A STUDY OF THE IRON ORES

AT

IRON MOUNTAIN, MISSOURI

by

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I. INTRODUCTION

Iron Mountain is the largest iron ore deposit in Missouri and has produced a very large portion of the iron ore of the State. It is located in the southwest corner of St. Francois county, just over the boundary line from Iron county and 81 miles south of St. Louis on the St. Louis, Iron Mountain and Southern Railway.

Iron Mountain proper is a low conical knob rising to a height of over 200 feet above its base and projecting sout h from a larger and higher mountain forming one of the peaks of the St. Francois mountains. To the south it slopes off gradually to form Little Mountain, from the past known at Big Mountain.

The mine was first opened in 1845 and has been in almost continuous operation since that time. A recent drilling campaign carried out on this property has proved the existence of reserves greater than expected[1] and thus, it continues as the chief iron ore deposit of Missouri.

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[1] Bulletin #3, Technical Series Vol. II, May 1928. School of Mines and Metallurgy, University of Missouri - "The Laboratory Concentration of the Missouri Iron Ores of Iron Mountain and Pilot Knob."

II THE IRON ORES OF MISSOURI

a) Types and Location.

There has been several types of iron ore of commercial grade mined in Missouri. Each have been segregated sufficiently to form distinct districts. Crane has separated them into eight classes but this is due to his classification by districts as well as by types.[1]

Beuhler has limited them to the three main types which are actively exploited, as:[2]

1. Specular Hematite in Porphyry.
2. Hematite of the Filled Sinks.
3. Brown Ores.

The Specular Hematite in Porphyry is mined only in the Iron Mountain district and is found exclusively in the porphyry of the St. Francois mountains. It is described as a massive, crystalline blue specular hematite, often highly silicious.

The Hematite of the Filled Sinks is a red hematite occupying old cave or sink structures, originally filled with marcasite or pyrite. It occurs chiefly in the Central Ozark region. These deposits are very irregular and variable and are found only near the surface.

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1. G. W. Crane - The Iron Ores of Missouri; Missouri Bureau of Geology and Mines, Vol. X, 1912.

2. H. A. Buehler - Geology and Mineral Deposits of the Ozark Regions; A.I.M.E. Vol. 58, 1918, page 398.

The Brown Ores are formed of both primary and secondary limonite and occur only in surface clays. The major portion of these deposits are confined to the eastern part of the Ozark plateau altho they are found frequently in the western part as well. The Brown Ores have never been important and in production are greatly exceeded by the Hematites.

A brief summary of the physiography of Missouri and of the geology of the Ozark Plateau is presented later to set forth more fully the distribution of the iron ore districts and their relation to the stratigraphic formations.

b) Development and Production.

All the ores have been subject to a number of descriptive studies and investigations. Naturally, the Specular Hematite has received the greater portion of the investigations from their importance in comparison to the other types, with Iron Mountain as the typical deposit.

It is recorded that Marquette on a voyage down the Mississippi River in 1673 described a deposit of iron ore in the river's bluff in the southwestern corner of Perry County which is probably the first noted occurrence of iron ore in Missouri. Historical record was made of its recognition as early as 1789 by the inhabitants of

St. Genevieve.[1]

The first attempt to mine and smelt iron ore in the state did not take place until 1815 when the Ashebran furnace was erected near Arcadia, Iron county. This gives to Missouri the distinction of being the first state west of Ohio to mine and smelt iron ore. The ore was specular hematite obtained chiefly from Shepard Mountain altho some was mined locally.

The next attempt took place in 1819-1820 when the Harrison-Reeves furnace was built near Bourbon, Crawford County. The ore was derived locally from the red and specular hematite deposits and marks the first utilization of the Central Ozarks ore.

The first recorded attempt to make use of the Brown Ores was around 1823 at the time Perry's furnace was erected a few miles north of Caledonia, Washington county. It is stated, however, that this ore was mixed with specular hematite brought from Iron Mountain.

These early furnaces had a short life and produced only a small output. The one exception is the furnace erected in 1829 at Mermac Springs, near St. James, Phelps county, which operated intermittently for a period of over 30 years.

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1. G. W. Crane - Missouri Bureau of Geology and Mines Vol. X, 1912.

With the opening of the Specular Hematite deposits at Iron Mountain, St. Francois county and Pilot Knob, Iron county, between 1845-1850 Missouri came into prominence in the iron industry. For the next 30 years these deposits were actively worked and the industry flourished. At the end of this period the more available ore was exhausted and with a rapid decline in the price of iron due to the discovery of iron ore in the Lake Superior Region, Missouri suffered considerable reduction in its production of iron ores.

The Limonites, altho existing in abundant quantities, were only sporadically utilized. It was not until the beginning of the 1900's that any of these deposits were brought into steady production. From 1890 up to the present there has been a continuous but fluctuating production of all ores. It is to be noted, however, in referring to Table II, that the increased manufacturing and construction demands of the past decade has resulted in an increased production in Missouri. At present St. Louis is the center of the smelting industry for these ores.

TABLE I[1]

PRODUCTION OF IRON ORES OF MISSOURI
(Up to 1911)

Year	Gross Tons
Prior to 1850	100,000
1850-1860	310,000
1861-1870	625,000
1870	316,000
1871	240,000
1872-1879 incl.	Z.852,694
1880	386,197
1881-1882 incl.	604,007
1883	295,430
1884	233,235
1885	234,160
1886	379,776
1887	427,785
1888	217,931
1889	265,718
1890	232,835
1891	138,356
1892	126,000
1893	86,983
1894	73,688

1. G. W. Crane - Missouri Bureau of Geology and Mines Vol. X, 1912.

TABLE I[1]

PRODUCTION OF IRON ORES OF MISSOURI
(up to 1911)

Year		Gross Tons
1895		40,202
1896		41,826
1897		56,256
1898		81,799
1899		84,506
1900		88,791
1901		72,282
1902		73,609
1903		54,350
1904		49,045
1905		116,666
1906		103,992
1907		109,273
1908		95,721
1909		112,100
1910		78,691
	Total	9,134,624
Total Value		$32,576,179

1. G. W. Crane - Missouri Bureau of Geology and Mines Vol. X, 1912.

TABLE II [1]

PRODUCTION AND VALUES OF IRON ORES OF MISSOURI

1911-1929

Year	Hematite Ores Long Tons	Total Long Tons	Value
1911	60,479	72,783	$153,676
1912	39,721	42,120	92,996
1913	33,709	37,134	83,628
1914	32,054	37,554	75,696
1915	35,145	40,290	99,853
1916	27,568	34,914	116,484
1917	26,866	38,908	134,906
1918	56,755	72,708	270,337
1919	44,867	53,856	223,144
1920	42,754	54,994	230,827
1921	36,550	36,560	a)
1922	57,038	58,408	244,928
1923	40,630	53,546	247,975
1924	72,425	79,847	405,622
1925	40,043	40,043	a)
1926	120,000	124,731	532,536
1927	78,605	78,605	315,670
1928	94,899	94,899	377,847
1929	167,301	168,934	661,055
Total	1,117,409	1,220,469	4,267,180

a) Three shippers and permission to print values not given.

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1. Mineral Resources of the United States; U. S. Bureau of Mines.

TABLE III[1]

TOTAL PRODUCTION OF EACH TYPE OF IRON ORE

(Up to 1911)

Type	Tons	Percent of Total
Specular Hematite in Porphyry	5,627,799	61.61
Red and Specular Hematites of the Central Ozarks	3,072,637	33.64
Brown Ores	291,656	3.19
Miscellaneous	142,532	1.56
Total	9,134,624	100.00

TABLE IV[1]

TOTAL PRODUCTION BY MINES OF SPECULAR HEMATITE IN PORPHYRY.

(up to 1911)

Mines	Tons
Iron Mountain	3,939,299
Pilot Knob	1,589,640
Shepard Mountain	75,000
Cedar Hill	25,000
Buford Mountain	3,000
Russell Mountain	3,000
Shut-in	600
Miscellanous	1,260
Total	5,627,799

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1. G. W. Crane - Missouri Bureau of Geology and Mines Vol. X, 1912.

c) Theories of Origin.

In 1854 Whitney described Iron Mountain and the ores but at that time the main ore body had not been disclosed and only the loose boulder ore at the surface was being worked.[1] Corresponding to the erruptive character of the porphyry held at that period, the iron ore was also considered to be of a similar eruptive origin.

The first report of the Missouri Geological Survey to deal with Iron Mountain was issued by Prof. Pumpelly, then director, in 1872 in which Dr. Schmidt described the deposits and studied their probable origin.[2] Now that the ore in the solid porphyry had been discovered and worked the problem became one of the relation of the ore to the Porphyry. Schmidt rejected all probabilities of a magmatic origin, opposed the idea of segregation by percolating waters of magmatic source but argued for the possibility of infiltration and percipitation in cavaties and fissures by meteoric iron-bearing waters from the overlying sedimentary rocks.

Twenty years later when Missouri had fallen from 6th to 13th place in the production of iron ore in the United States,[3] the Missouri Geological Survey issued

1. J. D. Whitney - Mineral Wealth of the U.S. 1854
2. A. Schmidt - The Iron Ores of Missouri; Report of the Missouri Geological Survey for 1872.
3. F. L. Mason - Iron Ores of Missouri; Missouri Geological Survey, Vol. II, 1892 - Letter of Transmittal.

another report on the iron ores, Concerning Iron Mountain Nason agreed with Schmidt in the fact that they were filled fissure deposits.[1] He derived the ore, however, from the original iron oxide content in the porphyry which had been eroded away.

The latest and most complete report[2] was published in 1912 by the Missouri Bureau of Geology and Mines. By this time Harworth[3] had completed his studies of the crystalline rocks of Missouri and more exact relations between ore and porphyry had been investigated. Hence, Crane proposed that deposition of the ore was brought about by fissure filling accompanied by replacement of the porphyry thru the agency of hot magmatic solutions. Furthermore, he held replacement to be the major phase.

Additional contributions to the literature of the iron ores of Missouri since Cranes work has been confined solely to the subject of the district of Iron Mountain. The foregoing articles have discussed the other ores altho mention of it has not been made in this paper. Per Geijer,[4] after an inspection of

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1. F.L. Nason- Iron Ores of Missouri; Missouri Geological Survey Vol. II, 1892.

2 G.W.Crane-Missouri Bureau of Geology and Mines, Vol. X, 1912.

3 E. Harworth-The Crystalline Rocks of Missouri; Missouri Geological Survey, Vol. 8, 1894.

4 Per Geijer-Iron Ores of American and Sweden; Economic Geology Vol. X, 1925, page 299.

several ore deposits in the United States in 1915, made some comparisons of these deposits to similar iron ore deposits of Sweden and Finland and classified them as fissure fillings by solutions approaching magmatic temperature. He believed Crane exaggerated the amount of replacement altho he admitted replacement was present.

No further investigation of these ores occurred until Spurr[1] visited the area with members of the Missouri Geological Survey in 1927. His observations led him to consider the ore to have been fissure filling by essentially fluid iron ore not predominantly gaseous or aqueous. In 1929 Singewald and Milton[2] published a paper after inspection of the area and study of thin sections. They came to the support of Crane by attempting to demonstrate replacement and to prove subordination of fissure filling.

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1. J.E. Spurr - Iron Ores of Iron Mountain and Pilot Knob Engineering and Mining Journal Feb. 26, 1927, page 363.

2. J. T. Singewald and C. Milton - Origin of Iron Ores of Iron Mountain and Pilot Knob, Missouri; Transactions of the A.I. M.E. (Year Book) 1929, page 330.

PHYSIOGRAPHY OF MISSOURI

Missouri is separated into three distinct physiographic regions:

1) The Upland Plain

2) The Ozark Plateau

3) The Swamp area of the Southeast.

According to Fenneman's Physical division of the United States it falls into the two major divisions of the Interior Plains in the North and the Interior Plains of the South.

Interior Plain

a) Central Lowland

1) Dissected Till Plains

2) Osage Plains.

Interior Highlands

a) Ozark Plateaus

1) Springfield-Salem Plateaus.

The Central Lowland occupies the entire State north of the Missouri River, called the Dissected Till Plains and the small northwest corner south of the Missouri River, which comprise the Osage Plains. The Ozark Plateaus occupy the remainder of the State with the exception of the extreme southeast corner. This is the Mississippi Alluvial Plain which is part of the Atlantic Costal Plain.

Fenneman's Central Lowland is identical with the Upland Plain area. It is a region of broad undulating prairies underlain by a great series of shales, sandstones and limestones whose surface is slightly inclined to the south. The Strata are very regular and even but pitch at a low angle to the north, opposite to the slope of the surface. It rises toward the North to reach an elevation of 1000 feet at the northern boundary line of the State.

The Ozark Plateau is a dome-like region which slopes gently in all directions from the eastern highland area of the St. Francois Mountains and has a general elevation of over a 1000 feet. The St. Francois Mountains are an extensive group of granite and felsite porphyry hills of rounded or conical masses more or less grouped altho individual hills are frequently isolated. The peaks have no general average height and vary from a hundred to several hundred feet above their bases. The highest reaches up to an elevation of 1800 feet. The hills are separated by rather broad, somewhat tortous valleys usually floored by sedimentary rocks. The flanks of this central highland are gently inclined limestones with some shales and sandstones. To the east of the St. Francois Mountins they have a much steeper dip than to the west, to which they extend a greater distance. As the border of the Plateau is reached the stream gorges become deeper and the surface increasingly rugged. Due to the characteristics of the limestone, springs, caves and sink holes are numerous.

The Swamp area to the southeast is in marked contrast to the other regions. It is a flat poorly drained area, not more than 300 feet above sea level, consisting of Tertiary gravels and recent alluvials.

IV GEOLOGY OF THE OZARK REGION

The major structure of the Ozark region of Missouri is a gentle elliptical dome-like plateau with its axis running from near St. Louis to the southwest for a distance of 140 miles. The eastern slope of the surface is approximately one degree while to the west it is much less. To the west, north and east the slope is imperceptibly joined into the Plains. To the south and southeast it terminates more abruptly.

The core of the plateau is the igneous rocks which form the St. Francois Mountains. They are situated slightly east of the actual central area and dip away under the sedimentary rocks in all directions. These igneous rocks are comprised of granties and porphyries with the major portion formed of the porphyry which is more prevalent to the west. The entire crystalline rock area covers above 70 square miles.

The stratigraphic horizon of nearly all of the sedimentary rocks of the Plateau proper is limited to the Cambrian Ordovican and Silurian formations which outcrop in roughly concentric bands around the St. Francois Mountains. The formations are mainly cherty and non-cherty dolomites and limestones with a few sandstones and occasionally shale. The Middle Cambrian is contiguous to the igneous rocks and starts with a basal conglomerate. The larger part of the region is underlain by the Upper Cambrian and Ordovician. Along a narrow band on the eastern edge of the Missouri there are found Silurian and Devonian strata. The younger Palaeozoic sedimentery rocks practically surround the edge of the plateau. These younger sediments formerly covered the entire area but have been eroded away. In General the beds lie approximately horizontal showing little signs of disturbance but gently dipping away from the central igneous area. To the east where the dip is steeper the beds outcrop in comparatively narrow belts paralleling the Mississippi River.

There has been some slight faulting which occurs chiefly in the region of the St. Francois Mountains. In the other areas it is quite localized. Igneous activity is absent with the exception of a few basic dikes in the igneous rocks.

To present the geological history briefly it is first to be noted that between the Pre-Cambrian and the Cambrian there was a very long period of erosion of the igneous rocks before deposition of any sediments. To the end of the Cambrian, when a general uplift occured, there was continuous deposition. The break between the Cambrian and the Ordovician is marked by an extreme unconformity after which deposition was again commenced and continued undisturbed up to the end of the Mississippian when another erosion interval occured. Following the Pennsylvanian there is another unconformity overlain by unconsolidated Tertiary sediments outside of the Ozark area.

The characteristics of the sediments are believed to indicate a deep sea condition during the early periods followed by a more or less shallow sea which shows many fluctuations. In late Palaeozoic time this area was never far below or far above sea level.

The iron ore deposits occur exclusively in the Ozark Plateau both in the igneous area of the St. Francois Maountains and in numerous and scattered localities in the surrounding sediments.

It is believed that the ores of the igneous rock area was originated by magmatic solutions related to the source of the igneous rocks. The other ores are replacements or depositions resulting from meteoric solutions leaching the iron content from the overlying sediments.

The geological column which follows bears several notes on the stratigraphic occurrence of the iron ores and also shows the types of sediments.

GEOLOGICAL COLUMN

QUATERNARY		
Recent		
Alluvial Deposits		gravels, sands and clays
Residual Deposits		chert, sands and clays.
Pleistocene		
Loess		fine yellow clay
Glacial drift		gravel, sand and clay
TERTIARY		
Lafayette	50'	chert and gravel
Lagrange	50	loose sand and clay
Porters Creek	250	
- - - - - - - - - - - - - - Unconformity - - - - - - - - - - - -		
PENNSYLVANIAN		
Missouri	1075	shale, sandstone and limestone
Des Moines	700	
Pleasanton	75	shale
Henrietta	50	limestone, sand and shale.
Cherokee (a)	500	sandstone and shales.
- - - - - - - - - - - - - - Unconformity - - - - - - - - - - - -		
MISSISSIPPIAN		
Chester		
Birdsville	75	shales, limestones and sandstones
Tribune	50	grey limestone and marl
Cypress	50	ferruginous sandstone.

St. Louis.		
St. Genevieve	100	Thick bedded limestone
St. Louis	150	fine grained limestone
Spergen	100	oolitic limestone
Warsaw	75	colored shale
Keokuk	25	cherty limestone and shale
Burlington (b)	100	coarse grained limestone
Chemung or Kinderhook		
Chouteau)		fine grained limestone
Hannibal)	75	calcareous shale
Louisiana)		thin bedded limestone.
DEVONIAN		
Sulphur Springs	275	
Bushberg		yellow sandstone
Glen Park		sandy limestone
- - -		shale
Grand Tower		
Hamilton	75	sandy shale
Onondage	25	oolitic limestone
Clear Creek	100	cherty limestone.
SILURIAN (c)		
Bailey	100	cherty limestone
Niagara	25	clayey limestone
Girardeau	60	thin bedded limestone

ORDOVICIAN		
Hudson River	50	shales
Kimmswick)	200	coarse grained limestone
Plattin)		fine grained limestone
Joachim	100	thin bedded dolomite.
- - - - - - - - - - - - Unconformity - - - - - - - - - - - -		
St. Peter	125	massive sandstone
- - - - - - - - - - - - Unconformity - - - - - - - - - - - -		
UPPER CAMBRIAN		
Jefferson City (d)	500	dolomite
Roubidoux (e)	100	cherty sandstone
Gasconade (f)	250	cherty dolomite
Gunter	36	sandstone
- - - - - - - - - - - - Unconformity- - - - - - - - - - - - -		
Proctor	75	thick bedded dolomite
Eminence	100	cherty dolomite
Potosi (g)	300	sherty dolomite
- - - - - - - - - - - - -Unconformity- - - - - - - - - - - - -		
Elvins		
Doe Run	50	fine grained dolomite
Derby	40	dolomite
Davis	150	shales, limestone & conglomerate
MIDDLE CAMBRIAN		
Bonneterre (h)	350	heavy bedded dolomite
Lamotte (i)	250	fine grained sandstone.
- - - - - - - - - - Marked Unconformity - - - - - - - - - - - -		

PRE-CAMBRIAN

Diabase	greenstone
Breccia and Tuffs	felsite s and porphyries
Porphyry (j)	fine grained felsite
Granite	coarse grained grainte ranging to porphyry.

a) A few thin beds of earthy red hematite

b) Considerable importance as an iron formation

c) Clinton Iron Ore questionable

d) Many limonite deposits.

e) Directly associated with important deposits

f) One of the principal ore horizons in the State

g) A few important deposits of Brown Ore.

h) A few limonite deposits

i) Conglomerate contains ore boulders

j) Specular Hematite deposits.

This column was compiled from that found in the work by Crane[1] adjusted to agree with the column placed on the State Geological Map of 1922.

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1. C. W. Crane - The Iron Ores of Missouri; Missouri Bureau of Mines and Geology Vol. II, 1892.

V THE ORE AT IRON MOUNTAIN

a) Occurence

The workable ore at Iron Mountain is found in three distinct types of occurences

1) Boulder ore in the surface clay
2) Conglomerate ore in beds between the porphyry and overlying sedimentary rocks.
3) Vein ore extending in depth into the porphyry.

The boulder ore consists of varying sized boulders of specular hematite embedded in the colored clays at the surface. The larger and more abundant boulders are found near the top of the Mountain and decrease in size and frequency on the lower slopes. These boulders represent the remnants of the vein ore in the porphyry which has been partly eroded away and partly decomposed to form the clay surrounding the boulders. It was not until this boulder ore had been worked away that the vein ore in the porphyry was disclosed.

The conglomerate ore is composed of angular and sub-angular boulders and pebbles of specular hematite embedded in a greyish arkosic sand. It rests unconformably upon the underlying porphyry and vein ore and is overlain unconformably by the sandstone and limestone formations. This ore is thought to be the result of the erosion of the porphyry and vein ore before deposition of the Cambrian sediments. At Big Mountain a conglomerate ore bed has been worked which extends over a thousand feet in length and up to 45 feet in thickness. It decreased in thickness as the ore was followed down the inclined porphyry surface. Conglomerate ore at Little Mountain has also been worked but at a much less degree. Some evidence was shown which indicates that the conglomerate was confined to ravine like depressions in the surface of the porphyry.

The vein ore is the parent mass from which the other types have been derived. It was best developed at Big Mountain where the main vein 60 feet in width was formed as an inverted "U" with the legs 15 to 18 feet thick. The porphyry, sometimes noticeably altered, contains many small irregular veins and masses of ore. With depth the veins diminish in width and in the case of the main vein at Big Mountain become too narrow to work at 150 feet in depth in the porphyry.

Locally the veins are vertical but generally occurs in nearly horizontal sheets or layers conformable to the rough flow-structure or bedding in the porphyry. The veins or seams vary greatly in thickness. Occasionally they enlarge to irregular masses of considerable size or on the other hand pinch out to reappear again only a few feet away. Frequently large and small fragments of the porphyry are embedded in the veins.

Rough comb or saw-tooth structure often invades the porphyry. Irregularity of the veins is one of the chief characteristics of the ore.

The undisturbed vein ore has never been found in the granites. It is entirely confined to the felsite porphyry of the igneous rock area. Figures 1 and 2 of Plate V and figures 1,2,3, and 4 show many of the characteristic occurences of the ore at Iron Mountain.

b) Character of the Ore.

The specular hematite vein ore is a dense steel gray crystalline hematite with a high metallic lustre. It has a fine to medium grained texture. Noticeable platy or lanellar structure is common and several grains made up of superimposed plates were observed. This platy structure is especially marked when viewed edge on.

It has an uneven fracture, usually cleaving off in wedge like pieces and at times splintery. It is quite generally magnetic altho not always attracted by the hand magnet. This magmatic property may be due to inclusions of fine grained magnetite. Octahedrons of Martite have been reported but none were observed in the specimens.[1]

Many inclusions of blade shaped silicate masses are present. In the veins, altho not everywhere, they are often large, at least a foot in length, and exceedingly numerous. They are characteristically formed extending perpendicularly out from the vein wall along which they occur. Figures 5 and 6 and Plate 8 and 9 show the vein ore accompanied by these silicate masses.

Specimens carrying yellowish brown to greenish garnet were examined. The garnet occurs as veins in the hematite or as a groundmass of a brecciated zone of the ore. Many well formed garnets were embedded in the less well formed garnet masses. The

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1. G. W. Crane - Missouri Bureau of Mines and Geology, Vol. II - 1912.

contacts of garnet and ore are mainly irregular in character, occasionally sharp but more commonly branching out into small irregular veins and protrubences into the ore. In the brecciated zones it surrounds the broken fragments of ore and also traverses them in small veins which tend to be controlled by the fracturing in the hematite. The garnet is intermixed as well as veined by quartz. Generally the quartz veins are comparatively narrow and cut across garnet and hematite alike. The quartz is commonly colored reddish by iron oxide stains. A few small open cavities in the quartz veins occur with a lining of fine needle like crystals which were determined to be tremolite.

Plates 6 and 7 are pictures of the garnet specimens.

The quartz veins are not only present in the ore associated with the garnets but are a common occurrence in the majority of the specimens.

VI THE FELSITE PORPHYRY

The porphyry in which the specular hematite occurs is a dull dark brown felsite with well distributed fine to medium phenocrysts. It weathers to a lighter brown speckled with whitish spots of the altered phenocrysts. The phenocrysts vary greatly with a maximum size of about a quarter of an inch and are often rod shaped when small. They have a yellowish to dark green tinge. Well defined boundaries is the rule yet frequently a fringe of lighter color with a wavy edge surrounds them.

The rock breaks with a sharp flinty edge and a fairly regular fracture. It is commonly traversed by veins and fractures. These are noticeable since they are of a lighter color and often have a wavy indefinite boundary like the phenocrysts. Specs and masses of hematite occupy some of these fractures while larger spherical masses are scattered thruout the rock.

In the study of the crystalline rocks of Missouri Harworth[1] found the porphyry varying from red to green

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1. E. Harworth - The Crystalline Rocks of Missouri; Missouri Geological Survey, Vol. 8, 1894.

in color. Red and brown varieties were found in the more centralized area of the igneous outcrop and are the types in which the commercial ore deposits are found.

The porphyries also vary in amount of phenocrysts. Some areas have porphyries with abundant phenocrysts and others are truly aphantic. The persistence in character, however, is marked, with the variations more local than widespread. A bedded or banded appearance is often given to the porphry which produces an apparent flow-structure and according to Harworth is due to the segregation of the feldspar phenocrysts.[1] Nason assigns this feature to the weathering of the rocks.[2]

Altho they contain no iron ore deposits the granites are allied to the porphyries. They lie beneath the porphyry and are similar in character and constituents. They are described as medium grained, pinkish or red colored granites altho gray varieties are known and like the porphyry have textural gradations.[1] The granite is con-

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1. Harworth - Missouri Geological Survey, Vol. 8, 1894.

2. Nason - Iron Ores of Missouri - Missouri Geological Survey, Vol. II, 1892.

sidered to be a part of the same magmatic derivation as the porphyry but later in sequence. Spurr has considered the porphyry as the first and upper extrusion from the magma which has been partly chilled and then disturbed to cause brecciation and flow-structure.[1] Or friction of the upper layers against the colder surface of the overlying rocks is suggested to explain the apparent flowage of the porphyry.

The Silicate Veins in Porphyry.

At Iron Mountain the porphyry is cut by a highly altered vein of silicates. It consists of dark grayish-green long bladed interpenetrating forms with good lustre when viewed on the prominent cleavage faces. These bladed forms are quite irregular in size and vary from an inch or two in length and up to half an inch in width to dimensions of considerably less magnitude but are always long in comparison to their width. When the intersecting blades are broken along their cleavage faces

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1. J. E. Spurr-Economic Geology Vol. X, 1915, Page 745.
Engineering and Mining Journal, Feb. 21, 1927.

there is a suggestion of a platy structure. At times, however, it has a more massive appearance. A less frequent but more prominent feature gives to it a presmatic character which is due to the rather irregular fracture at nearly right angles to the longer dimensions. Except when the cleavage is present it has an irregular fracture.

Along the edges of the fractures and cleavages, small fragments have a glassy lustre and are dark green to yellowish in transmitted light. Otherwise it is dark and opaque, often with a reddish tinge probably due to iron stains which is developed to a deep brown coloration on the weathered fractures.

Specs and irregular masses of hematite are scattered unevenly both in and between the silicate blades. Next to the contact between porphyry and silicate the hematite is much more abundant while the crystal forms are smaller and less regular.

Generally the silicate stand out lengthwise from the vein wall. It has no constant angle but it is usually nearer to a right angle than to one less than 45 degrees.

A fuller description of the silicate will be found in the study of the thin sections.

VII MISCROSCOPICAL RELATIONS

a) The Porphyry

The porphyry is composed of a holocrystalline but very fine groundmass of feldspar and quartz with abundant feldspar phenocrysts. The feldspar is orthoclase and a plagioclase between oligoclase and andesine with exceedingly rare mirocline. The feldspars are about equal in amounts which would indicate the groundmass to contain principally orthoclass feldspar.

The groundmass has a slight variation in grain size. With an increase in the size of grain the feldspars become lath-like which produces a prominent trachytic texture. It is this characteristic which causes the groundmass to have a flow structure. This is heightened by the fact that there is a tendency to flow around the phenocrysts. Small grains of hematite are scattered thruout the groundmass in various sizes and forms. It is found in individual grains, in strings of small grains, in spherical masses surrounded by a fringe of very fine grains which are blood red in transmitted light and also as a prominent border around many of the phenocrysts. The Iron Oxide is very persistent and abundant and all of the porphyries as well as the granites have this feature.[1] There are also many small scattered grains and bunches of leucoxene and epidote. However they are not nearly as abundant or as evenly distributed as the iron oxide. Yet Harworth found some of the porphyries so strongly impregnated with epidote as to give to it a green coloration.[2]

The phenocrysts are comprised wholly of feldspar. Many of the porphyries have quarty phenocrysts but it is a characteristic of the red and brown porphyries of the Iron Mountain district to have only feldspar phenocrysts.[2] They vary from very fine fragments difficult to distinguish from the grains of the groundmass to large euhedral grains. In general it is in well formed grains but showing considerable absorption and fracturing. When the phenocrysts are not deeply embayed by the groundmass the contacts may show very fine irregularities due

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1. E. Harworth - Missouri Geological Survey, Vol. 8, 1894.

2. E. Harworth - Missouri Geological Survey, Vol. 8, 1894.

to the indentation by the individual grains of the groundmass. At other times, the contact is wavy and undulatory. The phenocrysts are commonly broken or fractured and likewise for the feature of absorption there is no marked difference between the effects upon the orthoclase and the plagioclase. Distinctly angular pieces have been broken out of the large phenocrysts while many small angular fragments are scattered in the goundmass.

The Phenocrysts are usually free from the iron oxide grains. when present, however, they occupy fractures or are found along cleavage planes. The majority are bordered by a fringe of iron oxide grains. A few show slight kalonization. Others are altered to a chlorite while some are only partly changed. Rarely a few small epidote grains are found grouped in the interior of a phenocryst. Otherwise the feldspar is unaltered with the exception of a little highly birefringent mineral which is also sparingly scattered thru the groundmass.

Epidote is also found in many small irregular grains usually associated with a bordering mass of iron oxide and apparently occupying a former feldspar phenocryst. The alternation of the phenocrysts is generally observed to proceed in successive stages by the increased introduction of iron oxide in larger and larger amounts which has a spherical outline. Leucoxene is prominent. It is chiefly associated with the iron oxide and surrounds it as a rather wide border. It is found, as well, along the edges of the feldspar phenocrysts in masses of numerous grains. At intervals an apatite crystal was observed included in the phenocrysts or associated with the impregnation of the iron oxide into the areas of alterations.

b) The Hematite Veins

The contact between ore and porphyry or gangue minerals is extremely irregular and shows many deep embayments and protrubences. The embayments are angular with some suggestion of the feldspar phenocrysts of the porphyry in outline or of the blade shaped silicate associated with the vein ore. Occasionally an angular fragment is only partly penetrating into the ore with the part projecting out from the ore partly if not completely bordered by a band of the hematite. The numerous inclusions lying well within the hematitle and the others partly surrounded by the ore shows the successive stages of encroachment. In some areas thin plates or scales of the hematite stand out at a constant angle from the main mass. The plates are frequently intersecting and the angular spaces within are filled with gangue. This is an especially characteristic feature of the garnet boundary.

The ore veins are highly fractured and brecciated with the fractures filled with gangue. It also encloses well distributed inclusions of great variation in size, shape, amount and composition.

The presence of the ore has very slight effect upon the porphyry. There is practically always a border of gangue between the ore and the porphyry and in the one exception noted in which a mosaic of quartz is not a prominent feature, there is a band of leucoxene along the ore. The leucoxene is found in spherical masses around the individual grains and small masses separated from the vein and along the entire veinwall as a comparatively wide band.

Beyond this border of gangue next to the ore there is often a stringer of ore of irregular width and shape lying roughly parallel to the contact and next to the porphyry. Then there is a decreasing amount of introduced hematite grains and masses in the porphyry with increasing distance from the contact until normal conditions are resumed. With the exception of this increased amount of iron oxide and a slight but variable addition of gangue material and alteration adjacent to the contact, the porphyry has no different characteristics with increasing distance from the ore contact. There is an occasional fracture cutting across the porphyry and filled with varying amounts of hematite and gangue but even this causes no alteration in the porphyry.

When the hematite comes directly in contact with the porphyry it has an irregular shape and frequently the phenocrysts show replacement by the hematite along fractures and cleavage planes.

c) The Gangue.

The gangue minerals associated with the ore are

Quartz.	Tremolite.
Garnet.	Chlorite.
Calcite.	Leucoxene.
Epidote.	Apatite.
Rutile.	

Quartz - Quartz is the chief gangue mineral and it is exceptional when entirely absent. It occurs mainly as a comparatively wide mosaic of grains between the ore and the porphyry. Next in importance are the numerous and branching veins cutting across the ore or filling the fractures. In this latter case it is found in widely varying grains from extremely fine to large irregular sizes. It is also present as a groundmass or filling between the other gangue minerals.

The Quartz lying between the ore and the porphyry is usually quite fine grained which however, shows an increase in size towards the ore away from the porphyry. Yet it is never more than double or triple in size in that case. Here it fills the embayments and the inclusions in the ore and acts as if there had been replacement of the earlier materials. This border is free of hematite grains in contrast to the adjacent porphyry, which has a larger quantity of iron oxide than normally.

In the minute veins in the ore it is relatively fine grained, whereas in the large veins and fractures it has crystalized into good sized grains and shows uneveness in extinction. It is filled with gas or liquid inclusions in fine wavy streaks when in large grains. Yet the grains are regularly consistent in size within certain limits for each particular type of habit. The majority of the veins are irregular but have a general parallelism. Possibly this is accounted for by the size of the veins of ore or small areas of ore which could be found in the thin sections and will not hold for larger veins of ore. Nevertheless, this parallelism shows a significant feature for the angular fragments, now separated by quartz, could be matched into place again if the quartz was removed. In the veins, especially the larger ones, many inclusions of hematite fill the interstices between the quartz grains.

Garnet - Next to quartz garnet is the most conspicuous of the gangue minerals. It is abundant as yellowish shagreen euhedral grains embedded in quartz or at times in a very fine grained groundmass which could not be resolved ~~by~~ but showed resemblances to the groundmass of the partly altered porphyry. In some areas, very fine grained calcite forms the majority of the groundmass. Otherwise the garnet, and perhaps the larger portion, is massive and irregularly fractured without crystal outline. An equally important feature is its formation along the contact of the hematite where it is slightly deeper in color. It surrounds the plates and scales of the hematite and fills the interstices of the ore. Besides, it is found in inclusions and highly intermixed with the hematite ranging from a larger proportion of hematite to a larger proportion of garnet.

Furthermore, there is a less frequent association of garnet and ore in which the hematite apparently tends to replace the garnet along fractures and cleavages as well as forming cores and outlines of the garnet. And even less frequent than this is the opposing evidence of garnet veins cutting across the hematite. In one section several strings or veins of garnet were seen crossing an inclusion in the ore as if it had been formed in fractures. In this last case, however, the garnet made a border between the inclusion and the ore as well.

One remarkable feature is that part of the garnet is anisotropic and shows excellent zoning by alternating dark and light bands, This garnet was found to be optically uniaxial and positive and frequently in euhedral cubes and dodechedrons.

A chemical analysis to determine the constituents was considered but since separation of sufficient garnet from included hematite grains and other gangue minerals was unsuccessful resort was made to optical methods. By use of high temperature melts above the indices obtainable by index liquides the garnet was found to correspond to andradite.[1]

Calcite - Calcite is abundant but more localized than either quartz or garnet, and generally in very small grains. In some of the fractures in the ore it is isolated and surrounded by quartz or chlorite and assumes a larger grain size. Singewald and Milton[2] state that it has an unusual sphereulitic development. Some suggestions of such a development was observed but it appeared to be too poorly orientated to form a true sphereulitic mass altho the grain was exceedingly fine. When not associated with the quartz veins it is found replacing the garnet and filling the interstices of the ore.

One or two instances were noted where calcite had replaced euhedral grains embedded in the quartz.

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1. Dana-Ford; - A textbook of Mineralogy. Third edition, 1922, page 507.

2. Singewald and Milton - The Iron Ore of Iron Mountain and Pilot Knob. A.I.M.E. Trans. (Year Book), 1929, page 330.

It is considered that the mineral replaced was apatite from its perfect crystal outline.

Epidote - Epidote is scattered thru the mosaic of quartz in sparse quantities and at times in the silicate inclusions. It is usually in small irregular aggregates of a few small grains similar to its occurence in the porphyry. A few well formed grains embedded in quartz along the hematite contact is limited to a small area as well as being in the interstice between the ore and quartz.

It is sometimes associated with a light yellowish green material which under crossed nicols retains the greenish color and is shown to be a coloration of the quartz mosaic which is seen thru it. The epidote has the characteristic variations of birefringence colors. It is rarely found in close association with the garnet or in the fractures in the ore.

Tremolite - Several large blade like inclusions in the ore composed of a mosaic of medium ground quartz carries numerous colorless to pale green needles of tremolite. The needles are generally in parallel direction altho radiating masses are present. It ranges from a few isolated needles in individual quartz grains to quartz practically replaced by the tremolite. Garnet may be associated with the area in which the tremolite appears but it is usually absent.

Chlorite - Chlorite occurs as light green scattered masses and fine grains in the gangue minerals and interstices in the hematite. It is abundant as a vein filling associated with quartz and calcite and frequently is found with the tremolite.

It varies in size of grain and amount of birefringence. Usually it is very fine grained and with low birefringence but has gathered to form flakes of good size with a slightly higher birefringence.

Leucoxene - The occurence of leucoxene intimately associated with the hematite has been previously noted. It regularly forms spherical masses of white opaque grains along the hematite contact and is extremely limited in distribution. A few grains of the hematite ore was tested for titanium by the Hydrogen Peroxide method[1] which only gave

1. C. H. Warren - Determinative Mineralogy, second ed. 1922, page 69.

negative results.

Apatite - Very little apatite was observed. A few crystals were seen associated with the quartz. DeVaney and Cooke[1] found the Iron Mountain ore to contain only traces of phosphorous and say "in view of the consistently low value of phosphorous in the ore the amount of apatite must necessarily be low."

Rutile - Many of the quartz grains contained a few scattered to numerous dark hair like needles. The large crystals were light brown but were not of sufficient size to determine optical properties. It had a high index as well as a high birefringence. From the properties shown it is considered to be rutile. None of the leucoxene appeared in association with it.

The undetermined silicate in the altered veins cutting the porphyry and earlier than the ore was so badly altered in the thin section as to render it impossible of determination by petrographic methods. Difficulty was also met with along other lines of analysis. Listed below is its characteristics, and

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1. DeVaney & Cooke - Bulletin #3, Technical Series Vol. II, May 1928. School of Mines and Metallurgy, Univ. of Missouri.

a comparison to the Diopside - Hedenbergite series[1] to which it may possibly belong.

Property	Silicate	Diopside-Hedenbergite
Color	Pale green	Colorless to greenish black.
Crystal	Prismatic	Short prisms.
Cleavage	Prismatic	Prismatic
Figure	Biaxial	Biaxial
Sign	Plus	Plus
Optic angle	Medium to large	59°-60°
Mean index	1.695	1.678-1.745
Birefringence	0.20-0.25	0.30-0.18
Extinction	38°-45°	38°- 48°
Pleochroism	Absent	Lacking except in ferrous types.

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1. Winchell - Elements of optical crystallography, Part II 1927 page 183.

d) Polished Sections.

The specular hematite was white in plane reflected light and changing from white to dark grey in polarized reflected light when turned on the microscope stage. The anisotropic character of the ore was marked. Inclusions of other metallic minerals were not observed in polarized light but in plane reflected light with high magnification several small grains of brownish magnetite could be distinguished. From the character of the irregular contact between the magnetite and the hematite it appears as if the hematite was replacing the magnetite. In no case was the magnetite tending to run along the cleavage planes of the hematite while the somewhat compact magnetite was more strongly embayed by the hematite.

The hematite occurs in rounded to oval irregular grains of medium size often enclosing small grains in the interstices and with a slight change in grain size which is not prominent however. Plate XI shows the typical grains.

Along some of the contacts between gangue and ore much finer grains appear as will be seen in Plate

XII. These fine grains are normally intermixed with the gangue. The border between the two grains sizes is rather sharp altho irregular with frequent indentation of the main mass by the finer grains.

Lamellar texture is not abundant. Some areas are characterized with distinct lamellation which occurs in two habits. The irregular, ragged comparatively wide type is quite limited and was only found near the quartz veins. It is shown in Plate XIII to extend in three directions at quite constant inclinations with each set of lamellar. This structure is explained by the growth along rhombohedral faces which are viewed on a plane cut parallel to the base of the crystal.[1] The other type is shown in Plate XIV. It consists of thin lamellar intersecting at nearly right angles within individual grains and is greatly in excess of the first type. The angle of intersections is due to geometrical relations of the rhombohedral faces which meet at a 94 angle. Schneiderhohn and Ramdohr

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1. Dana-Ford - Textbook of Mineralogy, 3rd edition 1922, page 415.

refer to this latter type as a common occurence of twinning.[1]

Fine to large inclusions of gangue are numerous and well distributed with a greater preponderence of the finer sizes. The larger inclusions have the same relations as observed in the hand specimens and thin sections. The small inclusions are of various shapes and sizes. They occur as blebs, stringers, rounded masses and irregular shapes. In several instances there is a certain parallelism or alignment of these inclusions especially of the stringers. In polarized light a part of these inclusions showing alignment are seen to replace the hematite lamellar plates. Others, however, are observed to cut across them without deviation.

The inclusions tend to be more abundant nearer the larger ones and along the quartz veins. The contact between the ore and the gangue is often sharp but usually quite irregular with embayments or small

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1. Schneiderhohn & Remdohr - Lehrbüch der Erzmikoskopie II Band 1931 page 525.

indentations or even branching out into veins across the ore. There is frequent occurence of grains and amall masses of the ore embedded in the veins. The common characteristics of a garnet border along the contacts is shown in reflected light by the different lustre of the garnet and the groundmass.

The ore-porphyry contact appeared in its normal habit of angular embayment and angular inclusions wholly or partly surrounded by the ore. Plate XV is an example of this contact.

The veins of gangue crossing the ore are numerous and variable in sizes from minute cracks to broad quartz veins. They are irregular, changing in size and with an uneven contact with the hematite. Plate XVI illustrates the fractures filled with quartz. The angular character is especially well developed and shows that the ore might be rematched if the gangue is removed. Abundant areas of this character were observed throughout the ore.

In general it is clearly shown that the inclusions are formed with and after the ore while the veins are probably due to the fracturing of the ore.

VIII PARAGENESIS

A study of the relations of the gangue minerals brings out the probable sequence of mineralization. The relations are not absolute since many were not in close association.

The order of sequences beginning with the earliest is

Veins of Unknown Silicate.

Ore of Specular Hematite

Apatite

Garnet-Leucoxene.

Epidote

Calcite

Chlorite

Quartz

Tremolite

Rutile

Veining by Quartz.

The problem of quartz in two generations was complex. It is earlier than tremolite but also later than the other minerals and still later than the tremolite as shown by veins cutting across the tremolite needles.

Leucoxene was earlier than calcite but since it was limited in occurence with the other minerals its position is doubtful. Apatite only occured embedded in quartz and may be the most doubtful of all but has been placed in close association with the ore.

CONCLUSIONS

The deposition of the hematite by fissure filling and replacement of the porphyry is fully supported by its relations. The relative amount of replacement compared to fissure filling cannot be exactly determined. That it is a relatively large part if not the major portion cannot be refuted. It appears from the laboratory work as if replacement was the major phase.

That the condition of the ore at the time of introduction was in solution is supported by its habit. Schneiderhohn and Ramdohr[1] state that tabular structure which is abundant as plates and scales denotes hydrothermal development. The temperature has been considered to approach that of a magma.

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1. Schneiderhohn & Ramdohr - Lehrbuch der Erzmikoskopie II Band 1931 Page 525.

Its mineral association of garnet, apatite and anphibole, places it in the Hypothermal deposits of Lindgren[1] which range from 300° to 500° C. Since the ore was apparently early in the mineral sequence it was injected during the stage of highest temperature. Further proof of this range of temperature is again furnished by Schneiderhohn and Ramdohr[2]. They consider that the structure at high temperature is always compact and usually isometric. Since no evidence of isometric character was observed the temperature was well below a magmatic range.

Brecciation on the walls of the fracture is evidenced by the fine non-lamellar grains along the quartz vein contact. It has been determined that recrystallization does not develop lamellar intergrowth.[2]

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1. Lindgren - Mineral Deposits 3rd edition 1928, page 719.
2. Schneiderhohn & Ramdohr - Lehrbuch der Erzmikoskopie II Band 1931 page 525.

Hence the temperature did not reach high temperatures to any extent as such intergrowth is confined to the borders of the quartz veins.

Whether the ore was introduced as magnetite and oxidized to hematite is problematical. If such occured some evidence of magnetite structure should be retained by the hematite. Since this is not the case oxidization might be considered unlikely. The inclusions of fine magnetite, however, points to evidence of this oxidization.

The sequence of events thru which this area has passed to form these ore deposits has been outlined in the following manner;[1]

1. Extrusion of the igneous rodks, porphyry followed by granite.
2. Fracturing due to contraction on cooling.
3. Injection of silicates in porphyry fractures.
4. Intrusion of hot iron bearing solutions.

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1. G. W. Crane - The Iron Ores of Missouri; Missouri Geological Survey Vol. X 1912.

5. Erosion of area.

6. Intrusion of basic dikes at close of mineralization.

7. Deposition of Cambrian sediments.

8. Erosion of sediments and igneous rocks to form surface boulder ore.

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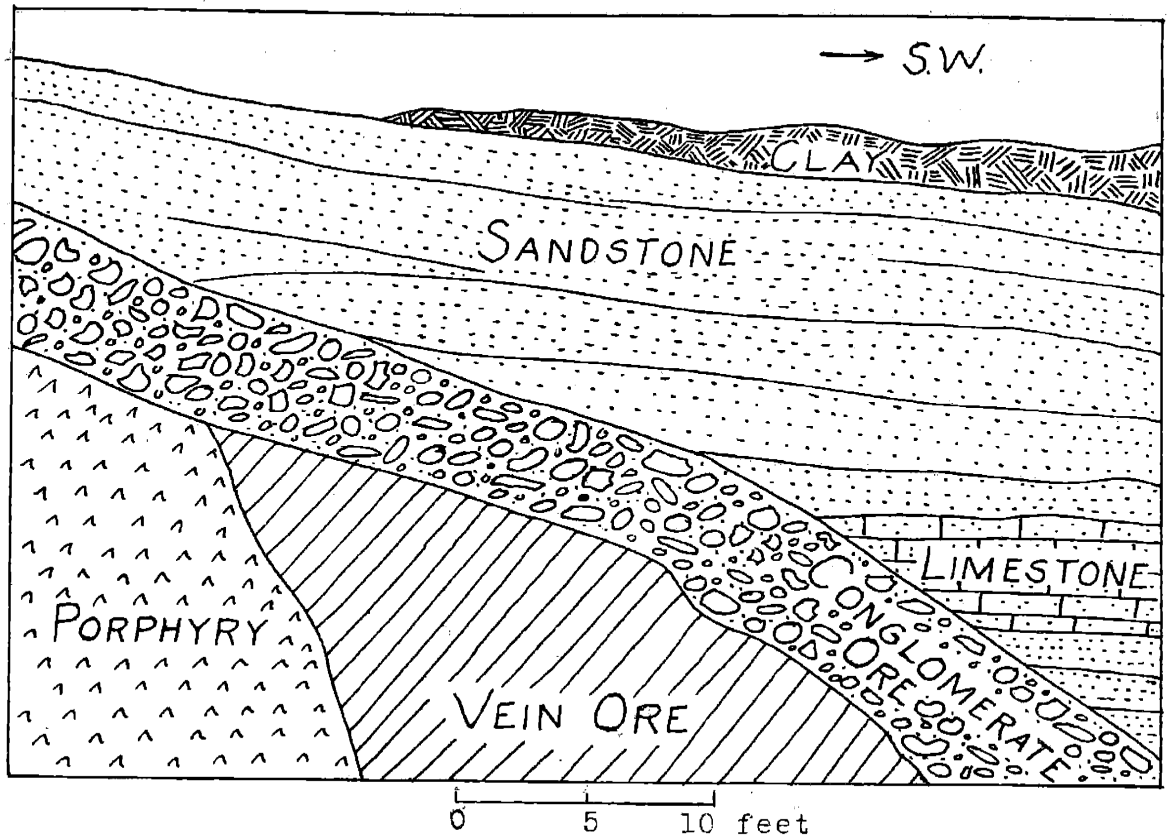


Fig. 1 Sketch of Conglomerate Ore at Iron Mountain

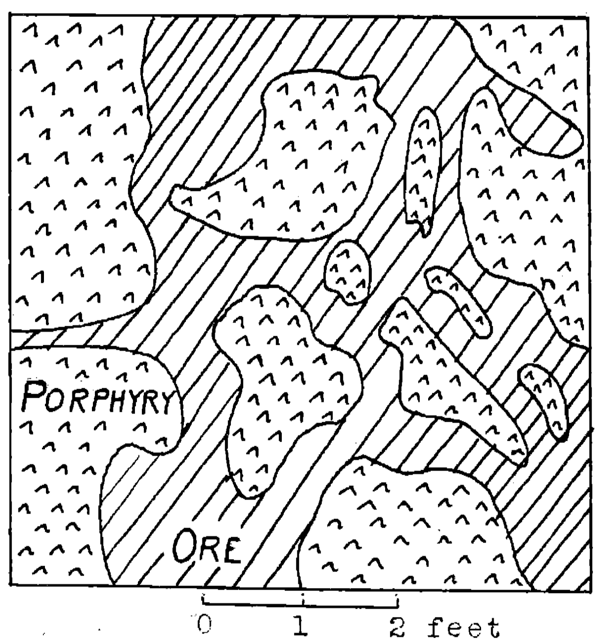


Fig. 2 Sketch of Ore Wall at Little Mountain cut.

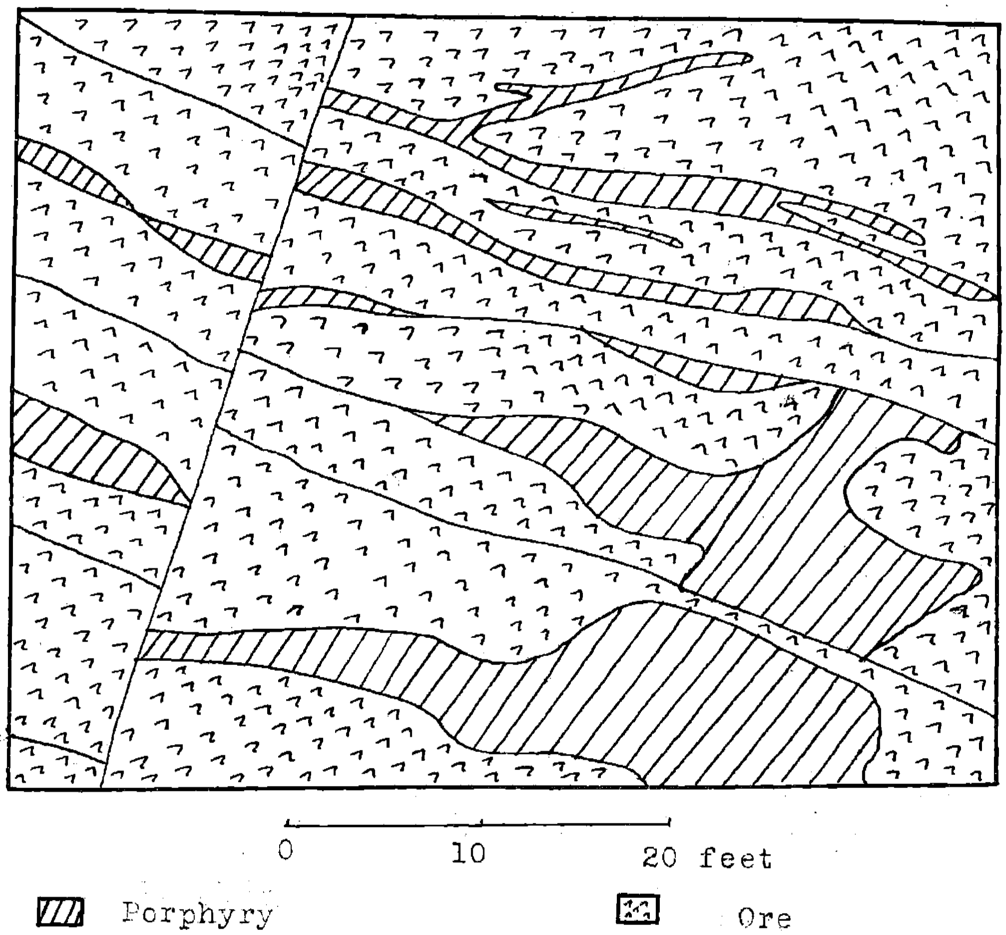


Fig. 3 Sketch of North face at Big Mountain

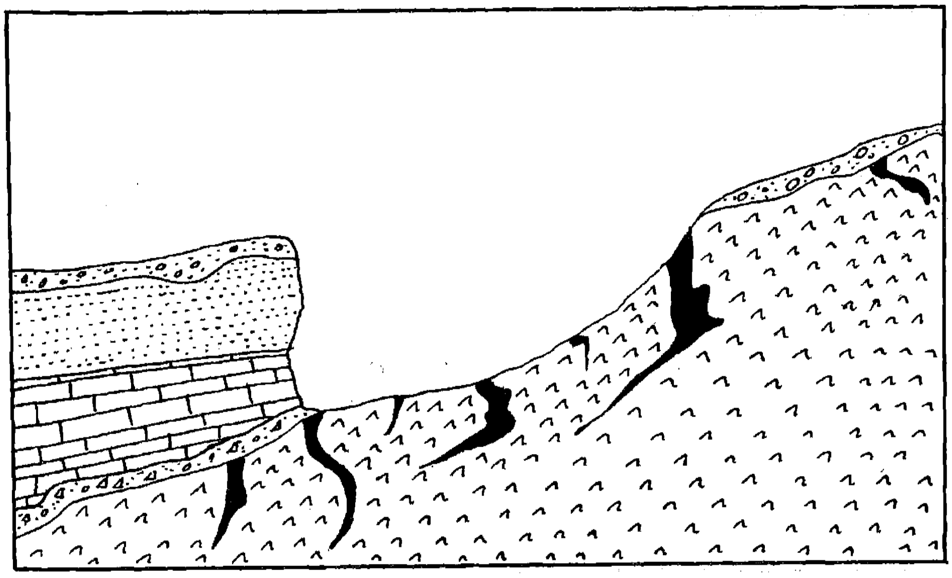


Fig. 4 Sketch of Little Mountain open pit cross section

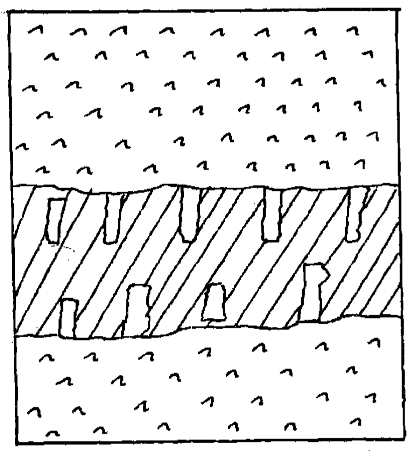


Fig. 5

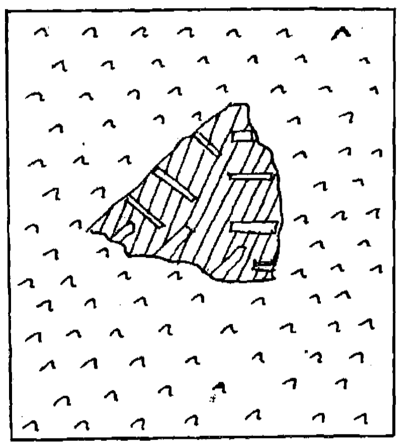


Fig. 6

Sketch of Silicates and Iron Ore

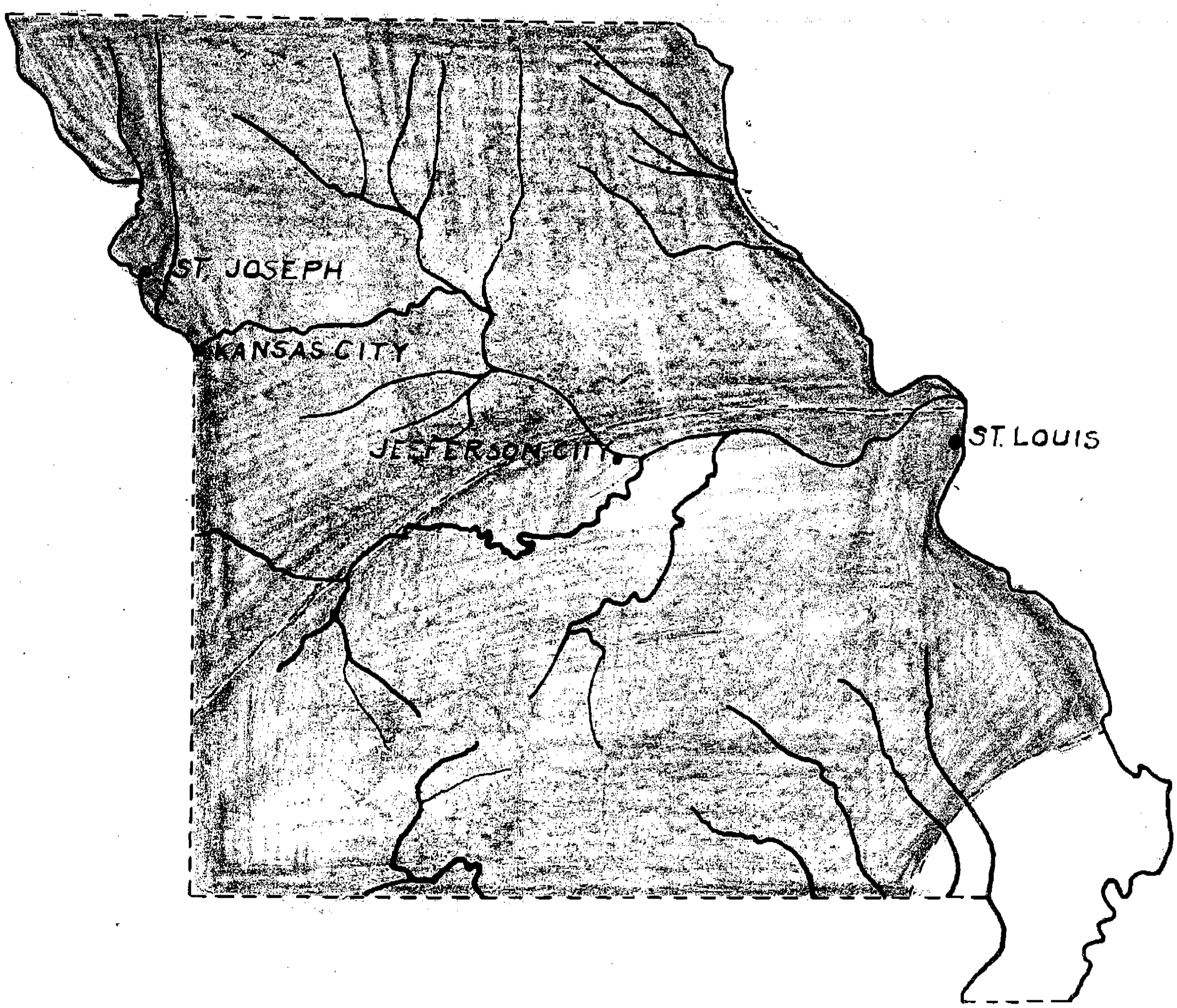
PLATE I

Legend

Blue- Upland Plain

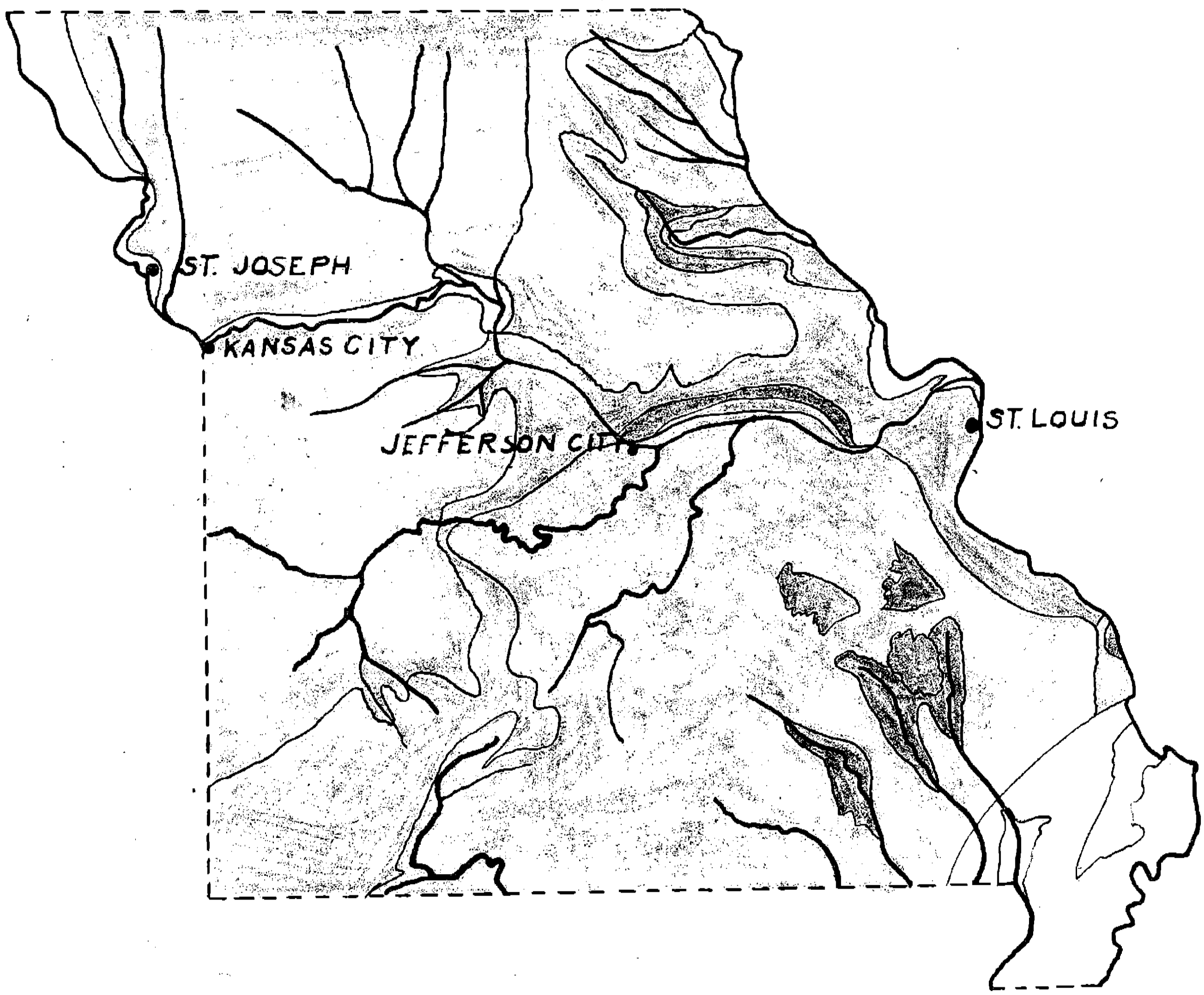
Brown- Ozark Plateau

Yellow- Swamp Area



STATE OF MISSOURI

PHYSIOGRAPHIC CHART



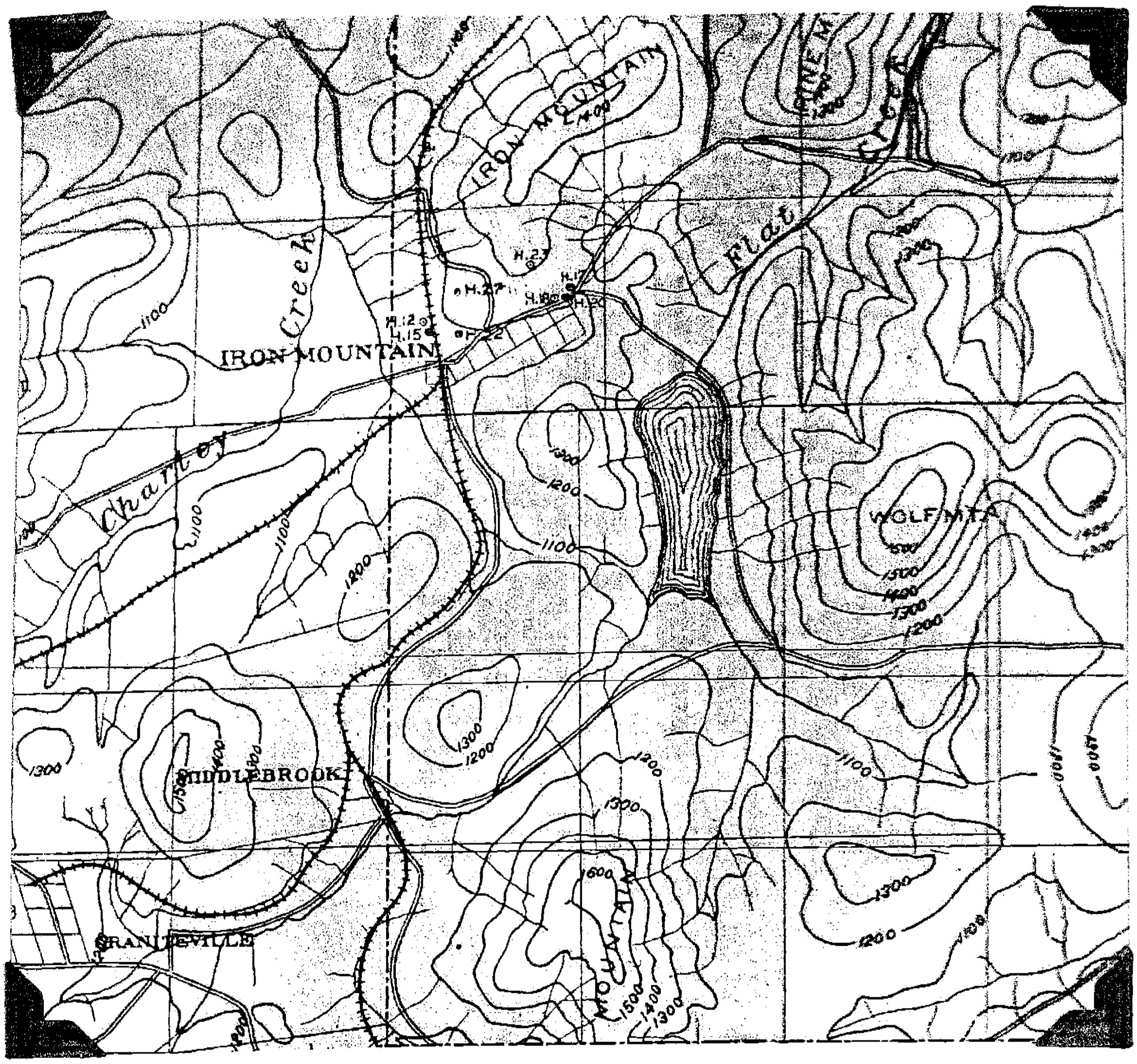
GEOLOGICAL MAP

STATE OF MISSOURI

Red - Igneous
Brown - Cambrian
Pink - Ordovician
Orange - Silurian
Purple - Devonian
Blue - Mississippian
Green - Pennsylvanian
White - Tertiary
Yellow - Quaternary

PLATE III

GEOLOGICAL COLUMN



Vicinity of Iron Mountain, Missouri

PLATE V

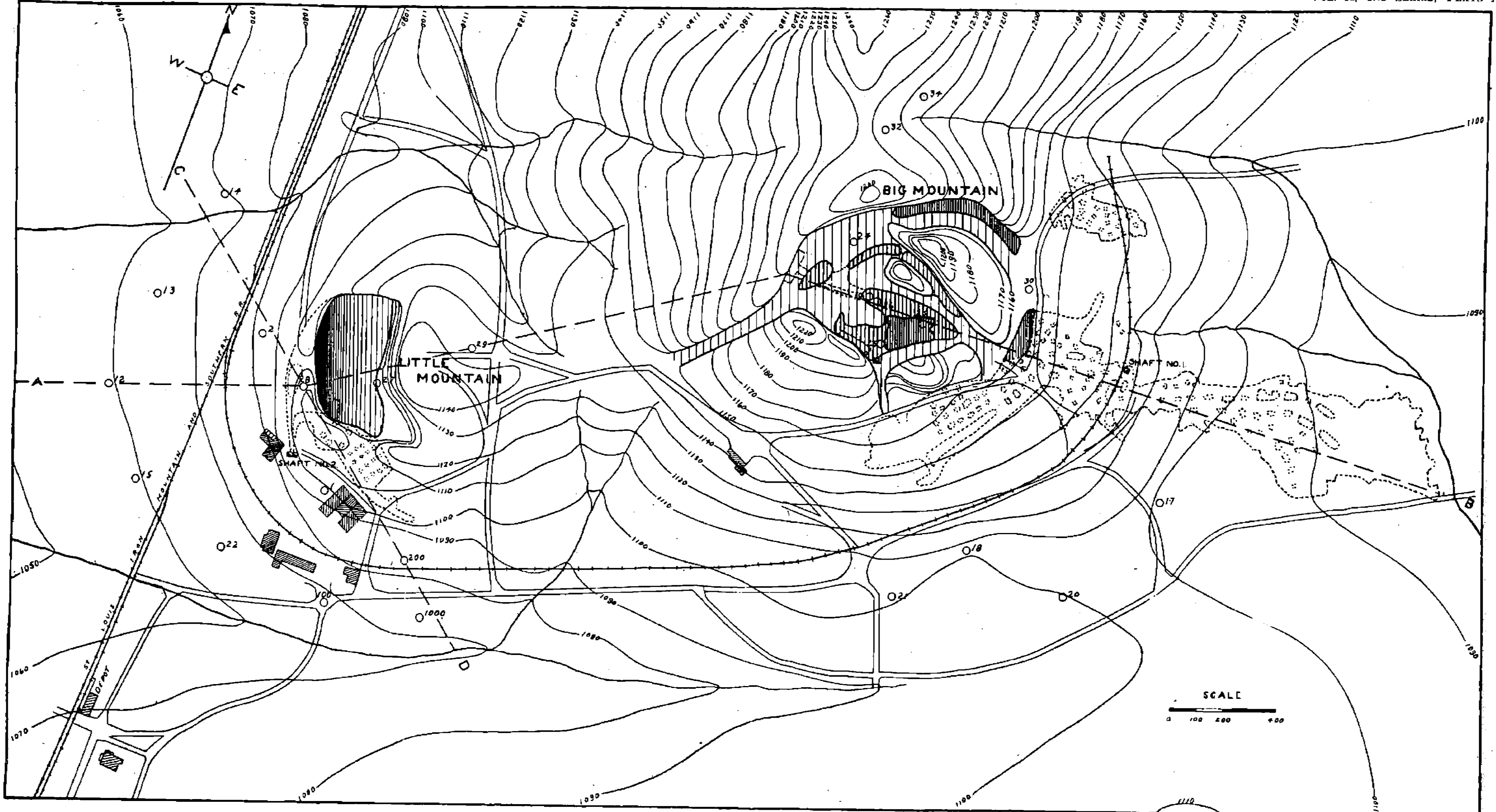


Fig. 1. TOPOGRAPHIC MAP OF IRON MOUNTAIN, SHOWING OPEN PITS AND UNDERGROUND WORKINGS AT BIG AND LITTLE MOUNTAINS.

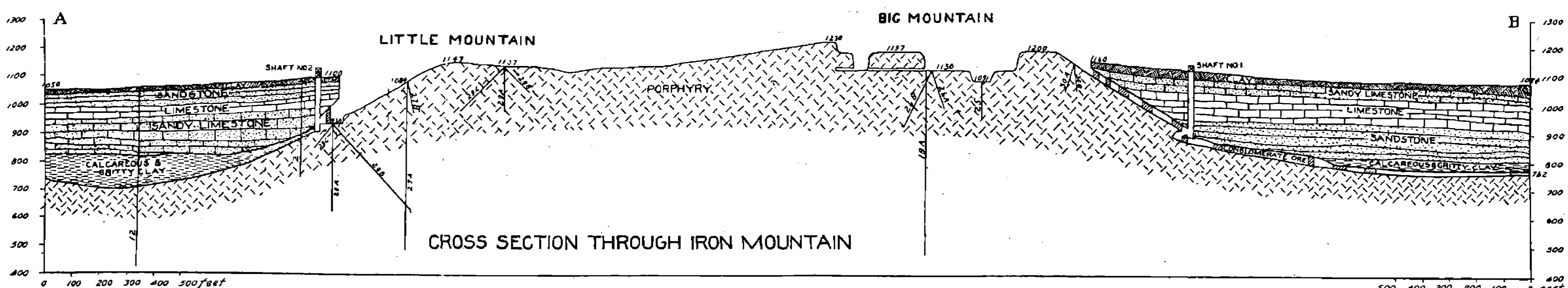
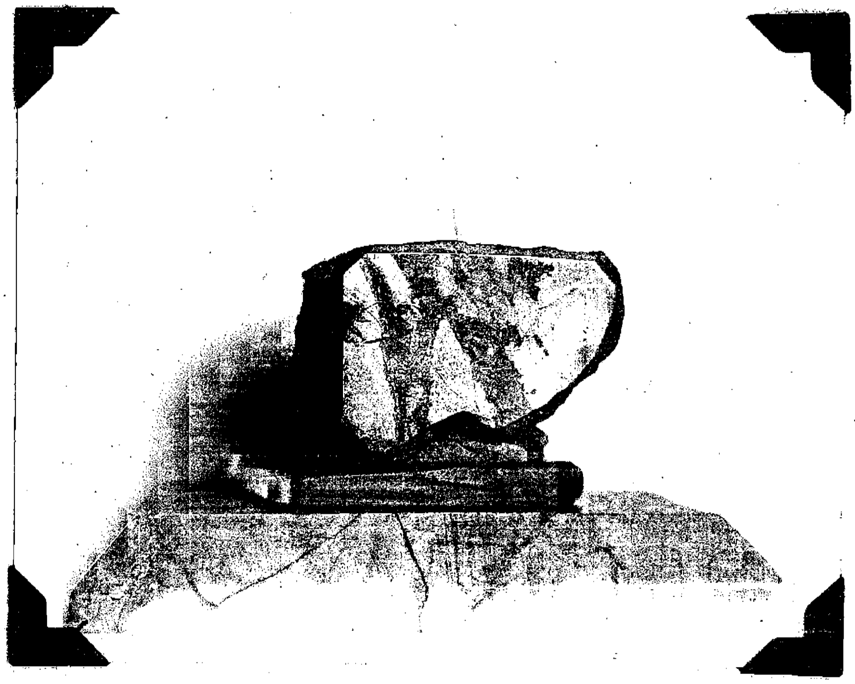


Fig. 2. PROFILE OF BIG AND LITTLE MOUNTAINS ALONG THE LINE A-B, Fig. 1. COMPILED FROM DRAWINGS BY W. B. POTTER.



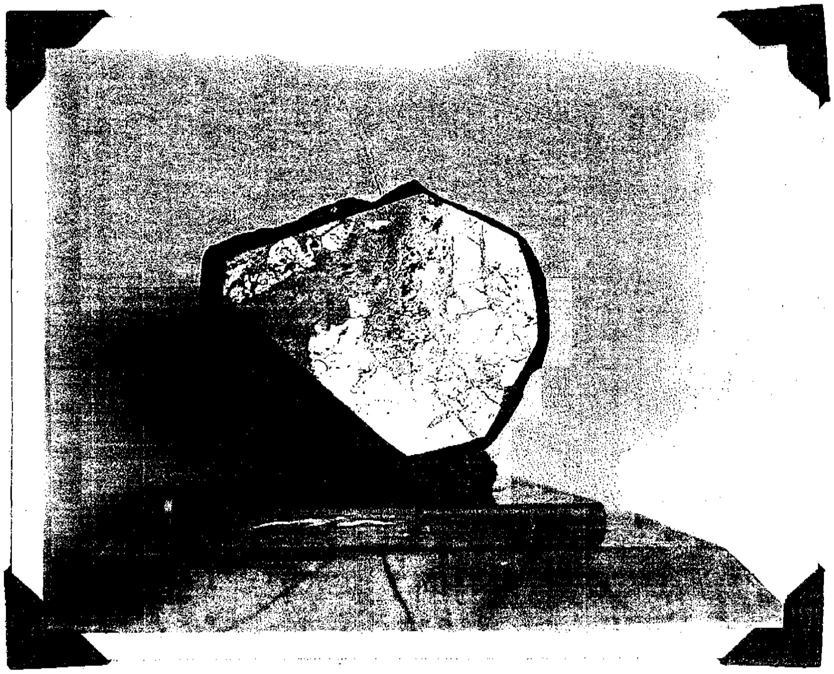
Veins of Garnet cutting across hematite ore

(One half size)

Light - Hematite

Dull - Garnet

PLATE VII



Garnet surrounding brecciated hematite ore.

(One half size)

Light - Hematite

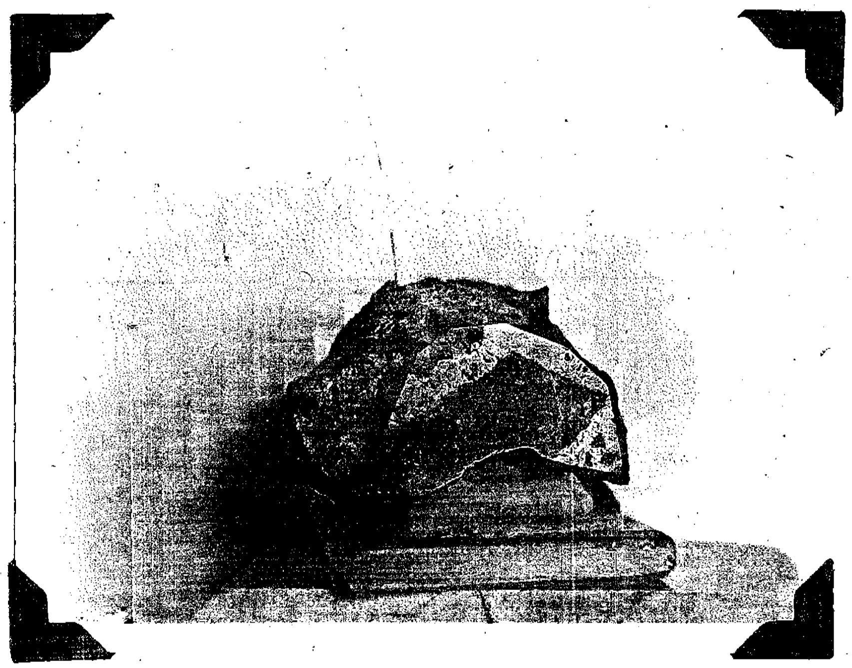
Dull - Garnet

Blade - shaped Silicates in ore along porphyry wall

(One half size)

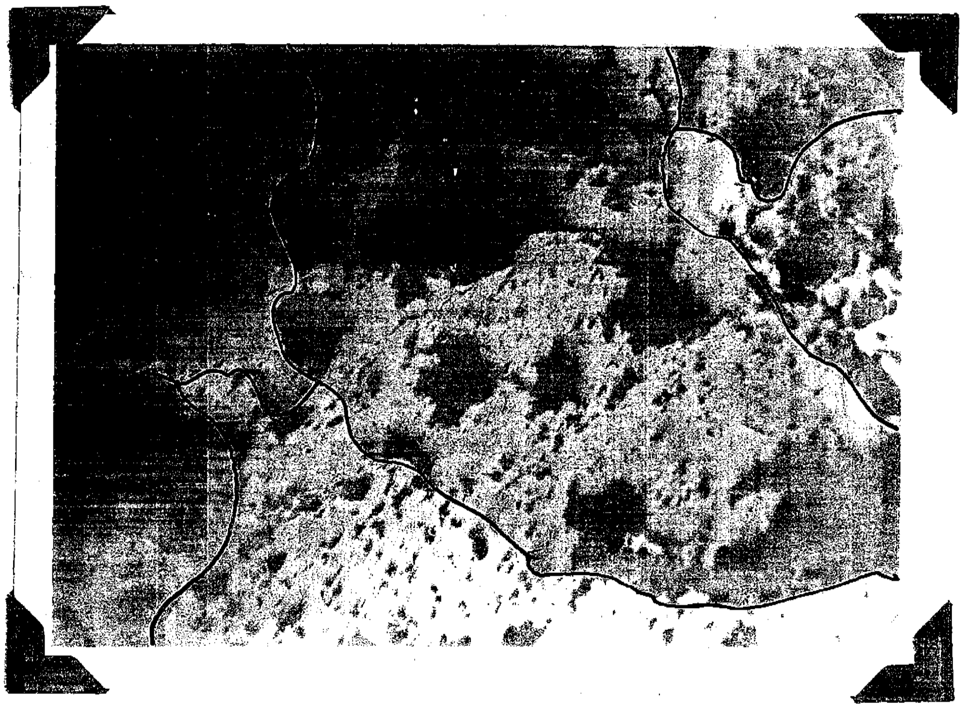
Blade - shaped silicates in ore along porphyry wall.

(One half size)



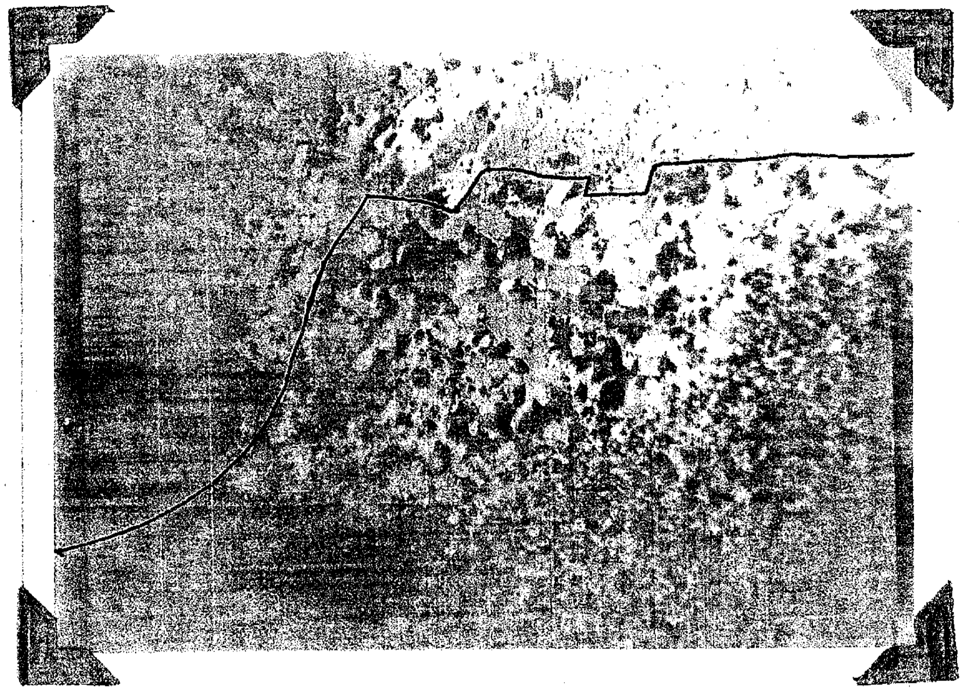
Inclusion of prophyry in hematite vein cutting through porphyry.

(One half size)



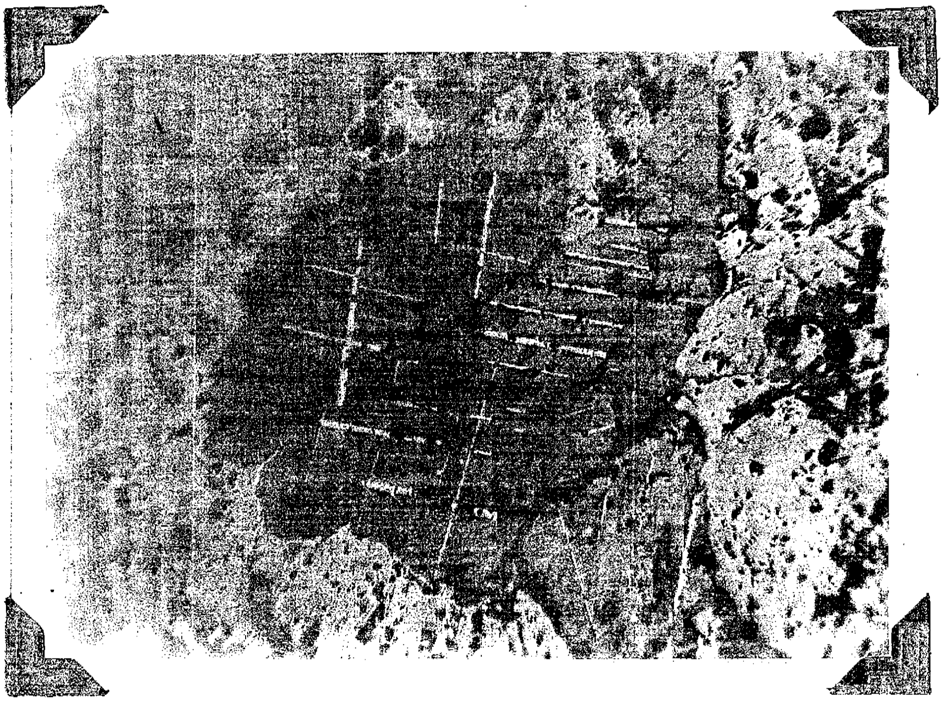
Hematite in polarized light and showing the typical grains.

Magnified 100 times



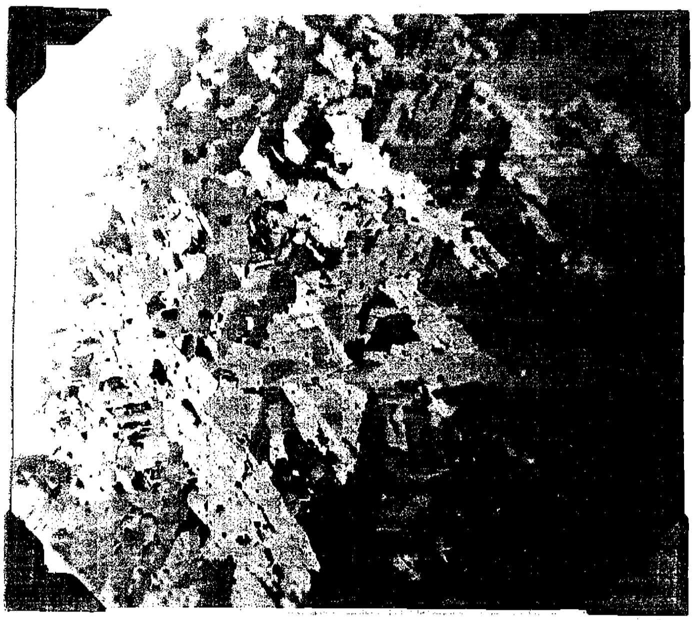
Fined grained hematite bordering the coarse grained hematite.

Magnified 100 times



Hematite in polarized light showing thin lamellae at nearly right angles.

Magnified 100 times



Hematite in polarized light showing intergrowth along rhombohedral planes.

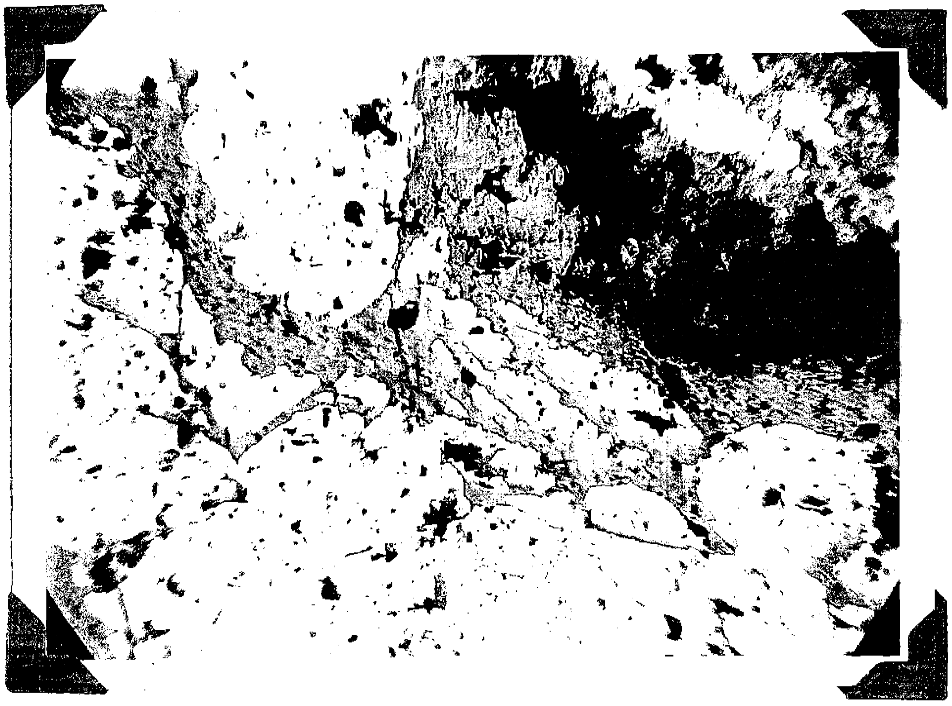
Magnified 100 times

Contact of hematite and porphyry showing porphyry inclusions in the hematite.

Magnified 100 times

Light - Hematite

Dull - Porphyry



Quartz vein cutting across the hematite and showing brecciated area in the hematite.

Magnified 100 times

White - Hematite

Grey - Quartz