COPPER.

COPPER DEPOSITS OF THE HARTVILLE UPLIFT, WYOMING.

By Sydney H. Ball.

INTRODUCTION.

While investigating the iron ores and pre-Cambrian geology of the Hartville iron range, Wyoming, in the field season of 1906, the writer visited the copper mines and prospects of this region with the exception of those in Muskrat Canyon. The following notes are the result of this work. Grateful acknowledgments are due to the mining men of the district, particularly to Messrs. Louis B. Weed, of Sunrise; C. A. Guernsey and W. T. Kelley, of Guernsey; Peter Hoyer, of Hartville; William Lauck and Joseph L. Stein, of Frederick; and Edwin Hall and Henry Metz, of Lusk.

The scant literature concerning these copper deposits is included in the following bibliography:

Mineral Resources U. S., 1882, U. S. Geol. Survey, 1883, pp. 229, 758–759.

Idem for 1883–84, p. 342.

Idem for 1887, p. 76.

Idem for 1888, p. 59.

Ricketts, Louis D., Ann. Rept. Territorial Geologist to Governor of Wyoming, January, 1888.

Idem for 1890, pp. 52–55, 77–78.

Knight, Wilbur C., Bull. Wyoming Exper. Sta. (Laramie, Wyo.) No. 14, Univ. Wyoming, October, 1893, pp. 135, 210.

Smith, W. S. Tangier, Hartville folio: Geologic Atlas U. S., folio 91, U. S. Geol. Survey, 1903.

The geography and the geology of the Hartville uplift are treated briefly in the article in this bulletin on the Hartville iron range (pp. 190–205). The geologic column consists of the following pre-Cambrian formations: A schist-limestone series, a quartzose and jasper series, diorites and gabbros and schists derived from them, granite, and diabase. Flat-lying Carboniferous rocks overlie the pre-Cambrian rocks. Of the two Carboniferous formations the Guernsey is the older and the Hartville lies upon it.

HISTORY AND PRODUCTION.

In 1878 John Fields, keeper of a stage station 14 miles north of Fort Laramie on the Black Hills and Cheyenne stage line, found copper ore piled beside a tunnel 1½ miles north of Frederick. Old trails, well worn, led up to the tunnel, and this may have been the work either of French trappers or of prehistoric races in search of the brilliantly colored chrysocolla. In 1879 the blanket vein of the Silver Cliff mine was discovered by John Madden, and two years later the Green Mountain Boy and the Sunrise deposits were discovered by Henry T. Miller, of Hartville. These mines and some of those of Muskrat Canyon were more or less actively exploited in 1881 and 1882, 75 miners having been employed at one time in the Sunrise mine. The more or less complete exhaustion of the copper deposits and the drop in copper prices, together with the great expense entailed in hauling ore and machinery to and from Cheyenne—distant 120 miles from the nearest mines—all contributed to their shut down. In 1888 the Sunrise mine was reworked for a few months. Later developments include the finding by Henry Metz of the Green Hope deposit in 1901, and the formation by Edwin Hall of the Copper Belt Mines Company at Rawhide Butte in 1906.

The production as given by Knight [a] is as follows:

Production of copper mines near Hartville, Wyo.

Sunrise mine	$209,282
Michigan mine (Muskrat Canyon)	40,000
Green Mountain Boy	30,000
	279,282

The estimate here given for the Green Mountain Boy is certainly $25,000, and probably $30,000, too low, which, together with the product of a number of smaller mines and prospects, would raise the total to $350,000.

ORE DEPOSITS.

GENERAL DESCRIPTION.

Geographically, copper is widely distributed in the Hartville uplift, and there is scarcely a square mile underlain by pre-Cambrian and Guernsey formations which does not contain copper showings. (See fig. 5, p. 192, for location of principal mines.) No very large mine has ever been discovered within the confines of the uplift, but copper is so widely distributed that the possibility of finding a mine or mines of some size is by no means unlikely.

[a] Bull. Wyoming Exper. Sta. No. 14, 1893, p. 135.

The copper deposits of the Hartville uplift are in the form of (1) fissure veins, (2) lenticular or globular masses of ore outcropping at the surface and pinching out at slight depths, and (3) blanket or bedded deposits at the base of the Guernsey formation. It is admitted that development on the supposed fissure veins has not advanced sufficiently to determine their character beyond all doubt.

Malachite, chrysocolla, and chalcocite are much the most important ores. Of less common occurrence are tennantite (?), native copper, azurite, bornite, covellite, cuprite,[a] and chalcopyrite. Closely associated with the normal green chrysocolla, and evidently contemporaneous with it, is a soft dark-brown substance. W. T. Schaller found this to contain iron, copper, silica, and water, and it is probably chrysocolla with considerable iron as an impurity. A yellowish-green mineral fills fractures at several prospects. This is, according to W. F. Hillebrand, a copper arsenate. Chalcocite in particular as a rule carries some silver, and native silver occurs at the Silver Cliff mine. Gold values are reported from iron-stained schist closely associated with the copper ores in several places. The gangue minerals, in the main of later origin, include quartz, calcite, chalcedony, selenite, and barite.

Copper ores occur in the pre-Cambrian rocks and in the Guernsey formation. No ore body has yet been found in the Hartville formation or in the rocks overlying it. A possible exception is the presence of slight malachite stains on blocks of Hartville sandstone in the talus overlying a copper deposit in Guernsey limestone in the center of the NE. $\frac{1}{4}$ sec. 36, T. 27 N., R. 66 W. This malachite stain is, however, superficial and was probably deposited after the block became a part of the talus. In consequence, in prospecting for copper, work should be confined to the area delineated on the geologic map in the Hartville folio[b] as being underlain by either pre-Cambrian or Guernsey formations.

The more important copper deposits were probably deposited by descending waters and have no apparent connection with igneous rocks nor, except in one place, with fault planes. The Guernsey formation, or some other which originally overlay it and which prior to the deposition of the Hartville formation was removed by erosion, was probably the original source of the ore of the larger deposits. The copper was probably included as a chemical or mechanical impurity in the Guernsey formation. Such a view necessitates the former existence of pre-Carboniferous copper deposits in the area from which the Guernsey formation was derived. Possible examples of such deposits are described as fissure veins in the following section.

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[a] Mineral Resources U. S., 1882, U. S. Geol. Survey, 1883, p. 758.
[b] Geologic Atlas U. S., folio 91, U. S. Geol. Survey, 1903.

FISSURE VEINS IN PRE-CAMBRIAN FORMATIONS.

The Copper Bottom prospect, owned by Henry Metz and situated in the south-central part of the SE. ¼ sec. 23, T. 29 N., R. 65 W., is located probably on a fissure vein. At the time of the writer's visit the shaft was 15 feet deep. The country rock is a slightly silicified dense yellowish limestone of pre-Cambrian age, which is cut by thin seams of hematite. The vertical vein, which strikes N. 20° W., cuts across the steeply dipping limestone. There is a fault of small throw on the east side of the vein, and fragments of limestone are included in the vein matter. On the east side of the shaft the vein is 4 inches wide at the surface and 22 inches at the bottom of the shaft; on the west side the vein comes in 3 feet from the bottom and there only as a thin stringer. The limestone for a distance of 1 foot on either side of the vein is heavily iron stained. An assay of an average sample collected by the writer across the vein on the east side of the shaft, 15 feet from the bottom, contained a trace of gold, 2 ounces per ton of silver, and 24.64 per cent of copper. The predominant ore is the brownish form of chrysocolla, blotched with irregular masses of green chrysocolla in the center of which is some malachite and rarely a little azurite. Tennantite [a] occurs in irregular masses up to 1 foot in length. Although chrysocolla is on the whole slightly older than malachite and the latter older than azurite, these ores with tennantite are approximately of the same age. Incrusting tiny cavities in this ore is some quartz, which in turn is coated with younger calcite. Clearly later than these ores and gangues and occurring in cracks in them are knife-edges of malachite, azurite, and a black sooty copper oxide or sulphide. The thickening with depth, together with its position along a fault, lead to the belief that this deposit is the oxidized portion of a fissure vein. The apparent thickening with depth may, however, be local.

The Charter Oak prospects, owned by Lauck & Stein, are situated on the south side of McCanns Pass, near the center of the SE. ¼ sec. 26, T. 27 N., R. 65 W. The deposits lie beneath apparent gossans of limonite and hematite, in pre-Cambrian muscovite schist and gray quartzose beds. Malachite, chrysocolla, and chalcocite occur in fractures, in one place within a cupriferous belt 4 feet wide and in another place along a vein 4 feet wide cutting across the vertical schist. The schist near the copper is said to assay from 80 cents to $27 in gold and 2 to 5 ounces of silver. The amount of development at this point is small, but these deposits have the appearance of being the oxidized zone of a copper vein.

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[a] W. T. Schaller states concerning specimens submitted to him: "Both samples contain the constituents of, and probably are, tennantite."

At several places near Haystack Peak, copper minerals fill tiny fractures or incrust cavities in pegmatite or pegmatitic quartz dikes. Chalcopyrite and chalcocite are original and malachite and covellite are their alteration products. Sulphides are rather abundantly present in the center of the NE. ¼ sec. 26, T. 27 N., R. 65 W., as cement to a breccia of schist. A sample collected at one of these prospect shafts, on the dump, which at the time of examination was boarded over, gave a trace of silver, but no gold, copper, or nickel.

LENSES OF COPPER ORE DEPOSITED BY DESCENDING WATERS.

The most common copper deposits in the Hartville uplift are lenticular or wedge-shaped masses of carbonates, silicates, and oxides and secondary sulphides which narrow with depth and finally disappear. These deposits, which occur in the Guernsey and several of the pre-Cambrian formations, are believed to have been laid down by descending waters, the ore presumably having been leached from the Guernsey or from some formation that was once superimposed upon it, but was removed by erosion prior to the deposition of the Hartville formation.

Lenses in the Guernsey formation.—Copper deposits in the Guernsey formation are practically confined to the immediate vicinity of Guernsey, the only deposit of consequence being that of the Green Mountain Boy.

The Green Mountain Boy mine is situated approximately half a mile east of the town of Guernsey, at the head of a broad valley. The production has been variously estimated at 300 to 500 tons, valued at $36,000 to $60,000. The ore is said to have averaged 37 per cent copper, with from one-third to one-half ounce of silver to each per cent or unit of copper, the total values averaging at the time of shipment $155 per ton. The silver, which was closely associated with chalcocite, was patchy in distribution, some assays of high value having been obtained.

The country rock is the upper part of the light-gray or white horizontal Guernsey limestone which at the horizon of the main workings contains many lenticular masses of brown flint. The flint nodules are from 2 inches to 4 feet long, and from one-half inch to 6 inches wide. Calcite-lined cavities 2 to 3 feet long occur in the limestone. The original lens was of chalcocite and is stated to have been 60 feet long, 30 feet wide, and from 5 to 9 feet thick. The long diameter of this podlike mass lay east and west across the valley. At the surface considerable malachite was associated with the chalcocite, but as the lens was followed into the hill malachite decreased in amount. The open cut and the three tunnels from it now open to inspection show but little ore, and the tunnels are barren 30 feet southwest of their entries. Twenty feet immediately beneath the ore lens a tunnel was driven 50 feet, and this, with the exception of a few small stringers of ore, is also barren.

The copper ores now seen here occur in three ways—as replacements of flint nodules, in veinlets, and as patchy malachite stains in the limestone. Chrysocolla, less commonly malachite, and still more rarely chalcocite replace the flint nodules. The three ores are contemporaneous. In a number of places the exterior of the flint is unaltered, the replacement having begun at the center. As seen under the microscope the copper minerals invade the chalcedonic quartz as irregular ramifying bodies with rounded ends, resembling the fronds of a maidenhair fern. The predominance of the replacement of flint by chrysocolla (a copper silicate) is probably due to the reaction of the siliceous flint on the copper-bearing solutions, as is the predominance of chrysocolla over malachite in copper lenses in pre-Cambrian schist. Since replacement the flint nodules have been cracked, and along these fractures are films of malachite. Fractures filled with veinlets of malachite and chrysocolla are common on the sides of the open cut and near the mouths of the tunnels. These stringers were evidently leached by descending waters from the main ore body or from the replaced flint nodules.

The ore body of the Green Mountain Boy was distinctly limited below, and scarcely a copper stain is visible 20 feet beneath the bottom of the canoe-shaped mass of chalcocite. The copper ores were evidently deposited by descending water, the mass leached probably having been the upper portion of the Guernsey formation. The ore body was largely a replacement deposit, in part of limestone and in part of flint. Since the original deposition the ore body has been fractured and surface waters have filled the fractures with malachite and chrysocolla.

Lenses in pre-Cambrian limestone.—The most widely distributed form of copper deposit in the Hartville uplift occurs in pre-Cambrian limestone, as a rule within less than 50 feet of the base of the overlying Guernsey formation. The deposits, in places at least, give out within 20 feet of the surface.

The ore occurs in veinlets along bedding planes, many of which are planes of differential movement, accompanied by brecciation; in veinlets along joint faces; and as replacements of limestone. Malachite predominates over green chrysocolla; and azurite, brown chrysocolla, chalcocite, and yellowish-green arsenate also occur locally. Mr. Peter Hoyer, of Hartville, reports that a canoe of chalcocite 12 to 14 feet long, 1½ feet wide, and 1 to 2 feet thick was encountered at the surface at the Empire mine, half a mile southwest of Sunrise. Quartz and calcite are the chief gangue minerals, and the gangue material is in many places either an iron-stained limestone or hematite. The veinlets of ore do not extend beyond these iron-rich substances in so many places that the natural inference is that the iron acted as the precipitant. Under the microscope a thin section of this ore shows that the copper ores occur as veinlets cutting the hematite and limestone and rim the hematite as if it had acted as the precipitant. Limonite is contemporaneous with the copper minerals. Since the hematite is locally the iron-rich base of the Guernsey formation recrystallized, extending down into joints in the limestone enlarged by solution, it is possible that the ore is all of post-Carboniferous age. The lenses of copper ore in pre-Cambrian limestone are certainly in some places and probably everywhere post-Carboniferous in age, and were formed by descending waters, the probable source of the copper having been the Guernsey formation.

Lenses in schist and other pre-Cambrian formations.—Similar lenses of ore with definite downward limitations occur in pre-Cambrian schist, quartzose, and jaspery rocks and in the chloritic schist derived through mashing from basic igneous rocks. In schist the ores, chrysocolla, and malachite, and in some places chalcocite and azurite, occur as thin sheets in the planes of schistosity and in small cross fractures. Microscopic examination also shows, in addition to innumerable tiny fractures filled with malachite, some replacement of quartz by malachite. At some places these deposits decrease in width with depth and at others they extend downward from blanket deposits of the Guernsey sandstone. The majority of them, at least, are thought to have been formed by descending waters, and the source of many was probably the Guernsey formation. Since the gray quartzose rocks and the jasper are very brittle, the ramifications of the copper veinlets through them are most complex.

Lenses in iron ore and heavily iron-stained jasper.—The most important example of the lenses in iron ore and jasper is the Sunrise mine, now the most productive iron mine west of the Mississippi, but in the eighties an important copper mine. It is situated on the southward-facing slope of a steep hill in the north-central portion of sec. 7, T. 27 N., R. 65 W. Its total copper output is given by Knight as 1,395,287 pounds, valued at $209,282. The copper content ranged from 6 to 20 per cent, with an average yield of 15 per cent. Knight states further that the ore carried from 2 to 3 ounces of silver per ton. The slag from the Fairbank furnace, where the ore was smelted, is now being shipped to smelters by C. A. Guernsey, of Guernsey, who states that it averages 5 or 6 per cent of copper. Malachite, leached from the slag since the shut-down of the furnace, occurs upon the surface and in the cavities of the slag fragments.

The country rock of the copper ore at Sunrise is schist, iron ore (hematite), and an impure flint which is stained by either limonite or hematite and which is evidently a relatively shallow alteration product of the schist, formed in pre-Carboniferous time.

The copper workings of the Sunrise mine have largely been cut away or rendered inaccessible by the Sunrise open cut, and at present but small portions of the ore body are open to investigation. Concerning the form of the deposit, Ricketts states[a] that it lies in lenticular bodies which expand and contract irregularly, in gashes, and in pear-shaped bodies, one of which was over 30 feet in height and 20 feet in diameter. These were irregularly distributed through the country rock. He also writes: "A stringer of ore was followed farther up the hill and led up vertically through the hematite to the overlying [Guernsey] limestone cap, where the hematite ceased. The copper, however, could be followed up as a stringer along jointing planes of the limestone and led to several small bodies of ore spread out parallel to bedding planes. A very interesting specimen from this horizon was a piece of copper ore with numerous pieces of Carboniferous fossils impressed on one side of it."[b] As seen in cross section on the side of the Sunrise open cut, the copper ores stop 60 feet below the former surface and no trace of copper is seen in any of the workings on the first, second, or third levels of the iron mine, although these completely undermine the ground beneath the deposit.

Within these lenticular or pear-shaped bodies the copper ores occur as ramifying veinlets and masses occupying joint and irregular fractures and cavities in the country rock. The copper ore is especially abundant in the more heavily iron-stained portions of the flint and in hematite. The ores, named in the order of their importance, are chrysocolla, malachite, chalcocite, azurite, and native copper. Ricketts states that copper oxides were present in considerable amounts. Malachite is finely granular, although in cavities it forms tufted aggregates of acicular crystals or mammillary masses of radiate structure. The glassy green or brown chrysocolla in cavities is botryoidal. Chalcocite, chrysocolla, and malachite are practically contemporaneous, the last two in particular replacing each other along the length of the veinlets. Azurite, which is especially characteristic of the immediate surface, is on the whole somewhat younger than the others, although in places contemporaneous with them.

Quartz and calcite and more rarely chalcedony, selenite, and barite occur as gangues. In general quartz is younger than the copper minerals, and either incrusts them in vugs or cuts them in veinlets. The quartz, though as a rule white, is in places stained green by copper salts. Many crystals of white or lemon-yellow calcite coat the quartz and are hence younger. The colorless gypsum called selenite is also younger than the ores, although in a few places it incloses fibers

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[a] Ann. Rept. Territorial Geologist to Governor of Wyoming, 1888, p. 66.
[b] Idem, p. 66.

of malachite. George Botsford, of Sunrise, reports that he has observed barite crystals covering the copper ores. During the deposition of these ores there was probably some slight recrystallization of hematite, since between fractures containing copper minerals the hematite is softer and of slightly coarser grain than that farther from the copper.

Two thin sections of copper ore in hematite were examined under the microscope. In each, malachite and chrysocolla fill fractures most intricately cutting the hematite, and in each the copper minerals partly replace hematite.

Field evidence in the Hartville uplift appears to show that hematite has been an important precipitant of copper. In addition to the phenomena at the Sunrise mine, the copper is intimately associated with an older, heavily hematized gangue in the pre-Cambrian limestones, and the bedded deposits at the base of the Guernsey formation are confined largely to heavily hematized portions of the sandstone.

The association of copper ores and hematite is not extraordinary, but deposits in which hematite is the country rock and is older than the copper ore are unusual. At the Soudan[a] and Chandler[b] mines, on the Vermilion Range in Minnesota, native copper and various carbonates and oxides secondary to it occur in fracture zones in iron ore. Hobbs refers the precipitation of the copper to the oxidation of ferrous iron compounds. Haworth[c] reports films of native copper in fractures in "Red Beds" at Enid, Okla., which are rich in hematite. He believes that the soluble salts of copper were reduced to oxides by the hematite and that the ferrous sulphate which formed, in the presence of free sulphuric acid, reduced the copper oxides to the native state. At the Sunrise mine ferrous salts might have been formed from hematite itself and by their oxidation precipitated the copper minerals.

In the Sunrise mine lenticular or pear-shaped masses of copper ore were deposited not only after the iron ores had been formed, but also after they had been fractured, the copper deposition having occurred in post-Guernsey time. The distinct termination of the ore with depth may indicate that it was deposited by descending waters, and since copper ore extends upward into the Guernsey formation that formation was presumably the original source.

The old Village Belle copper mine, now a part of the Sunrise mine, appears to have been of similar character, although native copper is said to have been rather common.

[a] Eby, J. H., and Berkey, C. P., Proc. Lake Superior Min. Inst., vol. 4, 1896, pp. 69-79. Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey, vol. 5, 1900, p. 885. Clements, J. M., Mon. U. S. Geol. Survey, vol. 45, 1903, pp. 113, 189. Hobbs, W. H., Am. Geologist, vol. 36, 1905, p. 185.

[b] Clements, J. M., Mon. U. S. Geol. Survey, vol. 45, 1903, p. 184.

[c] Haworth, E., Bull. Geol. Soc. America, vol. 12, 1900, pp. 2-4.

BLANKET DEPOSITS AT THE BASE OF THE GUERNSEY FORMATION.

Characteristics.—Copper ores are segregated in the sandstone at the base of the Guernsey formation at a number of places in the Hartville uplift. Malachite and chrysocolla and less constantly azurite and chalcocite are the more common ores, although native copper, silver, and copper arsenate also occur. Shipments of picked ore have averaged over 17 per cent of copper, and either gold or silver values are present in much of the ore. These ores occur as lenticular or tabular masses in the sandstone, where the copper minerals may form the cementing material of the sandstone. They also fill joint cracks and irregular fractures or form nodules. The ore bodies are in most places unconnected with fissures and nowhere with igneous rocks. No igneous rocks other than those of pre-Cambrian age are known in the Hartville uplift. The greatest dimension of these tabular ore bodies is horizontal, and they do not extend into the overlying limestone member of the Guernsey formation. In many places stringers of ore descend into the pre-Cambrian schist or limestone, which underlies the Guernsey formation unconformably, and at least in most of such stringers this ore has been leached from the blanket deposits. The bedded ore body is in general but 2 or 3 feet thick, although where it lies upon pre-Cambrian limestone the ore in the ramifying sandstone masses extending into the irregularities of the pre-Cambrian limestone is locally 20 feet thick. At the bottom of such pockets and small sink holes the ore has been concentrated against the limestone, forming local enrichments. As a rule the lateral extent of these deposits is small, although some of them are considerably over 100 feet in diameter.

In prospecting these deposits the lower limit of the flat-lying Guernsey formation immediately above the tilted pre-Cambrian limestones and schists should be followed. The geographic position of this line is shown on the geologic map of the Hartville quadrangle [a] by W. S. Tangier Smith and N. H. Darton. Iron-stained masses of the sandstone especially should be examined, since such portions are more favorable for copper ores. While no deposit of this class has yet proved to be of great size, the ore is cheaply mined by tunneling, and some of it can be worked at a profit.

As type examples of this form of deposit the Green Hope and Silver Cliff mines are described.

Green Hope mine.—The Green Hope mine is situated on the upper slope of a valley in the NW. ¼ sec. 26, T. 29 N., R. 65 W. Its product is variously estimated at 400 to 525 tons, carrying from 15 to 27 per cent and averaging 17 per cent of copper. The deposit has been exploited by two tunnels, from which three sinuous galleries extend.

[a] Geologic Atlas U. S., folio 91, U. S. Geol. Survey, 1903.

The base of the Guernsey formation is here a heavily iron-stained and slightly conglomeratic sandstone that is locally cemented with lime carbonate. The underlying pre-Cambrian limestone prior to the deposition of the Guernsey formation had a very uneven surface, roughened through the development by solution of enlarged joints, small sink holes, and irregular cave galleries. The ore-bearing sandstone, which is as a rule but 3 feet thick, extends down into these cavities, some of which are 20 feet below the normal contact of the Guernsey and pre-Cambrian formations. The complexity of the ramifications of such masses of copper-bearing sandstone is indicated by the fact that they are in places separated from one another by masses of pre-Cambrian limestone on the sides of the workings. Ore does not extend from the sandstone into the limestone member of the Guernsey formation. The mineralized zone is exposed for 150 feet along the valley side.

Malachite, chrysocolla, azurite, and chalcocite form the cement of the sandstone. The vividly colored copper-stained sandstone alternates sharply with patches of unstained pink or gray sandstone. The same minerals, together with the yellowish-green copper arsenate already mentioned, fill fractures in the copper-stained and unstained sandstone, forming veinlets and nodules of ore. Chalcocite is particularly common in this form. Some of these nodules fill cavities once occupied by pebbles of pre-Cambrian limestone which have been removed by solution. Where the cavities have not been completely filled by the ore, malachite forms tufted crystal aggregates, whereas chrysocolla occurs as botryoidal masses. White or yellowish calcite, of later origin than the copper minerals, incrusts them, and in many places films of bluish-white chalcedony cover the calcite. Although these gangue minerals are clearly of later origin than most of the ore, here and there a little malachite coats the chalcedony, indicating that the ore was undergoing recrystallization during a considerable period of time.

Malachite, chrysocolla, and azurite have been leached from this blanket deposit down into the pre-Cambrian limestones as irregular stains and as stringers descending from the blanket deposit.

Two thin sections of ore from the Green Hope mine were examined microscopically. One is a well-assorted quartzose sandstone in which the half stained by copper is separated with line-like sharpness from that stained by limonite. The portion of the rock without copper has as a cement finely divided kaolinitic matter, with probably a little sericite. In the other portion this kaolinitic substance is replaced by malachite either in a very finely divided and almost flocculent condition or in fibrous aggregates, the fibers of some of which are radially arranged. In one or two places malachite enters the quartz grains in blunted embayments and probably replaces it.

In the second thin section chalcocite as well as malachite forms the cement. Further, both minerals fill many fractures in the quartz grains. The areas of the copper minerals in the sandstone are so large and many of the quartz grains have been so greatly eaten into by malachite and chalcocite that it is evident that both copper minerals have replaced the quartz to an important extent.

Silver Cliff mine.—The Silver Cliff mine is three-fourths of a mile southwest of Lusk, the deposit crossing low hills in a southerly direction. Ore from this mine is reported to have assayed as high as $150 per ton in silver and copper. The pre-Cambrian formation here is a steeply dipping muscovite schist interbedded with thin lenses of limy schist. The flat-lying Guernsey formation above it is dropped down by a fault on the west side against the pre-Cambrian. This fault courses S. 10° W. and has a displacement of 20 feet.

The pre-Cambrian schist along this fault contains malachite, chrysocolla, and chalcocite, and a few leaves of native silver occur on fracture planes in the schist. The exposures are not sufficient to determine definitely whether this is a pre-Cambrian vein, whether the ore in the pre-Cambrian rocks was leached from the overlying Guernsey formation, or whether the copper ores in both pre-Cambrian and Carboniferous terranes were deposited by waters ascending along the fault plane.

In the iron-stained sandstone at the base of the Guernsey formation along the fault line is a blanket of copper ore from 20 to 40 feet wide, 2 to 5 feet thick, and several hundred feet long. In mineralogical composition the ore is in all essential particulars similar to that of the Green Hope mine previously described, except that native copper is reported to occur near the surface. A thin section of the Guernsey ore shows that limonite, malachite, and chalcocite replace the matrix of the sandstone, which is kaolinitic material and calcite. Kaolinized grains of feldspar are likewise heavily stained by malachite that apparently replaces the kaolinitic material. The copper minerals also replace quartz and occur in fractures in the quartz grains.

Origin of deposits.—In considering the origin of these blanket deposits the following facts must be taken into account: First, they lie upon an impervious stratum, and, with the exception of the Silver Cliff deposit, have a definite downward limit; second, the ores are mineralogically like those of the Sunrise and Green Mountain Boy mines, which are known to be deposited by descending waters; third, the deposits are, with the exception of that at the Silver Cliff mine, unconnected with fractures; fourth, they occur in a formation which is younger than any known igneous rock in the Hartville uplift; and fifth, in many places they are associated with and structurally resemble recrystallized detrital iron ores which occur at the base of the Guernsey formation and which have been derived from the mechanical breaking down of pre-Cambrian iron-ore bodies. (See pp. 194–195.)

The deposits were not laid down in the sea in the form in which they now exist. This is shown by the fact that they are not evenly distributed at the base of the Guernsey formation, as well as by the straight-lined contacts between copper-stained masses and those that are unstained by it and by the occurrence of the copper minerals as veinlets in fractures. It is believed, however, that the blanket deposits were segregated by descending and laterally moving waters from copper that was widely distributed in the Guernsey formation. This copper, presumably derived originally from fissure veins in the pre-Cambrian rocks, was probably included in the Guernsey deposits as either a mechanical or a chemical impurity at the time that formation was laid down beneath the sea. As Emmons[a] suggests, clays may have precipitated the copper from the sea waters, exercising the peculiar selective property called adsorption by Kohler.[b] That kaolinitic substances have acted as powerful agents in the recrystallization of the ores is shown by the replacement of the kaolinitic material both in the cement of the sandstone and in the feldspars. From analogy with the iron deposits at the base of the Guernsey formation (see pp. 198, 203), it is probable that, had heavy fragments of copper ore formed a part of the sand of the Carboniferous sea, they would naturally be concentrated in the small sink holes characterizing the surface of the pre-Cambrian limestone. Fragmental copper ore is, however, not observed in any of the deposits. The deposit at Silver Cliff, as before stated, may be of different origin, and the copper here may have been deposited by water ascending along the fault.

THE COPPER BELT MINES COMPANY'S HOLDINGS.

For convenience the mines and prospects of the Copper Belt Mines Company will be described together. These properties, which are grouped around the corner common to sections 2, 3, 10, and 11, T. 30 N., R. 64 W., lie on rugged hills half a mile west of the highest peak of the Rawhide Buttes. The rocks in the vicinity are of pre-Cambrian age and comprise an interbedded series of limestones and schists, and a granite and its associated pegmatite intrusive in them, which are probably equivalents of the pre-Cambrian rocks near Hartville. The limestones are crystalline, fine to medium grained, and white. The schists are more thoroughly metamorphosed than those in the vicinity of Hartville. The folding of the series is in many places very close, and the strike of the formations is broadly from northeast to southwest.

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[a] Emmons, S. F., Bull. U. S. Geol. Survey No. 260, 1905, p. 232.

[b] Kohler, Ernest, Zeitschr. prakt. Geologie, February, 1901, pp. 44–59. See also Sullivan, Eugene, Economic Geology, vol. 1, 1905, pp. 67–73.

The Lucky Henry incline, 288 feet deep, has a hanging wall of limestone and a foot wall of iron-stained schist. The limestone, which dips 45° S. 50° E., is but 2 to 4 feet thick, and in front of it lies a second schist band. Since the dip varies somewhat in amount, the hanging wall leaves the incline at several points, and at such places drifts extend to it. The ore lies in the schist against the hanging wall in two lens-shaped masses separated from each other by barren schist. These lenses are from 1 to 6 feet thick and appear to continue downward from the surface to the bottom of the incline with a width of 15 feet or more, although there may be breaks in the ore where the foot wall is not exposed. Within the lenses the schist contains ramifying veinlets and stringers of malachite and chrysocolla, with a little chalcopyrite. Chalcopyrite first appears at 50 feet from the surface and continues to the bottom. Veinlets of later origin, which are filled with calcite or quartz, cut the ore stringers. Edwin Hall, the president of the company, states that the lenses run from 2 to 8 per cent of copper, and that the iron-stained schist around the lenses carries from $1 to $12 in gold per ton, with an average of $3, and from 2 to 5 ounces of silver per ton. The lower 10 feet of the incline is slightly moist and surface water now follows the schist hanging wall downward. Development has not proceeded far enough to determine beyond doubt how this deposit was formed. Ascending water may have been the agent. If this is true, the original sulphides have been largely changed to carbonates and silicates by surface waters, descending along the schist foot wall.

The Gold Hill and Omaha shafts are situated on a band of schist from 7 to 20 feet wide lying between two limestone beds. At the Gold Hill shaft the dip is 45° S. 40° E., and at the Omaha 42° S. 60° E., the schist band between the two describing an S. In the Gold Hill shaft the ore is in a cross vein bounded by fracture planes which dip 60° S. 75° W. This vein is 6 feet wide and beneath it is a 2-foot belt of iron-stained schist which is said to assay in gold $4 per ton. Malachite, chrysocolla, and a little chalcocite occur within the shoot in veinlets parallel to and cutting the schistosity. A quartz vein parallel to the schistosity is shattered and in its fractures are stringers and nodules of chalcocite and bornite, probably original sulphides. These are partially altered to chrysocolla, malachite, and azurite.

At the Omaha incline chrysocolla, malachite, azurite, chalcocite, and chalcopyrite occur in schist in stringers both parallel to the schistosity and cutting it. Barite is present as a gangue. The ore-bearing zone reaches a maximum width of 4 feet and Hall states that it assays 2 per cent copper, although by hand picking the contents could be raised to 4 per cent. The copper-bearing lens is exposed more or less continuously for 204 feet. The open cut on the Emma claim discloses a fracture zone in schists containing quartz lenses parallel to the schistosity in which malachite, green and brown chrysocolla, azurite, chalcocite, and chalcopyrite occur in cavities formed by the fracturing of the country rock. The ore carries from 3 to 30 per cent of copper, masses of chalcocite weighing 47 pounds having been found. Malachite, chrysocolla, and chalcocite occur in limestone on the Omaha, Emma, Lucky Henry, and Metz claims. These deposits are probably similar to those described under the heading "Lenses in pre-Cambrian limestone" (pp. 98–99).

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