1947

Geology of the Ozark-Martin Mine area, Madison County, Missouri

William Clifton Hayes

GEOLOGY OF THE
OZARK-MARTIN MINE AREA
MADISON COUNTY, MISSOURI

BY

WILLIAM C. HAYES, JR.

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE, GEOLOGY MAJOR

Rolla, Missouri

1947

Approved by O. R. Grawe
Professor of Geology

CONTENTS

LIST OF PLATES

LIST OF TABLES

INTRODUCTION

Purpose and scope of report

General descriptions of the region adjacent to the Ozark and Martin Mines of Madison County, Missouri have been included in a number of early publications dealing with the Einstein Silver Mine area, but a detailed geologic map has not been made. It was thought that through detailed mapping and by a detailed analysis of all of the geologic features present, a more definite relationship between mineralization and structure might be determined.

During the months of June, July, August, and part of September 1946 two days each week were spent in making a detailed geologic map of the area and in collecting specimens for laboratory study. Special attention was given to the determination of the strike, dip, and relative strength of the veins, dikes, and joints in the area, which is underlain chiefly by granite and rhyolite. During the fall and spring semesters of 1946-1947 laboratory work consisted of the examination of thin sections of the rocks of the area, the study of polished sections of the vein material, and the study of the associated structural features.

Previous Work

The earliest description of the mineralized veins is the unpublished report by Wilson[1] in 1879. A description of the igneous rocks of the St. Francois Mountain region including those of the area studied were discussed by Haworth[2] in 1894. The area is also discussed by Keyes[3] in his publication on the La Motte sheet, published by the Missouri Geological Survey. Ross and Henderson[4] have briefly described the alteration and associated minerals at the Einstein Mine. Petrographic and mineralogic descriptions may be found in the report of Singewald and Milton[5] which includes detailed descriptions of the mineralization at the Ozark, Apex, and Einstein mines. The intrusive relationship of the granite into the rhyolite is treated in a report by Tarr[6], in which he presents direct evidence of intrusive relationship. The

---

1. Wilson, N. R., Review of the dressing works at the Einstein Silver Mine with a project for treating ore: Wash. Univ., Mining School, unpublished thesis, 1879.

2. Haworth, Erasmus, Crystalline rocks of Missouri: Mo. Geol. Surv., vol. 8, pp. 81-224, 1895.

3. Keyes, C. R., A report on Mine La Motte Sheet: Mo. Geol. Surv., 1st ser., vol. 9, Sheet Rept. No. 4, pp. 4-124, 1896.

4. Ross, C. S. and Henderson, E. P., Topaz and associated minerals from the Einstein Silver Mine, Madison County, Mo.: Am. Miner., vol. 10, pp. 441-443, 1925.

5. Singewald, J. T. and Milton, Charles, Greisen and associated mineralization at Silver Mine, Missouri: Econ. Geol., vol. 24, pp. 569-591, 1929.

6. Tarr, W. A. Intrusive relationship of the granite to the rhyolite (porphyry) of southeastern Missouri: Geol. Soc. Am. Bull., vol. 43, no. 4, pp. 965-992, 1932.

most recent report on the mineralization was published by Tolman[7]. The geology of the area is briefly described and the mineralization and character of the deposits are described in detail.

Acknowledgments

This problem was undertaken at the suggestion of Dr. O. R. Grawe, Chairman of the Geology Department at Missouri School of Mines who spent many days in the field giving helpful advice and criticism. Thanks are also due Dr. Grawe for his continual guidance and help during the preparation of the report.

Dr. R. H. Cowie spent a day in the field directing magnetic surveys; and Dr. G. A. Muilenburg offerred helpful suggestions in the interpretation of thin sections.

The citizens of the area extended numerous courtesies to the writer during the field work, for which he is thankful.

Location

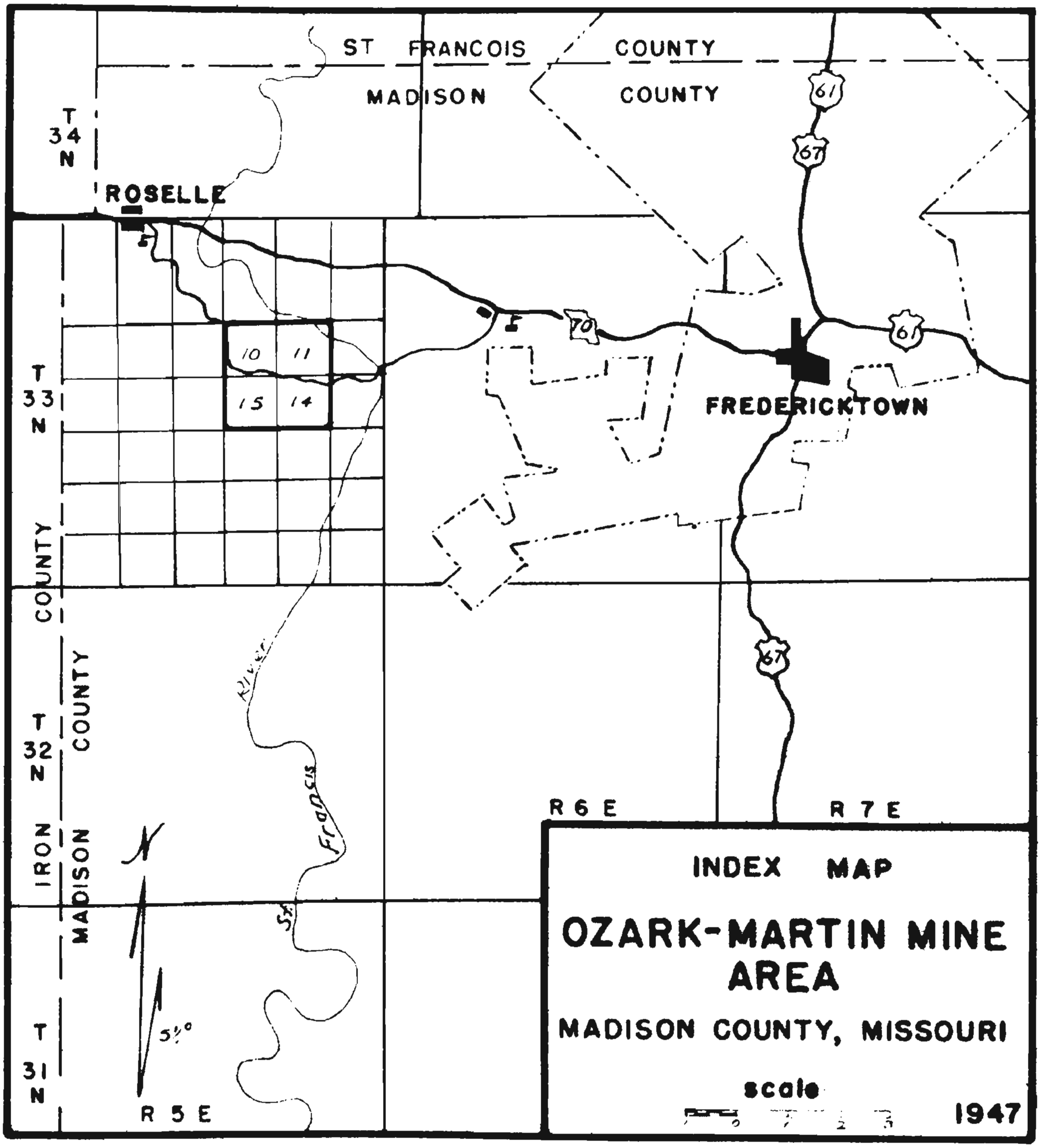
The Ozark-Martin Mine area is in the southeastern part of Missouri, approximately 9 miles west of Fredericktown, Madison County, Missouri. The area included in this report consists of sections 10, 11, 14, and 15, T. 33 N., R. 5 E. (Plate I).

---

7. Tolman, Carl, The geology of the Silver Mine area, Madison County, Missouri: Mo. Bur. Geol. and Mines, 57th Bienn. Rept. app. 1, 1933.

PLATE 1

Index Map
Ozark-Martin Mine Area
Madison County, Missouri



Most of the area is in Clark National Forest.

Roads

The area is about 6 miles south of Missouri State Highway No. 70 and may be reached by gravel roads, in fair condition, either from Roselle or from Oak Grove. These county roads are connected by an east-west gravel road which traverses the approximate center of the area, and passes Silver Mine Post Office. Wagon roads and logging trails are numerous throughout the area, but are in poor condition.

Drainage

The surface drainage of the area is carried south by the St. Francis River which empties into the Mississippi River on the east border of Arkansas. The greater part of the area is drained by Mud Creek which flows northeast to the St. Francis River. A small tributary to Mud Creek drains the southeastern part of the area. Bucklick Creek drains the northwestern part of the area. The drainage pattern in the granite area is controlled by the numerous joints.

Subsurface drainage is limited in the granite and rhyolite porphyry to joints and other fractures. No springs are in evidence. Residential water supply is from cisterns. A few seeps are to be found in low places where the soil is thin. These probably are caused by vadose water seeping along the contact between the earthy mantle and the top of the igneous rocks.

Relief

In section 11, the St. Francis River flows southeastward through the extreme northeast corner of the section. This is the lowest point in the area, being approximately 620 feet above sea level. The highest point is Blue Mountain, along the west edge of section 15, the altitude of which is approximately 1380 feet above sea level. The maximum relief is about 760 feet.

The streams in the northern portion of the area flow in steep granite-walled valleys. The divides are comparatively flat. In the southern part of the area, which is underlain by rhyolite porphyry, the valleys are wider and the divides are more narrow than in the granitic area.

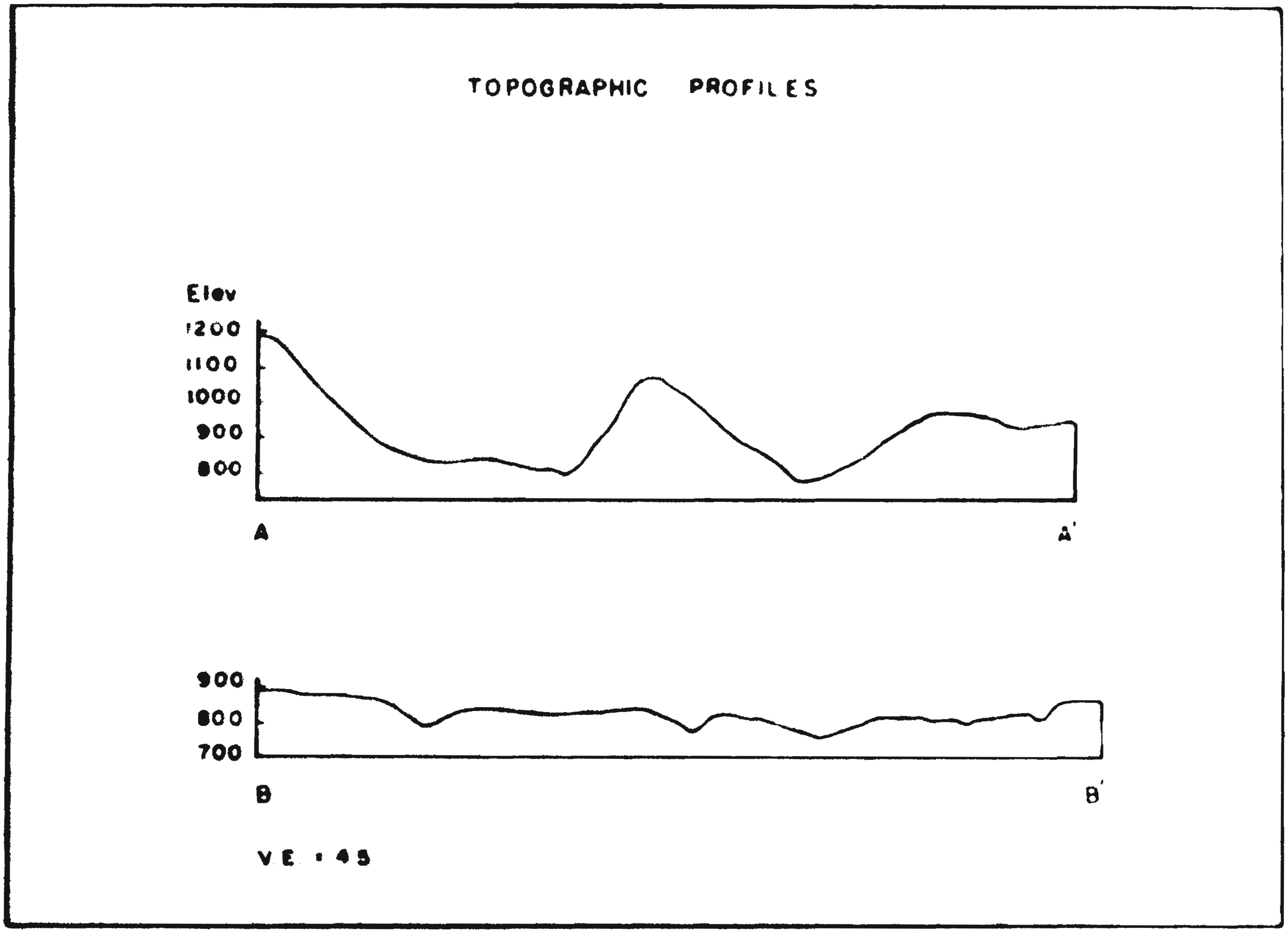
A comparison of the topography as developed in the porphyry (Profile A-A') with that as developed in the granite area (Profile B-B') is presented in Plate II. The exact location of the profiles is indicated on the geologic map (Plate III).

Scenic Attractions

There are many popular fishing and camping localities along the St. Francis River. The pine trees, granite bluffs, and the large granite boulders in the river bed, make it a place of scenic beauty.

PLATE II

Topographic Profiles



Industry, Culture

Timbering was an active industry in the past. Many old logging roads traverse the area. Few, if any, virgin pines remain in the area and second growth oak now predominate the wooded areas. Farming is done by the inhabitants on a small scale. Corn, hay and oats are the main crops. The corn usually is grown in the bottomland, hay and oats on the upland flats. A few hogs, cattle and chickens are raised on each farm, but most of the farm products are consumed at home. Most of the men now living in the area have supplemented their incomes by working in the local mines or in the lead mines near Fredericktown.

DESCRIPTIVE GEOLOGY

The principal rocks exposed in the area are rhyolite porphyry and granite together with other rocks of Archean age: tuff, basalt, diabase and mineralized quartz veins. These ancient rocks in places are covered by younger sediments, which in ascending order are: the La Motte conglomerate of Upper Cambrian age, Tertiary gravels and Recent soil and alluvium.

Igneous Rocks

Archean

Rhyolite porphyry

Distribution

Rhyolite porphyry forms more than one half of the surface rocks of the area. It underlies approximately the southern half of the area, except for the small granite outcrop in the southeast corner of section 14 and the southwest corner of section 15, T. 33 N., R. 5 E. The best exposures are found on Bald Knob and on Blue Mountain.

Lithologic character

The color of the rhyolite porphyry varies from gray-brown to red-brown, usually with a slight purple tinge. The ground mass, or matrix, is fine-grained, and often shows flow structure around the phenocrysts and inclusions. Phenocrysts of quartz and feldspar are readily vidible, some being 6.0 mm.

long. Dark minerals are not usually apparent in the hand specimen. The rock breaks with conchoidal fracture forming sharp edges.

The weathered surface of the rhyolite porphyry has a leached appearance, and the weathered zone may be several inches deep. The rhyolite porphyry characteristically is the surface rock of the high hills, while the granite usually forms the valley floors and low rounded hills.

Petrographic character

Most of the specimens studied in the laboratory contained quartz and feldspar, and were porphyritic. This places the rock in the rhyolite, or rhyolite porphyry group. Most of the specimens were holocrystalline and had a microgranular to sutural texture.

Quartz, perthite and albite are present as phenocrysts in the rhyolite. The feldspar phenocrysts are usually somewhat larger than the quartz phenocrysts, the maximum dimension observed being 2.2 mm. and 1.5 mm. respectively. The average length of the phenocrysts in thin section is approximately 0.8 mm. They are subhedral, very commonly showing embayed and corroded edges. Approximately 35 to 40 per cent of the phenocrysts are quartz. All the phenocrysts make up about 10 per cent of the rock.

Quartz, orthoclase, and albite make up most of the groundmass. The grains range in size from 0.02 to 0.1 mm., with the average size approximately 0.04 mm. The grains are at times intricately intergrown, producing a sutural texture. Micro-granular and mosiac textures were observed in some sections.

Accessory minerals observed are magnetite, apatite, zircon, fluorite, and a few sporadic occurrences of augite. All these accessory minerals may account for 1 or 2 per cent of the rock. The magnetite occurs as grains and subhedral crystals from pin-point size to 0.25 mm. The larger grains were observed in the rhyolite near the Martin Mine. Apatite crystals, as long as 0.06 mm. were observed in the quartz phenocrysts, and smaller apatite crystals are present in the groundmass. The zircon occurs as short stubby crystals which are approximately 0.04 mm. long. Fluorite is present in small irregular patches and veinlets. Most of the fluorite is clear, but some has a slight purple tint.

Secondary minerals identified were chlorite, limonite, kaolinite and sericite.

At the Ozark Mine, the country rock appears to be a tuff. Megascopically the tuff is light gray in color, shows banding and fragmentation, and is very tough. At a casual glance it might be mistaken for a dense, siliceous limestone. The larger fragments which show the banding, have been cemented into a breccia.

Several thin sections showed that the fragments are composed of quartz and feldspar. The texture of these fragments is essentially like the groundmass of the rhyolite. These masses average about 0.5 mm. in diameter, and the individual quartz and feldspar grains comprising the fragments are approximately 0.04 mm. in diameter. They are interpreted by the writer as representing original rock fragments in the tuff. individual fragments of quartz and feldspar are also present in the tuff. From 60 to 70 per cent of the rock is topaz, in euhedral crystals replacing the earlier quartz and feldspar. Quartz forms 20 to 25 per cent of the rock, with many individual grains showing secondary growth and very irregular edges.

Sphalerite is present in irregular grains which parallel the banding and make it more pronounced. Individual grains may be 1.5 mm. in size. This mineral forms perhaps 3.0 per cent of the rock. Pyrite occurs in a similar manner. Its average size is about 0.24 mm.

Fluorite is quite apparent in the rock, forming approximately 2.0 per cent. Some of it is clear and some is light purple in color. It occurs in small bands and veinlets, some of which are over 1.5 mm. long.

Granite

Distribution

Granite is the surface rock in the northern part of the area. It also outcrops in the southeast corner of section 14,

T. 33 N., R. 5 E. and in the southwest corner of section 15, T. 33 N., R. 5 E. The best exposures are found along Bucklick and Mud Creeks, and along the St. Francis River.

Lithologic character

The granite is medium-grained, essentially equigranular, but at times somewhat porphyritic. It is light colored, varying from mottled pink to light gray. The mottling is due to the slightly porphyritic texture and to the variation in color of the feldspars. Green splotches, apparent in hand specimens, are due to chlorite and epidote. Quartz, orthoclase and plagioclase are distinguishable.

Where exposed, the granite is jointed and occurs in large blocks which are produced by weathering of the granite along the joint surfaces. Where the granite is not exposed, it gradually merges into the soil, through a transition zone of arkosic gruss.

Petrographic character

Quartz forms an average of 20 per cent of the rock. It is present in anhedral grains which usually are clear, but frequently contain "dust" particles and gas bubbles in liquid inclusions. In several of the smaller inclusions (approximately 1.0 to 1.5 microns in diameter) the bubbles are observed to move quite rapidly. This movement may possibly be caused by Brownian movement. The maximum size of these inclusions is less than

2.0 microns, and the quartz around 3.0 mm. The average size of the quartz grains is 0.6 mm. The feldspars which were identified are orthoclase, perthite, and albite. Orthoclase forms from 15 - 25 per cent of the rock; perthite, up to 25 per cent at times; and albite, from 20 to 75 per cent, averageing about 30 - 40 percent of the rock. The feldspars are anhedral to subhedral. The average size is approximately 0.4 - 0.5 mm., but perthite and albite have been observed up to 5.0 mm. in diameter, giving a somewhat porphyritic appearance to the rock. The albite was determined by maximum extinction angles and indices of refraction to be approximately $Ab_{10}An_0$ - Ab_9An_1. Interpenetrating and zoned crystals are quite common. The centers of the latter show more hydrothermal alteration than the borders.

Hornblende occurs as subhedral crystals which are pleochroic, light green to colorless. The maximum size observed is 2.0 mm., the average size being about 0.25 mm. It may form less than 5 per cent to slightly over 10 per cent of the rock; and commonly shows replacement and alteration to chlorites, antigorite and penninite.

Biotite may comprise from 5 to 8 per cent of the rock. It is subhedral to anhedral, and has an average size of 0.2 mm. There usually is less biotite than hornblende. The biotite also shows alteration to the chlorites. Pleochroic halos are to be seen seen surrounding small included crystals of zircon.

Magnetite occurs in small anhedral grains and in euhedral crystals, having an average diameter of about 0.07 mm. Because of the relative abundance of leucoxene, some of the opaque mineral may be ilmenite. A heavy mineral separate was made using acetylene tetrabromide (Sp. Gr. 2.96). Two size fractions were used; one between 0.149 mm. and 0.112 mm., and the other below 0.112 mm. The dust in the small fraction was removed by washing. The strongly magnetic minerals were extracted, and the slightly magnetic minerals of the residue were tested for titanium. A negative reaction was obtained in each test. The magnetite contains some titanium, for grains were observed which showed alteration rims of leucoxene. The magnetite is commonly associated with the chlorites and biotite, and occurs along contacts of other minerals.

Apatite is present in small euhedral, lath-like crystals, some of which are 0.6 mm. long with an average width of 0.08 mm. Most are clear, but many are light blue-gray in color. Tolman[8] reports that in some samples, apatite makes up as much as 44 per cent of the heavy accessory minerals of the Silvermine granite. It was observed in all thin sections of the granite, as inclusions in the quartz and feldspars.

Titanite occurs in small diamond or wedge shaped, almost

---

8. Tolman, Carl and Koch, H. L., The heavy accessory minerals of the granites of Missouri: Wash. Univ. Studies, new ser., no. 9, pp. 30, 1936.

euhedral, crystals, and as anhedral grains. It is abundant in all thin sections of the granite, and Tolman[9] states it averages nearly 60 per cent of the non-magnetic heavy accessory minerals. The alteration of titanite to leucoxene is apparent in all sections studied.

Zircon is a widely distributed accessory mineral in the granite. It is commonly present in the hornblende and biotite, producing pleochroic halos. It occurs as small euhedral crystals, as much as 0.4 mm. long and about 0.07 mm. wide. Some crystals are clear, but more often they are zoned and show parallel and random fractures. The most common forms are the first order prism and dipyramid.

Pyrite was identified by its brass-yellow color in reflected light. Its occurrence and size is similar to that of magnetite, but it is not as plentiful. Several crystals show alteration to limonite around the edges.

A few grains of topaz, fluorite, and rutile were recognized, but their occurrence is very limited.

Secondary minerals

Kaolinite occurs as hydrothermal alteration mineral in the feldspars, giving them a cloudy appearance. The specimens near the dikes and near the contact of the rhyolite and granite show

---

9. Tolman, Carl, Ibid. p. 39

more of this alteration than do other specimens.

Sericite occurs in small flakes scattered through the feldspars, and in several veinlets in the granite. Certain twinning laminae of the feldspars seem to be more susceptible to this replacement than other twinning laminae.

Leucoxene was identified as an opaque mineral in transmitted light and white to light brown in reflected light. It occurs in irregular grains and veinlets closely associated with the chlorites, magnetite and titanite.

Epidote occurs in widely distributed granular aggregates, and appears to be an alteration of the amphiboles and feldspars. It was distinguished by its high indices of refraction, parallel extinction in longitudinal sections, and by the fact that its optic plane is normal to the cleavage.

Penninite was observed along seams as an alteration of biotite and the amphiboles. It was recognized by its light green color, pleochroism, parallel extinction, the anomalous "Berlin Blue" interference color, and indices of refraction greater than those of quartz.

The occurrence of antigorite is similar to that of penninite, and was determined by its yellow-green color, pleochrosim, pale yellow-green interference color, and indices of refraction close to, or somewhat lower than those of quartz.

Limonite was observed in small streaks and grains, and as rims around pyrite and magnetite.

A carbonate, probably calcite, was observed in several specimens closely associated with the feldspars which were weathered.

A specimen (50-B) taken 3 inches from the contact of the large dike in the N.W. cor., sec. 11, shows only a small amount of quartz and orthoclase. Approximately 80 per cent of the rock is albite. This mineral exhibits many curved twinning laminae, fracturing, zoned extinction, and a high degree of kaolinization and sercitization. Perthite shows alteration to a higher degree than the albite.

One foot from this dike (specimen 50-A) quartz and orthoclase are present in average amount. The albite here shows complex intergrowth. Hornblende makes up 10-15 per cent of the rock, much of which shows alteration to penninite. The feldspars are highly kaolinized and sericitized, but not to the extent of those closer to the dike. Coarse perthitic texture is developed, and such areas show stronger alteration than the orthoclase and albite.

Thin sections of the granite near the area of basic segregations in the St. Francis River bed, northwest of the large dike, show the secondary growth of the feldspars very clearly. The centers are albite, about 0.3 to 0.5 mm. long, and exhibit extensive hydrothermal alteration. Around many of these crystals is a zone of albite, oriented in like manner to the original crystal. The secondary zone is from 0.17 to 0.25 mm. wide. Quartz and orthoclase enclose the secondary development.

Approximately 700 feet upstream along the St. Francis River, from the north section line of section 11, is a local area in the granite which contains numerous basic segregations. The outline of these segregations is not sharp, but somewhat transitional into the granite. Their shape is lens-like, and very often sinuous.

A thin section of the segregation shows 15 to 20 per cent of the rock is hornblende in grains which have an average length of 0.25 mm. and an average width of 0.05 mm. Some biotite is present, very much altered to chlorite. Perhaps 15 to 20 per cent of the rock is quartz, showing micrographic texture, and approximately 40 per cent of the rock is feldspar. From 70 to 75 per cent of the feldspar is albite, the remainder being orthoclase. Apatite is excessive, forming 5 - 10 per cent of the rock. Magnetite occurs in euhedral crystals and grains, forming probably 10 or 15 per cent of the rock.

The granite near the contact of the rhyolite, along the east side of section 10, is highly altered. No twinning could be observed in the feldspars due to the extensive alteration. The feldspars are about 0.35 mm. long. Corroded quartz fills the interstices between the feldspars. The amphiboles have practically disappeared, leaving a small amount of chlorite in their place.

A thin section (No. 66) showing the contact of a small basic dike with the granite in the center of section 11, shows a narrow zone along the contact, 0.08 - 0.75 mm. wide, made up of small irregularly spaced, angular fragments of quartz, orthoclase, and albite. It has the appearance of a micro-breccia, probably indicating that the granite was completely solidified at the time of the intrusion of the dike.

A thin section showing the contact of an aplite dike with the granite shows a zone 0.5 mm. wide, which has a micrographic texture. The aplite contains quartz and orthoclase, the average size of which is from 0.08 - 0.1 mm. Albite crystals are present, up to 0.3 mm. long. This mineral exhibits more alteration than the orthoclase.

Along a small ravine on the west side of Bald Knob in the SW$\frac{1}{4}$ SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 15, T. 33 N., R. 5 E., several light gray boulders of igneous material were found. The rock was not observed in place, due to the soil cover and perhaps to the limited occurrence of the rock. Several fragments were quite angular, indicating that they had been broken out of the bed rock at a comparitively recent date. There is evidence of an old prospect adit in the ravine, and it is probable that the rock was encountered in the working places.

The rock is coarse grained, porphyritic, and composed largely of feldspars. An amphibole may also be distinguished in the hand specimen. The phenocrysts are feldspars and amphiboles.

The fresh material is essentially composed of irregular intergrowths of albite and perthite, which form approximately 90 per cent of the rock. The maximum size of the albite phenocrysts is about 1.6 cm. in length.

Other phenocrysts present were identified as pargasite. The crystals are biaxial positive, faintly pleochroic, have high birefringence, high indices of refraction, a 2V of about 60 degrees, and posess cleavage of the amphibole group. The maximum size of a single crystal observed is 1.1 cm. in length.

Very little quartz is present; perhaps less than 5 per cent of the rock being quartz. The rock may be classed as a pargasite syenite.

Some fragments show a high degree of hydrothermal alteration. In these specimens, the feldspars were very irregular in outline, and frequent replacements by albite were observed. Kaolinization has altered the perthite and albite almost beyond recognition. A green mineral, with good cleavage, identified as actinolite, is present in fibrous masses. It is biaxial, negative, length slow, with maximum extinction angle with the cleavage of about 20 degrees, optic plane essentially parallel to the cleavage, and interference colors of the second order. The mineral contains minute inclusions of zircon surrounded by pleochroic halos.

Basic Rocks

Distribution

Basic intrusions, in the form of dikes and small irregular stocks or bosses, occur in the granite and rhyolite porphyry. The best outcrops, and numerous occurrences, are to be found in the granite along the St. Francis River. Many scattered boulders were found throughout the area, but because they could not be limited in extent, they are not shown on the geologic map.

Lithologic Character

Megascopically one may differentiate the intrusions into two textural groups; a basaltic group, and a diabasic group. Both varieties of the basic rock are dark green to almost black. They are fine-grained to medium-grained; and the following minerals were identified in hand specimens: Plagioclase phenocrysts in the diabase with a maximum length of 6.5 mm., pyroxene, magnetite, pyrite, olivine, and calcite. The rock in many of the dikes is too fine-grained or too highly altered to permit megascopic identification of any of the constituents.

Because of the abundant joints in the dikes, they usually weather into depressions in the granite. As a result of this weathering, the presence of many dikes is indicated only by rounded, dense olive-green cobbles and boulders, which are very difficult to break. Their weathered surfaces are dull gray crusts which often exhibit exfoliation.

One of the best examples of diabase occurs in the extreme northcentral part of the area. The outcrop was first observed in the valley in the northwest corner of sec. 11. Boulders of float were traced around the hill to the west to an outcrop in the valley of Bucklick Creek. The upper limit of the diabase float was traced from that locality northwestward around the slope on the west side of Bucklick Creek to an outcrop in the valley to the northwest. Float was also traced to the east of the northwest corner of sec. 11 to the next valley in that direction, but could not be traced farther. This occurrence seems to represent an essentially flat-lying injection, of approximately 8 to 10 feet in thickness.

Along the north side of the main road, on the east bank of Mud Creek, SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 11, T. 33 N. R. 5 E. is another outcrop of diabase. The outcrop consists of numerous boulders and considerable soil derived from the diabase but the exact areal extent could not be determined.

In the northeast corner of section 15, an outcrop of diabase is exposed along Mud Creek. The diabase is in contact with highly altered and fractured granite, and small apophyses of the diabase extend into the granite. The section exposed is vertical, and shows the contact on the west side dipping approximately 30° to the west, and the contact on the east side dipping approximately 30° to the east.

The outcrop extends upstream for a distance of 150 feet. In the stream bed, immediately downstream from the vertical exposure, small fragments of granite and rhyolite porphyry were observed in the diabase.

It is believed that this occurrence is an intrusion of a diabase stock; which has incorporated fragments of granite and rhyolite porphyry from the country rock as it was injected.

Diabase float was found in a prospect pit about 200 feet northeast of the Martin Mine, and also on the west side of Bald Knob. No outcrop could be found at these localities.

All other occurrences of the basic rocks were of basaltic character.

Of particular interest is a large dike in the St. Francis River bed in the NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 11. The dike measured 14 feet, 10 inches in width, with a strike of N. 30° E., and almost vertical dip. It is believed that this dike is larger than any basic dike previously reported in the area. A vertical exposure of 25 feet above the water level was noted. The dike can be traced approximately 600 feet along its strike to the southwest until it is obscured by soil on the hill along the west bank of the river. However, it may be continuous with the outcrop of basic rock in Mud Creek, about 400 feet to the southwest

Approximately 650 feet upstream from the large dike, there are several small basaltic dikes. They range in width from a fraction of an inch to slightly over one foot. They strike N. 60° E. and have approximately a vertical dip.

Where the St. Francis River intersects the north line of section 11, there is a dike 7 feet wide. It strikes N. 23° E. and dips 81° to the northwest. The strike of the dike closely parallels the strike of the main jointing in the granite at this locality.

Petrographic Character

The principal feldspar of the basic dikes is labradorite which occurs as phenocrysts having an average length of 0.7 mm. Several sub-hedral grains as long as 2.6 mm. were observed. Measurement of the maximum extinction angles on albite twins, indicates that its composition is approximately Ab_{45}-An_{55}. The crystals are frequently zoned and interlocking, and commonly show alteration to kaolinite and sericite. Labradorite may form from 55 to 60 per cent of the rock.

Augite is the second most abundant mineral. It is biaxial positive, has a maximum extinction of 38 degrees to the cleavage, and 2V of approximately 60 degrees. It fills the interstices between the labradorite as irregular grains ranging in size from 2.0 to less than 0.1 mm. Many of the pyroxenes seem to approach uralite through processes of hydrothermal alteration. The augite may form from 15 to 20 per cent of the rock.

Olivine is present in most thin sections as anhedral grains approximately 0.8 mm. in diameter. It commonly is included in the augite. It was identified by its parallel extinction, strong birefringence, large optic angle, biaxial positive interference figure and by the fact that the optic plane is normal to the cleavage. Most of the olivine is highly fractured and altered to antigorite, penninite, and possibly iddingsite, along the irregular fractures. Olivine may form from 10 to 15 per cent of the rock.

The main accessory minerals: biotite, magnetite, pyrite, and apatite; may form from 10 to as much as 20 per cent of the rock. Relict particles of biotite, with included zircon and magnetite, are present, but are almost completely altered to the chlorites. Magnetite, and possibly ilmenite, occur in small (0.05 mm.) euhedral crystals in the augite and biotite, and as grains in the plagioclase. Several relict crystals of magnetite altered to leucoxene were observed. The occurrence of pyrite is similar to that of magnetite, and shows alteration around the edges to limonite. A few apatite crystals, as long as 0.3 and 0.04 wide, were observed in several thin sections. Titanite and zircon are present in minute amounts. Calcite may be observed in the hand specimen in many of the rocks that have been highly altered. It also was observed quite commonly in thin sections as a secondary mineral. Penninite, antigorite, and iddingsite were identified as alteration products of the pyroxenes and olivine; sometimes as partial pseudomorphs, and sometimes as filling small cracks and fractures.

Thin sections of the large dike show numerous anhedral quartz grains from 0.15 to 0.17 mm. in diameter. Sections of several dikes to the northwest of the large dike also have quartz present. It seems to have replaced the augite in the interstices between the plagioclase. It may have been derived from the granite country rock as the dike was intruded.

Sedimentary Rocks

Upper Cambrian-La Motte

La Motte

The Archean igneous rocks are overlain by the beginning of the sedimentary series of the region, the La Motte formation of Winslow[10]. The name was proposed in 1894 from the type section as developed at Mine La Motte, Madison County, Missouri.

In 1911, Ulrich[11] placed the La Motte in the Upper Cambrian, and considered the formation as representing the initial sedimentation of the Upper Cambrian west of the Mississippi River.

The only outcrop of La Motte in the area is in the west central part of the NW$\frac{1}{4}$, sec. 11, T. 33 N., R. 5 E. It is exposed along the stream bed for approximately 400 feet. Because

---

10. Winslow, Arthur, Lead and zinc deposits, Mo. Geol. Surv, 1st ser., vol. 6, p. 347, 1894.

11. Ulrich, E. O., Revision of Paleozoic Systems, GSA Bull., vol. 22, p. 623, 1911.

of its limited outcrop, it does not have any topographic expression. The only relationship that may be observed in the area, is that the La Motte is post-granite. It outcrops in the granite area and is composed chiefly of weathered rhyolite porphyry boulders and pebbles. The entire outcrop is composed of rhyolitic material. Special effort was expended to find some granite boulders in the conglomerate, but none was observed. Many of the boulders are over a foot in diameter; others are quite small and form the matrix in which the larger particles are embedded. All the surfaces of the particles have been highly weathered. The majority of the fragments are sub-rounded to sub-angular. Much of the cementing material is ferriginous and arkosic. The deposit is very poorly sorted.

The conglomerate was assigned to the La Motte formation on the basis of its lithology and occurrence. Rhyolite conglomerate is common at the base of the La Motte in other places. The writer has observed similar occurrences in sec. 12, T. 33 N., R. 5 E. and in sec. 7 T. 33 N., R. 6 E. where the identification of the formation as La Motte is accepted.

Tertiary-Lafayette

The sediments normally found above the La Motte in Missouri are absent in the Ozark-Martin Mine area. The next younger formation consists of upland gravels, presumably of Tertiary age.

On many of the hill slopes and ridges in southeast Missouri, it is quite common for one to fine deposits of gravel and sand on the hilltops above the present stream beds. A few scattered gravels were observed throughout the Ozark-Martin Mine area on several of the ridges. The main outcrop is in the south-center of sec. 11, T. 33 N., R. 5 E. It is limited to a somewhat elliptically shaped area approximately 400 feet by 600 feet in extent. The exact limit of the gravels is difficult to determine because they grade into the recent soil cover. The gravel consists of well-rounded pebbles of quartzite and chert having an average diameter of 2 to 3 inches. They are uncemented.

Similar gravels were named Lafayette by Hilgard[12], who examined exposures in Lafayette County, Mississippi, where he first distinguished it from Eocene deposits. The Lafayette was considered as Tertiary in age by the United States Geological Survey, through the work of T. W. Vaughn.[13] The age was given as Pliocene (?). Later it became undesirable to retain the name because various workers applied the name to different deposits in different areas. Because of the varying lithology, limited paleontologic evidence, and sporadic but widespread

---

12. Hilgard, E. W., Orange sand, Lagrange, and Appomattox: Am. Geol., vol. 8, p. 130, 1891.

13. Vaughn, T. W., Information from USGS Bull. 896, Lexicon of geologic names of the United States, p. 1129, 1938.

occurrence of the Lafayette, it has been difficult to assign a definite age to the "high level gravels". It is perhaps best to speak of their age as Tertiary, and not limit their assignment to epochs until more information is available.

Recent

The high level gravels are succeeded in the geologic section by the most recent sediments of the area, the soils and stream alluvium.

The residuum, formed on the gently sloping areas is typically a light-gray to gray-brown, sandy loam. It passes through a weathered zone of arkosic material into the bed-rock below.

At times it appeared that the soil produced from the granite might be different and support different vegetation, than the soil of the rhyolite porphyry. However, no generalizations can be made; and they often can not be distinguished from each other.

The alluviuum is found in the beds of the creeks and in the St. Francis River Bed. These deposits are composed of rounded particles from silt to boulders. The particles may be composed of granite, rhyolite porphyry to various types of basalts and diabases. Many rounded fragments of chert may be found in the St. Francis River bed, and were probably derived from areas upstream.

Alluviuum also has been deposited at the base of Blue Mountain and cut the base of Bald Knob. At these localities the material is rhyolite porphyry. In several instances the deposits are quite thick and resemble alluvial fans.

GEOLOGIC HISTORY

In a small area such as the one under investigation, the geologic history cannot be determined completely. Information obtained in the field has been supplemented by that obtained from the literature.

The geologic history of the area is recorded principally in the Pre-Cambrian rocks which consist of granites, rhyolite porphyries, tuffs, diabasic intrusions, and mineralized veins. These are the surface rocks over most of the area except where they are covered by small patches of La Motte conglomerate of Upper Cambrian age, hgih-level gravels of probable Tertiary age, and recent alluvium and soil.

These formations are separated by great unconformities representing long periods of erosion, or perhaps periods of deposition of sediments which later were eroded away.

Pre-Cambrian

The igneous rocks of the area have been assigned to the Pre-Cambrian. Field relations cannot deduce this, for the ages of the igneous rocks can only be comparatively dated. Rhyolite porphyry boulders are present in the La Motte conglomerate; hence, the porphyry positively can be dated as pre-La Motte. The granite is found to be intrusive into the porphyry; hence it is younger than the rhyolite porphyry. Diabase dikes and stocks intrude the granite and porphyry and hence are younger than the granite.

The rhyolite porphyry is interpreted to be a series of surface flows, mainly because of the essentially horizontal lineation of the phenocrysts where ever observed. The relation between the rhyolite porphyry and tuff has not been observed. It is probable that the tuff has been inter-bedded between various porphyry flows.

There are several types of granite in the St. Francis region, and it is quite possible that there were several granitic intrusions. Tolman[14] considers the relation of the granite, diabase dikes and the veins at Silvermine to be indicative of at least two separate intrusions. The dikes are intrusive into both the rhyolite porphyry and the Silvermine granite, and may represent either the basic end product of magmatic differentiation, or they may be genetically unrelated to the granite. Basic dikes are not known to intrude the Graniteville granite farther to the north. The mineralized veins cut the dikes and hence are later than the dikes. With these relations and the results of his heavy accessory mineral studies in mind, Tolman[15] stated that there are certain features of the Graniteville

---

14. Tolman, Carl and Koch, H. L., The heavy accessory minerals of the granites of Missouri: Wash Univ. Studies, new ser., no. 9, p. 46, 1936.

15. Tolman, Carl and Koch, H. L., Ibid., p. 47

granite which seem to indicate that it is younger than the granite at Silvermine, and that it might even be genetically related to the mineralized veins.

The faults, or shear joints, cutting the granite and the dikes, as observed by the writer in sec. 12, T. 33 N., R. 5 E., may have been the result of a later period of granitic intrusion and may have been the channelway along which the mineralizing solutions migrated.

No igneous activity of the Pre-Cambrian is known to be later than this period of mineralization.

The interval between the time that the youngest Pre-Cambrian rocks were formed and the oldest Cambrian seas advanced over the area, represents the largest erosional interval in the State. The area was dissected by erosion to produce a relief of at least 600 feet. This is indicated by the present relief between the outcrop of La Motte and the tops of the adjacent mountains.

If the igneous rocks are of early Pre-Cambrian (Laurentian) age, the period of denudation preceding the deposition of the La Motte, surely represents an enormous time interval. How many periods of submergence and emergence took place during this interval, would only be a guess.

La Motte

Upon the Pre-Cambrian erosional surface, the La Motte conglomerate was deposited in Upper Cambrian time. The many lowlands between the hills of igneous rocks were the basins of deposition of the coarse clastic sediments. The seas were comparatively shallow, as indicated by the irregular lensing of conglomerate and sandstone, and by the poor sorting of these sediments. The primary and initial dips of the formation, where it rests upon the porphyry hills, has been observed in a number of places, especially by Bridge and Dake[16] Some of the igneous knobs may have been almost covered during the deposition of the La Motte. The outcrop of La Motte conglomerate in sec. 11 is composed entirely of weathered, rounded rhyolite porphyry boulders, but it is in the granite area at an altitude of 780 feet, well above the present major drainage.

Post-La Motte, Pre-Tertiary

The geologic record in southeast Missouri shows that the region was subjected to many uplifts and downwarps during the Paleozoic and Mesozoic Periods, but evidence of all these movements is absent in the area studied. No Paleozoic or Mesozoic sediments younger than the La Motte occur in the area.

Cenezoic

During Cenezoic time, nearly the entire state (except the

---

16. Bridge, Josiah, and Dake, C. L., Initial dips peripheral to resurrected hills: Mo. Bur. Geol. and Mines, 55th Bienn. Rept. State Geologist, 1927-1928, app. 1, pp. 93-99, 1929.

south-east corner) was a land area being subjected to erosion. The area was perhaps base-leveled during late Tertiary time. The "high level gravels" or the Lafayette gravels, have been tentatively assigned to the Tertiary, but their direct relationship is somewhat uncertain. After the base-leveling, there was probably a slow uplift, resulting in the entrenchment of the St. Francis River in the igneous rocks. The steep valley walls, minor development of small flood plains, and the fairly steep gradient of the streams indicate that they have not yet reached grade since this period of rejuvenation. At the present time soils are forming on the uplands and are being transported toward the St. Francis river by the intermittent streams.

The development of soils, and the deposition of alluvium in the stream valleys, are the most recent deposits.

STRUCTURE

Primary Structures

Major Features

A study of the genetic relationship of the granite to the rhyolite porphyry is impossible in the area because the contact between the two igneous rocks is not exposed. At every locality where a contact was expected, the surface was covered with soil. Haworth[17] believed that the rhyolite porphyry to be a border phase of the granite, and that the contact is gradational. Tarr[18] found exposures where the granite intrudes the rhyolite porphyry. The closest contact described by Tarr, is about 3 miles south of Roselle in sec. 6, T. 33 N., R. 5 E. along the north bank of Stouts Creek. Haworth[19] mentioned this locality and included analyses of the granites to show the gradational relationship. Tarr,however, found the contact between the coarse-grained granite and the dense, fine-grained rhyolite to be sharp and well exposed.

---

17. Haworth, Erasmus, Crystalline Rocks of Missouri, Mo. Geol. Surv., 1st ser., vol. 8, p. 61-224, 1895.

18. Tarr. W. A., Intrusive relationship of the granite to the rhyolite (porphyry) of southeastern Missouri: Geol. Soc. Am. Bull., vol. 43, no. 4, pp. 965-992, 1932.

19. Haworth, Erasmus, Op. cit., pp. 212-213

A contact 900 feet north of the southeast corner of section 10, T. 33 N., R. 5 E. may be ascertained within 25 feet, which is as close as the contact may be determined anywhere in the area, but the relationship of the porphyry to the granite cannot be seen.

The only age relationship of the rhyolite porphyry observed in the area, is that it is earlier than the basic dikes which cut it. Buckley[20] stated that the rhyolites are certainly Pre-Cambrian, and may be tentatively assigned to the Laurentian division of the Archean. Robertson[21] zoned the felsites,and the rhyolite porphyry of the Ozark-Martin Mine area probably is the equivalent of the middle purple rhyolite zone.

All of the granite within the area is the same. It has been named the Silver Mine granite by Tolman.[22] The granite also is cut by basic dikes and is unconformably overlain by the La Motte conglomerate. Haworth[23], in 1888, assigned the

---

20. Buckley, E. R., Geology of the disseminated lead deposits of St. Francois and Washington Counties: Mo. Bur. Geol. and Mines, 2d ser., vol. 9, p. 16, 1909.

21. Robertson, Forbes, The igneous geology of the eastern Ironton and western Fredericktown quadrangles: Wash. Univ. unpublished thesis, p. 90, 1940.

22. Tolman, Carl, and Koch, H. L., The heavy accessory minerals of the granites of Missouri: Wash. Univ. Studies, new ser., no. 9, p. 48, 1936.

23. Haworth, Erasmus, Contributions to Archean geology of Missouri: American Geol., vol. 1, pp. 280-297, 363-382, 1888.

granites to the Archean, and later Buckley[24] placed them in the Laurentian.

Minor Features

Linear flow structure, or lineation, was observed in the outcrops of the rhyolite porphyry. The feldspar phenocrysts are alined in a parallel manner, often curving gently around small included masses that are probably autoliths.

The trend of this linear flow structure is variable, invariably being different at each outcrop. The best examples may be seen in the rhyolite porphyry on the east side of Blue Mountain. Perhaps a detailed petrofabric study of the felsites of the region would be a contribution in itself to the tectonic history of the St. Francois Mountains.

A study of the granites indicates no particular tectonic or petrofabric design. The minerals show no parallelism, and are variously oriented.

The alignment of plagioclase phenocrysts parallel to the contacts of the diabase dikes has been mentioned with under the petrographic description of those rocks.

Secondary Structures

At the beginning of the investigation there were two factors indicative of a definite structural pattern in the area: the trend of the basic dikes and the drainage pattern, especially the course of the St. Francis River. Its many sharp bends, sep-

---

24. Buckley, E. R., Op. Cit., p. 16

arated by comparatively straight courses, indicate that the drainage pattern is controlled by some structural factors.

Faulting

Areal photographs of the area were studied by means of steroscopic pairs. Several definite structural trends were observed in sections 12 and 13, T. 33 N., R. 5 E. with strikes of approximately N. 30° E. with which were associated smaller cross-structures. Another structural feature with a strike N. 45° W. was observed just to the southwest of the southwest corner of sec. 15, T. 33 N., R. 5 E.

Two possible structures were observed from the photographs in the Ozark-Martin Mine area. If the strike of the fault between the Apex and Einstein mines in section 12, is extended N. 30° E. along its strike into the Ozark-Martin Mine area it would intersect the Ozark Mine. The area between the Apex and Ozark Mines was carefully walked-out along the probable strike of the fault but no definite evidence of faulting was observed.

The other trend, although somewhat obscure, also has a strike of N. 30° E. from the Martin Mine through the Hensen prospect. If projected along the strike, this structure intersects the Killian shaft in the NW¼ SE¼ sec. 12, T. 33 N., R. 5 E., continues along a straight ravine and intersects several prospect pits in the NE¼ NW¼ sec. 12, T. 33 N., R. 5 E. Shallow prospect pits and trenches are closely spaced along the strike of this structure, and slickensided surfaces were found at practically all the prospects.

Faulting in the area has not been reported, but Tolman[25] mentions that faulting may have offset the veins between the Apex and Einstein mines, but that no evidence of such a structure had been observed. However, Pomerene, who has recently worked this area, has shown that such faulting exists and that the veins themselves are definitely related to an early period of faulting.

Jointing

Prominent joint sets in the granite may be observed throughout the area. They are well developed in many places where weathering has enlarged them. Such weathering produces large boulders and blocks of granite bounded by joint surfaces.

The strike and dip of the joints were recorded in the field at a number of outcrops where the jointing is well developed. One joint of each observed set was chosen as the representative of that set, but shallow dipping joints that seemed to parallel the surface and are probably the result of relief of pressure due to erosion of the overlying rock, were not recorded. The dips of the joints are essentially vertical; very few dip readings being taken that were not between 80° and 90°, and for practical purposes the joints may be considered vertical.

---

25. Tolman, Carl, The geology of the Silver Mine Area, Madison County, Missouri: Mo. Bur. Geol. and Mines, 57th Bienn. Rept., App. 1, p. 35, 1933.

The most persistent joint set observed by the writer is the set striking N. 8-10° E. The set striking N. 30° E. is more apparent and more readily observed, but not as persistent. In Table 1 the joint systems observed by the writer are compared with the systems observed by Tolman and by Graves.

Table 1 Comparison of Joint Sets in Granite

Present Writer	Tolman[26]	Graves[27]
N 70 W		N 65 W
N 10 E		N 25 E
N 55 W		N 50 W
N 30 E	N 25 E	N 40 E
N 30 W	N 30 W	N 25 W
N 60 E	N 65 E	N 65 E
N - S		N - S
E - W	E - W	E - W
	N 50 E	

By comparison of the dike diagram (Fig. 2), and the joint diagram (Fig. 1), it is apparent that the dikes follow the N. 10° E. and the N. 30° E. joints. It would therefore seem that the northeasterly joints are the result of the tensional component, of any pre-basic intrusive stresses.

Joints in the rhyolite porphyry are numerous throughout the area, but their attitudes are very irregular and do not

26. Tolman, Carl, Ibid, p. 15

27. Graves, H. B., Jr., The Pre-Cambrian structure of Missouri: Trans. Acad. Sci. St. Louis, vol. 29, no. 5, 1938, p. 130.

PLATE IV

Strikes of Joints in Granite and Strikes of Dikes

Ozark-Martin Mine Area

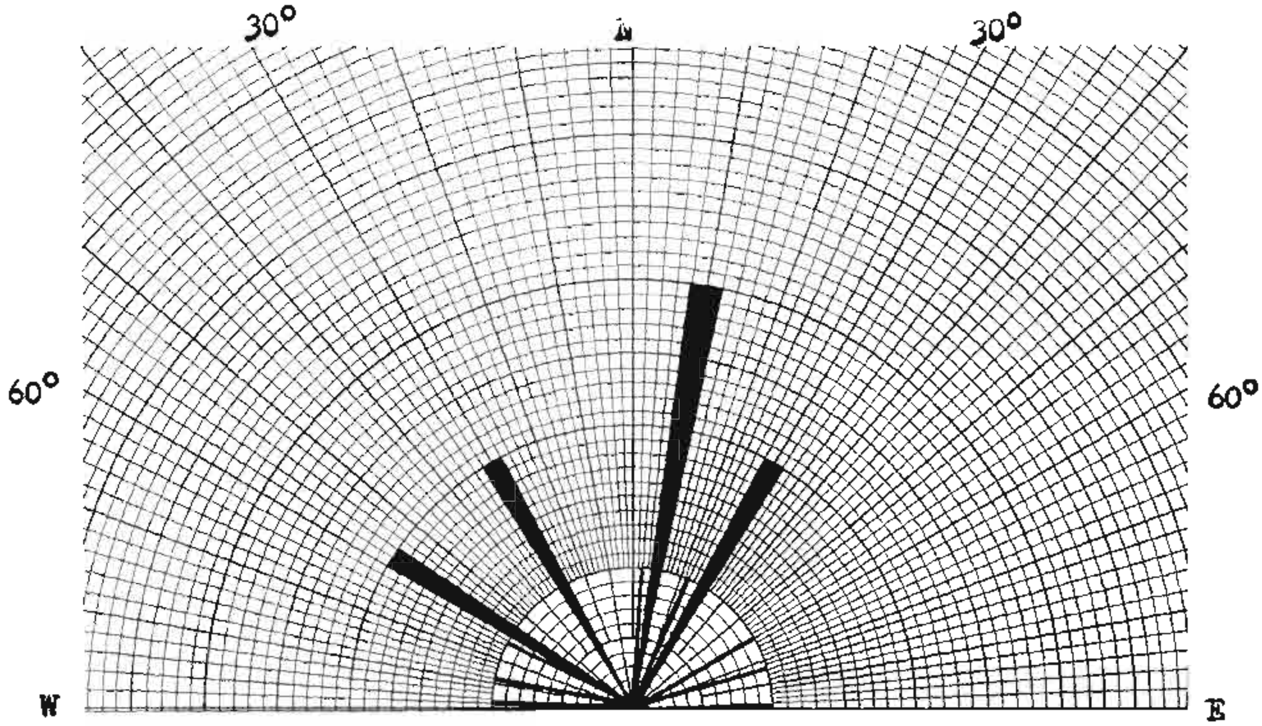
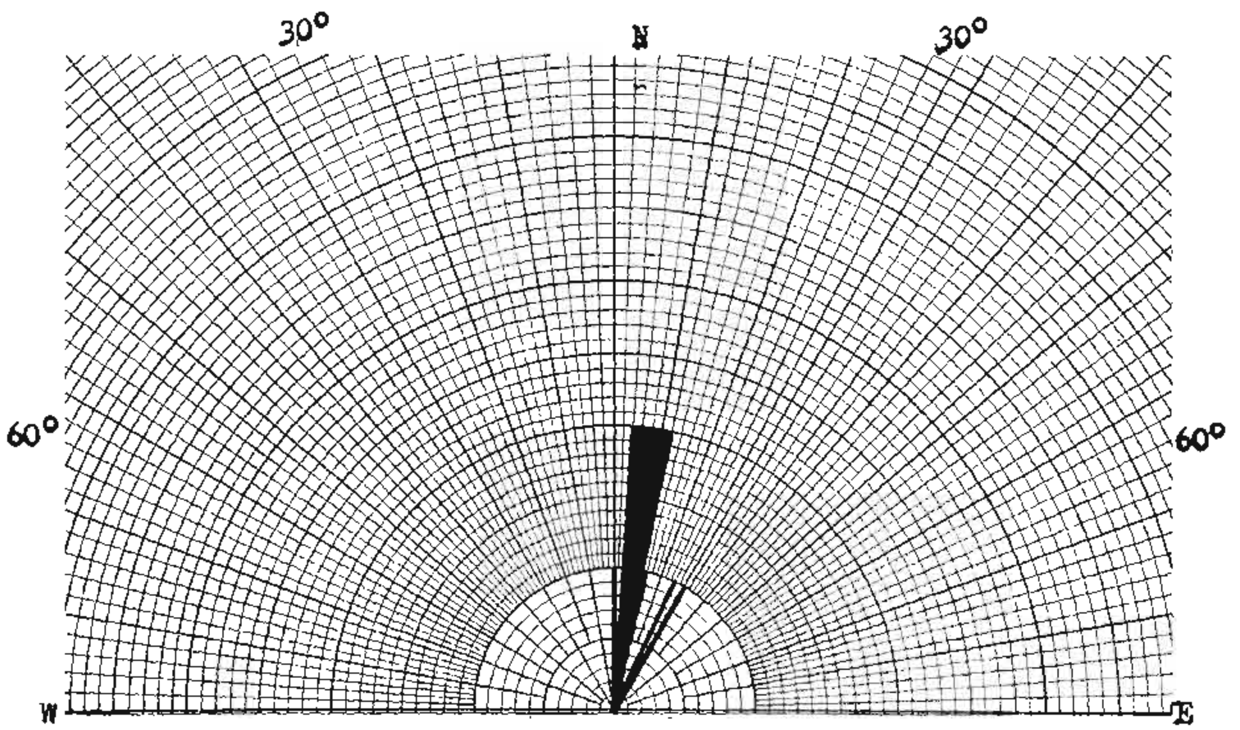


Fig. 1

Joint Diagram



Dike Diagram

Fig. 2

appear to form any definite pattern or system. However, those observed seem to be in harmony with the observations of Robertson, and are listed in Table 2.

Table 2 Observed Joint Sets in Rhyolite Porphyry

N 80-85 E
N 5-12 E
N 40-45 E
N 58 E
N 30-35 W
N 25 W

ECONOMIC GEOLOGY

Character of the ore deposits

Type of deposits

The mineralization at the Ozark and Martin mines, as well as that in the adjacent Apex and Einstein mines, represents a unique occurrence in the Mississippi Valley. At the Martin Mine, tungsten mineralization is associated with hydrothermal quartz veins characterized by intense wall rock alteration. The tungsten mineral present is wolframite. A minute quantity of argentiferous galena is also present. The wolframite at the Ozark Mine occurs disseminated throughout the brecciated tuffs, closely associated with topaz and sericite.

Wolframite, topaz, sericite mica, zinnwaldite and cassiterite are typical hypothermal minerals formed at great depths below the surface, or under conditions of high temperature and pressure. Zinnwaldite was not observed at the Martin or Ozark mines, but is present at the Einstein Mine in sec. 12, T. 33 N., R. 5 E., where the mineralization is of a similar type. Cassiterite was not observed by the writer, but is reported as occurring at the Einstein Mine by Singewald and Milton.[28]

Because of these associated minerals, the presence of

---

28. Singewald, J. T., and Milton, Charles, Greisen and associated mineralization at Silver Mine, Missouri: Econ. Geol., vol. 24, p. 586, 1929.

highly altered wall rock containing topaz, quartz, and sericite, and the location of the mineralizations in the pre-Cambrian area; it is quite reasonable to class the deposits as epigenetic, hypothermal, replacement veins.

Alteration

The metasomatic alteration of the wall rock may be ascribed to the process of greisenization.[29] The greisen is composed of quartz, topaz and varying amounts of sericite mica. The quantity of topaz and sericite indicate that mineralizing solutions, and perhaps vapors and gases, played a large part in the development of the altered wall rock. Topaz and sericite contain fluorine and water, and seem to require high pressure and the presence of mineralizers for their formation.

During the formation of the greisen, there seems to have taken place, an interchange of material between the country rock and the magmatic solutions. It would appear that the solutions had permeated the rock, introducing fluorine and water and removing whatever iron and alkalie elements were present.

Megascopically, the greisen resembles a dense quartzite. It is light gray in color, fine-grained and contains small particles of quartz.

---

29. Lindgren, Waldemar, Mineral Deposits, 4th Ed. (McGraw-Hill) p. 645, 1933.

Under the microscope, many of the quartz particles show secondary enlargement. This may have been due to the solution and redeposition of the original quartz contained in the rock, as well as the addition of silica from the magmatic solutions. The topaz has replaced the quartz, and at times forms an interlocking mass of subhedral grains. This interlocking of the topaz grains makes the rock very hard and brittle.

Mineralogy

Wolframite is a monoclinic mineral containing the feberite molecule ($FeWO_4$) and the hubnerite ($MnWO_4$) in all proportions between 20 percent $FeWO_4$ - 80 per cent $MnWO_4$ and 80 per cent $FeWO_4$ - 20 per cent $MnWO_4$. Hess[30] has limited hubnerite as not containing over 4.74 per cent FeO. An analysis of the tungsten mineral present in the deposits was given by Buehler[31] as containing 5.12 per cent iron oxide. This would place the mineral in the wolframite group, but with a relative large amount of the hubnerite molecule present. As the amount of iron and manganese may vary quite widely in a single deposit, or even in a single crystal, it is probable that much of the tunstate may actually be hubnerite.

---

30. Hess, F. L., Tungsten minerals and deposits: USGS Bull. 652, p. 22, 1917.

31. Buehler, H. A., Bienn Rept., State Geologist of Missouri: Mo. Bur. Geol. and Mines, p. 98, 1919.

The mineral is dark brown in color with a sub-metallic luster. At the Martin Mine it occurs in the quartz gangue in particles from microscopic size to crystals a few inches long. At the Ozark Mine, it occurs disseminated throughout the breccia in small particles. At times it seems to replace sphalerite and fluorite, but the majority is earlier than the sphalerite and later than the fluorite.

Galena (PbS) is more abundant at the Ozark Mine than it is at the Martin Mine. It occurs in small particles in the greisen and breccia at the Ozark, and is associated with the other sulfides. It is the latest mineral at both mines.

Sphalerite (ZnS) is present and resembles the wolframite in hand specimens. At the Ozark mine it occurs in irregular patches with irregular borders, and often includes relicts of earlier minerals. It appears to have replaced quartz and sericite more readily than topaz, and to be later than the wolframite. The sphalerite characteristically contains minute inclusions of chalcopyrite ($CuFeS_2$). However, chalcopyrite does occur in larger masses associated with pyrite and wolframite.

Large crystals of pyrite (FeS_2), several centimeters in diameter, were observed at the Martin Mine. It also occurs in irregular masses associated with the other sulfides. It is also present in smaller particles and in smaller amounts at the Ozark Mine.

Quartz (SiO_2) is the predominant gangue mineral at the Martin Mine. It is fairly coarse-grained, several crystals being observed which were over a centimeter wide and over two centimeters long. However, definite druse or comb structure is lacking. Secondary enlargement of the quartz at the Ozark Mine was observed. Two generations of quartz are present. The early quartz caused secondary enlargement of the quartz already contained in the rock, the late quartz filled fractures in the wolframite and breccia fragments.

Topaz ($Al_2(Fe,OH)_2SiO_4$) is the characteristic gangue at the Ozark Mine. Here the topaz has replaced the quartz, and other minerals so completely that the rock is practically all topaz. It occurs in subhedral to anhedral grains, the average size of which is approximately 0.06 mm. in diameter.

Sericite ($KAl_2(Oh)_2AlSi_3O_{10}$) is later than topaz. Sericite fills many interstices between the quartz and topaz and occurs in aggregates which are almost 1.0 mm. in diameter.

Fluorite (CaF_2) occurs as disseminated veinlets and patches, both at the Ozark and the Martin Mines. The veinlets are very irregular, and do not seem to replace the topaz. The purple color and cleavage of the fluorite may be seen in hand specimens.

Limonitic stains are present at both mines, resulting from the weathering of the sulfides containing iron, especially pyrite.

Scheelite, stolzite and ferritungstite were reported by Singewald and Milton[32] at the Ozark Mine, but were not observed by the writer.

Paragenesis

Insofar as was determined, the mineral succession at both mines is essentially the same. Quartz was the earliest mineral forming the bulk of the vein material. This was followed by topaz and sericite. The sulfides, pyrite and arsenopyrite were next. Fluorite deposition seemed to preceed the deposition of wolframite, which was followed by the chalcopyrite, sphalerite, and galena. A period of quartz deposition at the end of the series is indicated at the Ozark Mine, as it acts as a cement in the breccia.

Mineralizing Solutions

Source

Direct evidence as to the source of the ore-bearing solutions is lacking in the area. However, from the character of the deposits, it may certainly be said, that they are the result of ascending magmatic solutions.

There are several facts which may be of some consequence

---

32. Singewald, J. T. and Milton, Charles, Op. Cit. pp. 580-582

as to the origin of the solutions. No structures were noted in the granite which might have been formed during the flow stage, as the jointing observed throughout the area was undoubtedly formed in solid rock. The joints which trend northeast seem to have been tension joints, of which many were filled with basic injections. Several of these basic injections exhibit chilled borders, also indicating the granite was solid or cool when they were injected. The relationship between the dikes and the veins in sec. 12, T. 33 N., R. 5 E., definitely shows that the veins cut the basic dikes. It would seem, therefore, that there was a comparatively long time interval from the crystallization of the granite to the intrusion of the ore-bearing solution.

Because of the presence of greater quantities of fluorite in the Graniteville granite than in the Silver Mine granite, and the occurrence of fluorite in the veins, Tolman[33] states that the veins may be genetically related to the later granitic pluton to the north.

Perhaps it might be well for the geologists, with their limited surface exposures, not to theorize too quantitively on events that must be enormously complex; and to leave such work for the geochemist and the physical chemists.

---

33. Tolman, Carl and Koch, H. L., The heavy accessory minerals of the granites of Missouri: Wash. Univ. Studies, new ser., no. 9, pp. 46-49, 1936

Age

Mineralization such as that represented in the Ozark-Martin area is usually associated with granitic plutons, and in some cases, with pegmatitic occurrences. There has been no such granitic intrusion in the region since the Pre-Cambrian, as far as is known; and therefore the veins are considered to be pre-Cambrian.

Hypothermal deposits are thought to have formed at great depths below the surface, where high temperatures and pressures exist. It would seem, therefore, that at a time prior to the formation of the veins, there was an immense vertical section of rock above the present position of the veins.

It appears that such a thickness of overlying rock would more likely to have been present in pre-Cambrian time, as such a thickness of Paleozoic sediments in the area is unknown.

The veins are later than the basic intrusions, and as no indication of their relation with the La Motte has been observed, their definite age is obscure. It is believed that they are pre-Cambrian in age.

Description of the Mines

Ozark Mine

The Ozark Mine is in the center of the SE$\frac{1}{4}$, sec. 14, T. 33 N., R. 5 E., and may be reached by a wagon trail from the main road.

The country rock is a light colored rhyolite porphyry but in the immediate vicinity of the mine tuffs and breccias are present. The breccias appear to be secondary, as they are composed of fragments of the pyroclastics showing bedding planes, cemented by quartz, topaz, and sulfide minerals.

In the summer of 1927, the Ozark Tungsten Company sank a shaft through the iron-stained breccia surface rock. The incline strikes approximately S. 75° E. and dips 50° E.

At the time of investigation by Singewald and Milton[34] the depth was approximately 100 feet on the incline, and a drift had been driven N. 50° E. for a distance of 50 feet. The working places of the mine were in a gray siliceous rock with disseminated sulfides, and traversed by veinlets and irregular fractures filled with quartz, fluorite, and sulfides.

The sulfides identified by the writer occurring in the breccia are pyrite, chalcopyrite, galena, and sphalerite. The sphalerite is the most abundant of the sulfides. There also is a small amount of wolframite present in minute particles.

When visited by the writer, the mine was filled with water and was inaccessible. A small amount of tungsten was mined in the upper 45 feet of the gossan, the wolframite

---

34. Singewald, J. T. & Milton, Charles, Op. Cit., p. 572.

occurring in the matrix or cementing material of the breccia. The ore was concentrated at the Einstein mill. All production reports of the area are listed as being from the Einstein Mine.

Martin Mine

The Martin Mine is in the NE$\frac{1}{4}$NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 14, T. 33 N., R. 5 E., approximately 700 feet south of the main road.

The country rock is a purple rhyolite porphyry, the granite outcropping probably less than 150 feet to the north. Fragments of granite on the dump suggest that it was encountered in the workings. Fragments of a basaltic rock also were found on the dump which indicates that a basic dike was encountered underground.

At the time the mine was visited, the workings were inaccessible, being filled with water. The shaft is inclined S. 35° E. at an angle of 30°. The size of the shaft is about 6 feet by 10 feet.

The gangue is predominately quartz, with small amounts of fluorite, sericite, galena, sphalerite, pyrite, chalcopyrite, and arsenopyrite. The wolframite occurs as crystalline masses in the quartz from microscopic size to individual crystals several inches long. At times it is intimately associated with the sulfides.

There is no production record of tungsten ore from the Martin Mine.

Prospects

A prospect, known as the Hensen shaft, is in the NW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 11, about 650 feet north of the main road. It is essentially a vertical shaft with dimensions of 8 feet by 10 feet. There is very little material on the dump. It is mainly quartz, of which several large crystals were found. The weathered surfaces of quartz exhibit cubic voids from which the pyrite has been weathered away. Some of the quartz crystals are arranged roughly in a comb structure. A fragment of slickensided quartz was observed at this prospect, indicating post-mineral movement. There is a small pit approximately 50 feet N 30° E which shows a small amount of barren quartz.

In the SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 11, a small prospect pit appears to have been dug on a basic dike. No mineralization was observed, but many basaltic fragments are present on the small dump.

Two small vertical pits, which appear to be about 8 feet to 10 feet deep occur on the north side of the road in the SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 11. Fragments on the dumps indicate the presence of some pyrite, quartz, and chalcopyrite.

Another small pit in the SW$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 11, about 50 feet north of the road, shows very little mineralization and is full of water.

In a small ravine on the west side of Bald Knob in the SW$\frac{1}{4}$ SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 15, a small adit has been driven into the hill side. It has since caved and is covered by soil. At this localith boulders of diabase and syenite were found. The occurrence of these rocks in the rhyolite porphyry probably was the reason for the location of the prospect.

SUMMARY AND CONCLUSIONS

The area under investigation has, for some time, been of interest to geologists interested in the ore deposits of the Mississippi Valley because of the high-temperature tungsten veins found in the area. The detailed geologic map of the area is the main contribution resulting from the present investigation.

Petrographic descriptions of the granite and rhyolite porphyry concur with most of the previous work of the locality. An occurrence of syenite was observed for the first time on Bald Knob in the east center part of section 15. Petrographic characteristics are presented, which include the determination of the main amphibole of the rock as pargasite; here-to-fore undescribed from the area.

The occurrence of the diabase in the northeast corner of section 10 and in the northwest corner of section 11, is unique in the fact that it represents an essentially flat-lying injection of basic material into the granite. In the northeast corner of section 15, the outcrop of diabase appears to represent the top, or hood, of a stock. Such occurrences are not frequently observed, and none have previously been described in the area.

Evidence of some structural control of the mineralized areas, as observed on steroscopic photographs led the author to special investigation for such features. That the faulting is contemporaneous with, and perhaps overlaps the period of mineralization, is the belief tentatively held by the author.

BIBLIOGRAPHY

1. Bridge, Josiah, Geology of Eminence and Cardareva Quadrangles: Mo. Bur. Geol. and Mines, vol. 24, 2d ser., 1930.

2. Bridge, Josiah and Dake, C. L., Initial dips peripheral to resurrected hills: Mo. Bur. Geol. and Mines, 55th Bien. Rept. State Geologist, 1927-1928, app., pp. 93-99.

3. Broadhead, G. C., Report of State Geologist, 1873-74, pp. 348-367.

4. Broadhead, G. C. and Norwood, C. J., Geology of Madison County, Mo. Geol. Surv., Rept. on Field Work of 1873-1874, pp. 342-379, 1874.

5. Bucher, W. H., The mechanical interpretation of joints: Jour. Geol., vols. 28-29, 1920, 1921, 707-730, 1-28.

6. Buehler, H. A., Bien. Rept., State Geologist of Mo.: 1919 pp. 97-98.

7. Dake, C. E. and Bridge, Josiah, Buried and resurrected hills of the central Ozarks: AAPG Bull., vol. 16, pp. 629-652, 1932.

8. Dake, C. L., Geology of Potosi and Edgehill Quadrangles: Mo. Bur. Geol. and Mines, vol. 23, 2d ser., 1930.

9. Graves, H. B., Jr., The Pre-Cambrian Structure of Missouri: Trans. Acd. Sci. St. Louis, vol. 29, no. 5, 1938.

10. Haworth, Erasmus, Contribution to Archean geology of Missouri: Am. Geologist, vol. 1, pp. 280-297, 363-382, 1888.

11. Haworth, Erasmus, Crystalline rocks of Missouri: Mo. Geol. Surv., vol. 8, pp. 81-224, 1895.

12. Hess, F. L., Tungsten minerals and deposits: USGS Bull. 652, p. 35, 1917.

13. Kerr, P. F., Tungsten deposits of United States: Geol. Soc. Am., Memoir 15, pp. 201-202, 1946.

14. Keyes, C. R., A report on Mine La Motte Sheet, including portions of Madison, St. Francois, and Ste. Genevieve Counties: Mo. Geol. Surv., 1st ser., vol. 9, Sheet Report no. 4, pp. 4-124, 1896.

15. Leverett, Frank, Oldest (Nebraskan?) drift in western Illinois and southeastern Missouri in relation to "Lafayette gravel" and drainage and development (abstract): Geol. Soc. Am. Bull., vol. 35, no. 1, p. 69, 1924.

16. Robertson, Forbes, The igneous geology of the eastern Ironton and western Fredericktown quadrangles: Wash. Univ. unpublished thesis, 1940.

17. Ross, C. S., and Henderson, E. P., Topaz and associated minerals from the Einstein Silver Mine, Madison County Missouri: Am. Mineralogist, vol. 10, pp. 441-443, 1925.

18. Singewald, J. T. and Milton, Charles, Greisen and associated mineralization at Silver Mine, Missouri: Econ. Geol., vol. 24, pp. 569-591, 1929.

19. Tarr, W. A., The minerals of Madison County, Missouri: Am. Mineralogist, vol. 6, no. 1, pp. 7-10, 1921.

20. Tarr, W. A., A high-temperature vein in Madison County, Missouri (abstract): Geol. Soc. Am. Bull., vol. 34, no. 1, p. 99, 1923.

21. Tarr, W. A., Intrusive relationship of the granite to the rhyolite (porphyry) of southeastern Missouri: Geol. Soc. Am. Bull., vol. 43, no. 4, pp. 965-992, 1932.

22. Tolman, Carl, The geology of the Silver Mine area, Madison County, Missouri: Mo. Bur. Geol. and Mines, 57th Bien. Rept. App. 1, 1933.

23. Tolman, Carl, Volcanic activity in southeastern Missouri (abstract): Pan-Am. Geologist, vol. 65, no. 2, p. 160, 1936.

24. Tolman, Carl and Koch, H. L., The heavy accessory minerals of the granites of Missouri: Wash. Univ. Studies, new ser., no. 9, pp. 11-50, 1936.

25. Ulrich, E. O., Revision of Paleozoic Systems, Geol. Soc. Am. Bull., vol. 27, 1911.

26. Wilson, N. R., Review of the dressing works at the Einstein Silver Mine with a project for treating ore: Wash. Univ., Mining School, unpublished thesis, 1879.

27. Winslow, Arthur, Lead and zinc deposits: Mo. Geol. Surv., vol. 7, 2d ser., 1894.