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THE GRANITES OF MAINE

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WITH AN INTRODUCTION BY
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THE HARTVILLE IRON-ORE RANGE, WYOMING.

By Sydney H. Ball.

INTRODUCTION.

In the summer of 1906 the writer spent three months in studying the geology and the iron-ore deposits of the Hartville, Wyo., iron range. The following preliminary description of the results of the work will be followed in the near future by a more extended article, accompanied by adequate maps. Some of the conclusions here stated may be modified by a more detailed study of collections and notes. The writer wishes gratefully to acknowledge his indebtedness to Supt. Louis B. Weed, Engineer George C. Botsford, and Capt. Thomas Tucker, of the Colorado Fuel and Iron Company; to Mr. C. A. Guernsey, of Guernsey, and to Messrs. Lauck & Stein, of Frederick.

The literature concerning the iron of the Hartville range is summarized in the following bibliography:

Ricketts, Louis D., Ann. Rept. Territorial Geologist to the Governor of Wyoming, Jan., 1888, Cheyenne, Wyo., pp. 64–68. Briefly describes the geology and mentions the presence of large bodies of iron ore near Sunrise.

Ricketts, Louis D., Ann. Rept. Territorial Geologist to the Governor of Wyoming, Jan., 1890, Cheyenne, Wyo., pp. 51-61. Briefly describes the geology and reports upon the ore deposits in considerable detail, dividing them into three classes: (1) Lenticular masses between walls in crystalline slates, (2) stratified deposits at the base of the cap rock (Guernsey formation), and (3) residual deposits. He describes in detail the development of the Sunrise mine and the presence of ore in a number of other claims in the near vicinity, and from its trend infers that the ore of the Chicago claim is an extension of the Sunrise deposit. He gives a number of analyses of iron ore, all of which are notably high in iron and low in phosphorus and silica.

Knight, Wilbur C., Bull. 14, Wyoming Experiment Station, University of Wyoming, Laramie, Wyo., Oct., 1893, pp. 176–177.

Snow, E. P., Eng. and Min. Jour., vol. 60, pp. 320–321, 1895. General description. Mentions mining by the Indians. Estimates ore in sight at 10,000,000 tons.

Chance, H. M., The iron mines of Hartville. Wyoming: Trans. Am. Inst. Min. Eng., vol. 30, pp. 987-1003. In this excellent report Mr. Chance describes the original pre-Cambrian lenses of ore, as well as the deposits at the base of the Guernsey, and in addition placer and residual deposits. He gives a number of analyses of the ores. Mr. Chance's work is of great value, since he records the conditions in many shafts now inaccessible. This paper is accompanied by a map showing the location of the principal mines and prospects.

SMITH, W. S. T., and DARTON, N. H., Description of the Hartville quadrangle, folio 91, U. S. Geol. Survey, 1903. Describes the general geology, geological history, and economic geology of the Hartville quadrangle. The iron ore is briefly described.

BEELER, HENRY C., Wyoming mines and minerals in brief, Cheyenne, Wyoming, 1904, p. 6.

BEELER, HENRY C., Report of the State Geologist of Wyoming, Cheyenne, Wyoming, 1904, p. 37.

BROOKS, BRYANT B., The State of Wyoming, 1905, Sheridan, Wyoming, pp. 94-95.

GEOGRAPHY AND HISTORY.

The Hartville iron range, lying north and east of North Platte River, is situated in Laramie County, in east-central Wyoming. It forms a portion of the Hartville uplift, a broad and low domal mountain mass similar in many respects to the Black Hills in South Dakota. The maximum height of the uplift is about 6,000 feet above sea level, and the region is one of comparatively little relief. Near the iron mines erosion has detached many hills from the Carboniferous plateau. These are sharp granite peaks or flat-topped buttes capped by horizontal Carboniferous rocks. The area is dissected by intermittent streams, some with narrow gulches and others with broad, wide valleys. The climate is semiarid, and in consequence timber is confined to the higher peaks. Lower elevations are covered sparsely by bunch grass, cactus, and low desert shrubbery.

The iron range extends from Guernsey to Frederick, a distance of 8 miles. The iron-bearing rocks reach a maximum exposed width of 3 miles. The productive area is, however, considerably smaller and extends from Sunrise northeastward 2 miles and from the same point southeastward 1 mile. The towns of the iron range are Sunrise, Hartville, Ironton, and Guernsey. The principal mine of the range and the local offices of the Colorado Fuel and Iron Company are at Sunrise, a village having a population of 1,500. Hartville, a town of 150 people, is supported by the miners of Sunrise. Ironton is the mining camp of the Chicago mine. Guernsey is an ore-shipping town of 150 people. The Hartville iron range has two railroads; the Colorado and Wyoming Railroad extends from the Colorado and Southern Railroad at Hartville Junction to Sunrise and is the line by which the Sunrise ore is shipped; the Chicago, Burlington and Quincy Railroad has built a branch from its present terminus at Guernsey to the Chicago mine.

The history of the Hartville iron range may be divided into four periods: (1) That during which the Indians mined soft ore for war paint; (2) a period stretching from 1880 to 1887, during which the range was a copper-mining district; (3) an iron-prospecting period extending from 1888 to 1897, and, lastly, the period of productive mining, from 1898 to the present day.

The value of the iron deposits of the Hartville iron range was proved while copper was being mined at Sunrise. With the exhaus-

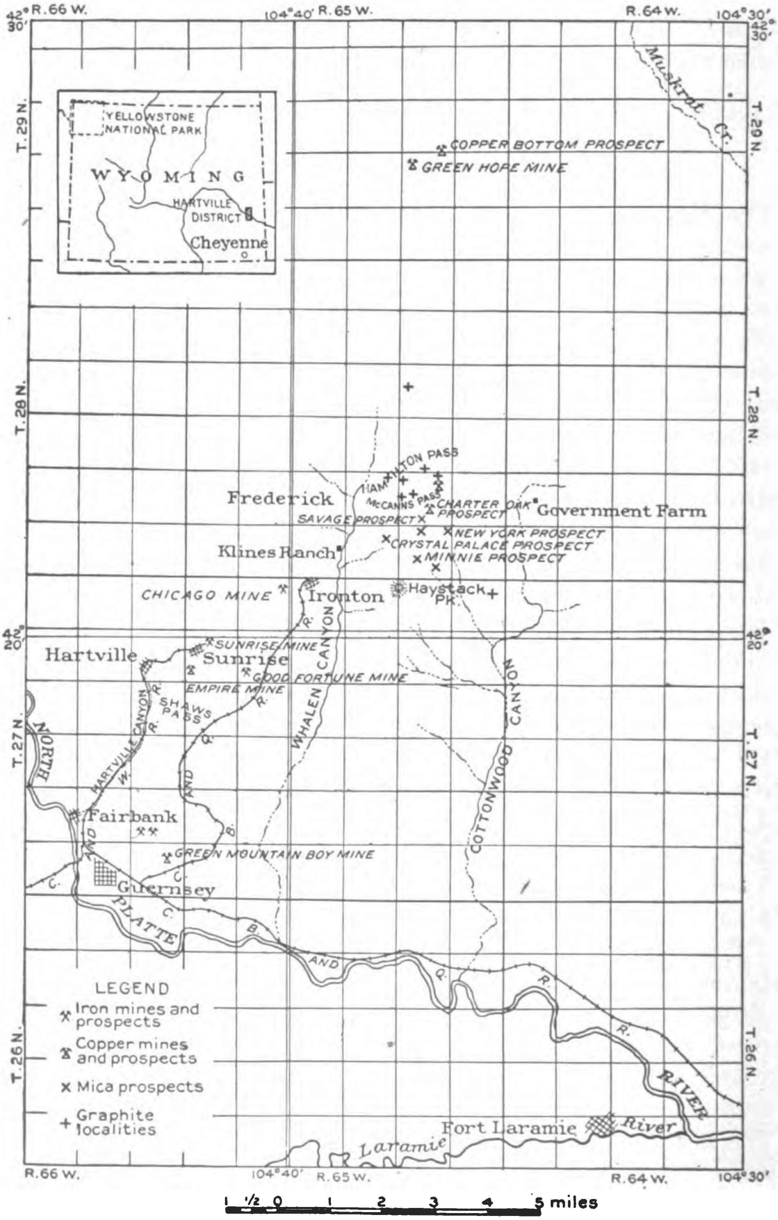

FIG. 5.—Economic map of the Hartville uplift, Laramie County, Wyo.

tion of the copper deposits, Messrs. I. S. Bartlett and C. A. Guernsey began to prospect for iron ore, and in 1900 Mr. Guernsey, having segregated most of the larger deposits, sold his group of claims to the

Colorado Fuel and Iron Company. Since that time this company has been adding to its holdings and now controls most of the more valuable claims. It is rapidly developing two mines, the Sunrise and Chicago, which now furnish the greater portion of the ore used at its smelters at Pueblo, Colo.

PRODUCTION.

The production of the Hartville iron range is tabulated below:

Production of Hartville iron range, 1898–1906.

Year.	Mine.	Quantity.
		Long tons.
1898–99	Good Fortune mine	30,000
1900	Sunrise mine	73,663
1901	....do	134,161
1902	....do	209,272
1903	....do	214,880
1904	....do	135,167
1905	Sunrise and Chicago	474,545
1906	....do	....

In 1905 the Sunrise mine was in point of production the twentieth iron mine in the United States, but two mines outside of the Lake Superior region exceeding it in output. The product of the range shows an encouraging increase, which will presumably become greater from year to year.

GEOLOGY.

STRATIGRAPHY.

The rocks of the Hartville iron range fall naturally into three groups: (1) The steeply dipping pre-Cambrian rocks, (2) the flat-lying or gently dipping Carboniferous and Mesozoic rocks, and (3) the rocks of Tertiary and Recent age encircling the older rocks and filling depressions of erosion extending up into them.

The pre-Cambrian rocks consist of metamorphosed sedimentary rocks and of igneous rocks and their mashed equivalents. The oldest rocks are an interbedded series of siliceous limestones, probably dolomitic, and muscovitic and biotitic schists. In all there appear to be about fifteen beds of limestone and schist, which alternate with one another. The beds vary in thickness from 20 to 500 or more feet. The schist also occurs as lenses in the limestone, these lenses grading both parallel to and across their longest direction into rocks that are intermediate in composition between schist and limestone. The limestone is typically a fine-grained rock of pinkish or grayish color and has a conchoidal fracture. Lenses and beds of cream-colored flint lie parallel to the original planes of stratification and to a minor extent cut these. The schists vary in color from silvery to very dark gray. They are typically fine grained and pass from biotitic to muscovitic varieties both along and across the bedding. Slaty schists and siliceous schists also occur. Interbedded with this old series are thin beds and lenses of gray quartzose rock and dark-brown or black jaspers.

In the broad schist area east of Sunrise a second sedimentary series lies unconformably upon the uppermost bed of the series just described. The unconformable character of this series is indicated by its location in synclinal troughs upon the uppermost beds of the older rock series, which is folded into a syncline, by a conglomerate that is present in some places at its base, by the fact that it slightly cuts across the beds of the older formation, and by its sharp contacts with and lithological differences from the older formation. This second series of sedimentary rocks is composed of gray, thoroughly crystalline quartzose rocks, which are at some places conglomeratic and at others nonconglomeratic. Associated with these altered sandstones are beds of jasper, which vary in color from gray through browns and reds into black. The banding of the jaspers is at some places close. Although most of the exposures are too poor to determine the younger age of the quartzose rocks and jaspers of all the areas, there is no doubt that two sedimentary series occur in the pre-Cambrian of this district and that many of the areas of siliceous rocks are younger than the schist-limestone series.

The next youngest pre-Cambrian rocks are gabbros, diorites, and allied porphyries and the same rocks mashed into hornblende and chloritic schist. These rocks grade into one another. At most places these igneous rocks are intrusive in the older pre-Cambrian sedimentary series. It is possible, however, that some of the chloritic and hornblende schists may represent later basic lava flows. The age relation of the rocks of the third to those of the second pre-Cambrian series is unknown, since at no place were the two observed in contact, although it is believed from differences in the amounts of folding suffered by the two formations that the sedimentary is the older series. The intrusion of the gabbros and the diorite was followed by that of a coarse-grained pink biotite granite, which at many places contains large feldspar crystals. It occurs in rounded, intrusive masses characterized by but few offshoots and in isolated dikes. Aplites and pegmatites allied in composition to the granite followed its intrusion. The last of the pre-Cambrian series is a diabase which occurs in dikes that are sparsely distributed throughout a wide area.

The Carboniferous series alone of the Paleozoic and Mesozoic rocks occurs in the immediate vicinity of the ore deposits. The Carboniferous consists of a basal member, the Guernsey, and an upper member, the Hartville formation. The Guernsey is normally 150 feet thick and comprises at its base either a conglomeratic quartzite, a quartzite, or a limestone containing sand grains. The upper part of the formation is composed of massive beds of gray limestone. Prior to the deposition of the Guernsey formation the pre-Carboniferous land surface was reduced to a peneplain. The contact between the pre-Cambrian and Carboniferous rocks is therefore a flat surface that has been locally warped by post-Carboniferous folding. When the Carboniferous rocks are in contact with the pre-Cambrian schist the contact plane is level, while the Carboniferous extends down into the pre-Cambrian limestone in many ramifying rounded bodies. Evidently where the pre-Carboniferous peneplain was underlain by limestone, solution formed caves with attendant cave galleries, sink holes, and irregular solution joint cavities. Unconformably upon the Guernsey lies the Hartville formation, which is at most places 650 feet thick. Its basal member is a deep red sandstone and above this is white or gray limestone. Some distance northwest of the iron range Messrs. Smith and Darton [a] found a number of Jurassic-Triassic and Cretaceous sedimentary formations.

The older rocks prior to late Tertiary times were deeply eroded, and the resulting older gulches, canyons, and valleys have been filled by the Tertiary sandstone, which in the folio already mentioned is called the Arikaree. The Pleistocene formations consist of terrace gravels, alluvium, and wash.

STRUCTURE.

The pre-Cambrian sedimentary rocks have been folded into a complexly folded trough or synclinorium with east and west axis. The axis of the synclinorium passes through Sunrise. The beds of the north arm near Sunrise course north of east. To the northeast they bend farther northward and at Frederick course east of north. North of Frederick the direction of the axis is north-south, its direction being determined by the contiguous granite mass. Between Sunrise and Guernsey the strike of the beds is practically east-west, although in the isolated hills south of Haystack Peak, across Whalen Canyon, the strike is again north-south. Presumably, therefore, beneath Whalen Canyon, east of Guernsey, the beds strike southeastward. In the main schist area east of Sunrise the folding is probably close, since it is known that the schist is repeated by folding at least four times. Minor folds in the synclinorium are of two kinds—(1) those formed contemporaneously with the main folding of the series, and (2) those due to buckling caused by the intrusion of the granite.

Faults, particularly those cutting the extension of the beds of the synclinorium at right angles, are common in the pre-Cambrian complex. The greatest fault in the area, however, extends eastward from a point one-half mile north of Guernsey. Here the pre-Cambrian and

[a] Description of the Hartville quadrangle: Geologic Atlas U. S., folio 91, U. S. Geol. Survey, 1903.

Guernsey formations are in fault contact, the amount of displacement being over 200 feet, with the downthrown side on the south. Brecciation has accompanied both faulting and folding, and the main ore deposits are intimately associated with it. There is evidence also that in some places the schist was opened along its planes of schistosity during the folding.

The Carboniferous formations occur usually as flat-lying remnants capping the pre-Cambrian hill. On the borders of the uplift, however, the Carboniferous formations at many places dip rather steeply beneath younger formations.

ORE BODIES.

FORM AND PLACE OF THE ORES.

The most important iron-ore deposits of the Hartville iron range are lenses that occur in schist on a limestone foot wall. The ore largely replaces the schist, although it partially fills cavities in the schist which are due to jointing, faulting, and brecciation. Detrital ores of secondary derivation from these deposits are situated (1) at the base of the Guernsey formation, (2) at the base of the Hartville formation, and (3) in the Tertiary lake and Pleistocene and Recent stream deposits. The pre-Cambrian jaspers, an amphibolitized phase of the schist, and the matrix of some of the conglomeratic facies of the second pre-Cambrian series, also locally contain considerable iron.

The most important ore deposits next to the lenses above the contact of the pre-Cambrian schist and limestone are situated along the fault already mentioned, north of Guernsey, between the pre-Cambrian series and the Guernsey formation. Although but little developed, these deposits will perhaps repay careful prospecting. Masses of hematite and limonite in the Haystack Mountains are evidently the iron hats or gossans of sulphide deposits and are economically important.

LENSES OF IRON ORE IN SCHIST UPON A LIMESTONE FOOT WALL.

GENERAL CHARACTER.

The principal bodies are irregular lenses, elongated parallel to the strike of the metamorphic sedimentary rocks in which they occur. Their range in width is from a few to 100 feet or more, and some of them are over 1,000 feet long. It is reported that one ore body in the district has been proved to a depth of 900 feet. The principal deposits of this type include those of the Sunrise mine and its practical extension—the Lone Jack—and the Chicago and the Good Fortune mines. Similar ore masses occur at a number of points between these ore bodies.

ORE AND GANGUE MINERALS.

The chief ore of these deposits is hydrated hematite. It is either (1) a hard gray ore filled with numerous cavities, which are lined with finely crystalline specular hematite, or (2) a soft greasy ore of brownish-red color. Fibrous varieties of hematite, including mammillary ore, grape ore, and stalactitic ore, occur less frequently. Minor quantities of siderite and limonite are associated with the hematite. The limonite is in some places compact and finely granular; at others it is mammillary, and at still others it is a soft yellow ocher. Magnetite is not present in masses large enough to attract the eye, although slight local magnetic variations noted at some places in the vicinity of the ore deposits may indicate its presence. Pyrite and marcasite were not observed and probably do not occur in the ore bodies.

The gangue minerals are calcite, quartz, gypsum, chalcedony, barite, and a kaolinlike mineral, and the copper minerals are chrysocolla, malachite, chalcocite, azurite, and native copper. Calcite occurs in colorless or slightly yellow crystals. The most important development of quartz, like that of calcite, is clearly later than the ore. It also occurs as brecciated fragments in the ore and is then older than the hematite, while to a less extent it is contemporaneous with the ore. At the Chicago mine the quartz sometimes is of a beautiful amethystine tint. The copper minerals[a] occur in fractures in the hematite and associated rocks and are the younger.

Irregular masses of iron-stained schist, "soapstone," and to a less extent iron-stained limestone and iron-stained siliceous rocks occur as vein material in the ore bodies. Schist and soapstone occur as irregular horses throughout the ore body. The "soapstone" is an unctuous substance of pale green color.

PARAGENESIS.

The hard and soft ores grade into schist and it is evident that each was formed through the replacement of the schist by hematite. The soft ore is thus in part derived directly from the schist, but a considerable portion of it is derived secondarily from the hard ore. Pseudomorphous replacements of hard ore by soft ore are common. Perhaps the best evidence of this change is seen in the pebbles of soft ore of beautifully rounded form that occur in the detrital deposits at the base of the Guernsey formation. Pebbles of this formation are usually of the dense hard gray ore, and it is absolutely impossible that a substance offering as little resistance to attrition as the soft ore could form such well-rounded pebbles. The secondary character of much of the soft ore is further indicated by the fact that on

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[a] See this volume, pp. 93-107.

the surface at the Sunrise mine the soft ore equals the hard ore in bulk, while on the lowest levels hard ore greatly predominates. In the Lone Jack tunnel, which after entering the hill gains considerable depth beneath the surface, the soft ore gradually decreases in amount from the entry of the tunnel to the breast, and at the latter point is practically absent. Alteration of the hard ore into the soft by percolating waters is well exemplified by the presence of soft ore along channels of maximum water circulation. There is also reason to believe that soft ore originates from the hard through shearing, since it occurs along many fault planes in the ore bodies.

The mammillary, grape, and stalactitic forms of hematite are clearly younger than the hard ore and in most places are younger than the soft ore. The mammillary ore occurs in fractures cutting the hard and soft hematite, while the grape and stalactitic ores cover cavities in the older varieties. Some of the mammillary ore was undoubtedly formed after the deposition of the detrital ore at the base of the Guernsey (Carboniferous) formation.

Limonite is a product of the surface alteration of the other iron-ore minerals. It occurs as pseudomorphs after both hematite and siderite. Great rounded bodies of limonite associated with an iron-stained flint are found in the Lone Jack and Sunrise open pits immediately beneath the Carboniferous rocks. The limonite and flint grade, on the one hand, into schist and, on the other, into hematite and are evidently a product of the surface alteration of the schist. Siderite occurs in cavities in the hematite and is clearly younger than it. After the deposition of the siderite came that of quartz in small crystals. Quartz is in turn at places coated with calcite. Of earlier origin than either the quartz or the calcite are the copper ores. These copper ores were, in the main, deposited after the Guernsey formation had been laid down, and in consequence the quartz and calcite were evidently formed in Carboniferous or post-Carboniferous times.

GRADE OF ORE.

The ore of the Hartville iron range is a high-grade hematite, some masses of which contain over 68 per cent of iron, although the ore as a whole will probably not average over 60 per cent. The iron content, where the contact of the ore and country rock is a fault, usually holds its grade up to the fault plane. The iron content in the Sunrise mine increases perceptibly with depth, indicating, perhaps, a considerable redeposition of iron at depths through secondary processes. The ore of the Hartville iron range examined by early writers was very low in phosphorus, many samples showing only a trace. At the present time much of the ore shipped is of a non-Bessemer grade. The earlier analyses are believed by the officers of the Colorado Fuel and Iron Company to have been made from picked samples, since their analyses from the same points show a higher content of phosphorus. Some of the ore is high in silica, its only other detrimental constituent. Sulphur, so far as known, is absent, while the copper minerals occupy such restricted areas that their presence is not troublesome in the sorting of the ores. The ore is rather heavy, occupying approximately 10 cubic feet per ton.

DISTRIBUTION.

The iron ore lenses all occupy similar positions in relation to the inclosing rocks. They lie in schist immediately above the uppermost limestone of the older pre-Cambrian series. This limestone swings from the Good Fortune mine east to Whalen Canyon, where it is covered by alluvium. Since limestone does not outcrop on the east side of Whalen Canyon south of this point the contact is perhaps situated near the center of the valley. In the other direction the contact courses from the Good Fortune mine north of west to a point where it passes beneath horizontal Carboniferous rocks. The contact between the schist and limestone in this direction is again exposed in the Republic shaft at the tail of the railroad Y in Sunrise. From here it courses to a point beneath the Colorado Supply Store, from which it goes north and then northeast, forming the foot wall of the Sunrise ore body. Thence it bows out to the northward, passing north of the Biwabik shaft beneath the Carboniferous, and appearing at the surface again 100 feet north of the Chicago open pit. The contact here is hidden in a valley, but appears again on the hill west of the Colorado Supply Store at Ironton. After passing beneath the alluvium of Whalen Canyon this contact next appears in a hill south of the house at Kline's ranch. From this point it courses practically due north to Frederick, where it lies slightly east of the ranch house. Along this contact, then, all of the larger iron deposits of the Hartville iron range occur.

The presence of large ore bodies is determined apparently by the minor structural peculiarities of this contact. For instance, in the Sunrise mine the two richest bodies of ore lie in minor synclines superimposed upon the main syncline. At the Good Fortune mine the ore is closely associated with a sharp minor fold accompanied by considerable brecciation. At the Sunrise mine the hanging wall and the foot wall are both schist, although on the foot wall the schist between the ore and the underlying limestone is thin. At the Chicago mine the ore on the north side is directly against the limestone or its iron-stained alteration products. At the Good Fortune mine a thin shell of siliceous iron-stained schist separates the ore from the underlying limestone. The contact between the ore body and the country rock is in some places sharp and in others gradational. On the whole, gradational contacts are probably more common, and it is evident that the ore is but a replacement of the schist, since no hard-and-fast line can be drawn between unaltered schist, iron-stained schist, siliceous ore, and good ore. Where the contact between the country rock and the ore is sharp, considerable differential movement has taken place, and most of such contacts are lines of recognized faulting.

ORIGIN OF THE ORES.

The ore lenses in the pre-Cambrian rocks are of secondary origin. This is proved by the close relationship between them and secondary structures, such as folding, jointing, faulting, and brecciation. Further, the ore was deposited by descending water. This is indicated by the position of the ore along a contact which is a maximum zone of downward water circulation and by the presence of lenses and veins of iron ore at a distance from the main ore bodies along joints and faults, natural sites of maximum water circulation. Further, the ore is associated with calcite, quartz, and limonite, minerals known to be deposited by water. Circulating waters naturally flow in some pervious stratum above an impervious bed, or follow more or less open channels along zones of maximum rock crushing. That the limestone is relatively impervious and the schist relatively pervious is indicated by a number of the characteristics of these rocks. Thus the pre-Cambrian diabase dikes in limestone are comparatively fresh, while those in schist are greatly altered. Likewise veins of pegmatitic quartz, presumably deposited by very dilute aqueous solutions, are much more abundant in schist than in limestone. Further, the limestone, when folded, appears to have escaped important brecciation, while the more siliceous bands of the schist were intensely fractured. The limestones naturally confined the circulation of the water to the more pervious rock that overlay it. The main circulation, then, was in schist down the dip slope of limestone. The faults crossing the pre-Cambrian formations would furnish outlets by which the descending water could reach the surface. From the depth of the deposits it is inferred that the topography, when the ores were deposited, was of a rugged character.

The possible sources of the iron ore are (1) magnetite, hematite, and pyrite in schist; (2) pyrite in quartzose beds; (3) iron carbonate in the limestone; and (4) hematite in the pegmatite veins.

Pyrite and magnetite are very common minerals in much of the schist of the Hartville iron range. Pyrite in diamond-drill cores of biotitic schist occurs usually along the planes of schistosity in very small flakes. In the muscovite schists, particularly in those near the ore bodies, are many tiny cavities which are heavily iron-stained. Some of these represent hematite and magnetite crystals; others are, without much question, the casts of small crystals of pyrite, which, to judge from their even distribution throughout large masses of the schist, were original to the recrystallization of the schist. Pyrite also appears to be present as an original constituent in some of the quartzose beds interbedded with the schist member. The chemical composition of the schist shows that it had a low iron content prior to its alteration.

Locally there are probably small amounts of iron carbonate, ferruginous dolomite, or ferruginous calcite in the limestone. The unstained character of much of its weathered surface, however, indicates that the quantities of such minerals in the limestone are so small as to be absolutely inadequate to supply material for the concentration of large iron-ore bodies. Further, this iron carbonate of the limestone lies below the main course of circulating waters. In the schist and limestone there are a few quartz veins, probably of pegmatitic origin, and a small amount of hematite forms a constituent of these veins. The rôle of the pegmatite as an original source of the ore may, however, be neglected.

It is believed, then, that the iron ores were concentrated by surface waters from magnetite and iron pyrite of the schist lying above the limestone foot wall. During pre-Cambrian erosion large bodies of this schist were carried away, and carbonated surface waters probably broke down the iron minerals into iron carbonate or other soluble iron salts. This material was carried downward in solution along the impervious limestone foot wall, where it was precipitated by oxygen-bearing waters descending more directly from the surface through cross faults or other passages of free water circulation.

AGE OF DEPOSITS.

These lenses of ore were evidently formed after the pre-Cambrian rocks had been subjected to the synclinal folding, which has already been described. This is shown by the fact that the position of the ore deposits depends closely upon rock structure. As to the relative age of the granite intrusion and the ore deposition certain evidence is lacking, although it is believed that the ore was deposited after the granite was intruded. This much, at least, is certain that in the ore deposits there are zones of brecciated quartz, which were probably once pegmatitic veins cutting schist that is now replaced by ore. It is also certain that in the main the ore was formed prior to the deposition of the Guernsey formation, since this Carboniferous terrane locally contains at its base pebbles of hard ore similar to that of the Sunrise deposit. To provide water circulation adequate for the deposition of bodies of iron ore that lay so deep the topography at the time of their formation must have had sufficient relief to cause deep circulation of surface waters. In consequence it is probable that the ore was deposited long before the production of the peneplain, which preceded the deposition of the Guernsey formation. After the iron ore was deposited, surface waters modified the deposit, forming considerable bodies of soft ore along planes of maximum circulation, a like effect being produced by movement along shear zones. Further, limonite has been formed along some of the water channels of the past and the present day.

RULES FOR PROSPECTING AND GROUND FAVORABLE FOR PROSPECTING.

The restriction of the important ore bodies of the Hartville iron range to a single contact has already been mentioned and the extension of this contact has been described. In prospecting it the diamond-drill holes should be located in the schist area at a distance of from 400 to 600 feet from the foot wall of limestone. Where the contact is covered by alluvium, as it is from Ironton to Kline's ranch, it will be necessary by churn or diamond drill to more accurately locate this contact. Drill data indicating the presence of minor folds should be carefully sought, for ore will probably be found in minor synclines. Whether this portion of the contact will prove as rich as that which has already been prospected may be questioned, but ore bodies probably exist within this new prospecting ground. The proximity of the detrital Carboniferous ore bodies, later to be described, is a further help in prospecting, since they are apparently confined to the immediate vicinity of iron-ore lenses in the pre-Cambrian rocks. The dial compass and dip needle are valueless for use in this iron-ore range, since considerable bodies of the iron ore are nonmagnetic, while some of the noniron-bearing formations, such as the gabbro, affect the needles appreciably.

The conditions that determine the presence of iron ore along the contact already described appear to be (1) the folding to which the rocks have been subjected and (2) the presence of a thick body of schist—to serve as a source of the ore—superimposed upon an impervious body of limestone. The schist-limestone contacts throughout the range are similar to this one as regards the folding. In most places, however, the schist above the limestone is too thin to be the source of large ore bodies. The only probable exception to this statement is the contact between the schist and limestone in the west half of sec. 26 and the east half of sec. 27, T. 27 N., R. 66 W. Along this contact north of the furnace at Fairbank there is a hill of pre-Cambrian limestone. North of this hill is a wide valley, beyond which pre-Cambrian muscovitic schist is exposed. This schist is very thick, and beneath it the limestone dips northward at an angle of 70°. It is believed that this contact, which is hidden in the valley, is worth careful prospecting. Farther north of east, in sec. 26, hornblendic schists cut out the muscovitic schist. The large body of detrital ore at the base of the Guernsey formation, 1,850 feet south and 525 feet west of the northeast corner of sec. 26, may have been derived from some pre-Cambrian ore lens along this contact.

DETRITAL ORES AT THE BASE OF THE GUERNSEY FORMATION.

The basal bed of the Guernsey formation, which is at many places iron stained, is a quartzite or a limestone containing clastic grains. When conglomeratic the pebbles ordinarily consist of quartz, but locally of iron ore. The iron-ore pebbles are usually confined to the immedate vicinity of known deposits of pre-Cambrian iron ore. The pebbles are well rounded, many of them being beautifully polished, and reach a maximum diameter of 1 foot. The ore is typically the hard gray ore, which in some places has been altered to soft ore. Where such iron-ore pebbles with the associated iron-stained quartzite lie in the irregular sink holes and cave galleries that extend into the pre-Cambrian limestone (see p. 195), the ore has in many places been considerably recrystallized. Each sink hole, when partially cut away by erosion, has acted as an impervious trough, in which iron has been concentrated by downward circulating waters. In consequence the quartzite is wholly or partially replaced by red hematite, which is often of excellent grade. In places the detrital iron-ore pebbles are intact; in others they have been completely destroyed by recrystallization. Calcite, quartz, chalcedony, siderite, and copper ore are at many places closely associated with this hematite and ordinarily fill fractures in it. So far as known, none of these deposits are of large size, and as a rule the ore is too siliceous to be of economic value.

DEPOSITS AT THE BASE OF THE HARTVILLE.

The base of the Hartville formation is an iron-stained sandstone which at a few places contains small pebbles of iron ore. The material of these pebbles was directly or indirectly derived from pre-Cambrian ore bodies through the breaking up of the detrital pebbles of the Guernsey formation. North and west of Hartville the base of the Hartville formation at a number of places is an iron-stained shale, upon which lies the typical Hartville sandstone. Where this shale has been folded into gentle synclines the iron of the sandstone has been redeposited upon the shale, and in consequence blanket beds of low-grade hematite mark this horizon. Ore bodies of this class will probably never be of economic importance.

RESIDUAL AND PLACER ORE.

In the early days of mining at Sunrise the surface was covered by bowlders of iron ore which were derived from the breaking down of the pre-Cambrian iron-ore body at that point. Although large amounts of this ore have been shipped, iron-ore float even now occurs throughout the productive portions of the iron range.

Pebbles of iron ore are found in the bed of Platte River some distance below the town of Guernsey. At Guernsey they are 1 inch or less in diameter and increase gradually in size upstream. The pebbles do not occur in the Platte above the mouth of Hartville Canyon, but are found in the canyon as far up as Sunrise.

IRON IN OTHER PRE-CAMBRIAN ROCKS.

The jasper of the second pre-Cambrian series contains at many places some hematite and limonite. Veins of hematite occurring in fractures cut it and irregular masses of hematite cement its brecciated fragments. The jasper itself is also more or less replaced by hematite and limonite, but no considerable body of ore has yet been discovered in it, and most of the ore found in it is probably too siliceous to be of value. South of Shaws Pass a peculiar metamorphosed type of the pre-Cambrian schist, containing a large amount of amphibole, is heavily iron stained. The matrix of the conglomeratic phase of the second pre-Cambrian series contains at many places considerable iron, but none of the prospects in such rocks have yet proved valuable.

DEPOSITS ALONG THE FAULT CONTACT OF THE PRE-CAMBRIAN AND THE GUERNSEY LIMESTONE.

Along a line beginning approximately one-half mile north of Guernsey and extending eastward across low hills to Whalen Canyon, the Guernsey formation and the pre-Cambrian rocks are in fault contact. The downthrown side of this fault is to the south and appears to have been dropped more than 200 feet. The fault plane is everywhere iron stained and a number of prospects are situated along it. Three shafts in the south-central portion of sec. 25, T. 27 N., R. 66 W., owned by Mr. C. A. Guernsey, are within 100 feet of one another. The northern or hanging wall of the ore body is smooth, and the contact between the ore and the pre-Cambrian limestone is sharp. Farther south the ore passes gradually into iron-stained Guernsey limestone. The iron ore lens, consisting of good soft and hard grades, is from 2 to 6 feet wide upon the surface, and widens somewhat toward the west. At the bottom of the shafts, which range in depth from 24 to 60 feet, the lens is somewhat wider and apparently increases in thickness with depth. One-quarter of a mile west of this locality several shafts and tunnels develop other ore bodies in breccia zones within the pre-Cambrian limestone, parallel to this fault. The ore here is a black pulverulent hematite containing considerable calcite and siderite. The appearance of the ore indicates that it contains manganese. Not enough development work has been done upon the ore bodies of this fault plane to determine satisfactorily either their commercial possibilities or their mode of origin. It is certain that prospect work should be confined to the fault contact between the two formations. These iron-ore lenses were deposited by water which circulated along the fault plane. It is unknown whether the water which formed the iron ore ascended or descended along this plane, although the close resemblance of the ore to much of that of the pre-Cambrian type indicates that the lenses were deposited by descending waters. In this connection, however, the apparent thickening of the ore bodies in depth should be borne in mind.

GOSSAN DEPOSITS.

In the Haystack Mountains, particularly in McCanns Pass, comparatively large areas are covered by a low-grade hematite, with which is associated some limonite. These minerals cement irregular fragments of schist. Here and there small amounts of iron pyrites occur and the deposit is in every way similar to the surface croppings of some of the copper deposits of the district. There is little doubt that this deposit is the gossan or iron hat of a sulphide vein. The mechanical impurities in the ore are so finely divided that its quality can not be bettered by hand picking, and sulphur is present as a chemical detriment.