PALEOMAGNETIC INVESTIGATIONS

IN THE ST. FRANCOIS MOUNTAINS

by

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INTRODUCTION

The determination of paleomagnetic properties has become a new parameter in the investigations and studies of the igneous rocks of Missouri. Probably the first paleomagnetic work on these rocks was that performed by John W. Allingham (1960) of the United States Geological Survey for the purpose of enhancing the interpretation of the aeromagnetic data available for Missouri. A few measurements were made and reported on by A. J. Franks (1959) of St. Louis University.

Under the auspices of a National Science Foundation Grant awarded to Washington University in 1959, an intensive paleomagnetic investigation was undertaken in order to determine the remanent magnetization characteristics of some of the Precambrian igneous rocks of the St. Francois Mountains of Missouri in an area centered in the Ironton and Fredericktown Quadrangles. This first grant was completed in November, 1960 (Hays, 1961; Scharon, 1960) while a second one for the purpose of continuing these investigations was awarded in March 1961, by the National Science Foundation.

PALEOMAGNETIC CONCEPTS

Magnetization is one of the most complex physical properties of a rock to investigate, for the net magnetization observed in a rock is, in general, the resultant of two components of magnetization. Each component of magnetization in the rock is unique in that it reflects the history of the Earth's magnetic field existing at the time that the particular component of magnetization was acquired.

Two basic components of magnetization in a rock, induced and remanent magnetization, are recognized. The fundamental distinction between these two components is that induced magnetization requires the application of an external field for its existance, while the remanent or permanent magnetization remains after the removal of the original magnetizing field.

Natural remanent magnetization -- The component of the remanent magnetization is acquired only when the applied field is increased above a critical value termed the coercive force. Above this force, the direction of magnetization in a single domain grain leaves the preferred axis and comes to rest along a new direction by virtue of having crossed over a magnetic barrier. In this case, when the magnetic field is removed, the newly acquired direction of magnetization does not return to its original position but retains its new position. The magnetization acquired by this irreversible process is a permanent or remanent magnetization.

In turn, the natural remanent magnetization of a rock may consist of several components corresponding to different events occurring during the rock's history, and the significance of the

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magnetization for applications such as the reconstruction of the Earth's magnetic field in the past can be fully accessed only after appropriate analysis.

It has been demonstrated by many investigators and well summarized by Cox and Doell (1960) that a rock may acquire a remanent magnetization parallel to the applied field by any one of several processes. These are: 1) isothermal remanent magnetization (IRM); 2) viscous magnetization; 3) thermoremanent magnetization (TRM); and/or 4) chemical magnetization.

There are cases in which the remanent magnetization is characterized by opposing directions of magnetization or simply a reversal of remanent magnetization. Two explanations have been presented: 1) that the Earth's magnetic field periodically reverses itself, and/or 2) that due to innate characteristics, the rock is able to become magnetized in a direction opposite to that of the magnetic field present and acting at the time the rock is magnetized.

Several mechanisms have been suggested whereby a rock might acquire a magnetization direction opposite to the ambient field. These are: 1) the presence of two magnetic constituents in a rock having different Curie temperatures which produce a magnetostatic interaction; 2) an exchange interaction across the common boundary of two constituents; and 3) self-reversal produced when cations migrate from a disordered to ordered distribution during cooling.

Other processes likewise affect the remanent magnetization. One is the anisotropy of the magnetic properties of minerals or magneto-crystalline anisotropy. Another, magnetostriction, is the effect of stress on magnetization. And finally, the influence of lightning on the intensity and direction of remanent magnetization. This is perhaps the best known single process affecting the remanent magnetization of rocks.

There is one final and important factor. Research in the field of rock magnetism has revealed that the magnetic properties of a rock are largely a function of the mineralogical and chemical composition of the rocks. In particular, the results of previous research have shown that the minerals of the $Fe0 - Fe_20_3 - Ti0_2$ system play the most significant role in rock magnetization and that the magnetic properties of a rock are directly related to the presence or absence of these ferromagnetic minerals in the rock.

GEOLOGY

The igneous rocks in the Ironton and Fredericktown quadrangles, an area typical of the entire 2,500 square miles of the St. Francois Mountains, are represented by extrusives and intrusives of felsite, a variegated series of granites, and a system of basic intrusives.

The felsites consist of a sequence of acidic flows, a series of interbedded pyroclastics, and a number of intrusive sill-like masses. Most of the felsites are rhyolitic in composition and are divisible into distinct sequences throughout the area. The felsite units commonly are so thick that more than two units are rarely observable on a single hill.

The granites are mainly exposed in the eastern two-thirds of the St. Francois Mountains. These granites consist of two groups which are closely related in mineralogical and textural characteristics. The granites are, in general, conspicuously free from dark minerals.

The basic rocks crop out in scattered localities as narrow dikes and small bosses. The rocks are gabbroic in composition varying from basalt to coarse-grained diabase.

The igneous rock units of the St. Francois Mountains have been delineated to a great extent; therefore, the classification proposed by Tolman and Robertson (1960) has been used throughout the investigations.

SAMPLE COLLECTION AND PREPARATION

Two hundred and forty-eight samples of the igneous rocks which crop out in the Ironton and Fredericktown quadrangles were collected for paleomagnetic investigations. Each sample was oriented in situ. After orientation, each rock sample was removed from the outcrop. At each outcrop, the attitude and character of the flow structure in the rock as well as megascopic mineralogical features, depth of weathering, and attitude of joint sets were noted.

From these 248 samples, 325 one-inch cylinderical cores were prepared. With the use of the remanent magnetometer of the Geophysics Branch of the U. S. Geological Survey, the following measurements were made: 1) direction and intensity of remanent magnetization, 2) magnetic susceptibility and direction of susceptibility anisotrophy, and 3) partial demagnetization.

It must be pointed out that one of the more important measurements made on the samples was that of partial demagnetization (Cox, 1961). Partial demagnetization of the sample is of interest in such an investigation because such a technique reduces the amount of scatter in the direction of magnetization without altering the mean direction of the thermoremanent magnetization. This allows for the determination of a more precise mean direction of remanent magnetization of a body. This is often of great interest in paleomagnetic work and further allows for a more intelligent interpretation of aeromagnetic maps.

RESULTS

The measurements of the magnetic susceptibility and the intensity and direction of remanent magnetization were made on the 325 cores prepared from the 248 samples of felsites, granites, and diabase exposed in the Ironton and Fredericktown quadrangles. These measurements show that the direction of remanent magnetization of these rock types, although somewhat variable, are significantly different from the direction of the present geomagnetic field in southeast Missouri. AC field demagnetization experiments were performed on 135 of the 325 samples. These experiments show that partial demagnetization in external fields of the order of 300-600 oersted greatly improves the initial scatter of the remanent magnetization.

VAN EAST GROUP

Stouts Creek rhyolite. — Sampling of the Stouts Creek rhyolite (indicated as Vs in accompanying tables) started at the Stouts Creek Shut-ins and was extended outward. Collections were made from outcrops on Grassy, Blankenship, Brown, Van East, Buford, Hogan, and Little Matthews Mountains. Although the appearance of the rhyolite varied somewhat over the collecting area, the samples were in general quite similar to the typical Stouts Creek exposed at the shut-ins. Most of the samples collected outside of the shut-ins have a reddish-maroon shade in contrast to the dark purple color of the typical Stouts Creek rhyolite. Exposures at all the sites exhibit a steep attitude of flow structure that is characteristic of the Stouts Creek Shut-ins exposures. Some of the exposures exhibit characteristics typical of flows. These structures have not only low angle flow structures but are often highly brecciated.

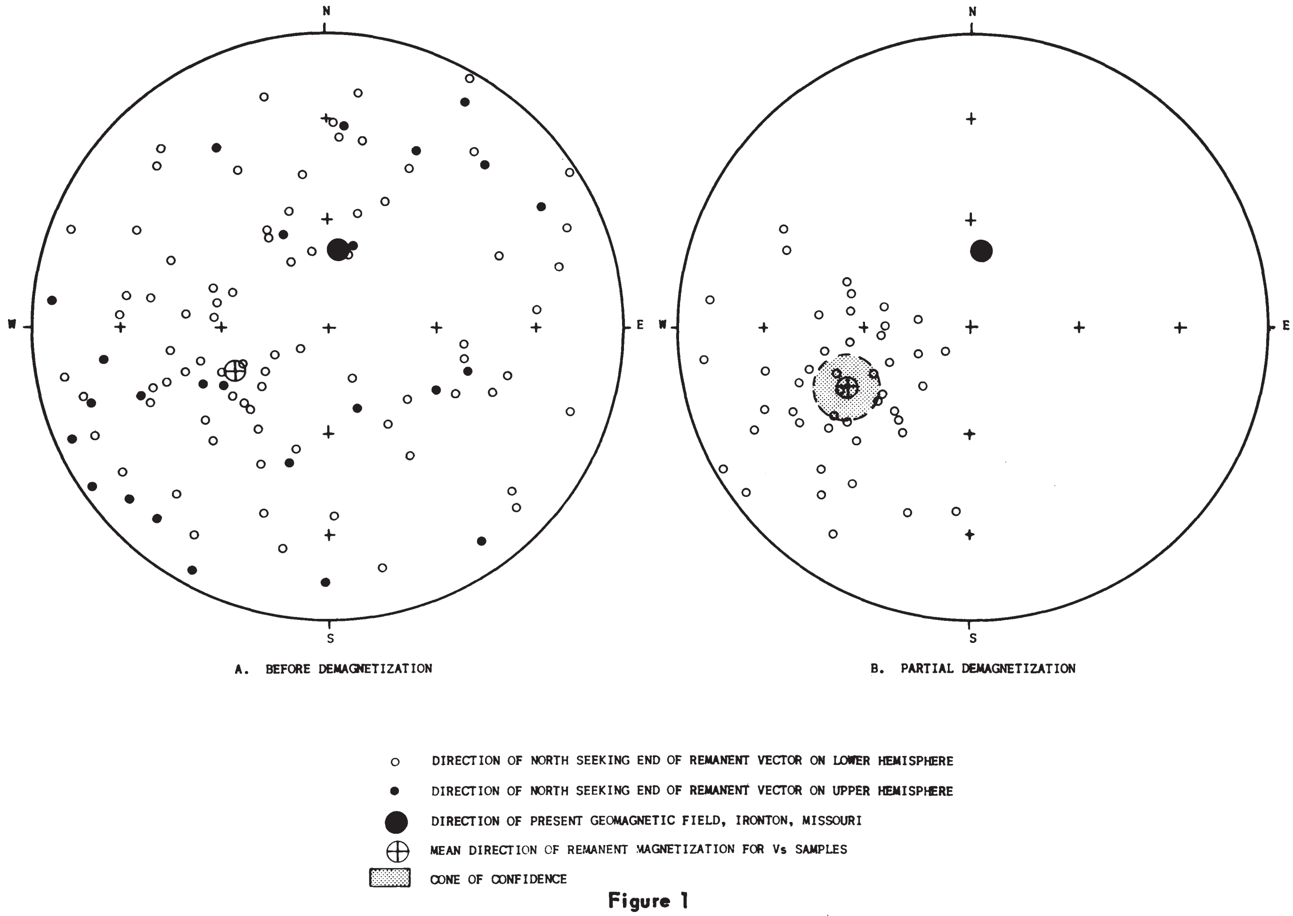
From this the Stouts Creek rhyolite can be divided arbitrarily into two groups: 1) intrusive rhyolite possessing a steep attitude of flow structure and containing magnetite as the predominate iron-oxide mineral, and 2) fragmental rhyolite displaying a gentler attitude of flow structure, containing hematite as the predominate iron-oxide mineral, and being virtually devoid of magnetite.

The directions of remanent magnetization for 106 Stouts Creek samples are shown in Figure 1A. The directions are widely scattered and show little tendency for grouping. Approximately one-third of the samples show reversed polarity. From this scattering, the mean declination and inclination and the cone of confidence as computed by Fisher's statistical technique are given in Table 1.

Table 1

Rock Type	Declination D_R	Inclination I_R	Cone of Confidence 95% Sig. Level
Vs intrusive	268° 20'	58°05'	23°11'
Vs fragmental	217° 20'	60°24'	33°29'
All Vs	244°45'	61°09'	19°31'
After demag.	243°25'	49°24'	8°55'

On 67 Stouts Creek samples, demagnetization experiments were performed which furnished a means of evaluating the stability of the samples as a group. These experiments show that most of the samples have an anomalous component of magnetization, and that in many cases the anomalous component is not removed by partial demagnetization. On the basis of these experiments, 46 Stouts Creek samples were selected as exhibiting the stability characteristics necessary for the determination of the true mean direction of magnetization. The direction of remanent magnetization and the cone of confidence of the selected samples are shown in Figure 1B as well as indicated in Table 1. The close grouping of the directions indicates the measure of improvement that partial demagnetization affords.



A. BEFORE DEMAGNETIZATION

B. PARTIAL DEMAGNETIZATION

Figure 1

Paleomagnetic results on Stouts Creek Rhyolite, Ironton – Fredericktown Quadrangles, Missouri.

Hogan Mountain rhyolite. -- Fourteen samples of the Hogan Mountain rhyolite (Vh) were collected over an area of 8 square miles in the vicinity of Hogan and Russell Mountains. Directions of remanent magnetization are extremely variable and widely scattered. Half of the samples exhibit a reversed direction of remanent magnetization, commonly with a low angle of inclination. Partial demagnetization experiments were performed on 8 of the samples indicating the presence of two components of remanent magnetization, a soft viscous component and a relatively hard component of thermoremanent magnetization. The Fisher's analysis for the Hogan Mountain samples (Table 2), provides a quantitative measurement of the scatter.

MIDDLEBROOK GROUP

The high degree of weathering in the available exposures limited sampling of Middlebrook (MBr) group. The greatest density of sampling was restricted to the felsites mapped as the Royal Gorge rhyolite in the vicinity of Cuthbertson Mountain. Seven samples were taken, and paleomagnetic measurements made. The scatter of the direction of magnetization was decreased for all but 2 of the samples by partial demagnetization. After demagnetization, a Fisher's analysis (Table 2) shows that the mean direction of remanent magnetization is very close to that of the Stouts Creek samples in spite of the small number of samples involved.

UNASSIGNED FELSITES

Eleven samples, 4 of which were ore, were collected from the andesite prophyry of Iron Mountain (IM). Partial demagnetization of these samples does not change the direction of remanent magnetization. In this particular case, the remanent magnetization properties of the ore samples are quite significant. They have a fairly constant direction, and all are strongly polarized with a remanent magnetization component of the order of 200-300 times greater than the induced component of magnetization. The Fisher's analysis of the mean direction of magnetization is shown in Table 2.

TAUM-SAUK-RUSSELL MOUNTAIN AREA

The felsite units exposed in the Taum Sauk-Russell Mountain area were not treated as separate units because of the large area covered and the small number of samples (26) collected and measured. Herein, the felsites are arbitrarily grouped together as the "T" group. A Fisher's analysis for the "T" group after partial demagnetization indicates that the mean direction of remanent magnetization is very significantly determined. The results (Table 2) are quite similar to those for the Iron Mountain samples and the Skrainka diabase discussed below.

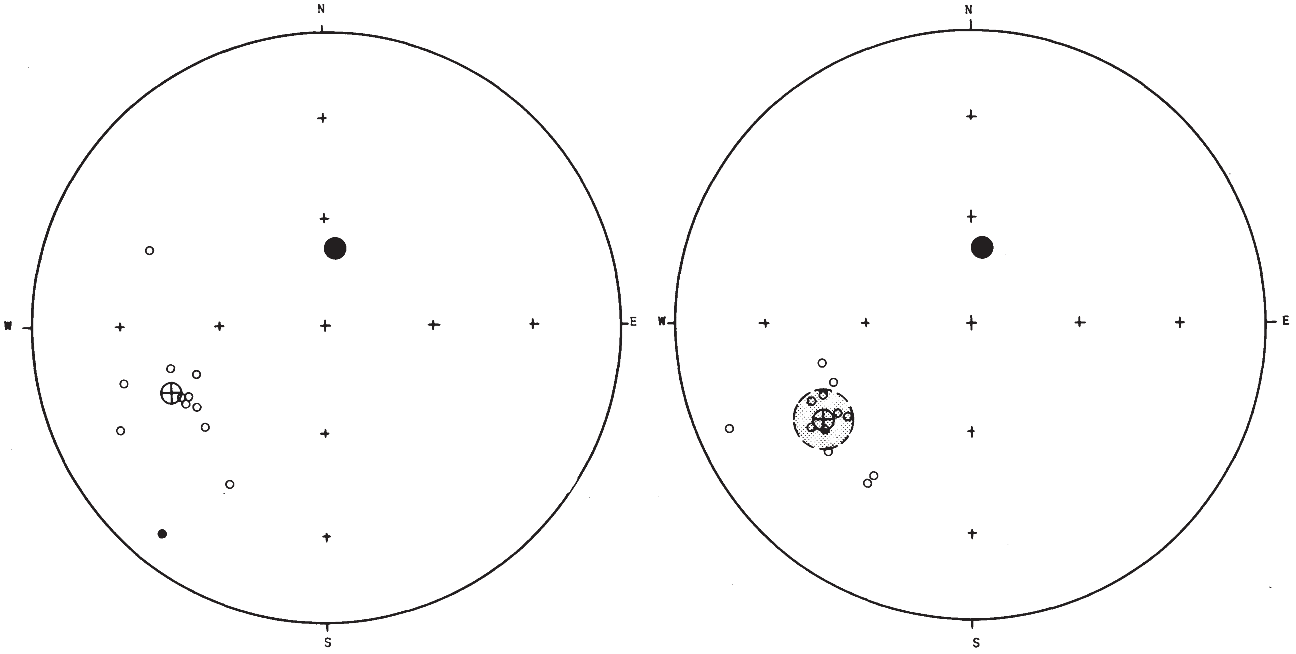
GRANITE UNITS

Although numerous granite exposures are available for sampling, the collection of samples for paleomagnetic measurements presents a problem. Granite outcrops are usually massive and are not well fractured. A typical granite outcrop is usually so highly weathered that it is sometimes difficult to collect fresh samples. In quarries, where fresh granite is exposed, a problem is posed because of the weak component of remanent magnetization.

Thirty-four samples were collected from exposures and quarries in the Ironton and Fredericktown quadrangles. These samples were distributed between 10 delineated units. No one unit was sampled in detail to provide an accurate determination of its mean remanent magnetization properties.. The directions of magnetization are quite scattered and exhibit both normal and reversed polarity. No calculation of the mean direction was made because such a calculation would be meaningless due to inadequate sampling.

SKRAINKA DIABASE

Nine samples of a shallow diabase body were collected from an inactive quarry on Skrainka Hill. In contrast to the felsite and granite rock units, the scatter of the directions of remanent magnetization in these samples is very small before demagnetization. Partial demagnetization indicates the presence of a very strong component of remanent magnetization which changes little in intensity and direction during such demagnetization. Figures 2A and 2B show the directions of magnetization, the mean direction of magnetization before and after partial demagnetization, and the cone of confidence. The values are also tabulated in Table 2.



A. BEFORE DEMAGNETIZATION

Figure 2

B. PARTIAL DEMAGNETIZATION

Paleomagnetic results of Skrainka diabase.

○ DIRECTION OF NORTH SEEKING END OF REMANENT VECTOR ON LOWER HEMISPHERE
• DIRECTION OF NORTH SEEKING END OF REMANENT VECTOR ON UPPER HEMISPHERE
● DIRECTION OF PRESENT GEOMAGNETIC FIELD, IRONTON, MISSOURI
⊕ MEAN DIRECTION OF REMANENT MAGNETIZATION FOR Sd SAMPLES
▨ CONE OF CONFIDENCE

Table 2

Rock Type	Par. Demag.	D_R	I_R	No. Samples	Cone of Confidence 95% Sig. Level
All Vs	No	244°45'	61°09'	106	19° 31'
All Vs	Yes	243°25'	49°24'	46	8° 55'
Vh	No	290°48'	31°48'	14	35° 51'
Vh	Yes	243°40'	42°30'	8	14° 45'
MBr	Yes	256°50'	37°35'	7	51°30'
IM	Yes	244°30'	58°00'	11	17°06'
"T"	Yes	250°00'	49°06'	26	12° 19'
Sd	No	246°40'	42°33'	11	10°58'
Sd	Yes	325°25'	39°37'	11	8°27'

VIRTUAL GEOMAGNETIC POLES

In paleomagnetic data, it is of significance to represent such data in terms of the geocentric dipole that would give rise to the measured direction of magnetization in the sample. This representation, when referred to the present magnetic poles of the earth, provides an estimate of the departure of the magnetic field in the past from the present configuration.

The mean, virtual geomagnetic, "North" pole positions of the various Precambrian rocks in the St. Francois Mountains were determined by a Schmidt, equal-area, stereographic projection. The mean directions and inclinations of the remanent magnetization data were used after the samples had been partially demagnetized. The mean positions are shown in Table 3 and are plotted on Figure 3.

Table 3

MEAN, VIRTUAL GEOMAGNETIC, "NORTH' POLE POSITIONS

Sample Group	Longitude	Latitude
Vs	151°30'W	2°N
Vh	149°50'W	2°N
MBr	158°48'W	6°12'N
IM	145°55'W	5o17'N
"T"	149°00'W	9°20'N
Sd	148°00'W	3°21'S

These data are actually a confirmation of the presence of a Precambrian geomagnetic "North" pole in the vicinity of 150° W longitude and 50° N latitude, placing the Precambrian geomagnetic pole in the vicinity of Christmas Islands in the North Pacific, a position that is very near the geographic equator.

GEOPHYSICAL SIGNIFICANCE

The similarity of the mean directions of remanent magnetization which results after partial demagnetization and the precision of the determination of the rhyolite felsite units (Stouts Creek rhyolite, Hogan rhyolite, and Royal Gorge rhyolite) suggests that these rock units are contemporaneous and possibly genetically related. The similarity of the mean direction of remanent magnetization for the andesite felsite at Iron Mountain and the Skrainka diabase suggests that these rock units are contemporaneous with the rhyolite felsites and that the formation of all five rock units probably represents a relatively short interval of Precambrian time.

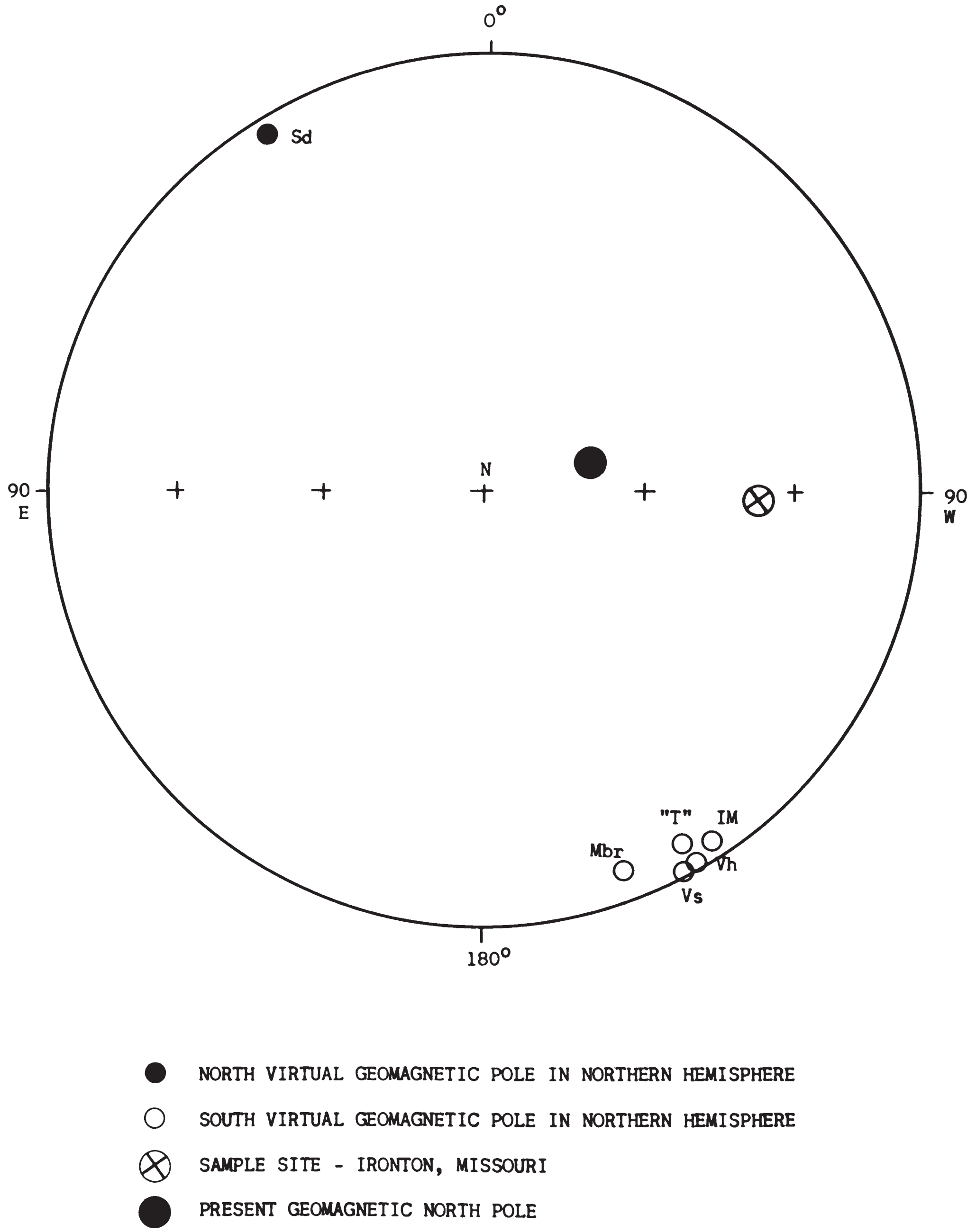


Figure 3

Precambrian pole positions as determined for various igneous rock types, Ironton-Fredericktown Quadrangles, Missouri.

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PHYSIOGRAPHIC FEATURES OF THE ST. FRANCOIS MOUNTAINS

by

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Precambrian igneous rock exposures of Missouri are limited to part of the area known as the Ozark Plateau (Fenneman, 1938) which is commonly referred to as the Ozarks. Fenneman's boundaries of the Ozarks are essentially coincident with those described by Marbut (1896, p. 16); however, the Missouri Geological Survey does not recognize the Springfield structural plain as being a part of the Ozarks. In this restricted sense, the Missouri Ozarks consist of the Salem Plateau and the St. Francois Mountains. Exposed Precambrian igneous rocks form the hills and knobs which make up the St. Francois Mountains in Iron, Madison, and St. Francois Counties and parts of Wayne and Reynolds Counties.

The St. Francois Mountains were named by Winslow (1896, p. 4). In them, there are many narrow, steep sided valleys with floors 500 to 700 feet below the tops of the igneous hills. The crests of the igneous hills are not as concordant as those developed on the surrounding Salem Plateau owing to the removal of the sedimentary rock cover which was widespread on the Precambrian basement; whereas, on the thick sedimentary cover of the Salem Plateau all the streams are flowing in sedimentary rock. These buried, but yet resurrected granite and felsite knobs (Dake and Bridge, 1932), are roughly conical or dome shaped and are often quite symmetrical.

DRAINAGE

The St. Francois Mountains are drained by tributaries of the St. Francis River which flows southward into Arkansas. The extreme southwest slopes of the St. Francois Mountains are drained by the Black River which flows southward into Arkansas and joins the White River. Some of the northern slopes of the mountain area are drained by Big River which flows northward to the Meramec River.

Most of the streams draining the area flow on the Paleozoic rocks which lie between the hills of igneous rock, and in a general way the stream courses follow older Precambrian valleys. Erosional terraces are present along many of the valley walls. Bonham (1948, pp. 142-153) has projected the profiles of many of the streams of the area and has thereby demonstrated the existence of at least ten erosion surfaces. The oldest and highest surface is regarded as the Tertiary peneplain of Keyes (1895, p. 9), Marbut (1896, p. 22), and Hershey (1901, p. 41). The next four younger surfaces are believed to be previously undescribed and are named surfaces I to IV in descending order. Below these are five still younger, well developed surfaces which are referred to Fisk's (1944) series of terraces.

In some places where streams flow on granite and felsite, they have eroded constricted canyon-like gorges referred to as "shut-ins" or "narrows". These shut-ins represent a feature of great scenic and recreational interest. Their origin has been referred to the superposition of the streams on the more resistant ridges of the Precambrian felsites. However, work by Bonham (1948) describes several erosional surfaces in the St. Francois Mountain area and refers the formation of the shut-ins to nick points developed on surfaces of erosion.

The nick point hypothesis was advocated by Penck (1924, 1925) and independently developed by Meyerhoff and Hubbell (1927, 1928). The hypothesis holds that when a region is elevated a stream forms rapids or falls near its mouth as a result of the increased slope and the rapids or falls gradually migrate upstream forming a nick point. The sides or walls of the rejuvenated

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valley retreat, and in many places terraces are formed that may be traced along the valley walls upstream to the nick point. Nick points, therefore, infer more than one cycle of erosion, and each nick point along a stream is the result of a separate cycle of erosion with the successive nick points forming a stair-step pattern in the grade of the stream. This step-like pattern prompted the invention of the name "treppen" for the concept of multiple erosion cycles.

One of the better known shut-ins is the Stouts Creek Shut-ins which is 2 miles east of Ironton on Missouri Highway 72 where the highway crosses Stouts Creek in the west-central part of Section 2, T. 33N., R. 4E., (Route Log 1). One reason for this particular shut-ins' widespread popularity is that it is so accessible. Lake Killarney, downstream from the shut-ins, has been constructed for recreational facilities in the area.

Johnson Shut-ins State Park (section 16, T. 33 N., R. 2 E.) may be reached via Missouri Highway 21 south of Ironton through Lesterville and then north on State Road M (Route Log 2B); or it may be reached by traveling State Road H west from Graniteville. The igneous rocks in Johnson Shut-ins consist of felsite, basalt flows, and tuff or ash beds. In some of these rocks, large pot holes have been developed by the swirling action of the water causing pebbles to erode holes into the normally very resistant rocks.

The Narrows, described by Keyes (1896, p. 86), located 2.5 miles west of Fredericktown in section 14, T. 33 N., R. 6 E., are situated where the Little St. Francis River has formed a shut-ins between Mt. Devon and Buckner Mountain.

A large and very long shut-ins occurs on the St. Francis River between Black Mountain and Marlow Mountain in sections 10 and 15, T. 32 N., R. 5 E. Colored photographs of this shut-ins have appeared in the St. Louis Post-Dispatch.

The Weiss Shut-ins at the south end of Van East Mountain (section 17, T. 33 N., R. 5 E.) is well noted for the native azaleas growing on the hill slopes. At Royal Gorge (south-central part of section 14, T. 33 N., R. 3 E.) Missouri Highway 21 has been constructed through the shut-ins providing fresh exposures of the Precambrian felsite and an excellent view of a typical shut-ins.

There are many fresh exposures of the granite along the St. Francis River, particularly in the Silvermine area where State Road D crosses the St. Francis River (section 12, T. 33 N., R. 5 E.). Upstream from the bridge, there are numerous large pot holes which have developed in the granite. Many of these pot holes are large enough to conceal an individual standing in them.

LIST OF SHUT-INS IN THE ST. FRANCOIS MOUNTAINS

Tp.	R.	Section	Name	Reference
31N	4E	N 1/2 NW 3	Crane	
32N	5E	10 - 15	Black	J. Connelly
32N	5E	NW19	Miller	J. Connelly
32N	5E	21	Durand	J. Connelly
33N	1E	E 1/2 3	Ottery Creek	Dake, p. 24
33N	1E	E 1/2 NE 10		Dake, p. 25
33N	2E	SW 16	Johnson	Dake, p. 24
33N	3E	NE 3		
33N	3E	9 - 10	Claybaugh	
33N	3E	SW NW 14	Claybaugh	
33N	3E	S_c 14	Royal Gorge	
33N	4E	SW N 1/2 2	Stouts Creek	Keyes, p. 86
33N	4E	2 - 11	Miller	

Tp.	R.	Section	Name	Reference
33N	5E	E 1/2 16	Little Rock Creek	J. Connelly
33N	5E	N 1/2 17	Weiss	J. Connelly
33N	5E	NW 33		J. Connelly
33N	6E	NE SE 14	The Narrows	Keyes, p.86
34N	2E	29 - 30	Shut-in Creek	Dake, p. 24
34N	2E	SE 35	E. Fork of Black R.	Dake, p. 25
34N	5E	33		
35N	1W	NE SW 24		Dake, p. 25
35N	1E	NE 13		Dake, p. 25
35N	1E	SE 22	Big River	Dake, p. 25
35N	1E	23	Big River	Dake, p. 24
35N	1E	SE SE 26		Dake, p. 25
35N	2E	3		Dake, p. 25
35N	2E	NE 13	Highway 21	Dake, p. 25
35N	2E	NW 17	James Creek	Dake, p. 25
35N	2E	SE SW 19		Dake, p. 25
35N	3E	S 1/2 18	Saline Creek	Dake, p. 24
35N	3E	SW 18	Cedar Creek, Highway 21	Dake, p. 25
36N	2E	SW_c35		

WEATHERING

Weathered surfaces of granite and felsite show contrasting features. The surfaces of the granite become typically smooth and rounded in the gross form, whereas the felsite surfaces are very sharp and angular. Weathering of the granite usually results in large areas of considerable thickness of decomposed granite or grus. In spite of a few exceptions, most granite outcrop areas do not contain continuous exposures because of the accumulation of grus. In many places, the granite has weathered to depths measured in 10's of feet before fresh rock is encountered. Some of the exceptions to this general rule are where large residual boulders are found that have been developed by weathering along joints in the granite. Perhaps the most famous of all localities where this feature is present is the site of the Elephant Rocks at Graniteville in Iron County. The formation of these residual boulders resulted from physical and chemical weathering along widely spaced vertical and horizontal joint planes. These weathering processes gradually widened the joints and rounded the corners and edges of the rock until large, rounded forms of granite now remain. Comparable weathering of the granite in the basin of Bear Creek (T. 27N., R.6E) and just west of Klondike Hill (T. 35 N., R. 5E.) also produced large, residual, granite boulders.

Most of this weathering has probably taken place since the end of the Paleozoic as there is little evidence that such boulders have been incorporated in the Paleozoic rocks deposited on the Precambrian surface.

Typically, felsite is complexly jointed and fractured, consequently the rock breaks down in small angular fragments at surface exposures. The residual fragments are seldom rounded or smooth, and the edges and corners are sharp. Only under the influence of stream action are felsite fragments found that are well rounded. Because of the very fine-grained texture of the felsites, they are more resistant to mechanical disintegration such as freezing and thawing than the granites of the region. Thus, in many areas, not only these angular fragments of felsite but also the outcrop itself displays an angularity which is quite distinctive from that of the granites.

Weathering along the joints in felsite has produced several interesting features. The "Pinnacles" (NE 1/4 SE 1/4 sec. 24, T. 33 N., R. 5 E.) are the result of weathering along vertical joints in felsite. Many of the rivers flowing over the felsites have developed steep cliffs and have accentuated the vertical jointing of the felsites. This is particularly well shown by the felsite porphyry "Columns" on Marble Creek near French Mills in the SE 1/4 sec. 21, T. 32 N., R. 5 E. Another feature produced by weathering along joints in felsite is known as the Devil's Toll Gate in section 8, T. 33 N., R. 3 E. The Devil's Toll Gate is on the Taum Sauk Trail of the St. Louis Council of the Boy Scouts of America. This feature has received its name because the pioneers were compelled to unload their long wagon trains and swing them around by hand in order to get them through the sharp turn of the passage. This is on the old Military Trail which was the only trail to the southwest during the pioneer days and led to what is now Arkansas and Indian Territory now known as Oklahoma. It is the "Trail of Tears" over which the army-deported Cherokees passed and died by the hundreds during this journey.

At the crest of Hughes Mountain, in the south-central part of section 28, T. 36N., R. 3 E., at an altitude of 1,200 feet, joints in the felsite have produced hexagonal columnar jointing similar to the organ pipe type of jointing developed in Devil's Tower, Wyoming. This type of jointing forms as a result of cooling of an extrusive lava flow, the joints being developed perpendicular to the cooling surface. This is one of the best examples of this type jointing in the St. Francois Mountains.

Mina Sauk Falls, on a tributary to Taum Sauk Creek (NW 1/4 NE 1/4 sec. 8, T. 33 N., R. 3E.) falls 132 feet in three cascades. It is sometimes called Evangeline Falls in reference to Longfellow's famed poem "Evangeline". The flow is intermittent, and the most spectacular view is in April and May when the volume of water is generally at a maximum.

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NOTES ON THE GEOLOGY OF THE TAUM SAUK AREA

by

R. Ernest Anderson [1] and H. LeRoy Scharon[2]

INTRODUCTION

The Precambrian rocks of southeastern Missouri comprise an igneous complex which is characterized by several thousand feet of extrusives overlying and surrounding numerous high-level granite intrusions, the sum of which attains batholithic proportions. This report concerns only a restricted portion of the volcanic sequence exposed in the vicinity of Taum Sauk Mountains.

Among the specific problems which have concerned geologists working in the Missouri Precambrian, detailed volcanic stratigraphy and structural geology have received the least attention. The neglect of these two very important disciplines has given rise to some doubtful correlations and improbable structural relationships on several geologic maps. Geologic mapping in several volcanic provinces such as the British Tertiary, central Nigeria, southern Sumatra, and Oslo, Norway, has revealed extreme structural complexity which, when worked out in detail, evolves into simple structural patterns. Similarly, simple patterns can be recognized in the Missouri Precambrian, if the structural details are carefully mapped. To this end, a large body of structural data has been assembled. Many of these data are meaningless at the time of this writing because they have been collected over a broad areal extent in the course of the geologic study which complimented the paleomagnetic investigation of Scharon, Hays, and Anderson the results of which are published elsewhere in this guidebook. However, detailed field mapping is in progress at present with the principal emphasis being placed on structural geology, and this report may be considered a statement of progress on the Taum Sauk area.

The area is situated along a line extending westward from Vail Mountain, which is 3 miles southwest of Ironton, to the north end of Proffit Mountain which is located in the northeast corner of Reynolds County. It is an area of about 12 square miles and includes portions of Vail, Russell, Taum Sauk, Wildcat, and Proffit Mountains.

Most of the rocks comprising this east-west strip are acid volcanics. According to the Precambrian Geologic Map of Missouri compiled by the Missouri Geological Survey (1960), the volcanics are divided into two units. The eastern third is mapped as the Stouts Creek rhyolite and the western two-thirds as the overlying Hogan felsite, both of the Van East group. A very persistent tuff horizon separates these two units in the Taum Sauk area. The present investigation has revealed the presence of several distinct flow units within both the Hogan felsite and the Stouts Creek rhyolite. The individual flow units are also separated by tuffs and do not differ from one another in any important way. For this reason, it will be necessary to make a finer division and redefinition of the recently accepted flow sequence. This is not attempted in the present writing.

We wish to gratefully acknowledge the total financial support of the National Science Foundation which has made this study possible through a grant awarded to the junior author.

PETROLOGY

In previous investigations, it has been possible to distinguish petrologic units within the

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fine-grained, acid volcanics of the Missouri Precambrian on the basis of large numbers of chemical analyses. The very subtle differences are scarcely reflected in the mineralogy, and, thus, similar distinctions are rendered difficult by petrographic methods and are virtually impossible to make in the field. For this reason, we have relied heavily on the variations in primary structures and textures for the mapping of individual units.

A complete petrologic description of the volcanic sequence recognized to date is not presented here. It is necessary and instructive, however, to define the principal characteristics of a typical flow unit. Such a unit may have a thickness from a few tens of feet to several hundred feet. The base is typically a porphyritic felsite characterized by the intense development of flowage structures. Megascopically, these structures appear as thin, delicate, closely spaced, subplanar fluxion bands which have an attitude parallel to the base of the unit. Microscopically, they appear as minute comb-structured veinlets with feldspar borders and quartz centers. They are typically less than 1.0 mm in thickness and may measure as much as a meter in the plane of flowage where they have a subcircular form. They generally persist far up into the unit where they become much reduced in their long dimension and less abundant. Coarser eutaxitic structures commonly occur with the delicate fluxion bands. The eutaxitic structures are typically one-half to a few centimeters in thickness and may be over a meter in length near the base of a unit, but they become shorter and more pod-shaped upwards. If they persist to the top of the flow unit, they are often practically ovoid in form. They are filled with a fine-grained, granitoid, quartzofeldspathic aggregate which generally bears most of the accessory minerals contained in the rock. These structures are believed to be deformed gas or liquid cavities contained in the primary flow, whereas, the finer fluxion structures are believed to be a product of some crystallization phenomena produced in the partially cooled groundmass by flowage stresses. The typical unit grades upward into a porphyritic, welded tuff which generally lacks the above structures but may be distinctly trachitic. Finally, the top of a unit is composed of a bedded tuff which lacks flowage features and phenocrysts.

The flow units, which are several hundred feet thick, possess a very pronounced deformation pattern throughout most of their medial portions. Folds range from open types to complex contortions, typical of plastic deformation. Fractures are very rare. The deformation is always confined within the undeformed boundaries of the unit. The fold axes are generally parallel to the strike of the unit boundaries, and where subsidence has occurred the axes are parallel to the boundary faults as discussed below. The deformation occurred after the planar features were developed and before consolidation and are interpreted as a response to gravity forces acting on a body which had its laminar flow impeded by partial consolidation.

Numerous variations from the typical flow unit, thus defined, are recognizable. For example, the upper portion of one unit is highly fragmental and more closely resembles an ignimbrite than a tuff. In spite of such variations, the similarities are extensive enough to bear significance. First of all, the consistent structural changes from base to top within each unit suggest that the units did not build up slowly but, instead, resulted from rapid individual outpourings that were capped by tuffs. Secondly, they record some sort of a recurring cycle of extrusion which began with the outpouring of large volumes of volatile-rich material and ended with a more passive effusion which produced layered and bedded tuffs. Thirdly, some knowledge of the scale of individual erruptions can be derived. One of the flow units which crops out on Taum Sauk Mountain is at least 500 feet thick and has been traced almost continuously to the west-north-west where it crops out on the unnamed knob northwest of Lindsey Mountain, a distance of 11 air miles. In this distance, the unit retains a constant thickness and internal character. Such a unit, which is not the thickest in the sequence, must represent several cubic miles of erupted material.

STRUCTURE

The most distinctive structural feature within the area is a large south to southwest dipping block of layered volcanics that extends from Russell Mountain westward to Proffit Mountain.

The eastern part of this block dips 15 degrees to the southwest thereby exposing the truncated edges of the layered sequence on the north-facing spurs of Taum Sauk Mountain. At least 2,500 feet of volcanics, composed of no less than six distinct flow units, are exposed from the top of Taum Sauk Mountain to the southern slope of Buck Mountain. The western part of the block which is exposed on the north end of Proffit Mountain dips very gently to the south and exposes only the upper 1,000 feet of the sequence. Several small faults of minor displacement cut the block in this vicinity.

The eastern one-third of the area is composed of the upper units of the western block together with other units which have been faulted or intruded into a complex relationship.

At least two generations of faulting are recognized; an earlier Precambrian faulting of volcano-tectonic nature, and a later purely tectonic faulting of regional character and probably also of Precambrian age. The earlier faulting produced two fault systems striking N. 70° W. and N. 10° to 20° E. with steep dips. They form the boundaries between subsided and deformed blocks such as the central parts of Vail and Russell Mountains. In every case, the faults are completely healed and, therefore, have little effect on the topography. The fault zones generally resemble intrusive breccias with a fragment to matrix ratio which is low in the central part, increases outward, and takes the form of simple net veining at the margins of the block. The matrix and fragments are both rhyolitic in composition. There is some doubt as to whether these fragmental phases truly represent fault intrusions, or whether the matrix material is simply the mobilized borders of the unconsolidated, subsided blocks.

One of the principal features of this earlier deformation is the fold pattern displayed by the subsided blocks. As an example, the upper part of Russell Mountain is composed of a delicately banded, intensely folded, granophyric rock. Near the south and west boundaries of the block, the folds are open with axes which tend to parallel the boundaries. The central part is more intensely folded into isoclinal folds and complex contortions. Where the unit is highly contorted, it has a total exposed thickness of 500 feet. In contrast, it only has a thickness of about 150 feet directly west of Russell Mountain where it makes up part of the layered sequence mentioned above. On the basis of these and other facts, it is concluded that the unit was originally a very incompetent, layered volcanic which was deformed by gravity sliding into the central part of a subsiding block.

The second generation of faulting has produced steeply dipping systems with many different attitudes some of which are N-S, N. 35° E., N. 65° E., and N. 60° W. The larger faults have produced breccia and alteration zones several hundred feet in width. These larger zones commonly contain mylonite and fault gouge together with massive quartz veins which attain thicknesses of several feet. In general, the topography and vegetation is strongly influenced by the faults of this generation. The displacement on the faults seldom exceeds a few tens of feet, although in the eastern part of the area it may be much greater.

EXPLORATORY DRILLING AT UNION ELECTRIC'S TAUM SAUK PROJECT

by

Richard P. O'Brien[1]

The project is located on the East Fork of the Black River at Proffit Mountain, about 100 miles south of St. Louis, Missouri. Proffit Mountain is the termination of a ridge extending southwesterly from Taum Sauk Mountain, the highest point in Missouri. This ridge is a southwest prong of the St. Francois Mountains, which is the structural center of the Ozark uplift.

The region has been dissected to early maturity and consists mainly of peaks and ridges of Precambrian rhyolite porphyry and granite porphyry, with Cambrian and Ordovician sediments and recent alluvial deposits occupying narrow valleys between them. Relief in the area is great, varying from 200 to 1,000 feet; a necessity for this project. There are no known faults in the immediate area.

The preliminary borings were carried out as part of a cost study, prior to the actual decision to construct the project. This preliminary drilling program was laid out by Dr. F. A. Nickell, the consulting geologist on the project, and was designed to secure a maximum amount of information from a minimum number of drill holes.

The planned program consisted of 14 drill holes located at points on the major features of the project (Fig. 1) as follows:

Feature	No. Holes	Depth	Comment
1. Lower Dam	2	75'	On axis, abutment at flowline
	1	50'	Axis, valley center
2. Power Station Tailrace	3	80'	Evenly spaced along channel to grade.
3. Power Station	1	125'	Hillside of suggested excavation location.
4. Tunnel Line	4	250'	3 at equal intervals on slope on centerline, and one in saddle.
5. Intake Shaft	1	700'	Angle hole, full depth of 55° shaft.
6. Upper Reservoir	2	50'	Floor of reservoir, in regard to seepage if unlined.

This program was carried out during the fall and winter of 1959 under the supervision of Sverdrup and Parcel and Associates, Incorporated, the consulting firm retained by Union Electric to make the cost and feasibility study. The information obtained is summarized as follows:

1. The lower dam location, which is a water gap cut through a rhyolite porphyry ridge by the East Fork of the Black River, appeared to offer excellent foundation conditions for any type of dam. Bedrock, consisting of practically unweathered rhyolite porphyry, was visible on each side of the stream at the abutment locations. One hole was drilled, instead of the 3 planned. This hole was on a gravel bar near the center of the rock gorge, the stream having meandered to the east side. The log showed 20 feet of alluvial sand and gravel, then solid unaltered rhyolite porphyry. This was a churn drill hole.

2. The power station tailrace location, running some 1,400 feet across the valley floor, from

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[1] Field Engineer, Sverdrup and Parcel and Associates, Incorporated.

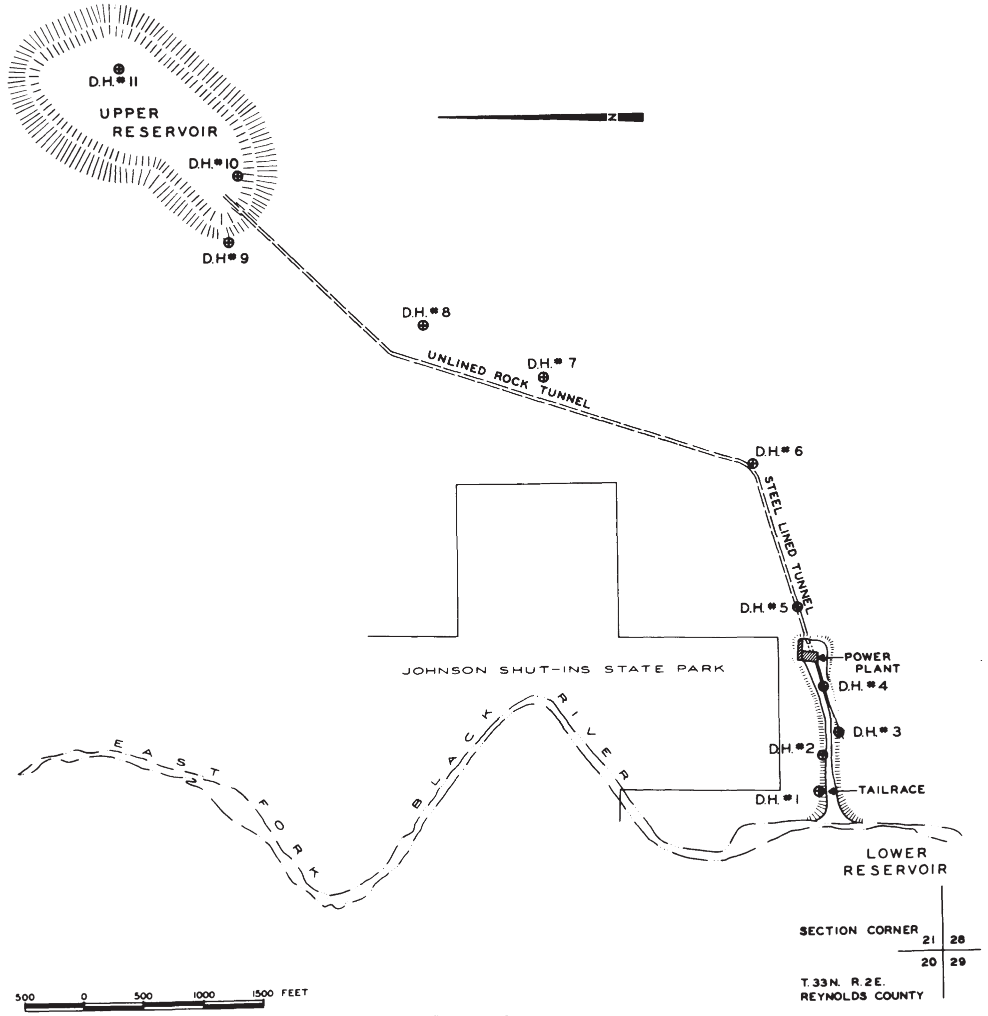

Figure 1

Plan view of Taum Sauk project showing the location of the exploratory drill holes.

the power station location at the base of the mountain to the river, appeared to offer no serious excavation problems. The logs of the 3 holes spaced evenly along the centerline showed an average depth of sandy clay and gravel overburden of about 30 feet. Below this, the bedrock consisted of the Bonneterre formation, the basal Cambrian formation at this location. These holes were sunk with churn drills, to depths of 66, 75, and 95 feet respectively, and they were all bottomed in the Bonneterre formation.

3. The hole at the power station location was a diamond drill hole, cored NX. The log showed 6.5 feet of sandy clay and gravel overburden, and the hole was bottomed at 98 feet and was still in the Bonneterre formation. This formation would have provided excellent foundation material for the power station.

4. The 4 holes drilled on the tunnel centerline were all diamond drill holes, cored NX. Pressure seepage tests were made at 10-foot intervals, applying 200 psi for 10 minutes and metering the water loss, to obtain some indication of the permeability of the formations through which the tunnel would be driven. Information gained from the

Missouri State Geological Map of the area, plus field reconnaissance, had indicated that a broad granite porphyry dike or knob made up the southern tip of the rhyolite porphyry ridge, of which Proffit Mountain, the location of the upper reservoir, was a part. Thus, this granite porphyry knob occupied a position between the power station and the upper reservoir location, a distance of some 6,600 feet.

The information yielded by the drill holes verified this, and indicated that the major portion of the water conveyance tunnel would be in this granite porphyry. The cores further indicated that the rock was quite massive and would probably have excellent tunneling characteristics. The pressure tests showed negligible water losses, indicating that no lining would be necessary in the major portion of the tunnel.

The first 2 drill holes on the tunnel centerline were #5 and #6. Hole #5 penetrated the Bonneterre formation and was bottomed at 197 feet in rhyolite porphyry. Hole #6, some 1,250 feet farther along the tunnel centerline, was bottomed at 250 feet in granite porphyry all the way down. The contact between the granite and the Bonneterre was, of course, somewhere between the two holes (Fig. 2). This simply meant that the first 800 to 1,000 feet of tunnel would have to be driven through the Bonneterre formation and probably some rhyolite porphyry, as the contact between the two is extremely irregular. It was not deemed necessary to locate the contact between the granite and the other formations any closer than this.

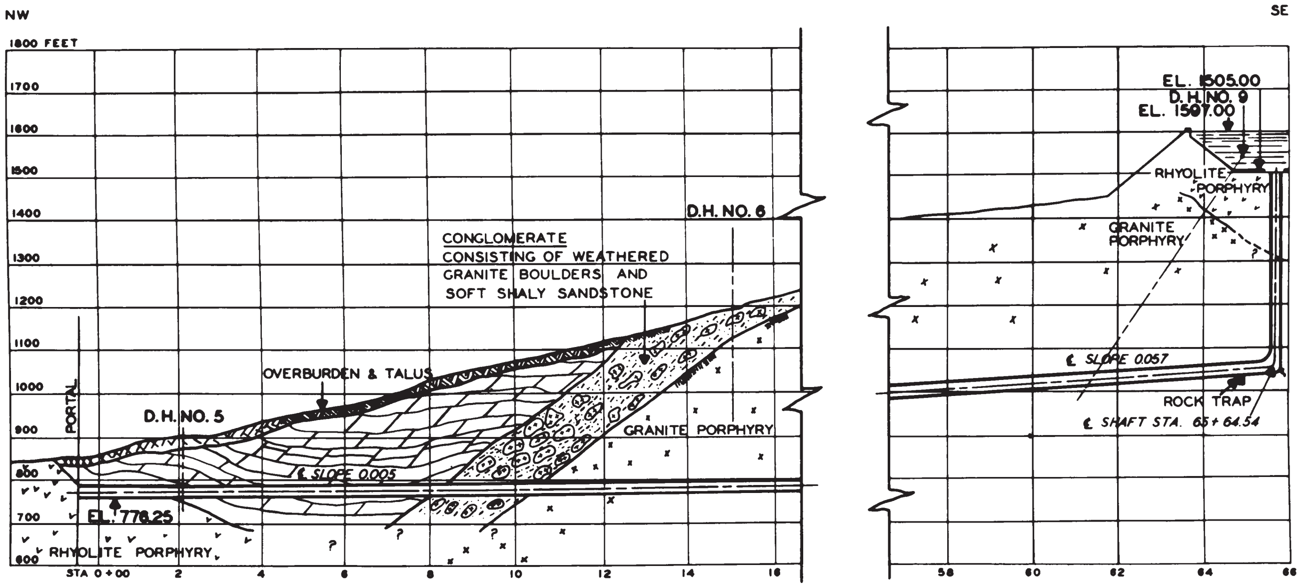

Figure 2

Profile of Taum Sauk Tunnel showing a cross section of the geologic structure and rock types.

5. The shaft connecting the upper reservoir and tunnel was at this time planned as a shaft 700 feet deep inclined 55 degrees from the horizontal. Accordingly, Hole #9 was diamond drilled at this angle to an angular depth of 700 feet. This hole was started NX in size and gradually reduced to AX with increasing depth. The core showed 165 feet of rhyolite porphyry at the top, then passed through a contact zone into granite porphyry and was bottomed at 700 feet in granite porphyry. The cores from the rhyolite porphyry and the water pressure tests in this area indicated strongly that the part of the shaft located in the rhyolite porphyry would have to be lined. Preliminary estimates took this contingency into consideration.
6. The two 50-foot NX diamond drill holes drilled in the upper reservoir are #10 and #11.

The cores and pressure seepage tests indicated that the rhyolite porphyry was jointed or fractured very extensively, and its permeability was very high due to closely spaced joints or fractures. Thus, the upper reservoir would undoubtedly have to be floored with an impervious cover over the rhyolite porphyry bedrock to prevent excessive leakage.

These two holes showed an overburden depth of about 10 feet, but there were also many outcrops of rhyolite bedrock visible in the reservoir area, and it was concluded on this basis that no large amounts of overburden would have to be stripped. This conclusion was in error, as was discovered during the secondary drilling program.

The results of the preliminary drilling program showed clearly that the project was quite feasible from a geologic standpoint. Also, that in view of the uncomplicated geology of the site, not too extensive a secondary drilling program would be required to begin actual design of the project.

The secondary drilling program was started during the spring of 1960. Meanwhile, the decision to construct the project had already been made on the basis of the preliminary borings, and the construction contract had been let. The sêcondary drilling program was then carried out simultaneously with the first construction operations.

The areas in which more detailed information was desired, were the shaft location, upper reservoir, and lower dam. It was felt that in other areas of the project, not enough additional useful information could be gained relative to the high cost of diamond drilling to warrant further exploration.

1. On the upper reservoir site, 10 additional NX diamond drill holes were put down. The holes located in the floor area of the reservoir were taken to Elev. 1,500, well below the proposed floor elevation, and pressure seepage tests were made on these holes. The holes in the rockfill dike area were all carried to a depth of 50 feet into bedrock. When it became evident during the drilling of these holes, that substantially greater depths of overburden were being encountered than had originally been anticipated, the drilling program was implemented by a series of 14 test pits dug by bulldozers, and distributed at strategic spots between drill holes over the 50-acre area. Also all visible bedrock outcrops were located by surveying and elevations taken on them.

   When all the data from this program was assembled and correlated, a rock contour map was drawn of the upper reservoir area. This was then compared with the aerial contour maps and it became evident that the overburden depth over the area as a whole was about twice that anticipated.

   In addition, it became evident that there was an area of very deep overburden and mass kaolinization of the rhyolite porphyry on the west side of the reservoir area.

The results of the pressure tests demonstrated conclusively that it would be necessary to have an impervious floor in the reservoir.

After all factors were taken into consideration, it was decided that the extra overburden, while troublesome, would not be prohibitive, and that a design change in the shape of the reservoir would avoid most of the deeply weathered area. Since the impervious floor had already been included in the estimate, the location was approved for construction of the reservoir.

2. The intake shaft design had been changed from a 55 degrees inclined shaft to a vertical shaft on the advice of several tunnel contractors. A vertical diamond drill hole, NX in size, was then sunk at the new tentative shaft location which was some 400 feet northeast of the 700-foot inclined hole location and in a direct line away from the previously encountered contact of the rhyolite porphyry and granite porphyry. This hole was cored

all the way to a depth of 217 feet, but the contact was not found, indicating that the contact must be dipping rather steeply to the northeast (Fig. 2). The cores also showed that the rhyolite porphyry even at this depth was very closely jointed, and that the portion of the shaft sunk in the rhyolite porphyry would have to be lined as had been anticipated from the initial boring program. Pressure seepage tests made in this hole further confirmed that lining of the shaft in the rhyolite porphyry would be necessary.

3. The lower dam site appeared to offer few, if any, problems as far as foundation conditions were concerned. However, two 50-foot NX diamond drill core holes were sunk on the dam axis at the abutment locations on each side of the rock gorge. Pressure seepage tests were made at 10-foot intervals in these holes.

The cores from these holes indicated that although the rhyolite porphyry here had a closely spaced vertical joint system, it was not altered at all by weathering and was very hard, sound, dense rock. The hardness was such that it required 30 new NX diamond bits to drill each of the 50-foot holes. The pressure seepage tests indicated that a grout curtain cut off below the dam and around the abutments was absolutely necessary to avoid excessive leakage. The type of dam finally decided upon for this location was a concrete gravity, overflow structure. No foundation problems were anticipated, and none have come up as of this writing, when 50 percent of the foundation excavation has been completed.

Since the completion of the secondary drilling program in the summer of 1960, construction has proceeded on the project to the point where it is nearing completion as regards major excavations for the main features. No major deviations in the geologic conditions as anticipated from the exploratory drilling programs has occurred. A minor change in the tunnel alignment and lined portion was occasioned by the discovery of a basal conglomerate between the Bonneterre formation and the granite porphyry that was not shown by the drilling program (Fig. 2). A slight change in location of the power station higher up on the flank of the mountain resulted in the power station foundations being in rhyolite porphyry instead of in the Bonneterre.

During the overburden stripping operations in the upper reservoir area, the contact between the rhyolite porphyry and the granite porphyry was uncovered. Evidence was found that clearly indicated that the rhyolite had flowed out on the weathered surface of the granite, scorching and baking it. This indicates that at least at this location the granite prophyry is older than the rhyolite porphyry and is not intrusive into it contrary to some earlier speculations on this question.

It is believed that the exploratory drilling program carried out in two phases at Taum Sauk has been successful in that the geologic conditions predicted by the program agreed quite well with what was actually encountered during construction.

No unanticipated problems of a major nature have been encountered, and all necessary geologic information has been gained with a minimum expenditure of time and money.

A BRIEF DESCRIPTION OF PILOT KNOB

by

Clayton H. Johnson[1]

Pilot Knob is located in the St. Francois Mountains in the S-1/2 sec. 29, T. 34 N., R. 4 E., about one mile north of Ironton, the county seat of Iron County, Missouri. It is also about five miles south of Iron Mountain, where iron ore is presently being mined, and one mile east of the village of Pilot Knob. Sporadic prospecting and mining have marked the history of Pilot Knob from 1835 to the present.

Pilot Knob is a nearly circular, cone-shaped mountain which is approximately three-fourths of a mile in diameter at its base. Its altitude is about 1,500 feet, and its summit is about 600 feet above the surrounding valley. It is almost completely isolated from surrounding mountains. The lower 450 feet of Pilot Knob, as well as nearby mountains, is composed of fine-grained, compact, purple to red, porphyritic rhyolite and quartz latite - commonly known as "porphyry" and designated as the Pilot Knob felsite by Tolman and Robertson (1960). The upper 150 feet of the knob is characterized by bedded tuffs and breccia of the rhyolite and quartz latite. Most of this part of the mountain is ferruginous, and the lower and more tuffaceous parts of the upper portion have supplied the iron ore.

The porphyritic rocks of the lower part of the mountain (the footwall) are generally massive or display indistinct, irregular flow lines. Flow structure and relict spherulitic structure are discernible in some thin sections, indicating that the rock is, at least in part, devitrified glass. There is almost no specular hematite in these rocks.

The contact of the massive rhyolite and quartz latite with the overlying ferruginous tuffs and breccias has been described as gradational by Crane (1912). However, the rough upper surface of the rhyolite and the presence of a thin layer of clay between the rhyolite and the tuffs are evidence to the contrary. These features can be seen near the present entrance to the underground working on the west side of the mountain.

The tuffs and breccias of the hanging wall possess many of the characteristics of a sediment. These include bedding, decrease in grain size upward within individual layers, ripple marks, and indications of cross-lamination. The grain size ranges from a few microns in the tuffs and in the breccia matrix to more than a foot in the breccia. The tuffs are distinctly and evenly bedded, and some bedding occurs in almost all the rock of the upper 150 feet. Large fragments lie in lipped depressions on the bedding surfaces of the tuffs, indicating that the fragments fell onto the fine material and partially displaced it. The bedding dips toward the southwest at angles from 10 to nearly 30 degrees.

The materials of the tuffs and breccias are composed mostly of fragments of rhyolite and quartz latite and of individual grains of feldspar and minor quartz. The tuff and the matrix of the breccia have been partially replaced by specular hematite. This mineral also forms very thin veinlets in the fragments of the breccia and partially replaces the rock along the walls of the veins. Unlike the mineralization at Iron Mountain, there is almost no apatite associated with the hematite.

Workable ore is limited mostly by the grading of the host rock into breccia containing a low percentage of fine matrix and, therefore, lacking the replacement hematite. Apparently, there also is thinning of the mineralized zones to the extent that they can not be mined profitably.

In places, the tuffs appear somewhat slaty or schistose because of their fine lamination and the pseudo-micaceous habit of the replacing specular hematite. This type of material is best

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exposed in the eastern end of the big open cut on the north side of the mountain where the material contains 45 to 50 percent iron. The remainder of this rock is unreplaced rhyolitic tuff in which the silica content may approach 20 per cent.

The increase upward in the number and thickness of breccia beds with respect to tuff limits the richer mineralized zones. The upper 100 feet of the mountain contains a very low percentage of hematite. Parts of the breccia show little evidence of sorting and layering which would result from being deposited in water. Also, some of these upper breccias seem to grade laterally into massive porphyritic rock.

The mineralized zone had been naturally exposed on the steep northern slope of the mountain prior to the deposition of Cambrian sediments. Consequently, a large deposit of hematite-rich boulders accumulated at the foot of the mountain and on the lower slope. This material was highly weathered before it was partially covered by Cambrian Sediments. Much of the early ore production was from this boulder conglomerate deposit, and scars of the old workings can still be seen on the northern lower slope.

At present, there is a surface accumulation of boulders similar to those of the conglomerate except that they are comparatively fresh and hard. Good specimens of almost pure hematite and of the finely banded, richly ferruginous tuff can be found among the surface boulders. Most of these boulders are on the northern and northwestern slopes.

Theories on the origin of the Pilot Knob hematite deposit include magmatic injection, replacement of stratified rhyolite by the action of iron-bearing surface waters, sedimentary accumulation, and selective replacement in tuffaceous layers by the action of infiltrating iron-rich, hydrothermal solutions.

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UNDERGROUND GEOLOGY AT IRON MOUNTAIN

by

John E. Murphy and Victor M. Mejia

INTRODUCTION

This brief description of the geology of the Iron Mountain Orebody has been written for the 1961 field trip of the Association of Missouri Geologists. The paper touches lightly on the topics mentioned and is not intended to be a detailed description of the deposit.

HISTORY OF IRON MOUNTAIN

A few years before the Louisiana Purchase in 1803, the Spanish Government gave a tract of land to a Joseph Pratte for services rendered. This land included Iron Mountain, but it was not until some 40 years later, in 1843, that it became a producer of iron ore.

The first ore mined consisted of boulders of hematite in a matrix of clay which covered the top and slopes of the southwest end of the hill called Iron Mountain. This mining eventually exposed two additional types of mineable ore; these are (1) vein ore in porphyry and (2) conglomerate ore. The vein deposits were mined as open pits. The conglomerate ore occurred above or rested on the Precambrian surface and extended down and out into the valley floors beneath the Cambrian sediments. This ore was mined by underhand stoping.

Production was fairly continuous for approximately 50 years until the iron ranges in Minnesota and Michigan were discovered and developed. The ownership of the property passed through various hands from the latter part of the 19th century until 1927 when the M. A. Hanna Company first took an interest in it. In the period from 1927 until 1930, diamond drilling and dip needle work partially delineated the two ore bodies presently being worked. During the year 1930, depression conditions forced the closing of the mine. In 1942, wartime ore demand created renewed interest, and drilling was started to test further the old open pits. Production started in 1944 with open pit mining. Since 1954, production has been entirely from underground.

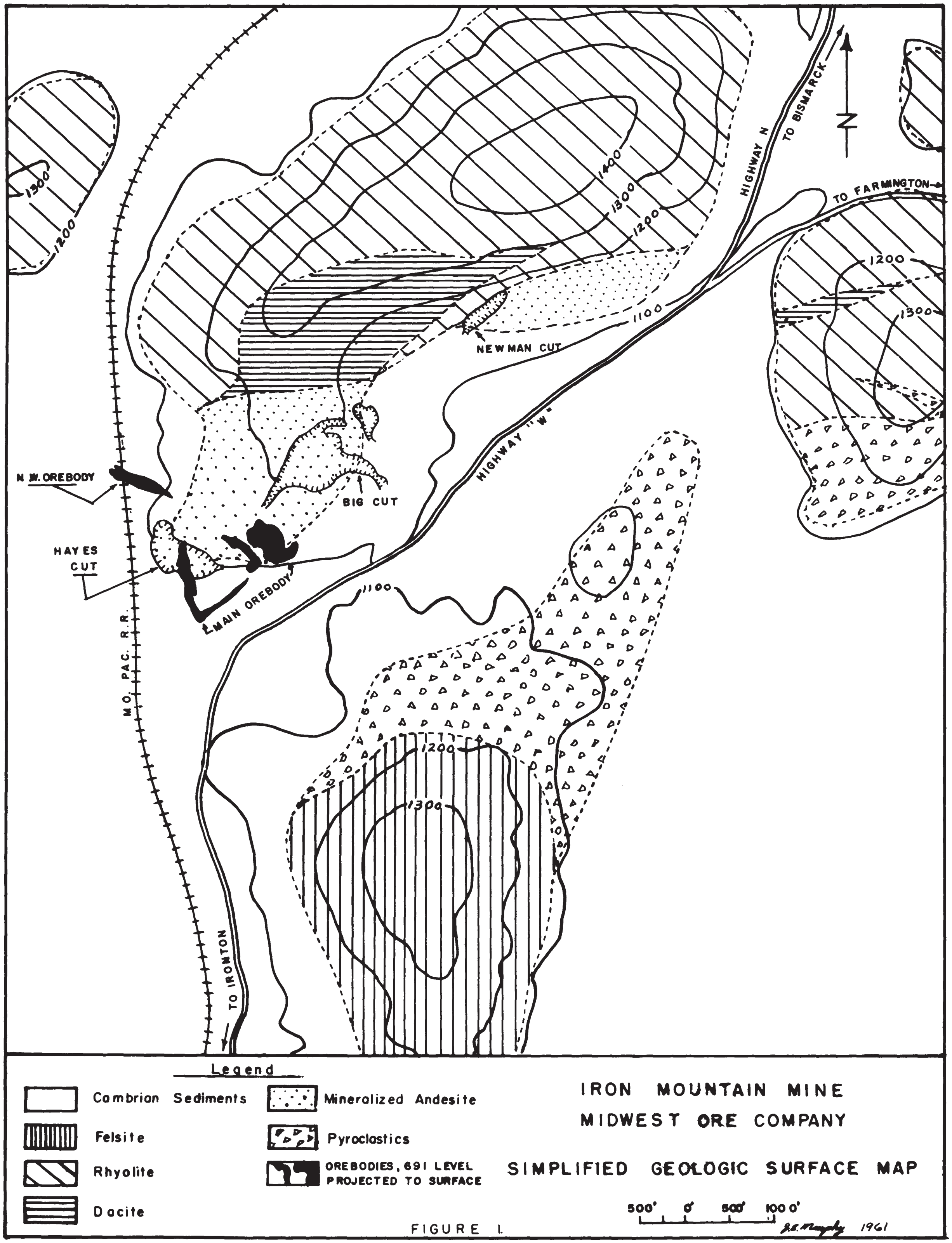
During the span of 117 years, the mine has produced over 7,600,000 long tons of concentrates.

GENERAL SURFACE GEOLOGY

On the knobs around the Iron Mountain hill, a complex of Precambrian flows, fine pyroclastic breccia, and small intrusive (?) bodies crop out. The valleys are underlain by upper Cambrian sediments which dip away from the Precambrian knobs and are rather flatly dipping in the valleys. The dip of the sediments is considered to be initial and is generally gentle; however, near Hayes Cut it is as steep as 27 degrees (Fig. 1).

The stratigraphic sequence of the Precambrian rocks as indicated by mapping and drilling is as follows (Fig. 1):

Pyroclastics.-- This unit seems to be the oldest rock outcropping near Iron Mountain. Grouped in the unit are reddish, coarse, volcanic agglomerates, dark, fine, volcanic breccia, and black, glassy, locally banded, volcanic flows.


TO BISMARCK
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Legend
Cambrian Sediments
Felsite
Rhyolite
Dacite
Mineralized Andesite
Pyroclastics
OREBODIES, 691 LEVEL PROJECTED TO SURFACE
IRON MOUNTAIN MINE
MIDWEST ORE COMPANY
SIMPLIFIED GEOLOGIC SURFACE MAP
500' 0' 500' 1000'
J.E. Murphy 1961

FIGURE 1.

Southern Rhyolite.-- This rock is resting unconformably (?) on top of the pyroclastics. It is a fine-grained, reddish, locally banded porphyry containing scanty amounts of small feldspar and quartz phenocrysts.

Dacite.-- The dacite is a black, banded, locally fragmental porphyry containing a few feldspar and quartz phenocrysts. It is a marker which separates the northern and southern rhyolites. The dip of the banding is irregular, but generally it is vertical.

Northern Rhyolite.-- The northern rhyolite is a red, locally banded, porphyritic rock containing abundant euhedral feldspars and quartz phenocrysts.

Mineralized Andesite.-- This is a dense, reddish to brown, porphyritic rock which is difficult to place in the stratigraphic sequence. Its textural and field characteristics suggest that it is an intrusive, in which case it would be younger than the dacite and northern rhyolite. A more detailed description is given below.

Felsite.-- The felsite unit is a brown to gray, aphanitic to fine-grained, locally banded, flow rock containing occasional hematite filled vugs.

All the primary deposits at Iron Mountain are confined to the mineralized andesite, locally known as the Iron Mountain andesite. For this reason, we feel that this rock merits a longer description. Winchell (1927) describes the Iron Mountain andesite as "porphyritic with very large phenocrysts in a very fine felsitic ground mass. The phenocrysts are andesine and the feldspar microlites are also andesine (or possibly basic oligoclase) at least in part; I can find no orthoclase though a part of the groundmass which is glassy may contain uncrystallized orthoclase and silica. Ferromagnesian minerals are very scantily present. The rock is an andesite porphyry."

Several prominent Missouri Geologists deny that the porphyry is an andesite. However, we will continue using this term until we have completed a study of the porphyry.

Steidmann (1928) made a detailed study for the Hanna Company and referred to this rock as an andesite porphyry.

The lack of extrusive textures, such as flow banding, parallel orientation of phenocrysts and vesicles, together with the fact that the andesite transects contacts of different rock units, suggests an intrusive origin for this rock. The porphyritic nature could indicate a shallow intrusive with a low content of volatiles which cooled rather quickly.

STRUCTURES OF THE MAIN AND NORTHWEST OREBODIES

The shapes and locations of the Main and Northwest Orebodies can be understood more quickly and efficiently by looking at Figures 2, 3, and 4. The nature of the mineralization in both the Main and Northwest Orebodies may be described as veining, breccia filling, and very minor dissemination.

The dome shaped Main Orebody, located approximately 150 feet below the present erosion surface, is relatively flat on top and rolls down and outward in depth. At the 654 Level (above sea level), the orebody has the shape of a triangle with each limb approximately 1,500 feet long with the base at the north end and the apex pointing south (Fig. 4). Mine development has shown that the base of the triangle is closed by mineralization at two places, one is at the top of the dome and the other at the 654 Level. Probably other closures will be found below the 654 Level.

The Northwest Orebody, when viewed in cross-section, appears to be sickle-shaped with a vertical lens curving upward into a horizontal lens. The horizontal lens crops out at the

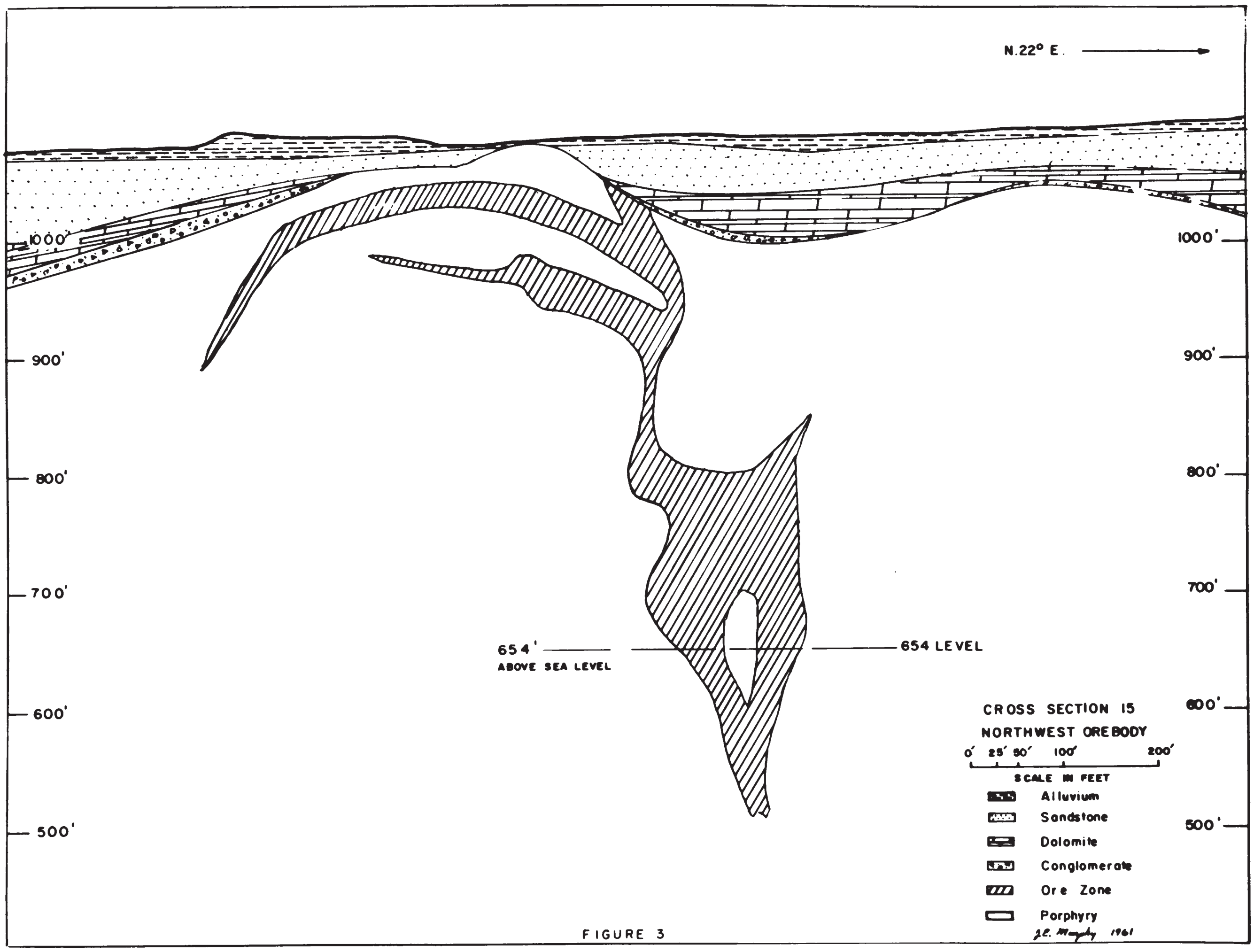


FIGURE 3

Precambrian surface and is 30 to 50 feet below the ground surface as shown in Figure 3. The steeply dipping limb starts approximately 150 feet below the ground surface and is connected by a very narrow limb to the horizontal part of the orebody. The plan view of the 654 Level shows the orebody to be shaped like an elongated tear drop.

Numerous vertical, or near vertical, post-ore andesitic dikes have intruded the host rock and the orebodies. These dikes entered along zones of weakness paralleling the present joint system. The dikes strike east, northeast, and northwest and some of them have been intruded by a low angle dike which we call the "main" dike. This "main" dike strikes east-west and dips from 5 to 45 degrees to the north.

The porphyry was subjected to faulting, following deposition of the ore and intrusion by the dikes. These faults strike northeast, dip vertically, and have minor displacements.

Primary mineralization, dikes, and faults do not extend upward into the Cambrian sediments. The local hematite conglomerate, resting on the Precambrian surface, is the result of erosion of the mineralized andesite porphyry.

The deposition of the Main and Northwest Orebodies was controlled by pre-ore fracturing of the andesite porphyry. This fracturing might have originated in one of several ways; however,

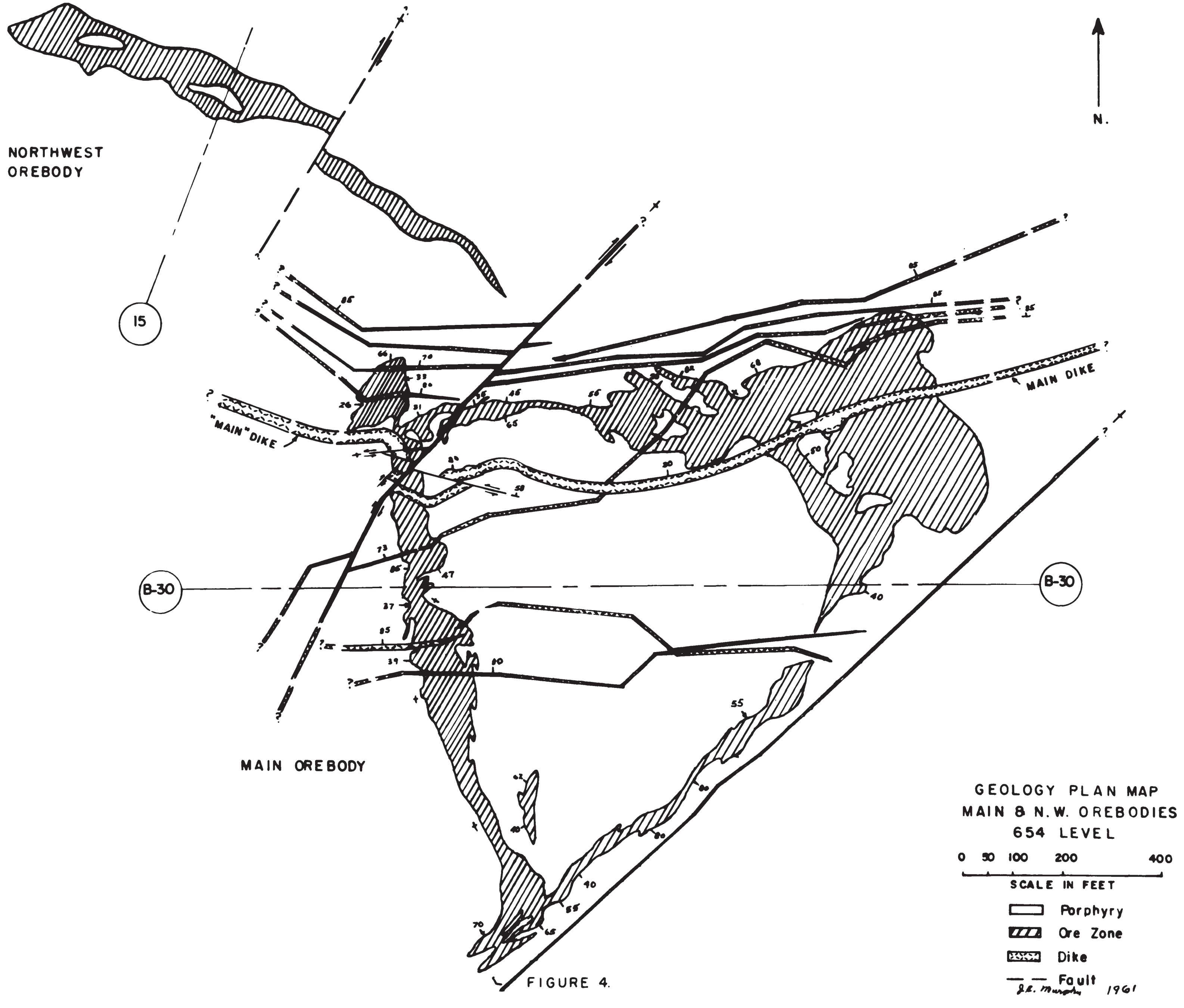

N.
NORTHWEST
OREBODY
15
"MAIN" DIKE
MAIN DIKE
B-30
B-30
MAIN OREBODY
GEOLOGY PLAN MAP
MAIN & N.W. OREBODIES
654 LEVEL
0 50 100 200 400
SCALE IN FEET
Porphyry
Ore Zone
Dike
Fault
J.E. Murphy 1961

FIGURE 4.

time permits discussion of only the one that we presently favor.

The dome orebodies at Iron Mountain resemble dike cone-sheet structures. The origin of the cone-sheet structures was explained by Anderson (1924) as resulting from intrusive activity when the hydrostatic pressure of a magma is less than the lithostatic pressure in the surrounding rocks. When the lithostatic pressure pushes on the magma, the magma pressure will exert the least important stress along trajectories radiating out from the magma reservoir and the lithostatic pressure will exert the principal stress along the trajectories nearly parallel to the magma chamber. A competent rock (in our case the Iron Mountain andesite) under these stresses will finally yield to tensional and shear jointing. The tensional joints would form parallel to the principal stress trajectories, and two sets of shear fractures might form making angles of 30 degrees with the tensional joints. These shear fractures will be curved planes with their concave surfaces facing the intrusive. The three dimensional shape of the shear joint system would be a curved cone or dome with its apex directly above the intrusive body.

Referring back to the Iron Mountain andesite porphyry, after the systems of joints were developed the lithostatic pressure forced the magma to retreat, leaving the jointed porphyry without its basal support. The lack of support caused a collapsing of the porphyry forming a dome shaped block, opening joints, and further fracturing the porphyry. The slumping of the dome was a tilting as well as vertical movement. The zone where the dome pivoted for this tilting had minor relative displacement, accounting in this way for the lack of economic mineralization in some areas of the dome shaped orebodies.

MINERAL COMPOSITION OF THE ORE

The main ore minerals at Iron Mountain are hematite and magnetite with the latter making up 10 to 20 percent of the total. The main gangue minerals consist of silicates, carbonates, and an apatite. Although magnetite is found on all levels, it occurs mainly on the southeast limb of the Main Orebody. Mapping shows that along this limb the change from hematite to magnetite is gradational. In a few local cases, there are indications that hematite preceeded magnetite, but at the present time we do not have sufficient evidence to say that this is true throughout the mine. The chief silicate minerals are actinolite, andradite garnet, and quartz. Calcite and dolomite are the carbonate minerals.

The authors who have written papers on Iron Mountain do not agree concerning the paragenetic sequence, and in turn we differ in certain details with all of them. Comments by Singewald and Milton (1929), Lake (1932), Allen and Fahey (1952), and Ridge (1957) on the paragenetic order are summarized briefly as follows:

1. Singewald and Milton (1929) do not give a complete paragenetic order of deposition, although they do say that garnet and calcite are earlier than hematite.

2. Lake (1932) said that apatite and tremolite are contemporary with hematite and are followed by garnet, quartz, and calcite in that order.

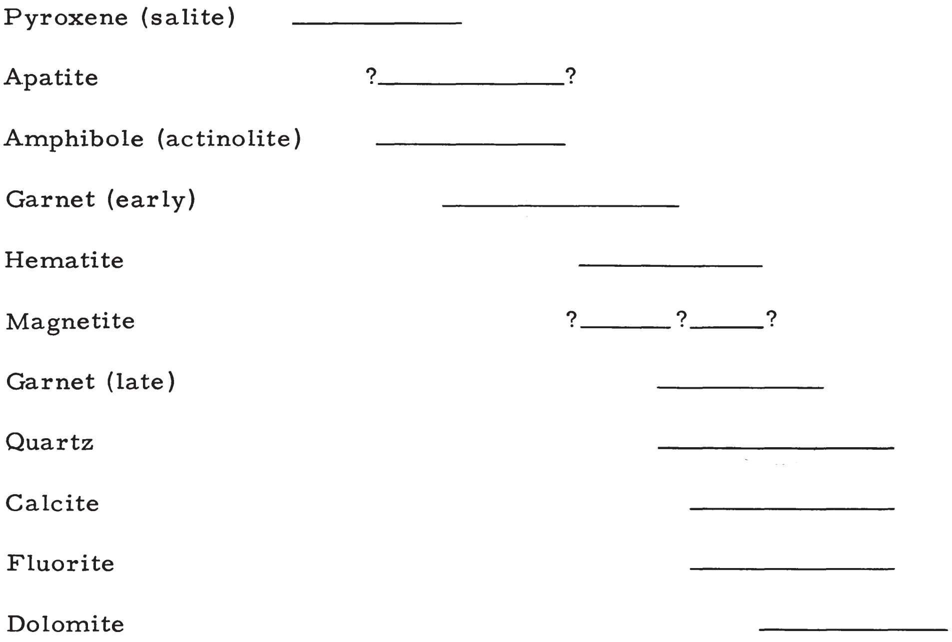
3. Allen and Fahey (1952) indicate that the sequence of minerals was salite (a pyroxene intermediate between diopside and hedenbergite), actinolite, andradite, hematite, calcite, quartz, and fluorite.

4. Ridge (1957) gives the paragenetic sequence as pyroxene, apatite, amphibole (early), garnet (early), amphibole (late), garnet (late), hematite, quartz, calcite, fluorite, and dolomite.

In general, we agree with Ridge, and with Allen and Fahey as to paragenesis except that we believe that the late garnet should be placed after hematite in the sequence rather than where it is placed by Ridge, because this mineral is found cementing hematite breccia and as veinlets in the hematite. Our paragenetic sequence for the major minerals is shown in Table 1.

Table 1

Paragenetic Sequence at Iron Mountain, Missouri



Rare occurrences of galena, bornite, and pyrite have been found cemented by quartz. Also, rare occurrences of pyrite have been found in magnetite.

MAIN THEORIES FOR THE GENESIS OF THE IRON MOUNTAIN ORE DEPOSITS

Several theories have been advanced to explain the origin of the Iron Mountain deposits. Whitney (1854) classified them as of "eruptive" in origin. Schmidt (1873) considered them as fracture filling by thermal "chalybeate" waters of meteoric origin. Crane (1912) considered the Iron Mountain deposits as fissure fillings and replacements by hot iron-bearing solutions of magmatic origin (hydrothermal solutions). Geijer (1915) and Spurr (1927), on the other hand, favored magmatic injections as the mode of origin of the ore.

Through the years, the hydrothermal replacement theory has been supported by Singewald and Milton (1929), Lake (1932), and Allen and Fahey (1952). Magmatic injection of a water-poor, iron-oxide-phosphate-carbonate melt along pre-existing fractures was advocated by Ridge (1957).

On the basis of our daily observations of the ore deposits, we favor the magmatic injection theory for the following reasons:

1) Hydrothermal replacement action generally, but not always, produces extensive wall rock alteration which is closely related to the ore deposits; this is not the case in the Iron Mountain mine. Wall rock alteration can be observed locally near the iron oxide veins, but it is irregular, may be only a few inches wide, and consists of a change of color of the porphyry from brown to light red with the development of epidote, chlorite, and sericite. The relatively weak nature of wall rock alteration of the present orebodies lends little support to a theory of hydrothermal replacement; whereas, the presence of relatively fresh fragments of angular porphyry in the breccia zones suggests magmatic injection. These porphyry fragments,

cemented by near massive iron oxides, have sharp and straight boundaries, and the feldspars appear fresh with no signs of alteration. Thus, alteration or replacement did not occur on these small fragments of country rock surrounded in three dimensions by massive iron oxides.

2) The texture of the early crystallized actinolite and apatite embedded in a finer matrix of iron oxides is quite similar to the igneous texture observed in porphyritic rocks. Such texture could result from the crystallization of an injected melt.

3) The replacement of the amphibole by the andradite garnet is one of the points advanced to support the hydrothermal replacement theory. This was explained by Ridge as the reaction of early crystallized actinolite and the still molten and miscible iron-silicate-carbonate melt.

4) The supporters of the hydrothermal replacement theory point to the irregularity of the vein walls as proof of replacement. This situation is locally true but is far from the rule. This was not an entirely water-free melt. We believe that some replacement took place, enough to obliterate the shape of the vein walls locally, to cause minor wall rock alteration and to produce disseminated iron-oxides. We do not think it was the main process by which the ore was emplaced. It is natural to expect some resorption and alteration of the country rock when it is in direct contact with a melt at magmatic temperatures.

5) Commonly, hematite veinlets have a central band of garnet. This zoning could be cited as support for hydrothermal processes, but alternately the garnet may have been a late stage injection of silicate melt into fractures of the hematite veinlets.

6) In the paper presented by J. S. Owens during the Symposium on the Precambrian of Missouri at Rolla in 1959, he compared the Iron Mountain deposits with the vein type deposits at Shepherd Mountain and with the mineralized pyroclastics at the old Pilot Knob mine. Owens' conclusion is that "replacement in a large scale has operated in favorable host rocks (porous pyroclastics), but that these do not include the dense impervious felsites and porphyries". Further drilling in the Iron Mountain mine has proved that at least in three holes, the Iron Mountain andesite is underlain by a fine pyroclastic breccia. However, this breccia has only traces of mineralization. An explanation of this situation may be found in the two different theories of origin advanced for the Pilot Knob and Iron Mountain deposits. At Pilot Knob, the ore seems to have been emplaced by a very mobile hydrothermal solution with a high water content capable of percolating through the porous pyroclastics replacing the fine matrix of the tuff and breccias; whereas, at Iron Mountain the ore solution is conceived as having been a viscous magmatic melt which moved through open fractures and breccia zones of the Iron Mountain andesite but was unable to percolate through and replace the underlying pyroclastics.

The source for the mineralizing melt may have been the residual magma of a deep seated intrusive enriched in iron oxides.

The nearness of an intrusive granite to the Iron Mountain deposits has been suggested by granite blocks found scattered within a vertical post-ore andesitic dike exposed by our underground mining.

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The below errata sheet is an enclosure for this document. Most of the items require pen & ink changes which were not easily made by direct edit. R.C.B.

ERRATA

Guidebook to the geology of the St. Francois Mountain Area
R. I. No. 26
Missouri Geological Survey and Water Resources

On pages 13, 14, 22, 85, 86, 87, 89, 91, 92, and 93 change all "Magee" to "**Breadtray**" and all "Wills" to "Slabtown."

p. 7 First paragraph, line 5: change Richard D. to Richard E.
p. 20 Mileage 7.80, third paragraph, line 3: change thread to trend.
p. 22 Second paragraph, line 5: change averages 50 to averages 20.
p. 23 Mileage 30.55, third paragraph, line 3: change tested to milled.
p. 34 Correct spelling of tornado.
p. 39 Mileage 0.95: change Stouts Creek to Royal Gorge.
p. 40 Mileage 2.30: change Stouts Creek to Royal Gorge.
p. 41 Mileage 5.40: change Saum to Taum.
p. 43 In title: correct spelling of Johnson.
p. 56 Mileage 25.70, second paragraph, line 8: change 1960 to 1961.
p. 57 Mileage 36.35, second paragraph, line 9: change silicote to silicate.
p. 79 Mileage 1.75, line 3 and 4: change granite porphyry to diabase. Make some change in Fig. 1 and change orthoclase to plagioclase.
p. 102 Correct spelling of Geophysics in footnote.
p. 129 Add footnote: Geologists, Midwest Ore Company.