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Stratigraphy and correlation of Precambrian volcanic rocks, Eminence, Missouri

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STRATIGRAPHY AND CORRELATION OF PRECAMBRIAN VOLCANIC ROCKS, EMINENCE, MISSOURI

BY

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A

THESIS

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ABSTRACT

A portion of the Precambrian rocks located in the vicinity of Eminence, Missouri are studied and described. These rocks are exposed as rhyolitic knobs protruding through hills of Ordovician sediments.

The Precambrian rocks under study consist principally of rhyolite, with smaller amounts of tuff and breccia. The rhyolite is a potash rhyolite porphyry, both flow banded and unbanded, with phenocrysts of kaolinized orthoclase in a matrix of quartz and orthoclase. The tuffs contain devitrified glass shards and occasional ash balls such as those exhibited at Coot Mountain.

A stratigraphic sequence was determined with the oldest rocks to the south at Stiegel Mountain and the younger rocks at Coot Mountain to the north. The tuffs occur between rhyolite flows. The entire sequence has a general dip to the north; but local variations in dip and strike occur.

Basal conglomerate formed from rhyolite boulders occurs within the Ordovician sediments, particularly at the Little Rocky Creek Ford knob.

The possibility that the Eminence rhyolites are ignimbrites was studied and rejected.

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I. INTRODUCTION

Precambrian rocks outcrop in two principal areas in southeastern Missouri. The largest of these areas centered about the town of Ironton is normally referred to as the St. Francois Mountains. Forty miles to the southwest, a smaller area of Precambrian knobs occurs near the town of Eminence. While the Precambrian knobs in the larger area have received considerable study, those in the Eminence area have received less emphasis.

A. Acknowledgments

Thanks goes to Dr. Geza Kisvarsanyi of the University of Missouri at Rolla for first arousing interest in the Precambrian of the Eminence area. The writer wishes to thank Dr. Richard D. Hagni of the same institution who suggested a stratigraphic and structural study of these Precambrian rocks, and who directed the field and laboratory work for this thesis. Appreciation is due Dr. William Hayes, of the State of Missouri Geological Survey and Water Resources, for permission to examine the forthcoming report on the Precambrian rocks of Missouri.

B. Objectives

The main purpose of this investigation was to map, study, and describe Precambrian rocks within a small portion of the Eminence region and to construct the stratigraphic and structural relationships in that restricted area. The stratigraphic sequence and structural relations would then be extended to adjacent knobs and hopefully by future studies throughout the entire Eminence area of Precambrian knobs.

The writer also was very interested in the genesis of these Precambrian rocks. Are the volcanic rocks predominantly flows or ignimbrites? Ignimbrites were believed by Anderson (1962) to constitute many of the volcanics which he mapped in part of the St. Francois Mountains. Since ignimbrites characteristically exhibit great lateral extent, they tend to provide marker beds which would make correlation between knobs less difficult.

C. Previous Investigations

The Precambrian rocks of the Eminence area have received little detailed study. Previous investigations either have been of general scope or have concentrated on the economic geology of the area.

The earliest description of this area was given by Greason (1876)[1] in which he described copper deposits at some of the mines. He indicated that the "porphyries," as these Precambrian rocks are sometimes called, were older than Silurian in age, and belonged to the Archaean. The porphyries were described as consisting of quartz crystals, feldspar crystals, and streaks of quartz, in a matrix which varied from light to dark purple, black, or light red color. Greason also believed that these rocks were a continuation of the porphyries of the Iron Mountain area.

Haworth (1895), in his report on the igneous rocks of Missouri, pictured igneous outcrops in the Eminence area on his map, but he did not describe those rocks.

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[1]Arthur Greason, "Copper Ores and Deposits of Shannon County Missouri" (unpublished Master's thesis, Missouri School of Mines and Met., 1876), p. 3.

Bridge (1930) studied the geology of the Eminence and Cardareva quadrangles. While Bridge was primarily interested in the Paleozoic sediments of the area, included in his report were descriptions of several Precambrian volcanics from the Eminence area, mainly from the Slater Knob and Jerktail Mountain. The locations of knobs as given in his report is the most comprehensive study made and was most helpful in the present writer's work.

Graves (1938)[2] described structures in the Precambrian rocks of Missouri. Those in Shannon County he grouped into a block whose rectangular surface expression trends northwesterly. Based on Bridge's statement that the mineralization of the southwestern edge of the knobs is indicative of buried faults, Graves felt that pressure from the southwest and its subsequent release formed faults outlining the block. Later compression from the southwest and southeast was believed to accentuate the block structure.

World War II increased the demand for manganese. A report by Grawe (1943) described the occurrence of manganese minerals in Missouri and the prospects made for them in the state. Descriptions of the Eminence deposits from his report are in a later section of this thesis.

Although copper mining had been carried on intermittently since the 1870's, there was a space of 81 years between Greason's report and that of Evans (1959). In a thesis, Evans described the various copper minerals of the defunct Slater, Sutton, and Jerktail mines. According to Evans, the deposits occurred in rhyolite and in the basal conglomerate which surrounds some of the knobs. The rhyolites and tuffs which are found

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[2]Howard B. Graves, "The Precambrian Structure of Missouri," St. Louis Acad. Sci. Trans., vol. 29, no. 5, p. 146.

at those mines were petrographically described.

Adams (1959) described Precambrian rocks from various wells which were drilled throughout Missouri and brought together much of the existing information on Missouri Precambrian rocks. None of these specimens were from the Eminence area. From his studies, he decided that the Precambrian rocks consist of a thick series of extrusives which were later intruded by a granitic batholith, and then intruded by diabase sills and dikes.[3] The extrusives were divided into an older and a younger group. During the time interval between extrusion of these two groups, the older series was partly eroded and redeposited in shallow water. The younger series was extruded upon this surface. Adams believed the Precambrian rocks of the Eminence area to connect those in the St. Francois Mountains beneath the Paleozoic sedimentary cover.

Mantei (1962) made laboratory studies of the Precambrian rock specimens that he collected throughout Missouri; the localities of which were selected by Hayes of the Missouri Geological Survey. The only specimen from the Eminence region came from Stegall Mountain. The Stegall rhyolite was believed by Mantei to belong to the older Middlebrook group, of Missouri Precambrian rocks, on the basis of its Na:K ratio.[4]

The latest publication dealing with the Precambrian rocks in the Eminence region is the forthcoming report of the Precambrian of Missouri,

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[3]James A. Adams, "Rocks of the Precambrian Basement and Those Immediately Overlying It in Missouri and Parts of Adjacent States" (unpublished Master's thesis, Univ. of Mo.), p. 222.

[4]Erwin Joseph Mantei, "K_2O/Na_2O Content as a Possible Index to the Chronological Sequence of some Precambrian Igneous Rocks of Missouri" (unpublished Master's thesis, Univ. of Mo., School of Mines and Met.).

which will be published by the Missouri Geological Survey. The Precambrian rocks forming Stegall Mountain are separated into two rhyolite flows by an interrelated flinty felsite. This felsite is interpreted to be a devitrified glass.[5] The rhyolites are said to dip less than 15° to the north.

Although Anderson (1962) did not study Precambrian rocks in the Eminence area, the nature of his study in the St. Francois Mountains to the east was similar to that of the present investigation. Anderson was able to correlate map and also lava units for distances of several miles. He also concluded that many rhyolites which were thought by others to be lavas and tuffs were actually ignimbrites.

Other references on the Precambrian rocks of the St. Francois Mountains are not reviewed here, but the more important ones are included in the bibliography.

E. Method of Investigation

Field examination of the Precambrian knobs began with a detailed study of Coot Mountain. Careful study of lithology, flow banding and other lava characteristics allowed the writer to delineate three rhyolite units at that knob. The contacts between these units and flow banding attitudes, measured with the aid of a brunton compass were plotted on an airphoto base. The units determined at Coot Mountain were correlated with rhyolites outcropping along the strike at knobs to the east and west. Petrographic study of 56 specimens collected in the field aided in determining variations in rhyolite lithology.

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[5] Forbes S. Robertson and Carl F. Tolman, "Exposed Precambrian Rocks, Precambrian of Missouri," Missouri Geol. Surv. and Water Resources, in press, p. 66.

II. GEOGRAPHY

A. Location of Area

For the purpose of this thesis, the Eminence area is considered to cousist of land bounded on the north by 37° 14' latitude, on the east by 91° 15' longitude, on the south by 37° 3' latitude, and on the west by 91° 23' longitude. The Precambrian knobs of the area all lie within these boundaries. The area lies principally within Shannon County but its southeast corner is in Carter County. The Eminence area is located in the eastern half of the Eminence and the western half of the Cardareva Quadrangles. The location of the thesis area is shown on Figure 1.

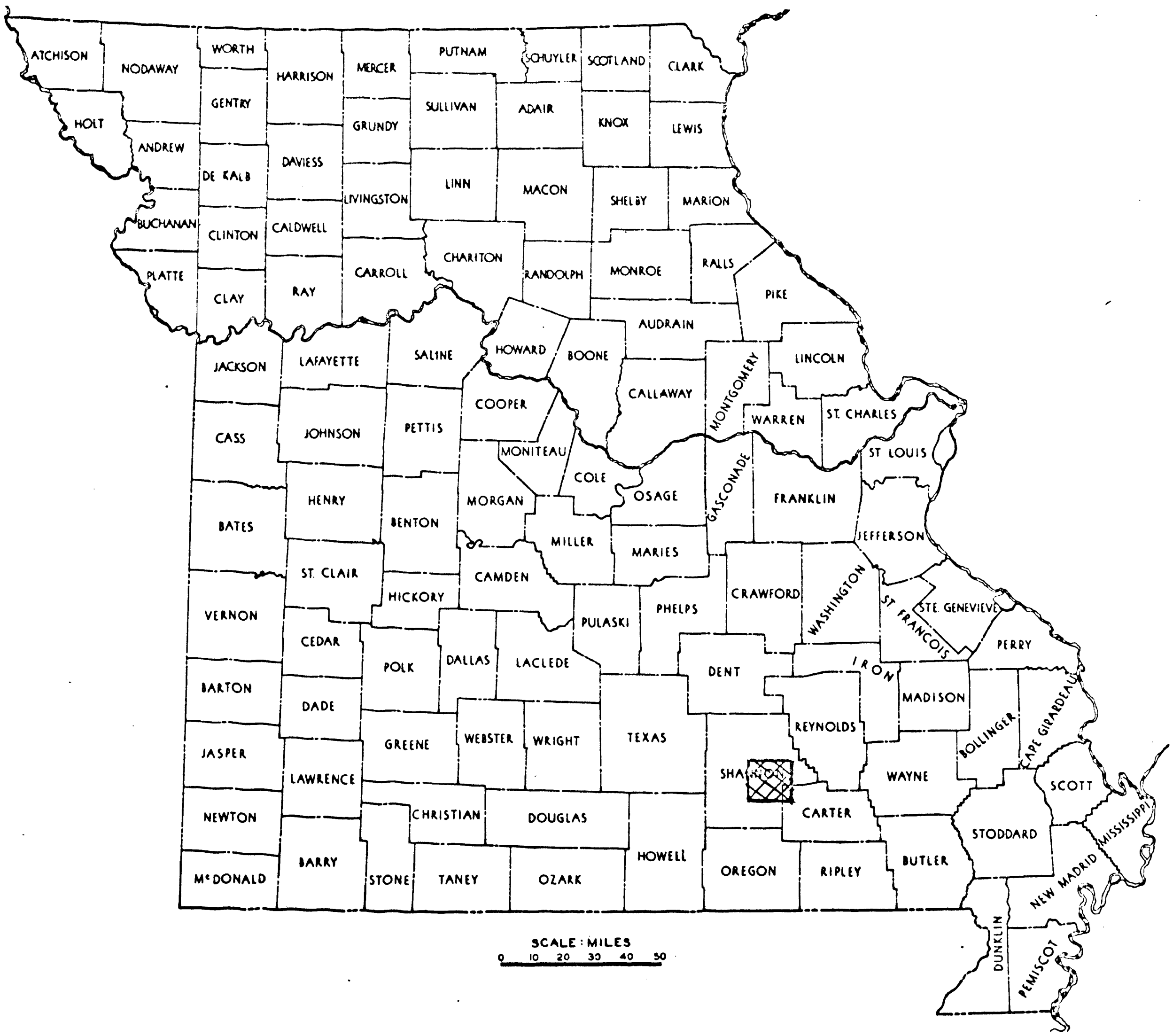
Access to the area divides it into a section north of the Current River and a section south of the river. The northern section can be reached from Bunker, 25 miles north of Eminence, by a series of dirt roads, or from the south by ferry across the Current River. The southern area is readily accessible from the town of Eminence.

B. Population and Industry

The area is rural with a low density population. There are three main towns in the area; Eminence, West Eminence, and Winona. Eminence is the county seat of Shannon County and had a reported population of 516 in 1960. Winona lies just south of the Eminence area.

Lumbering was at one time the major industry of the area with pine and hardwoods as the most valuable timber. Sawmills were erected which led to the hasty and unwise cutting of this crop. The cut-over

INDEX MAP
of the
EMINENCE REGION, MISSOURI



Thesis Area ⊠

Fig. 1

Plate I. General view of the Eminence area looking southeast from the Coot Mountain firetower.

land generally has not been reforested and much of it is too steep for farming. Federal, state, and local forestry groups have recently begun reforestation of certain portions of the land. An excellent example of this can be seen at Stegall Mountain. Private land is now mainly used for hog and cattle grazing.

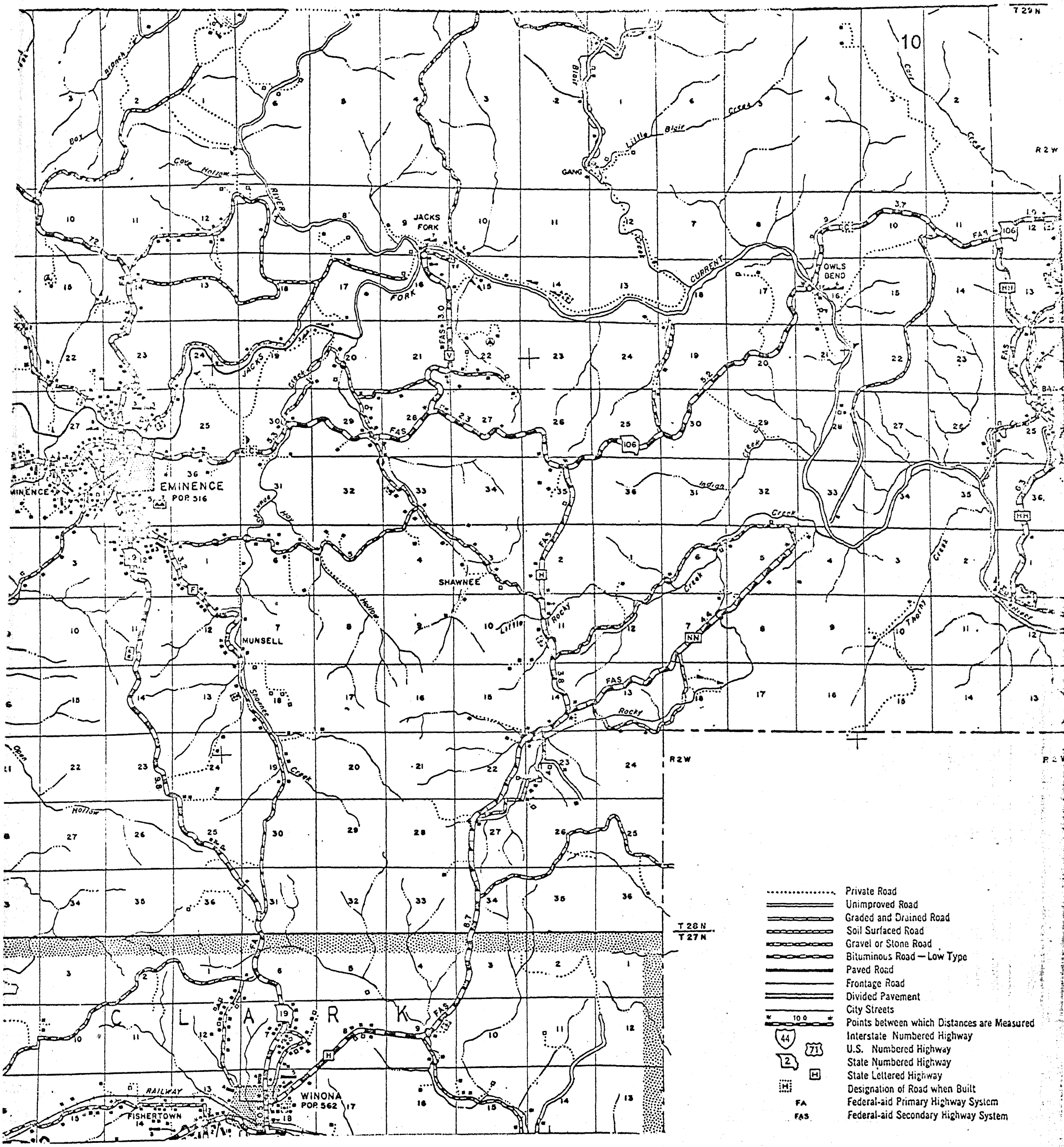
A clothing factory employing about 150 people is located within the town of Eminence. The tourist trade is an aid to the economy during the summer, and the new National Monument, the Ozark National Scenic Rivers, can be expected to attract additional tourists to the rivers of the area.

C. Roads

The best roads in the area are Missouri State Highways 106 and 19. Highway 106 crosses east-west through the middle portion of the Eminence area, and highway 19 trends north-south through the western part. These are the only paved roads in the area. Shannon County roads V, H, and NN lead to some of the knobs, and improved and unimproved dirt roads lead to others. All knobs are within one-half mile of one of these roads. Old logging roads and state conservation roads generally can be traveled only by jeep. Many of these dirt roads are shown on the air photos taken in 1938. Some of the state, county, and private roads do not appear on the topographic quadrangles.

D. Rivers and "Shut-ins"

The largest river in the Eminence area is the Current River, which originates at Montauk Springs in Dent County. The second largest river is the Jacks Fork River which begins in Howell County and empties into the Current River about five miles northeast of Eminence. These two



General Highway Map

Southwest Portion Of
SHANNON COUNTY
Missouri

After Missouri State
Highway Department

SCALE

1 0 1 2 3 4 MILES

Fig. 2

rivers are popular vacation spots and are renowned for their beauty and excellent fishing.

Smaller streams such as Prairie Hollow and Little Rocky Creek cut deep gorges into Precambrian rocks in portions of some valleys. These gorges are known locally as "shut-ins." They were formed by the downward cutting of streams through less resistant sedimentary rocks into more resistant Precambrian rocks, where the streams were not able to change their courses. Stream erosion of the Precambrian rocks formed the small steep-walled valleys or shut-ins. Their steep walls provide excellent cross-sections through the knobs in which one can examine the structure of the Precambrian rocks. Individual shut-ins within the Eminence area are described along with the knobs into which they cut.

III. CORRELATION OF VOLCANIC ROCKS

Extrusive rocks are poured out upon the earth's surface in roughly horizontal units, one above the other. Thus, the principles of correlation commonly applied to sedimentary rocks may also be used to advantage for volcanic sequences.

The simplest and most direct way to correlate any two volcanic rock outcrops is by direct tracing of the bed, from outcrop to outcrop. This will indicate whether both outcrops belong to the same rock unit, or not.

When continuity of the unit is broken, due to erosion, or subsequent disposition, other methods of correlation must be used. A stratigraphic sequence such as a red brown sandstone, overlain by a brown shale, brown rhyolite and finally by a brown limestone may be equated to a similar sequence in another area. Correlation becomes more certain if the roaks underlying or overlying the rhyolite in one sequence are correlative to those in the second sequence. In the absence of sedimentary units the presence of a distinct marker bed within a series of volcanics is of great aid. Such a unit, completely different from the others, having distinct color, mineralogy, or structure, may be used as a particular horizon, and the position of other flows related to this. Correlation becomes more tentative with increasing distance between outcrops.

Barring the presence of a key marker unit, the individual extrusive unit in question must be examined. Gross features common to igneous and sedimentary rocks such as color, joints, weathering features, mineralogy, may be used. Sedimentary rocks contain fossils, ripple marks, mud cracks, etc.; but as these features are absent in extrusive rocks others must substitute for them. Flow banding, joints, inclusions of foreign material (not volcanic); presence of vesicles, ash balls, glass shards, may be used.

On the microscopic level mineral composition and percentages, and unusual minerals can be used for correlation. The mineral sphene was used by Mackin (1960) in correlation of certain volcanic rocks of the Great Basin.

One special class of volcanic rocks, ignimbrites or ash-flow tuffs, are excellent for correlative purposes, and can be treated as sedimentary rocks. They have a sequence of formation, are stratified, have nearly horizontal upper surfaces, and they may extend over hundreds or even thousands of square miles. In the San Juan Mountains, for example, ignimbrites cover an area of 12,000 square miles. Due to their rapidity of deposition, a single unit can be thought of as having formed everywhere at essentially the same time. In interpreting the geology of the Great Basin, Mackin (1960) used the Quichapa formation as a key marker unit. This formation contains three or four ignimbrites, each having its own lithologic features making each ignimbrite easily identifiable. The ignimbrites were treated as sedimentary rocks in the mapping of the area.

IV. REGIONAL GEOLOGIC SETTING

A. Stratigraphy and Lithology

The stratigraphic record (Table 1) of the Eminence region consists of Precambrian and Paleozoic rocks.

While the Precambrian rocks in the St. Francois Mountains have been tentatively grouped as shown in Table 2, the stratigraphic arrangement of those in the Eminence area is undetermined. The Eminence rocks consist of rhyolites, tuffs, agglomerates, granites, and diabase, of which the rhyolites present the most variety.

Rhyolites are by far the most common of the Precambrian rocks in the Eminence area and they are present on all of the knobs. Tuffs are much less common but they occur at Coot Mountain, Stegall Mountain, Slater and Goose Bay Creek knobs. These tuffs are characterized by a fine aphanitic texture and by the presence of phenocrysts. Tuffs at the Slater knob exhibit bedding and rarely cross-bedding. With the aid of the microscope one can detect devitrified glass shards in these tuffs.

At Coot Mountain and Goose Bay Creek Knob the tuffs form the lowest layer; some rhyolites, are younger, while others are older in the Eminence area. At Stegall Mountain they form a layer between two rhyolite flows.

Agglomerates are quite common as float and in outcrops of the south slope of the rhyolite forming the western end of Liberty School Knob. They also occur along the eastern edge of the Goose Bay Creek Knob just above the tuff-rhyolite contact.

STRATIGRAPHIC SEQUENCE IN THE EMINENCE AREA

Era	Period	Epoch	Formation and Thickness	Character
Cenozoic	Quaternary	Pleistocene	Recent 0'-50'	Residual soil and alluvium
Paleozoic	Pennsylvanian	Desmoinesean	Cherokee (?) 50'-75'	Red, yellow, and white clays with some sandstone
	Mississippian	Osagean	Keokuk Burlington 5'	Residual boulders of white, fossiliferous chert
	Ordovician	Canadian	Cotter Jefferson City 50'	Residual boulders and nodules of chert. Sparingly fossiliferous
			Roubidoux 150'-200'	Sandstone and thin-bedded cherty dolomite
			Gasconade 260'-280' Gunter member 15'-20'	Gray, crystalline cherty dolomite with cryptozoon reef. Massive sandstone or sandstone and dolomite
	Cambrian	Upper Cambrian	Eminence 250'-310'	Massive, gray, crystalline, poorly bedded dolomite. Weathers to rusty porous cherts
			Potosi 50' on outcrop 167+ in wells	Dark gray and brown finely crystalline cherty drusy dolomite
			Bonneterre 60'	Light gray, coarsely crystalline dolomite, non-cherty
Precambrian				Rhyolite porphyry, tuffs, and agglomerates

After Bridge, 1930; Koenig, 1961

Table 1

PRECAMBRIAN ROCK UNITS IN THE ST. FRANCOIS MOUNTAINS

POST-BATHOLITHIC BASIC ROCKS

Strainka diabase

BATHOLITHIC ROCKS

Mudlick latite

Bevos group (misc. units)

Silvermine granite	Breadtray granite
Graniteville granite	Butler Hill granite
Brown Mt. rhyolite porphyry	Knoblick granite

Musco group (misc. units)

Stono granite	Buford granite porphyry
Slabtown granite	Munger granite porphyry
	Carver Creek granite porphyry

PRE-BATHOLITHIC ROCKS

Van East group (misc. units)

Hogan Mt. rhyolite	Annapolis rhyolite
Stouts Creek rhyolite	French Mills felsite

Ketcherside tuff

Middlebrook group (misc. units)

Pilot Knob felsite	Oak Mt. felsite
Royal Gorge rhyolite	Marlow Mt. rhyolite
	Clark Mt. rhyolite

After Hayes, 1961

Table 2.

Granite is not exposed in the Eminence area, but is known to the south and east. A small granite exposure occurs south of the Eminence area in the SW ¼ of Sec. 29, T. 27 N., R. 1 E., about 3 miles southeast of Van Buren. Another exposure is 10 miles north of Ellington. Within the Eminence area, granite is known to occur beneath the rhyolite where it has been encountered in drill holes around the rhyolite exposures at Jerktail Mountain. It is not known whether this granite is older or younger than the exposed rhyolite. Tarr's (1932) demonstration that the granites intrude the rhyolites in various localities in the St. Francois Mountains,[6] suggests that this granite may be younger than the Eminence rhyolites.

While basic igneous rocks are not known to outcrop in the Eminence area, diabase float was found on Coot Mountain by the writer. This diabase is known as the "blue granite" by the local people.

The stratigraphic sequence of Precambrian rock units at each are discussed in the section on the individual knobs.

The Paleozoic rocks were not an objective of this study but the writer examined basal conglomerates where Precambrian erosional debris in the Paleozoic rocks comes in contact with the Slater, Rocky Creek Ford, and Goose Bay Creek Knobs. The conglomerates consist of rhyolite boulders within a matrix of dolomite. The conglomerate on the southern slope of Rocky Creek Ford Knob (see Plate XVa, b) consist of rounded granite boulders one-twenty-fifth of an inch to several feet across as shown in the plate. Ohle (1952) has described similar basal conglomerates in the Hayden Creek mine.

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[6]William A. Tarr, "Intrusive Relationship of the Granite to the Rhyolite of Southeastern Missouri," Geol. Soc. Amer. Bull., vol. 43, no. 4, p. 991.

B. Structure

The regional structure of the Paleozoic rocks in southern Missouri is that of a broad dome known as the Ozark Uplift. Toward the center of the dome there are two broad areas of scattered exposures of Precambrian rocks. The more extensive of the two forms the St. Francois Mountains. The second consists of more scattered Precambrian exposures southwest of the St. Francois Mountains, near Eminence.

In the Eminence area the structure of the Paleozoic formation is due primarily to the presence of Precambrian knobs. A fine example of a presumably buried knob occurs at West Eminence where Bridge (1930) described a well defined dome with nearly 200 feet of closure.[7] No Precambrian rock is exposed in this structure.

The exposed Precambrian areas in the Eminence region, which protrude through nearly horizontal Paleozoic rocks, represent the tops of knobs uncovered by erosion. A rugged topography must have existed on the Precambrian surface, before the deposition of the Cambrian, to have produced the steep sides of these knobs. An excellent example of local high relief is in Sec. 9, T. 29 N., R. 3 W., where a knob rises to a height of 920 feet beside a slightly lower Paleozoic hill immediately to the east. Other Precambrian knobs exposed through the overlying Paleozoic formations exhibit similar ruggedness.

With the coming of the Cambrian seas, the valleys were filled with sediments which eventually buried the highest Precambrian peaks under the Eminence formation. Each sedimentary formation tended to overlap the preceding one. These Paleozoic sediments exhibit dips as

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[7] Josiah Bridge, "Geology of the Eminence and Cardareva Quadrangles," Missouri Bureau of Geology and Mines, 2nd ser., vol. 24, 1930, p. 163.

great as 10^{o} - 20^{o} in all directions away from the Precambrian knobs. While this inclination may be partially due to initial dip as suggested by Dake (1930), others believe it may also be due in part to compaction of the sediments after they were deposited.

Small folds occur in the flow banding of the Precambrian rocks at various knobs in the Eminence area. Larger folds are mainly undetected at this time.

Flow banding is present in various degrees of development throughout the rhyolite. Good examples can be seen on the Goose Bay Creek knob, Coot Mountain, and Cardareva Ford knob; while the Indian Creek and Rocky Creek Ford knobs show poorer banding. The banding normally is 5 millimeters across and up to 40 centimeters long. The general trend of these bands is northwest-southeast with a dip of about 60^{o} to the north in the western part of the region, and a strike of northeast-southwest with a northward dip of 60^{o} in the eastern part of the region.

While faults are not visible, Bridge has postulated buried faults at the margins of the Precambrian block which form the Eminence area. A local fault of small displacement may occur at the northwest edge of Coot Mountain.

Joints are well displayed in all knobs but they were not the principal interest of this study. Bridge (1930) noted two vertical joint systems, one striking northwest and the other northeast. Horizontal joints, which can best be seen on the Rocky Creek Ford knob (Plate XV), may have formed by unloading. These three joint systems result in outcrops of rhyolite which weather into rectangular blocks with rounded edges.

Plate IIa. Common straight flow banding in the middle unit at Coot Mountain knob at the south entrance of the shut-in.

Plate IIb. Less common swirl flow banding in rhyolite of the middle unit at Coot Mountain knob at the south entrance of the shut-in.

Plate IIIa. Flow banded rhyolites from the western slope of the Cardareva Ford knob (upper specimen), southern slope of the Liberty School knob (lower left), and float from Stegall Mountain collected along the summit road (lower right).

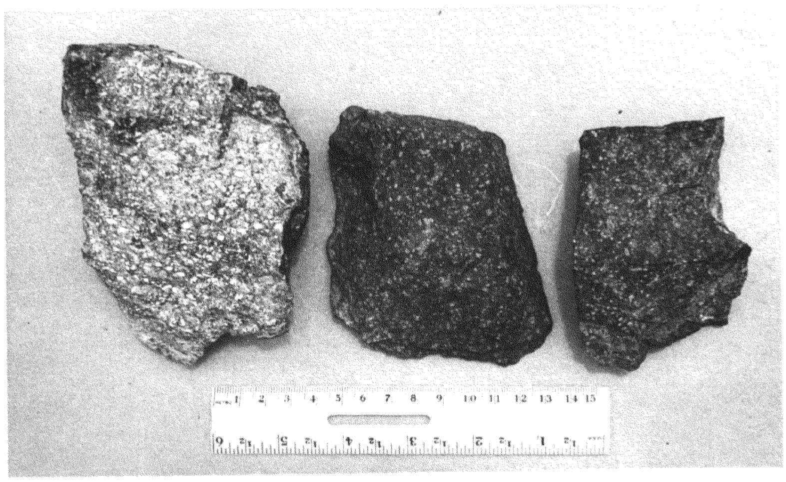


Plate IIIb. Nonbanded rhyolites from the Reed School knob (left), and Stegall Mountain (center, right).

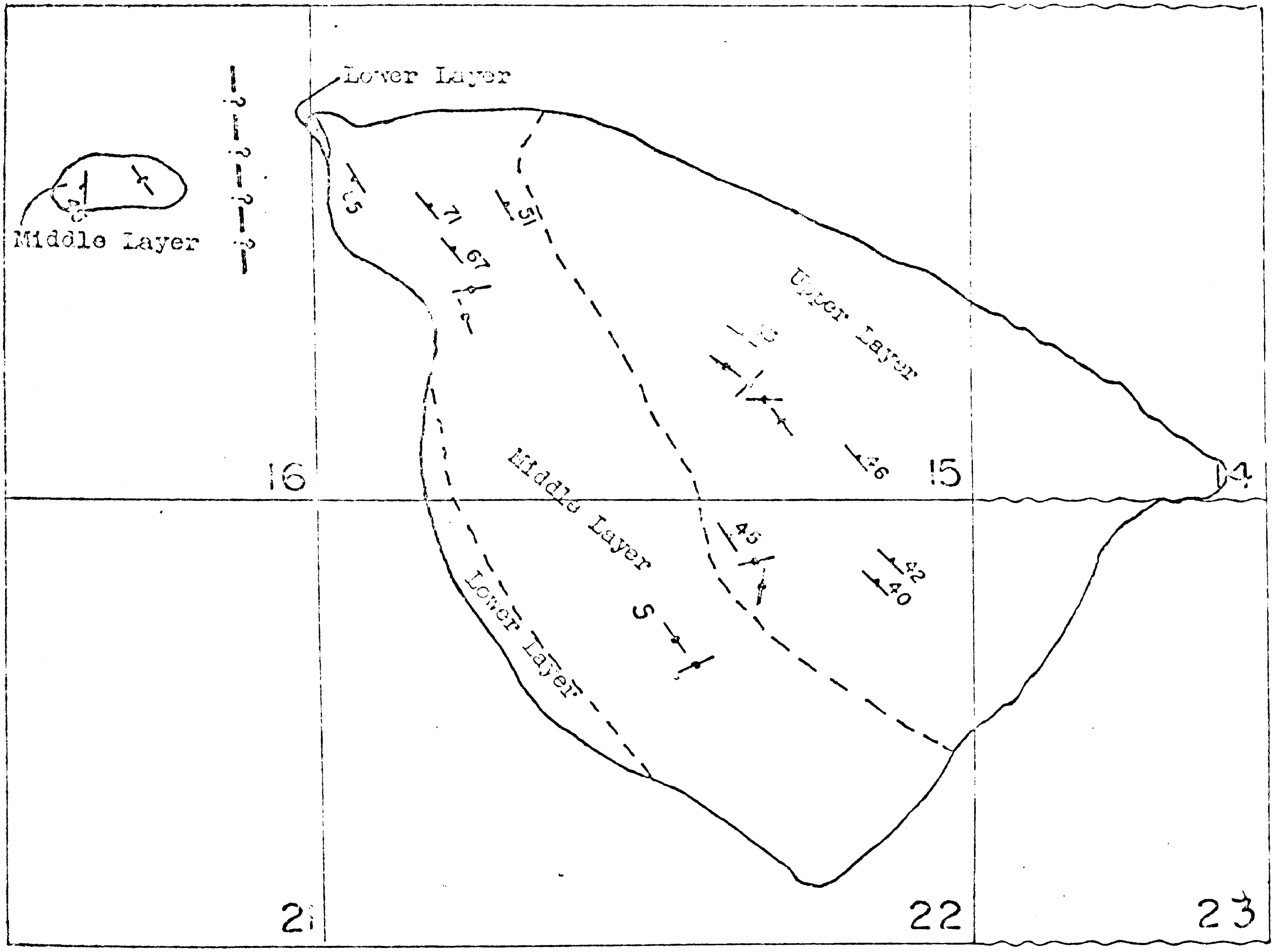
V. DESCRIPTIONS OF INDIVIDUAL KNOBS

The knobs studied by the writer lie south of the Current River, southward to Stegall and Thorny Mountains. The writer concentrated on those knobs because they were more accessible than those north of the river. The study began at Coot Mountain and proceeded southward and eastward. Stegall and Thorny Mountains at the south edge of the area were visited briefly but they were not studied in the detail devoted to the other knobs.

Locations of the "type" specimens from each knob are not given. Field examination of each knob will show that within a distance of one foot there can be a change from the "type" example to one which is quite different. The choice of the most typical rocks was determined only after studying each knob as a unit.

A. Coot Mountain

Coot Mountain was studied the most intensively of the knobs described in this thesis. The knob is easily reached by Shannon County Road V which runs north from highway 106. The area of Precambrian rock exposure is approximately two miles long and one mile wide, and it exhibits an irregular shape whose longest dimension lies northwest-southeast. It is located in the SW ¼, Sec. 14; S ½, Sec. 15; N ½, Sec. 22; NW ¼, Sec. 23, and with a protruding portion of the knob in the E ½, Sec. 16; all sections of which are in T. 29 N., R. 3 W., of the Eminence and Cardareva quadrangles. Coot Mountain's northern boundary is touched



GEOLOGICAL MAP OF

COOT MOUNTAIN

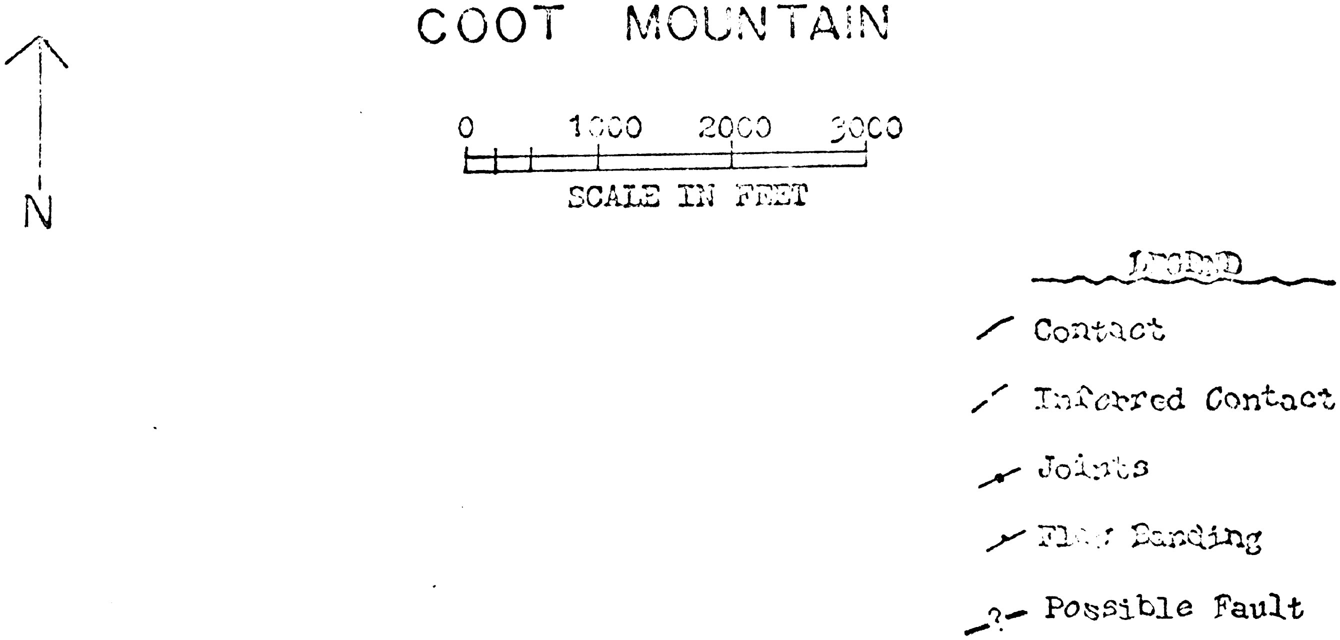


Fig. 4

by the Current River in two places, and it rises 688 feet above the river to an elevation of 1268 feet. At the summit of Coot Mountain, a Missouri Conservation Commission Fire Tower is erected. The tower is reached by improved dirt road, which is not shown on the 1939 aerial photographs.

On the northwest protruding portion of the knob exposure is a shut-in where excellent exposures frequently show flow banding. Other good outcrops occur along the road leading to the summit, and also along the ridge which forms the crest of the hill.

The general trend of flow banding, as shown in Plate V, is quite consistent on this knob, striking northwest-southeast and dipping steeply to the north. Dips range from 40° in the eastern part of the knob to 70° in the western portion. Locally, in some outcrops of the middle layer along the summit road, the flow banding exhibits swirls as exhibited in Plate IIb. In such places the flow bands are seen to curve changing strike and dip radically within a few feet.

The Precambrian rocks of Coot Mountain are bordered on the north by the Potosi Formation. This is one of the few cases in the Eminence area where the Eminence Formation does not completely surround a knob.

Precambrian volcanic rocks which constitute this knob were divided into three units as shown by Fig. 4. The lowest unit is a dense, red, aphanitic rock with conchoidal fracture. It generally is stained red by iron, but locally black by manganese. It weathers to a buff color. Microscopic study shows it to be a devitrified tuff. The tuff consists principally of very fine-grained crystallites which are less than 0.01 mm. across. The crystallites are in a semiparallel arrangement which have formed during deposition due to compaction. They exhibit low relief and very low birefringence and are believed by the writer to consist principally of quartz. Devitrified glass shards of the same size as the crystallites and arranged parallel to the crystallites constitute about 20 per cent of the rock. Bands of light and dark color which traverse the rock haphazardly appear to be iron stains. One vein of quartz was observed in the thin section studied.

Spherical objects (Plate IVa) which average 2 mm. and range in size up to 3 mm. across, are present in the bottom unit at Coot Mountain. They are quite common in the northernmost outcrop along county road V. Without the aid of the microscope these objects appear to be similar to spherulites, but microscopic examination did not reveal radiating or concentric structure. Devitrified glass shards are present both inside and outside these forms. The writer believes these objects to be lapilli of volcanic ash. These fragments of ash are flattened in one direction, and some appear to be broken. The borders of the ash fragments are outlined by a dark red-brown iron stain. The matrix of the rock is microcrystalline to almost cryptocrystalline. Since crystallite flowage is not exhibited in any of the specimens from the lower unit, it is believed by the writer that the breaking and flattening of the ash particles took place primarily during compaction.

The contact between the lower and middle units is exposed a few yards to the east of highway V in the NW ¼, Sec. 16, as previously noted by Evans.[8] Here the vertical contact curves slightly but the general trend of its strike is northwest-southeast. The actual contact was not observed by the writer elsewhere on Coot Mountain.

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[8]Larry L. Evans, "Geology of the Copper Deposits in the Eminence Region Shannon County, Missouri" (unpublished Master's thesis, Univ. of Missouri School of Mines and Met., 1959), p. 23.

Plate IVa. Lapilli-bearing volcanic tuffs from the Coot Mountain shut-in (right specimen), lower unit of Coot Mountain along Highway V (upper left), and the lower unit of Goose Bay Creek knob (lower left).

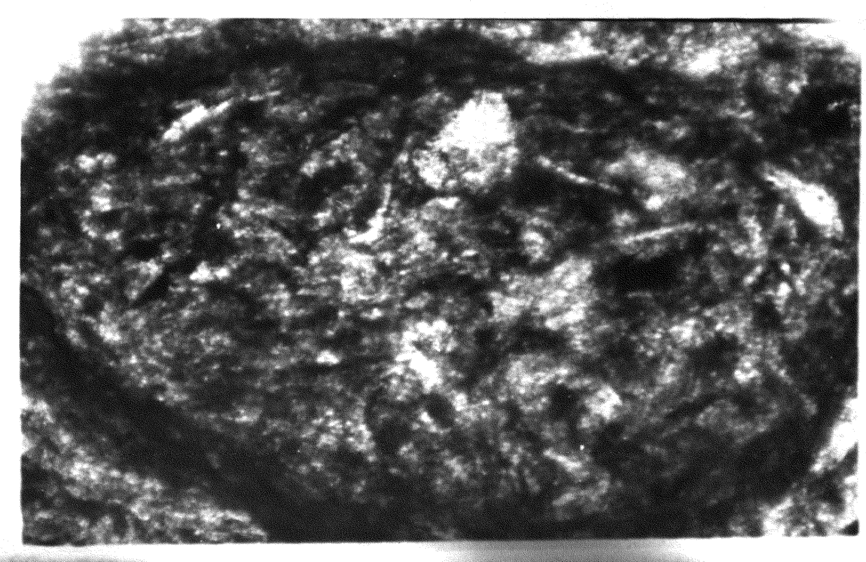


Plate IVb. Photomicrograph of lapilli in the lower unit at Coot Mountain knob. Indistinct devitrified glass shards occur in the center of the lapilli which is outlined by a dark elliptical band. Plane polarized light. 450X.

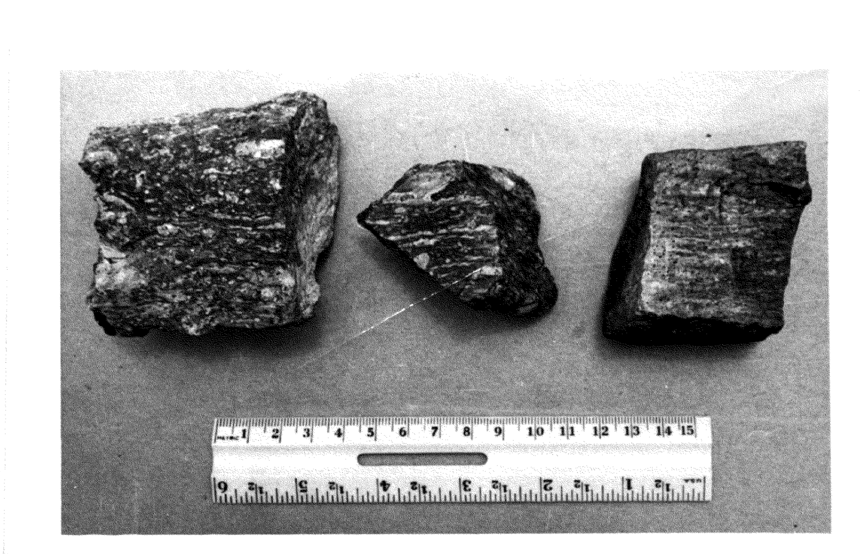


Plate Va. Flow banded rhyolites from the upper unit at Goose Bay Creek Ford knob (middle specimen) and the middle unit of Coot Mountain shut-in (left, right specimens).

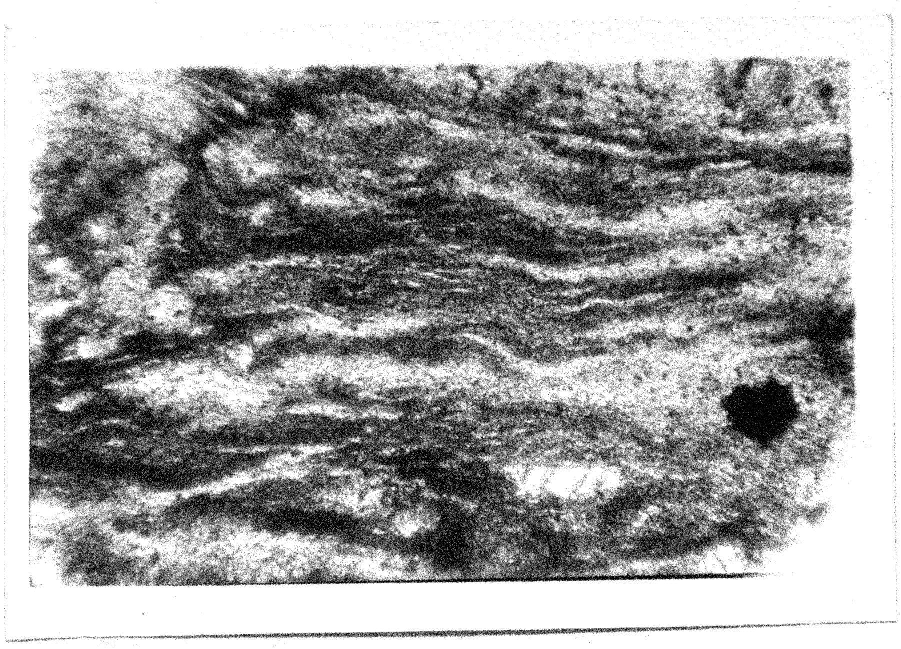


Plate Vb. Photomicrograph of flow banded rhyolite from the Coot Mountain shut-in. Plane polarized light, 100X.

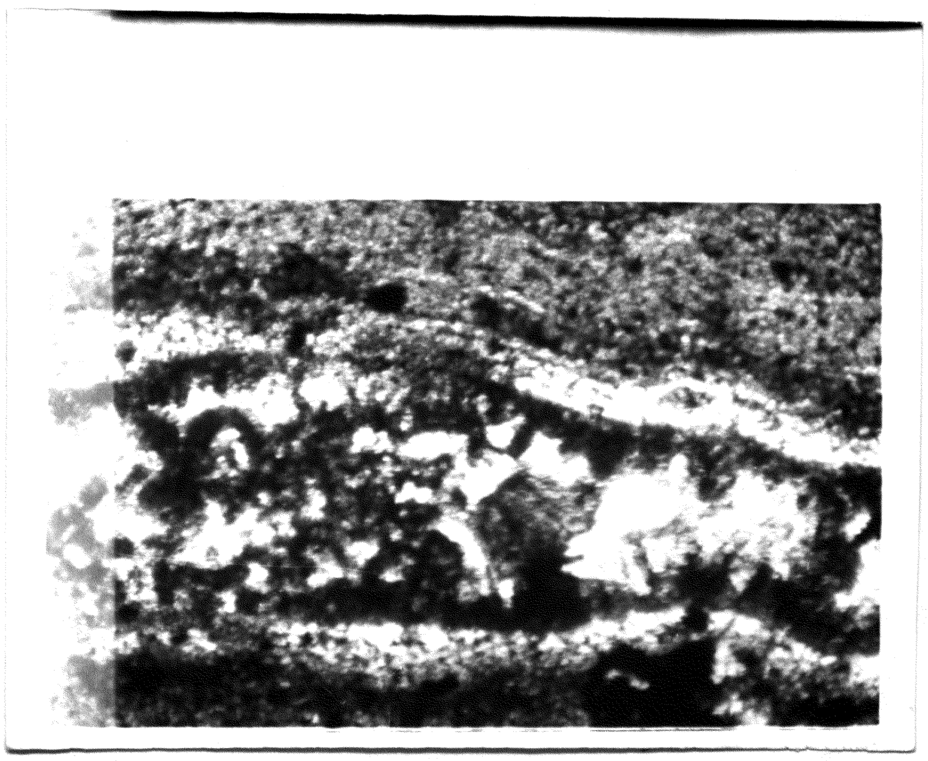


Plate VI. Quartz rich layer in flow banded rhyolite from Coot Mountain. Dark orthoclase crystals project into a center of quartz. Typical of rhyolites pictured in Plate Va. Plane polarized light, 100X.

The middle unit, which lies above and to the north of the lower unit, forms most of the southern slope of the mountain. Its northern contact is concealed but begins just below the summit ridge marking the upper unit. The thickness of this layer is 1500 feet, if an average dip of 50° can be assumed. Bridge (1930) computed 600 vertical feet of rhyolite from the Current River to the mountain's summit, but he did not consider the dip of the volcanics. Since the location of the lower contact of the lower unit and the upper contact of the upper unit are not known, the thickness of the other two units cannot be computed.

The middle unit consists of two principal rock types and two minor rock types. They have no discernible stratigraphic relationships to each other. The two principal rock types have a greater development of flow banding than any other Coot Mountain rock.

The more common principal rock type is a purple rhyolite porphyry with orange-brown feldspar phenocrysts, and quartz phenocrysts and veins. Microscopic study shows its texture to be hypidiomorphic and porphyritic. The red-brown matrix is composed of small quartz and feldspar crystals. Red-brown euhedral to subhedral orthoclase phenocrysts average 2 mm. in size and constitute 30% of this rhyolite. Some phenocrysts are as large as 4 mm., some of which are perthitic. Magnetite is present as rounded grains within the matrix and some orthoclase crystals, and forms as much as 10% of some specimens. One hematite grain appeared to be surrounded by borders of magnetite. The magnetite was identified by its attraction to a magnetized needle after small grains were pried from the rock slide. Quartz veins and masses cross portions of this rhyolite.

The other principal rock type occurring in the middle unit is a rhyolite which exhibits well developed purple flow banding. Some bands are stained red-brown. With the aid of the microscope flow structure can be seen to occur as bands passing through the matrix and around small phenocrysts. Most of the matrix is light red, but some is darkened adjacent to phenocrysts. The matrix, which consists of very small crystals with hazy borders visible only under crossed nicols, appears to be orthoclase and quartz. Equidimensional to tabular phenocrysts of light green and pink feldspar, averaging 2 to 3 mm. in size but ranging up to 5 mm., are scattered throughout the matrix. The pink orthoclase phenocrysts now are not individual crystals, but rather they are aggregates of smaller grains of kaolinized orthoclase. The phenocrysts form about 35% of this rhyolite. Corrosion of both feldspar phenocrysts is displayed by a few phenocrysts. Vesicular cavities, which resemble miarolitic cavities in that they are lined or filled with small quartz crystals, are pictured in Plate VIIa. These cavities are randomly arranged. Quartz veins are common in this rhyolite.

In addition to the principal rock types found in the middle unit, two minor rock types locally are present. The first minor rock type is a strongly flow banded dark purple porphyritic rhyolite with band of quartz which can be found in the shut-in at the west edge of Coot Mountain. The bands, which may be as great as 5 mm. wide and 10 cm. long, may be caused by varying concentrations of volatiles in the flowing magma; the quartzose bands developing from gas-rich layers that crystallized after the drier more feldspathic streaks. Pinkish phenocrysts as long as 8 mm. occur in both types of bands. With the aid of the microscope the strong banding in the feldspathic layers can be seen to curve around the phenocrysts. The banding is dark grey in color and probably due to finely divided magnetite. The quartz bands consist of red-brown kaolinized orthoclase and quartz crystals which were deposited on the wall of cavities. The orthoclase crystals were deposited first, the quartz last, probably during falling temperature. Phenocrysts of red-brown orthoclase are kaolinized and clouded with minute inclusions of iron oxides. Some phenocrysts are completely replaced by a mosaic of 0.05 mm. quartz crystals. Some magnetite is present in this minor rhyolite type.

The second minor rock type present in the middle unit is an earthy-lustered, light purple, porphyritic rhyolite containing orange-brown phenocrysts. It was observed only in one locality, one hundred feet from the road in the center of the NE ¼, Sec. 22, where it occurs near the top of this unit. It grades into the first described principal rhyolite type from the middle unit. With the aid of the microscope it can be seen to be a microgranitic rock with varying grain size. This rhyolite is comprised of 80% anhedral quartz grains and 20% orthoclase. Brown kaolinized orthoclase phenocrysts are as much as 1.5 mm. long and constitute 15% of this rhyolite. Some orthoclase grains are completely replaced by a mosaic of quartz crystals. Magnetite constitutes about 3% of this rhyolite.

The upper unit, which forms the northern slope of Coot Mountain, is a light purplish-brown to red-brown porphyritic rhyolite with phenocrysts of greenish-white and pink feldspar the range in size up to 4 mm. Flow banding is less abundant in this unit than in the middle one, and can be seen 100 feet south of the fire tower. With the aid of the microscope, the texture can be seen to be hypidiomorphic and porphyritic, although all grain boundaries are indistinct in this rock.

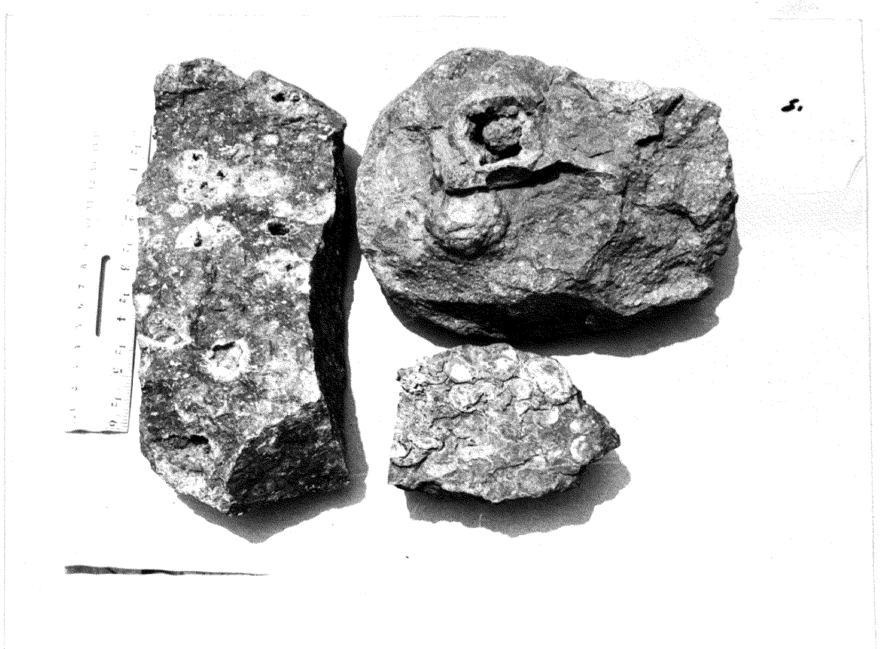


Plate VIIa. Quartz-lined vesicular cavities in rhyolite from the west slope of Liberty School knob (left), the middle unit at Coot Mountain (lower right) and float from Coot Mountain (upper right).

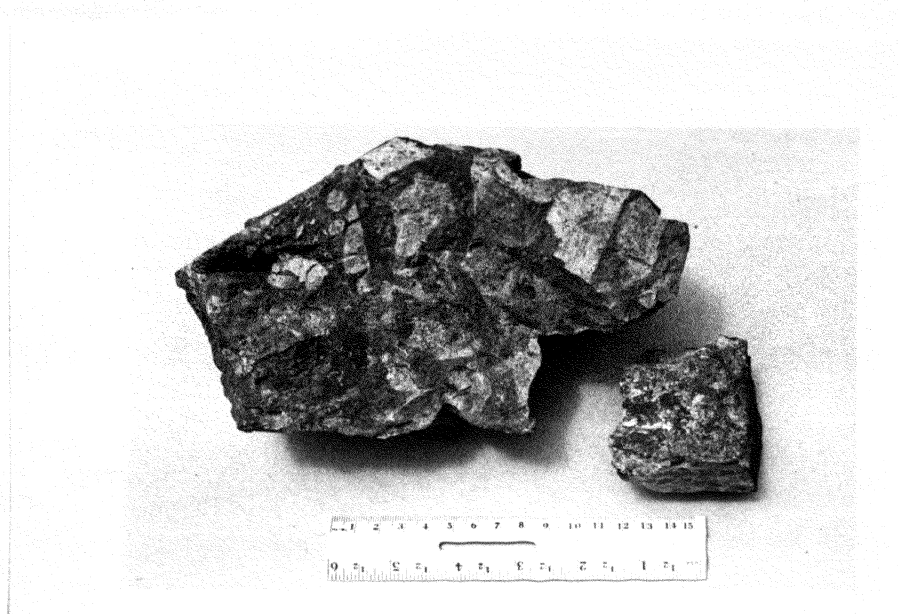


Plate VIIb. Agglomerates, from the base of the upper unit at Goose Bay Creek knob (small specimen) and float along the road leading to the Coot Mountain firetower (large specimen).

The matrix consists of quartz and kaolinized, iron stained, nearly opaque orthoclase. Red iron stain bands traverse the matrix. Anhedral magnetite grains comprise about 4% of the rock. Perthitic orthoclase constitutes less than 1% of this rhyolite. Quartz veins exhibiting comb structure often traverse this rhyolite. Two grains of fluorite were observed by the writer at the base of this unit along the road.

A low knob to the east of county road V is composed of rhyolite which is similar to that in the middle unit on Coot Mountain. This outcrop is isolated and located 800 feet west of exposures of the lower unit ash tuff. Three possibilities could explain the location of this small exposure:

(a) A concealed fault lies in the covered area between the exposures of the two rock types.

(b) The tuff forms the nose of a northwest plunging anticline and it bends around to again expose the middle unit.

(c) The small knob represents another unit below the tuff which has a lithology similar to the middle unit.

The writer favors the first possibility because of the strong similarity of this rhyolite with that of the middle unit. The low elevation between this small knob and Coot Mountain to the east could be caused by erosion along a fault. A local erratic flow banding strike of N. 15° W. and dip of 85° S. near the lower layer-middle layer contact suggests faulting.

Additional rock types are present in float on Coot Mountain. Three of these are breccias. One interesting breccia float which contains large rhyolite fragments in a tuffaceous groundmass is shown in Plate XII, left specimen. A second breccia contains red quartz fragments

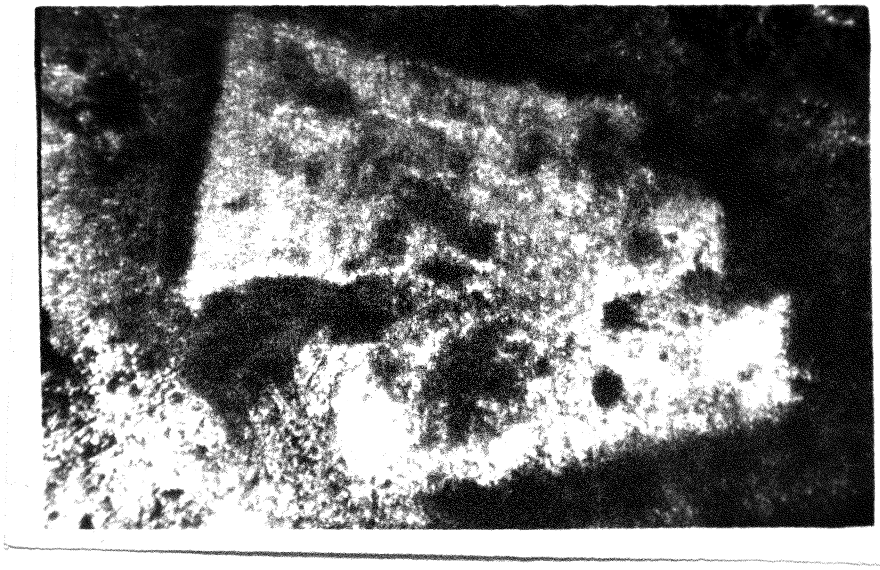


Plate VIIIa. Corroded, partly kaolinized crystal of orthoclase. The dark areas within the crystal are stained red-brown by hematite. Upper unit at Coot Mountain. Plane polarized light, 100X.

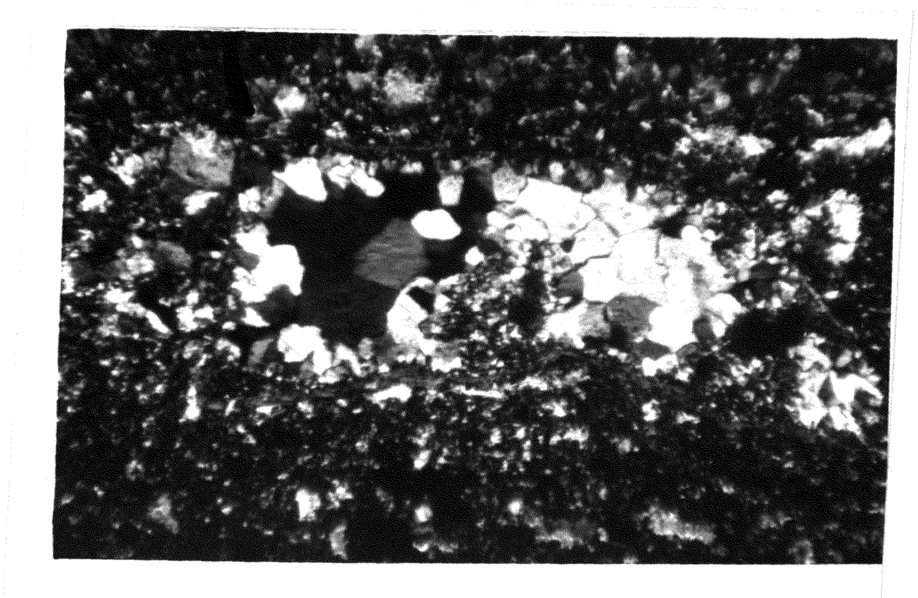


Plate VIIIb. Complete replacement of an orthoclase crystal by a mosaic of smaller quartz grains. Upper rhyolite unit at Coot Mountain. Plane polarized light, 100X.

in a quartz cement. A third type of breccia on Coot Mountain exists as flow banded rhyolite that has been broken and recemented by quartz.

Other rock-types are found in float at Coot Mountain. An interesting type is a blue-green silicified rock which consists completely of quartz except for a brown iron stain. This float was found near a trench one-quarter mile northeast of the fire tower. The trench had been excavated in an attempt to locate the "blue granite" or diabase which also occurs there as float. The 2 mm. size grains in this diabase exhibit typical ophitic texture. The diabase is composed of 10% augite, 55% andesine, and 5% magnetite. The andesine is well altered but some twinning is preserved. Chlorite which has replaced most of the augite constitute 30% of the diabase float.

Subhedral laths of hematite occur in some quartz veins traversing rhyolite float. These float fragments were observed by the writer on the southern slope of Coot Mountain in the middle of Sec. 22. Pyrite has been reported by local farmers to occur in pieces of float taken from the knob. Other mineralization is unknown.

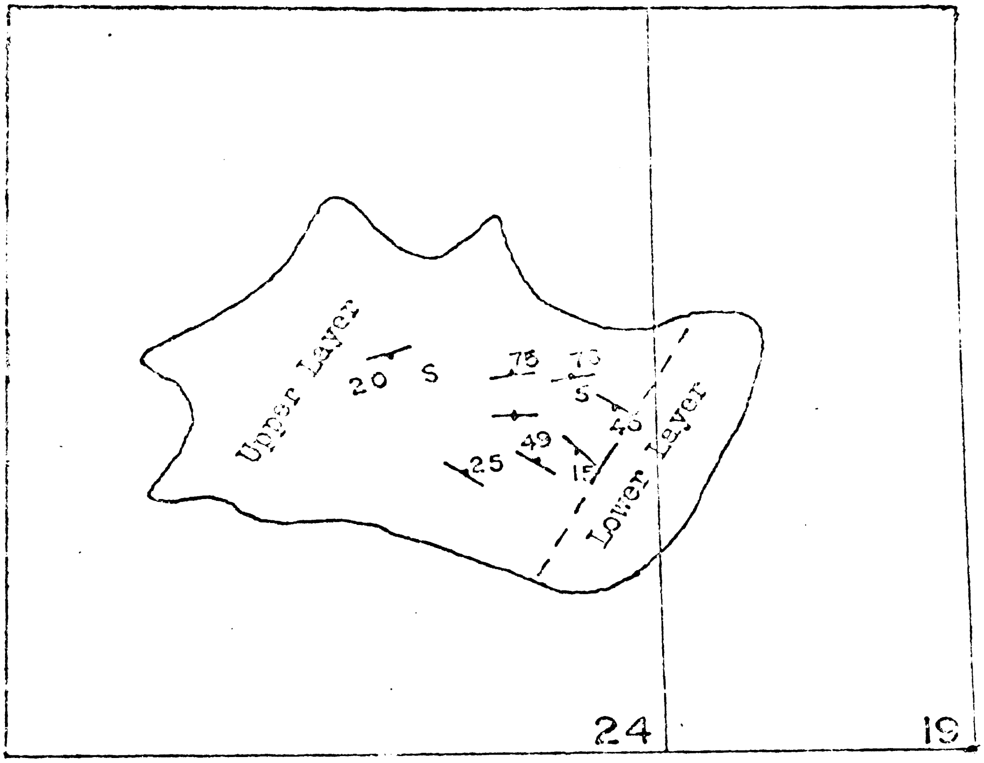
B. Unnamed Knob

The writer made a short visit to an unnamed knob north of the Current River, immediately east of the junction of the Current River and Jacks Fork, to inspect the rhyolite knob in the center of S $\frac{1}{2}$ of Sec. 9, T. 29 N., R. 3 W. The rhyolite at this knob closely resembles that of the upper unit of Coot Mountain. Orthoclase phenocrysts of pink and light green color occur in a light red-brown matrix. Flow banding in the rhyolite strikes approximately N. 45° E. and dips 45° N. The similarity in lithology and its position along the strike suggest this rhyolite is the same as the upper unit at Coot Mountain.

C. Goose Bay Creek Knob

This knob is located principally in the W ½, Sec. 24; T. 29 N., R. 3 W., but it extends into the W ½, W ½, Sec. 19; T. 29 N., R. 2 W. It is approximately one-half mile south of the Current River, and it is bordered to the east by Goose Bay Creek. The knob is easily reached by a private road which leads to the north from highway 106 in Sec. 25; T. 29 N., R. 3 W. Goose Bay Creek Knob, which is nearly rectangular in shape, is approximately one-half mile wide and three-fourths of a mile long. Its longest dimension lies east-west. The Precambrian exposures on this knob are limited to the top and to the eastern slope. The northern slope is covered by talus, and the other two slopes are concealed by soil.

The exposed Precambrian volcanics can be subdivided into two units. The lower unit is a dark purple, aphanitic rock containing minute spherical forms which are about 1 mm. in diameter. A three foot portion of this unit is exposed in SW ¼, SE ¼, NE ¼, Sec. 24 where it is in contact with an overlying rhyolite. The indistinct contact between these rocks types appears to dip to the west. With the aid of the microscope, this rock can be seen to be a microcrystalline devitrified tuff which contains small glass shards which are aligned mostly parallel to the bedding. The shards now are devitrified and they appear to consist of quartz and feldspar crystals which are only 0.01 to 0.02 mm. long. The spherical bodies are believed by the writer to be volcanic ash. The interior of these bodies contains devitrified shards which are similar in composition to the rest of the rock. Most of the spherical bodies have been flattened and broken, which probably is due to compaction. Patches of kaolinized orthoclase occur locally in this



GEOLOGICAL MAP OF

GOOSE BAY CREEK KNOB

0 2000 4000

SCALE IN FEET

N

LEGEND

Contact

Inferred Contact

Flow Banding

Joints

Fig. 5

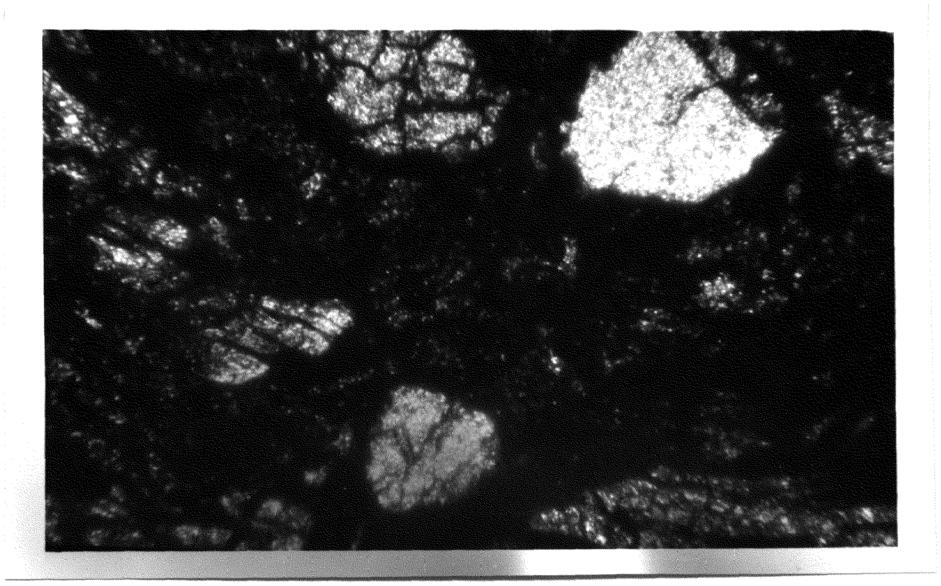


Plate IXa. Photomicrograph of a breccia from the base of the upper unit at Goose Bay Creek Knob. Hematite staining has darkened the rock. Plane polarized light, 100X.

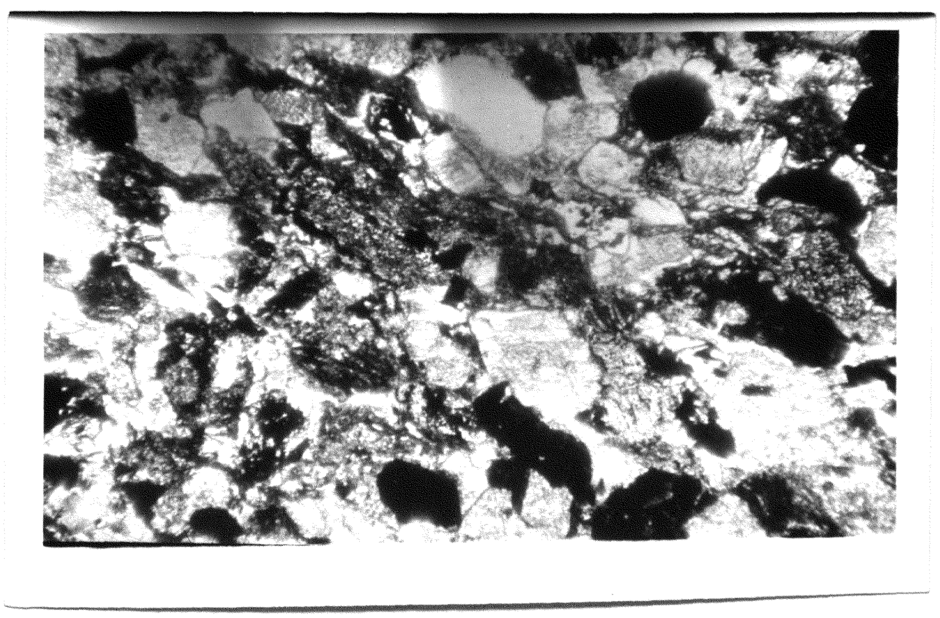


Plate IXb. Photomicrograph of intrusive rhyolite from a small dike in the upper unit on Goose Bay Creek Knob. The major constituent is quartz (light to medium gray). Magnetite (black) is much less abundant. Plane polarized light, 100X.

tuff. This tuff is similar in lithology to the previously described lower unit of Coot Mountain.

Near the top of this unit the tuff contains small phenocrysts of white orthoclase. The tuff grades upward into the upper unit at Goose Bay Creek Knob without sharp contact. Elsewhere the tuff is interbedded with the overlying rhyolite. The tuff generally weathers tan, although locally it is stained by manganese to a black color.

The base of the upper unit is brecciated. The breccia which is illustrated in Plate VIIb right specimen, is exhibited to best advantage on its weathered surface. It consists of small angular fragments of quartz and feldspar which are as large as 2 mm. Manganese oxides commonly stain the breccia.

The upper unit at Goose Bay Creek Knob is a flow banded rhyolite. The lower portion of this unit exhibits flow bands which strike N. 45° W., and dip about 60° N. The trend of the flow banding is even more irregular on the northern slope near the bottom of the Precambrian exposure. Here the flow lines change within ten feet from an east-west strike and a dip of 15° S. to a north-south strike and a vertical dip. Other irregularities in flow banding trends occur at the 900 foot elevation on the eastern slope where they tend to swirl and bend over areas as large as ten feet. On the northwest slope a flow banding with a dip of 20° S. is present locally. In spite of these local irregularities the writer believes the general trend of the flow banding on Goose Bay Creek Knob can be characterized by a strike of N. 45° W. and a dip of 60° NE.

The lithology of upper unit usually is a purple porphyritic rhyolite containing orange-brown feldspar phenocrysts; and is similar to the

Coot Mountain middle unit principal rock types. With the aid of the microscope this rock can be seen to be hypidiomorphic and porphyritic. The matrix, which is dark to nearly opaque due to red-brown iron staining, exhibits some flow banding. The phenocrysts are subhedral to anhedral orthoclase crystals which have their longer axes oriented roughly parallel. These phenocrysts range up to 2 mm. in length, but they usually are about 1.5 mm. long. Some are kaolinized and iron stained, and others are completely replaced by a mosaic of 0.02 mm. quartz grains. The latter are recognized only by their relict shape.

Another common rhyolite type occurring in the upper unit is a strongly banded rock which is similar to the middle unit exposed in the Coot Mountain shut-in. This rhyolite is found at the 1,000 foot elevation on the eastern slope of Goose Bay Creek Knob. Quartz bands up to two feet long contain orange-brown feldspar phenocrysts. The flow bands which are seen with the aid of the microscope to sweep around the phenocrysts are present in the quartz bands as dark lines traversing the quartz. Orthoclase phenocrysts, which are about 1 mm. in size, are kaolinized and iron stained red-brown, and some are partially or completely replaced by a quartz mosaic which is similar to that which replaced orthoclase phenocrysts in the previously described rock from the upper unit. Part of the quartz in this rock cements broken orthoclase grains. Anhedral corroded magnetite grains comprise as much as 5% of the rock. Zircon is present as a minor accessory.

Two small intrusive rhyolite dikes occur at the middle of the upper unit on Goose Bay Creek Knob. One intrusive, located on the eastern slope of this knob at the 950 foot elevation in the NW ¼, SE ¼; Sec. 24 exhibits sharp contacts with the surrounding rhyolite. The vertical dike, which is eight feet long and six inches wide, consists of a lense of dark brown granular material pinching out at either end. This rock is allotriomorphic and porphyritic. The phenocrysts which are mostly 0.1 mm. quartz grains comprise 50% of the rock. About 5% of the phenocrysts are orthoclase. The matrix is opaque. Rounded magnetite grains slightly smaller than 0.1 mm. in size forms 20% of the matrix; the remainder could not be determined but is believed to be iron oxides.

A second possible small intrusion occurs 150 feet south of the above described dike. It is approximately 100 square feet in area. The contacts of this rock with the surrounding rhyolite are transitional, but it is believed to be an intrusion because its lithology differs from the surrounding rock. The rock is a light purple rhyolite containing nearly 50% orange-brown orthoclase, greenish-white orthoclase, and black grains. With the aid of the microscope the rhyolite can be seen to be hypidiomorphic and porphyritic. The matrix consists mainly of small red-brown stained quartz crystals. The green-white phenocrysts, 3 to 5 mm. across, are comprised of tiny orthoclase crystals 0.01 mm. long. Orange-brown orthoclase phenocrysts exhibit dark reaction rims others are replaced by a mosaic of quartz grains.

D. Williams Ford Knob

A knob 1,000 feet south of Williams Ford on the Current River is designated the William Ford Knob in this thesis. It is located in the SW ¼, Sec. 18; T. 29 N., R. 2W. The hill representing this knob, which slopes sharply on all sides, appears to be incorrectly shown on the topographic map. The knob is about one-half mile long with its long axis lying northeast-southwest.

This knob was of special interest in an attempt to trace the red tuff found on the Coot Mountain and Goose Bay Creek knobs to the east. Although the red tuff is not exposed, it occurs as float.

The rhyolite on the Williams Ford Knob is well banded. Although the trend of the flow banding is N. 50° E. with a dip of 20° to 30° S., local banding which strikes N. 50° W. was observed in the southwestern portion of the knob.

Most of the rhyolite present on this knob is similar to the purple rhyolite with orange-brown phenocrysts which constitutes the middle unit at Coot Mountain and upper unit of the Goose Bay Creek Knob. No petrographic study was made of the rhyolite at Williams Ford Knob.

E. Slater Knob

The Slater Knob, which is located one and one-quarter miles east of Eminence, is crossed by highway 106. It lies in the N ½, Sec. 36 and S ½, Sec. 25 both in T. 29 N., R. 4 W. The small knob, which is roughly circular, has a diameter of about one-quarter mile. The old Slater copper mine is located on the east side of this knob. The knob was described by Evans (1959) in his thesis dealing with the copper deposits of Shannon County.

Most of the rocks at Slater Knob exhibit flow banding which has a variable trend. In the southern part of the knob it trends east-west and dips 60° S. To the west and northwest, but south of highway 106 the banding strikes N. 40° W. and is vertical. Further in that direction the dip is 75° N. North along the highway, and on the north side of highway 106 flow banding appears to be absent.

The rock types on Slater Knob exhibit considerable variety. Tuffs, interbedded with normal rhyolite, are traversed by rhyolite. The southern part of the knob consists of red and purple banded rhyolite which is traversed locally by a tan rhyolite. Its tan color may be due to alteration, or to a composition slightly different from that of the red and purple banded rhyolite. Fragments of the darker banded rhyolite surrounded by the lighter tan rhyolite are shown in Plate 4. The banded rhyolite is contorted into small folds which are one-half foot across. Interbedded with this banded rhyolite is a bed of reddish purple aphanitic tuff.

To the north, along the road, several varieties of tuffs which range in color from red-brown to gray locally contain pink feldspar crystals. One red-brown banded tuff exhibits numerous devitrified glass shards in the groundmass best observed in plane polarized light. The individual bands are cryptocrystalline. Phenocrysts of red-brown, kaolinized orthoclase are 5 mm. long and constitute 5% of the tuff. A dark gray tuff is an equigranular microcrystalline rock in which the crystals are 0.01 mm. across. Magnetite grains as large as 0.5 mm. across, but which average 0.03 mm., constitute about 3% of this tuff. Purple nonbanded rhyolite, which contains phenocrysts of white feldspar, occurs north of the highway.

Additional rock types occur in float at Slater knob. An interesting float type which occurs in the southern part of the Slater knob has been described by Evans.[9] It is a tuff exhibiting red and white bands which vary in width but average 1.5 mm. and along which the rock breaks. Microscopic examination of the rock by the present writer shows that it

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[9] *Ibid.*, pp. 23-24.

Plate X. Local breccia fragments of red rhyolite surrounded by tan, flow banded, rhyolite. North side of Slater Knob.

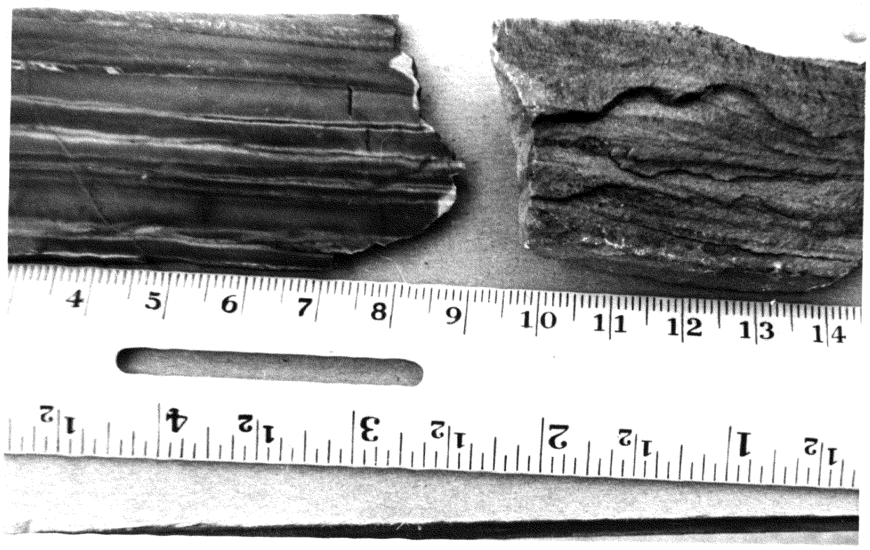


Plate XIa. Tuffs from Slater Knob. Note cross-bedding on specimen on the right.

Plate XIb. Photomicrograph of tuff in Plate IXa, left specimen showing faint bedding. Plane polarized light, 100X.

Plate XII. Photomicrograph of a gray tuff from Slater Knob showing devitrified curved glass shards. Plan polarized light, 100X.

is a microcrystalline tuff composed of fine grains of quartz and partly sericitized feldspar. Evans determined by staining that this feldspar is orthoclase. The present writer's petrographic study revealed devitrified glass shards which range in size up to 0.1 mm., and which are oriented parallel to the banding. Faint bedding is exhibited under the microscope as color bands.

Another interesting tuff occurs in the Slater mine dump. It is a purple tuff in which scattered spots weather to a white color with small cavities which are iron stained brown. Microscopic examination of these spots, which are slightly darker than the purple matrix suggests that they are lapilli. The banding in this tuff, which probably formed by compaction, curves around the spots. Microcrystalline quartz grains in the rock are iron stained. Devitrified glass shards are present.

A conglomerate which probably is a basal conglomerate of Paleozoic age was reported by Evans (1959) as occurring along the northeast protion of this knob, but the present writer did not find it.

F. Knob on Highway 106

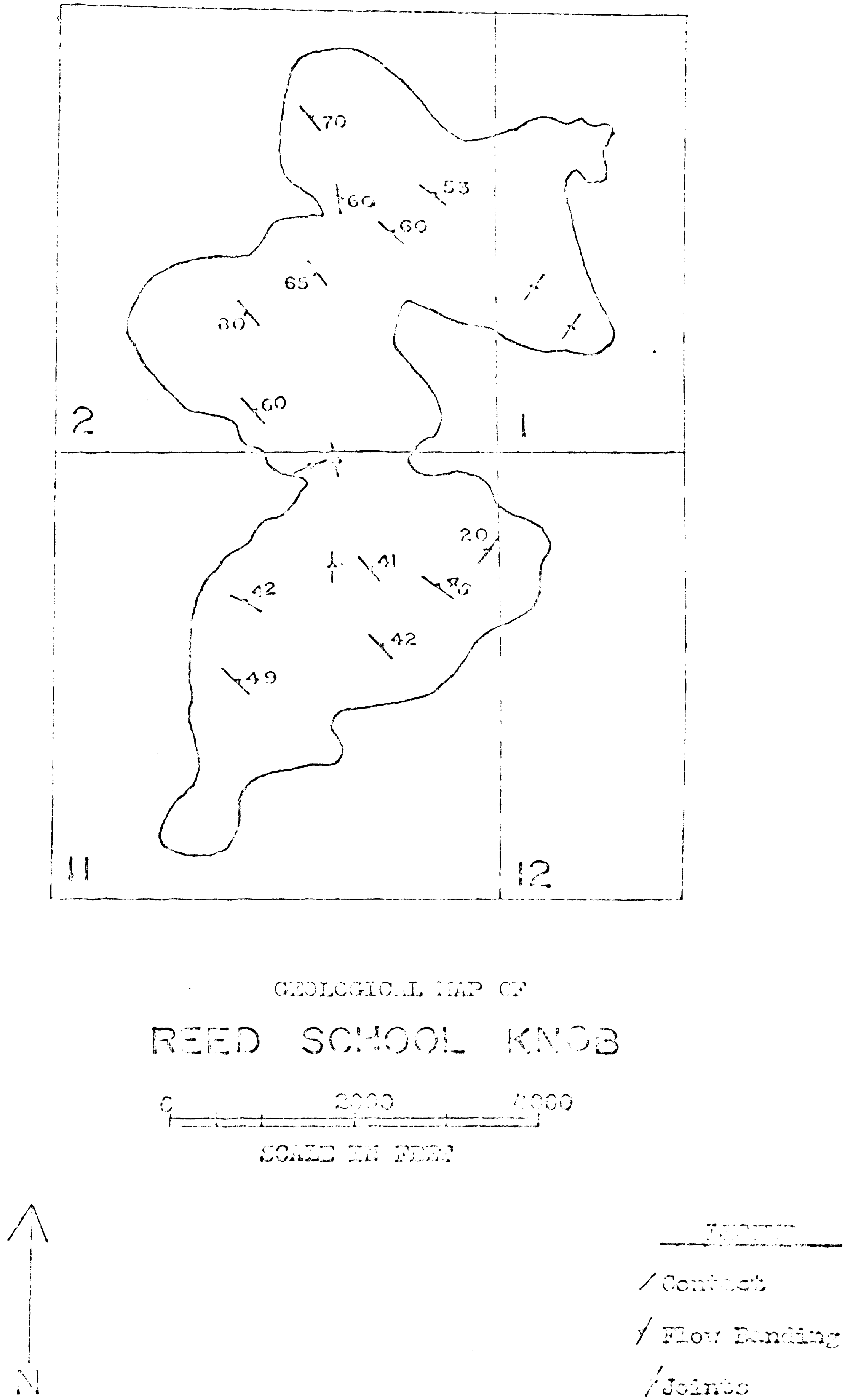
This knob, which occurs on the slope of a hill, is about one mile long and one-quarter of a mile wide. Highway 106 crosses east-west through the middle of the knob. The outcrop area of this knob trends northwest-southeast from the SE ¼, Sec. 26, through the SW ¼, Sec. 25, to the NW ¼, Sec. 36; all of which are in T. 29 N., R. 3 W. Since the knob does not extend high above the surrounding Paleozoics, it is covered by soil and vegetation. The best outcrops occur on the southern side along the highway.

The Precambrian rock exposed on this knob is a purple porphyritic rhyolite with phenocrysts of greenish-white feldspar and gray quartz. Lineation is absent. The rhyolite weathers to an earthy luster. With the aid of the microscope the rock is seen to be hypidiomorphic and porphyritic. The tan matrix consists of 0.04 mm. quartz crystals. Phenocrysts of subhedral quartz and anhedral orthoclase are about 1 mm. in size. The phenocrysts appear to be corroded. Small magnetite grains constitute nearly 5% of the rock. Portions of the rhyolite contain pink orthoclase in a reddish-purple matrix. This rhyolite can be distinguished from the above described rhyolites by its slightly vitreous luster on fresh surfaces due to the quartz.

C. Reed School Knob

The Reed School Knob is about two miles long, and the long axis of its shape is oriented approximately north-south (Fig. 6). The knob extends from the W ½, Sec. 1 through various parts of Sec. 2, south through most of Sec. 11; all of which are in T. 28 N., R. 3 W. Since the knob lies to the east of the Reed School, it is called the Reed School Knob in this thesis. The knob is easily reached by county road H which travels west of the knob. Road H has been shifted to the east of its position on the 1949 edition of the Cardareva Quadrangle. An improved dirt road crosses the knob close to the southern border, and passes by its southeast border to meet county road HH.

Since the crest of the knob extends only 240 feet above the surrounding Paleozoics at its highest elevation, the Precambrian rocks are not extensively exposed and the extreme northern part of the knob is entirely covered by soil. Some exposures occur on the slopes of the knob, but the best exposures are in two shut-ins. The northernmost


70
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42
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GEOLOGICAL MAP OF
REED SCHOOL KNOB
0
2000
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SCALE IN FEET
N
Contact
Flow Banding
Joints

Fig. 6

shut-in crosses the narrow portion of the Reed School Knob in Sec. 2. A small stream, which is not shown on the topographic quadrangle, flows from northwest to southeast through this shut-in. The southernmost shut-in which is located at the edge of Sec. 11 trends east-west. The walls of these two shut-ins are less steep than those of the Coot Mountain shut-in.

Although the general strike of the flow banding in the knob is to the northwest and the dip towards the north, numerous deviations from this general strike and dip were observed and recorded on the map of the knob (Fig. 6).

There are two principal types of Precambrian rhyolites on the Reed School Knob. The first type is nonbanded type which occurs to the north of the northernmost shut-in. It is a light purple porphyritic rhyolite containing 1 to 3 mm. size phenocrysts of white feldspar and quartz. Microscopic examination shows this rock is porphyritic and hypidiomorphic. The brown partly kaolinized matrix consists of small crystals of quartz and feldspar which are about 0.05 mm. in size. Phenocrysts comprise about 30% of the rhyolite. Locally this type grades into a rhyolite containing tan to white orthoclase phenocrysts together with quartz, which comprise 10% of the rock. Magnetite constitutes about 5% of this latter type.

The second principal type is a banded rhyolite which occurs to the south of the first type. It exhibits alternating light and dark purple bands which have an average width of one-half inch and which generally can be traced only two or three feet because of the abundant lichen cover. Feldspar phenocrysts, which weather to a tan color comprise 35% of this rhyolite. Hematite frequently stains these bands red.

Manganese oxides are prevalent at two localities on this knob. At one locality, approximately 500 feet south of the center of Sec. 2, the manganese ore occurs as float. At the second locality, in the SW ¼, NW ¼, NE ¼, Sec. 11, an outcrop of ore consists mostly of braunite with lesser amounts of pryrolusite.[10]

H. Liberty School Knob

The Liberty School Knob lies in the NW ¼, Sec. 5; NE ¼, Sec. 6; N½, Sec. 7; T. 28 N., R. 2 W. This knob which is about two miles long and up to one mile wide extends northeast-southwest, rises to a maximum height of 1180 feet in its northern portion. It extends southward where it connects with the Thorny Mountain Knob. The southern border of the knob is easily reached by county road NN; the northern part by an unimproved road which is an extension of the road passing by the Rocky Creek Ford Knob. The knob is bordered to the north by Little Rocky Creek and is crossed by Rocky Creek and its associated shut-in near the east line of Sec. 6. The abandoned Liberty Schoolhouse, which lies a few hundred feet of the knob in Sec. 8, gives its name to this knob.

Flow banding in the rhyolite of this knob has variable attitude. In the southwest portion of the hill it strikes N. 30° E. and dips about 60° SE, but in the northeast part of the hill it strikes N. 45° W. and varies in dip from 65° NE to vertical. In the shut-in the banding strikes approximately east-west and dips to the south.

The two principal types of rhyolite exposed on this knob, which the writer believes to be varieties of the same flow, are similar to

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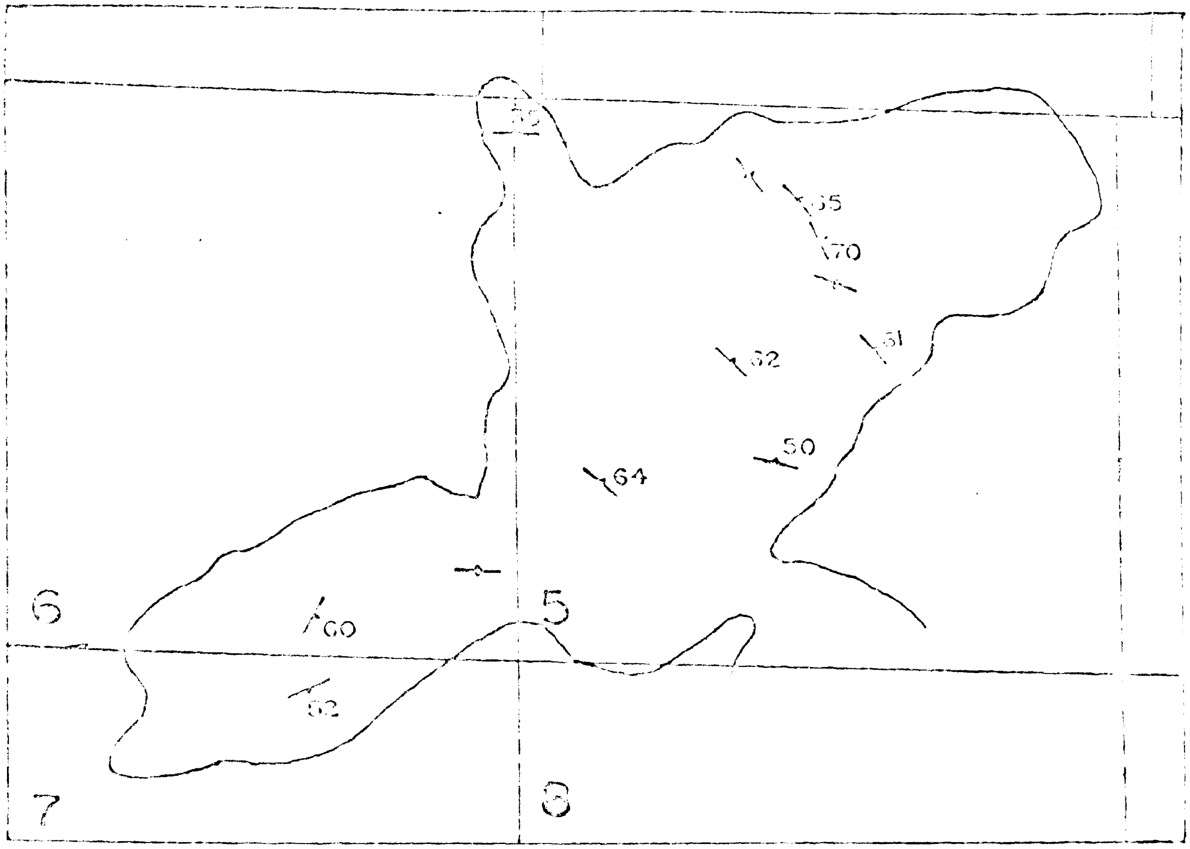
[10]Oliver R. Grawe, "Manganese Deposits of Missouri," Missouri Geol. Survey, Appendix 6, Bienn. Rept. for 1943, p. 73.



GEOLOGICAL MAP OF

LIBERTY SCHOOL KNOB

0 2000 4000

SCALE IN FEET

N

Contact

Flow Banding

Joints

Fig. 7

the two types of rhyolite on Reed School Knob. One type occurs along the northern parts of the knob, and it is a nonbanded, light purple porphyritic rhyolite which contains phenocrysts of light pink feldspar and quartz. The other type occurs from the crest of the knob southward, and it is a light and dark purple porphyritic highly banded type. The two types are distinguished only by the banding, because they are mineralogically identical. Microscopic study shows that these rocks are hypidimorphic and porphyritic. The matrix of each rhyolite is very clouded by kaolinite. While no difference in essential mineral composition could be detected between the different colored bands, the darker bands are more kaolinized iron stained. Fractured orthoclase and partly absorbed quartz phenocrysts average 1.5 mm. across and comprise 35% of the rhyolites. The kaolinized boundaries of the orthoclase phenocrysts are difficult to distinguish from the matrix. Thin quartz veins traverse the rock.

There are three minor varieties of rhyolite on this knob. The first type is a rhyolite on the southwestern part of the knob contains 2 to 11 mm. thick bands of reddish-purple rhyolite alternating with 2 to 4 mm. thick quartz bands, whose length may be as great as two feet. The quartz bands consist of fine grained quartz in which most of the grains are less than 0.2 mm. in size. Orthoclase has been deposited after quartz in some bands. The purplish bands consist of quartz and feldspar grains which are iron stained. The phenocrysts, which constitute 30% of this type of rhyolite, are subhedral orthoclase and anhedral quartz. Amygdaloidal quartz filling occur in this rhyolite at the 950 foot elevation south of the summit at the southwest edge of the hill in the SE ¼, NE ¼, NW ¼, Sec.7.

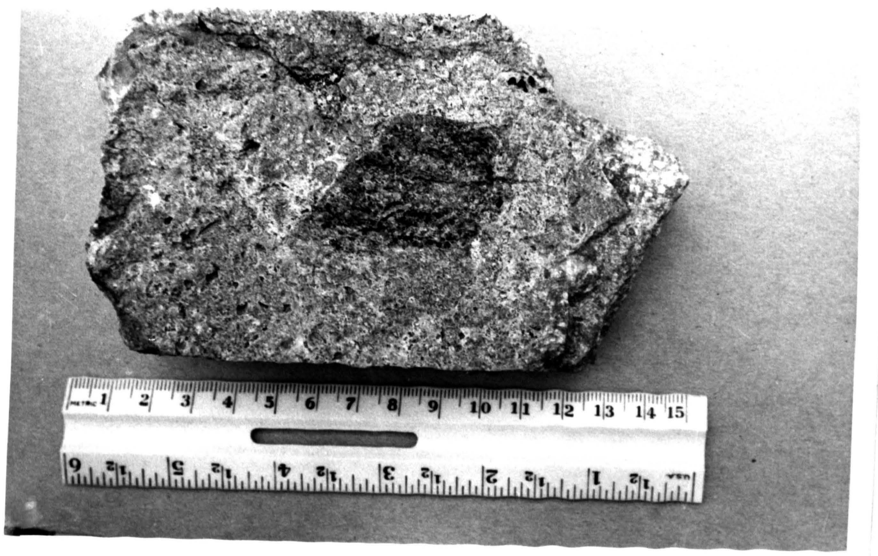


Plate XIII. Dark red-brown rhyolite breccia fragment enclosed by light tan rhyolite. South of the ridge crest at the west end of Liberty School Knob.

A purple rhyolite containing numerous fragments of red material occurs near the amygdaloidal rhyolite. They are illustrated in Plate XIII. The fragments have a composition similar to the surrounding rock, and they are outlined by a faint brown reaction rim which is best seen under the microscope. Some of these fragments appear to have a radiating structure visible under crossed nicols. Euhedral orthoclase crystals also are present in the fragments.

Nonbanded purplish-red rhyolite containing phenocrysts of tan orthoclase and purple quartz, which is either an intrusion or another variety of the main rhyolite flow, occurs in the floor of the shut-in in E ½, SE ¼, SE ¼, Sec. 6. This rock has a vitreous luster. Microscopic study reveals a light brown matrix comprised of quartz and feldspar grains which exhibit simultaneous extinction. The phenocrysts, which comprise 30% of the rhyolite, are mainly anhedral to subhedral, partly embayed, orthoclase. Quartz phenocrysts of 1 mm. size are less common. Magnetite constitutes less than 1% of the rock.

I. Unnamed Knob

This knob is located in the SE ¼, Sec. 30; NE ¼, Sec. 31; T. 29 N., R. 2 W. Its nearly circular shape has a diameter of one-half mile. Its summit is 1080 feet above sea level. The knob is easily reached from an unimproved logging road leading south from highway 106 in section 30.

An orange-brown rhyolite on the northern side of this knob contains more quartz than any other rhyolite examined in the Eminence area. Its orange-brown matrix contains phenocrysts of slightly darker feldspar and milky quartz. With the aid of the microscope, the rhyolite is seen

Plate XIV. Rhyolite breccia from the unnamed knob in Sec. 30 and 31, T. 29 N., R. 2 W.

to be hypidiomorphic and porphyritic. Phenocrysts of corroded to embayed quartz and anhedral orthoclase constitute 50% of the rock. Occasional orthoclase phenocrysts have been completely replaced by a mosaic of quartz grains.

About 1,000 feet northeast of the above exposure there is a 200 square foot area of brecciated rhyolite in which tan rhyolite fragments are cemented by a purple rhyolite matrix. Locally the breccia has a dull red matrix with orange-brown feldspar and fragments of white quartz. While the fragments range in size up to 12 mm., their average size is 6 mm. They comprise 50% of the rock. This rhyolite breccia weathers to a rusty iron stained color.

J. Indian Creek and Rocky Creek Ford Knobs

Since the Indian Creek Knob and the Rocky Creek Ford Knob are very close to each other and appear to consist of identical Precambrian rhyolite they are described together. The knobs are separated by only 100 feet at their closest point.

The Indian Creek Knob is located in the S ½, Sec. 29; N ½, Sec. 32; T. 29 N., R. 2 W. It is about three-quarters of a mile long and one-half mile wide. Its longest axis is oriented about northeast-southwest. The knob is reached from an unimproved road leading south from highway 106 in the southeastern part of Sec. 19. On its northern side it is bounded by Indian Creek for which it was named by the writer.

A knob located one-hal mile northwest of Rocky Creek Ford in the E ½ Sec. 32; W ½ Sec. 33; in T. 29 N., R. 2 W., is called the Rocky Creek Ford Knob in this thesis. The knob is about one-half mile in diameter. Its summit, which is 920 feet above sea level, is 100 feet lower than that of the Indian Creek Knob. Both knobs protrude above the surrounding Paleozoic rocks. The Rocky Creek Ford can be easily reached by an improved road leading north from county road NN near the end of the state maintained portion of the country road.

Faint layering in the Precambrian rhyolite on these knobs, which is best seen on weathered surfaces, dips 10° to the northwest. The exposures were so poor that the strike of this banding was not apparent.

Only one type of rhyolite occurs on these two knobs. It is a light purple porphyritic rhyolite containing 2 mm. size phenocrysts of light orange-brown feldspar and quartz. Locally the feldspar develops a pinkish color. The fresh rhyolite has a vitreous luster, but where it is weathered it has a pitted surface due to the destruction of feldspar phenocrysts. With the aid of the microscope, the rhyolite can be seen to be hypidiomorphic and porphyritic. Phenocrysts of corroded quartz and orthoclase are about 1.5 mm. in size and comprise about 50% of the rhyolite. The two minerals are equally abundant in the phenocrysts. The matrix is composed mainly of quartz with a little orthoclase.

A conglomerate in the Eminence formation laps on the southern slope of the Rocky Creek Ford Knob at the boundary line between Sec 32 and 33. Its undulating contact with the Precambrian rhyolite is sharp and well defined. The layer is 40 feet thick and 200 feet wide, grading laterally east and west into nonconglomeratic Eminence dolomite. The formation is unsorted and bedding is absent. The feldspar phenocrysts in some boulders has weathered to a yellow clay, while those of other boulders are almost completely unaltered. The surface expression of this layer is rough and locally stained black by manganese oxides.

Plate XV. Southern slope of the Rocky Creek Ford Knob. A roughly horizontal contact half way up the slope between Cambrian Eminence formation (below) and blocky Precambrian Rhyolite (above).

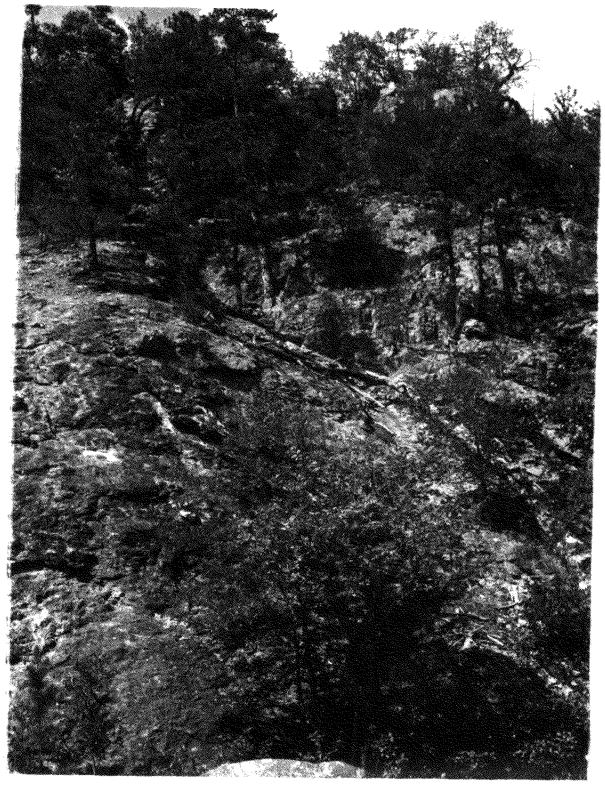


Plate XVIa. Closer view of Plate XV showing the undulating nature of the contact between the rhyolite (upper right) and the Eminence formation containing rhyolite boulders.

Plate XVIb. Closer view of small rhyolite boulders in the Eminence formation conglomerate on the Rocky Creek Ford Knob.

K. Cardareva Ford Knob

The Cardareva Ford Knob is in the W ½, E ½, and E ½, Sec. 2; NE ¼, NE ¼, Sec. 3; T. 28 N., R. 2 W.; and in S ½, S ½, Sec. 35; SE ¼, SE ¼, SE ¼, Sec. 34; T. 29 N., R. 2 W. The knob exhibits an irregular shape and its northwest trending long dimension extends 1½ miles. The southeast part of the knob, which is bordered by the Current River, is 300 feet west of the Cardareva Ford for which it has been named. The northwestern part of the knob is crossed by Thorny Creek which has formed a shut-in.

The Precambrian rhyolite on the Cardareva Ford Knob has well developed flow banding which exhibits a general strike of N. 30° W. The dip is 30° to the north in the southern part of the knob, but 75° to the north in the northern part of the knob.

The banded purple rhyolite on the Cardareva Ford Knob is unlike the rhyolites studied by the writer on other knobs in the Eminence area, although it appears similar to that on Thorny Mountain. This rock has well developed bands of purple rhyolite and quartz. The bands average 2 mm. in width and 10 cm. long. Hand specimens have a somewhat vitreous luster due to the quartz. With the aid of the microscope the rhyolite bands can be seen to consist of anhedral orthoclase grains with indefinite boundaries. Orthoclase phenocrysts, 3 mm. long, constitute 25% of the rhyolite. Quartz is not present as phenocrysts. Flow banding bends around the orthoclase phenocrysts. The quartz bands, exhibit central positions which are lined by orthoclase crystals, are similar to those described at Goose Bay and Liberty School knobs.

L. Stegall Mountain

The Stegall Mountain Knob was briefly examined to compare a Precambrian tuff, reported by Robertson and Tolman,[11] with those found on the Slater, Goose Bay Creek, and Coot Mountain knobs. It extends throughout Sec. 18, 19, 20, and 30; T. 28 N., R. 2 W.; and Sec. 23 and 24; T. 28 N., R. 3 W. The tuff is located at the base of a rhyolite flow in NE ¼, SW ¼, Sec. 24.

This tuff, a hematite stained aphanitic rock, is unlike the other tuffs studied by the writer. Microscopic study shows it to be microcrystalline. Dark opaque hematite bands separate 1.5 mm. long quartz lenses. The quartz lenses consist of devitrified glass shards, which now are filled with a mosaic of small quartz crystals.

The rhyolite above the tuff appears to be similar to the rhyolite at Reed School and Liberty School knobs. A single specimen collected at the summit of the mountain is a light purple rhyolite containing pinkish-white phenocrysts. At that locality the rhyolite is banded, and the flow bands dip 40° to the north. Microscopic examination of this rock shows it to be hypidimorphic and porphyritic. The brown, strongly kaolinized matrix consists of fine grained orthoclase and quartz. Brown kaolinized orthoclase phenocrysts comprise 20%, and quartz phenocrysts constitute 7% of this rhyolite. Magnetite constitutes less than 1% of the specimen examined by the writer.

A well banded rhyolite which occurs as float in the northern part of Sec. 30 along the dirt road leading to the fire tower was not observed on other knobs in the Eminence area. It consists of reddish-

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[11] Robertson and Tolman, _op. cit_.

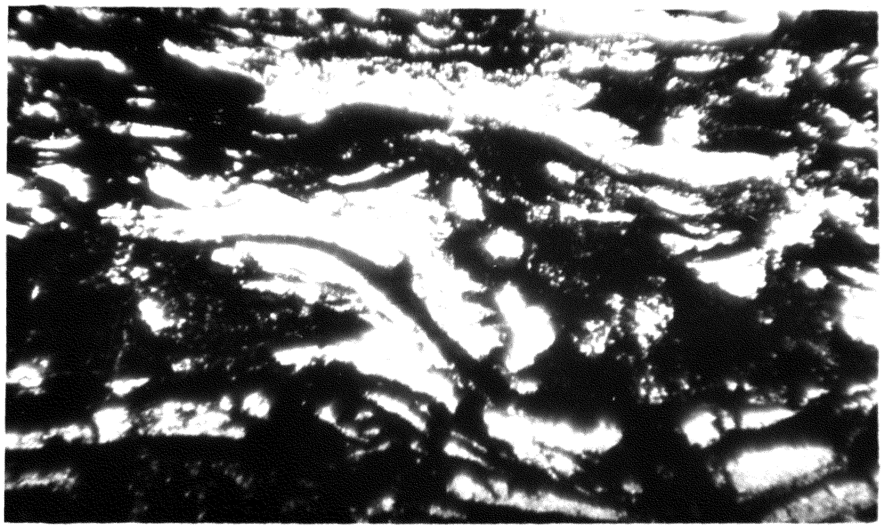

Plate XVII. Photomicrograph of red tuff from Stegall Mountain showing devitrified curved glass shards. Plane polarized light, 100X.

white quartz bands alternating with reddish-brown bands of rhyolite. The bands range in width up to 2 mm. across and some are as long as 6 cm. Many of the quartz bands contain fluorite, which may comprise as much as 5% of some boulders. With the aid of the microscope, the quartz bands are seen to consist of quartz mosaic of 0.01 to 0.02 mm. size crystals. Kaolinized orthoclase phenocrysts, 2 mm. long, are present in both types of bands and they constitute 15% of the rhyolite.

VI. THE QUESTION OF IGNIMBRITES

Certain volcanic rocks, previously thought to be normal extrusives, have more recently reinterpreted to be ignimbrites. Ignimbrites, or ash-flow tuffs as they are also called, have been recognized as the consolidated rock resulting from a nuee ardente. This type of volcanic eruption is characterized by two phases, an airborne cloud of gas, and an underlying mass of solid particles close to the ground. The solid particles are separated from each other by gases which give the solid phase its great mobility and velocity. A classic example of this type of eruption is that of Mt. Pelee on the island of Martinique on May 8, 1902.

Ignimbrites are pryoclastic and they are characterized by the presence of pumice and glass shards. Welding and compaction of the ash-flow tends to distort the pumice and shards producing a banding which appears similar to the flow banding of extrusive flows. The banding in the ignimbrite will extend for only a short distance according to Ross and Smith.[12] The presence of the shards may still be recognizable, depending upon the geologic activity the rock has undergone after devitrification.

Since Anderson believes many of the volcanics in the portion of the St. Francois Mountains in which he studies were ignimbrites, the

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[12]Clarence S. Ross and Robert L. Smith, "Ash-Flow Tuffs: Their Origin, Geologic Relations and Identification," U. S. Geologic Survey Professional Paper 366, p. 26.

present writer gave considerable thought to whether the igneous rocks in the Eminence area are flows or ignimbrites.

In the field, extrusive outcrops displayed banding which in places stretched over a foot in length. In the laboratory, hand specimens from the Eminence area were compared to ignimbrites from Utah collected by Dr. Paul D. Proctor. Collapsed and uncollapsed pumice, present in the Utah ignimbrites, was absent from the rhyolites from Eminence.

While microscopic examination of tuff from Stegall Mountain and Slater Knob revealed well preserved glass shard structures, pumice fragments or glass shards were absent from the rhyolites. The excellent condition of preservation of the shard structures in the tuff suggests that if they were ever present in the rhyolites they should be detected there today. Based upon these facts the rhyolites of the Eminence area are believed to be volcanic flows rather than ignimbrites.

VII. CORRELATION AND CONCLUSIONS

Correlation of the volcanic units of the knobs in the Eminence area is difficult. The knobs are often separated by large distances in which the Precambrian rocks are covered by Paleozoic sediments. Faults may be concealed in the covered intervals and the viscous rhyolite flows may have restricted lateral extents. In spite of these difficulties the writer believes that certain units can be traced across more than one knob.

The tuff which forms the lower unit at Coot Mountain is believed to be equivalent to the tuff located at the base of Goose Bay Creek Knob. This correlation is based upon similar mineral compositions, textures, colors, and stratigraphic positions below similar rhyolites. Further to the east at Williams Ford Knob, tuff is present in the float but it was not found in outcrop. The middle unit at Coot Mountain appears to be the same rhyolite as that rhyolite which forms the main portion of the Goose Bay Creek Knob and the rhyolite which occurs at Williams Ford Knob. The upper unit at Coot Mountain is believed by the writer to be correlative with the rhyolite which forms the unnamed knob east of the junction of the Jacks Fork and Current River. These three units exhibit a lithology which is different from the rhyolites to the south.

The rhyolites which occur in the knobs south of the above discussed knobs lack the orange-brown feldspar phenocrysts common to the rhyolite at those knobs. These more southern rhyolites also are distinguished by their abundant quartz phenocrysts, which normally are not abundant to the north. The southern portion of the Reed School Knob consists of well developed flow banded rhyolite, similar to that on the southern portion of the Liberty School Knob, but the northern portion of both of these knobs and knobs further to the north, consist of nonbanded rhyolite containing pink, tan or white orthoclase phenocrysts. Within the area the general sequence from oldest to youngest with geographic example is: rhyolite, tuff rhyolite (Stegall Mt.); 2 rhyolites (Reed School Knob); and tuff, rhyolite, rhyolite (Coot Mt.).

The general structure of the Eminence area seems to be one of moderate to steep northward dip. The northern area around Coot Mountain exhibits a general strike of northwest-southeast while the southern knobs exhibit a northeast-southwest strike. The attitude of the volcanics has been deduced both from the flow banding and from the contacts between volcanic units. Local deviations from this general attitude are common and believe by the writer to have formed during flow of the depositing lava. The dip of the volcanics indicates that the units on Coot Mountain, Goose Bay Creek, and Williams Ford knobs are younger than those to the south.

The volcanic rocks studied by the writer were compared with Dr. Hagni's collection and the Washington University collection, both from the St. Francois Mountain region. The three units at Coot Mountain, from lower to upper, appear to resemble the Ketcherside tuff, Stouts Creek rhyolite, and Hogan Mountain rhyolite. However, the great distance separating these Precambrian rocks, and the differences in thickness and lithology make this a very tentative correlation. Furthermore, the relationship between the Precambrian knobs in the Eminence area and the Precambrian exposures in the St. Francois Mountains is uncertain. There are three possible relationships between the two areas as outlined by Bridge:

1) They are erosional remnants of an essentially continuous volcanic field.

2) They represent separate centers of volcanic activity.

3) They are separated by block faulting, and each area represents the edge of a tilted block of Precambrian rocks.

Recent unpublished studies seem to favor the last relationship, in addition, the St. Francois Mountains may owe much of their present elevation to such block faulting.

The nontuffaceous rhyolites of the Eminence area are interpreted to be lava flow rather than ignimbrites, because of their well developed flow banding and the absence of glass shards and pumice.

VIII. ECONOMIC GEOLOGY

The Eminence area contains small deposits of copper, manganese, lead, clay, and sand. None of these deposits have been extensively developed, and there is no production from any of them within the Eminence area at this time.

A. Copper

The copper deposits are confined to areas where Precambrian rhyolite is exposed. The copper mineralization usually occurs in the basal conglomerates at the contact between the rhyolites and Paleozoic rocks. The principal copper minerals are chalcocite, chalcopyrite, malachite, and cuprite. These deposits have been studied by Greason (1896), Bridge (1930), and Evans (1959). While Evans believed they had formed from ascending hypogene solutions, Bridge thought that the copper was deposited in the Paleozoic sediments by organisms in the sea water, and was later concentrated in the basal conglomerate by ground water.

The principal mines and prospects in the Eminence area were the Sutton Mine, Casey Mine, Jerktail Prospect, Slater Mine, Bowlin Prospect, Jack Fork Prospect, and McKinney Prospect. The precise location of each mine and prospect is shown by Evans on a map.

Copper was first discovered in the Eminence area in the early 1800's by hunters and trappers. The deposits were first worked about 1837 by Joseph Slater, who started operations at the mine which now bears his name. According to Hodge, Slater produced 1500 tons of ore.

The land then changed hands several times and mining was not resumed until 1872 when the property was acquired by the Consolidated Land Company of Missouri which shipped 36,000 pounds of ore. The land changed hands again and mining was carried on sporadically until 1917, when the Slater Copper Company of Winona, Missouri, acquired the property. Four years later mining stopped and there has been very little activity at the Slater Mine since that time. Since 1917, the Shawnee Copper Company drilled seven test holes at the Sutton Mine. An additional ten holes were later drilled into this property by another leasee in 1955, and further drilling was done in 1958. The Bear Creek Mining Company has been active at the Jerktail Prospect, but no results are available from their explorations.

B. Manganese

Manganese occurs in the Precambrian rhyolite at numerous localities in Shannon County. With the advent of World War II, interest was aroused in these deposits within the United States. Deposits within Missouri were studied by Grawe (1943). The following description of manganese deposits in the Eminence area is condensed from his report.

A typical deposit occurring within the Eminence area is located on Thorny Mountain, and was worked in 1943. It is similar to the other deposits, where the black mineral braunite occurs in vertical veins and brecciated zones in the Precambrian rhyolite. On the outcrops they are less than two inches wide, but they tend to enlarge with depth. The ore is hard, dense, black, massive or compactly granular. It fills fractures and cements the broken fragments of wall rock into a breccia, also replacing both the fragments and wall rock. On Thorny

Mountain, the well defined mineralized zone which strikes N. 15° E. can be traced for several hundred feet. Although there appears to be a sharp contact between ore and wall rock, a study of thin sections reveals that there is a marginal zone between the two, where the rock has been replaced by clay minerals. There is a complete gradation from ore to wall rock.

The most serious drawbacks in working these deposits is their small size, the quantity of country rock that must be removed, and their location in the roughest part of the state.

The association of alunite, fluorite, and sericite with the manganese minerals suggests that the ore is of hydrothermal origin, and that it was deposited by solutions rising along fractures in the rhyolite.

Other manganese deposits in the Precambrian rhyolite in the Eminence area are the Daniells Prospect, Culpepper Prospect, Elliot Prospect, Liberty School Prospect, Reeves Prospect (Reed School House Prospect), Ross Prospect, Thorny Mountain Mine, and fifteen other minor occurrences.

C. Other Economic Products

Several materials, which are recovered elsewhere, are present in the Eminence area but remain largely undeveloped. These include rhyolite, hematite, fluorite, galena, gravel and clay.

The rhyolites can be used for building stone, but they are difficult to work because of their dense texture, conchoidal fracture, and numerous joints. They are used locally in rustic masonry with success. The recent development of the use of rhyolite for roofing granules at Annapolis, Missouri, suggests the possible use of rhyolite in the Eminence are for this purpose.

Pieces of hematite float were observed on Coot Mountain by the writer. They occur in small quantity.

Fluorite veins occur in float on Stegall Mountain. The float appears to have moved only short distance and may be derived from a bedrock deposit of some economic interest.

Small amounts of galena occur in the Paleozoic dolomites although none was seen by the author in any of the rhyolites. No important lead deposits are known in the Eminence area. Outside the Eminence area, north of Ellington, the Kennecott Copper Corporation is developing a major lead deposit in Paleozoic sedimentary rocks. Other lead mines are being developed further north.

The valleys of the rivers contain moderate size deposits of sand and gravel, but they are undeveloped at the present time.

Clay deposits in the vicinity of Bartlett appear pure enough to be used as pigments, but these deposits have not been thoroughly examined. Bartlett is six miles southwest of the Eminence area.

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VITA

Henry Hugh Fisher was born on November 11, 1936, in New York, New York. He received his primary and secondary education in Brooklyn, New York. From 1954 to 1958 he attended Brooklyn College, from which he graduated with a Bachelor of Arts Degree in 1959. He was drafted into the United States Army in September, 1960. In 1962 he was released from active service and enrolled in the geology department of the University of Missouri, at Rolla, where he engaged in graduate work. From January, 1962 to June, 1964, he was a Graduate Assistant in the Geology Department. After completing required course work, he accepted a position with the Bureau of Natural Gas, Federal Power Commission, in Washington, D.C. He is presently employed with the Soil Conservation Service, United States Department of Agriculture, in Columbus, Ohio.

LOCATION OF PRECAMBRIAN KNOBS
EMINENCE REGION, MISSOURI

EMINENCE QUADRANGLE

CARDAREVA QUADRANGLE

AFTER BRIDGE, 1930

SCALE

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

PRECAMBRIAN ROCKS (COLORED)

NORTHERN SERIES (COOT MOUNTAIN)

Upper Unit

Middle Unit

Lower Unit

SOUTHERN SERIES

UNDIFFERENTIATED