RARE METALS.

NOTES ON THE VANADIUM DEPOSITS NEAR PLACERVILLE, COLORADO.

By Frank L. Hess.

INTRODUCTION.

Late in the nineties a dull-green sandstone in the steep valley walls near Placerville, Colo., was found to be vanadium-bearing, and

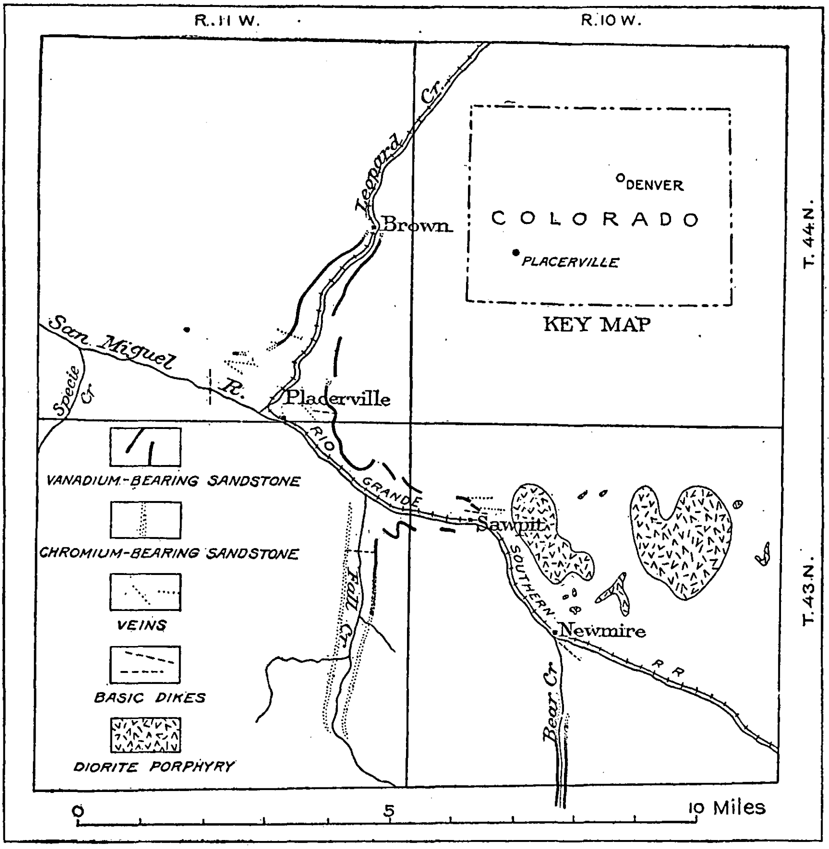

Figure 19.—Sketch map of the vanadium deposits near Placerville, Colo.

although its content of vanadium is low as expressed in percentage, the deposits have become of commercial value owing to the scarcity of sources from which vanadium can be obtained at a cost which will allow its profitable use in the arts and to the greatly increased demand caused by the use of vanadium in steel.

Placerville is located in San Miguel County, southwestern Colorado, at the western base of the Rocky Mountains. (See fig. 19.) It is on the east side of the deep, narrow valley of the San Miguel, which here has cut down to a depth of 1,500 to 2,000 feet below the mesa through which it runs. Sawpit is 4 miles and Newmire is 7 miles up the river (southeast) from Placerville. The Rio Grande Southern Railroad has a narrow-gage track following Leopard Creek and San Miguel River which furnishes passenger and freight connection with the centers of population and manufacture beyond the mountains.

In 1899, shortly after their discovery, the Placerville vanadium deposits were visited by F. L. Ransome, and descriptions of the geology and of the microscopical petrology of the deposits, to which were added chemical analyses and a discussion by W. F. Hillebrand on the composition of roscoelite, were published in 1900.[1] In 1905 this article was republished by the United States Geological Survey.[2]

In January, 1909, Herman Fleck and Sidney W. French[3] described the individual workings on the Placerville deposits and gave a large number of analyses for vanadium. In October of the same year Herman Fleck and William G. Haldane[4] published a short description of the vanadium-mining operations near Placerville with four pictures of the reduction plant at Newmire.

So far as is known to the present writer, practically nothing else has been written touching upon the economic geology of these deposits, but Whitman Cross and Chester W. Purington[5] have discussed the general geology of the Telluride quadrangle, which includes that part of the deposits which lies south and east of Sawpit. Although their work covered Newmire and Sawpit, it did not extend to Placerville. The notes on the stratigraphy given in this article are taken largely from Cross's descriptions.

No exhaustive study has yet been made of the deposits, and their origin and even the manner of deposition of the sandstone beds in which they occur have not been satisfactorily settled.

GENERAL GEOLOGY.

The country rocks are flat-bedded sediments, mostly sandy but including a few limy strata. Near the ore deposits the beds are cut by a few basic dikes and there is some faulting. The sediments as determined by Cross are of Jurassic and Triassic age and have been

[1] Am. Jour. Sci., 4th ser., vol. 10, 1900, pp. 120-144.
[2] Bull. U. S. Geol. Survey No. 262, 1905, pp. 10-21.
[3] Quart. Colorado School of Mines, January, 1909.
[4] Idem, October, 1899, pp. 7-11.
[5] Telluride folio (No. 57), Geol. Atlas U. S., U. S. Geol. Survey, 1899.

divided by him into three formations, of which the Dolores is the lowest, the La Plata sandstone the middle, and the McElmo the uppermost.

The Dolores formation consists of a series of sandstones, grits, conglomerates, and arkoses, mostly reddish, and forms the lower 500 to 800 feet of the walls of the San Miguel Valley near Placerville.

The La Plata consists of two light-colored sandstones with a thin limestone between. Through much of their extent both sandstones are thick, fine and even grained, showing no horizontal bedding, but in the particular area under consideration the upper member is in many places rather thin bedded. The limestone varies from point to point in thickness and in character and may be either thinly lenticular or blocky. It ranges in thickness from 1 to 10 feet.

The lower sandstone member of the La Plata is everywhere the vanadium-bearing rock, and although it has heretofore been treated as a single bed it is probably made up of two beds with an unconformity between them. In most places where vanadium occurs in the sandstone (and it was only at these points that the sandstone was carefully examined by the writer) the portion above the apparent unconformity is yellowish and that below is gray, almost white. The apparent unconformity in some places almost or quite reaches the base of the limestone and in other places is probably two-thirds of the way to the bottom of the sandstone. This part of the La Plata is probably between 35 and 60 feet thick where the vanadium deposits are found and in places is cross-bedded. Although generally very fine grained, locally it contains pebbles as large as small peas. Ordinarily the sandstone is cemented with calcite and is very friable.

The coarser-grained parts of the sandstone have in places rounded outlines, and the finer-grained sandstone when mined may peel from them like the skin of an orange. The peculiar distribution of the coarser sand, the presence of cross-bedding over thousands of square miles, and the evenness and thinness of the beds have made their origin very difficult to explain. To the writer these conditions suggest a body of water so broad and so shallow that winds could pile the water deeply in one part and leave practically dry areas of many square miles. The currents induced by the wind would distribute the sediments comparatively evenly and cross-bed them and would at times cut temporary channels and gouges, later to be filled with sands of varying size, depending on the intensity of the currents.

The structure, composition, and texture of the sandstone have been important in the deposition of the vanadium ore.

Dikes are not numerous, but several occupy prominent positions in relation to the vanadium deposits. One which crosses the mouth of Bear Creek (see fig. 19) is 4 or 5 feet thick and is conspicuous from the little hamlet of Newmire. It is described by Cross[1] as "a very

[1] Op. cit., p. 7.

simple normal basalt." Diabase dikes 3 to 6 feet thick cut the rocks adjacent to the vanadium deposit on the Golden Era claim, north of Sawpit, on Fall Creek, and east of Placerville. A vanadium deposit carrying some rich ore and showing considerable carnotite staining is closely adjacent to the dike near Sawpit. At Placerville, as exposed at the surface, the dike pinches a few feet below the vanadium deposit, and through the deposit the strike of the dike is marked by a fault accompanied by about 10 inches of porous silicified breccia, adjacent to which on the northwest the vanadium deposit is between 15 and 20 feet thick, though not rich, and contains many small irregular silicified bodies of sandstone. North of the point where the diabase dike crosses Fall Creek the vanadium deposits are richer than at any other known place along the creek. A monchiquite dike cuts the rocks on the north side of the San Miguel about 1½ miles below Placerville but is not near the present vanadium deposits. On Cross's geologic map of the district he shows a large laccolith of diorite porphyry about three-fourths of a mile east of San Miguel River, between Sawpit and Newmire, with its edge parallel to the river for nearly 2 miles. Opposite Bear Creek, north of Newmire, are several smaller outcrops of the same rock. The dikes and the diorite porphyry may be very closely related.

The known vanadium deposits of the Placerville region extend through a distance of a little more than 9 miles S. 20° E. from Brown, a Rio Grande Southern Railroad station on Leopard Creek[1] 4 miles above Placerville, to a point on Bear Creek 3 miles south of Newmire, crossing the San Miguel Valley with a long slant. (See fig. 19.) The deposits occur on both sides of Leopard Creek, extending with short interruptions to the valley of the river; thence they continue along the northeast wall of the river valley for a mile upstream, and beyond that less continuously to a point north of Sawpit. On the opposite or southwest side of the river no deposits of importance have been found below Fall Creek, but some occur on the east side of that stream, extending for a distance of about a mile above the mouth, and others are found on the south side of San Miguel River for a mile or more above Fall Creek. No other deposits of value are known to occur between these and Bear Creek, along both sides of which the deposits extend for about a mile upstream from a point 2 miles above its mouth.

At Brown, on Leopard Creek, and at the south end of the deposits on Bear Creek the streams have cut their valley floors just to the level of the La Plata sandstone.

In appearance most of the vanadium-bearing rock is a dull green to almost black, fine, even-grained sandstone. The color probably

[1] Leopard Creek, as the stream is locally known, is shown on some maps as Rio del Codo.

darkens almost directly as the content of vanadium increases, although certain specimens contain some dark coloring matter which is possibly organic, and in others there is some coloring due to iron oxides formed from the decomposition of pyrite. In still other places the color is slightly yellowish green from admixed carnotite.

There is considerable variation of color and richness in individual beds, and where the vanadiferous part of the sandstone is cross-bedded, as in the Primos Chemical Co.'s deposits on Bear Creek, the bedding is marked by different shades of green and by black. Some of the ore shows many small sage-green dots from the size of a pin-head to one-eighth of an inch across, which appear to be nuclei around which the roscoelite has formed.

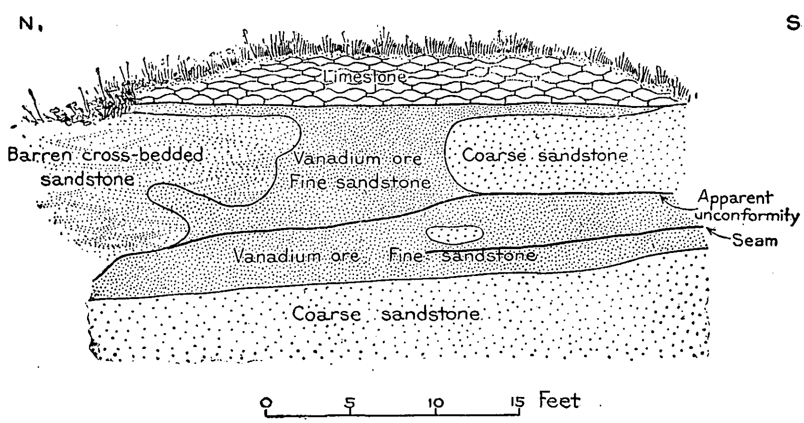

FIGURE 20.—Sketch of vanadium-bearing sandstone at Primos Chemical Co.'s mine on the east side of Bear Creek, near Newmire, Colo.

The vanadium deposits invariably follow the seam which indicates an apparent unconformity and may occur above, below, or on both sides of it, though probably most of the deposits are below it. In the deposits of the Primos Chemical Co. on the east side of Bear Creek, where the ore bed is very thick, there are two or possibly three such seams, but two are probably very local. (See fig. 20.)

In thickness the deposits range from 1 or 2 inches to over 30 feet. The richest ore is always near the seam and in many places a nearly black shaly layer from one-fourth to an inch thick which is said to be much the richest vanadium ore of the district lies along the seam. Such a thin layer of rich ore was seen on Bear Creek, north of Sawpit, east of Placerville, on the Rio claims on the south side of the San Miguel above Fall Creek, and on Fall Creek in the Vanadium claims. This layer is composed of roscoelite, quartz, and a little pyrite and is really a vein. The sandstone country rock evidently has been impregnated from it. Further remarks on the veins will be made in another paragraph.

The deposits are, broadly speaking, flat lens-shaped or tabular, the width, so far as has been shown, ranging up to at least 600 or 700 feet, with local thickenings or thinnings. The deposits were formerly very much larger, for they have been cut through by Bear Creek at the south end, and at one time there was undoubtedly a bed 1,000 feet across. (See fig. 19.) The same is true of the Leopard Creek and Fall Creek deposits, and the San Miguel must have eroded much more vanadiferous standstone than has been exposed by natural outcrops and prospecting, for the river has cut its valley half a mile to a mile wide almost lengthwise through the deposits.

In many places bands of nearly colorless quartzite from half an inch to 4 inches thick, known to the miners as "bone," alternate with the green sandstone and lie parallel to the line of apparent unconformity. There may be several such bands, generally though not always along the outside of the richest part of the deposit, or there may be alternate bands of rich ore and quartzite. A cross section of the deposit exposed in the workings on the Rio No. 1 claim, in a gulch tributary to the San Miguel just south of Fall Creek, is as follows:

Section of vanadium deposit on Rio No. 1 claim.

	Inches.
Sandstone, somewhat iron stained, part quartzite	3
Dark vanadiferous sandstone	4
"Bone," quartzite	2½
Dark vanadiferous sandstone	4½
"Bone," quartzite	2½
Dark vanadiferous sandstone	3½
Bottom of drift.	

The quartzite is generally barren of vanadium-bearing minerals, although on Bear Creek some silicified material appears to be vanadiferous. In other places, as in the deposit directly east of Placerville and in the Primos Chemical Co.'s deposit on the east side of Bear Creek, the quartzite forms exceedingly irregular masses scattered through the sandstone. The silicification seems to be, at least in part, later than the deposition of the roscoelite, for it incloses vanadiferous sections of the sandstone. There are in places similarly irregular bodies of sandstone stained by hydrous iron oxide.

It has been noted that in the deposits east of Placerville irregular spotting occurs in the main vanadium-bearing bed near a fault along which has been intruded a diabase dike that does not reach the vanadium deposits. At the mines of the Primos Chemical Co. the spotting occurs in 4 or 5 feet of rock above the main vanadium deposit. The uneven silicification causes very irregular breaking of the rock.

A little pyrite is scattered through the vanadium deposits, generally in minute grains, but along Bear Creek radial balls of pyrite one-half to three-fourths of an inch in diameter are occasionally found. The rusty spots and lines indicate that much of the pyrite has oxidized, and it is probable that if any of the deposits are opened into unoxidized ground much more pyrite will be found; in fact, some specimens from the faces of the longest drifts show thin strings of pyrite.

Faces along many joints of the vanadiferous sandstone are covered with canary-yellow, minutely crystalline carnotite which is clearly secondary and has evidently been leached from the ore-bearing rock. The quantity present varies from place to place. On Bear Creek there is very little, and the vanadium ore from the Primos Chemical Co.'s mines is said to show barely a trace of uranium. The vanadium ore here is green and shows little black in the richer portions. The ore from the deposits east of Placerville contains very much more carnotite, but it is irregularly distributed. Probably the Vanadium Nos. 3 and 4 claims on Fall Creek show the most carnotite of all the Placerville deposits. Here all joints, even those that are closely spaced, are brightly coated with carnotite. The vanadium ore is peculiarly black on these claims. In the deposit north of Sawpit the roscoelite vein is very dark and brownish rather than greenish, and there is more or less carnotite with it. The carnotite seems to be closely connected with the dark or black ores. The original mineral from which the carnotite was derived is unknown.

On the lower part of Bear Creek, on Leopard Creek, and along both sides of Fall Creek for several miles from the San Miguel Valley are lighter, brighter-green deposits which grade out from the vanadium deposits. In places the middle part may have the familiar dull green of the vanadiferous sandstone and carry up to 2 or 3 per cent of V_2O_5, but the lighter-green sandstone ordinarily gives no more than a trace. It receives its color from a chromium mica which is probably mariposite. That chromium gives the color is well known among the prospectors and miners of the region, who refer to the light-green sandstone as "chromite" sandstone, though chromite is, of course, quite another mineral from that coloring the sandstone.

Mariposite is found in small quantity in an arkose of the Dolores formation at Sawpit and in a recrystallized limestone of the Dolores northwest of Placerville.

Near both Placerville and Sawpit there are chromium stains in the La Plata sandstone several feet below the vanadium deposits. On the west side of lower Leopard Creek chromium stains reach 10 feet in thickness, with only a little vanadium present. There is also much of the chromium staining on Bear Creek north of the vanadium deposits.

MICROSCOPIC APPEARANCE OF THE VANADIFEROUS SANDSTONE.

The sand of which the lower sandstone of the La Plata is composed is generally very fine, 0.05 to 0.15 millimeter in diameter, with here and there grains 0.5 to 0.9 millimeter thick. Much the larger part of the grains are quartz. Those less than 0.5 millimeter in diameter are subangular to angular, and many have an elongated cross section, being two or three times as long as broad. This is one of the striking features of some thin sections of the sandstone. The larger grains are beautifully rounded.

Among the grains are a few of feldspar, and other feldspar grains have been replaced by calcite, roscoelite, or roscoelite and quartz. There are also a few grains of chalcedony, vein quartz, an exceedingly fine grained quartzite, zircon, and tourmaline.

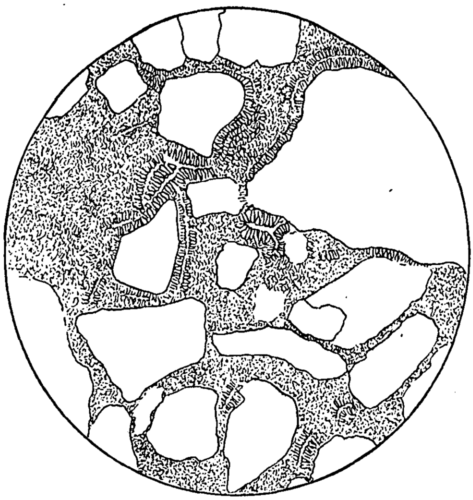

FIGURE 21.—Section of sandstone having wide pore spaces filled with roscoelite, partly radial. White space, quartz; shaded area, roscoelite. Enlarged about 225 diameters.

Roscoelite, yellowish green by transmitted light, forms most of the cementing material in the vanadiferous sandstone but occurs in flakes so fine that most of them appear indefinite even under high-power lenses. Generally some calcite is present and specimens that are poorer in roscoelite show more calcite. It is probable that where roscoelite occurs in the sandstone it has in general replaced calcite. In places the pore space has been large and the quartz grains are coated with roscoelite flakes standing on edge. (See fig. 21.) The flakes are so small that they do not everywhere fill the spaces, and quartz occupies the vug. Where roscoelite has replaced feldspar it shows a radial tendency.

The vein following the apparent unconformity is made up mostly of roscoelite and the individual flakes are large enough to show the optical character and allow identification. The roscoelite flakes combine in peculiar ropy forms which inclose lenticular spaces filled with clear quartz. (See fig. 22.) No quartz grains from the inclosing sandstone have been seen in the sections, but there are a few grains of tourmaline and zircon and a few round radial masses of roscoelite which are probably replacements of feldspar. If quartz grains were ever included in the vein they have been dissolved and removed or totally recrystallized.

OTHER VEINS.

Gold deposits in the limestone bed in the La Plata sandstone, directly above the vanadium-bearing sandstone, were worked north of Sawpit before the vanadium deposits were discovered, and work was done also on several veins near Placerville. These veins are in the immediate vicinity of the vanadium deposits. The gold mines at Ophir are 7 miles southeast and the Telluride-Ouray group of mines 10 miles east. Neither of these groups of veins contains vanadium minerals, nor are they known to have other resemblance to the vanadium veins. The nearest known other deposits of vanadium ores are probably 30 or 40 miles west.

The gold deposits near Sawpit, on the Golden Era and the Belle Champion claims, which are no longer worked, were in close connection with the vanadium deposits and with a diabase dike. According to Purington[1] the ore bodies were replacements of the limestone and followed east-west fissures. The ore minerals were pyrite and galena and their decomposition products. Four-fifths of the value was in gold. Vertical veins filled with calcite extend downward into the red beds of the Dolores formation, and Purington thought that they might have acted as mineralizers for at least part of the ore bodies. He also recognized the possibility that the dike played some part in the mineralization. A narrow vein follows the dike on the Golden Era claim.

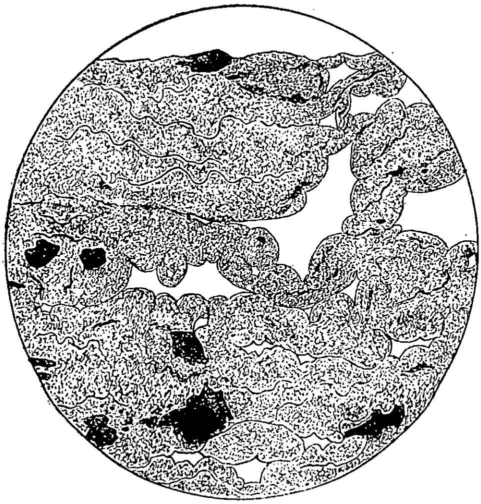

FIGURE 22.—Section of roscoelite vein. Shaded area, roscoelite; white area, quartz, except at the top, which shows the edge of the section; black area, pyrite. Enlarged about 225 diameters.

East of Placerville, about halfway between the river and the vanadium deposits, a vein striking northwest and dipping 80° SW., accompanied by 3 or 4 feet of crushed material, follows a normal fault of about 3 feet throw cutting the Dolores rocks. Considerable drifting has been done on the vein and some ore was sacked. The

[1] Cross, Whitman, and Purington, C. W., Telluride folio (No. 57), Geol. Atlas U. S., U. S. Geol. Survey 1899, p. 18.

ore consisted of chalcocite, chalcopyrite, azurite, and malachite in a gangue of barite and calcite. In the vein is also some hard shiny asphaltic material in small pellets and fragments one-eighth of an inch across.

A somewhat similar vein, also in the Dolores formation, occurs 1½ miles northwest of Placerville on the Evans claims, but its mineralization is more complicated. The vein is along a fault striking N. 60° W. and dipping 62° N. 30° E. On the footwall there is several feet of crushed rock and on the hanging wall more than a foot of alternating layers of a shiny black asphaltic material and calcite with barite. Here and there on the footwall side are irregular lenses of the asphaltic material. Azurite, malachite, chalcopyrite, chalcocite, molybdic ocher, molybdenite, galena, erythrite (cobalt arsenide), autunite, gold, silver, and vanadium also occur in the vein. Possibly more careful examination would reveal other minerals. Milton Evans, the owner of the claims, stated that a carload of ore from the vein, shipped in 1902, carried 14.8 per cent of copper and 0.11 ounce of gold and 3.5 ounces of silver to the ton. The asphaltic material at one place extends from the vein in small irregular pockets 1 to 4 inches thick into a limestone, in which, 50 feet north of the vein, it forms peculiar masses with an oblong cross section 1 or 2 inches wide by 4 or 5 inches long. The center is much the purest part of these masses, which become gradually poorer from the center outward until the limestone shows little or no asphaltic material. The central portions of some of these masses will break off in nearly concentric shells to an almost spherical ball half an inch or more in diameter. Other parts of the limestone show lesser impregnations. One test on the asphaltic material showed a fraction of 1 per cent of uranium and vanadium, both in the vein and in the limestone; another showed none. Orr J. Adams, of Telluride, stated that he had found uranium but no vanadium in the asphaltic material.

The presence of the asphaltic material with uranium, vanadium, and copper at once suggests comparison with the deposits in Wildhorse Canyon, in the San Rafael Swell, Utah, and with other deposits of the same State, where there is in a general way such an association of minerals.

Adjacent to the vein on the hanging-wall side is a peculiarly granular limestone, colored bright green by chromium mica, probably mariposite. The limestone has been recrystallized, probably by the solutions which brought in the chromium mica. The calcite granules are coated with the mariposite, and the rock was supposed to be a sandstone when examined in the field.

About 400 feet to the northeast is a barite vein along a vertical fault striking N. 80° W. The vein is said to carry some galena. On a cliff above this vein are vanadium and chromium stains, which are of small extent, but a thin seam is rich in mariposite, having a yellow-green to blue-green pleochroism.

On the west side of Leopard Creek, 1½ miles above Placerville, is a barite vein which reaches several feet in width. It contains also calcite, quartz, copper minerals, and a little gold and silver and is reported to carry some molybdenum. Copper-bearing minerals are said to occur also on the opposite side of the creek, but they were not examined.

ORIGIN OF THE DEPOSITS.

The data at hand are insufficient to give a basis from which to form a definite conclusion as to the origin of the vanadium deposits, but they seem to indicate some important conditions of deposition. Some of the facts will be reviewed.

The deposits are found in the lower member of the La Plata sandstone. They follow a line which seems to indicate an unconformity in the sandstone and along which occurs a vein up to three-fourths of an inch thick, composed of roscoelite and quartz, with a little pyrite, and in places an unknown black mineral that may be organic. Along the parting marking the apparent unconformity, although the vein in many places is practically or wholly lacking, the sandstone is impregnated with roscoelite, accompanied by a little pyrite, which is generally oxidized, and probably a little organic matter.

The vanadiferous deposits in a number of places gradually diminish in their vanadium content both laterally and vertically and a chromium mica thought to be mariposite succeeds the roscoelite. At some points it occurs also in the sandstones a number of feet below the vanadium deposits. Mariposite is also found in a recrystallized limestone along a vein 1½ miles northwest of Placerville. The vanadium deposits are accompanied by carnotite, which occurs on the faces of joints and which is evidently secondary and has leached out of the vanadium deposits. The roscoelite and the mariposite, however, are primary.

The La Plata sandstone, like the rocks of the McElmo formation above and the Dolores below, has undergone no general alteration and is as a rule poorly cemented and friable, but near the vanadium deposits there is more or less quartzite, which is found nowhere else. However, quartz does not cement the parts in which the vanadium occurs and the quartzite is ordinarily practically free from vanadium.

No manner can be conceived for the formation of the quartzite except through the action of hot water, and this is equally true not only of the roscoelite veins along the parting representing the apparent unconformity but of the roscoelite and mariposite impregnating the sandstone.

The parting frequently referred to evidently furnished an excellent channel for the water. The roscoelite and quartz were first deposited, and the mariposite, which was apparently capable of remaining in solution in cooler water, was deposited farthest from the source of mineralization.

Whence the heated water came is less evident, but in this connection attention may be directed to the general parallelism of the dikes, the vanadium and other vein deposits, and the river valley, and to the fact that by far the larger part of the vanadium has been lost through the erosion of the river. That the asphaltum-bearing vein on the Evans claims probably once carried hot water is shown by the recrystallized limestone containing chromium mica. The dike east of Placerville was probably also accompanied by hot water, as shown by the silicified breccia along the fault where it cuts the vanadium beds. The deposit is thicker at the point of contact than at any other place in that particular deposit, and there is much silicification of the sandstone within 100 feet on the northwest. At Sawpit a deposit of vanadiferous sandstone of small extent and showing considerable silicification occurs close to a dike, as do also gold and silver bearing replacement deposits in the limestone, and a vein of calcite and iron oxide (probably from pyrite), 2 or 3 inches wide, follows the dike. These deposits indicate the circulation of hot water, and the vein along the dike indicates that the water may have accompanied the dike. On the Vanadium claims on Fall Creek, where a dike crosses the La Plata sandstone, there is an abrupt enrichment and silicification of the deposits that extends for several hundred feet to one side.

These data suggest but by no means show conclusively that the dikes may have had much to do with the mineralization. On the other hand, the richest known deposit, that of the Primos Chemical Co., on Bear Creek, has no visible connection with dikes. This fact, however, is not weighty evidence against the possible connection of the deposit with a dike, as the dike may be under cover and may never have reached the surface nor have been exposed by erosion.

On the south side of San Miguel River at Placerville is a spring, the water of which has a temperature of about 90° and gives evidence of having been much warmer at some time. It has deposited much sulphur and iron oxide, though at present it gives no evidence of hydrogen sulphide. This is only another item showing the quantity of hot water that has been available for depositing ore.

The parallelism of the dikes and veins to the river suggests that possible channels through which the ore may have ascended have been obliterated by erosion and its incident débris.

The laccolithic diorite porphyry intrusions near Sawpit and Newmire are close enough so that waters accompanying or subsequent to their intrusion might have traveled the distance to the deposits before their load of minerals was precipitated.

No vanadium minerals are known to have been found in the dikes or diorite porphyry.

SIGNIFICANCE OF THE MARIPOSITE SANDSTONE.

Attention has been called to the fact that in places the roscoelite gives way to mariposite vertically and nearly everywhere laterally. Mariposite is reported to occur along Fall Creek for 4 or 5 miles and the writer followed it for the larger part of that distance. Nowhere else does it visibly extend so far from vanadium deposits and it seems possible that its great extent here may mean either that vanadium deposits with which it was more closely connected once existed in the rocks eroded from the present valley of Fall Creek or that it borders vanadium ores lying between Fall Creek and Bear Creek.

Ransome [1] reports similar green sandstones colored by chromium on the west side of Sinbad Valley, 60 miles west of Placerville, in proximity to the carnotite deposits, and Gale [2] has recorded a similar association in Routt County. Fleck and Haldane [3] also note the occurrence of green sandstone in the Roc Creek carnotite district, one specimen of which carried 0.11 per cent of V_2O_5. They mention the occurrence of green sandstone at several other places but give no details of composition. This sandstone may be chromiferous, for they seem to have noted the sandstones that are colored by copper. These occurrences of such unusual minerals with a common mineralogic association would seem to indicate a likeness of origin, and suggest that the carnotite of all the occurrences may have come from some easily decomposed uranium-vanadium mineral which was originally brought in by solutions that deposited roscoelite and mariposite with a very small quantity of the uranium-vanadium mineral in the Placerville area, mariposite with the uranium-vanadium mineral and a very little roscoelite where Roc Creek now is, and the uranium-vanadium mineral with copper minerals and little or none of the micas at other points. In other words, it seems possible that the deposits of the several areas may have been formed in similar manner, but that the minerals carried by the invading solutions carried different proportions of the minerals.

It is possible that when the workings in the Placerville area reach sufficiently far from the surface the unaltered uranium-vanadium mineral may be found, but from the solid appearance of the ore as now mined it will probably be in microscopic particles.

---

1 Ransome, F. L., and Hillebrand, W. F., On carnotite and associated vanadiferous minerals in western Colorado: Bull. U. S. Geol. Survey No. 262, 1905, p. 14.

2 Gale, H. S., Carnotite and associated minerals in western Routt County, Colo.: Bull. U. S. Geol. Survey No. 340, 1908, p. 261.

3 Fleck, Herman, and Haldane, W. G., A study of the uranium and vanadium belts of southern Colorado: Rept. Colorado Bur. Mines for 1905-6, Denver, 1907, pp. 80-81.

WHY THE MINERALS ARE IN THE LA PLATA SANDSTONE.

Just why the vanadium deposit is in the lower sandstone of the La Plata rather than in another sandstone or a limestone lower down can only be conjectured. Conditions of water pressure below this level may have been such as to prevent the lateral flow of the solutions. The porosity, texture, and chemical composition of the vanadiferous rock can all be practically duplicated below the La Plata. However, the fissure marking the apparent unconformity in the lowest member of the La Plata made an excellent channel for the solutions to follow, and this they did for long distances. Though some feldspar grains have been replaced, they did not determine the selection of the locus of deposition, for some of the rocks below carry much more feldspar than the La Plata.

ECONOMIC CONDITIONS.

The individual deposits may not be described on account of the objections of one of the principal companies.

As stated in the beginning, the Rio Grande Southern Railroad is a narrow-gage line, consequently it must transfer its freight to broad-gage cars at some point. The transfer, the heavy haul over the mountains, and the long distance to market make freight rates high.

The Primos Chemical Co. controls and operates the reduction plant built by the Vanadium Alloys Co. at Newmire in 1905, and it reduces its own ores to ferric vanadate, which is shipped to the East for reduction to ferrovanadium. The company has an ample supply of ore and buys none. The ore is reported to carry no more than a trace of uranium, and the little carnotite visible in the ore seems to bear out this statement. The two metals are said to be difficult to separate in a commercial way. As the company pays freight on a concentrated product it can presumably use an ore carrying a less percentage of vanadium than other companies.

So far as known, the General Vanadium Co. was the only firm buying ore in the field in 1911, though the General Vanadium Co. and the Standard Chemical Co. bought and mined carnotite ores from the Paradox Valley and shipped them through Placerville. The General Vanadium Co. ships its ore to Liverpool for reduction and to make a profit can handle nothing carrying less than 3 per cent metallic vanadium, and most of the ores of the Placerville area carry much less than that. It follows that when the ore is mined to sell under these conditions a large quantity which carries a considerable percentage of metal but is not up to the mark for shipping must be thrown aside or left in the ground.

[1] Carl, P. H., Vanadium as a staple Colorado product: Min. Sci., vol. 65, May 9, 1912, p. 409.

Ore has been bought or mined and shipped by the General Vanadium Co. from claims on Fall Creek, several points along the south side of San Miguel River between Fall Creek and Sawpit, from a deposit north of Sawpit, and possibly from a few other points on the north side of the river.

The claims along Leopard Creek have mostly shown lower-grade ore as developed and have considerable chromium staining, but individual specimens show good percentages of vanadium.

Analyses of samples collected by Sidney W. French[1] along Leopard Creek gave results varying from 0.21 to 3.23 per cent of metallic vanadium. More than half the samples collected gave less than 1 per cent of vanadium, about one-fourth gave between 1 and 2 per cent, and one-seventh gave more than 2 per cent. Only three or four analyses of samples from claims in other parts of the field gave more than 2 per cent of metallic vanadium. One analysis of material from Bear Creek showed 8.3 per cent. The specimen is described as "a piece of very dark green sandstone which occurs in a thin layer along a bedding plane."[2] It is undoubtedly a piece of a roscoelite vein.

The analyses are of use as indicating the richness of vanadium mineralization, but of course they give little idea of the quantities of ore available. It is safe to say that there are many thousands of tons of sandstone which will show between 1 and 2 per cent of metallic vanadium and much more running between 0.5 and 1 per cent. But to give a profit the rock will probably have to be treated on the ground, as is being done by the Primos Chemical Co. From present developments probably only a few thousand tons of ore carrying over 3 per cent can be mined profitably.

Sufficient ore has been mined in this area and to a less extent in the carnotite fields 40 or 50 miles farther west to cause the price to be reduced in the last three or four years from $5 a pound of metallic vanadium in ferrovanadium to $2.50 or less. The most seriously competing deposits are those of vanadium sulphide at Minasragra, Peru, controlled by the American Vanadium Co., of Pittsburgh, Pa.

---

[1] Quart. Colorado School of Mines, vol. 3, January, 1909, pp. 33-35.
[2] Idem, p. 30.

VANADIUM IN THE SIERRA DE LOS CABALLOS, NEW MEXICO.

By Frank L. Hess.

During 1910 and 1911 considerable attention was attracted to the vanadium deposits in the Sierra de los Caballos by numerous articles in the mining press,[1] which reported the erection of a plant at Cutter for the manufacture of vanadic oxide and the mining of the ore in the mountains 12 to 15 miles southwest of that place. Cutter is in Sierra County and is a station on the Atchison, Topeka & Santa Fe Railway, 149 miles south of Albuquerque and 104 miles north of El Paso.

The Sierra de los Caballos, in which are the vanadium deposits, lies along the east side of the Rio Grande and can be reached from Cutter or from Engle, 10 miles north of Cutter. As described by Schrader,[2] the mountains form a range trending nearly north and south and reaching a maximum height of 10,000 feet at Timber Hill, south of the vanadium deposits. He says:

> The range consists mainly of a monocline bounded on the west by a great north-south fault scarp overlooking the Rio Grande. * * * In the vicinity of Palomas Gap the average elevation of the crest is about 6,500 feet; the average width of the mountains is 4 to 6 miles, including a foothill belt several miles wide on the east. The most prominent feature of the mountains is the great limestone and quartzite series, 1,200 to 1,400 feet in thickness. It consists chiefly of heavy-bedded massive gray or blue limestone, with some intercalated shale, and has at its base about 100 feet of hard quartzite. Much of the limestone is semicrystalline, and some of it contains black flinty or cherty nodules or inclusions. Part of it is greatly crushed and recemented by calcite veins.
>
> The quartzite at the base of the limestone series ranges from 50 to perhaps 200 feet in thickness; it is massive or heavy bedded and consists of black and red beds resting upon the granite. Its age is probably Cambrian.

[1] Among the articles appearing upon the subject have been the following:

Leatherbee, Brigham, Sierra County, N. Mex., vanadium deposits: Min. World, vol. 33, Oct. 29, 1910, p. 799.

Carrera, J. C., Vanadium; its importance in the Southwest: El Paso Min. Jour., February, 1911.

Johnson, E. D., The vanadium industry in New Mexico: Min. Sci., vol. 63, Mar. 9, 1911, p. 259.

Larsh, P. A., Caballo Mountain vanadium mines: Eng. and Min. Jour., vol. 92, July 15, 1911, p. 118.

Allen, C. A., Vanadium deposits in the Caballo Mountains, N. Mex.: Min. and Sci. Press, vol. 103, Sept. 23, 1911, pp. 376-378.

Clifford, J. O., Vanadium in New Mexico; Caballos Mountains deposits: Min. and Eng. World, vol. 35, Oct. 28, 1911, pp. 857-858.

[2] Schrader, F. C., in Lindgren, Waldemar, and others, The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910, pp. 284-285.

The granite is stated to be probably basal, but there are dioritic rocks that are apparently intrusive, and south of the vanadium deposits are porphyritic intrusive rocks. The limestones are of Carboniferous age and on the east are overlain by fine-grained red sandstones, also Carboniferous.

About two-thirds of the way toward the north end the range is cut by a narrow canyon known as Palomas Gap, in the vicinity of which are the vanadium mines. The mines were discovered in 1906 just after Schrader's visit to the locality.

At the mines the range proper shows nothing from the east side but the limestone. On the north side of the gap the limestone is in open folds. A valley follows the range here, running about N. 25° W. (magnetic), which suggests a fault separating the limestone and the red beds.

The vanadium-bearing veins lie at and about three-fourths of a mile south of Palomas Gap. They strike nearly northeast (magnetic) and dip from 60° NW. to vertical. They occupy fissures in limestone containing brecciated country rock cemented by calcite, with some white and amethystine fluorite, barite, and less quartz. The metallic minerals noted are galena, a little cerusite, copper carbonates, vanadinite, zinc-bearing cuprodescloizite, and another mineral which may be an amorphous form of cuprodescloizite. The galena alters to a black mineral that forms a narrow band around the crystals but occurs in too small quantity to determine. Besides these minerals, pyromorphite and wulfenite have been reported by others, although they were not recognized by the writer after diligent search for them during his short visit and on the specimens collected.

At Palomas Gap there are two such veins, one on either side, on the property of the Vanadium Mines Co. The vein on the north is known as the Dewey, and that on the south as the White Swan. Both are developed by shafts, but permission to enter them was refused, so that observations could be made only upon surface workings and a drift on the Dewey opening into Palomas Gap, across which the vein cuts. In the drift the vein has been taken out for a width of 6 to 12 feet and has been stoped to a height of 30 feet. The vein is spongy and much weathered. On the north side of the gap, which is not over 100 feet wide at this point, in a prospect hole 8 or 9 feet deep, part of the limestone is coated with a yellowish-green crust not over one-sixteenth of an inch thick. Under the microscope part of it is seen to be brown vanadinite with a thin powdering of the green material, but other specimens show much more of the green matter. Purer material from the Red Top claim is crystalline but seems to be the same green mineral, carries vanadium, lead, copper, and zinc, and is probably cuprodescloizite.

A shaft has been sunk on the east end of the outcrop of the vein. A keg of rich ore contained lumps of hair-brown vanadinite in a pinkish clayey material. The crystals reach one-eighth of an inch in diameter, many are hollow, and of those which are not hollow many show two distinct stages of growth in their cross fracture.

The White Swan vein, on the south side of the gap, has been developed by a shaft and by open-cut work. The vein is very similar to the Dewey but is vertical and is said to carry wulfenite (lead molybdate), though none was seen in the exposed portions of the vein nor in the ore on the dump. The visible portions of the vein carried calcite, quartz, barite, colorless and amethystine fluorspar, galena, copper carbonates in small quantity, and vanadinite.

The vanadinite is mostly in hair-brown crystals which are so small that cavities lived with them in the spongy calcareous gangue look velvety. Under strong magnification they form a beautiful bristling array, pointing in all directions from protuberances and surfaces. Many of the cavities lined are evidently left by the decomposition of galena. The crystals are so fine that there must be great loss unless the ore is very carefully handled.

Some very unpromising-looking limy material from the dump gave good reactions for vanadium, and microscopic examination showed that through the calcite were great numbers of colorless or nearly colorless vanadinite crystals so minute as to be invisible to the unaided eye.

Persons familiar with the ground stated that the shaft was 400 feet deep and that 800 or 900 feet of drifting had been done. It has also been stated that a fault, corresponding to the surface indications as mentioned, has been struck on the east.[1] The mined ore is hauled by wagon to a mill about 1½ miles south and the concentrates are hauled to Cutter, where a plant was erected for making vanadium oxide and lead sulphate. It is understood that a few hundred pounds of vanadium oxide had been produced up to the time the locality was visited.

Much money was expended to obtain water. A pumping plant was erected and a number of wells dug 4 miles east, and a disagreeably alkaline water was piped to the mill and mine. At the time the property was visited good water had been found across the narrow valley, only a few hundred feet from the mines.

About three-fourths of a mile south of the Dewey and White Swan veins Ralph Widener has claims known as the Gladys, Red Top, Red Top Annex, and Billiken, named seriatim from southwest to northeast. All are situated on the same vein. On the northeast J. H. Hardin has a claim called the Owl which is apparently also

[1] Allen, C. W., op. cit., p. 378.

on the same vein. The strike is parallel to the Dewey and White Swan veins (about northeast, magnetic), and on the Gladys claim the dip is 60° NW. (magnetic). In a prospect shaft 15 feet deep on the Gladys claim the vein was shown to be about 3 feet wide and appeared not to be fully exposed on the footwall side.

The vein consists of crushed limestone, considerably disintegrated and cemented by secondary calcite, with white and pink fluorspar. In the hasty examination made no barite or copper minerals and very little quartz were seen. Some galena is scattered through the ore. About a foot of the vein is very spongy, and the cavities are lined with small hair-brown crystals of vanadinite, in places shading into brownish yellow and colorless. The largest crystals are probably not over one-sixteenth of an inch long and very slender, so that although they make a beautiful appearance in the mine they are so fragile that it is almost impossible to transport good specimens, for all crystals not in cavities are broken by the almost inevitable rubbing incident to handling, and many others are broken by small fragments of rock which become loosened and strike them. The ore on the other claims is similar, but the exposures were not so good.

Some cuprodescloizite found on these claims is apparently fairly homogeneous and is crystalline. The determination was made on ore from the Red Top.

Across the valley to the northeast are other claims upon which vanadium minerals are said to have been found, but the time at the writer's disposal did not allow examination.

Nothing definite is known of the richness of the ores. The vanadium content has been estimated to be from a fraction of 1 per cent to 3 per cent, but the latter figure is probably much too high.

Other lead-bearing veins occur along the Sierra de los Caballos within a mile south of the Red Top, and these are reported by Larsh [1] and others to carry no vanadium, although the veins evidently belong to the same group, apparently have the same gangue minerals, and cut the same country rock.[2] These facts would seem to indicate that the vanadium did not come from the country rock. The veins do, however, carry wulfenite.

[1] Larsh, P A., op. cit., p. 118.

[2] Schrader, F. C., op. cit., p. 285.

CARNOTITE NEAR GREEN RIVER, UTAH.

By Frank L. Hess.

On the east side of the San Rafael Swell, at a locality marked on some maps as Tidwell, about 15 miles S. 85° W. of Green River, Utah, attempts have been made for a number of years to exploit deposits of carnotite. The deposits were visited by Boutwell[1] in 1904 and briefly described. They are now being actively worked and were visited by the writer in July, 1911.

The San Rafael Swell is a broad, oval, mountainous elevation, the long axis of which runs somewhat east of north. The Swell is about 40 miles long and 10 to 20 miles wide and is possibly underlain by a broad intrusion of igneous rock. On the east side of the Swell a great series of sandstones, fine conglomerate, shales, and gypsum are tilted to angles of 10° to 60°. Some of the softer beds have been eroded, forming a valley which follows the Swell for miles. San Rafael River flows eastward across the northern part of the Swell, turns abruptly to the south, where it strikes the valley, and 2 miles below turns through the valley wall to the east on its course to Green River. The country is practically a desert, but there are arable lands along the valley of the San Rafael on which alfalfa and other crops are grown. The well water of the valley is disagreeably alkaline, but a good spring exists about a mile west of the carnotite deposits.

The carnotite deposits are situated on the east wall of the valley, extending from a point between 2 and 3 miles north of the portal through which the river leaves the Swell to a point a mile or more south of the river at Mexican Bend, its place of departure from the valley, a total length of probably between 5 and 6 miles.

The east wall rises about 300 feet above the floor of the valley and from the top slopes to the east at nearly the same angle as the strata, about 10° or 15°. As they dip to the east the strata form low hills whose relations to one another may be compared to those of the shingles on a house if they were reversed.

The rocks are thought to be the Flaming Gorge formation, regarded as the equivalent of the McElmo formation at Placerville, Colo.,

[1] Boutwell, J. M., Vanadium and uranium in southeastern Utah: Bull. U. S. Geol. Survey No. 260, 1905, pp. 208-209.

which there overlies the La Plata sandstone, the lower member of which contains deposits of vanadium. Most of the carnotite deposits are situated on the ridge overlooking the valley, but a little carnotite has been extracted from claims along a lower ridge half a mile to the east. All the deposits are in a coarse, loosely consolidated cross-bedded sandstone, which is in places finely conglomeratic. The sandstone is cemented with calcite and carries much petrified wood, many imperfect plant remains that appear to have been reeds, and many fossil bones. Some of the petrified wood is in logs 2 or 3 feet in diameter and 10 feet or more long. The structure of the wood is, however, not well preserved. The supposed reeds are represented by cavities crossed by numerous septa suggestive of cat-tail leaves. In some of these cavities there is apparently some carbonized organic matter left; others are partly filled by manganese dioxide or iron oxide. None of the fossils seen were well enough preserved to offer hope of their identification. The bones are in part black from organic matter and retain much phosphorus in their composition. All seen were too fragmental to promise a possibility of identification. The plant remains seem to occur largely along one horizon in the sandstone and the carnotite is closely associated with them.

At numerous places there has been some slipping between the strata at this horizon. This is probably due to the bending of the beds by the formation of the San Rafael Swell. Possibly the presence of the great number of plant remains made this particular stratum one of the weakest, and when a strain came it was the one to give way.

There are a few quartz veins not more than half an inch thick, and some minor crushed zones in the sandstone. Along one of these crushed zones, on a claim known as the Wardvern, directly opposite the portal of the San Rafael Canyon, a deposit of carnotite was being worked by V. C. Ward and others at the time of the writer's visit. A small fault striking N. 80° E. with an almost vertical southerly dip is accompanied by 2 to 6 inches of crushed material. The beds here contain many plant remains, which appear to be partly carbonized, and some fossil bones. Rock stained with carnotite was being quarried through a width of about 4 feet and to an equal depth. The rocks were much stained with iron oxides, and pieces of limonite appeared to have been derived from pyrite. Carnotite fills the cavities in the spaces which seem to have been occupied by reeds, impregnates the sandstone, and coats joint faces.

Under a microscope the filling of the cavities shows cracks as if it had been deposited like a soft clay that had shrunk upon drying. Along the cracks appears to be a very thin film of crystalline material, but the middle part is apparently amorphous. The carnotite forming a thin coating over sand grains, etc., is crystalline, the thin tabular plates standing edgewise.

A carload of ore was shipped to Europe during the year by Mr. Ward and his associates and is reported to have been sold on the basis of 6.11 per cent of the combined oxides of uranium and vanadium—2.24 per cent U_3O_8 and 3.87 per cent V_2O_5. Preliminary tests had indicated that the percentage carried was 2.52 per cent U_3O_8 and 4.80 per cent V_2O_5.

Half a mile N. 70° E. a small amount of work has been done on two claims known as the Little Bessie and Little Vernon. About 2 tons of ore similar to that described had been taken out from a wall 20 or 30 feet high and the deposit appeared to have nearly pinched. Carnotite stains show in the wall for 200 or 300 feet. There is not so much iron staining as on the Wardvern claim, and no signs of faulting were seen. Several black bones about the size of ox bones were exposed at one place.

Half a mile south of the Wardvern claim is another known at the time visited as the Little Hulda. No work was being done on it, but a carload of ore is said to have been shipped a number of years ago and it is probably the claim examined by Mr. Boutwell. The ore was taken from shallow trenches and is said to have been shipped to Europe. It is reported that no returns were ever made for it.

The ore of the Little Hulda shows none of the organic remains of the other deposits, but it follows a small slickensided fault dipping 40° S. 80° E. Only 2 or 3 inches of rock next to the fault shows much staining from carnotite, but lighter stains show through more than a foot of rock. There is much staining from iron and a little from manganese through 2 or 3 feet of rock along the fault.

Across the San Rafael, more than a mile to the south, carnotite has been found but was not examined.

North of the Wardvern claim carnotite stains were followed for possibly 2 miles. They are at the same horizon as those already described, along the slipping plane before referred to as probably due to the bending of the beds. In this area there are many of the vegetable remains, both of reeds and trees, and considerable iron staining. The fossil wood is ordinarily coated with carnotite along joint planes; but apparently no special significance attaches to this fact, for the wood seems to be thoroughly silicified and the carnotite is simply deposited in it, as in cracks and openings in the sandstone. The impregnation is usually light, from 2 inches to 3 feet thick, but generally a few inches thick and lacking for considerable distances.

There are said to be other occurrences between 2 and 3 miles farther north.

It is to be noted that no vanadium minerals that do not carry uranium, no chromium or copper minerals, and no asphalt have yet been found in these deposits. They carry only the very mobile secondary minerals, carnotite and iron oxide. A few thin quartz veins cut the rocks but are not noticeably mineralized. It is also to be noted that all the deposits examined, except one, visibly accompany faults. Their presence with the organic matter seems to be fortuitous and due to the convenient cavities provided by its decay and removal or to its cracking.

Deposits of uranium are known to occur near Fruita, at the south end of the San Rafael Swell, and in Wildhorse Canyon, southeast of the Swell, and it seems probable that deposits may be found at other points on the eastern and southern parts of its periphery.

ZIRCONIFEROUS SANDSTONE NEAR ASHLAND, VIRGINIA.

By Thomas L. Watson and Frank L. Hess.

INTRODUCTION.

In 1910 August Meyer, of Richmond, Va., submitted to one of the writers a specimen, obtained 3 miles west of Ashland, which was thought to contain rutile. The specimen was a fine-grained friable rock of dark reddish-brown color, in which grains of ilmenite or some similar black mineral were distinctly visible. The color of the other grains was apparently similar to that of the rutile found 10 or 15 miles to the southwest, in Hanover and Goochland counties, and under a hand lens no difference in appearance could be distinguished. As the rutile of these counties occurs with a very black ilmenite, it was thought that the specimen might possibly be a fine-grained mass of the titanium minerals. Microscopic examination of a thin section, however, showed the rock to be a sandstone composed of very small grains of ilmenite and zircon (zirconium silicate, $ZrSiO_4$), together with a few grains of other minerals, chiefly quartz and silicates, cemented with limonite.

In June, 1911, the writers, in company with Mr. Meyer, visited the locality from which he obtained the original specimen, on the farm of F. B. Sheldon, 3 miles west of Ashland, Hanover County, and about 20 miles north of Richmond.

GENERAL GEOLOGY OF THE AREA.

The area of zirconiferous sandstone forms a part of the western edge of the Coastal Plain, near and along the overlap of the sediments upon the older crystalline rocks of the Piedmont Plateau. Along this edge (the "fall line") the surface is somewhat roughened from erosion, but to the east it becomes more gently rolling and is essentially flat and featureless. The area lies on the south side of South Anna River, but within its drainage basin and only a short distance southwest of its confluence with the North Anna to form Pamunkey River. There is much timber in the area, of comparatively young growth and small size.

The sandstone outcrops along a low ridge having gently sloping sides and a general direction of N. 20° E. At the point where the sandstone seems to be most abundant and perhaps richest in zircon the ridge marks the western edge of the Calvert formation, the lowest formation of the Chesapeake group (Miocene). Within this area and for some distance north and as far south as 25 miles from Petersburg the Calvert formation transgresses the underlying older Coastal Plain sedimentary formations, and its western margin rests upon the crystalline rocks of the Piedmont Plateau.[1] The Calvert formation in Virginia consists chiefly of sands, clays, marls, and diatomaceous earth, with fine-grained sands predominant. Diatomaceous earth has not been identified in the Ashland area.

Extending westward from the foot of the west slope of the low ridge mentioned above are the crystalline rocks of the Piedmont Plateau, chiefly granites and gneisses, which for the most part are of pre-Cambrian age. The contact between the sedimentary formations of the Coastal Plain and the crystalline rocks of the Piedmont Plateau extends across the State in a roughly north-south line and in position nearly coincides with the meridian 78° 30′.[2]

In the southern part of the State the Calvert formation is overlain by the St. Marys formation (middle Miocene), and along the western edge the St. Marys transgresses the Calvert and rests on the crystalline rocks.

OCCURRENCE OF THE SANDSTONE.

In the Ashland area the sandstone does not outcrop in a continuous bed. It was seen only in the form of irregular flat fragments lying loose upon the surface. The fragments are of the same reddish-brown to yellow color as the specimen submitted by Mr. Meyer. In size the fragments range from those as large as a man's fist to some measuring 2 feet long, 2 feet broad, and 6 inches thick. There is as much variation in texture as in size, and the rock accordingly ranges from a fine-grained sandstone to a moderately coarse conglomerate. Much of it is very fine grained, showing little visible quartz. Other pieces are of varying degrees of coarseness, some containing quartz and quartzite pebbles 2 inches in diameter. Some pieces show cross-bedded structure.

The largest number of the sandstone fragments were seen on a small mound 150 yards southwest of Mr. Sheldon's house, and scattered fragments can be found both to the north and the south for a distance of half a mile. On J. B. Davis's farm, which adjoins the Sheldon farm on the north, there are many pieces of the sandstone, though generally of smaller size. However, many of the pieces, especially those found farther north, are of lighter color and lower specific gravity than the fragments from the Sheldon farm, though

[1] Bull. Virginia Geol. Survey No. 4, 1912, pp. 126 et seq.

[2] See the geologic map of Virginia published by Virginia Geol. Survey, Charlottesville, 1911.

one of the richest specimens collected was from the line between the Thomas Kies and John Boschen farms, half a mile north of the Sheldon land. The specific gravity is of value in field examination, for the specimens of low specific gravity collected show only a few scattered grains of zircon, whereas those of high specific gravity carry a large percentage of the mineral.

It is probable that the hard lumps of sandstone represent the local cementation of a sandy bed which, in most places, is soft or but slightly consolidated, a characteristic of the Chesapeake group (Miocene). Partly or wholly indurated sands, yielding somewhat highly ferruginous crusts and beds of sandstone, are by no means uncommon in the formations of the Virginia Coastal Plain near its western margin. So far as the writers are aware these ferruginous sandstones have been generally regarded as composed chiefly of quartz grains cemented by iron oxide. At no point beyond the Ashland area, so far as known, have they been tested for zircon or other uncommon heavy minerals.

At the home of Benjamin Wright, three-eighths of a mile southwest of Mr. Sheldon's house, a highly zirconiferous and but slightly consolidated sand bed was cut in the lower part of a well 14 feet deep. This bed is probably the same one from which the indurated or hardened fragments of zirconiferous sandstone have come. Almost perfectly rounded waterworn quartz and quartzite pebbles, mostly quartz, up to 3 inches in diameter and usually white in color, were taken from this well at a depth of 14 feet. None of the zirconiferous material was found south of Mr. Wright's well, and decomposed granite is exposed in a road 200 yards southwest of his house.

A hundred yards northwest of Mr. Sheldon's house a bed of zirconiferous sand, similar to that cut in the Wright well, was exposed in a shallow prospect hole. The zirconiferous sand was 18 inches thick and was underlain by clay and covered by a few inches of soil.

From the appearance of the float and the sand cut in the prospect hole, the zirconiferous bed is thought to be probably not more than 2 or 3 feet thick. The data at hand indicate that it is probably a narrow lens five-eighths of a mile long and of unknown but probably less width.

TESTS.

The zircon was separated from six lump samples weighing from 50 to 100 grains each, as follows: The lumps were first treated with hydrochloric acid to dissolve the cement of limonite. In two specimens small lumps resisted dissolution and were treated with aqua regia on a steam bath for two days, which resulted in dissolving the cement and disintegrating the sand grains. After washing by decantation the sand was digested with a mixture of sulphuric and hydrochloric acids to remove ilmenite and quartz and then washed. The specimens thus treated yielded zircon as follows:

Zircon obtained from sandstone near Ashland, Va.

Locality.	Gross weight of sample (grams).	Zircon.	
		Grams.	Per cent.
Low hill on F. B. Sheldon's farm	50	14.955	29.9
Do	100	25.375	25.4
Do	52	6.280	12.1
100 yards northwest of F. B. Sheldon's house	100	15.890	15.9
Benjamin Wright's well	52	6.815	13.1
Top of hill on line between Thomas Kies's and John Boschen's farms	100	27.230	27.2
	....	96.545	....

Accessory heavy minerals in the form of impurities, such as cyanite, garnet, and staurolite, could not be separated from the zircon by the methods used, and the results given in the table above are perhaps 2 or 3 per cent too high, though certainly not more. Owing to possible losses through the severe treatment during separation and to the loss of fine zircon in decanting, the results are regarded to be as likely under as over the real quantity present. They are not, of course, to be regarded as exact, but the method of selecting random specimens from float rock would not warrant more accurate determinations.

The method used in separating the material is not thought to have introduced appreciable errors, as a blank test was run on finely pulverized zircon by treating it for three days with a mixture of sulphuric and hydrofluoric acids. At the end of three days the solution was tested and no trace of zircon was found.

The zircon crystals in the material are minute in size. Out of about 96 grams of zircon separated, a small quantity was caught on a sieve of 60 meshes to the linear inch; possibly 1 per cent would not pass through a sieve of 80 mesh; nearly 17 per cent (16.23 grams) passed through an 80-mesh and was caught on a 100-mesh sieve; 77 per cent (74.15 grams) passed through a 100-mesh sieve and was caught on a 150-mesh sieve; and more than 2 per cent (2.3 grams) passed through a 150-mesh sieve. Most of the accessory minerals (impurities) can be caught on an 80-mesh sieve.

CHARACTER OF THE ZIRCON.

The zircon crystals, as separated above, are mostly of short, stout form, with a smaller number of elongated forms, possibly 1½ times as long as thick. In mass they are of pinkish or pinkish-brown color, but on heating to redness they become colorless. Under the microscope individual crystals appear pink or yellow, but much the largest number are colorless. In most specimens the fragments are found to be somewhat worn crystals, but in the material from the prospect hole northwest of Mr. Sheldon's house many of the individuals show beautiful crystal form under the microscope. Though many pieces are undoubtedly worn, the wear in general may be more apparent than real, as small zircon crystals examined in place very commonly have outlines which do not show good faces or angles.

ASSOCIATED MINERALS.

Associated with the zircon are quartz and a variety of heavy minerals, including garnet(?), ilmenite, staurolite, cyanite, and an isotropic green mineral which has not been definitely determined but which may be pleonaste or hercynite. As stated above, these are all cemented with limonite, possibly in part siliceous.

Ilmenite is the most abundant mineral in the rich pieces and its grains are of about the same size as those of zircon. The quartz and cyanite grains are generally several times as large. In places the fine-grained zircon and ilmenite surround quartz pebbles an inch long with the other dimensions somewhat smaller.

No magnetite has been found in the material.

GENESIS.

The zircon and ilmenite concentration evidently represents an old beach segregation along but within the western margin of the Miocene sediments of the Coastal Plain, of Calvert age, and is similar to the black-sand beaches of New Jersey, California, Oregon, and numerous other coasts and to the gold-bearing garnet (so-called "ruby") sands of the beaches at Nome, Alaska.

The zircon and other heavy minerals resistant to atmospheric agencies were derived by weathering processes from the crystalline rocks, chiefly granites and gneisses, of the Piedmont Plateau, which extend westward from the Coastal Plain contact. These formed the country rock of the shore, and the zircon and associated minerals derived from them by weathering were accumulated by waters near the mouth of a small stream or behind a sheltering point, while the quartz sand was largely worn and carried away by the currents af the sea.

Zircon is an almost constant minor accessory mineral in the crystalline rocks of this old shore and its extension westward, and in places it occurs in large masses. Near Goulden post office, 10 to 15 miles southwest of the Ashland area, pieces of zircon 3 inches in diameter weathered out of pegmatite dikes have been noted on the surface. Massive zircon without crystal outline and measuring 6 by 4 inches has been observed in the pegmatites of Amelia County, Va. Similar dikes occur in the gneiss-granite complex of the Piedmont Plateau, forming the old shore line which extends entirely across Virginia from Maryland into North Carolina, roughly coinciding with the meridian of 78° 30′. It seems probable that similar zircon-rich rocks may occur at numerous points along this old shore line. Many zircon-bearing deposits may be covered by later sediments and some may have been removed by erosion, but it is probable that others, which may be richer or poorer, will be discovered along the contact of the granite and gneiss of the Piedmont Plateau with the overlying sediments of the Coastal Plain.

It is probable that some magnetite was present with the ilmenite, and glauconite is abundant at places in the Calvert formation. The alteration of either of these minerals might produce limonite, which forms the cementing material, but the most probable source of the limonite is precipitation from ferruginous waters.

USES.

Böhm[1] sums up the known and probable uses for zirconium substantially as follows:

Zirconia (ZrO_2) has been used in place of lime or magnesia as the incandescing material in the oxy-hydrogen blowpipe, and a very small quantity of zirconium nitrate is used in making mantles for gas lights. The use of zirconia in the Nernst lamp (a form of incandescent electric lamp in which a small stick of zirconia and yttria is used as a glower) formerly required large quantities, but the consumption is not now so large, owing to the competition of metallic filament lamps. Zirconium carbide has been used in making incandescent electric lamps, but it also has been superseded by the metallic filament lamps. The incandescent properties of zirconia have tempted arc-lamp manufacturers to use it in their electrodes, but thus far unsuccessfully, though this does not mean that the feat may not be accomplished. Zirconia is an excellent insulator for both electricity and heat and when mixed with a conductor can be used for electric heaters. In the Heræus iridium furnace the iridium may be protected by a glaze made from a zircon salt in place of the thorium or yttrium salts now used. Zirconia makes an excellent and very refractory crucible which is manufactured in many sizes by a German firm. Its refractoriness makes zirconia a suitable lining for electric furnaces, and Böhm suggests that it might be used for saggers, but for the ceramic trade it must be free from iron and cheap. He also suggests its use for the walls of furnaces, for the making of molds to withstand high temperatures, and for heat insulation. Owing to its inertness zirconia is suitable for chemical ware, and many forms are manufactured from it. The same property has led to its recommendation for certain medicinal uses, and in Röntgen ray therapy it is used in place of bismuth nitrate, which has sometimes given bad effects. Zirconia is a beautiful soft white powder which is well

[1] Böhm, C. R., Die technische Verwendung der Zirconerde: Chem. Zeitung, Jahr 35, Nov. 14, 1911, pp. 1261-1262.

adapted for making paints and lacquers, as it is unaffected by gases, acids, or alkalies and has good covering power. It makes a good opaque glass, but for this use the borate is better than the oxide. It is used for a polishing powder in place of tin oxide. Ferrozirconium is manufactured by one German firm for use in steel. Zirconium carbide is extremely hard and makes a valuable abrasive. Glass 7 milimeters (one-fourth of an inch) thick is cut with it as readily as with a diamond.

Clear zircons of brownish, orange, or reddish color are cut for gems and are then known as hyacinths. There is no likelihood of stones sufficiently large for cutting being found at the Ashland locality, but they may be present in some of the pegmatites.

ECONOMIC ASPECTS.

The uses enumerated are largely suggested rather than actual and their practicability is mostly dependent on the cheapness of the zirconia and the quantity available. Böhm [1] states that large quantities of native zirconia (zirconium oxide) known as baddeleyite are found near São Paulo, Brazil, and that much has been shipped to Germany. This material at the time he wrote was being furnished at the following prices:

Composition and prices of baddeleyite.

Designation.	ZrO_2 (per cent).	Fe_2O_3 (per cent).	SiO_2 (per cent).	Price per ton (2,000 pounds).
Zircon-S-Erz	90-92	1	8	$151
Zircon-Z-Erz	90-92	7	1	155
Zircon-NS-Erz	98	0.8	[1] 1	215

[1] Remainder H_2O.

The mineral quoted is already in the form of oxide and for most purposes would be more desirable than zircon, which would have to be reduced to the oxide, and should sufficient native oxide be found to supply demands competition would be difficult for zircon. For ferrozirconium or zirconium carbide the zircon could possibly be used without reduction to the oxide.

Should the demand for zircon and further testing of the Ashland deposit warrant exploitation, operations could be carried on with comparative ease. The rock can be crushed easily, the zircon and associated heavy minerals could be separated from the quartz by shaking tables, and the ilmenite could be picked out by a magnetic separator.

[1] Op. cit., p. 1261.

SURVEY PUBLICATIONS ON ANTIMONY, CHROMIUM, MONAZITE, NICKEL, PLATINUM, QUICKSILVER, TIN, TUNGSTEN, URANIUM, VANADIUM, ETC.

The principal publications by the United States Geological Survey on the rarer metals are those named in the following list. These publications, except those to which a price is affixed, can be obtained free by applying to the Director, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. The publications marked "Exhausted" are no longer available for distribution, but may be seen at the larger libraries of the country. No publications on Alaskan occurrences are listed here, but a list is given in Bulletin 520, the annual report on progress of the Survey's investigations in Alaska for 1911.

BANCROFT, HOWLAND, Notes on the occurrence of cinnabar in central western Arizona: Bull. 430, 1910, pp. 151–153.

——— Platinum in southeastern Nevada: Bull. 430, 1910, pp. 192–199.

——— Notes on tungsten deposits near Deer Park, Washington: Bull. 430, 1910, pp. 214–216.

——— Reconnaissance of the ore deposits in northern Yuma County, Ariz: Bull. 451, 1911, 130 pp.

BECKER, G. F., Geology of the quicksilver deposits of the Pacific slope, with atlas: Mon., vol. 13, 1888, 486 pp. $2.

——— Quicksilver ore deposits: Mineral Resources U. S. for 1892, 1893, pp. 139–168. 50c.

BLAKE, W. P., Nickel; its ores, distribution, and metallurgy: Mineral Resources U. S. for 1882, 1883, pp. 399–420. 50c.

——— Tin ores and deposits: Mineral Resources U. S. for 1883–84, 1885, pp. 592–640. 60c.

BOUTWELL, J. M., Vanadium and uranium in southeastern Utah: Bull. 260, 1905, pp. 200–210. 40c.

CHRISTY, S. B., Quicksilver reduction at New Almaden [Cal.]: Mineral Resources U. S. for 1883–84, 1885, pp. 503–536. 60c.

COLLIER, A. J., Chromite or chromic iron ore: Mineral Resources U. S. for 1906, 1907, pp. 541–542. $1.

DAY, D. T., and RICHARDS, R. H., Investigations of black sands from placer mines: Bull. 285, 1906, pp. 150–164. Exhausted.

EMMONS, S. F., Platinum in copper ores in Wyoming: Bull. 213, 1903, pp. 94–97. 25c.

GALE, H. S., Carnotite in Rio Blanco County, Colo.: Bull. 315, 1907, pp. 110–117.

——— Carnotite and associated minerals in western Routt County, Colo.: Bull. 340, 1908, pp. 257–262. 30c.

GLENN, W., Chromic iron: Seventeenth Ann. Rept., pt. 3, 1896, pp. 261–273.

GRATON, L. C., The Carolina tin belt: Bull. 260, 1905, pp. 188-195. 40c.
——— Reconnaissance of some gold and tin deposits in the southern Appalachians: Bull. 293, 1906, 134 pp.
HARDER, E. C., Some chromite deposits in western and central California: Bull. 430, 1910, pp. 167-183.
HESS, F. L., Some molybdenum deposits of Maine, Utah, and California: Bull. 340, 1908, pp. 231-240. 30c.
——— The Arkansas antimony deposits: Bull. 340, 1908, pp. 241-256. 30c.
——— Note on a tungsten-bearing vein near Raymond, Cal.: Bull. 340, 1908, p. 271. 30c.
——— Minerals of the rare-earth metals at Baringer Hill, Llano County, Tex.: Bull. 340, 1908, pp. 286-294. 30c.
——— Tin, tungsten, and tantalum deposits of South Dakota: Bull. 380, 1909, pp. 131-163.
——— Note on a wolframite deposit in the Whetstone Mountains, Arizona: Bull. 380, 1909, pp. 131-163.
——— Arsenic: Mineral Resources U. S. for 1908, pt. 2, 1909, pp. 599-601, 80c.; idem for 1911, pt. 2, 1912, pp. 855-856.
——— Antimony: Mineral Resources U. S. for 1908, pt. 1, 1909, pp. 709-711, 80c.; idem for 1911, pt. 1, 1912, pp. 973-975.
——— Bismuth: Mineral Resources U. S. for 1908, pt. 1, 1909, pp. 713-714, 80c.; idem for 1911, pt. 1, 1912, p. 976.
——— Lithium: Mineral Resources U. S. for 1909, pt. 2, 1911, pp. 649-653. 75c.
——— Selenium: Mineral Resources U. S. for 1908, pt. 1, 1909, pp. 715-717, 80c.; idem for 1911, pt. 1, 1912, p. 977.
——— Tellurium: Mineral Resources U. S. for 1908, pt. 1, 1909, pp. 719-720. 80c.
——— Tungsten, nickel, cobalt, vanadium, etc.: Mineral Resources U. S. for 1908, pt. 1, 1909, pp. 721-749, 80c.; idem for 1911, pt. 1, 1912, pp. 941-962.
——— Tin: Mineral Resources U. S. for 1908, pt. 1, 1909, pp. 771-779, 80c.; idem for 1911, pt. 1, 1912, pp. 963-972.
——— The arsenic deposits at Brinton, Va.: Bull. 470, 1911, pp. 205-211.
HESS, F. L., and GRATON, L. C., The occurrence and distribution of tin: Bull. 260, 1905, pp. 161-187. 40c.
HILL, J. M., Note on the occurrence of tungsten minerals near Calabasas, Ariz.: Bull. 430, 1910, pp. 164-166.
——— Mining districts of the western United States: Bull. 507, 1912, 309 pp.
HILLEBRAND, W. F., Nitrogen in uraninite, and the composition of uraninite in general: Bull. 78, 1891, pp. 43-78. 80c.
——— Distribution and quantitative occurrence of vanadium and molybdenum in rocks of the United States: Bull. 167, 1900, pp. 49-55. 15c.
HILLEBRAND, W. F., and RANSOME, F. L., On carnotite and associated vanadiferous minerals in western Colorado: Bull. 262, 1905, pp. 9-31.
HILLEBRAND, W. F., and SCHALLER, W. T., Mercury minerals from Terlingua, Tex.: Bull. 405, 1909, 174 pp. 20c.
HOBBS, W. H., The old tungsten mine at Trumbull, Conn.: Twenty-second Ann. Rept., pt. 2, 1902, pp. 7-22.
——— Tungsten mining at Trumbull, Conn.: Bull. 213, 1903, p. 98. 25c.
KAY, G. F., Nickel deposits of Nickel Mountain, Oregon: Bull. 315, 1907, pp. 120-127.
KEMP, J. F., The geological relations and distribution of platinum and associated metals: Bull. 193, 1902, 95 pp. 30c.
LINDGREN, WALDEMAR, Platinum and allied metals: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 987-1003.

McCaskey, H. D., Quicksilver: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 889–991.

Packard, R. L., Genesis of nickel ores: Mineral Resources U. S. for 1892, 1893, pp. 170–177. 50c.

Paige, Sidney, Mineral resources of the Llano-Burnet region, Texas, with an account of the pre-Cambrian geology: Bull. 450, 1911, 103 pp.

Phalen, W. C., Chromic iron ore: Mineral Resources U. S. for 1911, pt. 1, 1912: pp. 979–986.

Richardson, G. B., Tin in the Franklin Mountains, Texas: Bull. 285, 1906, pp. 146–149. Exhausted.

——— Antimony in southern Utah: Bull. 340, 1908, pp. 253–256. 30c.

Rolker, C. M., The production of tin in various parts of the world: Sixteenth Ann. Rept., pt. 3, 1895, pp. 458–538. $1.20.

Schrader, F. C., An occurrence of monazite in northern Idaho: Bull. 430, 1910, pp. 184–191.

Schrader, F. C., and Hill, J. M., Some occurrences of molybdenite in the Santa Rita and Patagonia Mountains, Arizona: Bull. 430, 1910, pp. 154–163.

Siebenthal, C. E., Cadmium: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 399–401.

Smith, G. O., A molybdenite deposit in eastern Maine: Bull. 260, 1905, pp. 197–199. 40c.

Sterrett, D. B., Monazite deposits of the Carolinas: Bull. 340, 1908, pp. 272–285. 30c.

——— Monazite: Mineral Resources U. S. for 1911, pt. 2, 1912, pp. 1193–1196.

Ulke, T., Occurrence of tin ore in North Carolina and Virginia: Mineral Resources U. S. for 1893, 1894, pp. 178–182. 50c.

Watson, T. L., and Taber, Stephen, The Virginia rutile deposits: Bull. 430, 1910, pp. 200–213.

Weed, W. H., The El Paso tin deposits [Texas]: Bull. 178, 1901, 15 pp. 5c.

——— Tin deposits at El Paso, Tex.: Bull. 213, 1903, pp. 99–102. 25c.

Weeks, F. B., Tungsten deposits in the Snake Range, White Pine County, eastern Nevada: Bull. 340, 1908, pp. 263–270. 30c.

IRON AND MANGANESE.

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, United States Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.; the monographs and folios from either that official or the Director of the Survey. The publications marked "Exhausted" are no longer available for distribution but may be consulted at the larger libraries of the country. Several geologic folios not given in this list contain descriptions of iron-ore deposits of more or less importance.

BALL, S. H., The Hartville iron ore range, Wyoming: Bull. 315, 1907, pp. 190–205.

——— Titaniferous iron ores of Iron Mountain, Wyoming: Bull. 315, 1907, pp. 206–212.

BANCROFT, HOWLAND, Reconnaissance of the ore deposits in northern Yuma County, Ariz.: Bull. 451, 1911, 130 pp.

BARNES, PHINEAS, The present technical condition of the steel industry of the United States: Bull. 25, 1885, 85 pp. 10c.

BAYLEY, W. S., The Menominee iron-bearing district of Michigan: Mon., vol. 46, 1904, 513 pp. $1.75.

BAYLEY, W. S., and others, Passaic folio (No. 157), Geol. Atlas U. S., 1908. 25c.

BIRKINBINE, J., The production of iron ores in various parts of the world: Sixteenth Ann. Rept., pt. 3, 1894, pp. 21–218. $1.20.

BOUTWELL, J. M., Iron ores in the Uinta Mountains, Utah: Bull. 225, 1904, pp. 221–228. 35c.

BURCHARD, E. F., The iron ores of the Brookwood district, Alabama: Bull. 260, 1905, pp. 321–334. 40c.

——— The Clinton or red ores of the Birmingham district: Bull. 315, 1907, pp. 130–151.

——— The brown ores of the Russellville district, Alabama: Bull. 315, 1907, pp. 152–160.

——— The Clinton iron ore deposits in Alabama: Trans. Am. Inst. Min. Eng., vol. 39, 1908, pp. 997–1055.

——— An estimate of the tonnage of available Clinton iron ore in the Birmingham district, Alabama: Bull. 340, 1908, pp. 308–317.

Burchard, E. F., Tonnage estimates of Clinton iron ore in the Chattanooga region of Tennessee, Georgia, and Alabama: Bull. 380, 1909, pp. 169–187.

——— Iron ore, pig iron, and steel: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 119–190.

——— Manganes ore: Mineral Resources U. S. for 1911, pt. 1, 1912, pp. 191–208.

Burchard, E. F., Butts, Charles, and Eckel, E. C., Iron ores, fuels, and fluxes of the Birmingham district, Alabama: Bull. 400, 1910, 204 pp.

Butts, Charles, Mineral resources of the Kittanning and Rural Valley quadrangles, Pennsylvania: Bull. 279, 1906, 198 pp.

——— Iron ores in the Montevallo-Columbiana region: Bull. 470, 1911, pp. 215–230.

Clements, J. M., The Vermilion iron-bearing district of Minnesota: Mon., vol. 45, 1903, 463 pp. $3.50.

Clements, J. M., Smyth, H. L., Bayley, W. S., and Van Hise, C. R., The Crystal Falls iron-bearing district of Michigan: Nineteenth Ann. Rept., pt. 3, 1898, pp. 1–157. $2.25. Also Mon., vol. 36, 1899, 512 pp. $2.

Diller, J. S., Iron ores of the Redding quadrangle, California: Bull. 213, 1903, pp. 219–220. 25c.

——— So-called iron ore near Portland, Oreg.: Bull. 260, 1905, pp. 343–347. 40c.

Eckel, E. C., Utilization of iron and steel slags: Bull. 213, 1903, pp. 221–231. 25c.

——— Iron ores of the United States: Bull. 260, 1905, pp. 317–320. 40c.

——— Limonite deposits of eastern New York and western New England: Bull. 260, 1905, pp. 335–342. 40c.

——— Iron ores of northeastern Texas: Bull. 260, 1905, pp. 348–354. 40c.

——— The Clinton hematite: Eng. and Min. Jour., vol. 79, 1905, pp. 897–898.

——— The iron industry of Texas, present and prospective: Iron Age, vol. 76, 1905, pp. 478–479.

——— The Clinton or red ores of northern Alabama: Bull. 285, 1906, pp. 172–179. Exhausted.

——— The Oriskany and Clinton iron ores of Virginia: Bull. 285, 1906, pp. 183–189. Exhausted.

Harder, E. C., Manganese deposits of the United States; with sections on foreign deposits, chemistry, and uses: Bull. 427, 1910, 208 pp.

——— The Taylor Peak and Whitepine iron-ore deposits, Colorado: Bull. 380 1909, pp. 188–198.

——— The iron ores of the Appalachian region in Virginia: Bull. 380, 1909, pp, 215–254.

——— Manganese deposits of the United States: Bull. 380, 1909, pp. 255–277.

——— Some iron ores of western and central California: Bull. 430, 1910, pp. 219–227.

——— Iron ores near Dayton, Nev.: Bull. 430, 1910, pp. 240–246.

——— Deposits of brown iron ore near Dillsburg, York County, Pa.: Bull. 430, 1910, pp. 250–255.

——— Iron-ore deposits of the Eagle Mountains, California: Bull. 503, 1912, 81 pp.

Harder, E. C., and Rich, J. L., The Iron Age iron-ore deposit near Dale, San Bernardino County, Cal.: Bull. 430, 1910, pp. 228–239.

Hayes, C. W., Geological relations of the iron ores in the Cartersville district, Georgia: Trans. Am. Inst. Min. Eng., vol. 30, 1901, pp. 403–419.

——— Manganese ores of the Cartersville district, Georgia: Bull. 213, 1903, p. 232. 25c.

——— Iron ores of the United States: Bull. 394, 1909, pp. 70–113.

Hayes, C. W., and Eckel, E. C., Iron ores of the Cartersville district, Georgia: Bull. 213, 1903, pp. 233–242. 25c.

Hill, J. M., Mining districts of the western United States: Bull. 507, 1912, 309 pp.

HOLDEN, R. J., The brown ores of the New River-Cripple Creek district, Virginia: Bull. 285, 1906, pp. 190–193. Exhausted.

IRVING, R. D., and VAN HISE, C. R., The Penokee iron-bearing series of Michigan and Wisconsin: Tenth Ann. Rept., pt. 1, 1889, pp. 341–507. $2.35.

IRVING, R. D., and VAN HISE, C. R., The Penokee iron-bearing series of Michigan and Wisconsin: Mon., vol. 19, 1892, 534 pp. $1.70.

KEITH, ARTHUR, Iron-ore deposits of the Cranberry district, North Carolina-Tennessee: Bull. 213, 1903, pp. 243–246. 25c.

KEMP, J. F., The titaniferous iron ores of the Adirondacks: Nineteenth Ann. Rept., pt. 3, 1899, pp. 377–422. $2.25.

KINDLE, E. M., The iron ores of Bath County, Ky.: Bull. 285, 1906, pp. 180–182. Exhausted.

LEITH, C. K., The Mesabi iron-bearing district of Minnesota: Mon., vol. 43, 1903, 316 pp. $1.50.

——— Geologic work in the Lake Superior iron district during 1902: Bull. 213, 1903, pp. 247–250. 25c.

——— The Lake Superior mining region during 1903: Bull. 225, 1904, pp. 215–220. 35c.

——— Iron ores in southern Utah: Bull. 225, 1904, pp. 229–237. 35c.

——— Genesis of the Lake Superior iron ores: Econ. Geology, vol. 1, 1905, pp. 47–66.

——— Iron ores of the western United States and British Columbia: Bull. 285, 1906, pp. 194–200. Exhausted.

——— The geology of the Cuyuna iron range, Minnesota: Econ. Geology, vol. 2, 1907, pp. 145–152.

——— Iron ore reserves: Econ. Geology, vol. 1, 1906, pp. 360–368.

——— A summary of Lake Superior geology with special reference to recent studies of the iron-bearing series: Trans. Am. Inst. Min. Eng., vol. 35, 1904, pp. 454–507.

LEITH, C. K., and HARDER, E. C., The iron ores of the Iron Springs district, southern Utah: Bull. 338, 1908, 102 pp.

PAIGE, SIDNEY, The Hanover iron-ore deposits, New Mexico: Bull. 380, 1909, pp. 199–214.

——— Preliminary report on pre-Cambrian geology and iron ores of Llano County, Tex.: Bull. 430, 1910, pp. 256–268.

——— Mineral resources of the Llano-Burnet region, Texas, with an account of the pre-Cambrian geology: Bull. 450, 1911, 102 pp.

PHALEN, W. C., Iron ores near Ellijay, Ga.: Bull. 340, 1908, pp. 330–334.

——— Origin and occurrence of certain iron ores in northeastern Kentucky: Econ. Geology, vol. 1, 1906, pp. 660–673.

——— Economic geology of the Kenova quadrangle (Kentucky, Ohio, and West Virginia): Bull. 349, 1908, 158 pp.

SMITH, G. O., and WILLIS, BAILEY, The Clealum iron ores, Washington: Trans. Am. Inst. Min. Eng., vol. 30, 1901, pp. 356–366.

SMITH, P. S., The gray iron ores of Talladega County, Ala.: Bull. 315, 1907, pp. 161–184.

SPENCER, A. C., The iron ores of Santiago, Cuba: Eng. and Min. Jour., vol. 72, 1901, pp. 633–634.

——— Manganese deposits of Santiago, Cuba: Bull. 213, 1903, pp. 251–255. 25c.

——— Magnetite deposits of the Cornwall type in Berks and Lebanon counties, Pa.: Bull. 315, 1907, pp. 185–189.

——— Three deposits of iron ore in Cuba: Bull. 340, 1908, pp. 318–329.

——— Magnetite deposits of the Cornwall type in Pennsylvania: Bull. 359, 1908, 102 pp.

——— The Jauss iron mine, Dillsburg, Pa.: Bull. 430, 1910, pp. 247–249.

SPENCER, A. C., and others, Franklin Furnace folio (No. 161), Geol. Atlas U. S., 1908. 25c.

SWANK, J. M., Iron and steel and allied industries in all countries: Eighteenth Ann. Rept., pt. 5, 1896, pp. 51-140.

VAN HISE, C. R., The iron-ore deposits of the Lake Superior region: Twenty-first Ann. Rept., pt. 3, 1901, pp. 305-434. $1.75.

VAN HISE, C. R., and BAYLEY, W. S., Menominee special folio (No. 62), Geol. Atlas U. S., 1900. 25c.

VAN HISE, C. R., and LEITH, C. K., The geology of the Lake Superior region: Mon., vol. 52, 1911, 626 pp. $2.50.

VAN HISE, C. R., BAYLEY, W. S., and SMYTH, H. L., Preliminary report on the Marquette iron-bearing district of Michigan: Fifteenth Ann. Rept., 1894, pp. 477-650. $1.70.

——— The Marquette iron-bearing district of Michigan, with atlas: Mon., vol. 28, 1897, 608 pp. $5.75.

WOLFF, J. E., Zinc and manganese deposits of Franklin Furnace, N. J.: Bull. 213, 1903, pp. 214-217. 25c.