drilling on a magnetic high on the flank of a major magnetic anomaly. The mine went into full production in 1968 and closed down permanently in November 1980. Its total production amounted to about 22 million tons of magnetite ore.

GEOLOGY

Pilot Knob is near the northeastern boundary of the proposed Taum Sauk caldera (Anderson and others, 1969). The hematite deposit is within a series of ash-flow tuffs, bedded air-fall tuffs, and lava flows cut by mafic dikes and sills. The volcanic rocks comprising Pilot Knob were mapped in detail by Mejia (1959). In ascending stratigraphic order the following five units are distinguished:

1. *"Lower Red Rhyolite."* This, the oldest mapped unit, exposed at the base of the mountain, is a fine-grained, dense, red to reddish-brown, fragmental ash-flow tuff with faintly discernible flow lines, spherulitic structures, contorted pumice fragments, and phenocrysts of feldspar. Its lower contact is not exposed. The best outcrops are on the northwestern flank of Pilot Knob, about 1225 ft above sea level (STOP 1B, fig. 68, Road Log No. 3), and on the eastern slope of the hill, about 1300 ft above sea level.

2. *"Purple Rhyolite."* This is an aphanitic flow containing only a few small phenocrysts and disseminated hematite. Its purple color is caused by iron oxide. In the lower part of the unit, prominent spherulitic structure can be seen in several outcrops. Near the top of the unit there is a brecciated interval that forms the footwall of the ore. The contact of the breccia with the ore is well exposed in several places on Pilot Knob (STOP 4, fig. 68, Road Log No. 3).

3. *"Ore Beds."* The ore deposit consists of fine-grained, laminated hematite possessing sedimentary features (ripple marks, mud cracks, graded bedding, cross bedding, raindrop prints). This unit also contains quartz and feldspar bands and lithic fragments. Its contact with the "Purple Rhyolite" is sharp or gradational; the ore often encloses rhyolite clasts near the contact. The upper contact of the ore grades into the "Volcanic Agglomerate"; the number of lithic fragments increases towards the upper contact of the ore.

4. *"Volcanic Agglomerate."* This unit consists of angular to subangular fragments of red to reddish-brown rhyolite porphyry cemented by fine-grained siliceous hematite. The fragments vary from a few mm to 30 cm in diameter. Locally, the fragments are oriented with their longest dimension parallel to the bedding. Because of its iron content, this unit is considered to be part of the ore. The contact of the "Volcanic Agglomerate" with the overlying "Upper Red Rhyolite" is not exposed.

5. *"Upper Red Rhyolite."* This is a fine-grained, red ash-flow tuff with sparse phenocrysts of quartz and feldspar, and minor hematite and magnetite. The unit is light gray in outcrops on the south side of the mountain. Shard structures and collapsed pumice fragments were reported in it by Anderson (1976).

A breccia, cemented by hematite and magnetite, is exposed on the northwestern flank of Pilot Knob (STOP 1, fig. 68, Road Log No. 3). Hematite apparently replaces magnetite. Like the veins on Shepherd Mountain, the breccia strikes northeast-southwest. It is similar to breccias on Cedar Hill and has some of the characteristics of the "Volcanic Agglomerate." However, as it apparently cuts the "Lower Red Rhyolite," I believe it to be a distinct mineralized unit. Several small pits indicate an attempt to mine it.

THE HEMATITE DEPOSIT

The hematite deposit has been subdivided into four units. In ascending stratigraphic order these are as follows:

1. The lower ore bed, 6 to 30 ft thick
2. The clay seam, 1 to 3 ft thick

3. The upper ore bed, 10 to 30 ft thick
4. The "Volcanic Agglomerate," approximately 100 ft thick

The lower ore bed consists of fine-grained, hard, dense, steel-gray, thinly laminated specular hematite. Its lower portion has ripple marks and raindrop prints (STOP 2, fig. 68, Road Log No. 3). Gangue minerals include quartz, feldspar, barite, and trace amounts of zoisite, sphene, and apatite. In the big cut area the ore is 30 ft thick, but it thins along its strike and dip. To the north and northeast, the ore is cut off by the outcrop; to the east, south, and west, it thins and grades into volcanic rock (Crane, 1912). At the "Ice Cave" (STOP 4, fig. 68, Road Log No. 3), the ore is about 10 ft thick and grades laterally eastward through a breccia into the "Purple Rhyolite." The contact of the lower ore bed with the footwall is gradational and irregular (STOP 4, fig. 68, Road Log No. 3). A transitional contact consisting of alternating beds of banded iron-bearing rock and breccia occurs over an interval of 2 to 3 ft at STOP 2 (fig. 68, Road Log No. 3). The average grade of the lower ore bed is 58 percent iron and 17 percent silica.

The clay seam is a soft, light-gray to yellow clay identified by Anderson (1976) as a sericitized tuff. Crane (1912) described it as a shear zone consisting of talcose, thinly laminated rock. Locally, it encroaches on the thin beds of the overlying banded ore and may be gradational into it both above and below. This gradational zone is 6 to 10 in. thick. At the "Ice Cave," the clay seam pinches out to the west, in the "Purple Rhyolite" footwall.

The upper ore bed is thinly banded, fine-grained, bluish-gray hematite characterized by uniform bands of quartz and feldspar parallel to the bedding. Ripple marks and mud cracks are found in this zone (STOP 2, fig. 68, Road Log No. 3). Thin layers of lithic clasts parallel to the bedding become prominent upward near the contact with the "Volcanic Agglomerate." The upper ore bed is absent in the "Ice Cave," but is well exposed in the old cut, where it is about 30 ft thick. The average grade of the upper ore bed is between 40 and 50 percent iron, and between 15 and 20 percent silica. Ore grade decreases toward the "Volcanic Agglomerate."

The "Volcanic Agglomerate" is exposed in the upper face of the old cut and at the crest of Pilot Knob (STOP 3, fig. 68, Road Log No. 3). The average grade of this unit is about 20 to 23 percent iron. Drillholes indicate that the "Volcanic Agglomerate" grades laterally into slightly brecciated rhyolite porphyry believed to be equivalent to the hanging wall "Upper Red Rhyolite."

The ore body is L-shaped, forming a plunging syncline that pitches southwest about 20 degrees. Conglomerate ore was once mined in the north cut, near the base of Pilot Knob (fig. 68, Road Log No. 3). It is a talus deposit on the Precambrian surface, derived by weathering of the bedded ore, and partly covered by Upper Cambrian sedimentary rocks. The average grade of hand-picked, soft ore was reported to be 56 percent iron and 10 percent silica (Crane, 1912).

ORIGIN OF THE HEMATITE: HYDROTHERMAL REPLACEMENT OR SEDIMENTARY DEPOSITION

The origin of the Pilot Knob hematite deposit has been and will probably continue to be a subject of controversy. Many geologists have studied the deposit, the best contributions having been made by Crane (1912), Singewald and Milton (1929), Geijer (1931), Steidtman (1933), Meyer (1939), Mejia (1959), Kisvarsanyi (1966), Anderson (1976), and Panno (1978).

Singewald and Milton (1929) described hand specimens and thin sections that show that hematite replaces quartz-sericite felsite near the contact of the ore with the footwall. They noted that the quartz phenocrysts are more resistant to replacement than the felsite. Hematite was found to intrude the footwall rock 25 ft below the ore bed and to fill voids around breccia clasts. Singewald and Milton (1929) concluded that the ore was introduced as an iron- and silica-rich end product of a deep-seated granitic magma and that the fine-grained pyroclastic tuff was more thoroughly replaced by the ore-bearing solutions. The grade of mineralization is proportionately higher as the grain size of the tuffs decreases.

Geijer (1931) noted similarities between agglomerates at Pilot Knob and the Kiruna district of Sweden in that they are hydrothermally altered and impregnated with hematite.

Steidtman (1933) studied thin sections from the upper and lower ore beds and noted that angular fragments at certain horizons are silicified and sericitized. The margins of fragments are often embayed and replaced by crystalline hematite. The agglomerate displays similar replacement characteristics, and the clasts are cut by hematite veinlets. Steidtman (1933) suggested that the host rock was deposited in shallow water as a volcanic ash and that ore-bearing solutions replaced and altered it; the finer grained sediments were replaced more extensively than the coarser grained sediments.

Meyer (1939) mapped the lithologic units on Pilot Knob and studied polished sections of the ore. He suggested that the deposit is the result of hydrothermal replacement of water-laid pyroclastic rocks. Mejia (1959) established the stratigraphic succession on Pilot Knob and the informal nomenclature of the different lithologic units, which have remained in use by Pilot Knob Pellet Company geologists.

Kisvarsanyi (1966) investigated the trace-element characteristics of the deposit and supported the hydrothermal replacement origin, on the basis of the geochemistry and textural relationships of the ore and gangue minerals. Features such as recrystallization, random orientation of hematite grains, and variations in grain size, as well as the trace-element data resemble those in hydrothermal replacement deposits. Veinlets and cavities filled by barite, fluorite, quartz, and calcite also suggest a late hydrothermal phase.

Anderson (1976) emphasized the sedimentary characteristics of the deposit and suggested that the iron minerals were deposited syngenetically as particulates with pyroclastic materials in a shallow-lake environment. He considered replacement to be minor and due to remobilization of iron after the deposition of the hematite and also suggested that the iron was derived from fluids related to the injection of the Pilot Knob (subsurface) magnetite deposit.

The syngenetic theory does not account for the gradational contacts of the footwall with the ore. The iron content gradually decreases away from the ore over a distance of several feet, a relationship that cannot be explained by sedimentation. Also, if the hematite deposit is related to the injection of the magnetite ore body at depth, it would be younger than the host rock of the latter, yet the hanging wall of the magnetite ore body has not been encountered in drill-holes on Pilot Knob. Instead, the hematite deposit is emplaced in rocks that appear to be correlative with the footwall rhyolite of the magnetite deposit; hence, the Pilot Knob (surface) hematite deposit is apparently older than the Pilot Knob (subsurface) magnetite deposit, or possibly, they are the same age.

Although evidence for both hydrothermal and syngenetic theories can be found in the deposit, neither fully accounts for all the observed features. I favor a theory of a hydrothermal fluid partly replacing, and filling voids of a porous and permeable tuff. However, replacement was not extensive enough to destroy the sedimentary features of the tuff.

Sources referred to in this paper are listed in the combined bibliography at the end of this Guidebook.

EPILOGUE

The St. Francois Mountains constitute a "window" through which a segment of the Late Precambrian continental crust — its evolution, structure, and potential for mineral and energy resources — can be investigated. Basic geologic studies of the area are important in determining the types of natural resources that may occur in this particular type of igneous terrane. With the help of direct data from drillholes, and geophysical maps, the knowledge thus gained can be extrapolated to characterize the buried Precambrian terrane.

Studies of the continental basement have both scientific and practical objectives, but the latter cannot be achieved without the former. In mineral resources research, the ultimate goal of locating ore deposits cannot be accomplished without a basic understanding of ore-forming processes. As surface and shallow deposits become depleted, the search for ever deeper resources will intensify, and the vast resources inherent in the ancient crystalline rocks of the basement will become valid exploration targets. In earthquake studies, better definition of basement structures and fault zones, and their possible relation to recent faulting, are essential in siting industries, dams, and hazardous-waste disposal facilities. Because the St. Francois Mountains represent an easily accessible exposed "sample" of continental crust, past, present, and future geologic research here have long-range societal implicatons.

We hope that you have enjoyed your tour and that we have succeeded in better acquainting you with the geology of this scenic and picturesque region.

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