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GENERAL CORRELATION AND SYNCHRONY OF COLORADO ORE DEPOSITS

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Mr. Lovering's second paper[1a], upon ore deposits, presented before the Society, deals only with that part of the Colorado "mineral belt", as he terms it, which lies in the Front Range where he has done his field work. The belt continues to the southwest, and other Government geologists (Messrs. Butler, Larsen, Burbank, Behre, Goddard, Singewald, Vanderwilt, and others), working under the present cooperative arrangement with the State of Colorado, or completing Federal work already started, have been studying this belt from the Front Range to the San Juan Mountains. The earlier reports by Emmons, Cross, Colorado geologists and others, together with the results of recent field work of an economic character read before the Society, have covered an area approximately 250 miles long and, in its middle and southwest parts, 100 to 125 miles wide. There is much field work still to be done, and it is under way, but it now appears appropriate to make, so far as may be, a broad correlation of results to date for the benefit of those who are interested in the outcome of local field studies and their possible benefit to the mining industry.

The Mineral Belt—The belt includes the mining districts of Boulder, Clear Creek, Gilpin, Lake, and Summit Counties; Gilman (Redcliff) in Eagle County; Aspen, in Pitkin County; Monarch and other districts, in Chaffee County; the Elk and West Elk mountains of Gunnison County; Lake City, Creede, Ouray, Telluride, Silverton, Ophir and Rico districts of the San Juan region; and such border districts as Cripple Creek, Silver Cliff, Summitville, Bonanza and La Plata.

[1]Geologist; President of the Society, 1929-30.

[1a]Lovering, T. S., Localization of ore in the schists and gneisses of the mineral belt of the Front Range, Colo.: Colo. Sci. Soc. Proc., Vol. 12, pp. 233-268, 1930.

There are in the belt three main types of ore, classified according to conditions of depth and temperature operating at the time they were deposited: (1) hypothermal deposits in pre-Cambrian and other ancient rocks, such as the molybdenite at Climax; (2) mesothermal deposits of gold, silver, lead, zinc and copper, as veins and replacements in Paleozoic and Mesozoic sediments and in deep Tertiary igneous rocks; (3) gold and silver, with varying amounts of the base metals, deposited under epithermal conditions and directly associated with the mid-Tertiary eruptive rocks in areas where erosion has been moderate.

The Igneous Belt—Throughout the area indicated above, the metalliferous belt coincides with an igneous petrographic province crossing the mountain ridges almost at right angles. At intervals along it are exposures of monzonite batholiths, suggesting that there may have been a continuous deep magma reservoir throughout the belt at the time of their intrusion, around the beginning of the Tertiary. Then about Miocene time there were scattered volcanoes that discharged magmas, generally of intermediate composition, over much of the same area.

Late Tertiary and Recent basaltic lavas, widely distributed and not associated with ore deposits, and isolated rhyolitic outbursts, such as Hahns Peak, have no apparent relation to the Miocene igneous belt, and are more plentiful outside of it than in it.

At the northeast end of the belt eruptive early Tertiary andesites have been eroded away and laid down in great volume in the Denver and Middle Park beds on both sides of the Front Range, indicating their abundance at the time they were ejected. In the range they are now represented by dikes that were probably intruded at the time of eruption. Lovering has presented evidence[2] to show that the Denver formation is late Cretaceous, but the uninterrupted sedimentation following it in overlying formations in the plains, the continuity of types of plant life through the Denver and above it, also the indica-

[2]Lovering, T. S., Colo. Sci. Soc. Proc., Vol. 12, pp. 91-93, 1929.

tions in other areas of the igneous belt that the igneous activity started at or near the beginning of Tertiary time, induce many of us to regard the eruption of the rocks redeposited in the Denver beds and the accumulation of the beds themselves as local incidents of the world-wide continental readjustments that introduced the Cenozoic Era.

Both eruptives and intrusives are found in the Mosquito, Park, and Sawatch Ranges, outcropping conspicuously, for instance, between Cripple Creek, Silver Cliff and Breckenridge, so that Cripple Creek and Silver Cliff, instead of being isolated centers, appear to be on the edge of the belt; also the La Plata Mountains, though a local volcanic center, may be regarded as the southwest end of it. The Gunnison eruptives are nearly continuous with those of the San Juan region and once were continuous with them. With the latter should also be grouped the andesites, rhyolites and latites covering great areas in Saguache, Mineral, Grand and Conejos Counties. In the middle parts of the belt it is probable that eruptive rocks also covered large areas, as in Chaffee County, but these have been mostly removed by the deep erosion of the Arkansas valley.

The Tertiary intrusions of dikes, sills, and stocks along the belt are found both as offshoots from the earlier batholiths and as injections radiating from later volcanic centers.

The pre-Cambrian is found to have been an igneous area in many places where exposed along the belt. It may be that it influenced the alignment of the latter, or local parts of it. The Miocene Cripple Creek volcano, for instance, broke to the surface on the margin of a pre-Cambrian batholith. The San Juan eruptives, and the monzonite bodies there, came up in an area where there had been, in pre-Cambrian times, intense igneous activity, as is exhibited along the Animas Canyon. It is to be remembered that the lapse of indicated pre-Cambrian time equals all subsequent time. In each of its several recognized igneous periods ore deposition was accomplished in many centers of special activity on this and other continents, as in the great Canadian shield, Northern Rhodesia and nearer

at hand in New Mexico and Arizona. If such old igneous centers can be located and defined, it is possible that ore may be found in them.

Conclusions as to Colorado ore deposits—The discovered and undiscovered ore of Colorado therefore may be arranged into three main groups:

(1) Mid-Tertiary (Miocene and post-Miocene), the youngest of the deposits, have supplied most of the State's past metal production. These are the ores easiest to find. They outcrop in many places, as in the Front Range districts, Breckenridge, Montezuma, Cripple Creek, Silver Cliff, and parts of the San Juan. But a great percentage of even these younger deposits do not appear at the surface. In Leadville none of the great ore shoots outcrop and much patience and great outlay of money have been required to find them. One meager outcrop and the gulch placers led to the development of the district. In the central San Juan the late rhyolites (Potosi series), capping high areas, were unfavorable to ore deposition and do not contain outcrops. In such places ore bodies in underlying formations were discovered from tunnels driven below the rhyolites.

(2) Burbank[2a] has described before the Society, for the first time, another and older series of deposits in the San Juan region, earlier than the volcanic rocks and buried by them or by early Tertiary sediments, but later than the older intrusive rocks. These ores are ascribed to monzonite intrusions and associated igneous bodies as their mineral sources. Burbank's observations tend to show that these intrusions mark the introduction of the Tertiary Revolution in that locality. If so they are separated in age from the Miocene ores by a considerable time interval, say 40,000,000 years. Erosion has exposed them at only a few places in the San Juan region. On the other hand, the deposits in the Front Range have been thoroughly uncovered by erosion. At Climax the great Mosquito fault has assisted erosion to reveal the deep-seated molybdenite, which may belong in age with this second group.

[2a]Burbank, W. S., Colo. Sci. Soc. Proc., Vol. 12, pp. 151-232, 1930.

(3) Although ores which are certainly pre-Cambrian have not as yet been found in Colorado, conditions may exist somewhere in the State that resemble those responsible for the the enormously productive pre-Cambrian pyritic copper deposits at Jerome, Arizona, and the zinc-lead ores of Pecos, New Mexico. We have reason to believe that the wide-spread peneplain at the close of pre-Cambrian, by retarding or suspending erosion, preserved many ore bodies, now buried, which, *if they could be found,* would be of great importance. This peneplain, which is so clearly recognizable in New Mexico and Arizona, should have extended into parts of Colorado where Paleozoic sediments buried it and have protected it from erosion to the present time. This could be the case in about half the mineral belt, and over a larger territory northwest of it. Methods have not been devised by geologists for finding and outlining buried igneous areas or directing the miner to their possible associated ore deposits, but in recent years progress has been made in converting geological theory into actualities, and further progress is to be expected.

To summarize, it can be stated with considerable confidence that undiscovered ores of the first category exist under late Tertiary formations and under Recent mountain-slope and valley debris in the mineral belt; of the second, under the base of the Tertiary eruptives and sediments; and of the third, under our Paleozoic formations.

Discussion

B. S. Butler,[3] Golden, Colo.—Mr. Finch has called attention to the two widely separated periods of igneous activity and ore deposition that have been definitely recognized in the southern Rocky Mountain region, namely; the pre-Cambrian and the Tertiary.

Lindgren[4] has given us some of the characteristics of the pre-Cambrian deposits as contrasted with the Tertiary de-

[3]Professor of Geology, Univ. of Arizona, Tucson, Ariz., and Geologist, U. S. Geol. Survey in charge Colorado Cooperative Geological Survey.
[4]Lindgren, W., Notes on copper deposits of Chaffee, Fremont and Jefferson Counties, Colorado: U. S. Geol. Surv. Bull. 340, pp. 157-174, 1908.
[5]Lindgren, W., Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Surv. Prof. Paper 68, pp. 48-51, 1910.

posits; but a general study of the pre-Cambrian deposits of the southern Rocky Mountain region, with a view to bringing out their geological occurrence and mineralogical characteristics, and their broader distribution with any possible geological control, remains to be done. Lindgren has pointed out that the pre-Cambrian deposits are of the deep-seated type, but since there are also Tertiary deposits of deep-seated type, it is not a simple problem to determine in which of the two ages a deposit belongs. Deposits that are most certainly determined as pre-Cambrian are those that are unconformably overlain by Paleozoic sedimentary rock, like the Pecos mine deposit of northern New Mexico and deposits at Jerome, Arizona.

Lindgren states that the ore deposit of the Sedalia mine, near Salida, Colorado, is cut by a pegmatite dike of pre-Cambrian age, which would seem to fix the age of that deposit; but the fact that this and other deposits in pre-Cambrian rocks nearby lie between two rather extensive bodies of post-Paleozoic intrusive rock might cause one to suspect a later age.

The important metals in the known pre-Cambrian deposits of the southern Rocky Mountain region are copper and zinc, with some gold. Other metals, as lead and silver, are present but not in large amount. It might be expected that the pre-Cambrian, which was a period of extensive intrusive activity, would have yielded extensive ore deposits in the southern Rocky Mountain region as it has in other parts of the world; and in the Jerome district of Arizona we do have one of the great copper deposits of the world. In Colorado, however, deposits of known or supposed pre-Cambrian age are not large.

It has been emphasized in recent years[5] that some of the pre-Cambrian areas of Colorado have been old positive elements and have been deeply eroded. It seems probable that

[5]Lee, W. T., Building of the southern Rocky Mountains: Geol. Soc. Am. Bull. vol. 34, No. 2, pp. 285-300, 1923.
Lovering, T. S., Geological history of the Front Range, Colorado: Colo. Sci. Soc. Proc. vol. 12, pp. 62-111, 1929.
Ver Wiebe, Walter A., Ancestral Rocky Mountains: Am. Ass. Pet. Geol. Bull. vol. 14, pp. 765-788, 1930.

the erosion has been so deep in most of the exposed areas of pre-Cambrian in Colorado as to have swept away any ore deposits that may have been present. That there may be more important pre-Cambrian deposits in areas that have not been positive elements and consequently were not subjected to as extensive erosion is entirely possible and any ideas that would help, not simply to locate such negative areas but to suggest whether or not they were mineralized, are much to be desired. Such areas are largely or entirely covered by later formations and there is no indication in these later covering rocks of possible ore deposits beneath them so that as yet we are entirely in the dark regarding them.

It may be noted that two of the valuable pre-Cambrian deposits of the Southern Rocky Mountain region, the Jerome deposits of Arizona and the Pecos deposit of New Mexico, are just at the edge of a covering of Paleozoic rocks, and their discovery has been made possible by the erosion of the Paleozoic rock. It would take courage indeed to prospect the pre-Cambrian under a covering of later rocks unless some positive evidence of mineralization were available.

Golden, Colo., July 9, 1930.

John W. Finch, Moscow, Idaho: I agree with Dr. Butler that it would be courageous, no doubt it would be reckless, of a mining company to attempt blind development in search of buried pre-Cambrian ore deposits. Attention was called to their theoretical existence as a deliberate challenge to geologists to develop, if possible, criteria establishing their presence or absence, and, if it appears reasonable that they do exist, to give some thought to possible methods of finding them.

Of the following suggestions the first tends to indicate that such deposits are not necessarily removed by erosion even where they have outcropped for long periods. The second sketches a possible plan of search which might be tried out in the field.

1. Paleogeography and Paleophysiography

Dr. Butler suggests the relevance of these suggestions in his comments when he expresses the opinion that Colorado pre-Cambrian ores may have been destroyed by erosion. Why are there any ore deposits whatever left in the pre-Cambrian, and why, especially in regions known to have been land surfaces exposing pre-Cambrian rocks for a great part of geological time, should all ore deposits not have been totally removed by erosion? These are obvious questions. Yet it is in just such regions that pre-Cambrian ore deposits of the first magnitude have been found. In the great Canadian-Siberian shield and that of Central Africa, one is astonished to find that their pre-Cambrian outcrops were not covered by sedimentation during most of Paleozoic time; the Pecos vein in New Mexico was exposed through Cambrian and Devonian. At Jerome, Arizona, the ore outcropped through the long period of time required for a land of presumably great relief to be reduced to a peneplain, and to base-level over great areas.

Dr. Butler has called attention to the prevalence of ore deposits around the margin of the Colorado Plateau positive element[1], and in his discussion of pre-Cambrian ores suggests the dependence of their survival upon physiographic events. That they have survived in some of the positive areas suggests a revised conception of such segments of the earth's outer shell. It has been thought that they tend to rise and the negative masses tend to sink. Apparently the negative masses do both and the positive on the whole do neither. It is evident from known examples that pre-Cambrian ore-deposits were formed in both, but some of the greatest are in ancient marginal igneous belts within the present boundaries of positive areas, as in Canada.

The Himalaya range, the world's most striking negative element, was a mediterranean basin which progressively sank to great depth below sea-level as it filled with sediments, then in the Tertiary emerged to an equally great or greater eleva-

[1]Butler, B. S., Colo. Sci. Soc. Proc., Vol. 12, pp. 23-36, 1929.

tion above sea-level, making a total vertical journey of ten miles or more. The vast Siberian-Canadian shield to the north of it remained inert and stationary for a great part of post-Proterozoic time subject to little erosion or sedimentation. The lesser positive Thibetan block, inert previously, as had been the larger element, trailed upward bodily for a mile or thereabouts along with the Himalayan uplift and is now a young physiographic unit. Much of the southern marginal part of the pre-Tertiary Thibetan block was involved in folding and faulting on the edge of the great uplift. The Colorado Plateau stands in a similar relation to the Rocky Mountains.

2. TRACING PRE-CAMBRIAN FLOAT IN SEDIMENTARY BEDS

Though this may not sound promising, possibly it is worthy of trial in the field. One illustration may indicate its possibilities. Here and there in the terrestrial Red Beds through a great vertical range and along a north and south belt extending roughly two-thirds of the width of new Mexico, in and near the east foot hills of the Rocky Mountains, we find local concentrations of copper and other metals derived from elastic vein materials laid down with these beds.[2] The beds are sandstones and arkoses derived from a pre-Cambrian land area and were spread out on slopes of slight inclination by deploying streams, intermittent and of great transporting capacity when they operated, because they were streams in a semi-arid country.

Detailed study of the vein fragments and mapping belts where they are coarsest and most prevalent in particular beds might reveal the directions of streams which laid down the beds, and enable lines to be drawn to localities in the low upland areas of that time where the outcrop sources of the vein matter existed. Such lines might not focus into definite small areas, but might narrow the pre-Cambrian territory to be searched beyond the western edges of the beds. The sharp

[2]Lindgren, W., and Graton, L. C., Ore Deposits of New Mexico, U. S. Geol. Surv. Prof. Paper 68, 1910. Finch, John W., A. I. M. E. Trans., Vol. 76, pp. 378-392, 1928.

canyons of the mesa topography should then be studied minutely for exposed pre-Cambrian rocks, igneous centers and evidences of veins.

Vein fragments should also be sought in modern stream debris. The pre-Cambrian Pecos outcrop is a small one from which overlying Pennsylvanian beds have been eroded off in a narrow canyon bottom. Occasional fragments of float from the outcrop can be found below it in the gravels of the Pecos River. Overlying the marine Pennsylvanian there are near at hand upper Pennsylvanian beds, partly marine and partly terrestrial, the latter containing disseminated copper vein fragments as described above, and local secondary concentrations of copper. Therefore copper veins in place in the pre-Cambrian lie somewhere westward. They have necessarily suffered somewhat more erosion than the Pecos outcrop.

Much the same conditions are found west of the Rocky Mountains in eastern Utah and northern Arizona.

3. GEOPHYSICS

In restricted areas where beds are not thick along Paleozoic and later shore lines and under the thin edges of terrestrial beds, after pre-Cambrian ores are indicated by geological study, geophysics, as instruments and technology improve, may some day locate ore bodies of copper, lead and zinc, if they are large. Gold-quartz veins or small veins of any metal, are not likely to be found in this way.

University of Idaho, July 20, 1931.