PRELIMINARY NOTES ON ASPEN, COLO.

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The mining district of Aspen bears singular relations to that of Leadville. Each is on the shore-line of the old Archean island of the Sawatch; the one on the west, the other on the east side and about diametrically opposite to each other, there being not more than four miles difference of latitude between them. Further, each is at the point where this ancient shore line changes in trend from nearly due north and south to northeast and north west respectively.

Geologically the ore deposits of Aspen are found at the same general horizon as those of Leadville, viz: in the Lower Carboniferous limestone. This fact is rather in the nature of a coincidence than of an essential geological resemblance, that is, of one which has had influence upon the concentration of metallic minerals in workable deposits. This horizon has been found to contain rich ore deposits at many points in the Rocky Mountains, it is true, but there are a still greater number of places where it is entirely barren. I lay stress upon this point because I realize myself that the fact of the great number of remarkable mineral discoveries at this horizon is apt to lead one to look for mineral in it simply because it is the Lower Carboniferous limestone, without reflecting that thereby one tacitly assumes that there was some inherent peculiarity in this particular formation at the time it was deposited at the bottom of the ocean, which rendered it more adapted for the concentration of ore deposits than any of the beds which were laid down before it or after it; an assumption that is not yet justified by demonstrated facts.

There are, however, other points of resemblance of greater significance in their bearing upon the probable causes of such great concentration of rich ore as is found in either district.

Both are in regions of intense dynamic disturbances which have been accompanied by immense intrusions of igneous rock through the sedimentary strata, though the superficial area occupied by actual exposures of these eruptive bodies at Leadville is far greater than at Aspen.

The process of ore deposition in either region has been an actual replacement of the country rock by vein material, and, where open cavities occur, they are found to be of later formation than the original deposition of the ore.

On the other hand at Aspen the ore is not found in actual contact with the eruptive bodies as is generally the case at Leadville; and the country rock instead of being entirely dolomitic, is only partially so, and whereas at Leadville there is reason to assume that it was originally deposited as a dolomite, at Aspen there is some reason for thinking that the dolomitization may have been, in part at any rate, a secondary process entirely subsequent to the deposition of the limestone.

These are a few of the prominent facts which may be observed in a hasty visit like that which I made to the district in September last. As a week was all the time I was then able to devote to its examination, it was manifestly impossible for me to attempt a final solution of the many interesting geological problems that present themselves in this complicated region.

Still I enjoyed a certain advantage over other observers from the fact that I had made a special study of the Leadville deposits, and had been occupied during the summer in making geological investigations in the neighboring Elk Mountains with which the region round Aspen is structurally connected. I have thought, therefore, that it might be of use for me to submit such facts with regard to the structure of the region as I was able to determine, and to point out such lines of further investigations as suggested themselves to me, in the hopes that others who may have opportunities of more prolonged and detailed work in the region may be led to follow them out to a final solution.

Roaring Fork river, on whose banks is situated the town of Aspen pursues a general northwest course from its source in the high summits of the Sawatch range to its confluence with Grand River at Glenwood Springs. In the upper portion its valley is carved out of the granites and gneisses of the Archæan, and has a relatively narrow bottom, but when it emerges into the upper sedimentary formations, as is generally the case with streams flowing nearly at right angles to the stratification, its bottom becomes rapidly wider when the formation through which it is passing is of a character to yield readily to the disintegration and abrasion of atmospheric agents.

It is on a broad bench on its southwest bank, after the stream has passed through the gateway formed by the relatively unyielding Cambrian quartzites (the base of the sedimentary series), into the softer beds of limestone and shale of the Carboniferous period, that the town of Aspen is situated. Just below this gateway two important tributaries flow into Roaring Fork, on the east and west sides respectively. Hunter's Creek, whose valley is nearly parallel to that of Roaring Fork enters it from the east, opposite the middle of the town, which extends about a mile down the valley of Roaring Fork from the gateway. The extreme point of the spur included between the valleys of Hunter's Creek and Roaring Fork, or that portion of it which lies opposite the upper part of the town of Aspen, is called Smuggler Mountain, from the important mine of that name on its slopes.

Castle Creek, as the larger stream on the west is called, enters the Roaring Fork valley below the town, of which it forms the natural limit on the northwest. The valley of Castle Creek has a general northerly direction, consequently forms an acute angle with that of Roaring Fork, and the mountain ridge or spur which separates them gradually widens to the southward. Its crest, however, keeps closer to the former valley than to the latter, in consequence of which the Castle Creek slopes are extremely steep, and the few streams on that side run in narrow precipitous beds.

A length of about four miles on the northern end of this spur, which consists of a straight narrow north and south ridge set off en échelon a little to the west of the main crest, properly constitutes what is called Aspen mountain, though it is possible that according to the records of claims, in which the geographical appropriateness of terms is not always kept in view, this name may be confined to that portion of the ridge which lies directly back of the town of Aspen. Aspen mountain, using the term in the above sense, is separated from the main mass of the spur by a deep narrow ravine, running nearly due north, and reaching the valley at the southern end of the town, which is called Spar gulch. Adjoining the lower portion of Spar gulch and separated from it by a narrow ridge formed of steeply upturned strata of Blue limestone, is a singular basin-shaped depression heading about half way up the slopes of Aspen mountain, known as Vallejo gulch. Beneath this gulch and on the ridge separating it from Spar gulch, which is known as Spar ridge from the mine of that name at its lower end, are the most important ore-bodies thus far opened in the district.

The head of Spar gulch, which consists of several little rounded valleys, is called Turtleout (Tourtelotte?) park, and over the divide forming the southern limit of Aspen mountain is the deep basin-shaped head of Queen's gulch. This gulch reaches Castle Creek about four miles above its mouth, just below a singularly shaped, isolated hill, formed of beds of red sandstone standing on edge, called "the Castle" by the settlers, and which is supposed to have given its name to the valley.

The other ravines which score the steep western slopes of Aspen mountain below this gulch are known respectively as Ophir and Keno gulches.

About six miles above the mouth of Castle Creek the stream forks, and above the forks the valley of the eastern or main branch bends slightly to the eastward as far as the mining town of Ashcroft, which lies about nine miles south of Aspen in a straight line.

It is to the geological structure of Aspen mountain, and of the western slopes of the main ridge between Aspen and Ashcroft that I desire especially to direct your attention ; but it is first necessary to consider the geological relations of this little strip of country to the regions around. It may be considered to constitute the dividing line between the two distinct uplifts of the Sawatch range on the east and of the Elk Mountains on the west, and to have been affected successively by the dynamic movements accompanying each of these upheavals. For purposes of this description it will be sufficient to consider the Sawatch upheaval as a slow gradual elevation of this mountain mass or, what amounts to the same thing, a gradual subsidence of the adjoining sea-bottoms, which had the effect of making the sedimentary beds deposited in those sea-bottoms slope up at varying angles all along the ancient shore line toward the central mass of the Archean island.

The Elk Mountain Range which extends to the west and south of this region, with its towering precipitous peaks and deep cañon gorges, presents some of the wildest and most picturesque mountain scenery in Colorado. Its geological structure is even more striking than the Alpine character of its scenery. Its upheaval, which was posterior to that of the Sawatch, must have been much more violent and catastrophic in its nature, and was accompanied by enormous intrusions of eruptive rock which were forced into the sedimentary strata, shattered by the forces of upheaval, in great laccolites or solid masses, and spread out through them in every direction in the form of dikes and intrusive sheets. The actual superficial exposures of some of these great bodies cover areas of 25 or 30 square miles, and it may be assumed that their extent below the surface is very much greater.

It is easy to conceive that the intrusion of such enormous masses of foreign matter must not only have been accompanied by great disturbances of the beds within the region of upheaval, but must also have so expanded the volume of the earth's crust in this region as to cause a severe lateral pressure in the adjoining regions.

It would be just in the strip of sedimentary beds along this ridge, which is backed by a projecting point of the unyielding mass of Sawatch Archean, that this compression would be most severely felt. It will aid greatly, therefore, in forming a clear idea of the geological structure of this region to distinguish as far as possible the effects produced by the Sawatch upheaval from those caused by the intense lateral compression of the adjoining Elk Mountain uplift.

Let us first consider the series of sedimentary beds which here rest upon the Archæan. They correspond in a general way with those found at Leadville, though one must not expect to find this correspondence very exact, for the latter were deposited in the partially enclosed bay which is now occupied by the South Park, while the Aspen beds were deposited on the west side of the Archean island in a wider and deeper sea, and it is generally found that on this western slope the beds are much thicker than those of corresponding geological horizons on the east. I had no time to measure any continuous section of these beds, but from information gathered from those familiar with the region, supplemented in part by scattered observations of my own, I would describe the series from the bottom upward somewhat as follows:

1. White quartzites; 200 feet.

2. Light colored silicious limestones, with some quartzite bands, and beds of coarse sandstone or conglomerate at top; 340 feet.

3. Darker limestones, rusty brown and dolomitic at base; blue, compact and pure at top; 240 feet.

4. Carbonaceous clays, with shales and thin bedded limestones; 425 feet.

5. A series of sandstone shales of greenish and reddish colors, somewhat micaceous, with occasional thin beds of limestones, probably passing upwards into prevailing red sandstones.

6. A great thickness of deep-red, fine-grained sandstones.

It is impossible to determine the exact geological age of these beds without more paleontogical evidence than has yet been found, but from general lithological correspondence with beds at Leadville and elsewhere, they may be assumed provisorily to represent respectively — 1, the Upper Cambrian. 2, Silurian. 3, Lower Carboniferous. 4 and 5, the Weber Shale and Weber Grits divisions of the middle Carboniferous. No. 6, which are generally considered Triassic because they occur below beds containing Jurassic forms, should theoretically be separated from No. 5 by the upper Carboniferous which I did not observe.

On Aspen mountain there is a bed of white porphyry (strictly speaking, a decomposed diorite) in the black shales, 60 to 100 feet above the top of the blue limestones. It is 260 feet in thickness on the slope immediately back of the town, but apparently thickens very considerably to the southward, in which direction I traced it as far as Ashcroft, where it is less decomposed and the original granular structure of the diorite is readily recognizable. Whether it extends across the valley of Roaring Fork into Smuggler Mountain has not yet been surely determined, though I found no evidence of it in the valley of Hunter's Creek. I found, also, small unimportant sheets of porphyry in the lower quartzites near the point of Aspen mountain, and on the east face of the main ridge opposite what I believe is called Richmond Mountain.

As affected by the Sawatch upheaval, these beds, as I have said above, wrap round the Archæan mass, resting against, or dipping away from it at varying angles. Let us consider first the three lower divisions—the quartzites and limestones. They cross the valley of Roaring Fork from Smuggler Mountain to Aspen Mountain, forming the gateway of the valley, and striking northeast and southwest with a dip to the northwest. The average angle of dip of these beds, as shown in the mines in Spar Ridge, is about 45°, varying in places, however, from a minimum of 30° to a maximum of 60°, in what might be called "flats" and "steeps."

At the upper end of Spar Ridge the blue limestone which forms it changes in strike from northwest to north, or in other words bends to the southward, and continues in this general direction to Ashcroft; the dip which is to the eastward, shallowing nearly to a horizontal at the head of Spar Gulch, and steepening again to 45° near Ashcroft, where the faces of the ridge on the east side of the valley are formed by the smooth, bare bedding-planes of the limestones.

In the hills forming the eastern border of the Roaring Fork valley, from Smuggler Mountain northwestward, is a continuous and apparently conformable series of beds from the Cambrian up to the Cretaceous, dipping with a regular angle to the northwest. Were this region affected by the Sawatch upheaval alone, we should therefore expect to find the same series sweeping continuously around and resting conformably on the flanks of the lower Palæozoic strata which, as above described, form the crest of the ridge from Aspen to Ashcroft.

Instead of this on the steep western slopes of Aspen mountain towards Castle Creek we find now the blue limestone, now the Cambrian quartzite, and again the Archæan granite abutting against the Triassic beds; and as we go northward along the east slope of the point of the mountain, back of the town of Aspen, after passing geologically upwards through the conformably dipping blue limestone, black shales, porphyry, and black shales again, we find the series repeated at the point of the ridge from granite up to blue limestone again, the latter beds lying in great slabs against its northern end, striking east and dipping about 60° to the northward.

Such a condition of things cannot be accounted for by any system of folding however complicated, and the alternative result of extreme compression, viz. faulting, must be called into play.

In point of fact we find not only one great fault but a system of smaller, more or less parallel faults, as is generally the case in regions of intense compression. It is evident, moreover, that this compression is the result of dynamic movements accompanying the upheaval of the Elk Mountains, which, as explained above, would have crowded the sedimentary beds against the unyielding Archæan mass, so that along its edge they have been broken across and shoved up past each other.

The line of the principal fault is easily traceable because its movement has brought the strongly marked Red Beds into juxtaposition with the limestones, quartzites and Archæan rocks on the east, but that of the minor faults in these latter rocks is less readily distinguished on the surface, as, being of less extent and smaller displacement, the discrepancies are less noticeable, especially in a region so largely covered with detrital material, mainly of glacial origin, as this is.

The main fault is first seen around the point of Aspen Mountain, where Castle Creek cuts into its northern foot, and discloses vertical red sandstones striking north and south parallel to the fault plane, and adjoining the steeply upturned quartzites which strike east and west across the northern end of the ridge. For several miles southward it runs along the foot of the hill slope, nearly parallel with the bed of the creek ; near the mouth of Keno gulch, however, the stream bends somewhat to the westward, and the foot hills of Aspen Mountain extend out correspondingly in that direction, so that the fault line, which is apparently pretty straight, comes higher and higher up on the spurs as one goes southward until at Queen's gulch it is over half a mile from Castle Creek. Beyond this I did not trace it, but above the forks of Castle Creek it probably comes down to the bed of the creek, and follows up on its west side under the detrital material which covers the lower slopes of the valley near Ashcroft. On the west side of the fault the Red Beds stand either vertical or with a steep dip eastward. In the hills on the west side of Castle Creek the same beds lie nearly horizontal, having a gentle dip, say 10° to 20°, to the northward or down the creek. The beds exposed are, therefore, successively lower as one goes up the creek, and there is some evidence that the same is true of the beds immediately adjoining the fault plane on the west likewise, since in the Queen's gulch one passes the deep red sandstones, going up its valley, through lighter grayish red, to greenish shaly and somewhat micaceous sandstones, with some thin argillaceous and calcareous beds immediately at the fault line. These have quite a decided eastward dip, diverging perhaps 15° from the vertical. They probably belong to the lower part of the Red Beds, or to the upper part of the Carboniferous. Thus if one were to restore the beds which have been carried away by the erosion of Castle Creek valley, in order to connect these upright beds with the nearly horizontal ones on the other side, the fold would be not an arch or anticline, as one might at first be led to think, but a syncline, and probably in the nature of what is sometimes called an S-fold, from the fact that at either end the curve of the beds is more or less the reverse of what it is at the other. It would perhaps make it more clear to your mind to say that the vertical beds between Castle Creek and the fault plane, as cut across by Queen's gulch, represent two sides of a very closely compressed U-fold, and, when restored to the form they held before being eroded, the upper part of the western side of this fold bent westward to connect with the horizontal beds beyond Castle Creek, the eastern eastward until cut off by the fault. Such a fold is in the nature of the closely appressed folds found in the Appalachians and in the Jura Mountains, and is, in itself, an evidence of the intense compression accompanying the faulting, which was thus sufficient to double together these heavy sandstone beds almost as closely as one folds sheets of paper.

A good illustration of the S-fold or reversed fold may be seen in the valley of Roaring Fork a little below the town of Aspen. Here is an isolated hill, rising out of the valley and cut in two by the stream, which is called, I believe, Queen's Butte. In this hill the upper strata, which are red sandstones, dip northeastward at an angle which steepens as the strata go downward, and on the southwest face are the white sandstones and variegated clays of the Jura and Dakota Cretaceous, also dipping into the hill or northeast. Thus they stand in a reversed order to that in which they were originally deposited. To the southwest of this hill, along the south bank of Maroon Creek, which is the tributary of Roaring Fork next north of Castle Creek, the same series of beds are found in their normal position, sloping up toward the spurs of the Elk Mountains or dipping northeastward, the Dakota and Jura on top, and the Red Beds beneath. If we reconstruct the probable course of these beds under the valley which intervenes between the two exposures, the curve must necessarily be like one end of an S, laid down on its side and somewhat flattened out, in order to account for the reversed position of the beds in Queen's Butte. Observing these beds as I did from Aspen mountain, for I did not have time to actually visit Queen's Butte, it was readily apparent that the eastern end of this Butte came close to the line of the great Castle Creek fault extended northward, and it is therefore fair to assume that this S-fold, like the more compressed one on the Castle Creek slopes of Aspen Mountain, was produced contemporaneously with and by the same forces that produced that fault. It will be interesting in this connection to observe whether the influence of the Castle Creek fault is felt in the hills to the northeast of Roaring Fork valley.

To return again to Aspen Mountain; the course of the main or Castle Creek fault and the structure of the beds to the west of it have been described in a general way. Actual mine openings on the line of the fault I had no opportunity of observing, but in Ophir Gulch, where its line is well marked by an outcrop of granite in the bed of the gulch, adjoining the sharply upturned red sandstones, I am informed that a tunnel has been run in on it, and that the fault plane or granite wall dips 45° to the eastward. If this is so, the fault at this point is what is called a reversed fault, because the upward movement of displacement was on the hanging wall side; whereas in most faults the hanging wall has gone down, whence that has been assumed to be the normal fault movement. Reversed faults are by no means uncommon, however, and the idea that the plane of the Castle Creek fault has an eastward instead of a westward dip is more in accordance with the fact that the beds immediately adjoining the fault on the west often dip east also. It would seem that at the time the faulting took place the beds west of the fault were more plastic than the older ones which now adjoin it on the east; for, while I observed no direct evidence of fracture in the former, the latter were broken by a great number of minor faults, generally more or less parallel to the main fault, while I found in them no evidence of such closely compressed folding as exists in the former.

In Queen's gulch white quartzite outcrops are the first found to the east of Castle Creek fault, then follow overlying brown limestones and, after a considerable covered gap, quartzites again appear dipping 45° west, the granite beneath them being exposed by a tunnel. Probably a thousand feet above this are the Queen's cliff outcrops of blue and brown limestone, which form the extreme southern point of what I have called Aspen Mountain.

On the ridge running westward from Queen's cliff, between Ophir and Queen's gulches, I found evidence of three minor faults to the westward of the main fault, and there are probably several more. To trace these out would require an accurate map and time to visit every mine opening, neither of which I possessed. The ground is too much covered by surface accumulations to judge from outcrops alone.

My information, beyond what I could see on the surface, was of this nature. At one shaft on the ridge, which was 160 feet deep, they had a fissure with porphyry on the east and limestone on the west. Below this another shaft had a limestone east wall, and a red sandstone west wall. A miner whom I met on the trail told me he had a tunnel down below in which he had been following the limestone, but was now in a granite dike. For persons in his position a knowledge of the geological structure of the region might save a great deal of useless labor and expense, for it is probable that he has crossed a fault line, and is now drifting into the mass of the Archæan.

On the summit of the ridge, at the head of Queen's gulch, on the other hand, the ground is less covered and outcrops are abundant. At Queen's cliff is an excellent exposure of the blue and brown limestone, several hundred feet in thickness, dipping about 15° to the west. On the main ridge east of this, and across the head of Spar gulch, called, I was told, Ajax hill, are the same series, possibly separated by a slight fault on the line of Spar gulch. Following down the east slopes of Ajax hill, one crosses successively (though not quite continuously, since there are many gaps covered by soil and débris) the lower limestones and Cambrian quartzites, all striking north and south and dipping gently westward, to the contact of the latter with the Archæan at the base of the first steep slope of the ridge, about 500 or 600 feet below the summit.

I have thus first described the outlying regions, away from the centre of richest ore deposition, since it is the order in which I study a mining district. In the mining centre the structure is generally more complicated and the rocks are more highly metamorphosed than at some little distance from it, and the geological structure consequently more difficult to unravel, but if one comes to it after having learned the characteristic features, both structural and lithological, of the region as a whole, its study becomes simplified and is reduced to the applications of certain known laws and to determining the exceptions to these laws, if there are any, and their causes.

Let us consider now the more northern portion of Aspen Mountain. For some distance north of Queen's cliffs limestone forms the cap-rock of the ridge, the overlying porphyry having been entirely removed by erosion. On the round-topped hill at the head of Ophir gulch, which is very nearly as high as the summit of Queen's cliff, and on whose east face is the Campbird mine, we find several hundred feet of porphyry overlying the limestone. Its sudden appearance is accounted for by a fault which crosses its southern end, running apparently somewhat west of north, and having its upthrow on the south. Northward from here, as far as the head of Keno gulch, porphyry forms the whole upper portion of the ridge, while below it, along the west wall of Spar gulch, the limestones and their ore-bearing zone are traced by occasional outcrops and by the workings of many mines.

The line between porphyry and limestone as thus roughly traced, descends to the northward, until the change of strike from north to northeast comes in, when, as is usual in such bends, the dip of the beds steepens. The blue limestone outcrop on Spar ridge runs diagonally across the course of Spar gulch, closing it in to a very narrow ravine in its lower portion, and finally, crossing it at the bottom, passes over the point of the main ridge to the east of it, to disappear beneath the valley of Roaring Fork.

The overlying porphyry sheet also bends around to the northeast conformably, and forms the ridge bounding Vallejo gulch on the north, on the sloping crest of which a number of shafts have been sunk in it to depths of several hundred feet.

There is some evidence that beneath the surface and to the northward, on the east slopes of Aspen Mountain, several hundred feet of dark limestones and carbonaceous shales rest conformably on this porphyry sheet, though near the surface they have been mostly eroded off.

The beds thus far described, together with those underlying them in the bed of Spar Gulch, seem to follow normally the outline of the Archæan, and not to be broken by any faults of sufficient amount to destroy their general continuity. It is probable that minor dislocations, following more or less closely the general direction of the Castle Creek fault, will be found as they are more thoroughly explored, like that which appears to run across Spar ridge above the Durant cliff, and to extend across the Bonny Belle ground on the south and the Aspen on the north. The general outlines of their structure are normal and comparatively simple. It is not so, however, with the northern portion of Aspen mountain, beyond the limits of the normally dipping porphyry sheet, about whose structure opinion is, not without reason, very conflicting and uncertain.

Before describing this I must call your attention to the fact that the lower slopes of the hills, bordering the valley of Roaring Fork below the gateway, are heavily covered by ancient moraines. The glacier which came down the valley of Roaring Fork must have filled this valley to near a thousand feet above its present level. The surface of the tributary glacier of Hunter's creek, whose present bed is several hundred feet higher than that of Roaring Fork, may have been even higher, since the material it brought down still covers Smuggler Mountain to a depth in many places of a hundred feet or more, and on the east side of Roaring Fork valley, below the mouth of Hunter's creek, there is a well marked bench three or four hundred feet above the valley level, mainly composed of moraine material. On the lower eastern slope of Aspen Mountain there is an immense accumulation of unmistakable moraine material, among which rounded boulders of granite weighing a hundred tons or more are not unfrequently found, which must have been brought from the Sawatch Mountains on the back of the Roaring Fork glacier. I did not determine accurately the upper limit of this material, but should roughly estimate it at 800 to 1,000 feet above the valley. Such an accumulation, of course, effectually hides almost all the rock outcrops, and the details of underground structure can only be arrived at by careful study of underground workings with the aid of a good topographical map. In view of the possible wealth of ore under this accumulation I should think it would repay some enterprising mining engineer to make such a map of the mountain on a sufficiently large scale to plat on it the data gathered from the various shafts and drifts of mines, and thus work out in detail the underground structure. I can only give the surmises I have been able to make from observation of actual outcrops above the drift limit, governed by the structural laws already enunciated.

From the head of Keno gulch northward, the ridge of Aspen Mountain is set off *en échelon* a little to the west of the main ridge, in the same way that the whole body of the mountain is set off from the main ridge at Queen's cliff. The highest and most southern point of this ridge, overlooking the head of Keno gulch, which I will call Acquisition hill from a prominent mine of the name on its eastern face, is separated from the main ridge by a narrow V-shaped depression, running north and south. In this heads a shallow gulch, called by Prof. Lakes Pioneer gulch, which takes all the superficial drainage of the northern part of Aspen Mountain. Most of this drainage, however, sweeps through the morainal drift, and does not appear on the surface at all.

On Acquisition hill one finds brown limestone, granite and white quartzite, the former at the southern end and running along the eastern face in a northerly direction; the granite adjoining it on the west, and the quartzite resting on the latter, on the north and west. It is evident that faulting must have brought the limestone and granite into juxtaposition; what is probably the same fault plane is actually cut in the Late Acquisition mine on the northeastern slope of the hill, whose tunnel is said to have passed from brown limestone into granite at about 300 feet from the surface.

Following the ridge northward one finds beds of limestone and quartzite, striking generally in a north and south direction and with steep dips in varying directions, until about half way to the north point granite comes in and forms the crest of the ridge as far as where the successive great slab-like masses of quartzite and limestone strata, resting against it and dipping steeply northward, form the singularly protruding extremity of the mountain.

On the south and east of this mass of granite the beds are unquestionably broken by a series of minor faults or dislocations, running generally north and south. I myself observed in some tunnels near the Pioneer mine, which is in the brown limestone to the southeast of and not far from the contact with this granite body, vertical faults or slip planes running north and south, the striations on which indicate that the movement was upward at an angle of 60° to the horizon and toward the north, or, in a reversed direction, downward 60° toward the south.

The beds on the north of the granite which stand out so prominently have, as I have already said, an east and west strike, but show a tendency to wrap around the granite body in that on the east they curve in strike to the southward.

The idea I have formed, from the facts thus somewhat barely stated in regard to the structure of this ridge is, that by the movement of the Castle Creek fault this body of granite and the strata resting on its north side were dragged bodily upwards from their normal position on the downward dip of the beds now cropping in Spar Gulch, and with a relatively greater movement of displacement than the rest of the region, since they must have been lower down originally. Further, that the upward movement was relatively greater immediately adjoining the fault than at some little distance to the east, and that thus the west end of these uplifted beds was carried further upward and northward than the east end; in other words, their strike was shifted from northeast to east, and even a little south of east. That in the intermediate region to the southeast, between the granite body and the normally dipping beds north of Vallejo gulch, which is farther away from the fault plane, the beds were dragged up on the flanks of this upward moving granite body, not in a single mass like the strata to the north, but holding back, as it were, sloping up against it at steep angles, and slipping back along minor fault planes.

From the fact that on the steep side of the ridge along by the Pioneer mine the limestones dip generally eastward, it has been assumed by some that there was originally an anticlinal fold of the beds over the granite body, and a synclinal fold or basin between it and Vallejo gulch. While the position the various beds now occupy admit the assumption that there might have been a sort of abortive attempt to form some such folds, I think that the space was too limited for their free development, and that they were fractured before the folding was completed. Consequently I doubt if there will be found, when the structure comes to be worked out on a map, any continuous unbroken curves representing folds, except possibly in the reëntering angle of the hill formed by the upper part of Pioneer gulch. As shown by the New York tunnel, which at an elevation of 1,000 feet above the town runs 1,100 feet into the hill in a direction S. 20° W., the strata, which it crosses nearly at right angles, have a northwesterly instead of a northeasterly strike. It passes through 180 feet of wash and broken material, and 585 feet of conformable limestones, shales and included porphyry before reaching the top of the blue limestone. It is possible, though I think hardly probable, that a horizontal drift running southeastward along a given bed in this series, say the blue limestone, would make a continuous curve to the northeast, unbroken by a fault, before reaching the outcrops on Spar Gulch, and thus prove the existence of a synclinal basin under the northern portion of the porphyry outcrop. Of continuous folds north of this there is hardly a possibility, and while the Spar Ridge limestone probably stretches continuously across the line of Roaring Fork valley to Smuggler Mountain, and it is fair to assume that ore bodies may be found at this point beneath the valley, since they occur in the limestone on either side, the same continuity cannot be expected in the limestone beds of the northern point of the mountain. The beds in a corresponding position to them on the east side of the valley belong to a higher geological horizon, hence somewhere in the valley between they must be cut off by faults, and that probably nearer to Aspen mountain than to the other side of the valley.

I fear I may have exhausted your patience in this rather prolix account of the structural characteristics of the region without giving you a very clear idea of my meaning, which is rather a difficult task without maps. I will now turn to the ore deposits themselves, in regard to which my remarks will be rather in the nature of suggestions than definite statements, as in their case it is not possible to embrace any considerable area at a single glance as one can upon the surface.

Ore-Bearing Horizon.—The ore-bearing horizon is generally supposed to be at the contact of the so-called blue limestone with an underlying dolomite, called the brown limestone. The former is a bluish gray, compact, homogeneous rock consisting of almost pure carbonate of lime, with from a trace to one or two per cent. of magnesia. It is generally compact rather than granular or crystalline, but when crystalline the individual crystals are larger, and present broader facets than the brown limestone, in which, though generally granular, the elements are very small crystals of even size. This characteristic furnishes a most valuable practical method of distinguishing the two rocks underground, which was pointed out to me by Mr. F. G. Bulkley. When seen by the light of the candle the reflection from the faces of the calcite crystals in the blue limestone are relatively broad and irregularly distributed, whereas the reflections from the dolomite are minute evenly distributed specks of light. Once the eye becomes accustomed to this distinction it affords an almost infallible test, in the rocks of this district at least, for of course it is only applicable when the rock is more or less crystalline. The brown limestone when unaltered is of a dark blue color in the sunlight and its finely granular structure gives it a sort of steely glint: It is generally traversed in every direction by a net-work of minute veins containing salts of iron, which when oxidized color the surface of the rocks a rusty brown, from which it derives its name.

The oxidization along these minute veins or seams also makes it break easily into small lozenge or dice-shaped fragments giving a sort of crackly structure to the rock for which reason it is often called "short lime" by the miners.

When these seams are well developed on an exposed face, they divide the rock apparently into a series of angular fragments; thus it is often wrongly supposed to be brecciated or crushed, when in reality there is no evidence that it has been broken, its apparent fragmentary character being only the result of the action of oxidizing waters. The brown limestone, though somewhat variable in composition, generally approaches a true dolomite in its relative proportions of lime and magnesia.

Prof. Lakes gives the thickness of the blue limestone above the contact as 120 feet. At the Queen's cliffs I found 140 feet of beds above the contact, and it is to be presumed that a certain amount had been eroded off from the summit of the cliff. Below this contact it was all dolomite as far as I observed, and about five feet above this contact were four feet of dolomite within the blue limestone. Again on the cliff of blue limestone on Spar Ridge, above the contact at the Durant Incline, there are no less of six beds or seams of dolomite or brown lime within the blue limestone. These are readily distinguishable by the eye, because they weather more rapidly than the more compact limestones, and hence are marked by slight indentations along the face of the cliff. On Smuggler Mountain the blue limestone is said to be wanting; it will probably be safer to say it has not yet been found, since there are no surface outcrops that can be traced. These data are somewhat fragmentary but such as they are their evidence leads me to doubt that the contact is one and the same geological horizon throughout the region. This can only be satisfactorily determined when a number of sections across the entire limestone horizon, from shale above to conglomerates or quartzite below, have been measured.

From the nature of the rock fossils would be less well preserved in the dolomite than in the blue limestone, but from such remains as I have seen, and from the lithological characteristics of the bounding beds, I am inclined to think that both blue and brown limestone belong to one and the same geological horizon, viz: the Lower Carboniferous limestone.

I believe the theory has been advanced by some that the ore was deposited in a fissure formed by the movement of the blue limestone over the brown along the intervening bedding plane or contact. This theory I consider entirely untenable.

Such a movement is *a priori* highly improbable; and if it had taken place it would have left unmistakable evidences behind, not only in striated surfaces, but in a certain amount of crushed and ground-up material along the plane of movement. I found no evidence of the latter kind, and in only one place in the workings I examined did slickenside surfaces appear on the contact, and here it was a deceptive appearance. The beds were suddenly bent down from an angle of 40° to one of 60° or 70°; at the sharpest part of the bend a striated surface of fracture went off into the roof at a tangent with the curve, which at first glance appeared coincident with the contact on its steeper dip. Such a slight movement is not uncommon in sharply bent beds, owing to unequal plasticity of the successive strata.

I was told of other instances of striations on supposed contact faces, but if there has been movement of the steeply dipping beds over one another, I feel confident that on critical examination it will be found that this movement was posterior to the deposition of the ore, and not an antecedent condition. The ore itself will probably be found in places to have been striated by the movement, or perhaps cut across, or displaced.

Ore Distribution.—The outlines of the ore bodies are difficult—indeed almost impossible—to detect by the eye, so gradual is the transition from ore to country rock. Even in some of the rich bodies of almost pure galena, the grain of the limestone is so well preserved that only its metallic lustre and weight distinguish it. The ore is said to occur generally in the brown limestone, hence below the contact, but I observed several ore bodies extending 20, 30 or more feet above this contact, and in some cases following lines of cross-fracture entirely across the blue limestone.

I had come to the district with the idea, gathered from what I had read and heard, that the mineralization was there confined to a definite bedding plane or contact between two dissimilar beds, limestone and dolomite, and that the ore bodies had been formed exclusively by solutions percolating along the plane and from it eating into the underlying dolomite; I therefore looked particularly, in the underground workings I visited, for a confirmation of this idea. While this view might possibly be maintained if it were permitted to reason from what may be seen in a limited area alone, there are many facts with regard to the general distribution of the ore which I am unable to explain in accordance with it.

In the first place there is not one single contact between limestone and dolomite, but several, and, if this contact constitutes an essential condition of ore deposition, I fail to see why it should be confined to the one, and not be found on the others where the rocks have the same composition. Again I find it difficult to conceive how the ore-bearing solutions should eat upwards for any great distance from the contact planes, if they entered the beds only along this plane.

In the outcrops on Spar Ridge it is true that this contact plane is a very well defined line, which shows to the eye evidence of mineralization and is said to have been proved to contain silver at every point exposed. In the workings which have followed this outcrop down on the dip it is further stated that mineralization is practically continuous on the lines opened. I observed, however, that ore bodies occur above the contact as well as below it—the rock thus mineralized is, it is true, apparently "short line" or dolomite in most cases, but it is none the less above the bedding plane which is elsewhere called the contact and hence properly speaking in the blue limestone horizon. The miners, I found, were apt to neglect the strict geological significance of this bedding plane, which is difficult to trace where the rock on either side is thoroughly mineralized, and to consider it to follow the "hanging wall" of their ore bodies beyond which unaltered blue limestone exists, however devious the course of this wall might be.

In other parts of the region where ore bodies of greater vertical dimensions exist, I found definite evidence, moreover, that there had been fracturing across the beds. Such fractures, or rather fractured zones, are apt to be very irregular in limestones, and from the readily soluble character of the rock do not leave definite traces behind. I found, however, on certain lines an actual breccia of limestone fragments with a cement stained by oxides of iron and manganese.

Again over some of the ore bodies were lines of open cavities, often of very considerable extent, which evidently follow lines or zones of cross fracture; through these it is fair to presume the ore solutions passed which originally deposited these particular ore bodies. These caves are now being hollowed out by waters descending from the surface which exert only a dissolving action, and, as is usually the case in such caves, they grow upwards; that is, the waters which are forming them dissolve the limestone in the roof of the caves and flow off somewhere in its floor, to which the more insoluble portion of the rock drops in the form of a fine mud, composed mainly of silica alumina, lime, magnesia, iron oxide and water.

For these reasons I think it is premature to assume that the so-called contact line has been the only, or necessarily the main ore channel throughout the region, and that it is important to study carefully whatever indications may be found of other channels; it seems probable that portions of the ore bodies have been formed by solutions percolating through cross fractures or fractured zones, and afterwards spreading out more or less parallel to the bedding planes. This would naturally be the case if these solutions derived their metallic contents from the overlying sheet of porphyry, for this is separated from the limestone by a considerable thickness of argillaceous shales, which would be quite impermeable to water unless fractured across the bedding. On the other hand the analysis of the lime mud from the bottom of one of the caves in the blue limestone would indicate that the waters which dissolved it must have come through the porphyry. This showed 48.74 per cent. of silica, 15.20 per cent. of alumina and 2.76 per cent. of alkalies in the mud. Now neither limestone nor dolomite out of which the cave is hollowed contain any alkalies at all, and of insoluble matter, the one contains only 0.33 per cent., the other 0.84 per cent., which seems too little to account for so much in the mud. Hence the waters must have brought the alkalies, and probably part of the silica, with them from above; and of overlying rocks, the porphyry is the only one from which it is likely they could have been derived.

Dolomitization.—The question whether the dolomitization of these limestones is original or secondary is one of practical as well of scientific interest; it is also one whose definite solution is a somewhat delicate and difficult matter. In regard to this, three alternatives present themselves; either the various beds contained the same amount of magnesia which they now contain at the time they were deposited at the bottom of the sea; or they contained a certain amount of magnesia at the time of deposition and have received more since that time from percolating waters which have removed a portion of their lime and replaced it by magnesia; or they were all deposited as practically pure limestone, and their present condition of dolomitization is entirely due to the secondary action of magnesian waters. The confessedly imperfect data I have been able to obtain incline me decidedly against the first of these alternatives, but leave me somewhat undecided between the other two. At the same time I hold myself ready to be convinced in favor of either by any decisive proof that may hereafter be brought forward.

The arguments I find against the first alternative are: first, the irregular distribution of the dolomite beds in the limestone. I have mentioned already the numerous thin beds of dolomite in the blue limestone on the Spar Ridge cliff. I am further informed by Mr. F. G. Bulkley, in the accuracy of whose observations I have the greatest confidence, that these thin seams of dolomite are extremely irregular in depth. To quote his words, "the thin dolomite strata do not preserve the same thickness throughout, but widen from two feet to ten in a distance of 150 feet. Neither are they parallel, but approach to within one foot of each other and separate in a distance of 100 feet to 15 feet apart." I cannot conceive of conditions of deposition which would admit of such irregular successions of dolomite and limestones. An even more conclusive argument is afforded by the fact that in one mine I found a narrow irregular tongue of dolomite extending upwards for several feet into the blue limestone. Unwilling to trust alone to the test of the difference in the reflection of light I took a piece of this dolomite and had it analyzed in the laboratory of the survey. Analysis showed it to have the average composition of the brown limestone, and this is therefore an undeniable instance of secondary dolomitization.

Again the proportions of lime and magnesia in the dolomite beds are more variable than I should expect in beds which, like the blue limestone of Leadville, were probably deposited originally as dolomites, although the average composition of the thin beds in the Aspen blue limestone does not differ from that of the main mass of the brown limestone. The average proportion among the analyses I have seen is, moreover, not so near that of a normal dolomite as is that of the Leadville blue limestone.

Further, the peculiar crackly structure of the brown limestone favors the idea that there has been a secondary dolomitization, for the change involves the replacement of a molecule of lime by a molecule of magnesia. This would produce a certain contraction in volume of the rock itself, which in consequence would tend to separate into such angular fragments, the interstices between which would naturally be more or less completely filled by material more readily attackable than the mass of the rock.

If the dolomitization is wholly or in part secondary it is possible that the magnesian waters may have had some connection, either direct or indirect, with those which brought in the vein materials. In the case of the ore bodies I observed in the blue limestone I noticed that the partially mineralized rock on the borders of the ore body were apparently changed to dolomite. If I am correct in this observation, and it is found to be generally the case in such bodies, it would seem to indicate that dolomitization either preceded or accompanied ore deposition.

There are other questions of interest in regard to these deposits, on which, however, I have even less data to offer than the above, and as I have already taken too much of your time, I will simply enumerate them. First: did the porphyry intrusion precede or follow the principal faulting? This question I think will be answered in the former sense.

Second: Did the original ore deposition precede or follow the intrusion of the porphyry?

Third: Did the ore deposition precede or follow the principal faulting?

By principal faulting, I refer to the great movement of the Castle Creek fault, since it is possible that there have been minor movements of later date, and I found some evidence of movement in very recent times, not only after the original deposition of the ore, but since its oxidation or secondary alteration.

With regard to the last two questions, although I found no direct evidence either way, I will hazard the opinion that it will be found that the original ore deposition was later than both porphyry intrusion and faulting, but that the beds may not at that time have entirely assumed their present position, that is, that there has been a certain amount of movement since they were formed.