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NOTES ON SOME COLORADO ORE-DEPOSITS.

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I must ask the indulgence of the members of the society for the remarks that I shall make to-night, as I have not had time to prepare a finished paper. I shall present to you some observations upon mines that I have recently visited, and the suggestions that they have offered in regard to the formation of ore-deposits, thinking that possibly, though these notes are incomplete and very preliminary, they may be suggestive and lead to contributions of similar observations from other members who are examining mines; because such items, even though incomplete, might in time form an accumulation of facts which would tend to clear up many misconceptions in the prevailing theory of ore-deposits and to establish what is sound in those theories on a firmer basis.

The first point I shall dwell upon is the relation of faults to ore-deposits. The old idea of a vein, namely, that it is formed by the filling of a preëxisting, open fissure, seems to involve that of a fault, since it is by faulting that we can most readily conceive the formation of such an open fissure. Faults do not follow perfectly plane surfaces but are generally irregularly curved. Thus, according to this idea, if the movement of one wall against the other was somewhat lateral as well as vertical, the projecting points on either wall might be brought in contact and the relatively reëntering portions coming opposite each other would leave openings, more or less continuously, along the plane of the fault. Through these fissure-like openings ascending solutions or vapors might come from below and deposit their contents on either wall. By a change in the character of the material brought up symmetrical layers, parallel with the walls, would be formed, constituting what is known as the "comb" structure of veins. In order to verify the soundness of this theory it is important to observe, first, to what extent this parallel system of layers or "comb" structure is found in deposits, and second, how far ore-deposits occupy actual fault planes and how far fault planes are occupied by actual ore-deposits.

We can distinguish two classes of faults in nature; first, the great faults which involve in their movement great masses of rock strata, which have a displacement of many hundred or thousand feet and which can be traced on the surface often for miles in length, and may consequently be supposed to extend to proportionately great depths within the crust of the earth. Second, the minor faults, more in the nature of what are known as cross joints in rocks, which have but a slight movement of displacement, are of limited horizontal, and presumably also vertical, extent, but which may show the slickensides surfaces and also the clay selvages or gouges which furnish the generally accepted evidence of motion, as well developed as on the great faults.

According to the theory that the materials which fill these veins come up either in solution or vapor from some great but unknown depth below the surface, great faults would be the ones on which ore-deposits would be most readily formed and in the greatest masses, since they must extend to greater depths than the minor faults, and would be more likely to have actual direct connection with this unknown source.

The observations on ore-deposits which I have thus far had occasion to make lead me to believe that the supposed typical vein showing "comb" structure is the exception rather than the rule, and that minor faults of slight displacement and probably of very limited vertical extent are more frequently occupied by ore-deposits than the great faults. The points, observed during recent hasty visits to some of the prominent mining districts of the State, which bear upon the above theories are as follows:

First, on the Iron fault at Leadville. This fault, as many of you doubtless well know, runs along the west face of Iron Hill in a north and south direction and has a longitudinal extent of about two miles. By its movement of displacement a series of easterly dipping beds, together with a very considerable thickness of overlying porphyry, have been uplifted on the east side of the fault and form the present crest of the hill, while the western continuation of these beds has been supposed to be buried under about a thousand feet of porphyry on the west side of the fault at the foot of the hill. This deduction has been made from the location of their outcrop on Carbonate Hill, which lies still further west, and from their average angle of dip within that hill. The ore-deposit occurs in the upper part of the limestone body immediately below the porphyry and extending for varying distances down into the mass of the limestone.

A study of the geological structure of the whole region shows that this ore-body must have been originally deposited before the faulting, since the fault cuts through it as well as the bounding limestone and porphyry. Nevertheless it has been maintained by experts in law suits that the ore-body was continuous down through the fault fissure, and it was a desire to furnish actual proof on this point that first induced the Iron Silver Mining Company to make the numerous openings along the plane of the fault that have afforded so unusually accurate a knowledge of its location, form, and divergence from an actual plane surface.

In later years these explorations have been carried on to a far greater extent both horizontally and vertically for the purpose of extracting ore. An incline shaft, called the McKeon, has been sunk for about 700 feet, at an angle of 50°, in the east country a short distance from the fault plane, from which at different levels cross cuts are run westward to the fault and from these drifts pushed north and south along the fault fissure. The vertical depth of the present lowest or ninth station below the collar of the shaft is 534 feet. So much ore has been extracted from this shaft in late years, that it had become the belief of many intelligent people that its occurrence disproved the deduction, drawn from general geological structure, that the original deposition of ore was made previous to faulting.

It was in order to determine by personal observation what foundation in fact such a belief might have, that I recently examined all the workings of the McKeon shaft that are now accessible. The result of this examination only furnished further proof of the correctness of the deduction from geological structure, and disproved the idea that the ore might have been originally deposited in the fault plane. Inasmuch however as the misconception was not unnatural under the peculiar conditions in which the ore was found, it may be advisable to explain briefly what these conditions are.

From the first station of the McKeon shaft a large amount of ore was raised which came from the Blue Limestone on the east wall, about 40 feet below the contact or its upper surface. This was simply a continuation of the lower part of the regular ore-body of the Iron mine, which had not previously been discovered, and did not come from the fault plane proper.

Below this level, however, considerable ore was taken from the fault fissure itself. On inquiry it was learned that this ore was found entirely within the material filling the fissure, and in no instance in the solid rock of either wall. The fissure, though necessarily irregular in shape, is less so than might be expected if much lateral movement had accompanied the vertical displacement, and may be said to average two or three feet in thickness; its filling is a clayey mass saturated with oxides of iron and manganese, and bounded by slickensides surfaces.

It was further stated that where considerable masses of ore were found, sufficiently hard to show an outline, they were always rounded. It appears therefore that this ore is simply attrition material dragged down (or up) along the fissure, as the walls rubbed against each other. The walls in the distance under consideration are White Porphyry on the west, and on the east, beds, first of Blue Limestone, then of Parting Quartzite, then of Gray Porphyry, and below that White Limestone, passing down into Cambrian Quartzite. The granite forming the base of the sedimentary series was cut by the Star-of-the-West shaft a short distance to the south, but had not been reached by the McKeon workings. It is quite comprehensible that under the great pressure which must have accompanied the faulting, the edges of rock adjoining the faulting must have been ground off very considerably; wherever, therefore, the fault cut through an ore-body, both ascending and descending portions of this ore-body would leave particles of ore in the fissure.

Additional proof that this was the case in the Iron fault, where, as already mentioned, the ore in the ascending portion of the limestone (or on the foot wall) actually adjoins the fault, is found in the fact that the ore on the fissure was shown to be limited to a zone bounded by two vertical planes running through the points where the boundaries of the ore shoot in the Iron mine abut on the fault plane, and at right angles to that plane, and that beyond these imaginary planes, either north or south, no ore had yet been found in the fault fissure, though the drift on the second level had followed it 2,000 feet horizontally.

From the fourth level, or about 300 feet below the collar of the shaft, downwards, a different set of conditions prevail. On this level, in the language of the miner who pays more attention to the ore itself than its geological surroundings, the ore-body runs out to the westward nearly horizontally in a "flat" for about 100 feet, then bends down perpendicularly again, being underlain, and in some parts overlain by Blue Limestone. This flat is of limited extent longitudinally, that is along the direction of the fault plane, and does not appear opposite the incline. A similar flat is found on the intermediate level between the 5th and 6th, or about 400 feet below the collar of the shaft which is of somewhat greater horizontal extent, and which has a more decided dip to the westward. It also ends on its western limits in a "break," which is less steep in angle than that from the flat on the 4th level. From the foot of this break on the 6th level, or at 428 feet below the top of the shaft, an inclined winze follows the ore-body along the contact at an angle of 25° westward to the Blind Tom shaft on an adjoining claim. In this ground, I am assured by the owner, there are similar small breaks, and that the average dip of the contact is 25° to 20° W. The drift from the 9th level of the McKeon shaft—534 feet below the collar—runs westward through Blue Limestone and also connects with the Blind Tom shaft.

I have described very briefly the manner in which the ore occurs in these lower workings, as it would appear to one being taken through the mine by the foreman. In order to form an idea of the structural bearing of such occurrences one must be able to leave temporarily out of consideration many details, and keep in mind only the critical points that have a bearing on the structure. When the broad outlines of structure have thus been seized upon, it is well to examine all the details with an accurate map in hand and with the notes thus gathered one can afterwards construct actual profiles which will show and explain all these details. In the present case I had only time to examine the general outlines of structure and many details which are necessary to reconstruct an actual profile are wanting. It is evident, however, that these flats represent portions of the Blue Limestone body west of the fault broken off from the main body and carried up a short distance in the upward movement of the east wall, hanging on as it were to the wall. Moreover the general westerly dip of the limestone west of the fault (for it is hardly necessary to repeat to you that the ore-bodies in Leadville are mainly replacements of portions of the limestone strata and have as a rule a general parallelism with the stratification) shows that the block of ground between the Iron and Carbonate faults is a shallow synclinal fold, and that the faults themselves follow a line of tension, which might have developed into a sharp anticlinal fold had the strain not been relieved by faulting, a type of structure that is quite prevalent in the Leadville region.

Mr. G. F. Becker, in his monograph on the Comstock lode, shows that this lode occupies a fault plane and points out the parallel sheeting of the country rock, especially on the hanging wall side where some of these parallel fissures constitute actual lodes. He makes an elaborate mathematical demonstration of the effect of faulting on a body of practically homogeneous rock, and shows that the theoretical results of the dynamic forces involved would be to divide this body into a series of parallel sheets among which the movement would be distributed, illustrating it by the effect of a series of properly directed shocks on a pack of cards. He also shows that the slope of the surface of the ground where such faulting had taken place would be a logarithmic curve. Of course in Nature we can hardly expect to find these theoretical conditions actually fulfilled, as there would be many disturbing elements which the calculations could not provide for. Still it is interesting to trace a possible conformity with the theoretical condition. In the case of the Iron fault above mentioned it is possible that these flats represent parts of parallel sheets, and the fact that their movement seems to be less in each succeeding sheet, so that the profile would probably be like a series of steps each shorter than the preceding, is in so far confirmatory of this idea. Unfortunately the workings have followed the pay ore mainly, and below where the flats commence the main fault fissure, or rather its east wall, has not been thoroughly explored.

An analogous condition of things was observed by me on Carbonate Hill years ago, when I was making a study of the region. Carbonate fault occupies on Carbonate Hill a similar position to the Iron fault on Iron Hill. From the few points which were accessible in the west country I obtained evidence of a tendency to form parallel and minor faults. Those opposite to the Crescent and Catalpa claims amounted to only a series of short downward steps in the contact, if I may so express myself. On a line through the Ætna and Glass-Pendery ground, however, the structure was more easily read. A shaft was sunk in the former ground following the fault plane about 250 feet at angle of 65° W. to where the limestone was again found on the west wall. A certain amount of ore was taken from the fault fissure in this shaft which was evidently, like that in the Iron fault, attrition material, but its amount was naturally less, as no considerable ore-body was actually cut by the fault at that point. From the bottom of this shaft the limestone had a slight inclination westward and was cut off in the Glass-Pendery ground by a second fault, which I called the Pendery fault, at that point parallel with the Carbonate fault. The owners of this claim had sunk an incline on this fault for one hundred feet, and then stopped and drifted westward in the overlying White Porphyry. If my idea that the movement of these sheets decreases with the distance from the main fault plane is correct, this shaft would probably have reached the contact west of the Pendery within a hundred feet of where it stopped and if, as is possible, this contact had a decided western dip it would have solved the problem, of so great importance to Leadville, of the existence of Blue Limestone and consequently of ore bodies beneath the City of Leadville.

It seems therefore that the great structural faults which are necessarily the deepest reaching fissures in the

Leadville region do not contain original ore deposits. On the other hand there are a series of deposits of minor economical importance, such as the Colorado Prince, Printer Boy and others, which are often called gash veins and which occupy cross joints or fracture planes of small extent and slight displacements and probably do not extend beyond the particular stratum or rock mass in which they are found.

The San Juan region, from all accounts, affords an excellent field for the study of fissure deposits. During a recent hasty visit of a few days I saw portions of the region, my route following a north and south line from Durango to Ouray, with an excursion westward and through Ophir, Telluride, and the Marshall basin, and I was enabled to get a general idea of its geological structure, which fully confirms the above impression. The region has evidently been the scene of repeated and important dynamic movements, of great eruptions of igneous rock at different geological periods, and of intense metamorphic or solfataric action subsequent to these eruptions. One prominent result of the dynamic movements has been the production of systems of approximately parallel joints or fracture planes. One of these systems, whose direction is a little west of north, is very prominent in the Marshall basin, an elevated amphitheatre on the west slope of the mountains. Across this basin the outcrops of three large parallel veins which have this same direction can readily be traced. The most important of these is the Sheridan-Smuggler vein, which is said to have been traced a distance of two miles, and which is certainly visible across the entire extent of the basin, running up the bounding walls at either side. This I examined underground on the Sheridan claim and found that it was really a fault fissure; the vein matter consists of parallel sheets of country rock from a few inches to a foot or more in thickness, more or less altered and replaced by quartz, barite and silver-bearing minerals. In some cases the intervals between these sheets are as thick as the sheets themselves and are filled with vein quartz; these may have been interstitial spaces left open by the movement of faulting and subsequently filled by vein material. The vein as a whole is, however, a vein of replacement formed by waters following a cross joint or fault fissure. It is more or less mineral-bearing through its entire length, as far as prospected, though, as is usual in ore-bodies, the very rich portions or bonanzas are of limited extent. The ore-body in the Sheridan mine is a powerful and unusually rich deposit. It stands nearly vertical, having a dip of 70° to 80° to the west. My examination was of necessity an extremely hasty and superficial one and devoted mainly to determining the character of the fissure; the details with regard to the manner of occurrence of ore within it were therefore in a great measure derived from information rather than from personal observation. The width of pay vein material varies from three or four to fifteen feet or more. In this width there is a richer portion which is found sometimes nearer the hanging but more generally towards the footwall side. Sometimes the one wall, sometimes the other, is more distinct and well defined, but in all cases the so-called country rock is impregnated with metallic sulphurets; to what distance cannot well be determined, as such rock is of too low grade to be mined. Horses are often found within the vein, which are broader sheets of country rock more or less impregnated with ore minerals; and stringers often lead off into the country on either side, constituting what the miner calls "blind leads" since they are apt to lead away from the main fissure. All the phenomena are easily explainable on the supposition that this is a fault-fissure in which the movement combined with the immense lateral pressure produced, instead of one single fault plane, a sheeting of the rock mass along a narrow zone. Such sheets are naturally not as uniform or as continuous as the cards or sheets of paper which Mr.

Becker uses to illustrate his theory, any more than is a fault plane a geometrically plane surface. They vary in width from point to point, wedge out, and are taken up by another sheet *en échelon* as it were. Thus the dividing planes would sometimes run out into the adjoining solid rock, as do the blind leads. Percolating solutions would concentrate in the dividing planes between such sheets, deposit vein material in the interstitial spaces, and replace to a greater or less extent the material of the sheets of country rock; the completeness of this replacement being in the main dependent upon the relative ease of access afforded the solutions by the continuity or abundance of the dividing planes or joints. The country rock in this case is an eruptive rock, generally brecciated in structure, which shows a rude sort of horizontal bedding; it is two or three thousand feet in thickness and forms the upper portion of this part of the region and, judging from distant views from high peaks, extends over a great portion of the entire mountain mass. The deep cañon cutting at the head of the neighboring San Miguel valley shows that it rests upon sedimentary beds, of which the upper member is a conglomerate whose age, though not exactly determined, is probably as late as Mesozoic.

This then is an instance of an ore-deposit occupying a fault fissure. What the amount of displacement of this fault is, it was not possible to determine with definiteness owing to the generally homogeneous character of this breccia throughout. Still the evidence of the horizontal lines, whether those of bedding or not, where the fault could be seen crossing the face of a cliff, tended to show that this movement was but slight and therefore that, in spite of its great length, it belongs rather to the second class of faults of which I have spoken. Whether or not the other veins in the basin also occupy fault planes no opportunity was afforded of observing, but analogy renders it probable that they do. It would be a matter not only of scientific interest but of practical importance to the owners of the claims on the Sheridan lode to be able to determine to what depth this fissure may be expected to extend, since neither it nor any other fissure is probably of unlimited extent vertically, any more than it is horizontally.

In rock fractures which are the result of dynamic movements the vertical extent should bear some proportional relation to the horizontal. The latter is always easy to determine and I would suggest that whenever an opportunity is afforded of forming even an estimate of the vertical extent of an ore-bearing fissure, such an estimate and the grounds on which it is based should be put on record. Thus in time it might be possible to frame some sort of law which would enable one to predicate the probable depth of such a fissure as the Sheridan—whether for instance it is likely to extend below the eruptive rock into the underlying sedimentary beds. The innumerable tunnels that have been driven into the sides of our mountains to strike a vein whose upper portions have been worked to a certain depth, and which have not found the vein, furnish practical evidence that such veins are not of unlimited extent in depth, but I know of no record having been made in such cases of the relation between their vertical and horizontal extent.

While speaking of the San Juan country I cannot forbear to mention another series of phenomena whose study promises to prove of exceeding interest. These are the results of what I have called above metamorphic or solfataric action. Neither of these terms affords an entirely satisfactory characterization of what I refer to. Metamorphism in its broad sense includes all the internal changes that a rock has been subjected to since its original formation, and therefore, while correct, is not sufficiently explicit. Solfataric action, which is the term more generally used to describe this particular phase of metamorphism, is in one sense misleading since it might convey the idea which is associated with its original use, that it is an action of gases or of sublimation, whereas its present general application is to phenomena which result from the action of heated waters. The appropriateness of its use, on the other hand, lies in the suggestion conveyed by it that the great heat necessary to produce such locally energetic action must have been derived from slowly cooling masses of eruptive rock in the vicinity of the scene of action. The only opportunity of studying this action underground was in the vicinity of the town of Red Mountain, but superficial indications show it has been widespread throughout the greater part of the region visited by us. Here I examined the workings of the National Belle and the Yankee Girl mines, and, in some detail, the surface geology at the head of Red Mountain Creek. As seen here this solfataric action has resulted in the almost complete removal of all the basic constituents of certain portions of the original eruptive rocks, leaving a granular, often cavernous, mass of silica, with frequent accumulations of kaolin in the hollows or small caves left by this action. Probably the deposition of metallic minerals was also a part of this process, but whether this occurs contemporaneously or as a separate phase my examination was not sufficiently extended to definitely determine. The superficial evidence of this action is seen in certain areas or zones of light colored or bleached rock, which contrast strongly with the general dark color of the eruptive rocks, and which at first glance might appear to be bodies of a more recent acid rock cutting through them. A slight examination however is sufficient to show that these lighter colored rocks are highly metamorphosed, and while it would require a very extended observation to trace them back to the original unaltered rock, it seems not at all improbable that this was the prevailing dark breccia, altered along certain lines of fracture or jointing which have afforded more ready passage to the heated solutions. Quite frequently these lighter zones, where highly silicified, have resisted erosion better than the

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immediately adjoining rock and stand out as small ridges. Such a ridge is seen on the Guston claim, which owing to its want of relation to the drainage system of the ground might be taken for a moraine ridge, were it not found to be composed of hard rock instead of gravel.

Yet the result upon the region has apparently been to render it more easily abraded, judging from the general appearance of this part of the region as seen in a *coup d'œil* from neighboring mountain summits. Thus the north and south ridge which has received the general name of Red Mountain, owing to the brilliant coloring of its many talus slopes of disintegrated débris, is seen to be relatively more eroded than the surrounding mountain ridges which are from 500 to 1,000 feet higher. Yet all this region was probably once a comparatively level plateau out of which the present valleys have been eroded, and the amount of erosion may be realized when I tell you that the basin at the north end, where are the mines above mentioned, is 2,000 to 2,500 feet below the summits of the steep bounding ridges. Solfataric action may not have been the only cause of this more abundant disintegration of the country rock, but it has probably rendered it more susceptible to the disintegrating action of surface waters, and an important agent in the disintegration has undoubtedly been the abundant deposits of metallic minerals throughout this ridge, some of which have already been discovered. The action of these surface oxidizing waters on the iron sulphides is seen in the abundant iron springs which issue from its sides, depositing large mounds of bog iron on the flanks and in the neighboring valleys. I have spoken on this point less with the intention of contributing an actual geological description of this region, for which my data are too inadequate, than to warn those of you, who may have occasion to make examinations there, against certain errors into which you might be misled in a hasty visit, for I feel sure that phenomena similar to those of Red Mountain are by no means uncommon throughout the whole region.

The first error to avoid is the considering of these zones of bleached rock as necessarily of different origin from the comparatively unaltered ones adjoining them. In the case of those which are almost entirely silica, it will be difficult to determine what the unaltered condition originally was, but in any case this can only be done by tracing back the successive phases of diminishing effect of solfataric action.

Second. Do not confound this silicifying action with that of modern springs, which are now making important deposits, especially of bog iron in many parts of the region. It presents undoubtedly certain analogies with spring action, since it may have been caused by rising currents of heated waters; but it was an action which took place at considerable depths, not at the surface and under the influence of atmospheric agencies. At Red Mountain, for instance, it is probable that it took place long before the erosion, which carved out this basin, commenced. Again, the silicifying action was less an action of deposit than of removal or replacement. This silica now found there is mainly that which has always been in the rock, and has been left after other more soluble constituents have been removed,—to a certain extent, of course, it may have changed its position, and what was taken up in one portion of a passage which admitted the heated waters, may have been redeposited a short distance off.

The second point upon which I wish to touch this evening relates not to the original formation of the ore-deposit, but to its secondary alteration. In studying the formation of an ore-deposit it is of prime importance that the observer should distinguish carefully the minerals which are of secondary formation from those which are in the condition in which they were originally deposited. As I have observed that in reports upon mines this is not always done, and that hence a certain confusion arises in the mind of the observer in trying to trace the manner of formation of the deposits, I think it will be useful to point out what are some of the forms resulting undoubtedly from secondary alteration-in-place of the ore-deposit, and for this purpose I will describe briefly what I observed during a recent visit to Red Cliff, Colorado.

The sedimentary rocks at Red Cliff correspond very closely with those at Leadville and constitute part of the same littoral deposit around the Archæan land-mass now represented by the Sawatch range. The topographical conditions of the two places differ in that at Leadville the broad Arkansas valley separates the present beds from the Sawatch, whereas at Red Cliff, which is on the north flank of the Sawatch range, they slope directly up on its spurs and are cut through, down to the underlying Archæan, by the narrow winding cañon of Eagle river. These beds dip gently northward at an angle of about 15°, and are not broken by great faults, nor intruded and traversed by innumerable eruptive bodies, as at Leadville. The new town of Clinton, around which the now prominent mines are located, is on a shoulder or jutting point of the cliff walls on the north side of Eagle river about three miles from the older town of Red Cliff, which is situated on the valley bottom further up the stream. The lower Palæozoic series, that is, the beds extending from the Archæan up to the top of the Blue or Lower Carboniferous Limestone, has here a thickness of less than 500 feet against an average thickness of nearly 600 in the Leadville region. The difference seems to lie mainly in the middle member, the White or Silurian Limestone; the Cambrian Quartzite at the base and the Blue Limestone at the top of the series have all the characteristics of the corresponding beds at Leadville and apparently about the same thickness. The Parting Quartzite, as such, was not definitely recognized, though there are several thin beds of quartzite at the horizon which should represent the Silurian Formation.

The ore is found at two horizons, first, at the contact of the Blue Limestone with an overlying sheet of porphyry, second, in the transition beds at the top of the Cambrian Quartzite. The first type of deposit, in its original form, was deposited like those at a similar horizon at Leadville, by a process of replacement or metasomatic interchange between the vein material brought in in solution by percolating water and the dolomitic limestone in which it is now found. With regard to this original deposit, which was in the form of sulphides of iron and lead, I saw nothing worthy of remark. It is the secondary alteration of these original deposits to whose analogies to, and differences from, those of Leadville, I wish to call your attention.

The most noticeable difference is the fact that the prevailing oxidation product of galena is here the sulphate, anglesite, instead of the carbonate, cerussite; it is found, however, likewise in the form of minute crystals, or "sand" as the miners call it, though of a somewhat coarser appearance than the carbonate sand at Leadville.

Now the result of the study of the Leadville ores has been to show that the formation of the carbonate is a more complete oxidation or rather the result of longer exposure to oxidizing agencies than has been required to form the sulphate, since the lead passes first through the form of sulphate before reaching that of carbonate. This is not due to any chemical differences in the surrounding rock, since the composition of the Blue Limestone of Red Cliff is identical with that of Leadville. It must therefore be a greater abundance or a freer access of oxidizing agencies brought in by surface waters that has been the cause of this difference, and in point of fact we find that Leadville deposits are peculiarly exposed to oxidizing action in both these respects. The numerous faults and folds afford more outcrops and more frequent passages, for the admission of surface waters; the high mountains, on the slopes of which the deposits of Leadville are situated, induce abundant precipitation, and the covering of Wash acts like a sponge to retain the waters running down from the mountains and gives them more time to sink into the rocks beneath than if they flowed freely on a hard surface. At Red Cliff, on the other hand, no faults or folds are seen; the cañon of Eagle River shuts off the drainage of the Sawatch Range from the deposits on its north side, and there are no morainal deposits.

It might be expected, for the reasons given above, that unaltered sulphides would first be found at greater depths at Leadville than at Red Cliff, since it is to the agency of surface waters that the alteration is due, whereas from the limited observation I was able to make this did not seem to be the case. In the Black Iron mine, for instance, which is opened on the dip for 1,200 feet from the surface, unaltered sulphides had not yet been reached. Experience shows, however, that the depth at which unaltered sulphides are first found in permanent form is dependent not directly upon the abundance of surface waters but upon the so-called water level, whose depth varies greatly in different regions. For instance at Eureka, Nevada, it is at a depth of 1,000 feet or more. In Leadville it would probably be impossible to determine one depth of water level for the whole region. It would vary greatly from one synclinal basin or area and from one mine to another. The permanent water level at any point beneath the earth's crust and within the range of human observation is evidently that level to which the water will rise by the filling of a hydrostatic basin (which may consist of any system of channels permitting its ready circulation, such as joints, fissures, bedding planes, or porous rocks) up to the point of its overflow, or where it would drain out either to the surface or into another hydrostatic basin. The water filling such basins is originally supplied from the surface, but after a comparatively long passage through the rocks during which its oxidizing agencies, such as air, organic acids and so forth, may be supposed to have become neutralized or to have exhausted their power upon the rocks through which they have passed. The water or moisture which furnishes the active agents of secondary decomposition of ore-bodies must, on the other hand, come to them directly from the surface and not be neutralized by a long passage through rock material, or by mingling with a large body of already neutralized water such as that which exists below water level. This seems to me to be the explanation of the fact that surface waters act as oxidizing agents above water level and as a protection against such action below the water level. On this hypothesis the depth, or distance below the surface, to which secondary decomposition extends is dependent upon the geological structure which determines the character of the hydrostatic basin above mentioned, while the intensity of the oxidation produced during secondary decomposition is dependent upon the abundance of the supply of direct acting surface waters.

The chemical processes of secondary alteration of the original sulphide deposits are, as might be expected, essentially the same at Red Cliff and in Leadville, but at the former place I found all the successive stages of the change from pyrite and galena to limonite and sand ore actually shown, whereas in tracing this process during my study of the Leadville deposits I had been obliged to supplement some of the intermediate stages by hypothesis. The opportunity for observing these stages was found in the Black Iron mine, the superintendent of which told me he had the apparent anomaly of having a large body of unaltered sulphide, two-thirds down his incline, whereas the ore at the bottom of the incline several hundred feet further down was still completely oxidized. The explanation of this anomaly I found in the immense size of the original body of sulphide (pyrite and galena), which, though oxidized for many feet from its periphery inwards, still contains at the centre a large body of pyrite which retains its metallic lustre; whereas, owing to the relative thinness of the vein material below, which was only a few feet thick, oxidation had completely penetrated every part.

A drift ran through this large and incompletely altered body of sulphide, which permitted the taking of specimens of the various stages of decomposition, which had a rudely concentric or zonal arrangement.

The first result of the decomposing action induced by surface agencies was the change of the originally solid mass of sulphides to a loose friable mass of small crystals of pyrite. This seems to be analogous to the primary results of decomposition upon the dolomite, producing dolomite sand, which occurs as frequently at Red Cliff as at Leadville. This latter decomposition I had attributed to the dissolving out of the cementing material which held the grains together in the original rock, and which must have had essentially the same composition as the mass of the rock, since analysis showed no essential difference between this and the sand. An examination of the pyrite grains under the microscope showed, however, that the surfaces of most of them were slightly pitted, as if by a commencement of dissolution. It would be interesting to know if the pyrite thus altered is entirely in the form of marcasite which is supposed to be much more readily decomposed than the isometric form. The little galena that occurred in this mass was entirely altered to white sulphate, showing that the oxidation of this sulphide, here at least, was more rapid than that of pyrite.

In the next zone is an ever increasing amount of clear green crystals of copperas, or melanterite, mixed with the pyrite, which finally results in large masses of the vitriol. This very rapidly decomposed, however, on exposure to the air.

The next zone is the yellow ochreous material to whose persistence under the carbonate bodies of Leadville Dr. L. D. Ricketts was the first to call attention, giving it the name of "basic sulphate." Mr. Hillebrand's analyses of several specimens from Leadville showed a great variation in composition, though the external appearance did not vary correspondingly. They all seemed to be mixtures, however, of various materials contained in the ore-body, with jarosite, a hydrous sulphate of iron and potash. Some of the specimens from this mine are seen under the microscrope to be made up of minute but perfect crystals, and are therefore a definite mineral whose composition will soon be determined by analysis. Within the mass of ferric sulphate are found considerable amounts here and there, of native sulphur, of anglesite, and of a curious porous material not unlike a volcanic pumice, and which was, I remember, described to me as such by some one who brought it to me from Red Cliff several years ago. Its porosity is probably due here not to the escape of gases, as in pumice, but to the dissolving out of some more soluble material. It has yet to be examined chemically.

The end product of the various stages of decomposition would be limonite (which under peculiarly favorable conditions may lose its water and become red hematite) and anglesite (which may become cerussite). Although pyrite and galena may not necessarily in every case pass through all these stages, it is useful to be able to trace the complete series, and thus to be able to recognize the probable origin of the peculiar materials that are found, as they not unfrequently are, in such conditions that the connecting links are not to be recognized.