Do Not Sale!

BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES

Volume 20, Part 1 — January 1973

CONTENTS

Brigham Young University Geology Studies

Volume 20, Part 1 — January, 1973

Contents

A publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Editor

Jess R. Bushman

Brigham Young University Geology Studies is published semiannually by the department. *Geology Studies* consists of graduate student and staff research in the department and occasional papers from other contributors.

Distributed January 31, 1973

Price $4.50

Geology and Iron Deposits of Iron Springs District, Iron County, Utah

KENNETH C. BULLOCK

ABSTRACT.—Iron Springs district is the largest iron-producing district in the western states; as a result, Utah is the fifth ranking state in the nation in iron-ore production. The district lies on the east edge of the Basin and Range province in southwest Utah. Ore bodies lie 12 to 20 miles west of Cedar City in Iron County. Several open pit mines in operation are controlled by three major iron-producing companies. Iron ore was discovered in 1849; commercial production started in 1923.

Iron deposits are clustered along the margins of three quartz monzonite porphyry intrusions that form the dominant topographic features of the area. These intrusives form the Iron Mountain, Granite Mountain, and Three Peaks bodies. Exposed intrusions are oval in plan, are three to five miles in diameter, and are aligned in a northeast direction. Jurassic, Cretaceous, and Tertiary sedimentary rocks and Tertiary volcanic rocks flank the intrusive bodies. Margins of two intrusions are complexly folded and faulted.

Principal iron-ore minerals are hematite and magnetite. The ore occurs as igneous-metamorphic replacements and breccia fillings mainly in Jurassic limestone, but also occurs in younger strata and porphyry intrusions. Small fissure veins of magnetite occur in all three porphyry intrusions. From 1923 through 1971 the Iron Springs district produced 83,618,141 long tons of iron ore. Estimates based on drilling operations, geophysical data, and geologic information indicate a probable ore potential in the district to be more than 300,000,000 long tons.

CONTENTS

Location

The Iron Springs mining district lies on the east edge of the Basin-and-Range province in southwest Utah, about 20 miles west of the Markagunt Plateau and the Hurricane fault scarp which form the west boundary of the Colorado Plateau. Ore bodies lie from 12 to 20 miles west of Cedar City in Iron County and occur in T. 35, 36, and 37 S., R. 12, 13, and 14 W. (See Text-figure 1). Iron Springs district is the largest iron ore-producing district in the western states. Several open-pit iron mines are in operation in the district and are controlled by three major iron producing companies. Originally the Iron Springs district included only Granite Mountain and Three Peaks deposits and the Pinto district included Iron Mountain operations. The Iron Springs district now includes the three iron-producing areas, covering a region about 4 miles wide and 21 miles long.

Stages of Iron Industry

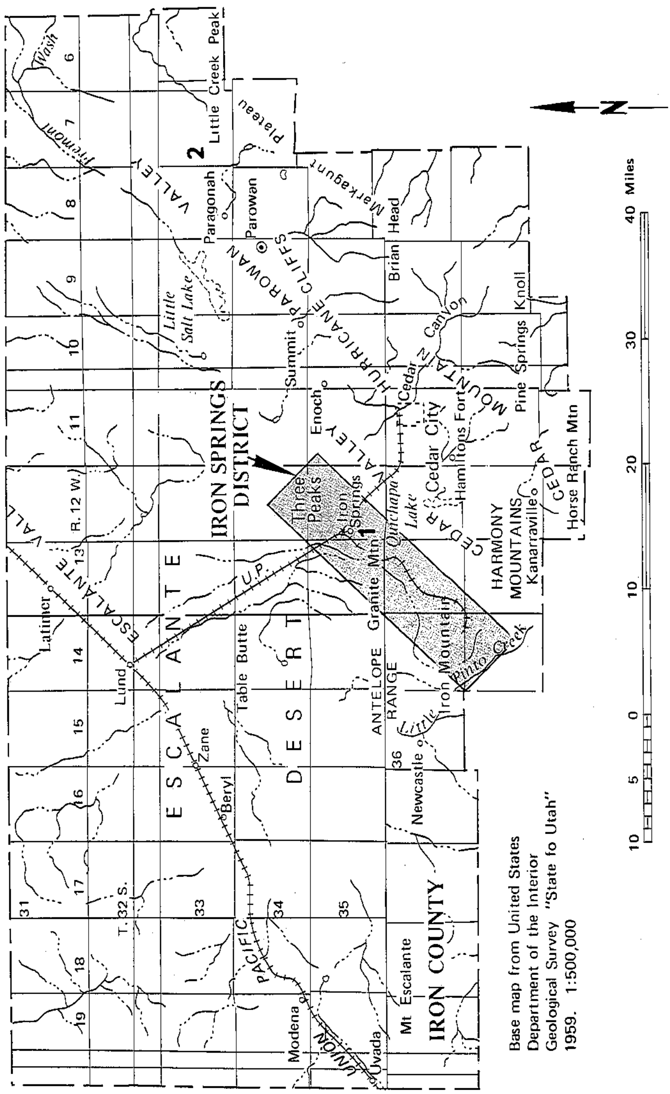
Iron ores in Utah were first discovered in 1849 in the Iron Springs district in Iron County, and major iron production from this district began in 1923. During the past half century the Iron Springs district has become the largest iron-producing district in the western states, making Utah the fifth state in the nation in iron-ore production. The Utah iron mining industry may be divided into five stages in time over the past 120 years.

The first stage, from 1849 through 1884, marked by Mormon pioneer efforts to produce iron from Iron County deposits, was doomed to failure principally because of lack of funds and good coking coals and because of the competition of cheaper imported iron products after the completion of the Transcontinental railroad through Utah. Only a few thousand tons of iron ores were mined and processed into finished products.

The second stage, starting about 1869 with the coming of the railroads to Utah and continuing until about 1922, marked the development of the nonferrous mining industry in Utah and the use of iron ores, chiefly limonite gossans, for fluxing purposes in the smelting of lead, copper, zinc, silver, and gold ores. Several hundred thousand tons of fluxing iron ores were used during this time by Utah smelters. Small amounts of magnetite and hematite ores are still being used today.

The third stage of iron mining in the state, the Ironton Works stage, was a 20-year period from 1923 to 1942, marked by the completion of the Ironton blast furnace near Provo. Ore production from the Iron Springs district averaged 230,585 long tons annually, all of it shipped to Ironton. Iron mining was conducted by the Utah Iron Ore Corporation and the Columbia Iron Mining Company during this period.

The fourth stage began with World War II and extended to 1961 with the wartime construction of a huge steel plant at Geneva, near Provo, now known as the Geneva Works and owned by the U. S. Steel Corporation. Production in the Iron Springs district averaged 2,108,820 long tons annually during this time. The Columbia Iron Mining Company, a subsidiary of U. S. Steel, greatly increased its shipments of ore to the Geneva and Ironton Works. CF&I



TEXT-FIGURE 1.—Location Map of Iron Springs district. *1.* Iron Springs district. *2.* Iron Peak prospects.

Steel Corporation began production from its properties in the Iron Springs district in 1943 and made shipments of ore to its furnaces at the Minnequa Works, Pueblo, Colorado. In 1944 Utah Construction and Mining Company started independent iron-ore production at its properties in the Iron Springs district. Its principal sales were to the Kaiser Works at Fontana, California, and later to foreign markets. In 1958 the company made a long-term contract with U.S. Steel to ship ore to the Geneva Works.

In the fifth stage, after 1961, iron-ore production from the Iron Springs district was curtailed because the Geneva Works used about 1.5 million gross tons annually of taconite ores from U. S. Steel Corporation's operation at Atlantic City, Wyoming. Since 1962 the average annual iron-ore production from the Iron Springs district has been slightly less than 2 million long tons. Taconite ores will continue to compete with iron-ore production in Iron Springs district, since taconite concentrates average more than 60 percent iron content and Iron Springs district ores have averaged 52.7 percent since 1923.

Previous Work

The first concerted geologic investigation of the Iron Springs district was made by Leith and Harder (1908). They mapped the area, described the sedimentary and igneous rocks, discussed some of the exposed ore deposits, and proposed a contact metamorphic origin for the ores. The work of Leith and Harder was accepted with little question for several decades. Butler (1920) made a brief study of the district and expressed agreement with the work of Leith and Harder; however, he regarded the intrusive bodies as stocks rather than laccoliths. Rohlfing (1923) and MacVichie (1925, 1926) described some of the known ore bodies in the district based on outcrops and shallow development workings.

A detailed investigation of the Iron Springs district was started during World War II by J. H. Mackin of U. S. Geological Survey as a strategic mineral project. Plane-table mapping of mineralized border zones of intrusions was accompanied by magnetometer surveys and diamond drilling by the U. S. Bureau of Mines. Final reports covering magnetic studies and drilling were published by Young (1947), Allsman (1948), and Cook (1948, 1950). A preliminary geologic report on structural control of mineralization, with a map of the Three Peaks intrusion, was published by the Utah Geological and Mineralogical Survey (Mackin, 1947a). Mapping was subsequently extended throughout the district, and in 1951 a preliminary aeromagnetic map of the district was completed (Dempsey, 1951). In 1954 a geologic map of the Granite Mountain intrusion was published (Mackin, 1954). Jaffe (1959) gave lead-alpha age determinations of igneous rocks in the district, and Bellum and Nugent (1963) and Granger (1963) briefly describe the general nature of ore deposits and mining operations in the district. In their textbook, Park and MacDiarmid (1964) review the literature of the Iron Springs district and describe the general geology and deuteric origin of the ore deposits as proposed by Mackin.

Lewis (1958) and Ratté (1963) made detailed investigations on rock alterations in the Iron Springs district. Slawson (1958) and Dahl (1959) performed detailed trace element studies on ores of the district, and Everett (1967) made a similar study on the Carmel Formation. Magnetic beneficiation and concentration of iron ores in the district are treated by Erspamer (1964), Juvelin (1965), McArthur and Porath (1965), Juvelin and McArthur (1967), and

O'Carroll (1967). Reports on a gravimeter survey (Cook and Hardman, 1967a, 1967b), an aeromagnetic survey (Blank and Mackin, 1967), and a preliminary report on the iron-ore deposits (Mackin, 1968) of the Iron Springs district have recently been published. This writer gives a review of the studies of previous writers in addition to his own investigations and interpretations of the Iron Springs district. Detailed accounts of other investigations can be found in the cited literature.

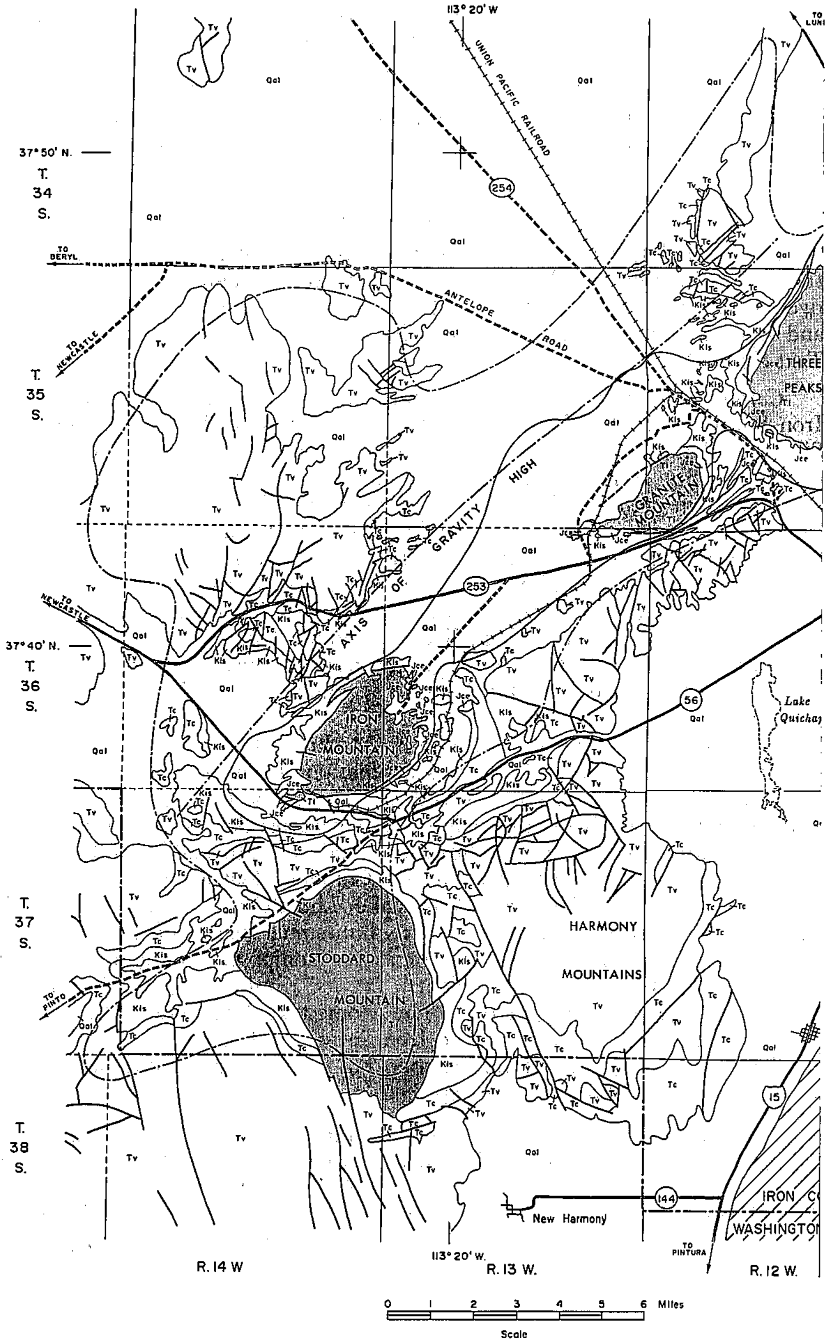
Sedimentary Rocks

Jurassic and Cretaceous sedimentary rocks crop out in the Iron Springs district near the iron-ore deposits. Jurassic marine limestone and siltstone are overlain by Jurassic and Cretaceous terrestrial clastic rocks. Tertiary sedimentary and layered ignimbrite volcanic rocks lie along the fringes of the district (See Text-figure 2).

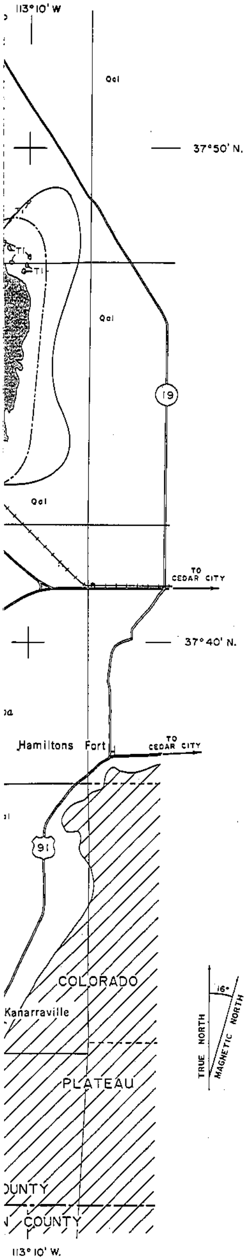
Carmel Formation is the oldest (Jurassic) stratigraphic unit exposed in the Iron Springs district and is composed of the Homestake Limestone and a Basal Siltstone Member. These strata form the innermost of several concentric belts of sedimentary and volcanic rocks around the igneous intrusions. The Basal Siltstone is in contact with quartz monzonite porphyry intrusions and is typically hard, fine-grained, and generally thin-bedded but may be massive. The color varies from light to dark greenish gray or grayish tan. Maroon banding and mottling are common, and rock coloration frequently is spotted or splotchy as a result of irregular alteration. A portion of the siltstone member is noticeably granular and is composed of small quartz grains. The Basal Siltstone varies in thickness to 100 feet, with an average thickness of approximately 50 feet. Variations in thickness are caused primarily by minor crosscutting by the intrusive contact.

The Homestake Limestone Member (Mackin, 1954) of the Carmel Formation consists of massive to thick-bedded limestone from 210 to 300 feet in thickness, averaging approximately 250 feet. It consists chiefly of gray, blue gray, and black limestone that is locally shaly or carbonaceous. Several beds contain a few Jurassic marine fossils which indicate it is equivalent to middle and upper portions of the Carmel Formation in the Colorado Plateau. Leith and Harder (1908) erroneously classified Homestake Limestone as Carboniferous. The upper 5 to 20 feet of the Homestake Limestone consist of light-gray, thin-bedded, argillaceous and siliceous limestone composed locally of soft, gray-green, earthy limestone distinguished by its ripple marks and mudcracks, providing a good horizon marker. The Homestake Limestone is the host rock for the iron-ore replacements in the Iron Springs district. Ore normally replaces the lower half of the limestone member, but with increasing intensity of metallization the full thickness may be replaced.

Entrada Sandstone. The Homestake Limestone Member of the Carmel Formation is overlain conformably by a clastic unit believed to be equivalent to Upper Jurassic Entrada Sandstone of the Colorado Plateau (Gregory, 1950). Entrada Sandstone in the Iron Springs district is quite unlike the red and white beds of friable, gypsiferous sandstone of the Colorado Plateau. In the Iron Springs district it consists of thinly stratified maroon and gray-green shales and siltstones and medium- to coarse-grained gray or gray-green sandstone. A basal unit composed of maroon and gray shale measures about 40 feet thick and often contains blebs of finely crystalline rose quartz and calcite which give the



TEXT-FIGURE 2.—Geologic Map of Iron Springs district, Utah.



CENOZOIC
- Quaternary
  - Qal — Alluvium and lake deposits, undifferentiated
- Tertiary
  - Tv — Volcanic rocks, undifferentiated
  - Ti — Intrusive rocks, quartz monzonite porphyry
  - Tc — Claron Formation

MESOZOIC
- Cretaceous
  - Kis — Iron Springs Formation
- Jurassic
  - Jce — Carmel Formation, Entrada Sandstone, undifferentiated

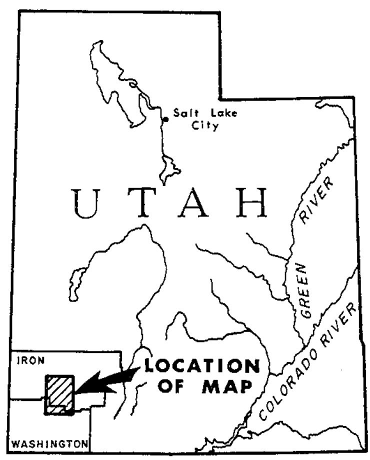
Contact

Fault, dashed where inferred

Outline of Iron Springs intrusions, suggested by U.S. Geological Survey aeromagnetic survey

Outline of Iron Springs intrusions, suggested by gravity surveys (after Cook and Hardman)

Axis of gravity high



INDEX MAP

rock a pink and spotted appearance. An overlying sandstone about 20 feet thick contains deep maroon spots up to one-quarter inch in diameter; it is a distinctive horizon marker throughout the district. Upper Entrada Sandstone consists of medium- to coarse-grained channel sandstone with interbeds of shale and siltstone. Layers of quartz sandstone usually occur as thin beds; layers of arkosic sandstone are normally thick bedded; and both interlens with variegated shale and siltstone. The upper 30 to 40 feet of Entrada Sandstone often contain pink blebs of rose quartz and calcite similar to those in the basal unit.

Thickness of the Entrada varies to 250 feet in the district. Variations in thickness are created by erosion previous to deposition of the overlying Iron Springs Formation. Unaltered Entrada Sandstone is readily recognizable in outcrop and in drill cores by its maroon color. Where Entrada Sandstone has been altered by the intrusions, the formation has been modified to various shades of gray by emanations from intrusions.

Marshall Creek Breccia. The local talus-fanglomerate Marshall Creek Breccia, of Cretaceous age, occurs along the margins of the Iron Springs intrusions (Mackin, 1947b, 1954). It occurs at a disconformable contact between Entrada Sandstone and the overlying Iron Springs Formation. It has no counterpart in the Colorado Plateau and owes its existence to local post-Entrada deformation in the Iron Springs district. The Marshall Creek Breccia lenses irregularly, varying in thickness to 100 feet within short distances along the strike. It consists largely of angular blocks of Homestake Limestone up to 5 feet in diameter and smaller fragments of Entrada Sandstone. The matrix commonly is maroon calcareous siltstone, which may or may not contain limestone fragments. Thin, irregular bands of jasper occur frequently in the matrix.

Iron Springs Formation. The Entrada Sandstone and Marshall Creek Breccia are overlain unconformably by the Iron Springs Formation (Mackin, 1947b, 1954, 1968) which is probably of Late Cretaceous age. This formation is composed of lenticular beds of sandstone, siltstone, shale and conglomerate with local beds of limestone and coal. The beds are so irregularly distributed throughout the section that the formation is difficult to subdivide. The lower 400 feet of the formation are composed of a basal conglomerate made up mainly of quartzite pebbles, with some limestone pebbles, in a gray quartzitic matrix. This grades upward into variegated fresh-water limestone and sandstone with small conglomerate lenses. This in turn grades into interlensing coarse gray-and-brown limy sandstone and predominant limestone conglomerate.

The remaining 2,600 feet of the Iron Springs Formation consist of sandstone, siltstone, and shale, with small lenses of limestone and conglomerate. Conglomerate and sandstone are predominantly brown in color; shales and siltstones are variegated, ranging from red through gray to green; and the limestones vary from gray to reddish. A few thin lenses of coal are present. The Iron Springs Formation varies in thickness to more than 3,000 feet in the district, owing partly to relief of the surface during deposition but chiefly to folding and subsequent erosion prior to deposition of overlying Tertiary rocks.

Claron Formation was first described by Leith and Harder (1908) in the Iron Springs district. The formation consists of Early Tertiary fluvial and lacustrine sediments ranging from 1,000 to 1,500 feet in thickness (Mackin, 1968). The Claron Formation is composed of conglomerate, red and gray sandstone and siltstone, and pink and white limestone. These strata rest unconformably on the Iron Springs Formation; in places the pre-Claron erosion surface truncates the Iron Springs Formation and the Entrada sandstone so that the Claron rests directly upon Homestake Limestone.

The Claron Formation is correlated with the Eocene Wasatch Formation (Gregory, 1950) in the Markagunt Plateau at Cedar Breaks, 20 miles east of the district. The Claron consists of two principal members: the lower, Red Claron, made up chiefly of conglomerate, sandstone, and freshwater limestone characterized by their red color; the upper, Gray Claron, composed chiefly of light-gray sandstone and conglomerate with some interbedded layers of white limestone. The upper Gray Claron Member contains increasing amounts of tuffaceous materials toward the top. Recent age-dating (Armstrong, 1963) of the overlying Needles Range Formation indicates a mid-Oligocene age and suggests that at least the upper, Gray Claron Member, which contains pyroclastic materials, could possibly be Oligocene in age.

Igneous Rocks

Igneous rocks in the Iron Springs district are composed of three pre-intrusive volcanic sequences with a maximum aggregate thickness of 2,300 feet, three quartz monzonite porphyry intrusives with which the iron-ore deposits are associated, and two younger volcanic sequences with a maximum thickness of about 2,000 feet. The volcanic rocks are mainly ignimbrites rather than lava flows and were probably formed by *nueés ardentes* which spread laterally as density currents. Maps of these sequences show that they form sheets substantially uniform in thickness. Mackin (1960) gave formal stratigraphic names to these volcanic sequences in southwest Utah and in the Iron Springs district. Correlation of volcanic stratigraphic units by distinctive lithologic features has been independently verified by quantitative study of phenocrysts in volcanic rocks (Williams, 1960). A brief summary of the igneous rocks occurring in and near the Iron Springs district is given above (See Text-fig. 2).

Needles Range Formation. The beginning of volcanism in the Iron Springs district is signaled by shards of glass near the base of the upper Gray Claron Member, which becomes increasingly tuffaceous toward the top. The Needles Range Formation is the first major volcanic unit in the Iron Springs district. It overlies the Claron Formation and measures up to 1,000 feet in thickness. The type locality is on the east side of Needles Range in Beaver County and consists primarily of crystal-rich ignimbrites. The formation has two and, at some sections, three, ignimbrite members. Colors are pink to dark red-brown but range from black welded vitrophyre phases near the base to light gray near the top. Potassium-argon dates (Armstrong, 1963) for the Needles Range Formation are 28 to 29 million years, placing it in the mid-Oligocene.

Isom Formation. At the type locality in the Iron Springs district, the Isom Formation rests on the Needles Range Formation and, in some places, directly on the Claron Formation. Isom consists of three members with a total thickness of about 200 feet. The lower member consists of rather uniform tuffaceous ignimbrite materials and occurs only locally. The overlying Baldhills Member, composed of black to dark-brown latite porphyry, forms the bulk of Isom volcanic outcroppings. The uppermost member, Hole-in-the-Wall, consists of purplish gray latite porphyry about 40 feet thick. Baldhills and Hole-in-the-Wall members exhibit some ignimbrite features but have internal structures indicative of viscous lava flows. The Isom Formation is probably Middle Oligocene in age.

Quichapa Formation. The Iron Springs district is the type locality for the Quichapa Formation, which consists of four ignimbrite members with a total thickness of nearly 1,100 feet. Leach Canyon Tuff is the lowest member and is about 500 feet thick. The rock is a gray to flesh-colored rhyolite tuff which encloses conspicuous lithic fragments of dark red felsite, pumice, and broken pyrogenic minerals. The overlying Swett Tuff Member of the Quichapa Formation ranges from 30 to 45 feet in thickness and occurs only locally. It is composed of a thin basal vitrophyre and a massive lithoidal rock, both with a high degree of induration.

The overlying Bauers Tuff Member of the Quichapa Formation is about 200 feet thick and consists of a strongly indurated red to deep-red-brown rhyolite tuff. Bauers Tuff is characterized by a low content of pyrogenic minerals (10 to 15 percent), by a high degree of welding, and by flattened white pumice fragments or lenticules. Harmony Hills Tuff forms the uppermost member of the Quichapa Formation and measures up to 350 feet in thickness. The rock is tan to light-red-brown latite tuff containing up to 45 percent pyrogenic minerals.

The Quichapa Formation is the youngest of the pre-intrusion volcanic sequences. Leach Canyon Tuff, the oldest ignimbrite member of the Quichapa Formation, has a lead-alpha date of 28 million years (Jaffe, 1959), indicating that the Quichapa Formation is probably Middle to Upper Oligocene in age.

Quartz Monzonite Porphyry intrusions. Three bodies of quartz monzonite porphyry crop out in the Iron Springs district: Iron Mountain, Granite Mountain, and Three Peaks. These intrusive bodies were emplaced at or near the end of the Quichapa episode of volcanism. They may be floored in part by Jurassic Navajo Sandstone. The emplacement occurred along the base of the Jurassic Carmel Formation, arching the sedimentary and volcanic roof rocks and producing steep-sided topographic and structural features. Navajo Sandstone, however, has not been seen in outcrop nor has it been penetrated by drilling. Marginal contacts of the intrusions are concordant with the Carmel Formation or are ruptures in roof rocks formed during emplacement. The three intrusions are aligned along a northeast-trending Laramide anticlinal flexure which is locally overthrust. Each intrusion is oval in plan, is three to five miles long, and its long axis trends parallel to the regional alignment. The intrusions have fine-grained, chilled borders, and though they lack noteworthy assimilation effects along the margins, they definitely resulted from forceful injection of a viscous melt. Along the southeast side of Iron Mountain the intrusive contact is a breccia zone on a Laramide thrust.

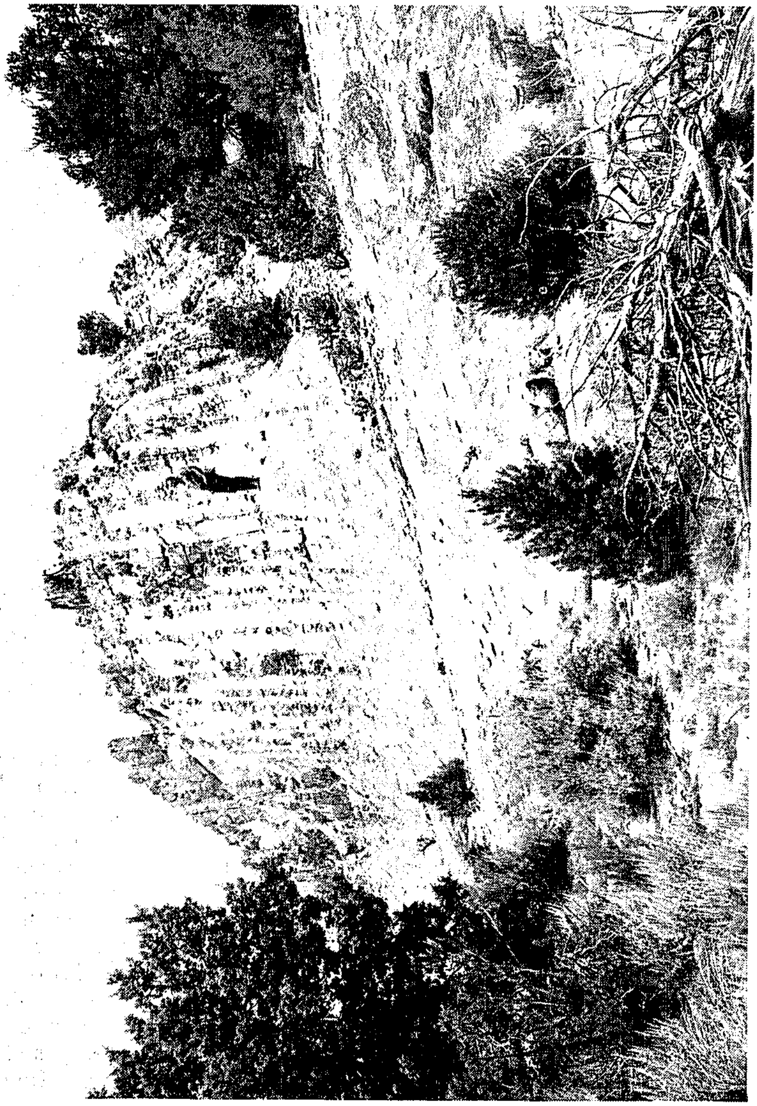
Detailed studies of the Iron Springs district by Mackin (1947b, 1954, 1968), Lewis (1958), and Ratté (1963) show that the three intrusives possess a zonal arrangement of three phases of quartz monzonite porphyry. These phases are a peripheral shell, a zone of selvage joints, and an interior phase. The peripheral-shell phase developed along the sides and across the top of the intrusions as a chilled border zone. The thickness is probably variable but usually ranges from 100 to 200 feet. Erosion has bared the Iron Mountain intrusion, exposing primarily the peripheral shell phase in most outcrops. Deeper erosion at the Granite Mountain and Three Peaks intrusions limits the peripheral shell phase to cappings of higher peaks and appearances along the margins of intrusions, except where faulting has brought sedimentary rocks in contact with the other two phases. The peripheral-shell phase consists of fine-grained quartz monzonite porphyry which is resistant to weathering, forming bold outcrops and ledges. The rock is fresh and hard in outcrop, has a light- to medium-gray color, and contains sparkling crystals of black hornblende and biotite.

The second zone is an interior phase that consists of coarse-grained quartz monzonite porphyry. Chemical composition and mineralogy are substantially identical to the peripheral shell. Because of alteration of mafic minerals, the interior phase weathers easily to grus. The rock has fresh plagioclase phenocrysts. Rocks of the interior phase, which is characterized by low crumbly knobs or flat barren areas, seldom occur as outcrops. The outcrops have a coarse granular, friable texture. In large outcroppings the porphyry forms rounded knobs with thin concentric exfoliation shells. The interior phase is well exposed at the Three Peaks intrusion, but only small outcrops are found at the Granite Mountain and Iron Mountain intrusions. Numerous xenolithic blocks believed to be Navajo Sandstone are found in the interior phase of the Three Peaks intrusion.

The third and intermediate zone in quartz monzonite porphyry intrusions in the Iron Springs district is the zone of selvage joints (See Text-figure 3). Rocks from this zone form an area of rugged topography. Selvage joints are composed of roughly parallel ribs of highly resistant porphyry. Quartz monzonite porphyry on each side of any individual joint is bleached and hardened through a width across the rib ranging from a fraction of an inch to one foot or more. Differential weathering produces a ribbed topography: each selvage joint forms a resistant linear outcrop pattern which stands above the adjacent porphyry. Selvage joint ribs grade from within one-half inch to crumbly, altered quartz monzonite characteristic of the interior phase. The rock is light-gray to greenish-gray and is occasionally pink. The zone of selvage joints is well exposed at the Three Peaks intrusion, forming a belt from one-half to one mile wide and separating interior and peripheral shell phases. Most surface outcrops at Granite Mountain are composed of this zone of selvage joints, although there are some border exposures of peripheral shell zone. Iron Mountain has very few exposures of the zone of selvage joints, apparently because of the limited depth of erosion of the intrusion.

Rencher Formation is regarded as evidence of the first important volcanism that accompanied and followed emplacement of igneous intrusions in the Iron Springs district. Intrusions produced dome mountains with heights up to several thousand feet. Lowlands between the domes became sites of deposition of volcanic products and detrital materials supplied by erosion from the domes. The Rencher Formation (Cook, 1957) consists of ignimbrites and other volcanic rocks with a thickness to 1,000 feet in southwest Utah. The rocks are welded tuffs and tuff breccias of rhyodacite and quartz-latite compositions. The formation apparently fills depressions between intrusive domes and lies on the surface of folded and eroded rocks. It rests directly on the Harmony Hills Member of the Quichapa Formation in the Iron Springs district, on aprons of detritus bordering intrusive domes, and unconformably across truncated edges of eroded strata on the flanks of some domes. It is regarded as probably of Miocene age.

Page Ranch Formation overlies the Rencher Formation in the Iron Springs district. The type locality (Cook, 1957, 1960) lies on the southwest end of the Iron Springs district. The Page Ranch Formation is composed of two members (Mackin, 1960) and is nearly 1,000 feet thick. The lower member consists of crudely bedded fanglomerates made up chiefly of subangular blocks of older



TEXT-FIGURE 3.—Selvage joints in bold relief, Three Peaks intrusion.

volcanic rocks and is designated the "Ironton Member." The upper part of the Page Ranch Formation is known as "Kane Point Tuff" and is composed mainly of rhyodacite ignimbrites. This member is a vitric to crystal tuff, moderately welded; it contains a few lithic fragments and is gray-brown to purplish-brown. Jaffe (1959) determined the age of Kane Point Tuff to be 19 million years and therefore Miocene.

Structural and Age Relationships

Concordant contacts. The primary structural relationship in the Iron Springs district is concordance of intrusive porphyry contacts with sedimentary bedding at the same stratigraphic horizon. Concordance of intrusive porphyry is with the basal siltstone member of the Jurassic Carmel Formation. This relationship is proven by detailed mapping of border zones of intrusions, by hundreds of drill holes to 1,000 feet down-dip from surface outcrops and by many scattered drill holes up to several miles from the intrusive contact. About one-half of the exposed length of the intrusive contact is faulted, yet drilling on the downthrown sides indicates that the contact remains concordant with the same stratigraphic horizon.

Intrusive relationships. During late Oligocene or early Miocene, the Iron Springs district intrusions were formed by injection of magma along a zone of incompetent sedimentary rocks between Navajo Sandstone and the Carmel Formation. The top of the Navajo Sandstone is commonly the sole of bedding thrusts in southwest Utah (Miller, 1966) and southeast Nevada (Longwell, 1940). Tectonic gliding along incompetent Carmel members between the Homestake Limestone Member and Navajo Sandstone has been suggested (Mackin, 1954). Field studies indicate this relationship for the Laramide Iron Springs district structure which trends about north 30° east through the district.

Iron Mountain, Granite Mountain, and Three Peaks intrusions are believed by the writer to be essentially stocklike. Originally, advancing magmas were injected through several feeders that served mainly to further distort pre-intrusive structures. Magma reached the incompetent zone in the lower Carmel Formation and was forcibly inserted into this zone in a sill-like fashion, with a mushrooming effect, and by lifting the roof rocks in a concordant manner. Intrusions made room for themselves mainly by doming and upfaulting the roof, which consists of basal siltstone and Homestake limestone members of the Carmel Formation and from 3,000 to 6,000 feet of overlying sedimentary and volcanic rocks. Magmatic stoping, melting, and assimilation must have taken place at depth (as evidenced by xenolithic blocks of Navajo Sandstone in the interior zone of the Three Peaks intrusion) all of which enlarged the intrusive bodies to stocklike forms and dimensions.

Size of intrusions. Each of the Iron Mountain, Granite Mountain, and Three Peaks intrusions is oval in plan, is three to five miles long, and is aligned for 18 miles along a northeast trend. Their total surface exposures are less than 14 square miles. Aeromagnetic surveys by Dempsey (1951) and by Blank and Mackin (1967) roughly delineate the lateral subsurface extent of the three intrusions. Study of the Three Peaks intrusion shows that the northwest boundary is an intrusive fault and that the southwest and south margins form a series of monoclines and monoclinal flexures. The northern part of the intrusion is largely buried beneath pediment gravels but extends at least two miles north from the main surface outcroppings. The east margin terminates along a line believed to represent the trace of a fault. This fault postdates the intrusion and probably displaced it for several hundred feet. The subsurface margin of the intrusion is apparently about one mile farther east of the fault. Surface exposures of the Three Peaks intrusion cover an area of more than 6 square miles. The aeromagnetic survey of the area suggests that the subsurface size of the intrusion is at least 18 square miles, three times as great as that exposed by erosion (See Text-fig. 2).

The Granite Mountain intrusion is the easternmost and the structurally highest bulged part of a largely concealed intrusive body. The intrusion is many times larger than the surface outcrops and peaks from which it gets its name. Isomagnetic contours of the Granite Mountain intrusion show that porphyry extends beneath sedimentary and alluvial cover for about 4 miles southwest, and 2 or 3 miles west and northwest of Granite Mountain. The exposed Granite Mountain bulge is bounded on the southeast by the Cory-Armstrong fault and on the northwest by the Clive fault. Granite Mountain is regarded as an intrusive horst laid bare by erosion. The exposures of the Granite Mountain intrusion cover slightly more than 2½ square miles. The aeromagnetic survey of the area suggests that the subsurface size of the intrusion is at least 24 square miles, nine times greater than that exposed by erosion.

Margins of the aeromagnetic anomaly at the Iron Mountain intrusion correspond more closely to the porphyry outcrop margins than do the other two intrusions and suggest a more limited subsurface expansion. However, westward continuity of the south-dipping sedimentary rocks along the south margin of the Iron Mountain intrusion, weak incomplete magnetic anomalies, and penetration of the intrusion by deep test drilling in the area all suggest a westward expansion of the intrusion beneath alluvium and bedrock cover. The Iron Mountain intrusion is marked by severe intrusive deformation. Surface exposures on the intrusion cover an area of slightly more than 5 square miles. An aeromagnetic survey of the Iron Mountain area suggests a subsurface size of the intrusion of at least 11 square miles, more than twice as great as that exposed by erosion.

Shape of intrusions. The nature of igneous intrusions in the Iron Springs district has long been a controversial issue. Leith and Harder (1908) classified the intrusions as "laccoliths." They based their conclusions on the more or less circular outline of the intrusions and the manner in which the sedimentary rocks encircle the intrusions. Butler (1920) regarded them as "stocks," since their laccolithic character had not been demonstrated. With no discussion, Wells (1938) referred to the igneous intrusions simply as "plugs" or "stocks." Granger (1963) considered the intrusions to be stocks. Ratté (1963) suggested that the intrusions began as laccoliths but later, as a result of wholesale foundering and assimilation of Navajo Sandstone and subjacent rock, became stocklike. Mackin (1947b, 1954, 1968) regarded the intrusions as "laccolithic blisters," but had based his premise entirely on such circumstantial evidence as concordance of contact, limited contact metamorphism, flattish planar flow structures, radial pattern of primary tension joints, aeromagnetic data, and the floored Pine Valley laccolith south of the Iron Springs district.

A gravity survey of the Iron Springs district (Cook and Hardman, 1967b) shows a continuous gravity high about 30 miles long extending over the Iron Springs district and including the Stoddard Mountain intrusion south of Iron Mountain. Gravity surveys, aeromagnetic and ground magnetometer data, geologic relationships, and scattered exploratory drill-hole data suggest that a large porphyry body of batholithic dimensions underlies the Iron Springs district. A common source of magma is indicated by the quartz-monzonite composition of Stoddard Mountain, Iron Mountain, Granite Mountain, and Three Peaks intrusions. The gravity survey further shows a gravity ridge centered one to two miles west and northwest of the intrusions in the Iron Springs district. This offset suggests that the main body of porphyry is probably buried at a relatively shallow depth beneath the gravity ridge (See Text-figure 2).

The writer doubts the circumstantial evidence advanced by Mackin (1947b, 1954, 1968) that Iron Springs intrusions are all floored and concludes that only a small portion of the intrusions can be floored by Navajo Sandstone. The sandstone has never been encountered by the thousands of drill holes cut in the district nor by exploratory drill holes around the periphery of the district where all holes have bottomed in porphyry. Concordance of contacts has been overemphasized in the district since about one-half of the exposed length of intrusive contacts are faulted. Concordant roofs, on the other hand, are found among stocks as well as laccoliths. Limited contact metamorphism occurs wherever a magma lacks superheat and does not negate subjacent intrusive bodies. The planar flow-structures and the radial pattern of primary tension joints could be produced by central stocks feeding sill-like or laccolithic lobes. Aeromagnetic surveys do not show the depth of a thick causative body and therefore cannot provide conclusive evidence that the intrusions are floored.

It appears to this writer that the three intrusive bodies might be better interpreted as an igneous complex of semiconcordant stocks rather than simply as laccolithic blisters. The stocks in turn are underlain and were fed by a larger batholith. The above conclusions have been reached after evaluation of the following: gravity surveys of Cook and Hardman (1967b); aeromagnetic surveys by Dempsey (1951) and Blank and Mackin (1967); ground magnetometer data by Cook (1950) and by others; persistent bottoming of drill holes in quartz monzonite porphyry at the various iron properties, and similar bottoming by exploratory drilling throughout the district and in adjacent areas; the same quartz-monzonite composition for all the intrusions; and detailed geologic and geophysical investigations of the district by the writer, mining company geologists, and others.

Age of intrusions. The Iron Springs district intrusives are post-Quichapa and pre-Rencher in age. A lead-alpha date of the Three Peaks intrusion is 22 million years (Jaffe, 1959). A potassium-argon date for the same intrusion is 24 million years, +4 or -2 million years (Armstrong, 1963). These dates suggest a late Oligocene or early Miocene age. From combined lithologic and structural evidence, Blank and Mackin (1967) considered the Iron Mountain intrusion to be the oldest of the three Iron Springs district intrusions.

Mineralogy and Mode of Occurrence

The most important iron-ore minerals in the Iron Springs district are hematite and magnetite. These minerals are mixed in proportions that vary within a given area or deposit. Ores range from hard pure magnetite to soft friable varieties of hematite. Iron deposits have three primary modes of occurrence and one secondary origin. These are: replacement-type bodies in limestone; breccia fillings and replacements along faults and pipelike structures; fissure vein fillings in porphyry; and alluvial ores of secondary origin (discussed in a later section).

Mineralogy of ores. In addition to magnetite and hematite, some specular hematite and martite occur in a few ore deposits; and goethite, limonite, and turgite can be found in relatively small amounts. Gangue minerals in the ores are numerous and varied and include (in order of decreasing abundance) calcite, phlogopite, apatite (fluorapatite), quartz and chalcedony, pyrite, marcasite, diopside, azurite, malachite, chrysocolla, chalcopyrite, bornite, galena, magnesite, gypsum, barite, epidote, garnet, vesuvianite, scapolite, tourmaline, chlorite, tremolite, actinolite, and wollastonite.

Mineralogy of the various types of ore occurrences in the district is similar, but relative abundance changes considerably. Replacement-type ores in limestone are finely crystalline magnetite and hematite, the magnetite ranging from about 10 to 50 percent within each ore body. Disseminated in the ore in small amounts are fine-grained calcite, quartz, and garnet. Pyrite, apatite, and phlogopite often occur in small veins cutting the ore or as fillings in vugs. Large fissure veins and some open-space breccia fillings along faults contain coarsely crystalline magnetite octahedra. Long prismatic crystals of apatite are commonly intergrown with magnetite. Quartz, chalcedony, amethyst, and pyrite occur in vugs and in open spaces in veins and breccia fillings. Mineralization in small fissure veinlets and in many of the breccia fillings along faults consists of fine- to coarse-grained intergrowths of magnetite and hematite. Magnetite may be present in small quantities or may be absent. Calcite and phlogopite are often the main gangue minerals. Diopside, apatite, and dolomite may dominate small veins. Actinolite, tremolite, gypsum, and dolomite may be present in noticeable quantities. Pipe-like breccia fillings and replacement ore bodies differ from other occurrences mainly in that the ores are predominantly hard and coarsely crystalline magnetite, and in the Blowout and Little Allie ore bodies there is also an abundance of fibrous magnetite.

Replacement ore bodies. By far the most important ores in the Iron Springs district are replacement deposits in the Homestake Limestone Member of the Carmel Formation. Ore replaces the lower part of limestone first, but with increasing metallization the full thickness of about 250 feet may be replaced. Where the entire Homestake Limestone is replaced by iron ore, the lower half is high-grade ore containing from 50 to 58 percent iron, and the upper half of the formation averages 40 to 45 percent iron.

The limestone-replacement ore bodies are usually tabular and lenticular in form, occurring in off-dipping limestone along the contact zone of intrusives; they measure from a few feet to 1,000 feet or more along strike and down-dip. The footwall of the ore conforms with the stratigraphic base of the Homestake Limestone Member and is separated from porphyry by the Basal Siltstone Member of the Carmel Formation. Iron-ore replacements extend upward from the base of the Homestake Limestone, ranging in thickness from a few feet to the full thickness of the limestone, in which case the hanging wall is the Basal Shale Member of the Entrada Sandstone. If replacement is less than complete in the Homestake, the ore edges against limestone where the contact is sharp or grades off within a few inches.

The Lindsay ore body on the east side of Granite Mountain is a good example of an off-dipping homoclinal replacement ore body. The Shortline ore body on the southwest side of Granite Mountain is of the replacement type in a premineral graben block. Another variation is the April Fool ore body on the west side of Three Peaks, a replaced xenolithic slab or roof pendant of limestone completely surrounded by porphyry. Some of the major replacement ore deposits in limestone at Iron Mountain are A and B, Burke, Blackhawk, McCahill, Pinto, Rex, Comstock, and Mountain Lion ore bodies (See Text-fig. 4). At Granite Mountain are Desert Mount, Shortline, Pioche, Lindsay, and Vermilion ore bodies; and at Three Peaks are April Fool and Irene ore bodies. Deposits range from fewer than 100,000 to more than 100 million tons of iron ores.

Breccia fillings and replacements. Brecciated zones in the Carmel Formation, Entrada sandstone, Iron Springs Formation, and quartz monzonite porphyry contain iron-ore mineralization as breccia fillings and breccia replacements. Brecciated zones may occur within Homestake Limestone replacement ore bodies; or they may occur above, along the margins of, or below these ore bodies, or independent of these relationships. Breccia fillings and replacements of rubble occur in broken zones of the Entrada Sandstone and the Iron Springs Formation above the non-deroofed Rex ore body at Iron Mountain. Diamond drilling of the Rex deposit disclosed extensively replaced breccia extending through the main limestone replacement body. A basal breccia involving the siltstone member of the Carmel Formation and the outer part of the porphyry is found in parts of the footwall beneath the Lindsay ore body at Granite Mountain.

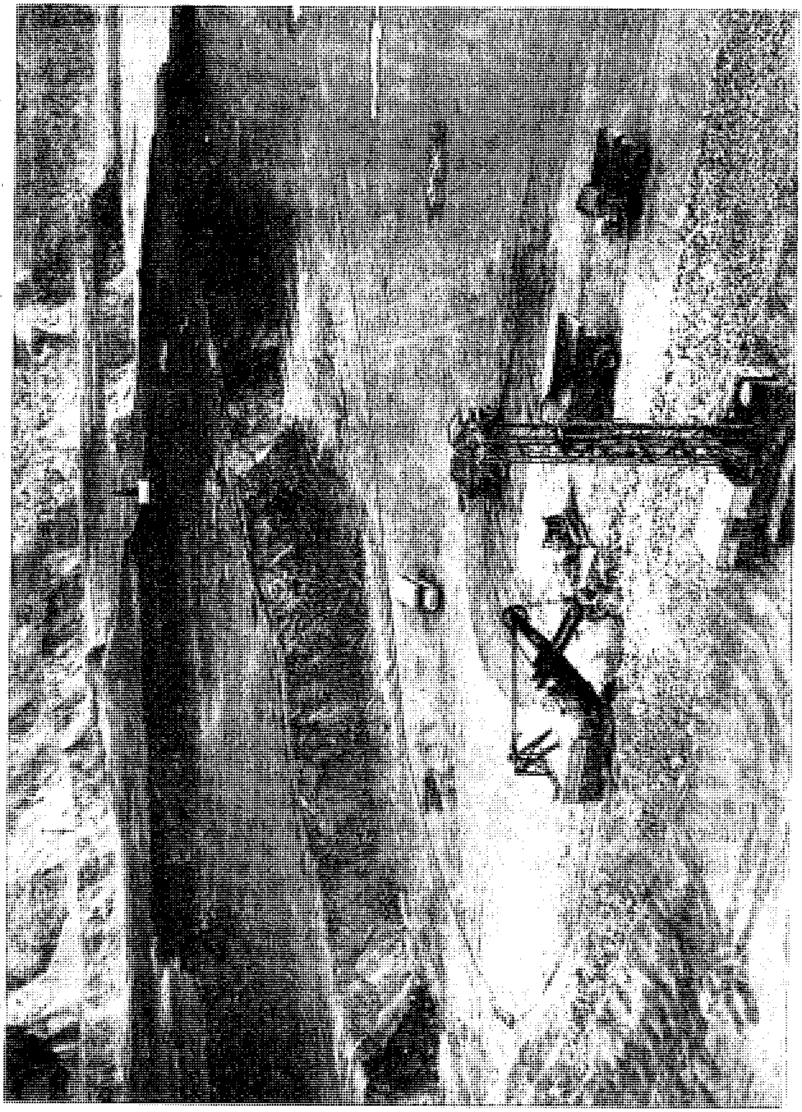
Mineralized brecciated fault zones associated with replacement ore bodies are typified by Shortline, Clive-Constitution, Little Allie, Armstrong, Lindsay, and others at Granite Mountain and by the A and B, Burke, Dear, Pinto, Comstock, Mountain Lion, and others at Iron Mountain (See Text-fig. 5). The Blowout and Pot Metals ore bodies occur along the Calumet fault zone (probably the mashed lower plate of the Laramide thrust in the district) and replaced this breccia. Basal Siltstone and Homestake Limestone members of the Carmel Formation lie in the overthrust block and are essentially unmineralized.

Some ore bodies in the Iron Springs district resemble breccia pipe structures and form crude cylindrical ore bodies. They lie on the periphery of intrusives along major faults or fault intersections. These breccia pipes occur mainly in the monzonite and may contain large angular to rounded blocks and fragments of porphyry or sedimentary rocks completely surrounded by ore. The principal ore mineral of the breccia pipes is magnetite. Examples of such breccia pipes are Blowout and Pot Metals ore bodies on the southeast side, the Dear claim in the Comstock area on the northeast side of Iron Mountain, and Armstrong and Little Allie ore bodies on the east side of Granite Mountain.

Drill-hole cores from the Rex ore body on the west side of Iron Mountain and the Desert ore bodies in secs. 2, 3, 4, and 9 which lie in the valley between Iron and Granite mountains show high brecciation. Tonnages of ore associated with breccia fillings and replacements are some of the largest in the district.

Fissure fillings. Most of the vein or fissure fillings, abundant in quartz monzonite porphyry intrusions, are too small to be of economic importance. Fissure veins occur in numerous selvage joints which cut intrusions and are radial, concentric, and oblique. Radial joints, which are continuations of the joint system from the interior zone, strike normal to intrusive contacts and have vertical dips. Concentric joints strike parallel to igneous contacts and dip into intrusives, normal to contacts. Oblique joints are curved types that swing from radial to concentric patterns.

Thirty to 50 percent of the selvage joints contain some magnetite and accessory hematite, apatite, calcite, pyrite, pyroxene, and other minerals. Comb



TEXT-FIGURE 4.—Limestone replacements, Comstock ore body, Iron Mountain.

TEXT-FIGURE 5.—Breccia fillings and partial replacements in quartz monzonite, Deer claim, Iron Mountain.

structures and vugs with abundant magnetite octahedra indicate that fissures were filled rather than replaced. Encrustations of magnetite crystals in many veins suggest that joints were opened repeatedly during the time of metallization. Contacts between the veins and porphyry are sharp. Inclusions of quartz monzonite porphyry fragments in some fissure veins represent either pre-ore breccia or stoping of joint wall rock by iron ore emanations.

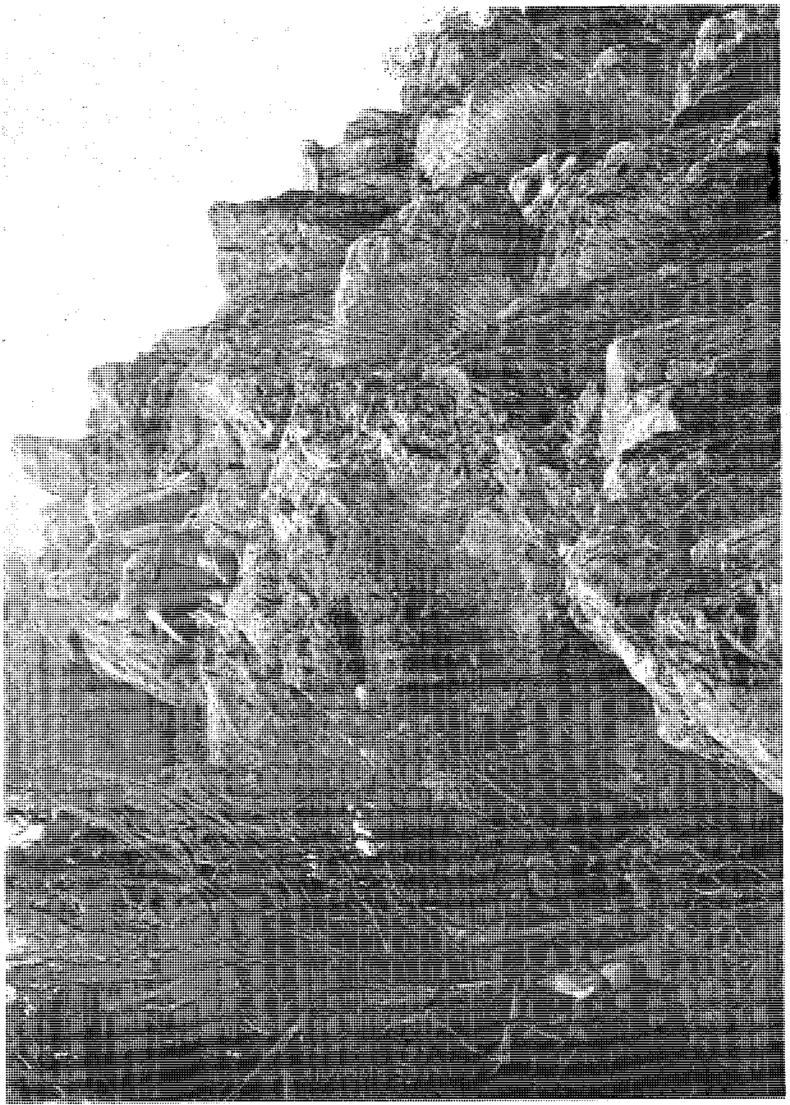
Fissure veins are unusually abundant in the porphyry intrusions. Thousands of the veins in the district are less than four inches in width, scores of them are several feet wide, and a few are more than ten feet in width. Most of the larger veins occur in radial joints, but some fill concentric and oblique joints. Radial fissure veins are typically wedgeshaped in both plan and cross section, with the thickest part toward the margins or borders of the intrusions. Some of the larger veins in the district are Great Western, Blackbird, and Zelma veins at Three Peaks, and Chesapeake, Excelsior, and Tip Top veins at Iron Mountain (See Text-fig. 6). Potential tonnage in the individual fissure veins ranges to about 100,000 tons.

Ore Deposits

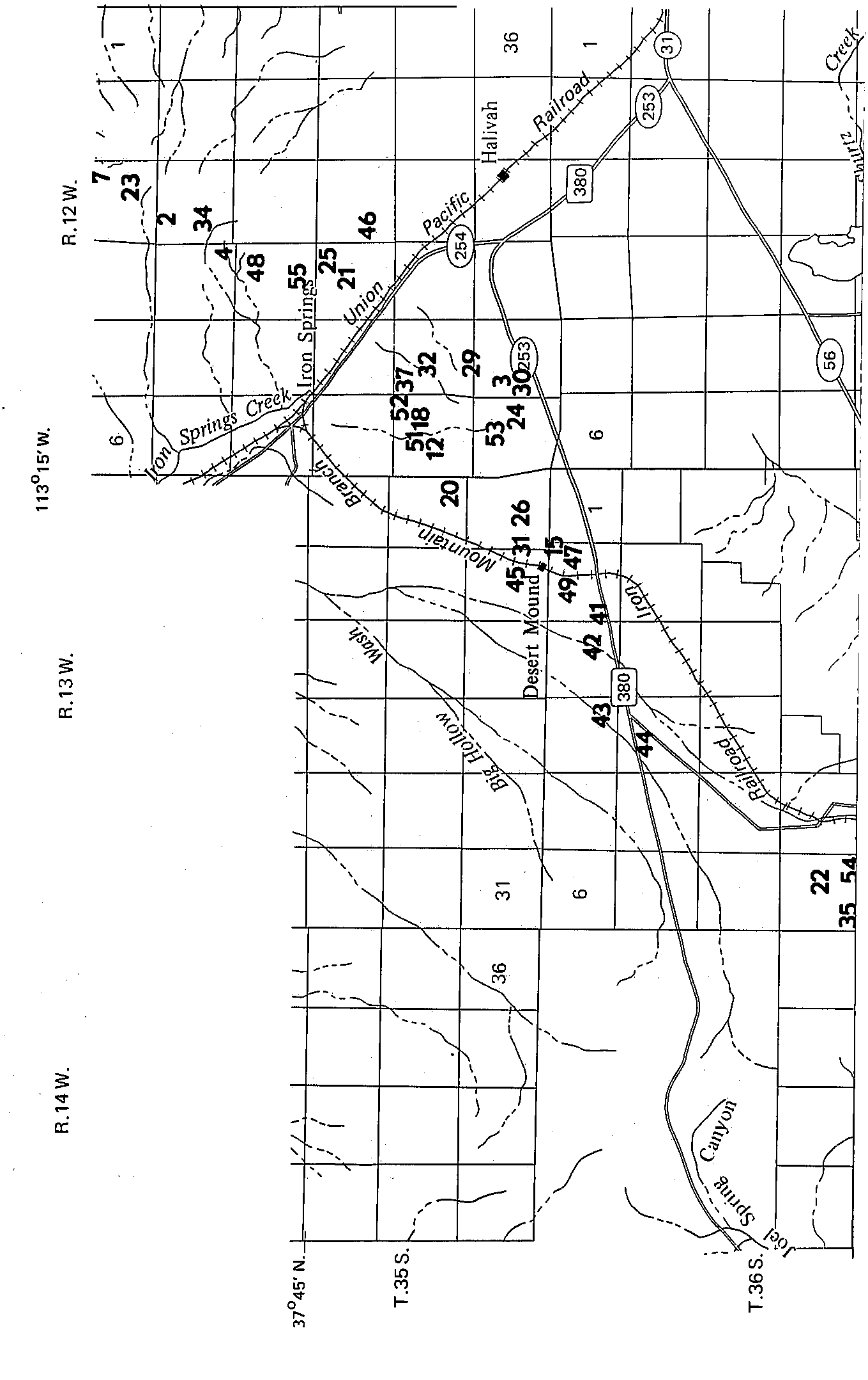
Iron Springs district, a belt about 21 miles long and 4 miles wide, has been the largest iron-producing district in the western states. Iron-ore bodies are clustered around three semiconcordant stocks as replacement bodies in limestone, as breccia fillings and replacements along faults and pipelike structures, and as fissure veins in quartz monzonite porphyry.

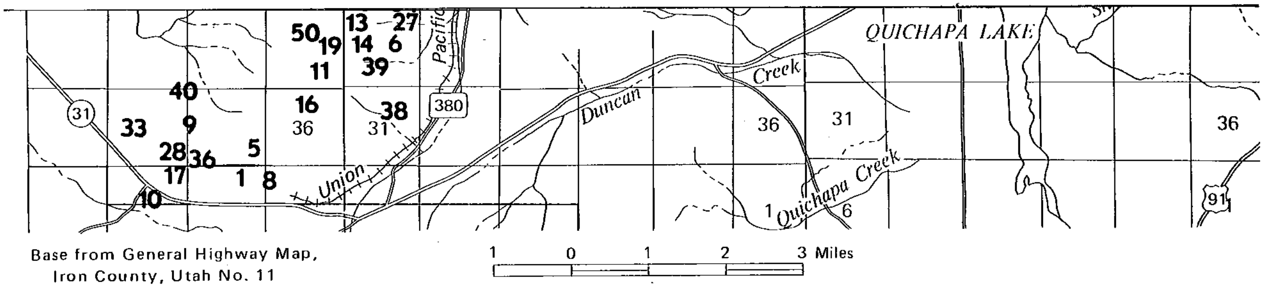
The Homestake Limestone Member of the Carmel Formation is exposed most of the way along the south and east margins of the Iron Mountain intrusion. On the west and northwest the Iron Springs Formation is in fault contact with porphyry for about 3½ miles. The northeast margin is bordered by alluvium. Blocks of Homestake Limestone, Entrada Sandstone, and the Iron Springs Formation also form roof pendants, particularly on the northeast side of Iron Mountain. Most pendants are less than 1,000 feet in length, but the one on which the Comstock and Mountain Lion group of claims is located is about one mile long and 2,000 feet wide. The main replacement ore bodies occurring along the margins of the Iron Mountain intrusive are the Rex and Burke ore bodies on the west side, A and B, Blowout, Duncan, Calumet, Limecap, McCahill, and Pinto ore bodies on the south and southwest sides, and Pot Metals, Yellow Jacket, and Homestake mine deposits on the east side. Black Hawk ore body on the south end, and Comstock, Mountain Lion, and Dear ore bodies on the northeast side of Iron Mountain are roof pendant replacements. Some of the larger fissure veins on Iron Mountain are the Tip Top, Chesapeake, Excelsior, and Black Magnetic deposits. Black Hawk, Burke, and Pinto ore bodies have been mined out. Mining operations are being conducted at the Comstock, Mountain Lion, and Duncan ore bodies.

At the Granite Mountain intrusion, Entrada Sandstone and Iron Springs Formation are in fault contact on the south, southeast, and northwest sides of the intrusive, and the Homestake limestone forms an intrusive contact on the east and north sides. Desert alluvium abuts porphyry on the west and southwest sides. Desert Mound, an east-west-trending hill that lies less than one mile southwest of Granite Mountain proper, is formed by monzonite and alluvium on the north side; Homestake Limestone, Entrada Sandstone, and Iron Springs Formation form the ridge and slopes on the south side. The principal ore bodies surrounding Granite Mountain on the southeast and east sides are Little Allie,



TEXT-FIGURE 6.—Fissure vein in quartz monzonite, Excelsior ore body, Iron Mountain.


R.12 W.
R.13 W.
R.14 W.
113°15' W.
37°45' N.
T.35 S.
T.36 S.
Iron Springs Creek
Iron Springs
Union Pacific Railroad
Halivah
Branch
Mountain
Desert Mound
Iron
Railroad
Wash
Big Hollow
Canyon
Joel Spring
Creek
380
253
254
31
56



1. A and B ore body
2. April Fool ore body
3. Armstrong ore body
4. Ashton ore body
5. Black Hawk ore body
6. Black Magnetic ore body
7. Blackbird ore body
8. Blowout ore body
9. Burke ore body
10. Calumet ore body
11. Chesapeake ore body
12. Clive-Constitution ore body
13. Comstock ore body
14. Dear ore body
15. Desert Mound ore body
16. Duluth ore body
17. Duncan ore body
18. Eclipse ore body
19. Excelsior ore body
20. Georgia ore body
21. Great Western ore body
22. Homestake mine ore body
23. Irene ore body
24. Jeanette ore body
25. Jones ore body
26. King ore body
27. Last Chance ore body
28. Lime Cap ore body
29. Lindsay ore body
30. Little Allie ore body
31. Little Jim ore body
32. Little Mormon ore body
33. McCahill ore body
34. McGarry ore body
35. Mountain Lion ore body
36. Pinto ore body
37. Pioche ore body
38. Pot Metals ore body
39. Queen of the West ore body
40. Rex ore body
41. Section 2 ore body
42. Section 3 ore body
43. Section 4 ore body
44. Section 9 ore body
45. Shortline ore body
46. Smith ore body
47. State Section 2 ore body
48. State Section 16 ore body
49. Thompson ore body
50. Tip Top ore body
51. Twitchell ore body
52. Vermilion ore body
53. Wall Street ore body
54. Yellow Jacket ore body
55. Zelma ore body

TEXT-FIGURE 7.—Location Map of ore bodies, Iron Springs district, Utah.

Armstrong, and Lindsay ore bodies, and Little Mormon, Pioche, Vermilion, and Twitchell deposits on the north and northeast sides. Two blind ore bodies along the Clive fault on the northwest side of Granite Mountain are the Clive-Constitution and Georgia deposits. Ore bodies of note at Desert Mound are Shortline and Desert Mound deposits, and nonoutcropping Desert ore bodies to the southwest of Desert Mound, including Thompson, Section 2, Section 3, Section 4 and Section 9 deposits. Shortline and much of the Lindsay ore bodies are mined out. Mines in operation are Lindsay, Armstrong, Pioche and Vermilion deposits at Granite Mountain, and Desert Mound ore body at Desert Mound.

Homestake Limestone is in intrusive contact on the south and west margins of the porphyry of the Three Peaks intrusion. The north, east and southeast borders of the intrusive are covered by alluvium. No large replacement ore bodies have been discovered along the intrusive margins at Three Peaks. April Fool, Irene, McGarry and Smith deposits are relatively small roof pendant ore bodies, occurring as partial replacements of Homestake limestone blocks completely surrounded by porphyry. Many fissure veins of magnetite are found in Three Peaks porphyry, the largest of which are Great Western, Blackbird and Zelma fissure veins. Mines are in operation at Smith and Irene ore deposits at Three Peaks.

A tabulation of some of the more important ore bodies discovered in Iron Springs district is given in Table 1; and a location map is given in Text-figure 7. The deposits are listed alphabetically.

Magnetic Concentration

Magnetic concentration of iron ores was introduced in the Iron Springs district by the Utah Construction and Mining Company, now known as Utah International, Inc. They began direct shipping of iron ores from the Iron Springs district in 1944. As their reserves of direct-shipping ore diminished and as the need for higher-grade furnace feed at the Geneva Works increased, beneficiation facilities were added to meet the specifications of the steel mills. Such a plant was installed at Iron Springs where it began operations in April 1961 (Erspamer, 1964). Grinding, scrubbing, and wet magnetic separation facilities were capable of handling 2,500 tons per day of minus 1¼-inch ore. Three years later a revised contract called for a higher-grade product, and the company expanded their Iron Springs plant to handle 4,000 tons per day of minus 1¼-inch ore. Nearly all run-of-mine ore is processed at the plant by crushing, grinding, screening, and open-hearth cobbing. West beneficiation of blast furnace ore is processed by scrubbing, wet magnetic separation, stockpiling, blending, and loading concentrates for shipment.

Alluvial Iron Ores

The principal iron-ore deposits in the Iron Springs district occur as irregular bodies of magnetite and hematite which replace mainly the Homestake Limestone Member of the Jurassic Carmel Formation and lie near contacts of Tertiary quartz monzonite intrusives. Alluvial iron ores are concentrated from weathered products of intrusive rock and iron-ore deposits. As weathering progressed, magnetite-hematite debris moved downslope and concentrated in alluvium on pediment and bajada slopes. The fact that alluvial deposits contained significant quantities of magnetic ore was known long before any serious con-

TABLE 1
ORE DEPOSITS, IRON SPRINGS DISTRICT, UTAH

Name of Ore Body	Location	Type of Deposit	Tonnage Potential (tons)
1. A and B	sec. 2, T. 37 S., R. 14 W., SW. Iron Mountain	Replacement	30 to 40 million
2. April Fool	NW.¼, sec. 10, T. 35 S., R. 12 W., NW. Three Peaks	Replacement	½ to 1 million
3. Armstrong	NW.¼, sec. 32, T. 35 S., R. 12 W., E. Granite Mountain	Replacement, Breccia filling	4 to 5 million
4. Ashton	SE.½, sec. 9, T. 35 S., R. 12 W., W. Three Peaks	Fissure vein	50 to 100 thousand
5. Black Hawk	SE.¼, sec. 35, T. 36 S., R. 14 W., S. Iron Mountain	Replacement	20 million
6. Black Magnetic	NE.¼, sec. 30, T. 36 S., R. 13 W., NE. Iron Mountain	Fissure vein	50 to 70 thousand
7. Blackbird	NE.¼, sec. 3, T. 35 S., R. 12 W., N. Three Peaks	Fissure vein	50 to 100 thousand
8. Blowout	NW.¼, sec. 1, and NE.¼, sec. 2, T. 37 S., R. 14 W., S. Iron Mountain	Breccia pipe, Replacement	10 million
9. Burke	SW.¼, sec. 35, and SE.¼, sec. 34, T. 36 S., R. 14 W., SW. Iron Mountain	Replacement	16 million
10. Calumet	N.½, sec. 3, T. 37 S., R. 14 W., SW. Iron Mountain	Replacement	2 million
11. Chesapeake	SE.¼, sec. 25, T. 36 S., R. 14 W., E. Iron Mountain	Fissure vein	100 to 200 thousand
12. Clive-Constitution	NW.¼, sec. 30, T. 35 S., R. 12 W., NW. Granite Mountain	Breccia filling, Replacement	1 million
13. Comstock	NW.¼, sec. 30, T. 36 S., R. 13 W., NE. Iron Mountain	Replacement	50 to 60 million
14. Dear	W.½, sec. 30, T. 36 S., R. 13 W., NE. Iron Mountain	Breccia filling, Replacement	1 million
15. Desert Mound	NW.¼, sec. 1, and NE.¼, sec. 2, T. 36 S., R. 13 W., SW. Granite Mountain	Replacement	20 million
16. Duluth	N.½, sec. 36, T. 36 S., R. 14 W., SE. Iron Mountain	Replacement	500 thousand
17. Duncan	SE.¼, sec. 34, T. 36 S., R. 14 W.; and NE.¼, sec. 3,	Replacement	3 to 5 million

	T. 37 S., R. 14 W., SW. Iron Mountain		
18. Eclipse	NE.¼, sec. 30, T. 35 S., R. 12 W., N. Granite Mountain	Replacement	500 thousand
19. Excelsior	E.½, sec. 25, T. 36 S., R. 14 W., E. Iron Mountain	Fissure vein	200 thousand
20. Georgia	SE.¼, sec. 25, T. 35 S., R. 13 W., S. Granite Mountain	Breccia fillings, Replacement	½ to 1 million
21. Great Western	NE.¼, sec. 21, T. 35 S., R. 12 W., S. Three Peaks	Fissure vein	50 to 100 thousand
22. Homestake	S.½, and NE.¼, sec. 19, T. 36 S., R. 13 W., NE. Iron Mountain	Replacement	5 million
23. Irene	SE.¼, sec. 3, T. 35 S., R. 12 W., NW. Three Peaks	Replacement	2 million
24. Jeannette	SE.¼, sec. 31, T. 35 S., R. 12 W., S. Granite Mountain	Fissure vein	Few thousand
25. Jones	NE.¼, sec. 21, T. 35 S., R. 12 W., S. Three Peaks	Fissure vein	Few thousand
26. King	SW.¼, sec. 36, T. 35 S., R. 13 W., SW. Granite Mountain	Breccia filling	50 to 100 thousand
27. Last Chance	NE.¼, sec. 30, T. 36 S., R. 13 W., E. Iron Mountain	Replacement	1 million
28. Lime Cap	SE.¼, sec. 34, T. 36 S., R. 14 W., W. Iron Mountain	Replacement	2 to 3 million
29. Lindsay	SW.¼, sec. 29, and NW.¼, sec. 32, T. 35 S., R. 12 W., E. Granite Mountain	Replacement	20 million
30. Little Allie	SW.¼, sec. 32, T. 35 S., R. 12 W., E. Granite Mountain	Breccia pipe, Replacement	3 million
31. Little Jim	SE.¼, sec. 35, T. 35 S., R. 13 W., SW. Granite Mountain	Breccia filling	Few thousand
32. Little Mormon	W.½, sec. 29, T. 35 S., R. 12 W., N. Granite Mountain	Replacement	1 million
33. McCahill	W.½, sec. 34, T. 36 S., R. 14 W., SW. Iron Mountain	Replacement	30 million
34. McGarry	W.½, sec. 10, T. 35 S., R. 12 W., W. Three Peaks	Replacement	500 thousand
35. Mountain Lion	SW.¼, sec. 19, and NW.¼, sec. 30, T. 36 S., R. 13 W., NE. Iron Mountain	Replacement	15 to 20 million

36. Pinto	SW.¼, sec. 35, T. 36 S., R. 14 W.; and NW.¼, sec. 2, T. 37 S., R. 14 W., SW. Iron Mountain	Replacement	10 million
37. Pioche	NW.¼, sec. 29, and NE.¼, sec. 10, T. 35 S., R. 12 W., N. Granite Mountain	Replacement	4 million
38. Pot Metals	NE.¼, sec. 31, T. 36 S., R. 13 W., E. Iron Mountain	Breccia filling, Replacement	1 million
39. Queen of the West	SW.¼, sec. 30, T. 36 S., R. 13 W., E. Iron Mountain	Replacement	500 thousand
40. Rex	SW.¼, sec. 26; SE.¼, sec. 27; NE.¼, sec. 34; and NW.¼, sec. 35, T. 36 S., R. 14 W., W. Iron Mountain	Breccia filling, Replacement	100 million
41. Section 2	SW.¼, sec. 2; and SE.¼, sec. 3, T. 36 S., R. 13 W., SW. Desert Mound	Replacement	10 million
42. Section 3	SE.¼, sec. 3, T. 36 S., R. 13 W., SW. Desert Mound	Replacement	2 million
43. Section 4	SE.¼, sec. 4, T. 36 S., R. 13 W., SW. Desert Mound	Replacement	1 million
44. Section 9	N.½, sec. 9, T. 36 S., R. 13 W., SW. Desert Mound	Replacement	35 million
45. Shortline	S.½, sec. 35, T. 35 S., R. 13 W., SW. Granite Mountain	Replacement	6 million
46. Smith	SW.¼, sec. 22; and SE.¼, sec. 21, T. 35 S., R. 12 W., S. Three Peaks	Replacement	2 million
47. State Section 2	NE.¼, sec. 2, T. 35 S., R. 13 W., SE. Granite Mountain	Replacement	1 to 2 million
48. State Section 16	SW.¼, sec. 16, T. 35 S., R. 12 W., SW. Three Peaks	Replacement	1 million
49. Thompson	NW.¼, sec. 2, T. 36 S., R. 13 W., SW. Granite Mountain	Replacement	1 million
50. Tip Top	sec. 25, T. 36 S., R. 14 W., Iron Mountain	Fissure vein	100 to 200 thousand
51. Twitchell	NW.¼, sec. 30, T. 35 S., R. 12 W., NW. Granite Mountain	Breccia fillings, Replacements	½ to 1 million
52. Vermilion	NE.¼, sec. 30, T. 35 S., R. 12 W., N. Granite Mountain	Replacement	2 million

Table 1 (Continued)

53. Wall Street	NW.¼, sec. 31, T. 35 S., R. 12 W., E. Granite Mountain	Fissure vein	50 to 100 thousand
54. Yellow Jacket	SE.¼, sec. 19; and NE.¼, sec. 30, T. 36 S., R. 13 W., N. Iron Mountain	Replacement	1 million
55. Zelma	SW.¼, sec. 15; and SE.¼, sec. 16, T. 35 S., R. 12 W., S. Three Peaks	Fissure vein	50 to 100 thousand

siderations were given to ore recovery. An innovation in the Iron Springs district was the installation of a mobile magnetic iron-ore concentrator by the Utah Construction and Mining Company (Juvelin, 1965, 1967). This is a dry magnetic separation plant, self-propelled and designed to treat low-grade alluvial deposits. The mobile magnetic iron-ore concentrator went into operation in 1964 (Juvelin and McArthur, 1967) on the McCahill and Thompson property on the northeast side of Iron Mountain.

Absence of titanium in the ore, relatively high magnetite concentration, and large quantities of debris between 28 mesh and 24 inches allow an especially favorable operation. The alluvial deposits average about 10 percent iron, ranging from 3 to 20 percent (McArthur and Porath, 1965). Three percent iron is roughly the inherent iron analysis of the intrusive rock. A cutoff as low as 6 percent iron is used in alluvial concentration. Mining depths to 100 feet or more are contemplated. The process used in recovering iron ore fom crude alluvium is essentially a size separation followed by magnetic separation of size fractions. Oversize is eventually used as open-hearth ore; the undersize, in blast furnaces. Annual production averages about 300,000 tons.

Production and Chemical Analyses

Iron-ore production from the Iron Springs district by Mormon pioneers was meager and sporadic, with only a few thousand tons of ore being processed. The first major development of metallic-iron production from iron ores was achieved in 1924 by Columbia Steel Corporation of California at the Ironton Plant at Provo, where a blast furnace with a rated capacity of 500 tons of pig iron daily, or 200,000 tons annually, was erected. The greatest ore production from the district prior to United States entry into World War II was 354,795 long tons in 1938. After the Geneva Works was completed, ore production rose to 1,931,795 long tons in 1945. From 1944 to 1961 iron-ore production averaged 3.25 million long tons annually. Under the stimulus of the Korean War, ore production from the Iron Springs district rose to 4,836,596 long tons in 1953.

Since August 1962 the Geneva Works has been receiving 1.5 million gross tons annually of agglomerated taconite pellets from U. S. Steel Corporation's mine at Atlantic City, Wyoming. Production of ore from the Iron Springs district has been greatly reduced since the use of taconite ore. From 1962 to 1971, ore production from the Iron Springs district has averaged 1.99 million long tons. Production during 1971 was 1,869,021 long tons (Skillings, 1922-1972).

Three major iron-mining companies produce ores from open-pit operations in the Iron Springs district: U. S. Steel Corporation, Utah International, Inc., and CF&I Steel Corporation. The largest pit in the district has a diameter of about 2,500 feet. Pit depths extend to 500 feet. Three active open pits were operated in 1970 by U. S. Steel: the Desert Mound, Pioche, and Mountain Lion pits; Utah International, Inc. has five operations: the Armstrong, Lindsay, Irene and Smith pits and the alluvial iron ore deposits. CF&I Steel Corporation has two active pits: the Duncan and Comstock deposits.

The main production from the Iron Springs district is direct-shipping ore. Generally the grade of direct-shipping ore ranges from 45 to 68 percent iron with an average iron content between 50 and 55 percent. This ore requires only crushing and screening prior to shipping. Ores with iron content from 20 to 45 percent are upgraded by the beneficiation plant at Iron Springs. This low-grade ore is being stockpiled by other companies for future processing. Open hearth and blast-furnace ores are shipped from the district. Open-hearth ore must be coarse, dense, of a high grade, low in impurities, and from minus 7 inches to plus 2½ inches in diameter. The finer and lower-grade ores, all minus 2½ inches in diameter, are used for blast-furnace ore. U. S. Steel's specifications (See Table 2) for iron ores vary somewhat, but the following examples are general guidelines which iron producers are required to meet.

Since 1962, about 70 percent of the iron ore produced in the district was shipped to the Geneva Works at Provo, and most of the balance went to the Minnequa Works, Pueblo, Colorado. From 1923 through 1971, the Iron Springs district has produced 83.6 million long tons of iron ore with a weighted average grade of 52.7 percent iron content. Table 3 shows the annual iron ore production from the district from 1923 through 1971 with weighted average grades of iron content for each year.

Ore Reserves

After observing surface exposures and depths of ore exposed by pits, drill holes, and erosional surfaces, Leith and Harder (1908) estimated the iron reserves of the Iron Springs district to be 40 million tons. The district had produced but a few thousand tons of ore when investigated by Leith and Harder. The largest single deposit estimate based on exposures was 15 million tons. They indicated that their tonnage estimate was too small rather than too large, since depths used in calculations were those actually observed; and nowhere were the bottoms of any ore deposits exposed to view.

Wells (1938) made a limited study of the Iron Springs and Bull Valley districts. He indicated that individual replacement ore bodies of 10 million

TABLE 2
IRON-ORE SPECIFICATIONS (BY PERCENT) OF U. S. STEEL CORPORATION

	Open-Hearth Furnaces	Blast Furnaces
Fe	58.0 minimum	50.0 minimum
SiO_2	7.0 maximum	10.0 maximum
S	0.05 maximum	0.10 maximum
P	0.40 maximum	0.25 maximum
Cu	0.04 maximum	0.04 maximum
Ni	0.04 maximum	0.04 maximum
Pb	0.01 maximum	0.01 maximum
Zn	0.01 maximum	0.01 maximum
As	0.01 maximum	0.01 maximum

TABLE 3

IRON-ORE PRODUCTION, 1923-1971, AND WEIGHTED AVERAGE ANALYSES OF IRON ORES FROM IRON SPRINGS DISTRICT, IRON COUNTY

Year	Long Tons	Iron Percent Weighted Average	Year	Long Tons	Iron Percent Weighted Average	Year	Long Tons	Iron Percent Weighted Average
1923	57,753	—	1940	326,500	54.9	1957	4,245,038	52.1
1924	164,154	—	1941	3555,006	54.4	1958	3,563,760	49.6
1925	270,029	53.0	1942	321,034	53.5	1959	2,762,155	50.1
1926	275,567	54.1	1943	922,959	53.7	1960	3,369,084	50.7
1927	222,879	52.0	1944	1,542,284	52.6	1961	3,832,550	51.2
1928	320,655	52.6	1945	1,931,749	52.8	1962	2,629,758	51.7
1929	320,960	51.7	1946	1,317,176	53.6	1963	1,880,683	52.8
1930	277,774	52.0	1947	2,823,853	53.3	1964	2,082,180	52.9
1931	183,668	53.0	1948	3,233,413	53.9	1965	2,138,674	53.4
1932	136,874	52.6	1949	2,712,390	55.9	1966	1,956,101	52.7
1933	95,129	52.2	1950	3,159,926	54.4	1967	1,708,044	53.2
1934	161,009	52.3	1951	3,902,594	55.1	1968	1,763,511	53.4
1935	161,010	52.3	1952	4,059,956	53.95	1969	1,920,869	52.9
1936	153,923	54.7	1953	4,836,596	54.1	1970	1,990,000	53.8
1937	190,908	54.5	1954	2,918,926	53.1	1971	1,869,021	53.8
1938	354,795	54.1	1955	3,806,367	53.4			
1939	262,087	53.1	1956	4,126,811	52.6	Total	83,618,141	52.7

tons of ore were known, and he estimated that the total tonnage in Iron Springs and Bull Valley districts was probably about 100 million tons.

Allsman (1948) of the U. S. Bureau of Mines estimated that 100 million long tons could conservatively be classified as measured, and indicated reserves with a grade of 45 to 50 percent iron content. This estimate was based on results from drilling, geology, and geophysics. An additional 250 million long tons were inferred from geological and geophysical evidence supported by very limited drilling.

This writer is impressed by the many large ore bodies delineated by magnetic surveys and by several large ore deposits whose tonnage has been determined by exploratory and development drilling operations. The Rex ore body exceeds 100 million tons of ore, and the Comstock and Mountain Lion deposits have at least 60 million tons. In addition to the 83.6 million long tons of iron ore mined from the district through 1971, the ore potential of the district exceeds 300 million tons. This estimate is based on ore occurrences in areas where the horizontal and vertical outlines of ore bodies are fairly well established by magnetic surveys and where detailed drilling has been done. Several areas in the district still are unexplored in detail but have been outlined in a broad way by aeromagnetic and gravity surveys. Some of these areas promise new deposits, especially since the geophysical data suggest the intrusive bodies are stocks rather than laccoliths in form.

Genesis of Ore Deposits

The genesis of iron ores in the Iron Springs district has long been a controversial issue. The first two concepts of origin were derived from casual studies and are only of historical interest. Proposed origins are metamorphosed sediments, ore magma, contact metamorphic, pyrometasomatic, pneumatolytic, deuteric alteration, and igneous-metamorphic. The writer proposes the last origin for the development of iron-ore deposits in the district.

Metamorphosed sediments origin. The first hypothesis of origin of Iron Springs ores was proposed by Newberry (1880, 1881a, 1881b, 1882). He suggested that the iron ores were metamorphosed sediments of probable Lower Silurian age. He considered the ores to be interstratified with layers of granite and based his conclusion on examination of the Blair placer, now known as the Great Western fissure vein in the Three Peaks area.

Ore magma origin. Jennings (1904, 1905) also studied the fissure veins in the Three Peaks area. He thought the iron deposits to be ore magmas resulting from differentiation of a basaltic magma at depth, and that ore magmas were forced to the surface in the form of dikes into diorite porphyry. He further suggested that when the quantity of material was more than sufficient to fill the fractures it overflowed in the form of sheets, and when the fractures extended into the overlying sedimentary rocks they were filled with ore.

Contact metamorphic origin. After study, Leith (1904, 1906) and Leith and Harder (1908) concluded that the ores were contact metamorphic in origin. They suggested that the ores were closely related in origin to intrusions of large masses of andesite taken to be laccoliths. The first effect of the intrusions was contact metamorphism of the limestone in the form of fusion of limestone, introduction of silica and the formation of anhydrous silicates. Ore-bearing solutions followed shortly after contact metamorphism of limestone and after the outer part of the intrusives had crystallized. They suggested that iron was carried in the form of ferrous chloride. The resulting ore deposits constitute fissure veins in the intrusive, fissure, and replacement deposits along both the contact zone in limestone and the breccia cement in Cretaceous strata. The source of iron-bearing solutions for the various types of deposits was the same, and they considered the mineralizing solutions to come from hot magmas of the intrusive interiors. Butler (1920) made a limited study of the Iron Springs district and agreed with the conclusions of Leith and Harder concerning the origin of the ores, except that he regarded the intrusives as stocks.

Pyrometasomatic origin. Lindgren (1925, 1933) called the Iron Springs district ores "pyrometasomatic" deposits associated with stocks. He defined the term as those deposits formed by metasomatic changes in rocks, principally in limestone, at or near intrusive contacts, at high temperatures, and under the influence of magmatic emanations. In his classification, however, he included numerous deposits remote from intrusive contacts. Tarr (1938), Knopf (1933, 1942), and Emmons (1940) agreed generally that Iron Springs ores are associated with stocks and classified them as pyrometasomatic or "contact metamorphic" deposits. Both terms, however, have become obsolete for ores associated with intrusive contacts.

Pneumatolytic origin. Wells (1937 and 1938) ascribed the origin of the iron ores in the district to high-temperature pneumatolytic action. Although he did not use the term, his description typified this process. He stated that during intrusion of monzonite porphyry stocks, the hoods and overlying rocks fractured, causing the sudden release of pressure and allowing water vapor and iron chloride gases to escape to the surface along tension fractures (without appreciably heating the country rocks), deposited magnetite and hematite in fissures, and replaced contiguous fractured limestone.

Deuteric alteration origin. Mackin (1947b, 1954, 1968) hypothesized a deuteric alteration origin for Iron Springs deposits. He delineated three zones in the intrusive bodies which he regarded as laccoliths. The first zone, a peripheral shell 100 to 200 feet thick, is composed of fine-grained quartz monzonite porphyry containing fresh biotite and hornblende phenocrysts. An interior zone is composed of coarse-grained porphyry in which biotite and hornblende underwent deuteric alteration. A third zone, of selvage joints, separates the interior from the peripheral shell. Rock on each side of individual selvage joints is bleached through a narrow zone to six inches thick on each side of the joint but ranging in thickness from less than one inch to several feet. Biotite and hornblende are completely altered in this zone. Mackin and Ingerson (1960) proposed a deuteric release of iron and associated substances from the bleached selvage zone to form the iron ores of the district. They considered the iron to be "sweated out" of the selvage joint rock by diffusion and deposited as fissures in porphyry and as replacements in limestone.

Mackin (1968) published the chemical composition of intrusive rock from the peripheral shell, interior rock, and selvage joint rock (Table 4). Iron content in the peripheral rock is 3.64 percent; in the interior rock, 3.26 percent; and in bleached selvage joint rock, 2.18 percent. The deuterically altered zone contains about the same amount of iron as the fresh peripheral zone, but bleached selvage rock contains somewhat less total iron. Mackin therefore proposed that bleached selvage rock is the source of iron-forming fluids, and that the mechanism of iron transfer to replacement bodies was diffusion.

Mackin was forced to infer a deuteric origin for iron because his conclusion that Iron Springs district intrusions were shallow laccoliths eliminated a deep source of iron-rich emanations. This writer questions the quantitative adequacy of this hypothesis since the selvage rock zone usually measures only a few inches thick on either side of any individual selvage joint. A deuteric theory of origin for the huge replacement ore bodies in the Iron Springs district appears to be entirely inadequate. Recent information further indicates that even if the intrusive bodies were floored, they are still sufficiently thick to produce ample residual iron-rich emanations to form Iron Springs ore deposits without requiring a deuteric release of iron from biotite and hornblende along thin bands of selvage joint rocks.

Igneous-metamorphic origin. This writer proposes an igneous-metamorphic origin for Iron Springs iron-ore deposits. The term connotes ore occurrences near intrusive contacts with an assemblage of high-temperature minerals and the introduction of constituents from the intrusive into country rocks and fissures in chilled intrusive margins.

Two main stages are visualized for magmatic emanations, alterations, and ore deposition at Iron Springs district: first, a late magmatic stage in which occurred deuteric alteration of porphyry, metasomatism of contact rocks, and formation of magnetite-apatite fissure veins; and second, a hydrothermal stage during which large limestone replacement ore bodies were formed. The late magmatic stage started shortly after the peripheral shell had formed, when crystallization was nearing completion in the upper magmatic chambers. Subsequently, surges of magma opened tension joints that extended into the largely consolidated interior-phase rocks. Early magmatic emanations were likely gaseous in nature, but liquid emanations probably dominated.

Escaping solutions from the cooling intrusions introduced silica and soda into the bleached porphyry adjacent the selvage joint, and at the same time leached iron, fluorine, and phosphorus from the porphyry (Table 3). When the

TABLE 4
CHEMICAL COMPOSITION (BY PERCENT) OF INTRUSIVE ROCK TYPES IN THE IRON SPRINGS DISTRICT, UTAH

	Peripheral Shell[1]	Interior Rock[2]	Selvage Joint Rock[3]
SiO_2	60.67	62.47	63.96
Al_2O_3	17.13	16.74	16.98
Fe_2O_3	2.22	3.04	1.08
FeO	2.28	1.52	1.31
Fe	3.64	3.26	2.18
MgO	2.53	2.19	1.16
CaO	4.57	3.95	3.91
Na_2O	3.19	2.35	4.05
K_2O	3.39	2.83	3.34
H_2O	1.02	1.71	0.69
TiO_2	0.78	0.76	0.79
P	0.09	0.09	0.07
S	0.06	0.01	0.01
F (ppm)	419	282	69

[1]Average of 15 analyses.
[2]Average of 10 analyses.
[3]Average of 8 analyses.

proper temperature, pressure, and concentration were attained, magnetite, apatite and chalcedony were deposited in open joints, giving rise to fissure veins. Iron is believed to have come also from residual fluids during this late magmatic stage of crystallization, contributing to the formation of fissure veins. Renewed openings produced encrusted fissure veins.

Ratté (1963) showed that large amounts of SiO_2, Al_2O_3, MgO, Na_2O, Fe, P, and F were introduced into sedimentary rocks of the contact zone, producing fine-grained skarn rocks. Contact metasomatic minerals that developed in altered Basal Siltstone of the Carmel Formation are actinolite, diopside, hedenbergite, phlogopite, scapolite, tremolite, vesuvianite, and wollastonite. The skarn minerals are fine-grained and are recognized from thin sections of the rocks. Mackin (1954, 1968) called the altered Basal Siltstone a "hornfels," emphasizing contact metamorphism and isochemical changes only. This writer prefers the term "fine-grained skarn rock" for altered Basal Siltsone and altered Homestake Limestone, emphasizing the introduction of constituents. Igneous emanations produced progressive metasomatic alteration of Homestake Limestone. This can be observed by tracing unaltered limestone through altered zones into large replacement ore bodies. First this metasomatic action bleached the limestone, then the grain size enlarged by recrystallization of calcite, followed by the development of phlogopite and vesuvianite. Continued metasomatism converted the limestone into a fine-grained skarn rock composed of apatite, calcite, diopside, epidote, garnet, phlogopite, quartz, vesuvianite, and wollastonite. The main skarn mineral is fine-grained andradite garnet. Altered siltstone and limestone are difficult to distinguish; however, the siltstone contains detrital quartz and feldspar, and the limestone typically contains andradite garnet.

Ore-bearing solutions entering the Homestake Limestone preferentially replaced first calcite, then silicate skarn minerals, and formed replacement ores of magnetite and hematite. A metasomatic origin of the ore bodies is indicated by the lack of overall differences in stratigraphic thickness between limestone and equivalent replacement ore bodies and is clearly demonstrated by detailed mapping and by numerous diamond drill holes. Bedding and other preore structures can be traced in places from limestone into ore with no break in continuity.

The main replacement ore bodies are the result of hydrothermal emanations, rising principally along faulted and brecciated zones that formed not only important channelways but also important loci for replacement deposits. The Shortline deposit is located along a graben block. A basal breccia, strongly mineralized, is exposed in the footwall at the Lindsay pit. The Clive-Constitution, A and B, and other ore bodies are located along intrusive faults. The Blowout and Pot Metals deposits replaced brecciated portions of the lower plate of a Laramide thrust. The A and B, Armstrong, Blowout, Desert Mound and Burke ore bodies occur along or near cross-faults. Breccia pipe structures occur at Blowout, Dear, Armstrong, Little Allie, and other ore bodies. These and other deposits indicate the importance of brecciation as channelways and in the localization of ore bodies. Breccia pipes in particular appear to have been feeder pipes for hydrothermal solutions. The Blowout, Little Allie, and Armstrong ore bodies occur along the contact zone but mostly in porphyry and are composed mainly of magnetite, representing deep-seated plumbing for hydrothermal emanations. The cores of these breccia pipes are high in quartz as amethyst, galena, chalcopyrite, bornite, and pyrite. The pyrite content increases with depth.

An igneous-metamorphic origin of the Iron Springs ore deposits is further indicated by detailed studies of ore mineralogy. Minerals associated with the ore deposits of the district are actinolite, albite, amethyst, andradite, ankerite, apatite, aragonite, azurite, barite, bornite, calcite, chalcedony, chalcopyrite, chlorapatite, chlorite, chloropal, chrysocolla, cinnabar, native copper, cuprite, diopside, dolomite, dufrenite, epidote, fluorapatite, galena, garnet, goethite, gypsum, hedenbergite, hematite, isoclasite, lepidocrocite, limonite, lodestone, maghemite, magnesite, magnetite, malachite, marcasite, martite, melanterite, metastrengite, memetite, pyrite, quartz, phlogopite, rhodochrosite, rockbridgeite, scapolite, scolecite, selenite, siderite, specularite, sphene, spinel, tenorite, tourmaline, tremolite, turgite, vesuvianite, and wollastonite. This list includes important contact metasomatic, hypogene, and secondary minerals. Those particularly indicative of hypogene or hydrothermal mineralization are apatite, barite, bornite, chalcopyrite, cinnabar, dolomite, galena, hematite, lodestone, magnetite, marcasite, pyrite, quartz, rhodochrosite, specularite and tourmaline. The presence of bornite, chalcopyrite, galena, and pyrite embedded in massive magnetite, pockets of cinnabar, and other sulfides in iron ore and the intimate association of finely disseminated pyrite with the ore are conclusive evidence of a hydrothermal origin for the iron deposits. Pyrite increases slightly with depth of mining, and some ore has such a high content of pyrite that it is removed to lean ore dumps.

In summary, the writer proposes an igneous-metamorphic origin for the main iron-ore deposits in the Iron Springs district. The deposits are concentrated along the roof and margins of semiconcordant stocks in the form of replacement bodies in limestone roof rocks, breccia fillings and replacements along faults and pipelike structures along intrusive margins, and fissure fillings in quartz monzonite porphyry. The iron is thought to have been derived principally from residual fluids resulting from magmatic crystallization of the porphyrys. These magmatic emanations were released in part during the late magmatic stage but principally during the hydrothermal stage of mineralization. The main channelways for emanations are mostly along faults and brecciated zones, in part along selvage joints. Some iron apparently was leached from the porphyry wall rocks by ascending hydrothermal solutions, but it was a minor source of mineralization.

REFERENCES CITED

Allsman, P. T., 1948, Investigation of iron ore reserves of Iron County, Utah: U. S. Bur. Mines, Rept. Inv. 4388, 3 p.

Armstrong, R. L., 1963, Geochronology and geology of the eastern Great Basin: unpub. Ph.D. dissertation, Yale Univ., 202 p.

Bellum, D. P., and Nugent, Lee, 1963, Iron mining, healthy Utah industry: Min. Eng., v. 15 (11), p. 34-38.

Blank, H. R., and Mackin, J. H., 1967, Geologic interpretation of an aeromagnetic survey of the Iron Springs district, Utah: U. S. Geol. Survey Prof. Paper 516-B, 14 p.

Butler, B. S., et al., 1920, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, 672 p.

Cook, E. F., 1957, Geology of the Pine Valley Mountains, Washington County, Utah: Utah Geol. and Mineralog. Survey Bull. 58, 111 p.

——— 1960, Geologic atlas of Utah, Washington County: Utah Geol. and Mineralog. Survey Bull. 70, 119 p.

Cook, K. L., 1948, Magnetic surveys in the Iron Springs district, Iron County, Utah (abst.): Geophysics, 13, p. 503.

——— 1950, Magnetic surveys in the Iron Springs district, Iron County, Utah: U. S. Bur. Mines, Rept. Inv. 4586, 78 p.

Cook, K. L. and Hardman, Elwood, 1967a, Regional survey of the Hurricane fault area and Iron Springs district, Utah, in Geol. Soc. Amer. Abst. for 1966: Geol. Soc. Amer. Special Paper 101.

——— 1967b, Regional gravity survey of the Hurricane fault area and Iron Springs district, Utah: Geol. Soc. Amer. Bull. 78, p. 1063-1076.

Dahl, C. L., 1959, Trace ferrides in iron ores from the Iron Springs district, Cedar City, Utah: unpub. M.S. thesis, Univ. of Utah, 62 p.

Dempsey, W. J., 1951, Preliminary aeromagnetic map of the Iron Springs district, Utah: U. S. Geol. Survey open-file map.

Emmons, W. H., 1940, Iron, Iron Springs, Utah, *in* Principles of economic geology: McGraw-Hill Book Co., New York, p. 269-70.

Erspamer, E. R., 1964, Magnetic beneficiation of southern Utah iron ores: open-file report, Utah Construction and Mining Company (paper given at Wyoming Mining Assoc. Conv., Jackson Lake Lodge, Moran, Wyo., June).

Everett, A. G., 1967, Petrology and trace element chemistry of the Carmel Formation (Jurassic), Iron Springs district, Utah: unpub. Ph.D. dissertation, Univ. of Texas.

Granger, A. E., 1963, The iron province of southwestern Utah, *in* Guidebook to the geology of southwestern Utah, p. 146-150: Intermountain Assoc. Petrol. Geol., 12th Ann. Field Conf. Guidebook.

Gregory, H. E., 1950, Geology of eastern Iron County, Utah: Utah Geol. and Mineralog. Survey Bull. 37, 153 p.

Jaffe, H. W., et al., 1959, Lead-alpha age determinations of accessory minerals of igneous rocks: U. S. Geol. Survey Bull. 1097-B, p. 65-148.

Jennings, E. P., 1904, Origin of the magnetic iron ores of Iron County, Utah: Salt Lake Min. Rev., 6, Apr. 30, p. 16-17.

——— 1905, Origin of the magnetic iron ores of Iron County, Utah: Amer. Inst. Min. Met. Eng. Trans., v. 35, p. 338-342.

Juvelin, C. R., 1965, How Utah Construction recovers iron ore from alluvial deposits: World Mining, August, p. 47-49.

——— 1967, Recovery of iron from low-grade alluvial deposits: open-file report, Utah Construction and Mining Company.

Juvelin, C. R., and McArthur, C. K., 1967, Mobile magnetic iron-ore concentrator: open-file report, Utah Construction and Mining Company (paper given at Pacific Southwest Mineral Industry Conf., Asilomar, Monterey Peninsula, California, May).

Knopf, Adolph, 1933, Pyrometasomatic deposits in ore deposits of the western United States (Lindgren volume): New York, Amer. Inst. Min. Met. Eng., p. 540-541.

——— 1942, Ore deposition in the pyrometasomatic deposits, *in* ore deposits as related to structural features: Princeton Univ. Press, p. 63-72.

Leith, C. K., 1904, Iron ores in southern Utah: U. S. Geol. Survey Bull. 225, p. 229-237.

——— 1906, Iron ores of the western United States and British Columbia: U. S. Geol. Survey Bull. 285, p. 194-200.

Leith, C. K., and Harder, E. C., 1908, Iron ores of the Iron Springs district, southern Utah: U. S. Geol. Survey Bull. 338, 102 p.

Lewis, A. E., 1958, Geology and mineralization connected with the intrusion of a quartz monzonite porphyry, Iron Mountain, Iron Springs district, Utah: unpub. Ph.D. dissertation, California Inst. Tech., 75 p.

Lindgren, Waldemar, 1925, Metasomatism: Geol. Soc. Amer. Bull., v. 36, p. 247-261.

——— 1933, Pyrometasomatic deposits, Iron Springs, Utah, *in* Mineral deposits: McGraw-Hill Book Co., New York, p. 715.

Longwell, C. R., 1940, Structure of the northern Muddy Mountains area, Nevada: Geol. Soc. Amer. Bull., v. 60, p. 923-968.

Mackin, J. H., 1947a, Joint patterns in the Three Peaks laccolith, Iron Springs district, Utah: (abst.) Geol. Soc. Amer. Bull., v. 58, p. 1255.

——— 1947b, Some structural features of the intrusions in the Iron Springs district, Utah: Utah Geol. Soc. Guidebook to the Geology of Utah, No. 2, 62 p.

——— 1954, Geology and iron ore deposits of the Granite Mountain area, Iron County, Utah: U. S. Geol. Survey Min. Inv., Field Studies Map MF 14.

——— 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: Amer. Jour. Sci., 258, p. 81-131.

——— 1968, Iron deposits of the Iron Springs district, southwestern Utah: *in* Ore deposits in the United States, 1933-1967, 2 vols., A. I., M. E., p. 992-1019.

Mackin, J. H., and Ingerson, E., 1960, An hypothesis for the origin of ore-forming fluids: U. S. Geol. Survey Prof. Paper 500-B, p. B1, B2.

MacVichie, Duncan, 1925, Iron fields of the Iron Springs and Pinto mining districts, Iron County, Utah: (abst.) Min. and Met. 6, p. 441.

——— 1926, Iron fields of the Iron Springs and Pinto mining districts, Iron County, Utah: Amer. Inst. Min. Eng. Trans., 74, p. 163-173.

McArthur, C. K., and Porath, R. P., 1965, Concentrating iron ore in a mobile plant: Min. Cong. Jour., v. 51 (10), p. 28-33.

Miller, G. M., 1966, Structure and stratigraphy of the southern part of the Wah Wah Mountains, southwest Utah: Amer. Assoc. Petrol. Geol. Bull., v. 50, p. 858-900.

Newberry, J. S., 1880, The genesis of the ores of iron: Columbia Univ. School of Mines Quart., v. 1, p. 9-12.

——— 1881a, The genesis of our iron ores: Eng. and Min. Jour., v. 31, p. 286-287, 298-300.

——— 1881b, The iron ores of southern Utah: Amer. Naturalist, v. 15, p. 410-412.

——— 1882, Origin of crystalline iron ores: New York Acad. Sci. Trans., v. 2, p. 13-15.

O'Carroll, H. J., 1967, The concentration potential of the ores at Iron Mountain, Utah: unpub. Ph.D. dissertation, Stanford Univ.

Park, C. F., Jr., and MacDiarmid, R. A., 1964, Igneous metamorphic deposits, Iron Springs, Utah, *in* Ore deposits, W. H. Freeman and Company, San Francisco, p. 259-266.

Ratte, C. A., 1963, Rock alteration and ore genesis in the Iron Springs-Pinto mining district, Iron County, Utah: unpub. Ph.D. dissertation, Univ. of Arizona, 149 p.

Rohlfing, D. P., 1923, Iron-ore deposits of southern Utah: Eng. and Min. Jour. Press 115, p. 716-719.

Skillings Mining Review, 1922-1972, David N. Skillings, publisher, 210 Sellwood Bldg., Duluth, Minn., v. 12-58.

Slawson, W. F., 1958, Lead in potassium feldspars from Basin and Range quartz monzonites: unpub. Ph.D. dissertation, Univ. of Utah.

Tarr, W. A., 1938, Iron, the deposits near Iron Springs, Utah, *in* Introductory economic geology: McGraw-Hill Book Co., New York, p. 106.

Wells, F. G., 1937, The origin of the Bull Valley, Utah, iron-ore deposits: Econ. Geol., v. 32 (2), p. 192-193.

——— 1938, The origin of the iron-ore deposits of the Bull Valley and Iron Springs districts, Utah: Econ. Geol. v. 33 (5), p. 477-507.

Williams, P. L., 1960, A stained-slice method for rapid determination of phenocryst composition of volcanic rocks: Amer. Jour. Sci., v. 258, p. 148-152.

Young, W. E., 1947, Iron deposits, Iron County, Utah: U. S. Bur. Mines Rept. Inv. 5076, 102 p.