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LEADVILLE MINING DISTRICT

COLORADO

An Analysis of Control of Ore Deposits

T. E. Gay Jr.

Mining 198

Spring 1948

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INTRODUCTION

Both to gain experience in the methods of mining district analysis and to see if such an analysis reveals information of value for the Leadville Mining District, Colorado, are the purposes of this paper. The method used is to correlate data published by various sources in a coherent, easily visualized form and to seek generalizations regarding ore emplacement throughout the district. It is desired to learn what are valid guides to ore and what influences affected the position of the orebodies - structure, favorable beds, depth zoning, proximity to intrusions, etc. An understanding of tectonic forces applied throughout the region is also necessary, the general picture of statewide geologic history being searched for its bearing on the ores of this district.

This paper offers several diagrams illustrating features of interest and some discussion of possible influences and correlations.

GEOLOGIC SETTING

Leadville is located in northeast central Colorado in the Mosquito Mountains of the southern tip of the Park Range, between the Front and Sawatch Ranges, formerly the northeast margin of the Paleozoic Colorado geosyncline. The rocks of the region are shallowly buried pre-Cambrian metamorphic basement overlain by about three thousand feet of Paleozoic quartzites, limestones, and dolomites intruded by dikes, sills, and irregular masses of monzonitic rocks.

After these rocks were in place and before the ore was deposited the region was uplifted, mildly folded, and faulted by thrust and transverse normal faults connected with the Laramide revolution.

In Tertiary time ore was deposited chiefly as sulfides of lead, zinc and iron with varying concentrations of silver and gold. The ore formed replacement "blankets" in the dolomitic limestone, as well as veins in the siliceous horizons. Structural control has not been generally recognized. Post mineral normal faulting; rhyolite agglomerate intrusions; and the spreading of glacial debris over the lower regions have combined to obscure visible relationships somewhat but have no direct effect on the ore emplacement.

DETAILED GEOLOGIC HISTORY OF THE REGION

Igneous activity and mineralization at Leadville are closely related to Laramide structural features, the understanding of which requires some background on the Paleozoic and Mesozoic conditions of the Colorado region.

Of the pre-Cambrian we only know that mica schist and gneiss are present into which batholithic bodies of pre-Cambrian diorite and granite were intruded. Between the pre-Cambrian and the Cambrian there is a great unconformity.

In upper Cambrian time most of the state lay in the Cordilleran northwest - southeast sea, with Leadville out in the trough, and the nearest landmass about fifty miles northeast. About 180 feet of Cambrian Sawatch Quartzite was deposited at Leadville, directly on the pre-Cambrian basement.

By upper Ordovician time the axis of the geosyncline had moved farther northeast, leaving Leadville in about the middle of the trough with landmasses about sixty miles southwest and about 70 miles northeast. During this period about 120 feet of White Limestone was deposited at Leadville.

Gentle, level uplift and subsequent erosion is believed to have occurred from this stage until late Devonian time at which time the ten to seventy feet of Parting Quartzite was deposited at Leadville. During the upper Devonian and lower Mississippian, seas covered most of the state, the important dolomitic Leadville or Blue Limestone being deposited at Leadville to a depth of about 200 feet. By the end of Leadville time there were an estimated 1000 feet of Paleozoic sediments in the center of the seaway in which Leadville stood, with shallowing margins.

During upper Mississippian time upwarping started in a generally north-south axis, forming the ancestral Wet Mountains and Front Range to the east of Leadville, but leaving the latter in its trough.

In Pennsylvanian time several landmasses, estimated at 1000 feet high were to the southwest and northeast of Leadville in northwest - southeast anticlinal uplifts in the position of the present Elk, Uncompahgre, and Park mountains. About 1000 feet of Weber shale, sandstone, and quartzite "grits" were deposited over Leadville.

In the Permian further uplift divided the former general geosyncline into three basins leaving Leadville still in a trough between the ancestral Elk and Park Range mountains.

During the late Permian and in the Triassic the San Juan Mountains high area, some 100 miles to the southwest, was deformed by further uplift, folding and faulting. During the Jurassic and Lower Cretaceous further broad crustal warpings occurred, while Leadville still, to all appearances, remained submerged. This set the stage for the Laramide revolution by providing several positive areas against which pressure could be applied; 1) the former buried "Colorado Range" geanticline (now the Front Range highland) to the northeast of Leadville, and 2) the San Luis - Uncompahgre geanticline backed by the San Juan uplift to the southwest of

Leadville.

The Laramide revolution of the closing Cretaceous had different effects on the half of Colorado lying north of Leadville and that half lying south of it, Leadville appearing to favor the northern type of action. During this revolution the central geosyncline in which Leadville was located was uplifted above sea level for good, between the actions of the Sawatch uplift to the southwest and the Front Range uplift to the northeast. The central region was uplifted to its climax but "because of the narrowness of the trough and the weakness of the thick sedimentary column, thrust faulting dominated the structure of the resultant (Park) mountain range." [3]

To the south, the thrust faults dipped southwest (into the Sawatch uplift) and the Paleozoic geosynclinal sediments were thrust eastward over the Cretaceous strata. In the north, including Leadville, the thrusts dip northeast under the Front Range. Overturning and thrust faulting towards the west is characteristic of the Paleozoic geosyncline west of the Front Range from the south Park Range north to Wyoming whereas a similar zone of oppositely dipping faulted folds extends through the Gore and Mosquito Ranges south to the Sangre de Christo mountains.

In Leadville the thrusts break through the crests of assymmetrical anticlines whose western limb is the steeper. At least four such thrusts, essentially parallel and striking slightly west of north, are seen on the accompanying map, and two more of considerable continuity are to be seen just east of that map, in the Alma district.

An interesting feature of Colorado geology is the belt of early Eocene porphyritic intrusive stocks which occurs from southwest to northeast at right angles to the Laramide compression, and is about 80 miles

[3] See references in BIBLIOGRAPHY at end of paper.

long and 20 miles wide. This intrusive belt localizes all the intrusives of this period and also contains most of the metalliferous deposits of Colorado either within it or along its flanks.

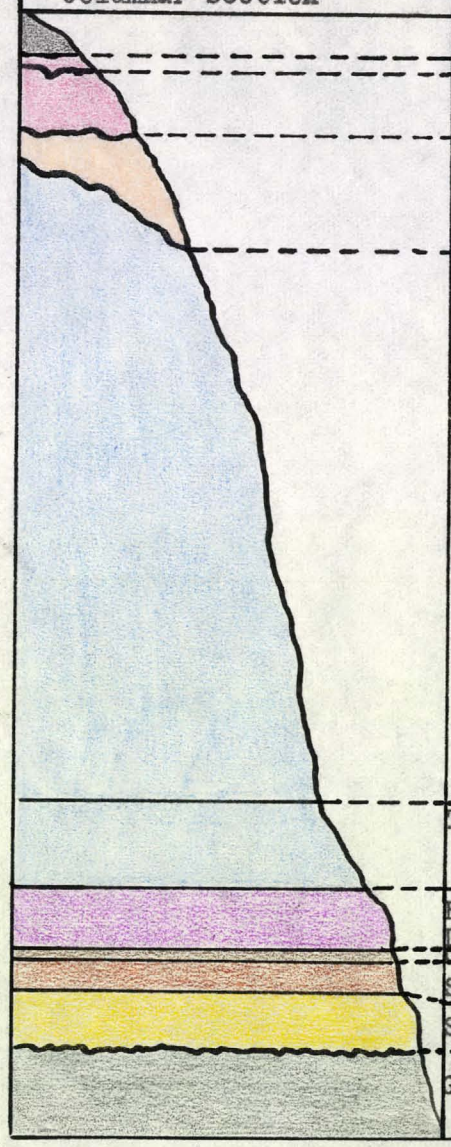
None of these intrusives appears in the Leadville district proper, but it seems to be more than coincidence that Leadville lies directly in the center towards the southwest end of the belt.

The belt cannot be ascribed to anticlinal uplift but is believed to follow a line of tensional stress at right angles across the Laramide compression. It appears to cross the mountains at about the region dividing the northern Colorado region of northeast dipping thrusts and the southern region of southwest dipping thrusts. Little coherent evidence of northeast faulting, fissuring, or intrusion is seen in Leadville proper but this orientation dominates among most Colorado veins.

Conclusions Drawn From Study of Regional Geology

Regional geologic conditions have slight effect on ore placement, except that the general Laramide northeast - southwest compression and the faulting normal to this axis, set the general direction for fissures and faults in the area. The northeast dipping pre mineral thrust faults have had a great deal to do with ore placement - providing channels in many instances, brecciating and folding wall rock to some extent, containing veins, and having parallel veins in sheeting zones alongside. These thrusts dip towards the Front Range uplift, steepening in depth toward it, and may be antithetic faults accompanying and flanking that uplift. (It appears more likely that they are related to that uplift than to the relatively minor - but closer - Sawatch uplift to the southwest, away from which they dip.) However the position of the orebodies as seen on maps does not indicate general alignment with the axis of this

STRATIGRAPHIC COLUMN OF THE LEADVILLE DISTRICT



Columnar Section	Description of Rocks	Formation Name	System & Series	
	glacial boulders	Moraines (unconform)		
	decomposed glacial debris	terrace gravel 0-500' (unconform)	Pleisto.	Q
	glacio-fluviatile marl, loosely coherent	"Lake beds" 0-500' (unconform)	Plio - Pleisto	T Q?
	arkosic & micaceous coarse sandstone & quartzite alternating with various shales. Impure ls lenses of nonpersistent nature. 940 '	Weber (?) 1000= (top eroded in Leadville District)	Pennsylvanian	Carboniferous.
	Thin bedded black bituminous shale 0-300'	200'		
	Heavy bedded dark blue Dolomite with shaly base	Leadville or Blue limestone	Miss. (Dev.?)	
	Coarse quartzite	Parting qtzite		
	Shaly, silicious lime.	White ls.	Ordovician	
	Shaly quartzite 180'	Sawatch qutzite (unconformity)	Cambrian	
	Granite, cut by aplitic and pegmatitic dikes	Granite	Pre Cambrian	

From Proffessional Paper 148
page 23.

faulting.

Some suggestion is offered by the ore pattern on Iron Hill and in the strongly veined region east of the Weston Fault of a northeast - southwest localization of the ore pattern. This may be partly attributed to the northeast - wouthwest direction of tension openings that would arise from the northeast - southwest axis of compression, particularly if any uplift had occurred along this belt. The general correlation of the ore alignment with the similarly directed belt of Eocene intrusive stocks may be significant in the light of a possible alignment of tension openings. Also the fact that the change in character of Laramide uplift-thrusting effects is approxomately divided by this intrusion belt may have importance, making it an area intermediate between differently behaving regions to the north and to the south.

However, with due regard for these possible theories, it appears from data recorded that local irregularities have had the most influence on the final placement of the bodies where they are.

GEOLOGY OF THE DISTRICT

An abbreviated discussion of sedimentary and igneous bodies should suffice.

The sedimentary succession is seen in the accompanying geologic column, of which the chief ore blanket bearing horizon is the dolomitic Leadville limestone which is quite generally overlain with White Porphyry - although the latter is also intruded in every conceivable attitude through and below as well as above it. Ore is also found in less extensive replacement blankets in the older White Limestone which is less dolomitic, thinner, and frequently interrupted with shaly layers, apparently making

it less subject to large scale replacement. Vein ore is found also in the several quartzite members and adjacent to and within igneous masses to a slight extent, chiefly depending on local permeability due to structural conditions.

In the district igneous intrusive porphyries have a close relationship to the ore. They were intruded during the Laramide disturbance, during late Cretaceous or early Tertiary time, chiefly as sills associated with several stock-like masses, and as dikes apparent in pre-Cambrian rocks. These sills were, as mentioned, chiefly concordant but quite unpredictable locally both as to attitude of passage through the sediments, and to the horizon which they may intrude. The porphyries are somewhat uncertainly divided into White (muscovite granite or salic granodiorite) and Grey (granodiorite to quartz monzonite) although they are too similar for ready distinction. Cross cutting and other relationships establish the White as the earlier, more abundant, and generally higher than the Grey, but the Grey is more closely tied in with the actual ore solution passageways, indicating the ore deposition occurred not long after its emplacement. Also a few late Tertiary or Quaternary post mineral rhyolitic agglomerate necks, or pipe-like bodies are seen but without structural importance.

STRUCTURE IN THE DISTRICT

Of principle interest in this analysis is the tracing down of the structural behaviour of the district for inspite of early emphasis of non-structural control of ore deposits, recent general work points more and more to the universal importance of structural features in the location of ore deposits. Leadville, a blanket-replacement type of district of gentle folding and block-like faulting has not been emphatically de-

scribed in the light of its structural features.

FOLDING

Average trend of major folds is between north and northwest, being generally unsymmetrical, the anticlines having their steeper west limbs broken by steeply east dipping premineral reverse faults. From the Paleozoic history of the region, the constant thickness of the beds, and the shallowness of burial of the pre-Cambrian basement, which has been fissured in relatively few places, it seems reasonable to suppose that the folding of the beds now seen actually represents warping and not configuration of the surface of the basement. The magnetude of the folding is minor - there being no sharp folding, and faulting occurring predominantly wherever stresses became great. Folding as now observed on cross sections is somewhat augmented, especially in the younger, upper beds by the intrusive porphyry sills which have bowed the beds locally somewhat unpredictably, even breaking through them in places.

FAULTING (See map for locations.)

As mentioned, the closeness of the crystalline pre-Cambrian basement to the surface means that deep faults have not had sufficient cover to die out in folds, or bedding faults as they approach the surface. Hence faulting predominates in the structural picture, buing tied in very closely with ore channels and with the intrusives.

Four main periods of faulting have been recognized:

1. fissures and local faults caused by the intrusion of the porphyries, generally obscured by later activity, but of undoubted importance.

2. northeastward steeply dipping reverse faults, auxiliary faults, and fissures accompanying regional deformation, possibly antithetic faults accompanying the Front Range uplift to the northeast of Leadville. Some

of this group also were active in later normal faulting periods.

3. normal faults and fissures formed subsequent to folding but prior to ore deposition.

4. post mineral normal faults dipping southwest, now the most conspicuous faults of the region, but not considered in this paper because of their lack of relation to ore placement.

These features are all explained fully in the literature, and have no place in this paper except insofar as they bear directly or indirectly on ore deposition. The faults are shown on the accompanying map, from which their areal relation to the orebodies may be seen. Veins, where not included in the main faults, are also shown on the map and their pattern is of interest.

ORE DEPOSITS AT LEADVILLE (See map for locations)

1. Hypothermal or contact metamorphic ores.

Implying high temperature genesis close to the parent intrusive body, such magnetite-specularite bearing ores are found in abundance only in the Breece Hill area, adjacent to the Breece Hill monzonitic porphyry stock. They occur replacing the limestone in blanket fashion but are limited in extent and low in commercial value except where precious metals have come in with later pyrite.

2. Mesothermal ores - veins.

Although blanket replacement deposits are the most important in the district, a large number of veins also occur. All the productive veins except six lie east of the Weston Fault, in four principal groups - the Ibex, Big Four, Resurrection, and Ella Beeler - and two minor groups - Iron Hill and Carbonate Hill - as well as a few important isolated veins such as the Winnie-Luema, Sunday, and Silent Friend.

Veins intersect all formations except the plio-pleistocene rhyolite agglomerate, and tend to cross rather than stay within beds, some passing from one formation to another in a "bewildering succession." Recent faulting has broken through some veins but not affected them seriously. They tend to be more continuous in the alternating sedimentary beds, and tend to die out in the massive porphyry layers.

Most of the larger veins are in faults of considerable size; for instance the Ella Beeler, in the Weston Fault; the Silent Friend, Nevada, Winnie-Luema, Modoc, Garbutt, and Ibex No. 4 in the faults of the same names.

Most of the veins do not outcrop on the surface, frequently proving discontinuous between successive mine levels. This is thought to be due in part to the shaly Weber beds, in which faulting tends to die out in local flexures.

Most of the veins dip at high angles, from 70° to 90° although a few deviate from this rule. Roughly considered the veins shown may be considered to belong to three main systems according to their strikes, and it is noted that the veins of one system do not intersect those of other systems.

The veins tend to be fairly irregular not only in strike and dip but in such features as minor parallel veins, pinches and swells, horses, and branchings. Parallel veins frequently carry more value than the gougier main fault. Where veins cut limestone layers, replacement lenticles or blankets tend to form in every case except where fault gouge effectively seals off the limestone from the solutions.

Most veins are unobserved in their terminations as these are too thin to be ore but they are seen to pinch to a knife-edge or to fray out into uneconomical veinlets in various instances. Thinning is seen both hori-

zontally and vertically, some veins appearing to be completely surrounded by undisturbed country rock. Terminations appear to be independent of country rock except that the Weber shales are often the bed in which the vein dies out upwards. Some veins terminate in large blankets in the limestone just beneath an impervious bed - usually porphyry. Others send shoots out into the limestone beds they pass through but continue upwards undiminished to other horizons. Where such offshoot blankets from veins occur they generally are elongated parallel to the vein or to splits or extensions of the vein.

The downward limits of the minor veins may be in one of the blanket deposits, or they may, as is the case with all major veins, continue out of sight downward beneath the level of economical ore.

Average length of Leadville veins is short - 700-800 feet - and the average width quite thin - three feet - although some are up to 1200 feet long and 100 feet wide locally. Their average depth is impossible to estimate.

Veins are for the most part replacement along shear zones and to minor extent cavity filling. The principal original mineral is pyrite, accompanied by minor amounts of sphalerite, galena, chalcopyrite, argentite, bismuthinite, and rarely tetrahedrite and pyrargyrite. Principal gangue is quartz and sericite with minor siderite and manganosiderite and local barite. Ores are divided into three classes 1) pyrite - chalcopyrite, 2) highly siliceous, and 3) mixed siliceous sulfide ore. Secondary alteration and replacement is common with the vein ores as it is with the blanket bodies.

In wall rock of quartzite, granite, or porphyry, mineralization consists of replacement of fragments within the sheeted zone, with abrupt walls on either side, although local variations are seen. Stockworks

have been developed where the veins connect with shattered quartzite, Weber "grits" or porphyry at fissure intersections. Only four such bodies have been found - the Ibex, Antioch, and two in the Cord mine.

In limestones however replacement is the important trend - few if any veins passing through limestone without some lateral extension due to replacement. If near their upwards termination the veins may just terminate in such a blanket replacement body.

3. Mesothermal ores - blanket bodies.

By far the greatest part of the tonnage of ore that has come from Leadville is from the limestone replacement blankets although smaller replacement bodies are also known in the quartzite and Weber "grits" bodies. The roughly radial arrangement of these bodies about the Breece Hill intrusive is their most striking feature, but their location seems to be principally controlled by other structural features such as the reverse and normal faults and fissures formed subsequent to the porphyry sill intrusions.

The most apparent relation of the various wall rocks is that the shales of the Weber and particularly the porphyry sills acted as impervious blankets keeping the solutions beneath them, leading them to replace chiefly the Blue limestone - most extensively capped by these beds - and the White limestone, which is less widely so capped, and slightly less favorable to being replaced as mentioned above.

However an almost infinite series of variations on this general theme appear. The diagrammatic representation of the various horizons and situations under which blanket deposits are known to form gives some notion of the complexity of the total problem. The safest statement can only be that local conditions control the continuity, form, and size of the body, and the beds between which it forms. The fissures bringing

the solutions up play a role of tremendous importance as well, and these, normal or reverse faults, are features of local variation.

Relation of the Blanket Bodies to the Veins

No conclusive evidence in the way of cross cutting relations has been found to show that either the blankets or the veins came earlier or later than the other. Where visible, evidence points strongly to essentially contemporaneous formation, the veins forming where fissuring predominated (in the east edge of the district) and the blankets where the damming layers of porphyry etc. were not fractured to a great extent, in the west edge. Higher temperature minerals of earlier introduced metals may have formed in the veins, and lower temperature minerals of later introduced metals may be in the outer replacement bodies, but there appears to have been only one period of metal introduction reasonably extended in time. Ore, as found in the blankets may be classed according to the dominant sulfides as pyritic, sphaleritic, galena, copper (minor), all of which grade into the commonest type of all - the mixed sulfide ores composed of mixed pyrite, sphalerite, and galena with subordinate quartz and manganosiderite. Small quantities of ores high in bismuth, silver and gold are found locally.

Temperature zoning about the Breece Hill stock is noted in part with the magnetite-specularite-silicate gangue being closest, and siderite and sulfides further away in blankets and veins. Evidence is incomplete however and the zoning is not extensive enough to be generally important.

Conclusions and Speculations

It is not the purpose of this paper to reproduce the substantial quantity of data about the Leadville district appearing in other publications,

and the foregoing summaries have been brief. The chief contribution is the accompanying map which represents a compilation of several sorts of data from several sources, not perfectly adapted to the desired purpose; namely to draw a reasonably decent set of structure contours for the district. The chief difficulty with the contours is the fact that the top of the Blue Limestone, most significant horizon, is enormously irregular due to the vagaries of the prophyry sills intruded into, above, below and through it. Also its surface outcrops are almost all hidden under glacial debris and the data on its elevations is largely inferred from relatively infrequent mine openings. In the latter connection further uncertainty is introduced due to the erosion of great areas of the beds, requiring the projection of their remnants for the structure contour. The postmineral normal faulting has not aided the presentation materially by breaking the area into many displaced blocks with contorted edges. However the structure contours are drawn in fair average relation to the actual conditions, it is hoped.

Disappointingly enough, no extensive correlations of the structure with the ore appear - at least very little appears which was not already strongly inferred by previous writers on the district. Gently folded basins and domes, usually of north-northwest alignment appear but the ore bodies have no visible relationship to them - occurring on the flanks of domes, anticlines, and synclines, on the crests of domes and bottoms of troughs, running continuously in belts directly across such features, and being totally lacking on other well formed structures.

This is a somewhat anomalous thing because study of the literature reveals that most of the deposits discussed owe their position more or less directly to fissures or faults of various sorts. These provided passageways for the ore solutions from their deep origin to the beds where replacement took place. It is difficult to visualize the structures having formed

as indicated yet having the faults and fissures aligned in apparently independent directions. It is definitely seen in and about the Tucson Maid thrust fault that ore placement in more than six mines was directly connected with openings produced by that fault. It if was caused by the same general compressive-uplifting forces which induced the gently structural features, it is strange that the structure should not bear closer relation to the faulting, although the latter was of minor displacement in the Tucson-Maid area. The distinct lack of coordination of the orebodies with either of those features is taken to mean that structure is of unimportant effect on their position, and that faulting and fissuring has less effect than some other condition.

Throughout the part of the map west of the Weston fault minor premineral faulting and fissuring (unmappable on the scale of the map) is known to be of vital importance within most of the various mines, however it makes no direct appearance on the regional picture. In this western area only six mines have stoped vein deposits as such, the ore being almost entirely from the blanket replacement deposits. There is a definite difference between this and the area east of the Weston fault where upwards of 120 veins have been stoped. The Weston fault is a particularly well-used fault line, registering both pre and post mineral movements of considerable magnetude, and makes a striking division between the two types of regions. Also suggestive is the position of the Breece Hill stock next to the fault but apparently conditioning mineralization on each side of it if zonal theory can be trusted. (Hyporthermal magnetite-specularite-quartz-gold ore occurs both in the Ibex group and the Penn group.) It is also interesting to observe that the orebodies arrange themselves roughly radially to the Breece Hill stock, although across such barren distances and faults as to force one to postulate coincidence rather than any directional control.

On the east side of the Weston fault veins carry a relatively much more important share of the ore, although blanket replacements still predominate in bulk. It is in this region that the premineral normal faulting occurred, apparently both from tension (pointing northeast-southwest with the axis of compression) and from subsidence following the reverse faulting (pointing north-south to northwest-southeast across the axis of compression.) The orebodies aligned with these faults tend to avoid the two indicated areas of strong folding and to have formed mostly transverse to such folding and in areas flanking the crests of uplift. Of possible interest, and focusing attention again on the Breece Hill stock is the complex Ibex-Garbutt-(Modoc?) group of faults which curve concentrically around the indicated edge of the stock, but across the Weston fault from it. They also steepen in depth as they dip towards it. However in no other quarter does a similar fault system point to the stock.

The areal distribution of the few stockworks is not informative, local conditions being known to have determined their formation.

In this discussion broad generalizations are attempted which are not sufficiently backed up by observed facts. The data that has been collected is only indicative and not complete due to 1) The great amount of information missed or lost during the period when the early mines were open, and now inaccessible; 2) Economic reasons - mines did not pursue veins or blankets beyond ore, and did not record veins and blankets on their maps if they did not show ore; 3) The obscuring effects of oxidation, although in fairness it must be admitted there would be very little to study about Leadville today if the valuable oxidized ores had not been there; and 4) The great number of minor, discontinuous faults and fissures of local importance in a given mine or orebody but which are too small to map generally.

CONCLUSION

Although the possible importance of structural control was sought, it was

not found in this study. It seems probable that regional structure plays a minor role in this district, local features (including local structure) being the important factor. Regional control is seen in the tremendous extent to which one bed - the Blue limestone - carries replacement bodies, but this is more chemical than structural.

Some of the fissure ore passages are mineralized veins, many are too narrow and discontinuous to be veins - some are too fine to be found while mining. Where no fissure is found it is accepted that the ore solutions did not come through such fissures but migrated along the base of one of the impermeable overlying bodies from a more distant trunk fissure for the distance required to fix the body where now found.

Veins and blanket replacements are of essentially the same generation of mineralization, the veins forming in quantity only where there were sufficient open vertical zones due to prevalent faulting (as in the east end of the district) and blankets forming in all portions of the district where the solutions came in lasting contact with replaceable limestone. Although the orebodies on the map are divided into only three different vertical positions, actually they occur in as many as twelve different horizons in the same section, a further example of the local variation in the district.

Leadville appears, after this study, to be a district where 1) faulting has provided passageways for the ore solutions to come up from depth to their present position; 2) where lightly folded, unbrecciated sills of porphyritic intrusive, and other unbroken beds, have provided impermeable coverings through which the ore solutions could not readily dissipate upwards; 3) where beds suitable to metasomatic replacement (Blue and White limestones) were present under the impermeable layers and were replaced by the sulfide solutions 4) wherever suitable access was provided by local conditions.

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to accompany

Map of Leadville Mining District, Colorado

Geology and horizontal control: Traced from Plate 13, Professional Paper 148 "Geologic Map of Leadville Mining District, Colorado" by J. D. Irving and G. F. Loughlin, scale 1:9600, surveyed in 1911 but geologic data presumably corrected to date of publication, 1927.

Veins in eastern part: Plate 56, Proffessional Paper 148, page 181.

Faults: Dated according to Plate 39, Proffessional Paper 148.

Orebodies: According to Plate 3, USGS Bulletin 779, 1926.

Structure contours: Drawn at top of Blue (Leadville) Limestone from data taken chiefly from plates 14, 15, 16, 17 of Proffessional Paper 148.

In many instances the Blue Limestone is seen in several widely separated horizons in the same section (up to 700' vertical spread between) so it is not certain in many cases that the actual top of the formation is being contoured. Additional uncertainty arises in that local contortions, and splitting of the limestone by the intrusion of the porphyry sills have caused deviations from a general surface, rendering a certain amount of 'averaging' necessary to produce the contours. The third factor of inaccuracy in the derivation of the contours is the necessity for projecting the Blue out over areas where it is actually missing, and measuring this extrapolated projected position of its top, rather than the actual top. Where inaccuracies due to the latter two factors were met with, the uncertainty of the contours is indicated by dashing the lines.

LEADVILLE

R.C.Pearson, Ogden Twete,T.W.Stern, H.H.Thomas, 1962: Age of Laramide porphyries near Leadville, Colo. USGS PP 450-C, C78-C80.

C78 Laramide orogeny began with homoclinal tilting of strata on E flank of great anticline to W,mpw marked by Sawatch range. Some faults during tilting and accompanying uplift but most formed later,dutting a s age marked by porphyry intrusion and uplift of fault-block Mosquito Range on E. Of 30 porphyrires,15 fall into well-established sequence. Many faults can be dated by relation to this sequence.

Oldest porphyry, Pando, 70 m.y. Youngest,Lincoln,64 m.y. Relation to faulting suggests that climax of Laramide orogeny at Leadville to k place in only 6 m.y. This span is only a fraction of total time of Laramide orogeny. Uplift,regional folding and much erosion occurred before stage of faulting and intrusion. Mineralization & waning fault movement continued after.

Climax in early Paleocene (Holmes,1959);late K (Kulp,1961).

VARIATIONS IN ISOTOPIC COMPOSITION OF OXYGEN AND CARBON IN LEADVILLE LIMESTONE (MISSISSIPPIAN, COLORADO) AND IN ITS HYDROTHERMAL AND METAMORPHIC PHASES

A. E. J. ENGEL, R. N. CLAYTON, AND S. EPSTEIN

Reprinted for private circulation from
THE JOURNAL OF GEOLOGY
Vol. 66, No. 4, July 1958
PRINTED IN U.S.A.

VARIATIONS IN ISOTOPIC COMPOSITION OF OXYGEN AND CARBON IN LEADVILLE LIMESTONE (MISSISSIPPIAN, COLORADO) AND IN ITS HYDROTHERMAL AND METAMORPHIC PHASES[1]

A. E. J. ENGEL,[2] R. N. CLAYTON,[3] AND S. EPSTEIN[4]
California Institute of Technology

ABSTRACT

GSA. Bull. vol. 71, 1960. p. 1829 (Rewri
Program, Denver Meeting, p. 61

CALCIUM/MAGNESIUM RATIO WALL-ROCK STUDIES, HILLTOP MINE, PARK COUNTY, COLORADO

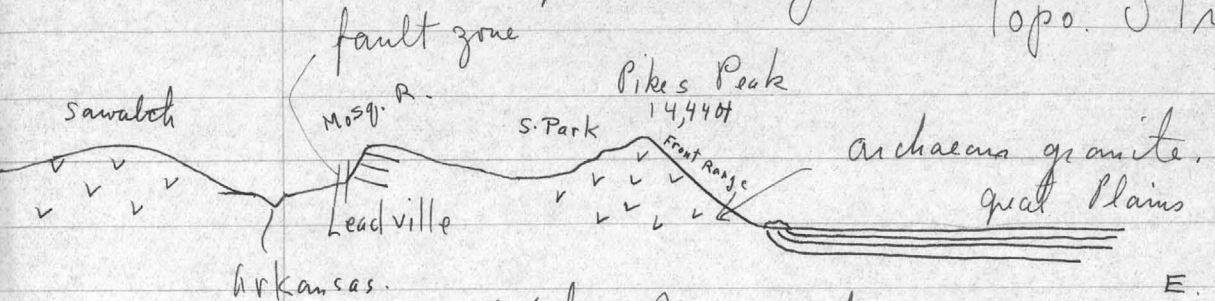
D. N. Bloom, M. A. Klugman, R. E. Bisque
Colorado School of Mines, Golden, Colo.

[redacted]

Leadville, W. Col.

Mosquito Range.

Topo. Structure.



The Mosquito Range is a typical fault block range.

Geology of Mosquito Range.

Oldest rocks are the archean granites, gneisses, amph. schist.

[Old ↓ new]

Next Cambrian - quartzite 200'

Silurian quartzite 160' ls. 40', Tot. 200'

(Some Ord.?) "sh."

Carboniferous. 1. Blue ls. 200'

2. Slates, grits. "Weber sh." "grits. 25-"

Miss. 3. ls., rdsh. ss., sh. 1500'

No Mesozoic rks. in Leadville camp, but plenty in vicinity.

Igneous rks.: Sills ∥ to strat. planes. Some dikes. Most of them just above "the" Blue ls. Locally called porphyries. - "white", "red" etc. These sills did not form until after the cretaceous, because they intrude Cret. seds. elsewhere in the vicinity. These sills participated in the fault movement that caused the range - ∴ movement occurred after

the Cretaceous - The sills are likewise pre-Tertiary as well as post Cretaceous, & the movement occurred also at this time. Also, the ores were deposited after the injection & before the faulting because they were subjected to the same fault movement & they occur near the contact of the porphyry in the ls.

Mosquito Fault - Max. movement 5000'. Fades into a fold at S. - Aggregate zonal displacement 10000'.

Nature of Ores. Ores 1st mined were gossan, Cerussite, $PbCO_3$, Horn Ag., Unox. PbS, in a clay, silica, Fe_2O_3, MnO_2, $BaSO_4$ gangue. The gangue was also a residual material, (2nd ary.)

Primary Ores were:

Galena
Pyrite
Zinc Blende.

Theory: Ores were dep. by metasomatic replacement in blue ls. They lay in tabular sheets ∥ to the strat. planes, lying far above the grnd water, & ∴ entirely gossan.

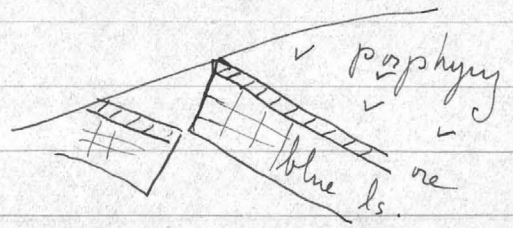
Emmons considered the ores oxidized remains of primary ores, ~~oxidized~~

Ores are found just below the porphyry sills in the blue ls. Emmons tho't them derived from the sills by downward waters percolating thru the sills & dep. ores on meeting the ls., by meta-somatic replacement. Ie ∴ tho't no ores would be found below the blue ls.,

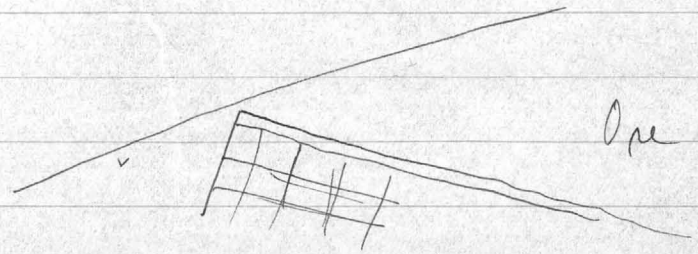
re-write.

& advised the miners to that effect. Finally the ore-bodies in the blue ls. become exhausted. Some mines sank into the Cambrian & Silurian, & fd. great bodies of fresh sulfides.

Everyone mistake was thinking that all ores would be ppted. on waters meeting Blue ls. He did not consider fault planes & devious circulation of the waters, ~~&~~ ~~superfluous~~ & the possibility of the waters getting around the Blue ls.



Ore exposed at surface.



Ore unexposed at surface.

Genesis of the Ores of Leadville.

By S. F. Emmons.

*The explanations given in the original reports on the Leadville district of the origin and formation of the ores in limestone have been in many respects very generally misconstrued in subsequent publications. In some of these the writer is assumed to have stated that the ores were brought in by waters descending directly from the surface; in others, that the metallic contents of these waters were derived from the overlying White porphyry, neither of which views he actually held. It would seem that the authors of these publications must have formed their opinion from reading only the preliminary statement, published immediately after the close of field work in 1882, rather than from the more complete explanation given later in the Leadville monograph. In the former[1] it was briefly stated with regard to the origin of the deposits:

1. That they have been derived from aqueous solutions.
2. That these solutions came from above.
3. That they derived their metallic contents from the neighboring eruptive rocks.

In the final report[2] this statement was made more explicit, as follows:

With regard to the *immediate* source from which the minerals forming these deposits were derived, the following conclusions have been arrived at:

1. That they came from above.
2. That they were derived, mainly, from the neighboring eruptive rocks.

By these statements it is not intended to deny the possibility that the material may originally have come from great depths, nor to maintain that they were necessarily derived entirely from eruptive rocks at present immediately in contact with the deposits.

The facts and reasons on which these conclusions are based will be given in the following chapters.

At the time the preliminary report was in preparation, capitalists were being urged by J. Alden Smith, State Geologist, to sink deep shafts immediately down to the Archean, on the theory that, since ore-bearing solutions came from below, the Leadville ores must necessarily have ascended through fissures in the underlying granitic rocks, and the orebodies found there, being nearer to the source, would be more valuable than those found in the limestone, his belief being that "these fissures and deposits will be extensively and profitably worked for centuries after the contact deposits now operated are exhausted."[3]

In the light of the geological investigations he had made, this seemed to the writer a mistaken idea, which, if followed, would result in pecuniary loss and might retard the development of the district; hence he made his statement strong, and, as results have since proved, rather too unqualified.

Geological studies of ore deposits up to that time had been, mainly, of veins that follow nearly vertical fissures in the rocks, of which the most natural explanation is that they are formed by ascending solutions; and in ordinary mine reports, for which, as a rule, but little study of the general geology of the district was deemed necessary, the rather perfunctory statement was generally made that the vein materials "came from below," without any very definite understanding on the part of the writer of what these words implied.

It was, moreover, generally assumed, that all waters circulating within the crust of the earth came originally from the surface, descending under the influence of gravity and ascending again under the influence of heat—either the normal increment of heat within the crust, or that due to proximity with some cooling igneous mass. The modern idea that cooling igneous masses have given off enough occluded water to furnish a continuous underground circulation was then, and for many years afterwards, not considered tenable.

In undertaking the study of the Leadville mines, the writer proposed to take a new departure in making, as a preliminary, a thorough study of the geological structure, not only of the immediate vicinity of the mines but of the whole mountain region within a radius of about 10 miles around, and to base his attempt to explain the manner of formation of the ore deposits on the geological data thus obtained, quite independently of whether the resulting explanation accorded with current theories or not. As it was his first study of any important group of ore deposits, he did not feel competent to go into abstract questions about their origin, much less to present a general theory of ore deposits, as some seem to have assumed he did; hence, in speculating as to the source of the metals, he thought it wiser, as the important object was to furnish a guide to the miner in his search for orebodies (as stated explicitly in the text, Monograph 12, p. 572), "to leave out of consideration altogether the ultimate and purely speculative source and to confine the investigation to the more immediate source, about which it was possible to obtain some actual and demonstrable evidence." Then, after stating that the commonly received explanation for vein deposits is that they have been formed by directly ascending heated solutions, he said: "In the case of the Leadville deposits, the inadequacy and even falsity of this explanation, *except as applied to the ultimate source from which the metals may have been derived*, is readily apparent." He then proceeded to give the reasons for this statement by showing that the form of the orebodies was such as to lead to the conclusion that the ore-bearing bodies entered the limestone from its contact with the porphyry sheets. These contacts being the main channels of circulation and mainly at the upper surface of the limestones, "the few approximately vertical bodies [of ore] that have come under observation afford no evidence that their walls form part of a channel through which the ore currents came up from below;" hence, he concluded, "the above considerations seem sufficiently conclusive evidence against adopting upward currents as the direct source of the ore deposits of Leadville."

In further argument against the necessity of resorting to the unknown depths to find the source of the metals, the author proceeded to give the result of chemical tests of the country rocks, especially those of igneous origin, which showed that small amounts of vein material were found in most of the latter and that most of the varieties of porphyry, except the White porphyry, contained appreciable amounts of silver. Then, without attempting to decide which particular variety of porphyry the metals came from (which he explicitly stated was "too difficult because of the amount that had been removed by erosion since ore deposition") he said: "The foregoing reasons seem to favor the probability that the ores may have been derived, in part at least, from one or more of the bodies of porphyry which occur in the region."

While the intimate genetic connection between the ores and porphyry was established, as he conceived, with reasonable certainty, he admitted that there was still some doubt about the ultimate source of the metals, remarking:

It is possible that in future years, when mine work-

*Abstracted from Bulltin No. 320, United States Geological Survey. 'The Downtown District of Leadville, Colorado.' By Samuel Franklin Emmons and John Duer Irving.

[1]Second Ann. Rept. U. S. Geol. Survey, 1882, p. 234.

[2]Mon. U. S. Geol. Survey, Vol. XII, 1886, p. 379.

[3]Report on mineral and other resources of Colorado for 1881 and 1882, p. 64.

ings shall have been extended over areas where the ore horizon exists at considerable depths below the surface and other eruptive channels have been found and critically examined, evidence may be obtained that ore solutions have ascended along these channels from below.

The idea that was in his mind in saying this was that inasmuch as the Gray porphyry within the mineral area is a distinctly later eruptive than the White porphyry, if the channels were found through which this porphyry had reached the Blue limestone horizon these might prove to be also the channels through which the ore-bearing solutions had reached that horizon.

In the time that has elapsed since the Leadville report was written some of the conclusions have been severely criticized by prominent geologists, notably the genetic connection of ore deposition with igneous eruption and the metasomatic replacement of limestone by ore, but practically all of these conclusions may now be regarded as universally admitted by economic geologists, with the exception of the determination of the source of the metals. With regard to this, it may be said that in treatises on ore deposits written within that time the general opinion seems to be that the writer wrongly conceived the ores to have been brought in by descending waters, but that mining engineers who had become more familiar with the deposits by later and more continuous underground observation had proved them to have been brought up from below by hot ascending solutions.

Having already endeavored to show in what respect the author's statements were misconstrued, it may be well to see how far these statements are justified by a careful consideration of the articles on which they were based.

The mining engineers to whose writings references had been made were Messrs. F. T. Freeland[5], Charles M. Rolker[6], and A. A. Blow[7]. Of these Mr. Freeland did not discuss at all the source or origin of metals. Mr. Rolker, confining himself to the direct source, objected chiefly to the assumed statement of the writer that the ore-bearing solutions descended directly and exclusively from the overlying White porphyry, inasmuch as his own observations show that on Fryer Hill, where he had had been in charge of an important mine, the orebodies do not occur exclusively or predominatingly on the upper contact of limestone with porphyry, and that they appeared to have a closer genetic connection with the Gray than with the White porphyry. His general statement with regard to the deposits of the district, however, is as follows:[8]

They are found mainly as contact deposits between the Carboniferous limestone and the overlying felsite, with additional or incidental ore accumulations in the limestone in irregular cavities, directly or indirectly connected with the plane of contact by irregular and often minute conduits, which a careful search reveals.

This statement, as far as it goes, is a confirmation of that of the writer.

In a subsequent article in the same periodical[9] the writer has pointed how far the apparent discrepancy of their views arose from a misconstruction, on the part of Mr. Rolker, either of his statements or of the facts.

Mr. Blow's article, based as it was on nine years' continuous observation of the practical extraction of ore in a part of the region where the orebodies have been deposited to a considerable extent along vertical fractures as well as on the more or less horizontal contacts and bedding planes in the limestone, constituted an invaluable contribution to the geological history of Leadville ore deposits, and his conclusions from actually observed facts, such as the origin of manganese in the oxidized ores, and of secondary enrichment, especially of zinc in the upper part of the sulphide bodies, showed remarkable acumen in observation and reasoning. The more theoretical part of his article, relating to what the writer would have called the ultimate source of the metals, is, however, less satisfactory, because, while professedly intended as a refutation of the writer's views, it starts with a misconception of those views, and also because it brings no observed facts to support those which he proposes as a substitute for them.

The misconception consists, first, in his failing to appreciate the fact that the writer was speaking only of the immediate source and declined to discuss the ultimate and theoretical source, and, second, in his mistaken assumption that the writer stated that the metals were derived from the White porphyry. The main part of his argument is devoted to the refutation of this latter mistaken assumption, and is purely negative; but, when he comes to his positive assertions, he simply gives as the alternative source the word 'below,' the use of which the writer had deprecated because of its indefiniteness; and as to the manner in which the solutions reached the present locus of the orebodies, or what the writer would have called the immediate source, he says:[10]

That such ascending solutions more readily penetrated the limestone along the planes of contact of the igneous and sedimentary formations, and through zones of least resistance in the latter previously marked out by the intrusion of the porphyries, and gradually replaced the limestone with the metalliferous contents in the form of sulphides.

The writer, in seeking for reasons for the location of the majority of the orebodies in the Blue limestone, states:[11]

The great intrusive sheets of porphyry are found to follow it most persistently, mainly along the upper surface, less frequently along its under surface, and also cutting transversely across it. These intrusive bodies are also found at other horizons, it is true, but at none so persistently and so uniformly as at this. Thus both ascending and descending currents would readily reach these beds, the latter trickling through the uniformly permeable eruptive rock, the former following up the walls of the channels, through which it was erupted.

Thus, taking into consideration the greater development of orebodies and intrusive sheets of Gray porphyry which had been shown to exist at the time Mr. Blow wrote, the difference in view between him and the writer is not essential, for he does not bring any facts to bear against the latter's third reason for declining to accept upward currents as the direct source of the ore, that is, "the noticeable absence, in the region of greatest ore development, of channels extending downward, through which the ascending solutions might have come." Indeed, in his descriptions he speaks of the ores as going downward rather than upward, and when they occur along vertical fractures he does not suggest their continuation below the Blue limestone, but simply argues against their immediate derivation from the overlying White porphyry, and is apparently no more a believer in Mr. J. Alden Smith's theory than was the writer. Yet the region he treats of is the one region in Leadville where vertical cracks are most frequently found in connection with ores in limestone, and it is upon their occurrence that Mr. Blow founded his theory of northeast shoots as the prevailing form of Leadville orebodies. Hence, the assumption of the various treatises on ore deposits that the writer's theory as to the source of the metals has been disproved by Mr. Blow seems to

[5]Sulphide deposits of South Iron Hill: Trans. Am. Inst. Min. Eng., 1885, Vol. XIV, 1866, pp. 181-189.
[6]The Leadville ore deposits: Ibid, 1885, Vol. XIV, 1866, pp. 273-292.
[7]The geology and ore deposits of Iron Hill: Ibid, 1889, Vol. XVIII, 1890, pp. 145-181.
[8]Loc. cit., p. 282.
[9]Genesis of certain ore deposits: Trans. Am. Inst. Min. Eng., 1866, Vol. XV, p. 125.
[10]Trans. Am. Inst. Min. Eng., Vol. XVIII, 1890, p. 174.
[11]Mon. U. S. Geol. Survey, Vol. XII, 1886, p. 541.

The Ore Deposits of Leadville, Colo.

S.F. Emmons. USGS PP: 148, 1927
+ Irving & Loughlin

Rock Formations.

Penn. Weber formation.	Grits........940'.	Intrusive sheet of white granite.
	Shales.......06300'	
Miss. and Dev.(?)	Leadville (Blue) Ls..200'	
Ordovician.	Yale Ls.	
	Parting qtzite..10670'	
	White Ls........ 120'	
Upper Cambrian.	Sawatch (Lower) qtzite.	
	Transition shales..0-40'	
	Quartzite.........50-140'	

PreCambrian Granite, gneiss and schist.

Intrusive Rocks. The age of intrusion was late Cretaceous or early Tertiary. The earlier, the White Porphyry is a muscovite granite or a salic granodiorite, as a great intrusive sheet between the Weber shales and the Blue ls, in the W part of the district. In the eastern part there are several smaller sheets, in the Blue ls.

The later intrusion, the Gray Porphyry occurs as a number of intrusive sheets, of which the largest overlies the White Porphyry in the NW quarter of the district. Others occur in the Blue and White ls. and the Transition shales. They have dike-like offshoots.

Faulting. 1. The intrusion of these irregular sheets disturbed the sediments, especially the Blue ls. , causing local fracturing and faulting. These are a guide to ore near the Gray Porphyry masses.

2. Folding and reverse faulting. The principal folds are anticlines, with N to NW trend, and gentle eastern limbs and steep or over-turned western limbs, broken by reverse faults. The main reverse faults in the Leadville area are the Colorado Prince, on the NE edge of Breece Hill, the Tucson Maid fault, exposed in the mines of Iron and Carbonate Hills, and an unnamed fault, a short distance west of the Tucson Maid fault, in Southern Iron Hill.

3. Small normal faults and fissures at right angles to the above reverse faults.

Next in chronologic sequence was probably the Breece Hill monzonit stock. Monzonitic intrusion followed the period of folding and reverse fault ing elsewhere in Colorado.

4. Minor normal faults, many with radial arrangement around the Breece Hill stock.

Ore deposition followed the stock-like intrusion at Breece Hill. It took place at higher temperatures close to the margin of this intrusive

than further away. The whole sequence, intrusion of White Porphyry to and including the deposition of the ore took place in the late Cretaceous or early Tertiary.

5. Late Tertiary. Normal faulting on a large scale. Cloud City, Pendery; Mikado-Iron-Dome group ;Adelaide, Moyer,Ulster-Newton,Emmett; Mike (normal movement on old reverse fault);Pilot;Mosquito (S part).

After ore deposition and after at least part of the post-mineral faulting,there was an eruption of rhyolitic agglomerate, N of Breece Hill and NE of Iron Hill. Four funnel-shpaed pipes of agglomerate cut off orebodies.

Breece Hill Stock.The only ore within the stock is in the upper portions of a few small siliceous pyritic veins enriched by chalcocite and gold. The walls are pyritic porphyry.

The irregular replacement bodies near the stock are almost entirely in limestone. Most of those nearest the stock are non-commercial. Some blocks of limestone enclosed in the stock have been replaced by silicate minerals and by magnetite and specularite. The Blue ls., on the N and E sides of the stock has also been replaced by magnetite and specularite. These bodies are earlier than the pyritic gold copper bodies and the silver-lead-zinc ores. They only destroyed ls. before valuable ores could reach it. In parts of the Ibex mine these magnetite-specularite bodies have been shattere and recemented by pyritic gold ore.

Other Siliceous Rocks. Orebodies in other siliceous rocks, including porphyry, Weber grits, quartzite and granite are mostly lodes, one or more parallel veins in fissure or fault zones. Their surface indications are debris of silicified and pyritized rock, leached and whitened by weathering. The trend of the productive veins is mostly NNE, in the E part of the district. The distribution of shale beds alternating with those of grit (micaceous feldspathic ss.) influences the ore deposition. The Garbutt vein narrows locally to a streak where shale forms one or both walls, and its pay shoots pitch at low angles along the more replaceable beds of grit. Many veins in the Ibex mine have been most productive where they pass from siliceous rock into ls.

Blue and White Ls. The orebodies in these are low in silica, and contain Zn,Pb,Ag, Fe, Mn. (The veins and stockworks in an adjacent to siliceous rock are mainly siliceous and valuable for gold, with or without copper or silver). Where veins crossing beds of ls. between roofs and floors of siliceous rock spread into blanket replacement bodies,the replacement bodies close to the vein fissure consist of siliceous gold ore,which grades within a short distance into Zn-Pb sulphide ore, or in the oxidized zone into lead carbonate ore.

The Blue ls. is thick-bedded, dolomitic,with no free calcite,and less than 3% insoluble. The White ls. is thin-bedded,with considerable free calcite,10-20% insoluble,the beds separated by partings of shale. The Blue ls is more subject to complete replacement than the White.

Nearly all orebodies in limestone are covered by roofs of impervious siliceous rock, mostly porphyry,but sometimes shale or quartzite. Some of the thickest orebodies have floors of impervious rock.

Ore Channels. 1. Tucson-Maid (Reverse) Fault. Displacement about 250'. For the most part the main fault was too full of siliceous gouge to serve as a channel. The more open auxiliary fractures along it served as channels. Where ore was deposited locally within the Tucson fault itself, siliceous pyritic ore was formed in contact with the siliceous fault material and this ore graded into Zn-Pb-Ag ore in the adjacent White ls. The siliceous ore was enriched by chalcocite, Ag, Au. The fissures in the associated bed of Cambrian quartzite near the fault contained an unusually rich ore, with the common sulphide minerals accompanied by an intergrowth of silver and bismuth sulphides. This ore contained 14 oz. of silver per ton.

In the Cord mine, orebodies replace masses of White ls. between sheets of porphyry at the intersection of the Tucson fault zone and a mineralized NE fissure.

The shales at the top of the Cambrian quartzite are less subject to fissuring than the quartzite or the limestone.

Stringers may be "feeders" leading to large replacement orebodies.

Oxidation subsidence is present.

Alteration Borders of Casings. Alteration near sulphide bodies consists of pyritization and silicification, manganosiderite. The silicification reache jasperoid in places. Too wide-spread for an ore-guide. Near oxide silver-lead bodies, this zone becomes "contact matter" consisting of iron-manganese oxides, zinc carbonate, and basic ferric sulphates. The mangano-siderite encases orebodies near the trunk channels of ore solutions. The jasperoid encases them at greater distances, hence is a less definite guide. The vein matter found along the porphyry-limestone contacts in the oxidized zone denotes the area within which the oxidized orebodies may be found, nothingmore. It consists of mixtures of iron oxides, clay, alunite and jarosite. It was formed by surface waters descending through pyritized porphyry, and has replaced the limestone. It is not a definite ore-guide, except where found in pre-mineral fissures. Where this contact matter is high in iron and low in clay or talc it is likely to be near an orebody. A common mode of occurrence of oxidized orebodies is for the lead carbonate, usually with moderate to high silver content, to lie close to the porphyry roof, and to be flanked and floored by contact matter. Orebodies with an original jasperoid casing passed outward and downward, after oxidation, into brown-stained jasperoid, below which the limestone became stained, to some extent, by brown iron oxide or low-grade zinc carbonate. Bodies of pure pyrite were oxidized to brown iron oxide close to the porphyry roof, and surrounded andunderlain by brown jasperoid. Shoots of lead carbonate may be found within the brown iron bodies along pre-mineral fissures.

The oxidized orebodies in limestone fall in two classes: Those with casings or floors of brown jasperoid and those without them. Where these casings are present, lead carbonate and brown iron ore, with high or low silver content, are confined within or above the casing, and fractures in the jasperoid may contain commercial silver. Low grade zinc carbonate will be found here and there below the casing, and its tonnage ratio to lead carbonate ore will be low compared with the Zn-Pb ratio in the average sulphide orebody. Where mangano-siderite as well as jasperoid accompanied the original orebody, black iron, high in silica, will be found. Oxidized orebodies derived from mixed sulphides without jasperoid casings include lead carbonate underlain by zinc carbonate and bordered in places by brown iron ore

by brown iron ore and black iron ore or iron-Mn ore low in silica. Those derived from pure pyrite are brown iron ore underlain and bordered by black Mn-Fe ore.

Enrichment in the oxidized zone was largely residual, but in part due to downward concentration. Silver was converted to the chloride and bromide without being removed from the lead carbonate shoots, but the remarkably high silver content in bodies nearest the surface suggests that the silver was in part concentrated downward as the outcrops of the orebodies were lowered by erosion.

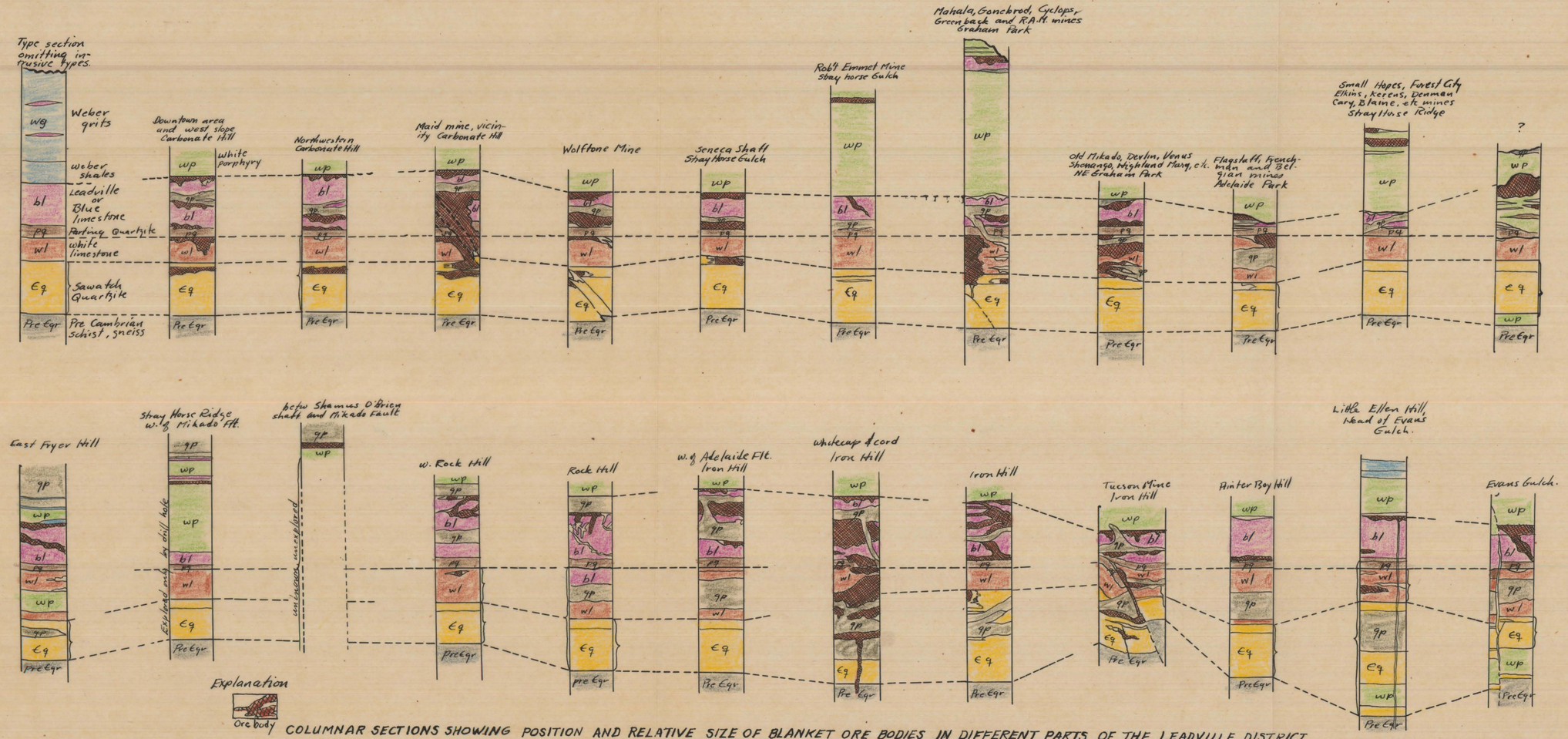
There is some native copper and argentite in the transition zone between the oxide and the sulphide blanket orebodies. Below this zone the sulphide ore was not enriched. Pyritic ore in the Tucson mine along the Tucson-Maid fault, well below the bottom of the oxidized zone, is enriched by chalcocite, associated with silver and gold. This sulphide enrichment was evidently confined to pyritic ores with small percentages of ccpy and occurred only in lodes and adjacent parts of connected replacment bodies where open structure and marginal impervious clay selvages concentrated the downward circulation. The chalcocite serveda as a strong precipitator of Ag and Au in the descending surface waters. Gold is also found concentrated in bunches of mixed sulphide ore, where closely associated with ZnS. It was carried down as soluble chloride, and deposited by reaction with ZnS plus ferrous sulphate.

GSA Bull. vol. 69, 1958, p. 1656

TIME RELATIONS OF INTRUSION, FAULTING, AND MINERALIZATION AT LEADVILLE, COLORADO

Odgen Tweto

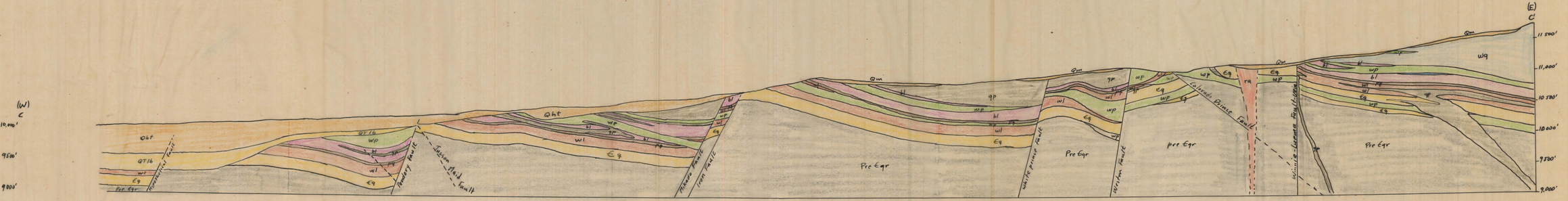
U. S. Geological Survey



COLUMNAR SECTIONS SHOWING POSITION AND RELATIVE SIZE OF BLANKET ORE BODIES IN DIFFERENT PARTS OF THE LEADVILLE DISTRICT

Professional Paper 148 - plate 59

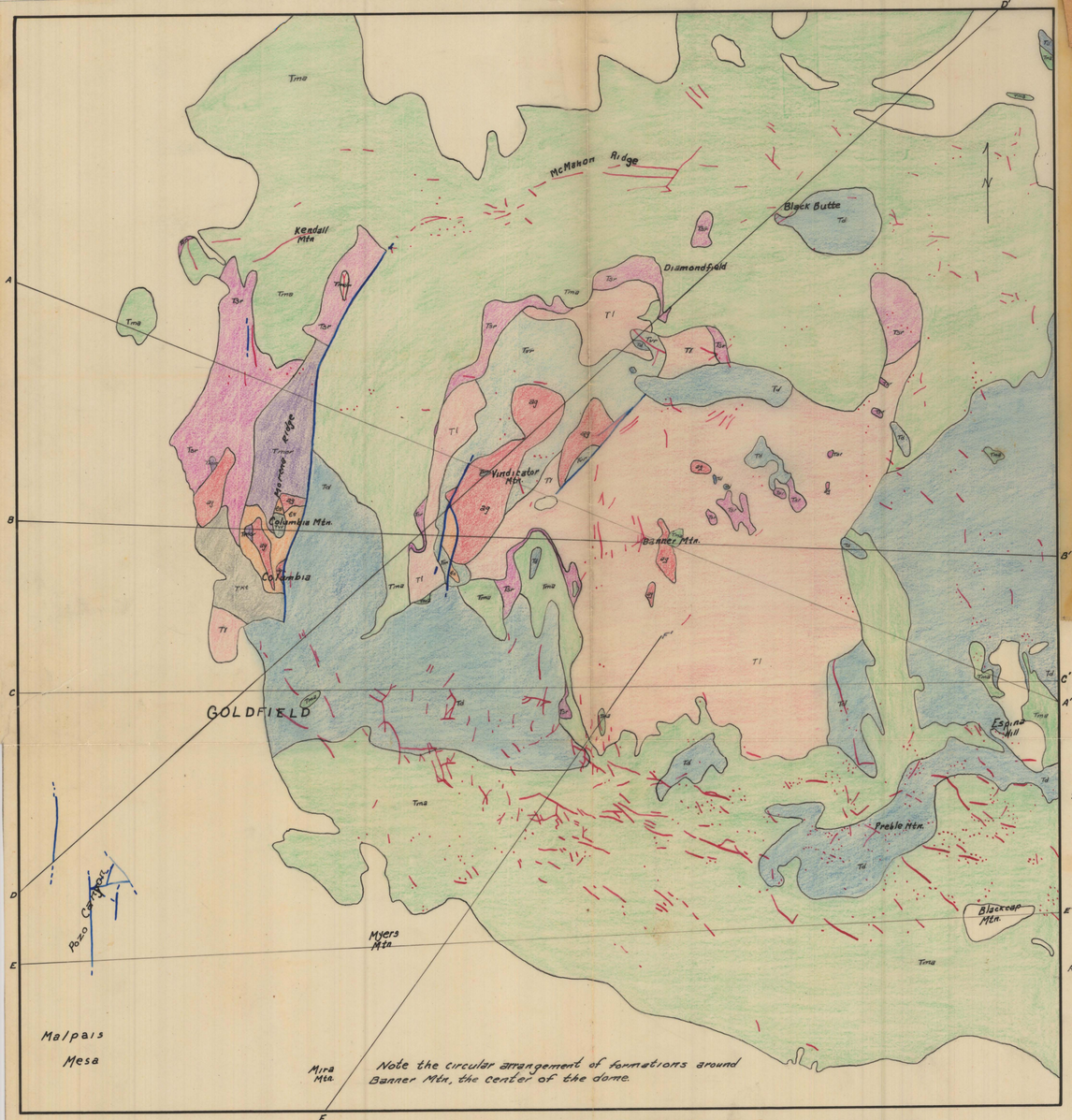
SECTION C-C' OF LEADVILLE MAP



SECTION C-C' OF LEADVILLE MAP

Showing average nature of the section in the district - several thrusts (Tucson - Maid and Colorado Prince), many post mineral normal faults, one pre-mineral normal fault-vein (Winnie-Luema) Note average East dip, faulted anticlines, irregular intrusives.

{From plate 13 Professional paper 148}

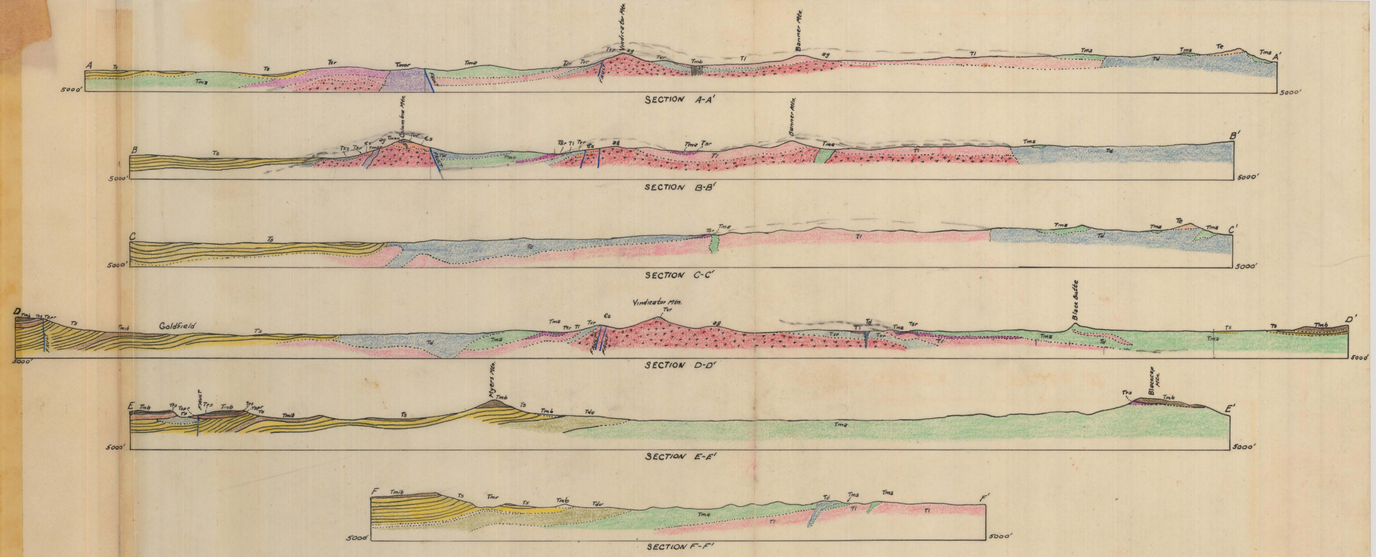


GEOLOGIC MAP OF THE GOLDFIELD DISTRICT, NEVADA

Plate III

Scale 1/2888

1 ¼ 0 1 mile



GEOLOGIC SECTIONS ACROSS THE GOLDFIELD DISTRICT, NEVADA

BY F. L. RANSOME

Horizontal and vertical scale 1/2888

1 ¼ 0 1 mile