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LOCALIZATION OF ORE BODIES AT RICO AND RED MOUNTAIN, COLORADO, AS CONDITIONED BY GEOLOGIC STRUCTURE AND HISTORY.

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In a district such as that around Rico, the search for ore is necessarily guided by some hypothesis that endeavors to explain why ore is more likely to be found in one place than another. If after several trials ore is not found where according to the hypothesis it should be, the hypothesis is modified or another substituted, until finally one is found that seems to be supported by facts.

The following pages summarize the hypothesis which, for this district in the writer's experience, seems best to harmonize with observed conditions.

It emphasizes the view that solution unaided did not form extensive ore bodies, but that movement, resulting in brecciation or multiple fracturing, was an essential factor. Moreover, where open spaces were filled—as seems to have been frequently the case at the contact of dissimilar rocks—the movement that created the opening must have been nearly contemporaneous with the deposition of ore.

This principle is one that for many years past has seemed to me to be necessary to account in a convincing way for many of the ore bodies around which my work has taken me. It is to my mind inconceivable that continuous open spaces (especially if flat or inclined) could have remained open for any considerable time (unless filled by incompressible magmatic fluid) beneath a rock cover hundreds or thousands of feet thick, a large percentage of which consisted of yielding shale. Many of the voids—whether open vugs

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or porous ore—in ore deposits are in the substance of the ore itself, and are apparently due to its occupying less space than the rock replaced, or to shrinkage of the filling material during solidification. Extensive filled spaces might be due to progressive enlargement, by tectonic stresses, of openings during mineralization. It sometimes happens that in the complete replacement of limestone beds the resulting ore bed (as in the Wellington and other mines at Rico where sulphides replace the thick beds of the Middle Hermosa) occupies exactly the same space as the original limestone bed. But it seems to me that if gradual solution, progressing from the exterior of a bed or from an intersecting channel, were the sole cause of the replacement, there must have been some "lag" before the space could have been completely filled, during which time the overlying strata would settle, so that the resulting ore bed would be appreciably less thick than the original stratum. Replacement from without of a solid bed of homogenous limestone, molecule by molecule, without change of volume, seems to me improbable. Fracturing, however slight, caused by movement along the same fissures that introduced the replacing fluid, would make the bed more susceptible to attack without appreciably affecting its sustaining power. On the other hand, the shale strata, which often overlie ore beds but themselves contain little ore, are brecciated only where they settled into spaces formerly occupied by strata which, like the gypsum beds of Newman Hill, have been removed by solution. Elsewhere they are seen to have been squeezed together and caused to flow so as to fill incipient openings.

In the Badger mine, adjacent to the Badger vein—which is a channel through which mineralizing solutions have passed for sufficient periods to have attacked the walls, and which is itself ore-bearing—the solid limestone beds of the Middle Hermosa, traversed by the vein, are attacked and dissolved, forming cuspoid openings filled with limonite. No ore has been deposited in the limestone, nor do the spaces extend out into the bed; for the reason, as I surmise, that the fissure was too clean-cut, and faulted without shattering the adjacent beds. The required conditions of permeability with partial damming of solutions were therefore not present in this case. Solutions unaided by fracturing did not cause replacement by ore, because insufficient surface was exposed to attack. Judging by the intense alteration of the porphyry, the parallel "Mud" vein, in this mine, seems *a priori* more likely to have caused replacement of the limestone by ore. Unfortunately the existing workings do not expose this vein where it traverses limestone.

In every place that I remember where ore occurs replacing limestone, the footwall underlying the ore is more or less broken or fractured: and R. C. Baer of Rico, from his greater experience, confirms this observation.

As is well known, the central part of the Rico mineral district is a structural dome of quartzite, coarse and fine-grained sandstone, limestone, and shale; with intervening sills of porphyry. Most of the ore except that in fissures occurs in limestone beds. In the earlier (so-called Devonian) and later (Middle Hermosa) strata, the limestone beds are thick and relatively pure. In the intermediate strata—which include most of the richer although not the larger ore bodies—the limestone beds are thin and usually impure. In this horizon, individual strata are discontinuous, so that I have never been able to correlate the stratigraphic sequence in adjoining areas. This however may be successfully accomplished by the complete geologic survey now in progress under Mr. E. T. McKnight. All the strata are cut by deep-seated faults and traversed by numerous mineralized fissures, a large proportion of which (especially those in the Lower Hermosa formation) terminate upwards where they encounter yielding shale beds. Laterally, however, the fissures extend for long distances. Above such shale beds other fissures are often found, but these are frequently not continuous through the shale, and it is then impossible to determine with certainty whether the fissures above and below the shale are identical. In the Lower Hermosa formation, the ore bodies tend to follow the lower sides of the shale beds, and to pitch along the line of the intersection of shale beds by fissures. Seen in section, the characteristic form is that of a mushroom with thin stem and cap, the latter being down-warped where the stem joins it.

The word "contact" has elsewhere been used interchangeably with "blanket" to mean a bed which, under suitable conditions, is replaced by ore or encloses it. To avoid confusion as far as possible without introducing other names, I will use the former word only in connection with the Enterprise "contact," and will refer to the other similar ore-carrying beds as "blankets." This follows the practice in the Union-Carbonate mine. There also the mineralized fissures are called "verticals."

The Enterprise "contact" has been remarkable for the high precious-metal content, not for the size, of the ore bodies contained in it. It seems originally to have consisted of a bed of gypsum, underlain by a thin brittle bed of limestone (the "short lime"), and overlain by one of impervious shale. Another bed of shale, of black color, lies below the "short lime." From a large part of the productive area the gypsum was removed by solution prior to the period of mineralization, leaving behind a layer of insoluble light-gray silt. On this layer the overlying shale has "slumped," resulting in an irregular bed of shale breccia; but the shale was sufficiently thick, so that as a rule the upper part was not brecciated; at all events the bed as a whole remained impervious, the shale breccia itself being indeed so cemented by silt as to be almost so. In the strata of shale and sandstone underlying the "short lime," a complex system of fault-fissures developed, most of which terminated upwards at the "contact." When normal faulting took place on these fissures, due as I surmise to settling from below, the contact was also faulted down towards the hanging-wall side of the fault-fissures. Because of the yielding shale above, it formed an ogee or S-shaped curve—a distinct characteristic shape which indicates to my mind that the bending of the shale roof was gradual. In these "flexed-mushroom" shaped spaces, ore bodies are found over many of the fissures, but are frequently more extensive over the typical northwesterly or "cross" fissures than over the northeasterly or "pay" fissures. The cross-fissures themselves, so far as is yet known, contain no ore; but the pay fissures are often filled with ore down to a depth of from fifty to one hundred and fifty feet below the "contact." The ore in contact and fissures is of similar appearance and grade, but in the former is usually denser and contains less quartz.

At the Union-Carbonate mine, higher up in the Lower Hermosa formation, there are several "blankets" of similar type, except that the structure is more obscure because of almost complete oxidation of the ore: and the precious-metal content is relatively low. The gypsum, and the characteristic silt resulting from its removal by solution, are not present. There is however in this mine one place, in an incline from the southeasterly extremity of the "Lower Tunnel," where a similar breccia of shale fragments overlies soft, silty material. Furthermore, in the Buckhorn ground, in an incline driven from the end of the "South Drift" from the Buckhorn Tunnel, there is a bed of shale which is contorted by "slumping," but hardly to the degree of actual brecciation. It also overlies silty material. This may represent the Enterprise "contact," or some similar blanket higher up.

In neither of these places does ore replace the silt, nor is there evidence of the former presence of gypsum; so that, if gypsum was removed in solution, it was probably an isolated lens rather than a continuous bed, else gypsum would be found where the overlying shale did not slump. As compared with the typical silt of the Enterprise contact, that of the two places just described is more ferruginous and more clayey.

Nevertheless, if the fissures ("verticals") of the Union-Carbonate series came up under and faulted the blanket, I should expect it under these conditions to have formed a favorable locus for ore bodies. The "verticals" are usually spaced so closely that it would be rather exceptional for an area of equal extent to contain none. One conceivable, but unlikely, explanation is that the workings are driven too high, so that neither verticals nor ore bodies are exposed. Other explanations of the absence of ore in the Union-Carbonate occurrence are that verticals may not here extend so far to the east, or they may have stopped at the lower blanket, which presumably lies beneath. Circulation may have been hindered by the clayey seams which in places are seen on minor slips. Or, perhaps most likely of all, removal of the soluble part—limestone or lenses of gypsum, which once filled the blanket, and the insoluble residue from which now forms the silt—may have occurred after the mineralizing period. At all events, the ore which might have been expected was not found, so close appears to be the dividing line between conditions which result in the formation of ore bodies, and those which do not.

In the central part of the Rico district there are at least five entirely separate and successive ore-bearing horizons, each of which may consist of several ore-bearing beds. It is unfortunate that as yet in no one mine (unless we call the Union-Carbonate and Buckhorn areas a single mine) is more than one of these horizons developed, still less has any single fissure-zone been worked throughout several of these distinct horizons. My present conception, however, is that the entire stratigraphic column overlying the hypothetical magmatic batholith which lies below the dome was permeated by mineralizing solutions given off by cooling magma and that these solutions, passing upwards through the fissures and beds—perhaps often deflected horizontally by impervious shale beds so as to shift laterally from one fissure or set of fissures to another—deposited their load where opening or partly-open spaces afforded opportunity, yet where the flow was somewhat restricted.

Due to the dip of the beds which resulted from the doming and to the great physical differences between sandstone, shale, and limestone, when faulting took place due as I suppose to settling from below some slippage and bed-faulting followed, especially underneath yielding shale-beds, and this caused fracturing and brecciation, which assisted the upward-rising mineral-bearing fluids to extend laterally through the brecciated portions of the beds, and particularly where confined by overlying, impervious shale beds. As stated above, many of the fissures seem to terminate at shale beds, while others continue above them. They are usually, however, offset to some extent by bed-faulting.

Accepting this conception, it would seem entirely possible that at some horizon—more likely near the center of uplift—we might find a layer of the harder rocks, or a sill of porphyry, shattered and mineralized so as to constitute an extensive low grade ore body of the disseminated type. A comparatively small ore body of this type (stockwork) has already been worked in the Silver Swan mine, adjoining the Maggie vein.

I do not, however, think that the art of ore-finding or the science of geology has yet progressed far enough to tell us where to look for such ore bodies; except that I would prefer to do so underneath some place where shale, exposed at surface, seems to have sunk, due to reduction in volume of underlying rock. But this suggestion is by no means new; every old Rico miner hopes for ore below a surface "sink," and expects a fault-fissure where a ravine on a hillside cuts the horizontal strata.

Throughout this discussion, I have excluded consideration of the effects of reduced temperature in localizing the ore, because, excepting as to the presence of considerable quantities of specularite in the Devonian limestone, close to the assumed source of mineralization, ore of similar type occurs in all horizons. To explain this by supposing that the temperature of the solutions was in each case lowered to an equal degree by meeting with cold surface waters percolating along the under side of the shale beds, seems rather fantastic. Another possible explanation to account for the deposition of similar types of ore throughout a wide vertical range is that the source of mineralization for each successive horizon was local, such as the porphyry sills which are intruded into the sediments east of the town. These hypotheses, while perhaps competent for some cases, are difficult of acceptance as general explanations of the fact that the ore from top to bottom is similar. The main difference is due to deposition in veins traversing siliceous rocks on the one hand (siliceous ore containing pyrite and copper minerals) and replacements in limestone beds on the other hand.

Apart from the specularite in the Devonian limestone, the only evidence, known to me, which points to zoning of ore, is the following:

1): In the South Park area, pyritic ore containing gold and copper, is said to have been encountered overlying the quartzite bed of that mine, which is certainly low down in the Lower Hermosa series, if not below it.

2): In the Jumbo No. 3 vein, about 500 feet east of the Pro Patria Tunnel, very rich gold ore was found at the tunnel level, 180 feet below the Enterprise "contact." This gold ore is said to have run 19 to 22 ounces in gold, in carload shipments, and is described by R. C. Baer as "hard quartz, containing a little galena and sphalerite in blotches, also some pyrite and chalcopyrite. It appeared to have been shattered, and the seams filled with rust." Thirty feet or so above the tunnel level, the gold content decreased and the silver increased, finally merging into typical Enterprise "contact" ore. The country-rock surrounding the rich gold ore was blocky sandstone, while the silver appeared to be in the shales and limestones.

3): In the quartzite mass, supposed to be pre-Devonian, exposed in Silver Creek above the South Park, high-grade gold-copper ore occurred, in narrow fissures.

As a general criticism, it seems to me that throughout the history of the district the barren-looking veins of quartz below the horizon of the Enterprise "contact" were never sufficiently tested for gold.

If settling of the domed area at Rico, together with the included sills, occurred simultaneously with mineralization, it may be conceived that the settling strata might have been successively fissured, brecciated, and mineralized; yet at approximately the same temperature. If this idea is admissible, it would suggest that at Rico, where favorable beds in many horizons are mineralized, the period when this took place was at a time when an underlying magma, upward pressure from which had caused doming of the sedimentary strata, had begun to consolidate and shrink. Barren fissures may have been formed during the elevation, and other barren fissures during the final stages of settling with the principal mineralizing stages intermediate. On this hypothesis, the task of the miner aided by the geologist is to distinguish between veins of the various stages, to ascertain which beds are favorable for ore deposition, and to ascertain the conditions under which they were most susceptible to the mineralising processes. These problems are by no means easy; yet it seems that in a district where there are so many productive horizons and so many fissures they should not be impossible of solution.

In the Union-Carbonate it seems to have been possible to find ore about half of the time by selecting a vein of the right type and following it up to its successive intersection with the lower and upper blankets. It is conceivable that elsewhere by selection of more favorable horizons—which probably exist—to do the same thing with an equal chance of finding larger ore bodies. Or, does their frequency in the ore horizons of the Union-Carbonate depend on their small size?

Many men, who completely lack systematic geological training, and whose geological reading has been without guidance and limited in scope, are nevertheless careful and accurate observers. On the other hand, some trained geologists of repute record observations which others cannot see, but which nevertheless become quoted and requoted until they form landmarks of geologic literature and other geologists build their geological theories upon them. Of the first type one of our Rico miners, Robert C. Baer, is a good example. Until recently, some of his theories of ore genesis were fantastic—or at least appeared so to me—but his observations were always close, and I think accurate.

Accepting the descriptions of the Enterprise contact given by Ransome,[2] and its relations to the residual gypsum silt and to the "pay" and "cross" fissures of the Newman Hill area, one can hardly avoid the conclusion that removal (by solution) of the gypsum antedated the formation of both sets of fissures and that the spaces which resulted before settling of the overlying strata had completely filled them, accentuated by faulting on the fissures and some bed-faulting on the plane of weakness represented by the layer of silt, had facilitated ore deposition from the fluids arising through the fissures. It is easier to understand why the "pay" fissures should have split up into small branching seams where they pass through the black shale bed under the "contact" if we suppose that at the time the fissures were formed the contact was partly open or filled with soft yielding material. The "contact" ore deposits above the "cross" fissures were more important than those above the "pay" fissures, perhaps because the open or partially silt-filled spaces were becoming enlarged by continued sinking of the underlying strata, after the filling of the "pay" fissures and during the final opening of the "cross" fissures. We may surmise that the "pay" fissures were mineralized down to a limit of 100 feet or so below the "contact" and the "cross" fissures not, because the "pay" fissures were dammed at the top to a greater degree than the "cross" fissures and because the final opening of the latter was, as a rule or always, later in age.

Robert C. Baer is quite emphatic in the statement that, in his experience, there was never any ore in the "contact" where gypsum was present; nor, in my more limited experience, did I see any. Where the upper or "contact" shale came down on the "short lime," miners began to expect ore.

The high silver content of the Newman Hill ore suggests that the hypothetical underlying magma and the solutions proceeding from it may locally have had a higher silver content than elsewhere. If this be the true explanation, it would

[2]Ransome, F. L., The ore deposits of the Rico Mountains, Colo.: U. S. Geol. Survey, 22nd Ann. Rept., Part II, pp. 273-80, 1901.

be useless to assume that the continuation of the Enterprise "contact" elsewhere in the district, even if the physical conditions were equally favorable, would be equally rich. Local variation of precious-metal content is further indicated by the fact that towards the north, in territory reached by the Pro Patria Tunnel, the ratio of gold to silver was usually higher than in the main part of Newman Hill. Farther north again, in the Union-Carbonate mine, some blanket replacements which accompany a group of small northerly-trending fissures, while of relatively low precious-metal content, have a still higher gold-silver ratio. These fissures, best seen in No. 5 incline, differ in course and character of mineralization from the characteristic Union-Carbonate parallel fissures, which run N. 65° W. Oxidation and post-mineral movement have obscured the age relations, but the northerly fissures seem to be earlier. Other local areas of high precious-metal content were around the South Park, in Horse Gulch, and at Burns, far to the north of the central dome.

In general at Rico, the period of mineralization not the course of the fissures nor the stratigraphic horizon of the beds replaced, is the significant thing in relation to type of mineralization and the assumption that all fissures of similar course may be grouped together and necessarily belong to the same period is, I think, responsible for some of the confusion heretofore experienced in deciphering the relation of fissures to ore replacements in this district. I hope that the re-survey now in progress will succeed in throwing more light on this question.

In the recent development of the Buckhorn area, north of the Pro Patria Tunnel, rich silver-gold ore was found in the Eureka vein, a "pay" fissure, under the contact. This vein was cut and faulted by "cross" fissures which, so far as yet developed, made no ore in the overlying "contact." It seems probable, however, that fissuring and faulting may have continued long after the magma (which hypothetically underlies the Rico dome) had ceased to emit mineralizing fluids, and that for this reason the latest cross fissures are barren. I have not seen the "contact" in this (Buckhorn) area as it had not been reached by raises made on the Eureka vein at the time I left Rico, but according to Mr. R. L. Pellet of Rico it contains the gray silt which I have always considered to be a residual product from solution of the gypsum, and if this is correct other cross-fissures of slightly earlier age, if present, may be expected to make ore in the contact.

It would appear to me that the hypothesis "which best reconciles the various observed facts" is one that supposes the northwesterly ("cross") fissures—or some of them—to have been first opened before the northeasterly ("pay") fissures, and to have been subjected to repeated movement during and after the opening and filling of the northeasterly ("pay") fissures. Thus they were subject to movement throughout a comparatively long period whereas the northeasterly ("pay") fissures were opened and mineralized during a shorter, and special, phase of that period.

One may suppose that the northwesterly "cross" fissures were not themselves filled with ore of the bonanza type for the reason that, owing to the repeated movement assumed, they were too open, and permitted the mineralizing fluids to pass through, without deposition, until the more confined openings in the blanket above were reached, where the ore was, in fact, deposited.

Apart from the deep-seated clay and breccia-filled faults, which may have been the channels through which passed the fluids that replaced the thick beds of the Middle Hermosa with ore, but of which my own observation is not sufficient to qualify me to speak, one may distinguish three types of veins, of slightly different character, all concerned in ore-forming processes, but in different ways:

(1) The Newman Hill northwesterly ("cross") veins, which are characteristically replacing veins and contain little or no ore, are channels, through which mineralizing fluids have ascended to where they found suitable material to replace, or spaces to fill under favorable conditions, that is, confined but open or opening; (2) intermediate veins like the Newman Hill northeasterly ("pay") veins, which themselves contain ore where the fluids were dammed back suffi-

ciently so as to have time to deposit their load, but which also deposited ore in or replaced beds to a smaller degree; and (3) filled veins like the Silver Swan and Maggie which more resemble the "vein-dikes" of Spurr and which were filled so quickly, perhaps, that there was not time enough for important action on the rocks through which they passed. The latter are less likely to form considerable replacement ore bodies in the "beds" or "contacts."[3]

At the Union-Carbonate mine, the northwesterly verticals seem more apt to mineralize the blankets than the more westerly verticals do although some of the former are so small that in the sandstone which underlies the blankets they are hardly distinguishable. In both blankets, "upper" and "lower," in this mine, a roof of shale seems to be almost essential for the presence of ore. Another blanket, called the "Jones blanket," about thirty feet under the "lower" blanket, has a shale floor and sandstone roof, and as far as it has yet been explored, shows very little commercial ore. There are said to be two other blankets at considerably lower horizons exposed in the old shaft, but they are not now accessible.

It seems probable, from Burbank's[4] work in the Ouray district, that the Rico mineralization may have been coincident in time and type with Burbank's earlier period. The principal productive horizons at Ouray are, however, much higher stratigraphically. In the Ouray-Telluride district, the contrast between the replacing and non-replacing types of vein are best illustrated by mineralization of the late period. (Miocene?) Filled veins (or what Spurr calls "vein-dikes"), such as the Smuggler-Union or Camp Bird, are in my opinion unlikely to have occasioned important replacement in underlying soluble strata. Irregular, compound or crossing fissure-zones, such as the "breaks" to which the more important and

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[3]During the discussion on this paper, Mr. D. M. Kline, Superintendent at Rico for the St. Louis Smelting & Refining Co., stated that subsequent development on these veins had disclosed replacement ore bodies proceeding from them into limestone beds, which is unfortunate for my third illustration, if not for my hypothesis.—[G. E. C.]

[4]Burbank, W. S., Revision of geologic structure and stratigraphy in the Ouray district, Colorado, and its bearing on ore deposition: Colo. Sci. Soc. Proc., Vol. 12, pp. 151-232, 1930.

continuous ore-pipes of the Red Mountain district appear to be due, and which were channels through which mineralizing fluids ascended, causing intense alteration of the country-rock, seem likely to have replaced with ore the underlying Ouray limestone, unless it was removed by erosion before the Tertiary Volcanics were extruded, and if therefore it still underlies the Red Mountain area. It appears to me that the degree and character of the action of mineralizing fissures on their walls, where they traverse relatively insoluble strata, may be a practical guide to their probable action on more soluble strata traversed by them lower down. In general, fluids that are seen to have mineralized the country-rock adjoining fissures through which they have passed, and to have deposited in it numerous spots and stringers of ore, are more likely to have been agencies of replacement than fluids that have passed through fissures without affecting their walls. The former were perhaps more tenuous, and possibly acted throughout a longer period. They would in this respect resemble the still more tenuous emanations which, at Red Mountain, effected wide-spread rock-alteration, prior to the ore-forming period. Even if Spurr's term "vein-dikes," applied to the filled type of vein, goes too far, the conception that different kinds of fluid were emitted from magmas at different stages—and that from their effects where we can see them we may infer proportionate effects where we cannot see them but where we are entitled to conclude that the fluids passed—seems to offer hope of real assistance to the miner.

Some of us used to think that the tendency of a limestone to be replaced by ore depended on its purity. During the early development of the Wellington mine at Rico, according to the personal communication of Mr. Albert Lofquist, it was customary to take frequent samples of the limestone and test them for insoluble, a few per cent of which was regarded as ground for concluding that the limestone was unlikely to contain ore. My own practice about that time was to take pieces of limestone (about half-an-inch cubes) and treat them with dilute acid (2 to 1). If after treatment with the acid overnight the limestone fell to powder, so occupying a much reduced space, I considered it amenable to replacement, even if the percentage of insoluble residue was high. As an indication of permeability combined with solubility, I still consider this test useful. But in general, experience has driven me to the conclusion outlined above—that the most favorable condition for replacement is one in which the rock has been shattered or intimately fissured, yet covered by impervious rock. Without openings, actual or incipient, solutions are not likely to extend far from the fissure and unless partly confined, they are soon dissipated.

This, however, is with me a conclusion from personal experience only although many others have come to the same conclusion. Nevertheless, mining literature contains many cases in which mineralizing solutions seem to have dissolved for themselves pipe-shaped channels through homogeneous limestone, and at the same time to have filled them with ore. I have seen deposits which appeared to have been formed in this manner, but never have had the opportunity to trace them by mine workings over long distances.

It has been suggested that in such cases the fluids that deposited the ore merely followed pre-existing channels, which had been formed as caves by descending surface waters, just as caves are formed today. The objection to this idea as a universal theory to explain such ore bodies is that very frequently (although not always) the channels are completely filled with ore. This condition would seem to be improbable, if filling of pre-existing caves were the only process by which ore is formed.

Insofar as filling of pre-existing caves is the true explanation of origin for these pipe-shaped ore deposits, it is obvious that when the caves were formed the limestone beds in which they occur must have been exposed to erosion, or at all events elevated above the then existing water-table. Such being the case, the question arises whether porosity of a limestone caused by percolation of surface waters[5] may not be

[5]See Murray, A. N., Limestone oil reservoirs, Northeastern United States and Ontario, Canada: Econ. Geol., Vol. XXV, pp. 452-469, August, 1930. Discusses availability of limestone as reservoirs for oil.

equally effective in establishing a condition conducive to replacement by ore. If so, this brings out another aspect in which determination of the history, as well as the structure, of rocks might assist in determining favorable locations for ore.

A bed would be relatively favorable for replacement if as a result of elevation and erosion it had been leached by meteoric waters, containing mineral salts, organic acids, or carbon dioxide, and above all, if this exposure had not preceded the mineralization by uprising magmatic emanations long enough to result in closing of the openings by cementation.

At Red Mountain these favorable conditions seem to have been present. It is virtually certain that the fractures which traverse the overlying volcanic rocks were deep-seated, and that the magmatic emanations rising through them effected extensive alteration of these rocks, and subsequently considerable, although less extensive, replacement of them by commercial ore. The Ouray limestone, if it is still present underlying the volcanics, is therefore likely to have been replaced by ore in greater measure. Prior to the Tertiary volcanism the sedimentaries had been eroded down to the limestone, possibly producing porosity and even forming openings. There was in this area probably an underlying reservoir of magma and as it consolidated, settling and fracturing resulted.

At Red Mountain the primary copper minerals, and some at least of the primary silver-bearing minerals, are of very high grade. It would seem that ore replacements in the underlying limestone, if present, are likely to be correspondingly rich in content of copper and silver.

Another point that seems to support the view that porosity (at all events if present to such a degree as to form continuous channels) and brecciation are of greater importance as conditions favoring ore deposition, than relative solubility, is that as mentioned by Murray the solubility of calcite is much greater than that of dolomite. Ore deposits nevertheless generally favor dolomite, rather than limestone composed of calcium carbonate. Hewett[6] points out that "most dolomitic ore deposits show dolomite breccia cemented by sulphide minerals," and considers that "rock alteration precedes deposition of metal sulphides." He thinks that alteration (to dolomite) occurs characteristically as a surrounding aureole, and that, as a guide to ore occurrence, it will be most helpful if the dolomitized aureole should range from 10 to 50 times the size of the ore deposit.

Murray concludes that little if any of the porosity observed in dolomitic limestones is developed by decrease in volume produced by molecular replacement. Data adduced by him suggest that in limestone, originally dolomitic, there was a tendency towards leaching of the calcium carbonate and retention of the magnesium carbonate, resulting in a porous structure. He adds (p. 463, loc. cit.)

"in a series of sediments where crystalline dolomitic limestones alternate with dense calcareous ones, solution takes place more rapidly in the former than in the latter. Waters percolating down through the former dissolve the calcite, producing porosity of the continuous type, whereas in the latter, solution takes place along joints and fissures, producing caves and underground streams."

It is realized, of course, that such porosity of a rock as renders it relatively favorable for replacement may be primary. It is, however, believed that any limestone, whether pure calcite or dolomite, which was exposed at some period during its history to percolation by meteoric waters, is more likely to have become porous and therefore suitable for ore deposition (unless in course of time the pores subsequently became sealed again).

In the Rico district, the general conception suggested is:

(a) Intrusion of an underlying reservoir of magma with accompanying sills and dikes, causing fracturing, doming, and reverse faulting.

(b) Consolidation and settling of the cooling magma, resulting in additional fracturing, attended by normal faulting.

Both phases caused some slippage, bed-faulting, and brecciation of the sediments overlying the uplifted dome.

[6]Hewett, D. F., Dolomitization and ore deposition: Econ. Geol., Vol. XXIII, pp. 821-863, 1928.

Throughout the entire period, hot emanations from the magma arose through the overlying strata, following the faults and spreading out through the more porous or more brecciated sediments. Accepting this conception—which seems to be that of the prevailing trend of geologic thought—I should expect the movement and the other processes which resulted in ore deposition to be most pronounced, other things being equal, near the center of the dome. The fissures that cut and fault the beds of limestone and limey shale that now contain the ore were not merely the channels through which mineralizing fluids ascended but also facilitated the process of mineralization, because during the faulting movements the adjacent portions of the beds were shattered and rendered pervious.