IRON AND MANGANESE.

SOME IRON ORES OF WESTERN AND CENTRAL CALIFORNIA.

By E. C. HARDER.

INTRODUCTION.

Iron-ore deposits are abundant in different parts of California, yet until very recently no ore had been mined from them. The only iron-ore furnace in the State is an experimental Heroult electric furnace installed in 1907 by the Noble Electric Steel Company at Heroult, on Pit River, Shasta County, and operated intermittently in 1907, 1908, and 1909. During 1909 a commercial furnace was erected. The ore used is mined in the vicinity of the plant. Besides the Noble furnace there are only four iron-ore furnaces in the Western States—the Minnequa coke furnaces at Pueblo, Colo., consisting of six stacks; the Irondale charcoal furnace at Port Townsend, Wash., consisting of one stack; the Black Sand and Gold Recovery Company's electric furnace at Hood River, Oreg., and the Oswego charcoal furnace at Oswego, Oreg., consisting of one stack. The Oswego furnace has not been active since 1894 and the electric furnace at Hood River is only in an experimental stage. The Pueblo furnaces, however, have been operated regularly for many years, their ores being obtained largely from Wyoming, Colorado, and New Mexico. The furnace at Port Townsend has been active intermittently, its ores coming from Texada Island, British Columbia, and from Washington. No California ore has been used in any furnace outside of the State.

The principal iron-ore deposits of California are the Pit River or Redding deposits, Shasta County; the Gold Valley deposits, Sierra County; the Minaret deposits, Madera County; the Iron Mountain, Cave Canyon, Providence Mountain, and Newberry deposits, San Bernardino County; and the Eagle Mountain deposits, Riverside

County. Of minor importance are the Patamocas or Beegum deposits, Tehama County; the Newtown and Indian Springs deposits, Nevada County; the Hotaling deposit, Placer County; the Detert deposit, Calaveras County; the Mount Raymond deposits, Madera County; the Perfumo Canyon deposit, San Luis Obispo County; and the Owl Holes, Kingston Range, Garlic Springs, and Iron Age deposits, San Bernardino County. Numerous other small deposits are known.

The Minaret deposits, situated near the summit of the Sierra Nevada, are said to be the largest in California and perhaps in the West. Of nearly equal size are the Eagle Mountain deposits, located near the boundary of the Mohave and Colorado deserts; all the rest of the deposits are much smaller. The only ores which have been worked with the intention of producing pig iron are the Hotaling deposit, operated some years ago unsuccessfully on account of the high cost of fuel, and the Pit River deposits, operated intermittently for the last few years to obtain ores for use in the Noble electric furnace. Practically, therefore, the iron ores of California are untouched.

The Eagle Mountain and Iron Age deposits, which were examined and mapped in detail during the summer of 1909 by the writer, with the assistance of John L. Rich, are the subjects of special reports. The Perfumo Canyon and Hotaling deposits and the iron ores of Calaveras County were examined briefly by the writer during the fall of 1909 and are herein described.

PERFUMO CANYON DEPOSIT, SAN LUIS OBISPO COUNTY.

The Perfumo Canyon iron-ore deposit is in San Luis Obispo County, about 5 miles south of west from San Luis Obispo, in the San Luis or Los Osos Mountains. It consists of a nearly vertical bed of limonite interlayered with dark shale and sandstone of the Franciscan formation (Jurassic). The bed strikes in general a little north of west and is said to be traceable for more than a mile,[a] but was followed by the writer through only about half of its extent. Its thickness varies from 8 to 12 feet.

Perfumo Canyon has a northeast-southwest direction where the iron-ore bed crosses it, the latter striking nearly east and west at this point but changing in direction to north of west as it runs up the hills on both sides. The principal outcrops are found where the bed crosses the creek, and where it crosses the road several hundred feet to the northwest, but smaller exposures occur to the north-

[a] Fairbanks, H. W., San Luis folio (No. 101), Geol. Atlas U. S., U. S. Geol. Survey, 1904, p. 14; Structural and industrial materials of California; Bull. California State Min. Bur. No. 38, p. 301.

west and southeast of these. The slopes of the valley are very gradual and the trend of the ore outcrops is the same as the general strike of the bed. Perhaps several hundred feet northeast of the ore bed lies the contact of the Franciscan formation with serpentine.

Where it outcrops on the creek, the bed is about 9 feet wide, strikes N. 65° W., and dips 68° S. North of it are dark grayish-brown interbedded coarse and shaly sandstones, the latter very ferruginous, especially near the ore. The contact between the sediments and the ore is well defined, however, and in places a few inches of soft ferruginous earth occurs along it. South of the ore bed the contact is not so well marked, the ore grading into dark ferruginous shaly sandstones which contain considerable iron within a foot from the contact. The shaly sandstones are broken up into small rounded blocks by numerous fractures. Within the ore bed are several beds or lenses of ferruginous shaly sandstone, varying up to 6 inches in thickness and extending along the ore bed for distances of 8 or 10 feet. The strike of all these lenses is parallel with the strike of the ore bed and the inclosing sediments. Their contact with the ore is sharp. The ore itself has a bedded structure, the beds ranging in thickness from a few inches to a foot and a half. The different beds are finely laminated parallel to the bedding planes.

On the roadside the ore bed is exposed in a cut. It is here about 11 feet thick, strikes N. 80° W., and dips 60° S. The component beds vary greatly in thickness, as in the exposure at the creek, the thick beds generally being made up of dark-brown glossy laminated ore, whereas in the thin beds the ore is somewhat mixed with shaly and sandy material. The bedding planes and laminations are very prominent throughout the bed. On both sides of the ore are beds of soft dark-brownish sandstone broken into blocks. The fracture planes are coated with limonite, but little replacement has occurred and the contact between ore and sandstone is usually sharp.

On the hillside several hundred yards east of the exposure in the creek a trench shows the ore bed to have a thickness of about 11 feet. Here also it is bounded on both sides by dark sandstones.

The ore is largely a dark-brown or black glossy limonite finely banded and laminated parallel to the strike of the bed. At some places the lamination is hardly visible, but at others it is strongly pronounced because of thin bands of yellow ocher interlayered with the dark glossy ore. These bands are rarely more than a millimeter thick, and are generally mere films separating thicker laminæ of dark ore. Numerous fractures run through the bed, so that the ore breaks up into small variously shaped blocks with plane surfaces. This condition is characteristic of the bed throughout its extent.

The following are analyses of the ore and the highly ferruginous shaly sandstone.

Analyses of iron ore and wall rock from Perfumo Canyon, California.

[Dickman & Mackenzie, analysts, 1120 Rookery Building, Chicago.]

		Iron.	Phosphorus.	Silica.
1	Ore outcrop near creek, 11 feet of ore	44.80	0.500	15.41
2	Ore outcrop 2,000 feet southeast of No. 1	47.60	.530	11.20
3	Ore outcrop 3,000 feet northwest of No. 1	46.10	.510	13.10
4	3 feet of ferruginous shale underlying No. 1	16.30		
5	Ferruginous shale, average	13.30		
6	Ferruginous shale, selected	13.40		

MIXTURE OF SAMPLES 1, 2, AND 3.

Iron	46.16
Silica	13.23
Phosphorus	.513
Alumina	1.42
Lime	6.00
Magnesia	Trace.
Manganese	0.20
Sulphur	.639
Titanic acid	None.

The analyses show that the ore is high in phosphorus and silica and low in iron.

It seems clear that the iron ore of Perfumo Canyon is an original sedimentary deposit formed during an interval in the deposition of the inclosing sandstones and shales. The character of the ore, the bedding and fine laminations, and the included sedimentary beds all point to this conclusion. It is probably of the nature of a bog deposit which has been consolidated during the compression and folding of the accompanying strata. Accepting this as the origin of the ore, we may make conjectures as to the depth to which the bed is likely to extend.

The ore may have been deposited in a circular basin with a probable diameter of 5,000 feet or more, which is the present length of the deposit, or in an elliptical basin with one diameter of 5,000 feet or more. Subsequent erosion after tilting has removed a large part of the bed. If it is considered that the deposit was originally circular in outline and that about half of it has been eroded, the vertical bed as it remains would have a depth of 2,500 feet or more at the center and would gradually decrease in depth toward the ends. On the assumption that the bed has a fairly regular thickness of 10 feet there would in this case be a great tonnage of low-grade ore left in the ground. However, the bed may have been originally elliptical instead of circular in outline, and if so the quantity of ore is uncertain within a wide range, depending on whether the larger diameter is horizontal or vertical. Another uncertain factor is introduced by the fact that either more or less than half the bed may have been eroded. These conjectures show the possibilities in a continuous though thin ore bed. For commercial purposes, however, it must be considered that the bed may vary in thickness beneath the surface, may pinch out altogether for long distances, or may grade into ferruginous sandstones at slight depths. A depth greater than 100 feet should not be assumed without exploration, and this would reduce the probably available quantity to a few hundred thousand tons of low-grade ore, which is a fairly safe commercial estimate.

IRON ORES OF CALAVERAS COUNTY.

Several small deposits of brown iron ore occur in Calaveras County as replacements in slate or schist. They are in the central portion of the Mother Lode district, in the western foothills of the Sierra Nevada. About 50 or 60 miles northeast is the summit of the Sierra; about 15 miles west is the edge of the Sacramento and San Joaquin valley. There is a gradual increase in relief from the great central valley of California toward the summit of the Sierra. In the area under discussion there is a difference in elevation of about 1,500 or 2,000 feet between the valley bottoms occupied by the larger streams and the general level of the tops of the foothills. Above this level, however, rise several higher ridges, such as the Bear Mountains, due doubtless to the resistant nature of the rocks composing them. The hills are covered with sparse forests of digger pine, live oak, and white oak, with here and there open grassy areas, cultivated fields, and brush-covered slopes. Yellow pine and sugar pine begin to appear in the eastern part of the area and increase in number toward the summit of the range.

There are three localities at which iron ores are known in Calaveras County, 1½ miles northeast of Valley Springs, half a mile north of Esmeralda, and 1 mile north of Murphy. All the bodies are small and consist of low-grade ore, so that they are of little or no commercial importance.

The occurrences of iron ore northwest of Valley Springs, the principal one of which is known as the Detert deposit, are replacements in a slaty rock mapped by Turner [a] as amphibolite schist (earlier than late Cretaceous); those near Esmeralda and Murphy are in the Calaveras formation (Carboniferous).[b]

The Detert deposit shows several irregular outcrops of iron ore scattered over an area 100 feet wide and 200 or 300 feet long on the top and slopes of a small knoll. The knoll, consisting of yellow and light-brown and red schist (amphibolite schist), juts southward from a slightly higher transverse ridge on which a capping of white, yellow, and reddish sandstone and conglomerate (Ione formation of Tertiary age) overlies the schist. North and northwest of this ridge the schist reappears and contains several scattered iron-ore and ocher

[a] Turner, H. W., Jackson folio (No. 11), Geol. Atlas U. S., U. S. Geol. Survey, 1894.
[b] Turner, H. W., and Ransome, F. L., Big Trees folio (No. 51), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

deposits. Closely associated with the amphibolite schist are bands of Mariposa slate (Jurassic). Auriferous gravels occur locally.

The largest ore body in the Detert deposit is 40 or 50 feet long and about 6 feet wide. It rises to a height of 15 feet above the general level of the knoll, on the summit of which it occurs in decomposed, sandy, ferruginous red, yellow, and brown schist. Five or six smaller bodies are present close by, ranging from a few feet to 20 feet in length and up to 3 feet in width. The slaty structure strikes approximately N. 35° to 45° W. and dips very steeply to the southwest. Owing to the great deformation and decomposition which the schist formation has undergone the bedding is practically obliterated. Most of the ore lenses strike and dip parallel to the schistosity, but some are irregular in structure.

The horizontally bedded sandstones and conglomerates of the Ione formation on the ridge to the north are in places deeply stained with iron in the lower part. They rest on the upturned edges of the schist. The iron-ore lenses in the schist area north of the strip of Ione formation are mostly of small extent, being between 5 and 10 feet in length and up to 2 feet in width. Several larger deposits, however, 30 or 40 feet long and 6 to 8 feet wide, occur on a ridge to the northwest. The smaller masses are generally parallel to the bedding; the large ones are irregular.

The ores are brown ores, commonly known as limonite or brown hematite. They are of two varieties—a dark-brown or black glossy ore and a lighter-colored, more earthy ore. The former was doubtless deposited in open spaces, such as cavities or fissures; the latter is clearly a replacement of the schist, the structures of which are in places preserved in great detail. Locally the schist is only slightly replaced, and from this there are all gradations to solid ore. Much of the earthy ore occurs as fragments separated by veins and masses of black glossy ore. The deposits have apparently originated by the infiltration of iron oxide from above, which replaced the schist and filled fissures and cavities in it.

North of Murphy there are several small exposures of brown iron ore occurring as replacements and fissure fillings in the quartzite and slate of the Calaveras formation (Carboniferous). The best known of these is the Big Trees or Sperry deposit, located on the north side of a narrow, deep canyon about 1 mile north of Murphy. The rocks of the north canyon wall consist largely of brown, iron-stained quartzite and chert with a small lens of limestone near the base. The quartzite is much fractured and brecciated along the canyon slope above the limestone, and in some of these fractures there are small infiltrations of iron ore. Three tunnels have been driven into the hill; two on the lower slope encountered some ore, but the third, about 90 feet in length, driven into the face of a quartzite cliff halfway up the slope, encountered nothing but iron-stained quartzite and chert. Surface fragments of iron ore are abundant, however, along the crest and slope of the ridge.

Other iron-ore showings occur on the land of Price Williams, about one-fourth and one-half mile southeast and 1¼ miles west of the Big Trees deposit. At these localities no development work has been done and the ore appears only in surface outcrops and fragments of float. The Esmeralda iron-ore occurrence is also in the Calaveras formation and is very likely a western continuation of the Murphy belt of deposits.

The Murphy and Esmeralda deposits were doubtless formed by deposition of hydrated iron oxide from iron-bearing waters percolating downward along a fractured zone in the quartzite. The waters penetrated the quartzite and stained it, but little or no replacement has occurred. The ore deposited in cavities is largely of a dark-brown glossy variety but some yellowish ocherous ore occurs. The iron was probably derived from beds which originally overlay the quartzite, but have since been eroded.

HOTALING DEPOSIT, PLACER COUNTY.

The Hotaling iron-ore deposit is 6 miles north of Auburn and 3½ miles northwest of Clipper Gap, Placer County. The workings, consisting of several trenches, pits, and shafts, are on a small wooded knoll extending southwestward from a higher ridge. One shaft has an engine house in connection. Ore was mined and smelted here some years ago and considerable ore is still in the dumps.

A band, perhaps several hundred feet wide, of fine-grained basic igneous rock, probably diabase, crosses the knoll in a northwest-southeast direction. Northeast of it, forming the higher ridge, is a mass of granodiorite;[a] to the southwest, on the slope of the knoll, are sediments of the Calaveras formation (Carboniferous), here largely quartzite, but elsewhere composed of quartzite and slate with local limestone lenses. The granodiorite is later than the diabase, and both are later than the Calaveras formation. The iron ores occur at the contact of the diabase and the quartzite and within both formations, though more generally in the diabase. The ore is magnetite, both fine grained and coarse grained, and with it are associated a large number of minerals, such as garnet (andradite), epidote, pyroxene (augite), amphibole (anthophyllite), calcite, pyrite, chalcopyrite, and quartz. Garnet, epidote, augite, and anthophyllite are very abundantly developed in the diabase, but sparingly in the quartzite. Magnetite, quartz, calcite, pyrite, and chalcopyrite occur both in the diabase and in the quartzite.

[a] Lindgren, Waldemar, Sacramento folio (No. 5), Geol. Atlas U. S., U. S. Geol. Survey, 1894.

The workings extend along the contact of the quartzite and diabase through a distance of 150 or 200 feet, and the extent of the ore beyond this in either direction is problematic. The width of the contact zone is probably about 50 to 75 feet. Some distance northwest of the workings, near the diabase contact, is a small area of limestone. It is possible that the quartzite at the workings is really a silicified limestone metamorphosed by the igneous rock. Its present texture is typically that of a fine-grained quartzite, in which, however, there are numerous veinlets of calcite and quartz, impregnations of magnetite, and small amounts of metamorphic minerals near the diabase.

From an examination of various specimens of contact material it appears that the minerals have been formed in the following order: Andradite, magnetite, augite, pyrite, chalcopyrite, anthophyllite, epidote, quartz, calcite, limonite. Andradite, magnetite, and augite, the typical metamorphic minerals, occur both along the contact zone and in the wall rock; to a small extent within the quartzite and to a larger extent within the diabase. The andradite is generally in coarse crystals or masses up to an inch or two in diameter; the magnetite and augite are mostly in small crystals and granular aggregates. In many places small veins of magnetite cut through garnet masses. Augite is intimately associated with the magnetite, either intermixed with it as fine grains or contained in it in small irregular masses. Pyrite and chalcopyrite are disseminated through the magnetite and also occur within the quartz and calcite veins cutting the metamorphic minerals. Anthophyllite is found in dark-green fibrous aggregates in calcite and quartz associated with the metamorphic minerals. Epidote is associated with calcite in veins in the diabase. From their association it appears that epidote crystallized first. Quartz and calcite occur in veins cutting the metamorphic minerals and wall rocks. Quartz is apparently rare in the diabase, but calcite occurs abundantly in both diabase and quartzite. Calcite veins cut quartz veins, and quartz in turn is deposited in the center of calcite veins. Chalcopyrite is common within both quartz and calcite veins. Limonite occurs at the surface as an alteration product of magnetite, pyrite, and ferromagnesian minerals.

Most of the ore is thoroughly intermixed with the metamorphic minerals and later vein minerals and is therefore of low grade. Locally, however, there are masses of clean and apparently high-grade ore. It is either coarsely crystalline or finely granular; no massive, glossy ore, so common in many magnetite deposits, occurs. The ore body is small and as a whole of low grade.

The nature of the ore and the presence of metamorphic minerals point to the fact that the ores originated from a deep-seated source.

Their occurrence at the contact of the quartzite and diabase would indicate that the solutions were derived from the diabase. This view is further strengthened by the fact that the contact minerals are very abundant near the quartzite contact and probably absent or at any rate much less abundant near the granodiorite. It is nevertheless possible that the solutions have originated from the large granodiorite mass and have come up along the diabase-quartzite contact. It is also possible, as has been intimated, that the present quartzite was originally limestone and that solutions from the granodiorite have broken through the diabase and have replaced the much more readily altered limestone. Whatever the original source of the solutions may be, the ore has been deposited along the diabase-quartzite contact and has partly replaced the quartzite, while the metamorphic minerals associated with the ore occur largely along the contact and in the diabase near it.

THE IRON AGE IRON-ORE DEPOSIT, NEAR DALE, SAN BERNARDINO COUNTY, CALIFORNIA.

By E. C. Harder and J. L. Rich.

INTRODUCTION.

During the summer of 1909 the writers examined and mapped in detail the Iron Age iron-ore deposit, near Dale, San Bernardino County, and the iron ores of the Eagle Mountain district, in northern Riverside County, Cal. The former is the subject of the present discussion; a separate bulletin is being prepared on the latter. The writers are indebted to Dr. A. C. Spencer for many helpful suggestions in the preparation of this paper.

Dale, so named from the Virginia Dale gold mine near it, is a mining camp of about half a dozen houses just north of the boundary between San Bernardino and Riverside counties. (See fig. 19.) It is connected with Amboy, on the Atchison, Topeka and Santa Fe Railway, by a stage road 45 miles long with biweekly service, but it can also be reached from Mecca, on the Southern Pacific Railroad. Dale is the only town in this part of the Mohave and Colorado deserts between the two transcontinental lines.

LOCATION AND GEOLOGY.

The Iron Age iron-ore deposit is 6 miles east of Dale and a mile or two north of the boundary line between San Bernardino and Riverside counties, in a barren desert region. It is located in the eastern part of a range of bare mountains extending east and west along the boundary line and connected by an area of low hills with the Pinto Mountains to the southeast. To the north and south of this range are broad, flat desert areas, beyond which lie other mountain ranges. To the south can be seen the Eagle Mountains, in which the largest iron-ore deposits of southern California occur. To the north are the Sheep Hole Mountains, beyond which is the main line of the Atchison, Topeka and Santa Fe Railway.

The deposit may be reached from Dale by a direct trail through the mountains or by a circuitous wagon road along the edge of the desert area to the north, a distance of 10 or 12 miles. The Dale pumping station, about 6 miles north of Dale, is the nearest watering place, and there is no other spring or well within a radius of 20 miles.

The mountain range in which the iron ores are located consists of intrusive dioritic, granitic, and syenitic rocks of varying texture—

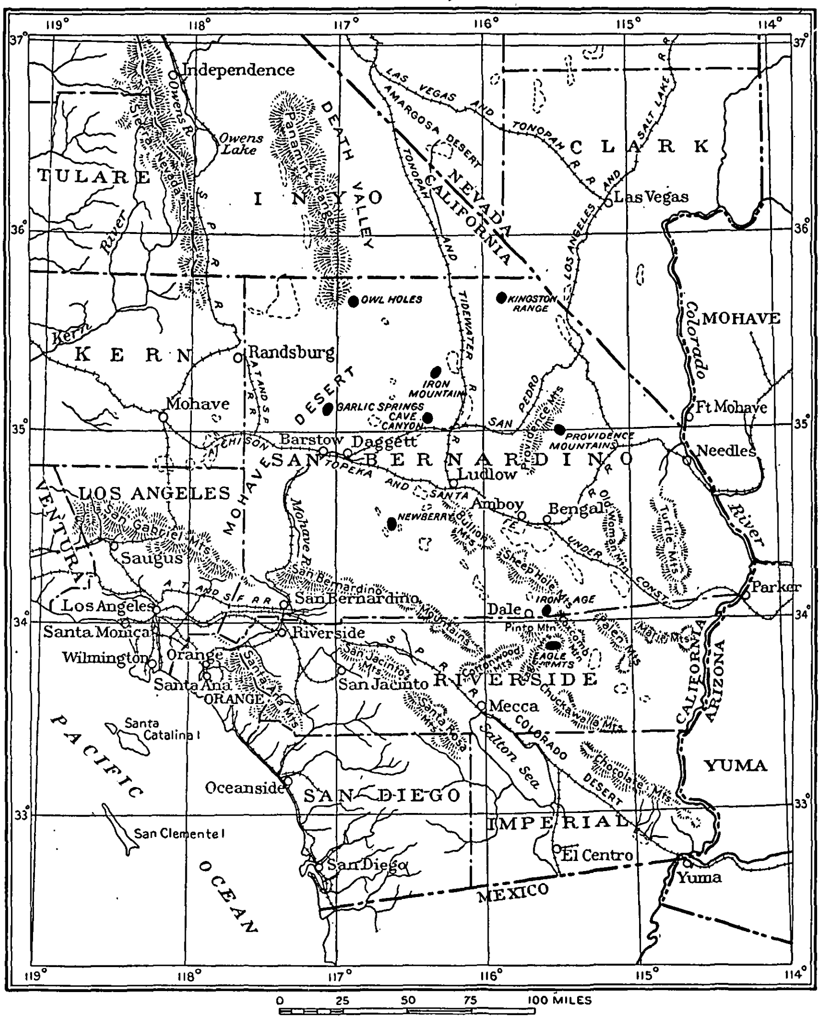

FIGURE 19.—Map of portions of southern California, Nevada, and Arizona, showing location of iron-ore deposits in Mohave and Colorado deserts.

granitic, porphyritic, and aphanitic. In the southern part of the Pinto Mountains metamorphosed sediments are associated with these rocks, but elsewhere no sediments occur.

Nothing is known of the age of the rocks except that the igneous rocks are younger than the sediments. Except in one small area, the formations of the southeastern Mohave and Colorado deserts have never been examined with the view of correlating them with rocks of known age in adjacent regions in California, Nevada, and Arizona. To the writers' knowledge no fossils have ever been found in any of the metamorphosed sediments of the region, and they have generally been supposed to be of pre-Cambrian age. The intrusive rocks have been thought to be much younger, some possibly as late as Tertiary. The one small area examined lies a few miles northwest of Siam, San Bernardino County, on the Santa Fe Railway. Here Darton [a] found unmetamorphosed sediments of Cambrian age.

Geologic work has been done recently by Lee,[b] Schrader,[c] and Bancroft [d] in western Arizona and by Mendenhall [e] in the San Bernardino Mountains and at scattered localities between that range and the Imperial Valley in southern California. The rocks of western Arizona consist of granite, gneiss, schist, and various metamorphosed sediments of pre-Cambrian age intruded by Mesozoic, granitic, and dioritic rocks and overlain by Tertiary rhyolites, trachytes, and andesites, Quaternary basalt, and unconsolidated or slightly consolidated desert deposits. To the northeast the Paleozoic rocks of the Grand Canyon section overlie the pre-Cambrian rocks and extend northward and eastward into Nevada, Utah, and northeastern Arizona. The pre-Cambrian and associated rocks have been followed by Schrader and Bancroft westward to a point a short distance beyond Colorado River. The Iron Age iron-ore deposit is about 65 miles west of the river in a straight line, but the rock formations of the two areas have not been connected.

The area of Mendenhall's work in the San Bernardino Mountains is about 60 miles west of the Dale region, and on this side also no work has been done in the intervening area. The rocks of the San Bernardino and San Jacinto mountains are largely intrusive granitic and dioritic rocks belonging perhaps to the same period of intrusion as the granodiorite of the Sierra Nevada. On the north slope and locally on the south slope and in the central portion of the San Bernardino Range are sediments of all degrees of metamorphism of unknown age, though older than the igneous rocks. Metamorphosed sediments, largely schists, older than the sediments of the San Bernardino Range, occur in the eastern part of the San Gabriel Range and in places in the eastward extension of the San Bernardino Moun-

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[a] Darton, N. H., Discovery of Cambrian rocks in southeastern California: Jour. Geology, vol. 15, 1907, pp. 470–473.

[b] Lee, W. T., Geologic reconnaissance of a part of western Arizona: Bull. U. S. Geol. Survey No. 352, 1908.

[c] Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz.: Bull. U. S. Geol. Survey No. 397, 1909.

[d] Bancroft, Howland, Reconnaissance of the ore deposits of central western Arizona: Bull. U. S. Geol. Survey (in preparation).

[e] Mendenhall, W. C., unpublished notes.

tains and in the Cottonwood, San Jacinto, and Santa Rosa mountains. Locally on the lower slopes of the ranges there are slightly consolidated sediments of late Tertiary or early Pleistocene age.

The sediments examined by Darton consist of a series of shales, limestones, sandstones, and quartzites of Cambrian age resting on a basement of granite. The area is about 40 miles north of the Iron Age deposit, and the intervening mountain ranges are made up largely of igneous rocks.

In the Eagle Mountains, Palen Mountains, and neighboring ranges the writers found metamorphosed sediments, schists, and gneisses, intruded by a great variety of igneous rocks. No fossils were found in any of the sediments.

The Iron Age iron ores are largely hematite altered from magnetite, in the form of veins cutting intrusive granite and granite porphyry. Metamorphic minerals, chiefly garnet and epidote, are locally associated with the ore and rocks. The principal iron-ore veins occur over an area about half a mile square, the larger veins, on account of their resistant nature, forming the summit of a large hill. Several small veins occur in the area between the Iron Age deposit and Dale. The ores are very pure and of high grade, but the veins are not of sufficient extent to make the deposit very attractive commercially.

DESCRIPTION OF THE INTRUSIVE ROCKS.

GENERAL STATEMENT.

There are two fairly distinct rock types associated with the Dale iron-ore deposit, though in the field no sharp lines can be drawn between them. In fact there is as much difference in general appearance between different phases of the same type as there is between the two main types. One type is an augite-soda granite with feldspars entirely albite or albite-oligoclase and a texture in general granitic or coarsely porphyritic. The other, which is distinctly and characteristically porphyritic, may be called augite granite porphyry. It differs mineralogically from the granite in that its predominating feldspar is orthoclase and that only subordinate amounts of albite are present. There is a marked variation in texture within each of these two types, but the general structure of each type remains characteristic, and the characteristic feldspars remain constant, though there is apparently a variation in the relative proportion of orthoclase and albite in different phases of the granite porphyries. The chemical difference between the two types as shown by the mineral composition consists in the absence of potash in the granite and the presence of both soda and potash in the granite porphyry.

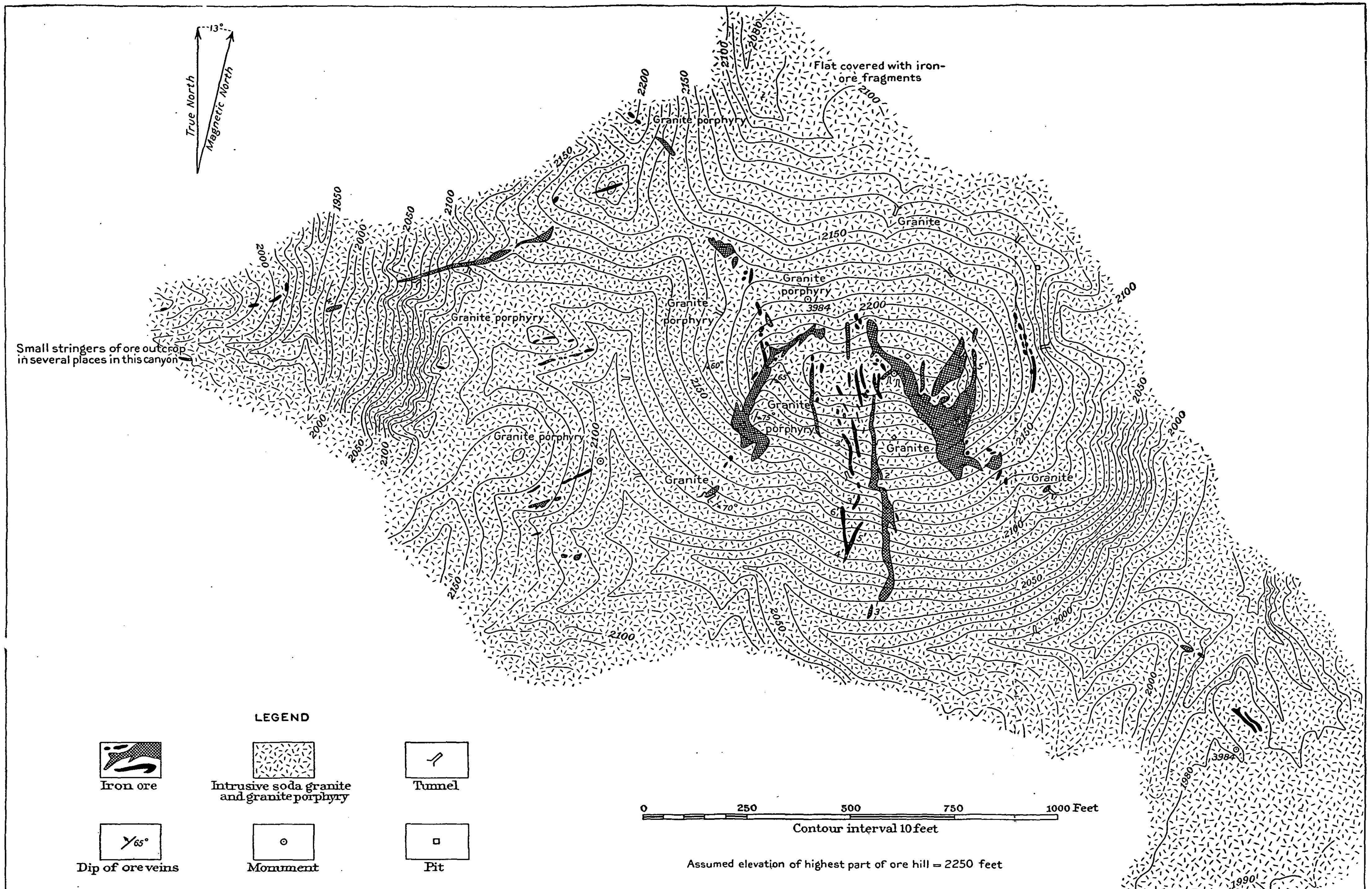
Quartz is present in both types, in approximately the same proportions. The augite in all the rocks is decidedly subordinate in amount. Most of it is partly and some of it entirely altered to green hornblende or chlorite. Locally all that remains to show the former presence of augite is a considerable development of secondary green hornblende, in which there is an occasional augite core. A small amount of biotite is present.

DETAILED DESCRIPTIONS.

Granite.—Rocks of the granitic type rich in soda are generally distributed on the east and south sides and top of the hill, and occur also in places on the west and north sides. (See Pl. II.) In the hand specimen they show in general a medium-grained granitic to coarsely porphyritic texture. Cloudy white feldspars, some of them considerably epidotized, quartz, and a ferromagnesian mineral of a light-green color may be seen with the hand lens. The porphyritic phases are simply portions where certain minerals have grown larger than those surrounding them. The groundmass remains of about the same texture as in the granitic type and with the unaided eye is easily seen to be well crystallized.

Under the microscope the rock of this type shows large phenocrysts of albite embedded in a medium-grained groundmass of albite and albite-oligoclase, quartz, and augite. Many of the albite phenocrysts show resorption boundaries. Micropoikilitic intergrowth of quartz and albite is very common and well developed. The quartz also occurs in good-sized phenocrysts, many of which were evidently early crystallizations of the magma, for they show considerable resorption. It is a very important constituent of the rock, making up nearly one-third of its mass. Augite is nearly all altered to green hornblende, though a few unaltered cores remain. There is also a little secondary biotite. The accessory minerals include apatite, sphene, a little magnetite, and scattered crystals of zircon. Apatite is abundant and represents one of the earliest crystallizations. Sphene is very abundant in all the rocks of this area. Epidote is plentiful, both in small anhedrons within the feldspar phenocrysts and as larger masses scattered through the rock. All the slides examined show occasional irregular masses of calcite.

Granite porphyry.—The porphyritic rocks are abundant in the western part of the iron-ore area and occur locally in the northern and southern parts. The most typical phase of the rocks thus classed together shows in the hand specimen large phenocrysts of a pink feldspar, many of them nearly an inch in diameter, embedded, together with smaller phenocrysts of a clear or cloudy white feldspar and a partly altered ferromagnesian mineral, in a very fine grained felsitic groundmass, too fine for the components to be seen with a hand lens. This groundmass has a gray to greenish-gray or pink color,



DETAILED MAP OF THE IRON AGE IRON-ORE DEPOSIT NEAR DALE, SAN BERNARDINO COUNTY, CAL.

varying in different specimens. In all it shows the felsitic character which serves to distinguish it from the porphyritic phase of the associated granite, though there is as much variation in general appearance within both the granites and the porphyries as there is difference between them.

Different specimens show great variations in the development of the phenocrysts. The most common phase, that with the large pink feldspars, has already been described. Another shows pink and white feldspar phenocrysts of about equal size and comparatively small (few of them reaching a quarter of an inch in diameter) in a similar felsitic groundmass. Still another is very fine grained and has very small phenocrysts, mostly of the clear white or colorless feldspar (albite).

Under the microscope all these phases exhibit practically the same composition, but even in different parts of one thin section there may be distinct variation in the development of phenocrysts. In the typical porphyritic variety the large phenocrysts are orthoclase and the smaller phenocrysts are quartz and albite with here and there an augite still unaltered. The groundmass is a very fine mosaic of quartz and orthoclase. The large phenocrysts of orthoclase and quartz show marked embayments, due to partial resorption by the magma. This is especially noticeable in the quartz.

Other phases have smaller phenocrysts of orthoclase and albite, both of approximately the same size, with similar development of quartz and remnants of augite and with a groundmass similar to that just described. Still others have smaller phenocrysts of all minerals and a groundmass made up of finely crystalline orthoclase with most of the quartz separated as small phenocrysts.

The augite is largely altered to chlorite and green hornblende, with a little secondary biotite. In a few cases good-sized augite cores, or even whole crystals, remain.

The accessory minerals of the porphyries are the same as those of the granites—abundant apatite and sphene, with a little calcite and considerable epidote.

PROBABLE RELATION OF THE GRANITE AND GRANITE PORPHYRY.

As the two rocks just described show no definite boundaries or contacts, and as they are in many respects essentially similar, they might be looked upon as pertaining to the same intrusion were it not for the fact that one has orthoclase as an essential constituent while the other contains none at all. If there were merely variations in the amount of potash in different parts of the intrusion, the relations might be explained as the result of segregation in the cooling mass; but in this case segregation may hardly be supposed to have gone so far as to remove all potash from a large part of the cooling intrusive body.

The moderately coarse granular texture of the granites, as contrasted with the distinctly porphyritic texture of the granite porphyries, indicates that the latter cooled more quickly than the former and hence must have been introduced at a different time. The granite porphyry was probably intruded into cold rocks and cooled quickly, while the granite was later intruded into the hot porphyry. The fact that there are no sharp contacts indicates that the porphyry was not entirely consolidated at the time of the intrusion of the granite.

From the above-stated considerations it is thought that the soda granites are the result of the intrusion and mixing into the partly consolidated granite porphyries of a magma containing no potash, but otherwise similar to that of the granite porphyries. The granitic rocks may possibly have been derived from the same parent magma as the porphyritic rocks, their variation in composition from the latter being due to differentiation, but more probably they were derived from an entirely different source.

METAMORPHISM AND WEATHERING.

The metamorphic changes that have taken place in the rocks since their intrusion are mostly of such a nature that they may be best explained as due to the effects of solutions which permeated the rocks at the time of the introduction of the ores, the alteration occurring under deep-seated conditions. The principal metamorphic changes are the alteration of augite to secondary products, the development of epidote, and the introduction of the ores. The alteration of the augite has resulted in most places in the formation of secondary green hornblende, and in some places of chlorite. Associated with the altered augites are notable quantities of sphene, which is in places grouped in bunches around the augite cores. The association suggests the derivation of the sphene from an augite containing a little titanium. Some of it may be an original constituent of the rock, but certainly not all.

The epidote is probably a product of this hydrothermal metamorphism. It occurs either in irregular grains scattered through the rock or as distinct veins. The feldspars of the igneous rocks are as a rule highly epidotized and have assumed a light-green color due to finely disseminated epidote. The minute needles of green hornblende which penetrate the rocks in all directions also combine to give a distinct green color to the igneous rocks.

The presence of magnetite within the quartz phenocrysts is another feature of some of these rocks which is thought to be due to the action of the solutions that brought in the ores. In the slides examined the development of magnetite in quartz was greatest in specimens taken near one of the larger hematite-magnetite veins. This fact, together with the observation that secondary green hornblende needles penetrate many of the quartz phenocrysts in all directions, leads to the belief that the magnetite within the quartz is secondary rather than original.

Surface weathering is comparatively slight in this desert region. In the ordinary exposure of compact rocks like the intrusive rocks now under discussion surface decay extends only to a small depth. Within this zone of decay the ferromagnesian minerals are completely altered to a yellow powdery material and the rock is usually soft and crumbly. Any metamorphic changes indicated below the zone of surface weathering must be attributed to the action of mineralizing solutions.

IRON ORES.

EXTENT AND STRUCTURE OF THE DEPOSITS.

The iron-ore veins composing the Iron Age deposit are fifty or more in number, of which less than ten are as much as 10 feet thick. There are four large veins, three of which are on the summit and south slope

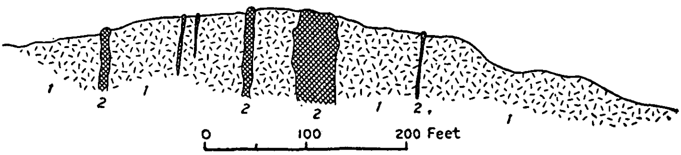


FIGURE 20.—Sketch showing structure of iron-ore veins of Iron Age deposit, near Dale, San Bernardino County, Cal. 1, Granite and granite porphyry; 2, iron ore.

of the hill and the fourth several hundred yards to the northwest. (See Pl. II.) The largest of these veins is about 425 feet long and varies from 15 to 100 feet in width. It is extremely irregular and has several large branches. The second largest vein is about 350 feet long and from 2 to 40 feet wide; the third in size is the longest vein in the area, being 500 feet long and from 2 to 25 feet wide. The vein northwest of the main hill is 375 feet long and from 2 to 15 feet wide. About 100 feet from the upper or east end of it, however, there is a short break. The smaller veins vary down to 5 or 10 feet in length and to 6 inches or less in thickness. But little development work has been done and the depth which the veins reach is unknown.

The veins occur both in the granite and in the granite porphyry. Their trend is predominantly north and south, though a few veins trend approximately east and west, and still fewer have intermediate directions. Most of them are nearly vertical, but some were noticed with dips as low as 60°. For the most part the veins are clean cut and have sharp contacts with the inclosing rocks. (See fig. 20.)

Along many of the veins there has been little or no impregnation of iron into the country rock, the latter being unaltered one-fourth of an inch from the contact except for the epidotization. Locally, however, the rock along the contact is brecciated for some distance, and elsewhere it is decomposed without much fracturing. Where brecciated it is in general strongly epidotized and impregnated with garnet and contains a network of small veins of magnetite, hematite, epidote, and garnet, with which are associated locally quartz, chalcedony, and calcite. The rock is brecciated at several places away from iron-ore veins, and at these places there is a similar impregnation and veining of iron and metamorphic minerals.

Adjacent to some of the veins the rock is kaolinized and stained brown by iron oxides for several feet from the vein contact. Small stringers of hematite, magnetite, or limonite traverse this decomposed zone and near them the rock is partly replaced by iron oxides. At many places the rock in contact with the main vein is altered for several inches to a yellowish or white kaolin-like material, soft and fissured. In a few places masses of much altered rock, some of them several feet in diameter, partly replaced by iron oxides, occur within solid iron-ore masses near their borders, showing that at least locally replacement has accompanied the vein filling during the ore formation. Such occurrences are related to the breccia deposits.

Near other veins where the rock is apparently unaltered except for the epidotization there is for 5 or 6 feet from the contact an abundant development of small iron-ore veins varying from mere seams to those half an inch in thickness, which appear to have produced little or no alteration in the adjacent rock. At one or two places it was noticed that the rock near the ore veins was aphanitic, but that from 3 to 5 feet from the contact large porphyritic crystals appeared, the groundmass remaining the same. Such changes in texture, however, are common throughout the area and probably are not the result of the ore formation, the occurrence near an iron-ore vein being merely a coincidence.

NATURE OF THE ORE.

The ore composing the veins is largely hematite, hard, reddish black, and crystalline. Magnetite is intermixed with it in many of the veins and is more abundant than hematite in a few veins. Limonite and goethite occur locally in negligible quantities along cracks and on surface exposures as shiny black, globular incrustations with needle-like texture. Limonite is found also in the yellow, porous, ocherous form. The hematite is by far the most important constituent, probably composing more than 90 per cent of the ore. The larger part of it is martite, pseudomorphic after magnetite, from which it was formed by oxidation. It varies in texture from very coarsely crystalline to finely crystalline and even granular. Some veins are so coarsely crystalline that partings parallel to the octahedral faces several inches in diameter are common. The coarsely crystalline hematite (martite) is comparatively free from magnetite, but all of the more finely crystalline ore carries disseminated magnetite. The magnetite also is in places coarsely crystalline, occurring in large octahedrons or dodecahedrons.

Quartz crystals are found in many of the veins, being generally stained red or brown in the hematite veins and white or colorless in the magnetitic parts. They have good crystal outlines, being usually isolated from each other. Quartz also occurs in the limonite and goethite incrustations. Calcite is found sparingly in small rhombic crystals associated with porous limonite and in fissures in the ore veins and breccias. Garnet and epidote do not occur with the ore in the veins but only in the breccias.

MINERALS ASSOCIATED WITH THE ORE.

The principal vein and metamorphic minerals developed in the intrusive rocks were probably formed in connection with the iron-ore deposits. They are largely epidote, garnet, and chalcedony, with a little vein quartz and calcite. Epidote is everywhere disseminated through the country rock. It occurs either as minute grains within the feldspars or as large irregular masses lying in any position in the rock or in fissures of varying width. In either situation it has evidently been formed through the alteration of feldspar by deep-seated solutions which brought in the lime and iron necessary for its formation.

Garnet occurs in veins with epidote and locally with epidote and calcite. Vein quartz and calcite cut the ore veins and rock here and there. Apatite occurs in some of the ore veins.

Small veins of magnetite or hematite traversing feldspar crystals show in many places definite crystal boundaries projecting into the feldspar. In several thin sections, especially those taken from the vicinity of large fissure veins of hematite or hematite and magnetite, many small crystals of magnetite may be seen developed within the quartz phenocrysts of the country rock.

As has already been stated, the general metamorphism to which the rocks of this area have been subjected and which probably accompanied the introduction of the iron ores has changed augite to green hornblende or to hornblende and chlorite, and has no doubt likewise brought about the extensive epidotization of the rocks.

The epidote in veins and breccias, as well as the fragments within the feldspars, is probably an alteration product from feldspar and was deposited in these places because of the mingling of solutions carrying feldspar decomposition materials with other solutions coming directly from a great depth. The epidote and garnet were apparently deposited at nearly the same time, the latter generally occurring in disseminated grains and bunches in the former. Locally, however, veins of garnet cut masses of epidote, showing that in such places the garnet came in later. The iron minerals were deposited still later in openings left by the garnet and epidote or in veins cutting them. In some of the brecciated areas epidote and garnet are rare and iron minerals alone form the cement by which the rock fragments are bound together. Chalcedony, quartz, and calcite are of later origin than the ore minerals, for they line cavities left by the preceding minerals and fill fissures that cut them.

The rock fragments composing the breccias and the more solid rock surrounding them are generally much altered and impregnated with secondary silicates and iron minerals. On the other hand, the rock near clean-cut iron-ore veins is as a rule but little altered.

Epidote and garnet are rare or absent in the clean-cut iron-ore veins, but quartz occurs abundantly and calcite locally. Most of the quartz is in crystals surrounded by hematite or magnetite, and was undoubtedly formed during the deposition of the iron ores. A part of the calcite is associated with garnet and epidote and is probably of the same origin as these minerals, but much of it is of later origin, occurring in fissures with limonite, with which some quartz also is associated.

Epidote and garnet, associated with quartz and calcite, occur at several places on the hill at some distance from iron ore, being found as small bunches surrounded by country rock, in small veins cutting the country rock, or as impregnations within the rock itself. Thus the iron minerals and the epidote and garnet, while undoubtedly related, occur at many places separately.

Surface deposits consisting of small angular fragments of iron ore intermixed with a few rock fragments and embedded in a compact cream-colored matrix of mixed calcareous and siliceous material occur at several places on the iron-ore hill, especially near the larger veins. Some of them are several feet in thickness and cover considerable areas, overlying either ore veins or country rock. Others fill open fissures in iron-ore veins. Fragments in these deposits may be several feet in diameter and such fragments may contain open fissures that are filled with the same cementing material. At a few points the deposits contain only rock fragments, iron-ore fragments being absent.

ORIGIN OF THE ORE.

The iron-ore veins composing the Iron Age deposit undoubtedly originated from hot, deep-seated solutions, being formed after the cooling and consolidation of the igneous rocks in which they occur. The principal facts pointing toward a deep-seated source for the ore-bearing solutions are the association of the hematite and magnetite with epidote and garnet, which are so characteristic of metasomatic replacement by deep-seated solutions, and the extensive epidotization of the rocks throughout the iron-ore area.

It is not possible to say definitely what was the nature of these solutions nor in what form the iron was carried. It is probable, however, that the solutions were hot, perhaps gaseous, because many of the veins are coarsely crystalline and in most of them the iron was originally deposited as magnetite. They carried lime as well as iron in solution, as is shown by the alteration of the soda feldspars to the lime-iron silicate epidote. The solutions came up from below through fissures and faults formed after the cooling and consolidation of the rocks. In many localities the wall rock was replaced by iron oxides to a considerable extent; elsewhere it was simply altered and decomposed by the solutions. Locally brecciated masses were encountered, and there, as well as in the larger fissures, the solutions spread out and deposited their material.

The formation of the epidote and garnet appears to have slightly preceded the deposition of the iron ore, or at least to have begun somewhat earlier. Quartz was deposited at intervals during the formation of the iron ore, and calcite in small amounts was deposited with garnet and epidote. The coatings of goethite and limonite with associated quartz and calcite are of later origin, being probably formed by deposition from meteoric waters.

The history of the intrusion and ore deposition may be summarized as follows:

(1) Intrusion of the granite porphyry into an unknown formation, followed closely by the intrusion of the soda granite, probably before the complete consolidation of the granite porphyry.

(2) Fracturing of the intrusive rocks after consolidation.

(3) Permeation of the igneous rocks by deep-seated mineralizing solutions, either liquid or gaseous, coming up through the fractures and probably containing as chief constituents iron and lime.

(4) Formation of epidote and garnet from materials derived from the partial alteration of the feldspars by the solutions, with the addition of lime and iron from the solutions, accompanied by the formation of small amounts of quartz and calcite. The epidotization took place throughout the rocks, but was most pronounced in brecciated zones. The solutions apparently carried but little silica, for the silica necessary for the formation of the silicates may easily have been derived from the altered rocks.

(5) Deposition of magnetite along fractures and in brecciated zones, associated with and followed by the deposition of small amounts of chalcedony and quartz.

(6) Alteration of magnetite to hematite by oxidation, followed by the local deposition of hydrous iron oxides, quartz, and calcite.

IRON ORES NEAR DAYTON, NEVADA.

By E. C. Harder.

LOCATION.

Dayton is a small village in eastern Lyon County, Nev., on the Carson and Colorado branch of the Southern Pacific Railroad. (See fig. 21.) It is best reached by the Virginia and Truckee Railway from Reno by way of Carson and Mound House. The village is on Carson River at the upper (southwest) end of a broad, flat desert, just below the point where the river runs out of the canyon below and east of Carson.

Two groups of iron-ore deposits are found near Dayton—a small one about 2 miles to the southwest, between the railroad and the river, and a large one about 12 miles to the northeast, on the boundary of Lyon and Storey counties. Only the latter is of commercial importance in the steel industry, but the ore from the former might be used in a small way as fluxing material.

DEPOSITS NORTHEAST OF DAYTON.

General distribution.—The iron ores northeast of Dayton are in an area of gently rolling hills which form the northeastern continuation of the flat desert area below Dayton. Northeast of the deposits there is another desert area with alkali flats, and beyond are other rolling hills. This generally low belt bounded on the northwest and southeast by mountain ranges is known as the Fortymile Desert. In the mountains to the northeast is the famous old Comstock lode, with Virginia City and Gold Hill high up on the slope.

The iron-ore deposits are near the northwest border of the desert belt. Outcrops of ore are distributed over an area roughly one-fourth of a mile wide and half a mile long (see fig. 22), the longer diameter being approximately north and south. At the south end of the area there is a hill rising about 75 or 100 feet above the surrounding area. Its crest is about 900 feet long and 200 feet wide and trends about N. 45° W. Iron-ore outcrops form the crest and extend some distance down the slopes. The northeast slope and the southeast slope below the iron-ore outcrops consist of a soda granite; the southwest slope is covered with rock débris. Below the iron ore on the northwest slope there is soda granite and crystalline limestone. South of the hill is a large area of horizontal conglomeratic limestone, probably a calcareous tufa, which in most of the area overlies soda granite. North of the hill is a broad, gently undulating flat extending for a mile or more, covered with float but showing a few ore and rock

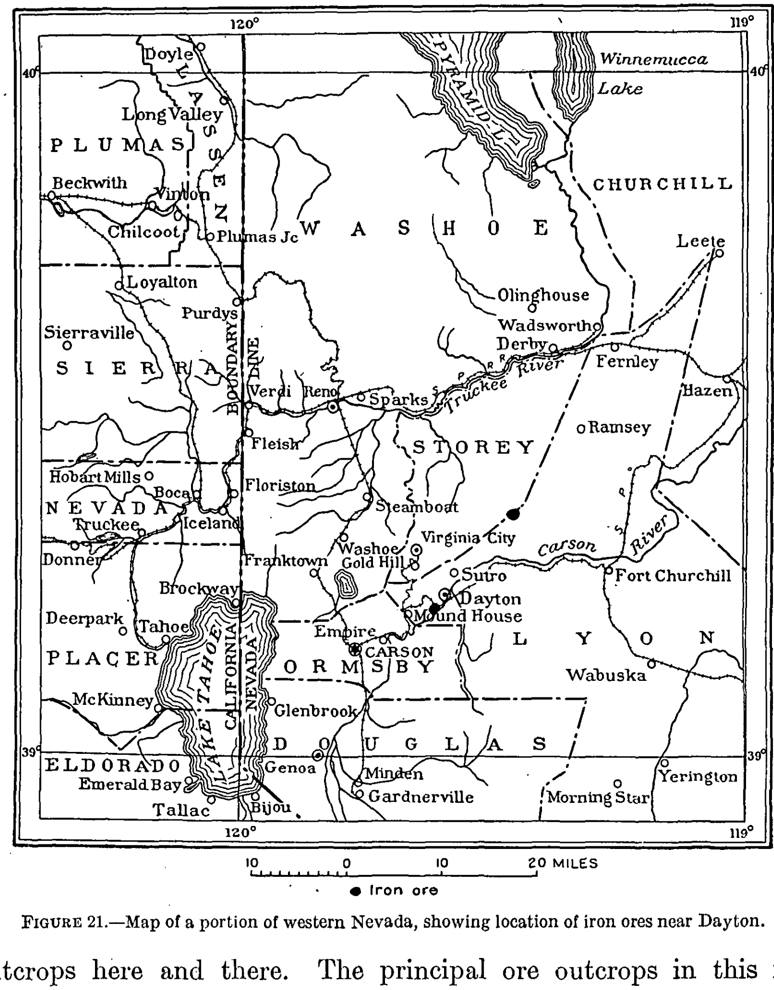


FIGURE 21.—Map of a portion of western Nevada, showing location of iron ores near Dayton.

outcrops here and there. The principal ore outcrops in this flat are about half a mile northeast of the ore hill. They consist of three masses arranged along a line about N. 60° W., and near them occur several outcrops of limestone and pits in soda granite. About 150 yards northwest of these outcrops, just west of a road that comes through the area from Dayton, there is a small knoll on which iron ore and soda granite outcrop. Two other ore outcrops lie close together about two-thirds of the distance from the three ore outcrops at the north end of the area to the main ore hill. A short distance southeast of these there is a low ridge on which granite and shale outcrop. No other outcrops occur within the iron-ore area.

A number of pits have been sunk on the flat north of the ore hill, but only three of them have struck bed rock, the others being in

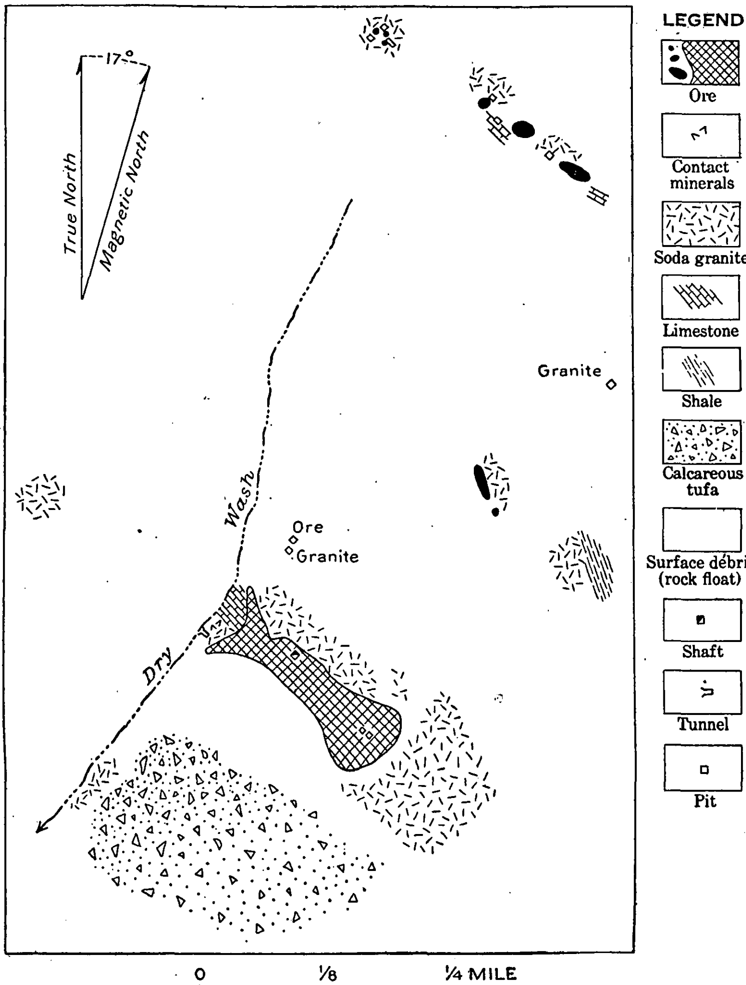


FIGURE 22.—Sketch of iron-ore area northeast of Dayton, Nev.

float to a depth of 10 or 20 feet. Of the pits which struck bed rock, one, a short distance southeast of the three ore outcrops at the north end of the area, reaches soda granite; of the other two, which are close together a short distance north of the ore hill, one reaches ore and the other soda granite. There are several tunnels and pits on the iron-ore hill.

From the distribution of ore and rock as shown by outcrops and pits it appears probable that the area is composed largely of soda granite, in part aplite, in which there are local masses of limestone and iron ore. Where the relation of the ore to the rocks is clear it is seen that the ore occurs at the contact of the limestone and granite. The soda granite has also broken into the limestone and ore masses in irregular intrusions. Metamorphic minerals, including garnet and epidote with a little albite, are developed locally.

Character of the rocks and ores.—The soda granite or aplite is a light-colored, medium-grained rock varying slightly in appearance in different parts of the area, because of the varying amount of dark mineral present. It is composed largely of orthoclase and quartz, in which are embedded larger crystals of albite and albite-oligoclase. Minor quantities of green hornblende, biotite, epidote, and chlorite occur. Locally the ferromagnesian minerals are almost absent and the rock is yellowish white and aplitic. The chlorite is derived from the alteration of the biotite, which has locally almost entirely disappeared. The feldspars are much altered to epidote and kaolin. Apatite and magnetite are accessory minerals.

The limestone where fresh is thoroughly crystalline and blue or white in color. Near the ore and granite, however, it has suffered some decomposition and is stained yellow or brownish. No bedding is apparent.

The calcareous tufa has a pronounced bedded structure and lies nearly flat. Some of the beds consist of massive though porous limestone; others contain an abundance of rock fragments and sand grains in a calcareous matrix.

The ore is a mixture of hematite, magnetite, and limonite, the hematite being the most abundant in the surface outcrops, though both magnetite and limonite occur with it and locally the magnetite is more abundant than the hematite. The ore is dull, hard, and somewhat porous at the surface; with increasing depth it becomes soft and granular and contains an abundance of calcite and locally gypsum (selenite) along fissures. The soft ore is largely magnetite. Garnet, quartz, calcite, epidote, and albite are present at several places along the contacts of ore and granite or limestone and granite. Epidote occurs in veins and masses cutting garnet. Albite is found in the epidote in such positions as to indicate that the latter is an alteration product of it. Here and there in the garnet masses are small veins of unaltered albite.

Occurrence of the ores.—The outcrops of ore on the hill at the south end of the iron-ore area occupy a space about 1,000 feet long and from 200 to 500 feet wide. Within this area there are one or two tongues of granite and the float between the outcrops may cover limestone or other granite bodies. The surface ore on the crest is hard and massive, though slightly porous in places. One shaft and several pits have been sunk into it. The pits have not passed through the hard ore, but the shaft goes into a soft, bluish, granular mixture of magnetite and calcite at a depth of less than 20 feet. Much selenite occurs with this soft ore.

On the northwest slope of the hill erosion has been very rapid because of an arroyo at the base; hence much of the hard surface ore has been removed and a soft granular mixture of magnetite and calcite similar to that in the pit on the crest of the hill is exposed in places. Here, also, selenite is abundant in cavities and along fissures. Some porous, hard, low-grade ore, with considerable impurities consisting largely of unreplaced siliceous rock, outcrops on the lower slope, but most of the ore outcropping on the upper slope is hard and massive, though mixed irregularly with it is the blue granular ore already mentioned. A mass of yellowish, somewhat altered crystalline limestone occurs near the base of the slope southwest of the low-grade ore exposures, and southwest of the limestone lie soda granite and contact rock, the granite occurring between the contact rock and the ore of the upper slope.

The contact rock consists of a mixture of epidote, garnet, and albite. The garnet was formed first, and the epidote occurs in it in veins and irregular masses. The garnet is reddish brown in color and is probably andradite. The epidote contains remnants of albite, of which it is probably an alteration product. Some veins of little-altered albite occur.

The granite near the base of the hill contains an abundance of biotite and is greenish gray in color. At other localities on the hill it is usually grayish white and contains biotite sparingly. A long tunnel entirely in dark granite is just above the wash at the base of the hill.

The three ore outcrops near the north end of the iron-ore area lie in a line about N. 60° W. The northwesternmost one is about 50 feet in diameter. Just north of it is a shallow test pit in granite and yellowish crystalline limestone. In this pit schistose granite occurs next to the ore, then limestone, and north of this blocky granite. Fragments of contact rock consisting largely of epidote, quartz, and calcite was found near the pit and probably came out of it. About 120 feet to the southeast is the second ore outcrop, approximately 100 feet in diameter. Between the first and second outcrops is an exposure of fresh blue and white crystalline limestone with nearly vertical north-south banding. A test pit has been sunk into it. The second ore outcrop is surrounded by float. The third ore outcrop is about 150 feet southeast of the second and is about 130 feet long and 60 feet wide. Between it and the second outcrop is a pit in fissured, blocky granite, and southeast of it is a small exposure of blue crystalline limestone banded in a northwest-southeast direction. The ore in all three outcrops is largely hematite, hard and massive, and of high grade.

On the knoll near the road there are several pits in iron ore and granite covering an area about 75 feet in diameter. The ore and rock are irregularly distributed, and no definite relation is apparent between them.

Of the two ore outcrops in the flat the one to the north is the larger, being 15 to 30 feet wide and 130 feet long. It trends approximately N. 15° W. and dips steeply to the west. East of it is granite; to the west is float. This ore is of very poor quality, being intermixed with much country rock, unaltered or only partly replaced by iron. The granite is stained and impregnated with iron oxide. One trench cuts across the ore band and a pit has been sunk at the contact of ore and granite. The other ore outcrop is about 25 feet in diameter, has a pit in the center, and is surrounded by float.

Origin and economic importance of ores.—From their occurrence the ores northeast of Dayton appear to be contact deposits formed during or after the intrusion of the granite into the limestone. This view is strengthened by the presence of minerals characteristic of intrusive contacts. The ores are probably partial replacements of the limestone, some of the original limestone being still present as local masses in the vicinity of the ore or occurring in the recrystallized form of calcite within the ore. The surface ore has been enriched and concentrated by the removal of calcite and probably by the deposition of iron oxides. The selenite may be simply a deposit near the surface from gypsiferous solutions or it may have been derived from the oxidation of pyrite, though this mineral has not been found in the ores.

Most of the surface ore is of high grade. In depth it appears, whenever penetrated, to be strongly impregnated with calcite. Locally enough calcite is present to make the ore self-fluxing, and therefore in reality the presence of calcite does not materially affect the value of the ore. The selenite may be abundant enough in places to necessitate dressing of the ore to reduce the sulphur content. If the ores were smelted in the electric furnace, however, the presence of selenite would not be objectionable. The depth to which the ores may extend is problematic, though the increasing amount of calcite with increasing depth suggests that the ore may become of too low grade to be worked. But the deposits are of sufficient size to be commercially important even if the ore is supposed to be relatively shallow. With a depth of 50 feet the deposit on the hill at the south end of the area would probably yield approximately 1,500,000 tons of ore. The deposits are on low ground and can easily be approached by a railroad either from Dayton or from the Nevada and California branch of the Southern Pacific Railroad to the east.

DEPOSITS SOUTHWEST OF DAYTON.

Veins of iron ore occur in a dark-green fine-grained andesite on the east slope of a ridge about 2 miles southwest of Dayton. They are seven or eight in number, and all except one are in a group, the exception lying several hundred yards to the north. The veins consist of a mixture of hematite and magnetite and vary from 25 to 100 feet in length and from 1 to 10 feet in width. In a few of the larger veins there are small lenses of schistose andesite, and along the walls of some of the veins the andesite is locally much fractured. Small ore veins occur as networks in the brecciated andesite. Apatite is an abundant constituent of some of the veins, crystals of it occurring transverse to the direction of the vein. Calcite occurs near the center of some of the veins and fills cavities in them.

THE JAUSS IRON MINE, DILLSBURG, PENNSYLVANIA.

By ARTHUR C. SPENCER.

The iron-ore fields near Dillsburg, York County, Pa., were described by the writer in 1908,[a] the description being based on a careful study of the surface geology and such observations on the mines as had been recorded by other geologists, as no mining operations were in progress during the summers of 1906 and 1907. In April, 1910, the Jauss mine had been unwatered and was visited by the writer in company with Messrs. John N. Logan and John Morris, of Dillsburg, and E. C. Harder, of the Geological Survey.

The Jauss vertical shaft is situated near the east bank of Stoney Run (or Fishers Run), about 1½ miles east of Dillsburg, at the terminus of the branch railroad. The following notes are quoted from Bulletin 359:

> The shaft was sunk at a point where the dip needle showed a marked magnetic attraction. About 72 feet of diabase was penetrated before the 7-foot ore bed was encountered. The floor of the mine is limestone conglomerate. As depth was gained the ore bed was found to thicken along the dip, and in the lowest workings, 205 feet below the surface, a large body of ore is reported. Stoping was carried about 30 feet above the point where the ore was cut through by the shaft. A survey made in 1888 shows the mine workings as extending 270 feet northwest of the shaft. In this distance the ore bed falls 133 feet, giving an average inclination of nearly 50 feet per 100, or about 30°. The dip appears to be somewhat steeper in the lower than in the upper workings.
>
> Material on the waste pile shows that some of the ore at least has been formed by replacement of limestone conglomerate, though most of the material intimately associated with the ore appears to be an altered shale. Although no fragments of any rock except diabase are to be seen in the field south of the shaft, there can be little doubt that the sedimentary rocks which accompany the ore would be found beneath a relatively shallow cover of soil.

It is now apparent that several statements in the foregoing quotation are incorrect, and the following description may be substituted:

The shaft was located by Mr. Logan because of a marked magnetic attraction. After about 72 feet of diabase had been penetrated ore

[a] Spencer, A. C., Magnetite deposits of the Cornwall type in Pennsylvania: Bull. U. S. Geol. Survey No. 359, 1908, pp. 71-96.

was encountered and found to be about 7 feet thick. On the south side of the shaft the diabase is seen to be very close grained and dense, and the contact dips in a southerly direction, which makes it appear that the intrusive rock is here cutting across the edges of the stratified rocks, which dip north-northeast. There is no indication that the ore continues toward the surface, so that the supposed sedimentary outcrop south of the shaft probably does not exist. The shaft seems to have encountered the crest of the ore body. In the western part of the workings diabase was noted in the highest stope. Here it apparently forms the roof over the north-northeastward-dipping ore.

Mr. Morris, who has been in touch with most of the mining operations in the Dillsburg field, believes that the upper ore layer in the Jauss mine lies very close to the bottom of the diabase. This view the writer is inclined to accept, but actual observations are lacking to settle the matter definitely, no diabase being visible in the mine at points other than the two already mentioned.

From the bottom of the shaft the ore was followed by a zigzag incline from which stopes were extended to the right and left. The general course of the incline is about N. 30° W., and its slope, varying from place to place, averages about 17°.

In general the dip of the ore layers seems to be steeper than the slope of the incline, so that the line of the track lies between the direction of average strike and the direction of dip. In the bottom of the mine the dip is 12° NNE.

About halfway down the slope the roof of the ore was broken through and a second ore layer discovered. The parting is a light pink dense rock, thought to be baked shale. In the lower part of the mine considerable good ore was mined from this upper layer. Here the workings have exposed the upper ore bed 5 feet, parting 3 feet, and main ore 7 to 8 feet. A drill hole in the floor is reported to have revealed a third ore layer 7 feet thick. The thickness of the parting between the lower and the main ore bed was not learned.

Examination of the stopes shows that the ore layers are lenticular in cross section, and it is presumed that the incline follows the thickest part of the main ore layer. Mr. Morris states that thinning of the ore bodies on both sides of an axial line is a marked characteristic of the Dillsburg field, being noted by him in the Bell, the King (or McClure), and the Longnecker.

Examination of the Jauss mine workings makes it very clear that the ore has been formed by the replacement of layers of stratified rocks and that the process of replacement was controlled by differences of composition in the strata involved. In the stopes the ore faces exhibit a characteristically mottled effect, which is the result of incomplete replacement of the rock constituting the ore layers. It appears that these layers were originally beds of limestone conglomerate and that the barren partings between the ore layers were beds of shale. During the period of ore formation iron-bearing solutions transfused through these rocks and replaced their constituents more or less completely in different situations. The mottled ore seems to represent what was originally limestone conglomerate in which the pebbles have been replaced by magnetite and associated pyrite more completely than the cement or matrix. In places where the ore is more massive than usual the whole rock (pebbles and matrix together) has been converted into ore. Unmetamorphosed conglomerate has not been encountered in the mine.

The proved existence of three layers of ore in the lower part of the mine leads to the suggestion that there may be at least one more vein beneath the ore encountered just under the diabase at the shaft. It would seem to be worth while to drill through the floor of the mine in several places and to carry test holes down as far as the rocks show evidence of having been metamorphosed. The presence of crystalline limestone or of fragments of chlorite (flexible green mica), garnet, or epidote in the drill cuttings may be safely taken as evidence of metamorphic alteration.

The limestone conglomerate beds of the Dillsburg field lie near the bottom of the Triassic rocks, and it is believed that blue Paleozoic limestone (like that which is quarried near Dillsburg Junction) exists at moderate depth beneath the Jauss ore. The distance to the underlying blue limestone may be less than 50 feet and can hardly be more than 100 feet, measured across the stratification.

It may be suggested that a favorable situation for ore deposition would be adjacent to the surface between the blue limestone and the Triassic strata. Such indeed is the position of the ore layers at Grantham station, 4 miles north of the Jauss mine, where along the railroad track the limestone conglomerate is found at the base of the Triassic overlap on the blue limestone.

DEPOSITS OF BROWN IRON ORE NEAR DILLSBURG, YORK COUNTY, PENNSYLVANIA.

By E. C. Harder.

GENERAL STATEMENT.

Dillsburg, Pa., is a small village on the Cumberland Valley Railroad, about 15 miles southwest of Harrisburg. It is situated just within the border of the Mesozoic belt southeast of South Mountain, which here consists largely of Cambrian sandstone and quartzite. Northwest of the mountain is the Appalachian Valley, underlain by Cambrian limestone, shale, and sandstone.

The Mesozoic belt, trending northeast and southwest, has a width of about 18 miles at this point, extending southeastward from Dillsburg almost to York. The rocks composing it are red sandstones and shales intruded by large masses of diabase. Near the intrusions the sandstones are baked and discolored. The red sandstones lie on a basement of Paleozoic or older rocks. Wherever they lie on limestone the basal part of the series contains numerous layers of limestone conglomerate. Within the general sandstone series are interbedded calcareous layers.

The iron ores of the Dillsburg district are of two types—magnetite deposits scattered through an area about a mile square, the center of which is about 1½ miles east of Dillsburg, and brown-ore deposits on the slope of South Mountain north of Dogwood Run, from 2 to 3 miles west of Dillsburg. The magnetite deposits are in Mesozoic sediments near the contact with intrusive diabase; the brown ores occur in variegated clays associated with Lower Cambrian (Antietam) sandstone.

The geology and magnetite deposits of the Dillsburg district are described in detail in a former report of the Survey.[a]

BROWN-ORE MINES.

LOCATION AND HISTORY.

The brown-ore mines near Dillsburg are situated in an area about a mile in length in a northeast-southwest direction and several hundred

[a] Spencer, A. C., Magnetite deposits of the Cornwall type in Pennsylvania: Bull. U. S. Geol. Survey No. 359, 1908, pp. 71-100.

yards in width, the easternmost mine in the belt, the Pinkerton bank, being about 2 miles west of Dillsburg. The area is near the foot of the southeast slope of the northern ridge of South Mountain northwest of Dogwood Run, which drains northeastward from the mountain into the Mesozoic area. This ridge rises about 800 feet above the floor of the valley of Dogwood Run. Southeast of the valley is another ridge which rises to about the same height. The general trend of South Mountain is northeast-southwest. Five or six mines were operated along this belt in former years, but eventually one after another stopped operating, and for many years no ore was produced. The old pits and underground workings fell in and were overgrown by underbrush and trees. The large open cuts, slush dams, and waste dumps, however, still bear evidence of former extensive operations.

The principal old mines along the belt were, from east to west, the Dogwood (McCormick), Knaub, Heck, Brant & Arnold (Lexier), and Markley & Shank (Old Wolf).[a] Of these the McCormick, with a formerly unworked area east of it, is now included in the Pinkerton tract; the rest are on the Marshall tract.

Recently mining operations have been recommenced on both of these tracts. On the Pinkerton tract an extensive open cut several hundred yards long and up to a hundred feet in width has been made along the slope of the mountain northeastward from the old McCormick workings. This has been simply a stripping operation, the barren surface clay and rock débris being removed and the underlying ore-bearing clay exposed and penetrated for a short distance. No ore has been produced and work has been temporarily suspended.

On the Marshall tract the old Heck mine is being operated. This mine consisted of an open cut several hundred yards long extending along the slope of the mountain and a long tunnel which tapped the ore body below the cut. A deep pit has been sunk in the bottom of the old cut at its southwest end and the ore is mined by the milling method, being delivered from the walls of the pit into the tunnel below it and hauled in cars to the washer. An incline has been sunk near the washer, which taps the ore body some distance below the tunnel level and here ore is mined by underground methods.

GEOLOGY.

South Mountain extends northeastward from Franklin County along the boundary of Cumberland and Adams counties and ends on the northwest border of York County. It terminates abruptly northwest of Dillsburg, dropping off on the north into the gently undulating valley region and on the east and south into the rougher

[a] D'Invilliers, E. A., Report on the iron-ore mines and limestone quarries of the Cumberland-Lebanon Valley, 1886: Ann. Rept. Pennsylvania Geol. Survey, 1886, pt. 4, pp. 1473-1480.

Mesozoic region, which consists of hills and ridges of trap, with intervening valleys, largely underlain by sediments.

The northeast end of South Mountain consists structurally of two parallel anticlines of northeast-southwest trend forming the two prominent ridges between which lies the synclinal valley of Dogwood Run. The summits of the ridges are composed of the Montalto quartzite; the lower slopes consist of Antietam sandstone. The valley of Dogwood Run is thought to be underlain by the Tomstown limestone, this being the normal Lower Cambrian succession.[a] No outcrops of it occur, however. About 25 miles to the southwest, in Franklin County, the Montalto quartzite becomes simply a member of the Harpers schist. The dip of the rocks on the slope north of Dogwood Run is at a steep angle to the south.

The Antietam sandstone is covered by a blanket of mountain débris of varying thickness, consisting of sand and brown sandy clay, in which are embedded angular fragments of the mountain sandstone. South of the Antietam sandstone are variegated clays which are in part residual from it but are probably in the main residual from the Tomstown limestone. The contact between the variegated residual clays and the Antietam sandstone is very irregular and numerous horses of sandstone occur in the clays near the contact. In these clays, along the nearly vertical contact with the Antietam sandstone, are the iron ores. The variegated clays reach a considerable depth, ranging perhaps up to several hundred feet vertically, and are presumably underlain by the Tomstown limestone. They are overlain by a blanket of mountain débris similar to that which overlies the sandstone on the slope above and which continues down to the valley. Little or no iron ore occurs in this blanket. It ranges in thickness from 5 to 30 feet and dips southward with the slope of the mountain. Its contact with the variegated clays is fairly regular.

The Antietam sandstone is generally white, grayish, yellowish, or reddish and coarse grained and does not appear to be quartzitic. The variegated clays are extremely varied in color and texture. They range from powdery yellow or brown ocherous material to dense, fine-textured clay of various colors, such as white, pink, purple, and red. Iron ores occur in all of them, but are most abundant in the yellow and brown ocherous clays, the color of which is due largely to the iron oxide they contain. The iron ores occur in seams, pockets, and irregular porous masses in the clay, without apparent definite relations to one another or to the inclosing clay. There is, however, a definite ore-bearing zone extending continuously along the slope of the mountain throughout the area, and along this zone all the principal deposits are found.

[a] Stose, G. W., unpublished notes.

ORE DEPOSITS.

The principal ore deposits occur in a vertical or steeply southeastward-dipping zone up to a hundred feet or more in width, extending northeast and southwest for perhaps over a mile. The outcrop of the zone is on the lower slope of the mountain, ranging from 50 to 150 feet in elevation above the valley bottom. A narrower zone occurs locally south of the main zone, being separated from it by a considerable thickness of barren clay. At the Heck mine the principal ore zone has a thickness of about 65 feet. The minor ore zone is said to be about 5 feet thick and is separated from the principal zone by about 50 feet of barren clay. It is not mined at the Heck mine. North of the principal ore layer at the Heck mine there is barren clay in the upper part of the pit, and beyond this, probably but a short distance, is the Antietam sandstone. In the lower part of the pit the sandstone occurs as horses in the ore-bearing clay near the north wall. The depth to which the principal ore zone reaches is not known, but it has been operated to a depth of about 125 or 150 feet from the surface. All the old mines, as well as the Pinkerton and Heck, are apparently situated along this ore belt.

The ore is brown ore intermediate between limonite and goethite. It occurs in large irregular masses, in seams, and in small pockets scattered through the clay. Locally pockets and seams are arranged along horizontal planes, but in most places their distribution is irregular. Single seams may vary down to a fraction of an inch in thickness and single pockets to a foot or less.

The texture of the ore varies greatly. Some parts of a mass may be compact, others porous and cellular. Some of the ore is massive and granular in texture, some is shaly, and some ocherous. Ocherous material usually occurs in cavities in the cellular ore. Much of the ore that occurs as seams is shaly, and the ore in compact masses is granular.

The proportion of ore to clay varies greatly, but in the ore mined at the Heck mine the proportion by bulk at present is about 1 to 2½. Twelve mine cars (capacity 1¼ cubic yards) yield after washing and concentration one dinky car (capacity 4½ cubic yards) of shipping ore. The average metallic-iron content of the shipping ore is 45 per cent.

MINING METHODS.

The methods of mining and concentrating employed at the Heck mine are typical of brown-ore mining operations elsewhere in the Appalachian region. The ore is removed from the walls of the pit by a combination of blasting and pick and shovel operations. It slides to the bottom of the pit, where it runs through chutes into cars in the tunnel and is hauled to the washer located near the bottom of the valley. In the incline the ore is mined by drifting and stoping and is raised in cars up the incline to the washer.

In the washer the ore is first crushed to a convenient size and then washed in log washers to remove the clay and screened so as to separate the coarse from the fine material. Both grades are concentrated by jigging, to separate the ore from rock fragments. Only the fragments lighter than the ore can be removed, and frequently there is considerable sandstone mixed with the ore, thus lowering the grade. In general, however, the shipping ore from the Heck mine is of better grade than that of most mountain brown-ore mines using similar methods of concentration.

ORIGIN OF THE ORES.

The brown ores near Dillsburg belong to the type known as "mountain" ores, which are common in the eastern part of the Appalachian Valley throughout its extent from Vermont to Alabama. They are clearly the product of concentration by meteoric waters. The iron was derived from iron minerals disseminated through beds which originally overlay the places now occupied by the ore bodies. These strata were shale, sandstone, and limestone. In the shale the iron was probably present largely in the ferrous silicates and as pyrite; in the sandstone it probably occurred largely as pyrite, and in the limestone as pyrite and iron carbonate. Although most of the ore was probably derived from sediments stratigraphically overlying the Antietam sandstone, with which the deposits are now associated, part of it was doubtless derived from portions of the Antietam that are at a higher elevation than the present ore deposits.

Solutions percolating downward through the sediments decomposed the iron minerals, carried the iron downward, and redeposited it where conditions were favorable. Several conditions may have favored the deposition of the ores in their present position. The Antietam sandstone may have obstructed the further downward percolation of the iron-bearing solutions, which consequently deposited much of their material along its upper contact. It is also possible that the present ore zone is on a line of faulting along which there has occurred a mingling of iron-bearing solutions with oxidizing solutions, causing the deposition of the iron as hydrous ferric oxide. Structurally, however, there is no evidence for such a fault, and the regularity with which the mountain ores throughout the Appalachian belt are associated with one particular sandstone formation beneath a great thickness of shale and limestone leads to the belief that a more general explanation is necessary. Such an explanation is offered by the hypothesis that the sandstone has acted as an impervious basement. Nevertheless, faulting may have been an important factor.

The iron was deposited immediately in its present form—that is, as hydrous ferric oxide in pockets and irregular masses in clay. Some of the ore masses were deposited in open spaces; others are largely replacements of clay. The ore bodies are now in the places in which they were originally laid down, or nearly so, and are not mechanical concentrations of masses of ore originally deposited elsewhere, as is held by some investigators.

The localization of the ore bodies is controlled by the structure and by the distribution in the sediments of the original iron minerals from which the ore bodies were formed. The largest deposits probably occur where the overlying sediments were richest in iron minerals or perhaps contained large bodies of pyrite. Faulting and other structural features, however, may also have had considerable influence on the localization.

PRELIMINARY REPORT ON PRE-CAMBRIAN GEOLOGY AND IRON ORES OF LLANO COUNTY, TEXAS.

By SIDNEY PAIGE.

INTRODUCTION.

The present report is a brief statement of the pre-Cambrian geologic relations in Llano and Burnet counties, Tex., with a summary of the important facts concerning the Llano County iron ores. A bulletin to appear later will describe the geology and iron-ore deposits in detail, with geologic maps, sections of mines, and other illustrations, and will include an account of the graphite, gold, and other minerals present in the region.

The writer wishes to acknowledge his association in the field and office with Dr. A. C. Spencer, whose experience in the study of pre-Cambrian geology and iron ores has been of great value. The work was assigned to the writer on Doctor Spencer's departure for another field.

GENERAL GEOGRAPHIC AND GEOLOGIC RELATIONS.

Llano and Burnet counties are located in central Texas. The region is accessible by the Houston and Texas Central Railroad, which terminates at Llano, the county seat of Llano County.

The region occupies a peculiar position in the broad geologic province of which Texas is a part. Located about midway between the western Cordillera and the Gulf of Mexico, it forms a portion of a broad regional coastward slope, with the peculiarity that erosion has revealed rocks of the oldest known periods in a suboval area largely included within the Llano and Burnet quadrangles, as mapped by the Geological Survey. This area is nearly surrounded by Cretaceous rocks on its outer border, but rocks of pre-Cambrian and Paleozoic age are revealed within it and about its edge. The most casual observer will be impressed with the basin-like form of the broad valley of Llano River. Standing upon an eminence such as Town Peak, near Llano, he can see a broad rolling plain stretching east, west, north, and south, interrupted only by isolated hills as far as the horizon line, which is marked by the encircling scarp of Paleozoic rocks. In traversing this broad stretch of territory one finds many minor irregularities. The basin is a structural and erosional feature, the physiographic signification of which will not be discussed here.

GEOLOGY.

The rocks of the Llano-Burnet region fall naturally into three broad subdivisions—(1) pre-Cambrian schists, gneisses, and granites; (2) Paleozoic sandstones, limestones, and shales; and (3) Cretaceous sandstones, clays, and limestones.

The Paleozoic and Cretaceous strata completely surround the pre-Cambrian area; the Paleozoic beds are more or less folded and faulted and are separated from the pre-Cambrian by a great time interval. The Cretaceous formations rest upon the Paleozoic rocks in almost undisturbed position, but are separated from them by a great erosional unconformity.

PRE-CAMBRIAN ROCKS.

GENERAL DESCRIPTION OF GEOLOGIC UNITS.

Pre-Cambrian rocks underlie by far the larger part of the Llano quadrangle and about one-third of the Burnet quadrangle. In the mapping of the area four major divisions have been distinguished—(1) a schist series, predominantly of a basic type, including amphibolite, mica schists, and old basic intrusives; (2) a schist-gneiss series, including quartzites or their derivatives, light-colored mica schists and acidic gneisses; (3) a very coarse grained pink granite which could not be separated over the entire area; (4) all remaining granites, including a number of varieties. In addition to these major distinctions, wherever possible limestone and wollastonite bands have been mapped and the outcrops of a quartz porphyry of peculiar type, locally termed "opaline granite," have been indicated. The location of iron ore and other prospects is also shown.

GRANITES.

The granite is invariably intrusive. It cuts the schist series in large and small masses, in dikes, and in sills and, in pegmatitic phases, may be found both in minute veinlets and in huge dikes and sheets. It is almost an omnipresent rock. Every gradation may be found between pure granite and pure schist. Certain localities are characterized by pure granite masses of batholithic type, such as the area of coarse granite in the southwestern portion of the Llano quadrangle, the area immediately west of Cedar Mountain, and the area east of Lone Grove. Other areas are occupied by an intimate mixture of granite and schist, the schist being the sponge which apparently has literally soaked up and become permeated with granitic material. Such occurrences are best developed about the edges of the large granitic masses, though not at all confined to these bodies.

The manner in which intrusion was effected varied. Portions of the schists were in a plastic state and flowed under the influence of pressure. At other localities the contacts of cutting dikes are sharp, indicating a condition of considerable rigidity. At still others the temperatures were such that the schist masses lost their identity and passed by gradual melting into solution. Following the planes of least resistance, granitic material was often forced between the layers of the schists, forming injection gneisses.

Each of the processes outlined above has taken place both on a small and on a huge scale. The whole assemblage of rocks affords a fine example of the condition existing about the borders of a great batholithic mass in contact with a sedimentary series.

Worthy of special mention are the dikes, sills, and broader masses of pegmatite which occur in great abundance and in all sizes; the broader masses are of special interest, being locally developed at crosscutting contacts of schist with granite dikes.

Two types of granite have been distinguished and mapped—a very coarse grained rock and a medium to fine grained granite. Microscopic examination has shown that the distinction is a purely textural one, the mineralogy of the two being essentially the same.

The coarse-grained granite has been mapped in two areas, one in the southwest corner of the Llano quadrangle, forming a large subcircular area with Prairie Mountain as a center, the other to the north in the vicinity of Smoothingiron Mountain. Rock of the same type is known to occur to the east and southeast of Lone Grove and in other localities but could not be consistently differentiated in mapping.

The granite of the second type, the dominant rock of the region, is, as has been pointed out, very widespread. It comprises various textural types, from very coarse to very fine grained, but the whole has been mapped as a unit.

An examination of numerous specimens revealed an abundance of microcline, with orthoclase, albite-oligoclase, hornblende, quartz, and biotite. The granites are distinctly potash rocks, though soda is almost invariably present. The usual accessory minerals, magnetite, apatite, titanite, etc., may generally be found.

Several hornblende granites were noted, but their distribution is limited to small areas.

The "opaline granite," which is properly a quartz-feldspar porphyry, occurs as dikelike masses cutting both the schist series and the granites.

SCHISTS AND GNEISSES.

DISTRIBUTION.

Two broad divisions of the schist-gneiss series may be recognized and have been mapped. One is a group dominantly basic and generally of dark color, containing much limestone and graphitic material; the other a group dominantly acidic, of light color, and containing some altered limestone. Bands of acidic material are present in the first group and bands of basic dark material have been included in the second. There is, therefore, a transition zone between the two groups, locally offering difficulties to the placing of definite boundaries. Likewise at many places within the acidic group the distinction for purposes of mapping between invading granites and gneisses is exceedingly difficult.

The distribution of the two series is dependent primarily on their major structural relations, modified by the effects of igneous intrusion. Their general northwest-southeast trend is determined by the major axes of folding, and their lack of continuity along this trend is due to the presence of granite.

Two major anticlinal axes are present, one passing northwest and southeast through the center of the mountainous mass just west of Oxford, the other passing from Packsaddle Mountain northwestward to a point several miles west of Babyhead. Between these two anticlinal axes lies a major synclinal axis passing northwest and southeast a short distance west of Llano. The broad band determined by this synclinal axis is composed largely of the darker schists; the anticlinal axes mark areas of the lighter rocks. The basic schists overlie those of the acidic type, and therefore are found on the eroded flanks of these great folds where not disturbed by granite masses. The major axes of folding do not represent a simple structure. Minor folds are imposed upon the major folds, with the result that local complexities of structure are numerous.

THE DARK-COLORED SERIES.

The darker-colored series of rocks includes mica, amphibole, and graphitic schists and crystalline limestones. Within the series are also lighter-colored, more feldspathic bands, resembling quartzites. Basic intrusive rocks of earlier age than the granite are also present, locally in considerable amount. They have been mapped separately from the remainder of the series at one locality only.

As a whole, these schists are characterized by an excellent cleavage which for the most part accords in attitude with an original bedding in the sediments of which they represent the metamorphosed equivalents. Commonly, though not invariably, the graphitic schists are closely associated with limestones. The limestones are developed to a varying degree, separate bands aggregating 1,000 feet or more in thickness being found in some places. In general they occur most abundantly in the dark-colored series of rocks and are in a measure characteristic of that series, but they occur also in the lighter-colored rocks, though usually in a yet more altered form—that is, as wollastonite bands. The graphitic schists carry varying proportions of graphite—locally, it is believed, a sufficiently high content to be of commercial value. A discussion of this point will be reserved for a later report. The remaining types include amphibole, mica, tourmaline, and quartz-feldspar schists.

THE LIGHT-COLORED SERIES.

The mapping of the light-colored group of rocks was locally attended with much difficulty, partly in separating them from the dark series, but primarily because of their relation to granitic intrusions which, as has been pointed out, are widespread and of all degrees of magnitude. As many of the light schists closely resemble the granites, especially where slight schistosity may have been impressed upon the latter, and as the contacts are exceedingly irregular, a feature characteristic of the borders of large intrusive masses, the boundaries placed on the map must not be considered without exception as definite lines, but many of them rather as an expression of dominance of rock type. In a region where intrusive material has so completely interleaved and often fairly impregnated a rock mass, and where all gradations from the pure granite through phases of a mixture to pure schist exist, such boundaries as have been used are a necessity to express the geologic facts.[a] It is believed also that included with the schists and gneisses of sedimentary origin are old gneisses of igneous origin.

It has been noted that the areas of light schists include dark bands, though not abundantly, and also bands of wollastonite, the metamorphosed equivalent of limestone.

ORIGIN OF THE SCHISTS AND GNEISSES.

The rocks described above, in both the light and the dark series, are all completely crystallized—that is, the arrangement and size and in part the composition of their mineral constituents are due to the influence of heat and pressure and partly to flowage as a mass. The presence of crystalline limestones, of graphite, and of mica and amphibole schists that are traceable for long distances and retain the characteristics of beds leaves no room for doubt that in great part these rocks were formed by the metamorphism of a sedimentary series. It is believed also that the presence of iron ore points to the same conclusions, but this matter can not be fully considered here.

[a] In many places, however, the boundaries are fairly sharp and are definite lines. It is not possible to discriminate on the map between the boundaries of the two classes.

Although, as has been pointed out, the presence of old igneous masses of acidic type is suspected, only rarely was a crosscutting acidic dike found which bore evidence of having suffered equal metamorphism with the schists that it cut.

Intrusives of a basic type, gabbros and diorites, occur within the schist series and in part have suffered a like degree of metamorphism, though in part not. They will be described more fully in a later paper.

IRON ORES.

GENERAL DESCRIPTION.

Iron ores composed essentially of magnetic iron oxide, or magnetite (Fe_3O_4), or of admixtures of magnetite with hematite (Fe_2O_3) occur in deposits of noteworthy size in Llano and Mason counties, Tex. During the progress of geologic mapping of the Llano quadrangle in 1908 and 1909 thirty-two more or less distinct occurrences of such iron ore were noted and studied with as much detail as was warranted by generally poor natural exposures and a very meager amount of exploratory development. A few of these localities are in eastern Mason County, but most of them are in that portion of Llano County which lies north of Llano River.

All the known occurrences of magnetite were visited, but it is believed that perhaps not more than three of the deposits promise to become of industrial value. No assurance can be given that the three most likely deposits can be developed into profitable mines in advance of adequate exploration by means of diamond drills or by sinking prospecting shafts in addition to those already opened. It is considered that the less promising deposits will not warrant any large expenditure for prospecting unless the market value of iron ores increases.

The permissible scope of the geologic work did not admit of magnetic surveys, but it is strongly urged that such surveys should be carried on in connection with any future exploration of the more promising magnetic deposits of this district. Rough surveys with compass and dip needle are perhaps never fully adequate guides in the preliminary exploration of iron-ore deposits, and work with the more delicate instruments known as magnetometers is ordinarily to be recommended. Such instruments in the hands of skilled operators are certainly demanded by the conditions encountered in the central Texas region, where different parts of any individual ore body possess magnetic permeability in different degrees.

Those who may take up the problem of the practical development of the Llano County iron ores will doubtless give due consideration to the possibility of applying magnetic concentration, as processes of this sort are becoming more and more firmly established in various parts of the world.

The following descriptions are preliminary statements. The deposits will be discussed in more detail in a forthcoming bulletin of the Survey.

The deposits of magnetite in Llano and Mason counties, Tex., are typically layered or stratiform ore bodies conforming in attitude with the layering of the somewhat schistose rocks by which they are inclosed. The feature of layering is more marked in the leaner ore bodies than in the deposits of higher grade, but may be made out in nearly every locality where the iron-bearing rocks are adequately exposed for any sort of an examination. So far as could be observed the iron ores are an integral part of the schist-gneiss series and exhibit much the same relationships to the other members as the limestones and graphite schists. The ore-bearing rocks are crystalline granular schists in which the ore occurs as more or less concentrated grains of magnetite (or hematite when weathered). A single exception noted is the small ore mass opened by the Gallihaw shaft, which occurs in a dike cutting across the layering of the local gneiss.

In so far as the geologic mapping may be relied on, the deposits are associated mainly with the lower of the two sets of gneisses which have been broadly separated. The difficulties of consistently discriminating between these rocks have, however, proved to be so great that it must be freely admitted that the immediate country rocks of the ores may be representative of the upper set of schists in certain localities. If any mistake has been made in the proper classification of the country rocks it is in places where the upper schists have suffered excessive metamorphism and where they occupy areas of minor extent.

Two extensive occurrences of magnetite were found within areas which are undoubtedly underlain by the upper dark schists, and a small amount of magnetite was noted at one other place in this rock. The Olive ore deposit, one of these occurrences, is in dark schists near beds of limestone and very near the edge of a great intrusion of coarse granite.

DESCRIPTION OF LOCALITIES.

OLIVE PROPERTY.

The Olive iron-ore property is located on Little Llano River about 6 miles east by northeast of Llano, 1 mile south of Lone Grove post-office, and 1 mile north of Llano River and the line of the Houston and Texas Central Railroad.

The property has been more extensively developed than any other in the district. It was opened by a shaft in 1892 or 1893. The shaft is situated on the east bank of the Little Llano just west of the main boundary of this area and therefore within the schists which belong to the upper set of metamorphosed sedimentary rocks characteristic of the region.

The rocks exposed in the vicinity include granite, hornblende-mica schist, graphite schist, and crystalline limestone. The granites are intruded into the other rocks in an intricate manner, which can not be fully made out because of rather poor exposures.

The stock pile contains perhaps 400 tons of ore of very good physical appearance. Most of the ore contains hornblende, and some of it carries iron sulphide in addition to magnetite. It is all more or less distinctly layered in its make-up.

The following analyses are given by the courtesy of Messrs. Johnston, Elliot & Co., of Dallas, Tex. Both samples represent the stock pile at the Olive mine:

Analyses of ore from Olive mine, Llano County, Tex.[a]

Iron	57.80	Iron	54.35
Silica	8.40	Silica	10.16
Sulphur	.28	Sulphur	.55
Phosphorus	Trace.	Phosphorus	.021

The Olive ore was discovered at a point about 95 feet north by northeast of the working shaft. There is no surface showing and the ore is said to have been uncovered by accident in a shallow excavation. The first development was by means of an incline about 30 feet deep and a southerly drift which was afterward connected with the vertical working shaft. The shaft, which was started in the hanging wall, encountered the ore below the level of the drift mentioned above. It was carried down through the ore, and three crosscuts were run out to the ore. The shaft is 230 feet deep.

The following note by J. B. Dabney, former superintendent of the Olive mine, is furnished by Prof. N. J. Badu, of Llano:

> * * * thickness of vein above first level, 3 feet; between first and second levels, 6 feet; between third and fourth levels, 8 feet; at fourth level, 2 feet; and at bottom of incline, 8 feet.

The horizontal extent of the ore has not been adequately tested.

BADER TRACT.

The property known as the Bader tract lies about 9 miles west of Llano and 9 miles south of the Iron Mountain mine. This parcel is adjoined on the north by a tract known as the Otto, the east-west property line being somewhat less than 2 miles north of Llano River.

Iron ore has been found at several places along a zone trending north by northeast, about 500 feet in width and nearly 7,000 feet in length. A shaft in the extreme southwest corner of the Otto tract encountered magnetite, which represents the most northerly known extension of the Bader ore range. Farther to the northwest there is no evidence

[a] Sampled by and analyzed for Robert Linton, of Atwater, Linton & Atwater, mining engineers.

of any exploratory work such as trenches, and careful search on the part of the geologists failed to reveal so much as a fragment of magnetite beyond the west line of the Otto tract. That the ore may continue in this direction is thought to be possible but improbable.

No importance can be attached to any suggestion that might be made in the direction of correlating the Bader range with other occurrences of magnetite in Llano County. There is certainly no adequate reason for regarding the range as in any way the extension of the Iron Mountain ore. Though the trend of the range would carry it to the ore on the Epperson tract, 3 miles to the northwest, there is a wide area of intrusive granite north of the Bader, and beyond this intrusion the structural trends are northerly rather than northwesterly.

Aside from very shallow pits or trenches at various points, the Bader range has been explored only near its north end, where the original surface indications appear to have been the best. Here trenches and float ore extend for a total distance of 1,000 feet in a southerly direction from the Otto shaft. Two lines of outcrop about 80 feet apart are noted in the vicinity of the Bader incline.

About 110 feet south of the incline an excavation in the lower ore ayer shows 31 inches of fairly clean ore dipping about 30° NE. There is also a 5-inch rider lying 2 feet above the principal ore layer and separated from it by feldspathic gneiss. In an adjacent opening on the upper layer the grain or layering of the ore appears to be nearly horizontal.

The Bader incline reveals two ore layers estimated to lie between 10 and 15 feet apart. The dip of these layers varies from 20° to 40°. The lower ore may be described as gneiss carrying thin and discontinuous layers of magnetite. This lean material is not more than 16 inches thick. The incline follows the dip of this ore for about 25 feet and then flattens so that the workings cut across the layering of the gneiss and encounter the upper ore bed. As exposed in the sides of the incline this second layer has a maximum thickness of 20 inches.

The dip length of the incline is estimated to be about 50 feet. All the ore on the dump is layered to a marked degree, much of it being sharply segregated into layers of more or less granular magnetite and of silicate minerals.

To one standing on the surface it seems likely that the lower of the two layers shown in the pits mentioned above is identical with the upper of the two opened by the incline, though this identification may not be affirmed. If it is correct there are at least three ore layers at this place, the lowest being nowhere exposed at the surface.

No definite conclusion concerning the possibilities of the Bader tract can be offered. Compared with the great cropping and abundant float at Iron Mountain, the surface showings would seem at first thought to be unimportant. It is believed, however, that caution should be exercised in accepting an unfavorable view with regard to deposits of the sort here presented, for experience in other districts has shown that the importance of magnetite ore bodies in gneisses may be seriously misjudged from surface indications. It is suggested that the Bader tract is worthy of more extensive exploration than it has received up to the present time, and particularly that preliminary work in this direction should include a refined magnetic survey of the range, which, as already stated, has a length of about 7,000 feet. It is thought that magnetometer observations might give indications of ore in the covered territory between the two ends of the Bader range.

IRON MOUNTAIN.

The Iron Mountain prospect is located 12 miles northwest of Llano and about 1 mile northwest of Valley Spring. The property, consisting of 640 acres, is owned by Robert Downman, of New Orleans. The ore body caps a low mound slightly above the elevation of the surrounding country and trends about N. 60° W. in a slightly curving line. The surface outcrop has a length of about 114 feet and a width of 22 feet at its center. It is slightly narrower at the northwest end and narrows down to about 6 feet at the southeast end. A granite intrusion cuts across the mass at the northwest end, apparently cutting off the ore. The surface cover prevents observations on the southeast end.

The ore body as revealed at the surface is a nearly vertical mass of very pure magnetite. Along its south side schists are exposed in several small cuts. They strike northwest with the ore, but in dip do not accord with the dip of the mass. On the north side a gneissoid rock of granitic type is observed. It is believed to be intrusive into the ore, but is an older intrusion than the granite which cuts across the northwest end. Unfortunately the surface cover has rendered the exact surface relations of the ore body obscure. The complex intrusion of granite into the schists, a condition described in an earlier part of this report, has at this locality also obscured the original relations of the ore to the inclosing rock.

A shaft was sunk near the southwest wall of the ore body. A crosscut has been driven at the 50-foot level, showing 25 feet of solid ore. This crosscut was continued for 54 feet. After passing through the 25 feet of ore a narrow mass of granitic schistose material was encountered, beyond which ore was again found. This second body was confined largely to the floor, and a winze was sunk in ore.

At the 100-foot level crosscuts and drifts were run, but ore was not encountered directly beneath the main mass. The country rock is a mixture of schist and granite. A raise from the 100-foot level connecting with the winze revealed 16 feet of ore in a body of schist dipping at a low angle to the east and grading downward into lean ore and granite.

The relations described above are due, it is believed, to faulting and will be described in detail with cross sections in the later report.

The important fact brought out by the development is the existence of the 16-foot bed dipping in an easterly direction at a low angle. The faulting accounts for the abrupt termination of the vertical bed.

Besides the development by shaft and tunnels above described, the property has been and is being prospected by several diamond-drill holes.

The following is a table of analyses of the Iron Mountain ore.

Analyses of ore from Iron Mountain, Texas.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Metallic iron	65.40	67.60	65.45	66.530	64.90	58.87	61.45	67.70	66.10	63.23	66.82
Phosphorus	.069	.093	.061	(a)	(a)	(a)	(a)	.045	.034	.008	Trace.
Silica	4.695	4.690								4.70	4.65
Sulphur										Trace.	.30
Specific gravity	4.724	4.677									

a Not determined.

1. General sample of surface ore; private report of E. V. d'Invilliers.
2. Sample 125 pieces of ore at depth of 50 feet in shaft; E. V. d'Invilliers.
3. Surface ore sampled by McCreath, clippings of large bowlders; E. V. d'Invilliers.
4. Surface ore, main exposure, sampled by representative of McCreath, 1889; E. V. d'Invilliers.
5. From shaft 8 feet deep, south side of main exposure, sampled by representative of McCreath; E. V. d'Invilliers.
6. From shaft 12 feet deep north side of main exposure, sampled by representative of McCreath, lower 8 feet of ore; E. V. d'Invilliers.
7. From cut 4 feet deep 150 yards east of main exposure, sampled by representative of McCreath; E. V. d'Invilliers.
8. From shaft at main exposure, ore from lower depth than Nos. 5 and 6, chiefly magnetic; E. V. d'Invilliers.
9. Iron Mountain tract, sampled and analyzed by Rattle & Nye; E. V. d'Invilliers.

10, 11. Iron Mountain mine, 50-foot level, taken by Robert Linton, for Johnston, Elliot & Co., of Dallas, Tex.

It would seem advisable to confine prospecting in this area largely to the north side of the line of strike of the ore body. If it can be shown that the flat bed has considerable extension in a northwest-southeast direction and also on the dip, a large body of ore may be present. If underground work is to be continued, it would seem advisable to make a raise from the end of the east drift on the 100-foot level at the point where a disconnected mass of iron was struck, to discover the presence or absence of the bed above. A careful magnetic survey of the territory adjacent to the ore body would be valuable.

VICINITY OF CASTELL.

In Mason County, about 4½ miles south and somewhat west of Castell, magnetite float and ore outcrops occur at several places within the drainage basin of Keyser Creek, also known as Old Place Creek.

Magnetite occurs also at several localities north and northwest of Castell in lean ore beds.

LIVELY TRACT.

The Lively property lies somewhat more than a mile southeast of Iron Mountain and three-fourths mile southwest of Valley Spring. There has been no development work here and the showing is confined to magnetite float in the wagon road northeast of Johnson Creek. This locality is near a line joining the ore at Iron Mountain, to the northwest, and the Becton ore, 4 miles to the southeast. Although the three localities are thus in alignment there is no adequate basis for the suggestion of any connection between these deposits or for any expectation that intermediate deposits are likely to be discovered.

SECTION 13 AND VICINITY.

The tract of 640 acres known as H. and G. N., sec. 13, lies about 4 miles south of the Iron Mountain property, on the southwest side of San Fernando Creek, at the mouth of Willow Creek. Magnetite has been found at several places on this tract and at several localities in the neighborhood on both sides of San Fernando Creek.

ORIGIN.

A discussion of the origin of the iron ores described in outline above will be reserved for the later report. It is believed that they represent metamorphic sedimentary deposits and in general resemble certain of the magnetite deposits occurring in metamorphic rocks in the Eastern States.

PRACTICAL CONSIDERATIONS.

How much iron ore must be assured to warrant the undertaking of mining operations in the Llano field? Though this very practical question may not be answered categorically or with any great degree of confidence, certain assumptions may be made and discussed to indicate the factors of the problem. It may be assumed that an iron mine located in the district should produce 100 tons a day or 30,000 tons a year of 60 per cent iron ore in order to find a ready market for its output and to insure moderate mining cost per ton. This amount would supply from one-third to one-half the ore required by a modern blast furnace. It may be assumed also that the life of the mine must be eight years. The size of an ore body to yield 8 times 30,000, or 240,000, tons must be 2,400,000 cubic feet, on the supposition that the ore measures 9 cubic feet to the ton and that 10 per cent must be left for pillars in the mine. With an average thickness of 10 feet, a mass of ore of the size specified must have a length of say 600 feet and a depth of 400 feet.

Leaner ores susceptible of enrichment by means of magnetic concentrators must be present in correspondingly larger masses to warrant profitable operations.

That bodies of iron ore fulfilling the above-stated moderate assumptions as to size and grade are present anywhere in the Llano district remains to be proved by more extended explorations than have been made up to the present time. It may be said that the geologic work in the district has not led to particularly favorable impressions of the possibilities of these ores, though the question is still an open one which must be practically decided by means of pits, shafts, and carefully placed diamond-drill holes.

SURVEY PUBLICATIONS ON IRON AND MANGANESE ORES.

A number of the principal papers on iron and manganese ores published by the United States Geological Survey or by members of its staff are listed below. The government publications, except those to which a price is affixed, can be obtained free by applying to the Director, U. S. Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.; the monographs from either that official or the Director of the Survey. In addition to these papers, several geologic folios contain descriptions of iron-ore deposits of more or less importance.

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ASPHALT.

SURVEY PUBLICATIONS ON ASPHALT.

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