CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
3550 N. Central Ave, 2nd floor
Phoenix, AZ, 85012
602-771-1601
http://www.azgs.az.gov
inquiries@azgs.az.gov

the conclusion of the regular meeting of the Institute a ...er of excursions were arranged for the members.

...cursions were held (1) to the works of the New Jersey Zinc ...pany at Palmerton, the works of the Atlas Portland Cement ...pany, of the Lehigh Portland Cement Company, and of the ...mas Iron Company, all of which companies had kindly ex-...d invitations; (2) to the works of the Ingersoll-Rand Com-... near Phillipsburg, New Jersey, and of the New Jersey ... Company at South Bethlehem.

...R. WALDEMAR LINDGREN, of the U. S. Geological Survey, ...returned from Paris and is now in Washington, D. C.

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SKETCH OF THE GEOLOGY AND ORE DEPOSITS OF THE CHERRY CREEK DISTRICT, ARIZONA.

JOHN A. REID.

INTRODUCTION.

A trip to the Cherry Creek mining district of Arizona, taken on mining business during the month of July, 1905, put the writer in possession of a few facts of interest and value, both to those interested in the geology of that region and to those studying the expanding literature of ore deposits. The geological importance of this locality is two-fold: First, from the standpoint of descriptive geology, concerning the structure and the relation of this structure to the physiography of the plateau region of Arizona; and second, from the standpoint of economic geology, concerning the peculiarity of ore deposition. The famous United Verde copper mine at Jerome is only about sixteen miles north of Cherry Creek on the same range, and the deposits of the two places are apparently very similar. The policy of a rigorous exclusion of outsiders is applied at Jerome, hence there is an additional value attached to the study of the Cherry Creek district.

As the title indicates, merely a sketch of the geology will be presented. The minutiæ of the subject must await that time when correlation with adjacent districts can be made, and the geology of all of this portion of Arizona becomes a unit. The aim of this [illegible] s at most merely to constitute a single stratum of the future [illegible] te series.

LOCATION.

[illegible] Cherry Creek mining district is situated in the northern [illegible] part of Arizona, in the Black Hills range of mountains. It is [illegible] nty-five miles from Prescott in an air line, in a direction [illegible] imately N. 85° E. The name is taken from that of a creek [illegible] through the area, a tributary of the Rio Verde, noted [illegible] e large number of wild cherry trees growing along its [illegible] s. Cherry Creek has its headwaters a few miles to the [illegible] f the small village of Cherry Creek, better known as Cherry [illegible] Office, through which it flows in its general easterly course. [illegible] tream is perennial and furnishes the water for the small [illegible] g, fruit and cattle-raising interests which support the inhab[illegible] in its vicinity. The district is reached from Prescott, first, [illegible] Prescott and Eastern Railway twenty-one miles to the rail[illegible] tation of Cherry Creek, or Dewey Post Office, thence by [illegible] eighteen miles to Cherry Creek proper. The United Verde [illegible] ies to the north, as stated; the Globe district is situated one [illegible] d miles southeast.

TOPOGRAPHY.

[illegible] mountain region of Arizona occupies a belt of country [illegible] g diagonally through the state from the northwest to the [illegible] ast, bounded on the northeast by the Great Plateaus and on [illegible] uthwest by the desert region. The mountain region con[illegible] f numerous ranges trending parallel to the direction of the [illegible] which they lie. This belt being somewhat curved, the [illegible] are not all parallel, but change from almost north-south [illegible] rly east-west, the average course being N. W.-S. E. The [illegible] Hills range, in which both Cherry Creek and Jerome lie, [illegible] tle north of the center of the mountain region. The trend [illegible] range is N. 35° W.; the length, as a distant unit, sixty [illegible] the width roughly eighteen miles. It is the first range to [illegible] st of the Great Plateaus in this part of Arizona, being sepa[illegible] from the mesa land by the valley of the Rio Verde. To [illegible] estward lies the Agua Fria valley, drained by Agua Fria

Creek, and separating the Black Hills from the Bradshaw range, in the northern part of which lies Prescott. In form, the Black Hills may be divided into two equal parts, separated by a lower narrower portion. The elevation of the two ends is over six thousand feet; the elevation of the middle portion is about five thousand two hundred feet. The Cherry Creek district lies in this low portion of the range, in the eastern part.

From the hill tops near Cherry Post Office, which here form the range summit, there is a truly magnificent view to the eastward. The slopes descend steeply for three thousand feet to the valley of the Rio Verde, across which the red and pink cliffs of the Plateau limestones rise sheer for several thousand feet, and extend north and south as far as the eye can see. Marvine,[1] who crossed this region in 1871, has presented a brief description of its larger geographic and geologic features.

The topography of the district is simple; the elements are not many and are easily distinguished. The highest hills are of the typical mesa form, and are found best developed immediately surrounding Cherry Post Office just above the valley of the Rio Verde. On the extreme east of the district the steep slopes below the flat mesa tops lead down to the low hills belonging to the river valley. To the west the mesa effect becomes obliterated; the hills rise to about the same level but are of rounded forms. Further west, the altitude becomes gradually lower until the range merges into the lowlands. The valleys separating the individual hills are due either to stream action, when they are wide and flaring, or to orogenic movements when they are sharp cut and narrow. The relief of the district, except on the long east slope of the range, is not great, the hill tops seldom rising more than four hundred or five hundred feet above the intervening valleys.

Cherry Creek is the chief stream draining the district. The divide separating its sources from those of the westward flowing streams lies in the western part of the area. In general, all secondary stream courses are at right angles to the range crest, but vary somewhat on account of faulting and differential weathering in the rocks.

[1] Wheeler Survey, Vol. III., 1875, pp. 207–208.

T... ...lack Hills, in this region, furnish fair amounts of timber, alth... much has been culled, and a sufficient supply of water for ...ng purposes. At the Pfau mine, on the eastern slope, a w... ...upply sufficient for the needs of a two hundred ton mill and ...ide plant is obtained by pumping from a shallow well.

GENERAL GEOLOGY.

T... ...eology of the district is not complex. Upon the pre-Ca... ...n complex of schists and granitic rocks rest, in a horizon... ...r nearly horizontal position, beds of limestone, with a tota... ...ckness of approximately one hundred feet. Only isolate... ...ches of this limestone remain, due often to the protecting infl... ...of late basalt, which occurs also in patches as remnants of a... ...es of flows lying nearly or quite horizontal over all other rocl... In the Cherry Creek district, granite, including dikes of gra... ...porphyry, is the only rock of the basement complex, and the ...nger rocks are found only on the hills along the range cres... It is these later rocks which, both by erosion alone and by ero... ...after faulting, have produced the mesas of the area. In the ...eme west of a section across the Black Hills at Cherry Cre... ...nly a few hundred feet above Agua Fria valley, occur sma... ...atches of schist embedded in the granite. To the east, bel... ...e steep eastward facing slope of the range, occur other sed... ...tary beds, largely sandstone, which form a series of low hill... ...l ridges extending out into the valley of the Rio Verde. Th... ...ventually join the low hills rising eastward up to the ste... ...carpment beyond, which forms the western edge of the Gr... ...lateaus. There is roughly a difference in elevation of tw... ...usand feet between the mesa tops near Cherry Creek and the ...est of the low hills below the eastern face. The accompa... ...section, following Marvine[1] for the portion east of the dist... under discussion, presents graphically the main geological fea... (Fig. 31). The cliffs to the east of the Rio Verde are for... by the **Red Wall series, with the Aubrey beds outcropping** fur... east. Marvine[2] notes that the Rio Verde flows over Red

[1] ...ler Survey, Part III., p. 226.
[2] ...ler Survey, Part III., p. 208.

Wall limestone, hence it is probable that the low hills which persist to the east face of the Black Hills belong to the Red Wall beds, above the limestone. These beds dip slightly to the east toward the river. At the Pfau mine, the largest of the district, situated some hundred feet above the low hills just noted, an isolated mass of distorted and broken limestone was found a short distance below the surface, covered by the ordinary products of rock decay. Directly up the slope above the mine is the range summit, capped by horizontal limestone beds. The age of this limestone is yet uncertain, as lack of time prevented search for fossils. The color of the stone is a light gray when fresh, weathering to a darker gray, and, although considerable amounts of iron are present, the rock does not assume the striking colors of the Red Wall beds across the valley. From field considerations, the writer is inclined to believe the age to be that of the Red Wall series, but only careful study can determine this point.

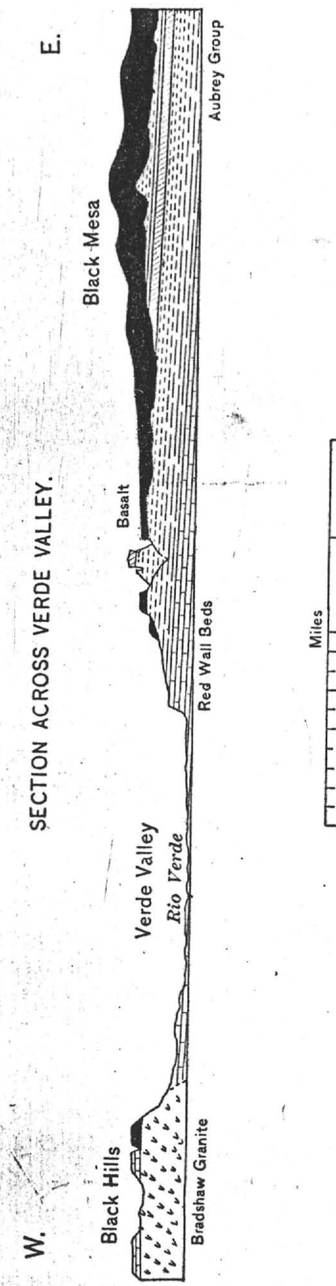

FIG. 31.

ROCKS.

No detailed petrographic work was done on any of the rocks of the district, but as the work of Jaggar and Palache covers all of the rocks but one, and as their field peculiarities may suffice at all times to identify them, the following brief discussion is given.[1]

Schist.—The oldest rock in the region is a metamorphosed sediment, a crystalline schist, or a phyllite with a well developed slaty cleavage. The occurrences are confined to the western portion of the Black Hills, in the lower part just above Agua Fria valley. This valley is itself cut largely from these schists, as shown further south in the Bradshaw Mountain Folio. The strike of the rocks is a little east of north, although in some of the detached fragmental areas the strike changes to west of north. The dip is about vertical, or highly inclined to the east. In appearance the rock is most often of a light gray color, with a lustre like satin due to flakes of muscovite, and with a well developed cleavage wherever seen. The name given to this rock by Jaggar and Palache is Yavapai schist. The age is lower Algonkian, corresponding to the Vichnu terrane of the Grand Cañon geologic column. The Pinal schists of Ransome,[2] in the Globe district, are probably of the same great series of pre-Cambrian sediments. In the Bradshaw Mountains these schists contain many valuable ore deposits; no veins are known in the small area of them west of Cherry Creek.

Granite.—The granitic rocks of the Black Hills in the vicinity of Cherry Creek are of two well defined varieties: a hornblende bearing biotite granite, making up most of the country rock, and a granite porphyry, in the form of dikes intruded into the granite.

The granite is a medium gray rock, with a decided pinkish tint. The grain is somewhat finer than in the same rock further east in the Bradshaw Mountains, the average size of grain being about three mm. The quartz is glassy and colorless, but contains inclusions of magnetite, biotite and hornblende. The largest grains are four mm. in diameter, and the mineral makes up about 35 per cent. of the whole. The feldspar appears to be chiefly orthoclase, cloudy and pink, with a granular texture due

[1] Bradshaw Mountain Folio, No. 126, U. S. G. S.

[2] F. L. Ransome, Professional Paper No. 12, U. S. G. S.

to the stresses and movements in the rock mass. One stout Carlsbad twin observed was four mm. long, but in the main the grains are much finer. Inclusions of the dark minerals are common. The feldspars compose about 40 per cent. of the rock. The biotite, of which there is a little more than 15 per cent. in the total occurs usually in ragged flakes, with a few well formed hexagonal crystals. The largest flakes are six to seven mm. in diameter, of a deep brown color when unaltered. Chlorite has been formed in sufficient amount to impart to most of the mica a green tinge. The hornblende is formed in distinct prisms, commonly small, about two mm. long, but at times in larger crystals up to six mm. in length. It makes up less than 10 per cent. of the rock. The larger prisms are frequently cracked and broken. Spots of secondary hematite are common throughout the whole.

This granite occurs as a direct continuation of the granitic area of the Bradshaw quadrangle,[1] and hence is a portion of the Bradshaw granite, as named by the authors of that folio. An interesting and necessary correlation is yet to be made between the granites of this area and the other known areas north and south.

The granite-porphyry is invariably fractured, shattered and decomposed. Quartz phenocrysts averaging two mm. in size and composing about 40 per cent. of the whole, are set in a fine-grained matrix, granular from earth movements. Ferromagnesian minerals are to be seen only as dark spots. Some limonite in pseudomorphs after pyrite occur. The color is a light pink, due to weathering. The greatest number of the granite-porphyry dikes run in a general north-south direction, varying from N. 38° W., about parallel to the trend of the range, to N. 35° E. The same dike may change its direction within a few feet, as at the Pfau mine. In the main, these dikes dip to the west at moderate angles; in the extreme east the dip is to the east at high angles. A few dikes run east and west, dipping to the north at low angles. The largest dike is the most easterly, that at the Pfau and Pfau Extension mines. This dips steeply eastward, is several hundred feet wide, and strikes at the Pfau mine N. 26° W., at the Pfau

[1] Bradshaw Mountain Folio, No. 126, U. S. G. S.

Extension N. 16° E., and further south N. 34° E. This dike appears to lie approximately in the plane of the steep eastern face of the Black Hills range. The granite-porphyry is in larger masses in the western portion of the range, where its darker color due to weathering serves to distinguish it. The topographic forms produced by both types of granite rock are gently flowing curves with but very rare outcrops. The erosion of the region has removed most of the sedimentary rocks overlying the basement of schist and granite, but this process has not proceeded as far as in the Bradshaw Mountains, where none of the Paleozoic beds are found.

Limestone.—The limestone lying upon the eroded surface of the pre-Cambrian terranes is a fine grained, light gray rock, weathering to a darker gray with a trace of red. It contains considerable amounts of iron, for nodules of rather pure limonite weather out, at times in profusion. As stated above, lack of time prevented a search for fossils, so that the age is not certain. Probably the rock is of the Red Wall series, hence belongs in the lower part of the Carboniferous. If this be so, and proof be forthcoming at a later date, a very important bit of geologic history will be obtained. The unconformity between the granitic basement and the limestone would represent a land mass and a period of erosion covering the time between lower Algonkian and Carboniferous. The alternative of a fluctuating land mass upon which some sediments were deposited and then completely removed before Carboniferous time is less likely, for only a short distance north the geologic column is complete, with the Tonto sandstone at the base. Moreover, the pre-Cambrian land surface reached a well developed peneplain condition in this area.

Basalt.—The basalt areas in the Black Hills cap only the summits of the highest hills, frequently over the limestone. This rock was outpoured in a series of Tertiary flows which now lie practically horizontal. The rock is a typical black lava, called locally " malapai," corrupted from " malpais," meaning bad land. It has been fully described in the writings of the pioneer geologists, and in the later works of Ransome, Jaggar and Palache. No dikes or intrusions of this rock were noted in the district. Its greatest importance lies in its effect upon the topography.

FAULTING AND STRUCTURE.

The faults of the range in the vicinity of the Cherry Creek district are divisible into two main systems: one a north-south, and the other an east-west system. On a second mode of classification, the faults are either pre-Carboniferous, if the limestone of the range top be of Carboniferous age, or post-Carboniferous, including movements up to the present. The older fractures have resulted in the formation of ore bodies; the later have produced the larger features of the present range. The later movements have in general paralleled the first, but are not necessarily coincident with them, There have been no post-Carboniferous movements along the planes of the veins examined.

In a granitic complex, faulting is often largely or wholly obscured, and physiographic criteria, checked by possible stratigraphic evidence, become the sole means of establishing planes of motion. In the Black Hills such evidence is not lacking, although the facts obtained are fewer than could be desired.

In outline, the section across the range at Cherry Creek, from east to west, shows first a steep rise from the valley of the Rio Verde to the summit, then a few miles of crest westward, passing into a comparatively gentle slope down to the Agua Fria valley. In other words, the curve through the hill tops would be an asymmetric arch, whose greatest elevation would be just above the steep eastern slope. It would seem, therefore, at first sight, that the granite exists merely as a huge dome, elongated north and south, whose larger form is due to its intrusive genesis. And such Marvine[1] assumed it to be. The limestone and basalt remnants do not, however, support this view. The steep eastern slope of the range is almost beyond doubt a fault cliff. At the summit, but westward a few hundred yards, the limestone lies horizontal upon the granite; at the base, a nearly horizontal series of sedimentary beds occur, abutting against the granite. At the Pfau mine, as already noted, a detached and broken mass of limestone was found below the surface on the granite slope. A full discussion here would be premature, as the whole range has not been

[1] Wheeler Survey, Part III., p. 208.

studied in detail, yet it is safe to assume that either a fault or a very sharply flexed monoclinal fold exists. The presence of other unmistakable north-south faults causes the balance of proof to fall on the side of a fault scarp forming the eastern face. Also, the profile of the bed of Cherry Creek adds to the probability of a large fault scarp. In the upper reaches this stream flows in a wide, flat bottomed bed, with a gentle slope. Some portions are of greater fall, indicating earth movements, but in general the stream has reached a mature stage. On coming to the eastern slope, however, the grade is abruptly changed, and topographic youth is strikingly apparent. The accompanying section expresses the main facts of the structure.

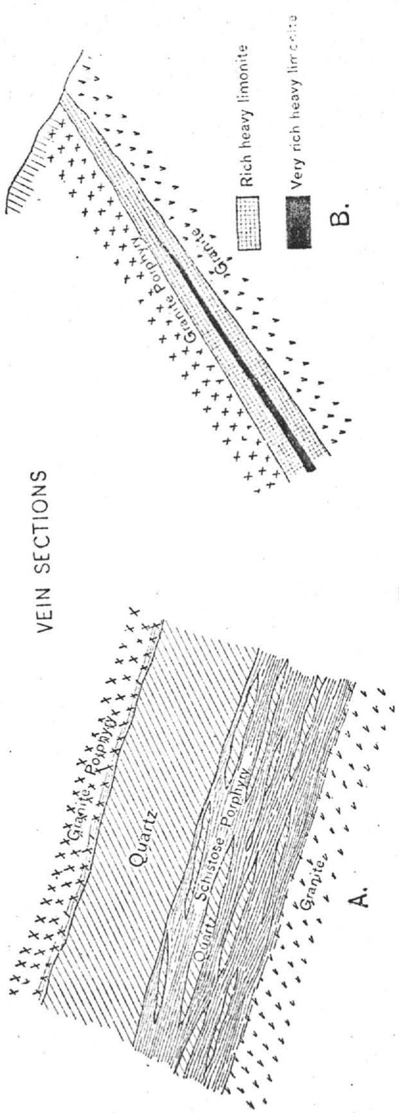

FIG. 32.

Earlier Faults.—The criteria for the proof of faulting before the granitic complex was baseleveled and covered by later sediments, lie entirely within the vein structure. The veins end beneath the limestone, with no continuation of motion upward into the overlying rocks. The veins are all associated with granite-porphyry dykes, which were themselves probably intruded along lines of movement when the mass was

in a semi-fluid condition. Later motion opened crevices within these dikes, the movement at this time being shown by the production of schistose granite and by the shattering of the dyke rock. Still later the veins were further opened by earth movements and more vein material deposited. These later movements were of varying and irregular intensity, as the second deposition of vein matter was unequal in the different veins. Finally, the dikes with their included deposits were greatly fractured, and the veins became open to surface agencies.

Later Faults.—The presence of faulting later than the deposition of the younger rocks is shown best by stratigraphic evidence. On Cherry Creek below the post office, where the stream flows in an east-southeast course, the south bank rises to a mesa capped by several hundred feet of basalt, while the north bank rises to the flat topped granite hill shown in figure 33 just above the eastern slope of the range. The unconformity is fully apparent. This line of movement is parallel to the outcrop of one of the larger east-west veins, which outcrops on the north bank just above the creek bottom. Also, in figure 33, the presence of a north-south fault is shown between the two hills, one capped with limestone, and the other of granite only. Many other instances can be cited, but these two are typical. The examination of the topography shows that a careful application of physiographic tests, when no rock but a crystalline one be present, may prove the existence of faulting. The stream valleys are prevailingly wide and flaring, the fault valleys are typically narrow and sharp cut. Also, the stream reaches in the granite indicate where differential motion has occurred. On this line of investigation, much unmistakable evidence for widespread faulting across the whole range can be obtained. The structure, then, can be summed up thus. The Black Hills range is due to differential uplift of a granite mass, the maximum elevation taking place on the east side. The essential lines of motion run northerly and southerly, parallel to the range; secondary movements occurred east and west, dividing the range into blocks, the detailed investigation of which is yet to be made.

ORE DEPOSITS.

Condition of District.—The Cherry Creek mining district produces some gold at present. Considerable prospecting is being done, and in time the region will figure as worthy of general attention from mining men. One mine is milling from one hundred to two hundred tons a day, and a second is shipping to Prescott a fair amount of smelting ore.

No deep prospecting has yet been done, the greatest depth yet reached by shaft, August, 1905, was only a little over one hundred feet, and an adit tunnel on another property was in about two hundred feet below the vein outcrop.

Veins.—As with the faults, two systems of veins exist. The major portion of those observed have a northerly strike and westerly dip; a few have a northerly strike and easterly dip, in the eastern part; a few have a westerly strike and a northerly dip. Both classes of veins have identically the same character of filling. The width averages about three feet at the surface, increasing with depth.

The veins occupy broken and sheeted zones within the porphyry dykes, which have been, subsequent to their formation, opened by later movements and new vein filling introduced. The earlier portions of the veins consist of stringers of quartz and ore in schistose and bleached granite-porphyry, the extraneous material making up usually less than one half the total width. Some of the veins have not advanced beyond this stage; the best of them have. The later fissuring, attended by faulting, has resulted in comparatively strong veins of massive quartz, above or below the first deposit, often forming the hanging wall of the dike. The latest movements in the veins have fractured the hard vein filling and opened the minerals to surface agencies, resulting in great secondary concentration of ores. Even the secondary surface ores have been reconcentrated in some instances. The accompanying sketches shown in Fig. 32 will give an idea of some of the typical veins.

Ores.—At present the mines are developing an oxidized, free-milling gold ore, with traces of sulphides with depth. The typical ore is heavily charged with limonite, locally called hematite, with

an aphanitic texture, and contains gold in bright shining flakes. The richest ore is nearly pure limonite, usually with some small amounts of silica. No other gangue minerals are found. With depth, kernels of unaltered pyrite are frequently found in the heavily oxidized ore, and this sulphide, together with chalcopyrite and bornite, occurs at times in isolated masses up to eight inches in diameter. In a few cases residual pyrite was found in the outcrop. The western viens have not yet shown copper minerals, chiefly because of lack of depth. This sulphide ore is invariably rich.

In the upper portions of the veins, the bleached and broken country rock is often milled as ore, though of low grade. On one mining claim a vein dips with the surface of the mesa, forming a dip slope. This has the peculiar result of causing the whole hillside to pan free gold and yield assay returns at times quite large. Such ore as this is almost entirely decomposed granite porphyry and granite, with a small amount of fine quartz fragments.

These peculiar aphanitic limonite ores, frequently contain-

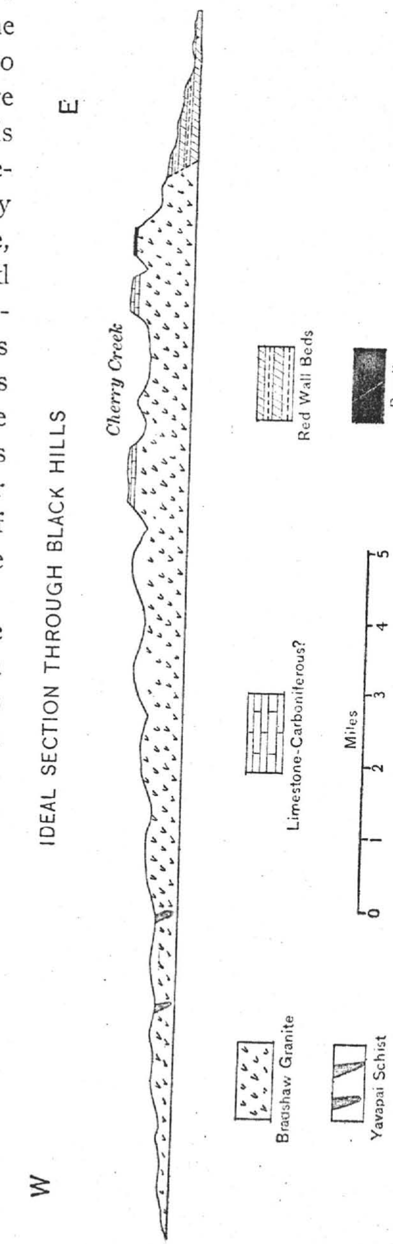

FIG. 33.

ing bright flakes of hematite, are not uncommon over the arid regions from Nevada southeastward. The chief interest connected with them lies in the controlling processes of secondary change. This is particularly true at Cherry Creek where the limonite-gold deposits change to copper deposits with depth.

SECONDARY CHANGES.

It is in the phenomenon of secondary deposition of minerals that the ores in the Cherry Creek district are peculiar and interesting, both from a mining and from a scientific standpoint. The development work in the mines has not yet progressed far enough to exhibit all the changes which have occurred, yet there can be no doubt that the four zones of Emmons[1] are almost ideally developed. Furthermore, the veins already opened show the instability of any one set of geological conditions, for the zone of impoverishment is invading the zone of rich oxides, which in turn is encroaching upon the rich sulphides below. The causes operating to make possible these continued changes are easily found. At least three distinct sets of movements fracturing the vein filling and enclosing dikes have occurred, so that the vadose waters have been free to circulate. The present water level in the mines is strikingly different from what it must have been in times past, for permanent water is found at about sixty feet, or even less in some mines, below the surface, while the heavy oxidized ore continues downward to unknown depths. A recent wet year is largely responsible for present conditions, but not entirely, for before the rains of 1904–5 the mines were water-bearing in some degree.

The zone of impoverishment, because of the continued leaching it is undergoing, presents several interesting features. As discussed by Emmons,[2] Weed[3] and others, this surface zone is characterized by low values, or lack of values, containing usually nothing but oxides of iron and silica. In Cherry Creek, however,

[1] S. F. Emmons, "Secondary Enrichment of Ore Deposits," *Trans. A. I. M. E.*, Feb., 1900.

[2] S. F. Emmons, *Trans. A. I. M. E.*, Feb., 1900, pp. 463–464.

[3] W. H. Weed, "Enrichment of Silver Veins," *Trans. A. I. M. E.*, Feb., 1900, p. 476.

a subzone of further impoverishment exists, from which not only the values have been leached, but also the iron oxides and even silica have been partially or very largely removed. The two factors of age and openness of veins have been chiefly responsible for this. At the surface, quartz, in most veins, outcrops in stringers and larger masses. Such surface quartz is not often prominent, because of the shattering of the material, although hard boulder-like fragments occur, surrounded by softer rock. In a few veins the outcrop is prominent, and is composed of quartz stringers in granite porphyry, the hard mineral restraining the erosion of the whole. Limonite, in stringers and veinlets, cements

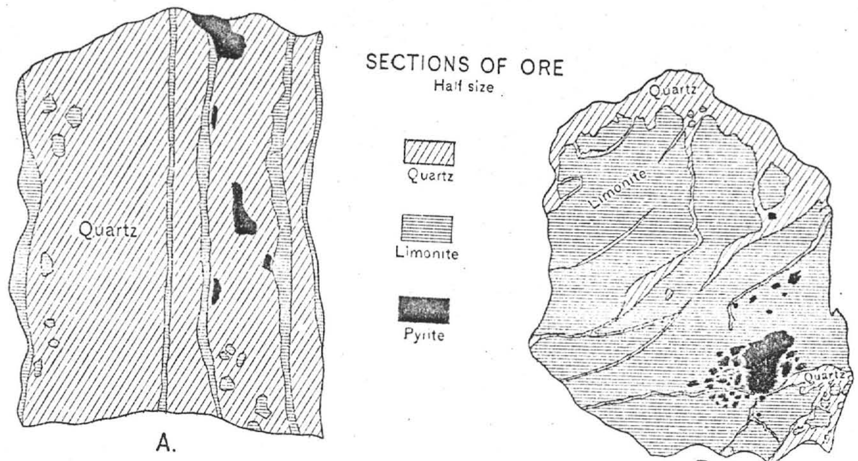

FIG. 34.

this broken quartz. The iron oxide frequently appears as pseudomorphs after pyrite, the form of the pyritohedron being very common. The main direction of breaking is parallel to the plane of the veins, hence the larger veinlets of limonite are more or less parallel, giving a rough effect of ribbon structure (see Fig. 34, *A*). Below the outcrop a few feet the quartz and contained limonite decrease in abundance, frequently disappearing entirely. Assay values showed the same, returns from the surface being notably higher in the majority of cases than five or ten feet lower down. Furthermore, in the instances where the quartz has only partly gone, the iron oxide has almost entirely been carried below, taking with it the gold values. In one of the larger east-west veins, the upper seventy-five feet has been thus leached of all but a trace, while below this depth good ore exists in quantity.

After the barren, or nearly barren, portion of the veins has been passed through, heavy rich limonite in quartz is encountered. The aphanitic texture is always prominent, and small shiny areas of unaltered pyrite are frequently present in the midst of the heaviest iron oxide (see Fig. 34, *B*). Secondary quartz, at times jaspery, is noticeable in this portion of the veins, and occurs both in irregular patches and in small veinlets in the limonite. The heavier the oxide, the larger the amount of secondary silica. At the Golden Idol mine, in which the vein material is about 90 per cent. iron oxide, the limonite extends to the surface. The outcrop is eighteen inches wide, assaying a low value; forty feet down the vein is five feet wide, of almost solid rich limonite, with a very rich ten inch streak in the center. The center streak is well defined and clearly a deposit later than the inclosing material (see Fig. 32). In the bottom of the workings rich sulphide ore is commencing to show, below the present water level. In the phenomenon of the veins being narrowest at, or just below, the outcrop, it is to be noted that the walls in the narrowest portions show evidence of lateral pressure and crushing, attendant upon the removal of material from between them.

At present writing the zone of secondary sulphides has been merely touched, only residual fragments of these minerals having been extracted. Their occurrence, however, demonstrates two facts: first, the actual presence of a zone of secondary sulphide enrichment; and, second, the gradual migration of this zone downward. The sulphides found are extremely heavy, and constitute some of the very richest ore. In the western veins copper sulphides have been found only in small amount; on the eastern slope chalcopyrite and bornite are found in increasing amount with depth. Not the most minute traces of oxidized copper minerals have been seen in any port of the district. At the Pfau mine, situated in the large dike on the east slope of the Black Hills, the ore is apparently very thoroughly oxidized, yet a search in material from the lower levels will be rewarded by lumps of copper

iron sulphides, often eight inches in diameter, covered with a half inch shell of earthy limonite. Chalcopyrite is in larger amount than the bornite. Pyrite occurs in the higher portions, just as in the western veins.

The peculiarity, then, of the secondary deposition of minerals is evident. The zone of oxide enrichment contains limonite and quartz, with free gold, and no traces of copper. The small amounts of sulphides are pyrite toward the surface, changing into copper minerals below, these latter minerals being best developed in the eastern veins. Further, the double sulphides of iron and copper are found exclusively, no chalcocite or covellite being present. What may be below is of course problematical, but it would not be surprising if the simple sulphides were there in abundance. It is worthy of note, in this connection, that the United Verde mine at Jerome was worked solely as a gold mine in the early stages of its history, and had a precarious existence until the rich copper ores were struck in depth.

In the typical copper vein the oxidized zones contain copper minerals, often in great abundance, and outcropping on the surface, as at Globe, Bisbee and Clifton, in southern Arizona. At Cherry Creek and Jerome, such oxidized copper ores are conspicuously absent, while the surface zone is wholly or partly leached, not only of its values, but also of its gangue. The conditions causing such a result are of two kinds: structural and chemical. The structural conditions are those of movements in the veins, shattering the country rock as well as the vein stone, thereby opening well the ores to surface agencies. The chemical conditions are, in their nature, more obscure, and can only be surmised at this writing. Azurite, malachite, cuprite, and chrysocolla, are stable under the common conditions found in the oxidized zones in copper veins, so that their complete absence proves the existence of a situation chemically somewhat unusual. Also, the peculiar effects noted in the veins at and just below the surface call for explanation. The most notable characteristics of the veins are: (1) The abundance of limonite; and (2), the prevalence of a gneissic or schistose structure accompanying the veins, and the bleaching of the rocks by the action of sulphuric acid. At times the action of the acid has proceeded sufficiently far to produce from the rock a white pulverulent mass. This intense action is always found in the very summits of the veins just below the outcrop.

The first striking feature, the quartz outcrop followed below by a vein filling, poor in all constituents of foreign source, can be easily explained. The active solutions start from the surface, enter the vein, and because their power is least at the start, and because fresh oxygen-bearing water follows, the actual outcrop is comparatively little attacked. On the other hand, the solutions passing through the first foot or two of surface vein filling, and taking up the acid found therein, are held in contact for some time with that portion and their leaching action becomes intense. The deposition of the material thus taken into solution necessarily follows as the waters percolate downward.

Secondly, with an abundance of iron and sulphuric acid, and with the free access of oxygen, the secondary copper minerals, so commonly found in the upper portions of veins, could not form. The cupric sulphate, produced both by the free acid and the ferric sulphate, would be carried down to the bottom of the zone of oxidation. Under these conditions the gold would also be leached from the surface and deposited on the oxidation of the iron salts to hydrate. Silica would also be deposited as the character of the solutions change. Rickard,[1] in his valuable paper, has presented the main facts regarding the enrichment of gold veins, although he leaves rather in abeyance the fact that sometimes gold migrates and at other times it does not. The migration in the Cherry Creek district is no doubt chiefly caused by the very large amounts of ferric sulphate present, aided possibly by chlorides from the overlying limestone. It is not clear exactly what solvents are responsible for the downward movement of the silica. That silica does so move is well known; witness the frequent sintery quartz of vein outcrops. Also, at the Comstock Lode, the vadose waters, containing 11 per cent. of soluble sulphates and 12½ per cent. of free sulphuric acid, hold in solution .55 per cent. of silica. Simple equations expressing graphically the relations outlined above, could be written, but it seems inadvisable to do so until our precise knowledge is greater.

[1] T. A. Rickard, "The Formation of Bonanzas in the Upper Portions of Gold Veins," *Trans. A. I. M. E.*, Feb., 1901.

A further point is this: Among secondary sulphides present, those bearing copper are invariably the double salts of copper and iron, with chalcopyrite in larger amount. The reasons for this may also lie in the excess of iron and sulphuric acid present in the vein. The presence of sulphuric acid necessitates a plentiful supply of oxygen, which is not at all at variance with the facts of vein shattering. If equations be written expressing the probable reactions producing the minerals chalcopyrite, bornite and chalcocite, or better, general equations summing up all intermediate reactions, it will be found that, in the main, chalcocite will form when the ratio of the copper to the iron is as 2 : 1; bornite when this ratio is 3 : 2, or, when both iron and a strong reducing agent are in excess, 3 : 1; chalcopyrite when this ratio is 2 : 3, or, when a strong reducing agent is present, 1 : 1. As the veins have been well opened to oxidizing solutions, in the upper portions of the veins strong reducing agents were lacking. In this case, these ratios of copper to iron for chalcocite, bornite and chalcopyrite are 2 : 1, 3 : 2 and 2 : 3, respectively. Thus, the excess of ferric salts and lack of strong reducing agents would favor the formation of double sulphides. It is needless to state that the whole subject of the physical chemistry of this comparatively simple process of secondary enrichment of copper ores, is in need of thorough experimental treatment before we shall be in a position rightly to interpret the facts. The working geologist lacks time and often the requisite knowledge for pursuing such investigation, and must, perforce, depend upon the labors of others. At Cherry Creek, however, the facts in the field, such as the great abundance of limonite with frequent kernels of pyrite, the vein shattering, and the bleaching action of sulphuric acid, appear to warrant the tentative conclusions above set forth.

PROBABILITIES WITH DEPTH.

With depth it is almost beyond doubt that the gold values will decrease, while the copper will increase in amount. At what depth a pronounced change will be found it is not possible to say. The deepest mine workings show ore thoroughly oxidized, with the exception of a few residual sulphide masses, and practically of the same chemical nature throughout. The ground water now being well above the bottom of the zone of oxide enrichment offers no criterion, but proves only the existence of a more arid past. The gold values will continue through the zone of oxidation and into the underlying zone of secondary sulphides, and there should be considerable depth to the gold bearing minerals. If the above ideas regarding the genesis of the double sulphides be correct, it is possible that chalcocite may be found with greater depth, formed after much of the iron has been left behind as limonite. In any case, there should be an abundant supply of good ore, both with gold values and with copper as the chief metal.

THE FORMATION OF ASPHALT VEINS.

George Homans Eldridge.

INTRODUCTION.

Asphalt veins as they occur in the superficial strata of the earth's crust afford a study in black and white of many features of ore deposition in general. Such veins are not only easy to follow when they are once opened, but they are often clearly marked across the country, especially where the surface is formed by a resistant rock rather than by one readily disintegrating into soil. It is possible indeed in certain instances to follow the outcrop of a vein for several miles by simply occupying some prominent point along its course and turning the eye in either direction.

Not only is the study one of simplicity, due to a sharp contrast of the black asphalt with the lighter colors of the adjacent rocks, but even in the character of soils and verdure the course of the vein is marked, either by a complete absence of plant growth or a change in the character of the vegetation. While these elements of contrast are to be observed in most occurrences of asphalt veins they may be studied under exceptionally favorable conditions in the enormous gilsonite veins of Utah.

OCCURRENCE OF ASPHALT VEINS.

Distribution.—As actually observed by the writer, asphalt veins occur in many parts of the United States, both east and west, in Cuba and in many other parts of the West Indies. By reference to literature on the subject it is evident that they are scattered through most of the explored territory of the earth and that they are of far wider distribution than veins of metalliferous materials. This is doubtless due to the limitation of metalliferous veins to the proximity of deep-seated mineral-bearing waters which have found a passage either through the older, crystalline rocks, or through such of the later sedimentaries as have been violently folded or otherwise rendered pervious. The wider

The Cherry Creek District - in S portion of Black Hills

Most of district is in the upland basin of Cherry Creek (5000 - 5500') ; part extends down the eastern slope of the Black Hills

District Producers were
Etta
Federal
Hillside

Monarch (Mocking Bird) Mine ~ largest producer in district.

Country Rock - f.g granite no alteration
Several veins N 10°-20° W dips 32°-45° W
lenses several ft across of coarsely xtalline white Qtz (5-6' wide)
develloped to ~300'
Mostly Free Milling w/some cpy gn,

Etta (S of Monarch) vein 5-6' wide develloped to 200' $129 ore

Others in vicinity
Gold Ring
Conger.
Pfau.

Bunker or Wheatley Property — 8 claims. 1/2 mi N of Cherry

0.75 - 2.0 oz/ton (?)

3 veins at an elev of 5700' which dip. gently SW about 25-45 ft apart. — average less than 1 ft but up to 6 ft

Au is very finely divided and assoc. w/ limonite within cellular & brecciated Qtz

Golden Idol (Hillside Mine) — 1.1/2 mi N of Cherry ~ 5400'

3 veins on property, one has incline 375' long on 35°W bearing. -4 ft. shear of granite w/ Bundles of Qtz. w/ tourm, & some Py & cpy. Contains solution cavities w/ limonite. $7-12 Au./ton (?)

Federal Mine W of Bunker 1.25 mi N of Cherry at an altitude of 5300' S dipping vein -260' incline, not much production

Leghorn Mine 1.75 mi N of Cherry -600' incline dipping 35°W 6000' workings ~ av 2' width; cpy & Au., lim, second Qtz problems below zone of oxid?

Gold (or Copper) Bullion Mine - 2 mi W-NW of Cherry -
660' incline & several 100 ft of shallower workings.

- Steep Westward dipping vein that Pinches & swells to max of 7'.
- lenses of QTz w/ locally abund Masses of hem & limonite Au is v.f. divided.
- locally contains irreg bunches of partially oxid galena & some CuOx's

Gold Coin Mine E of Hackberry Wash ~ 1/4 mi from Dewey Rd.
several shafts (2?) ~ 100' deep
Vein dips steeply eastward, is poddy & attains max width of ~ 3 ft.

Quail & Golden Eagle Mine - near Gold Coin
shallow workings on lenticular, steeply E dipping veins

Arizona Comstock or Radio Mine - near (E) of Hackberry Wash.
steeply SW dipping vein up to 20"
a shaft, winze and about 100' of drifts.

Golden Crown Mine   E of Hackberry Wash &
SE of Dewey Road.

vrreg vein up to 3.5' thick dipps ~25° SW
300' of drifting from shallow incline w/
abund water below ~50'

Massive to brecciated Qtz w/ abund limonite
derived from coarse grained Py.

Logan Mine   2 mi SW of Berry
Cu stained qtz.