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SUBJECT: Fracture Patterns, Stock Intrusion and Faulting on Hudson Bay Mountain

DATE: January 5, 1968

TO: File

FROM: D. C. Jonson

Rob - Enclosed are some preliminary ideas. Don + I will publish a paper after the April C.I.M.M. meeting, and by that time we will probably make some changes.
Dave

I. Probable Second Source of Moly Mineralization Under the Glacier

We will soon begin a long 3,500-4,000 foot drill hole from C.O. 9 at approximately minus 45 degrees, to be drilled westward toward the central icefall area. The geologic reasons for drilling this hole into a previously unexplored area are:

1) Intramineral Stock (Quartz Monzonite) - A radial swarm of feldspar-porphyry dikes has a common center in the icefall area. The dikes are intramineral - they truncate quartz veins and are cut by later quartz veins. Both ages of veins have weak moly.

An intrusive stock is the presumed source for both the dikes and the later quartz-moly veins. (The early veins are believed to be derived from the quartz porphyry stock south of the end of 161 S. Drift).

2) Mineralization Related to the Quartz Monzonite Stock

a) Concentric veins - On surface, "classic" Type II drusy, coarse crystalline quartz veins with weak moly grade outward into quartz-pyrite-pyrrhotite veins and strong iron-stained fractures. The veins and fractures show a pronounced concentric pattern over a 2 x 2½ mile area relative to the icefall area; nearly all veins dip west.

On the front of the mountain the concentric fractures and veins could be inferred to be related to the quartz porphyry stock, but the overall pattern is not concentric with this stock. This stock, or at least that portion delineated so far, lies 3/4 of a mile east of the center of the concentric fracture pattern.

(Underground, near the ore zone, the fracture pattern is apparently related to the quartz porphyry and the pattern is quite different from that on the surface. Most strong quartz-moly veins dip gently to steeply east and southeast, apparently concentric to the porphyry on its north side. This local vein set is nearly absent on surface and dies out quickly to the northwest).

The areal extent of surface concentric veining is most remarkable, and it's doubtful if most of this mineralization is derived from the quartz porphyry stock. For example, quartz-chlorite veins near the toe of the Toboggan Creek glacier, nearly two miles northwest of the quartz porphyry, fit the concentric pattern.

b) Radial veins - Steep fractures with pyrite and quartz-pyrite veins form a radial pattern relative to the icefall area on the north, west and south sides of the glacier. The pattern is weaker than the concentric fracturing. Again, it is doubtful if this mineralization is related to the quartz porphyry stock as quartz veins near the summit of H. B. Mtn. at 8,300 feet elevation, 1-1/4 miles to the west and 6,200 feet higher than the quartz porphyry, fit the radial pattern.

Vertical veins in the Grid Area, on the lower north wall and on the outcrop near the collar of hole 28 trend east-west or west-southwest and are probably radial veins derived from the icefall area.

c) Domal veins - Fractures with pyrite show a domal pattern around the icefall area, dipping very gently northwest, west and southwest. This pattern is strongly developed on a rock spine projecting into the west side of the glacier.

d) Geochem anomaly - A moly-tungsten-copper geochem anomaly extends over a very large area on the surface, corresponding roughly with the 2½ x 4½ mile area of alteration and iron-staining. The copper anomaly is especially strong (over 1000 ppm) on the south slope of the north wall near the radial dike swarm. It's again doubtful if this trace mineralization is entirely derived from the quartz porphyry stock.

e) Theoretical probability of two sources of moly mineralization - It's logical to assume more than one source of mineralization on a theoretical basis. The sequence of stock intrusion-dike intrusion-fracturing-mineralization is a normal, evolutionary relationship and Possibility A is therefore preferred to Possibility B which, although geologically possible, is much less probable.

Possibility A - Two sources of mineralization

Youngest Event

Mineralization - Surface Type II quartz-moly grading outward to quartz-pyrite-pyrrhotite-chalcopyrite-chlorite. (Possible Type I at depth.)

Fracturing - Concentric, radial and domal.

Dike Intrusion - Radial feldspar-quartz porphyry dike swarm.

Stock Intrusion (Quartz Monzonite)

Mineralization - Type I quartz-moly grading outward to Type II; banded veins; also pyrite-pyrrhotite-chalcopyrite veins?
- Intense quartz veining on upper stock contact grading outward to quartz-moly veining; post-quartz vein breccia*.

Fracturing - Largely concentric (at least on north side of stock); breccia*.

Dike Intrusion - Local aplite, porphyry and pegmatite dikelets near upper stock contact.

Oldest Event

Stock Intrusion (Quartz Porphyry-Granite composition).

* Weak moly mineralization and rhyolite dikes are intra-mineral relative to the breccia- probably derived from an interior source within the stock.

Possibility B - All mineralization derived from quartz porphyry stock

Youngest Event

Mineralization - Type II (Later than dike swarm)

Mineralization - None

Fracturing - Same as A

Dike Intrusion - do

Stock Intrusion - do

Mineralization - Same as A

Fracturing - do

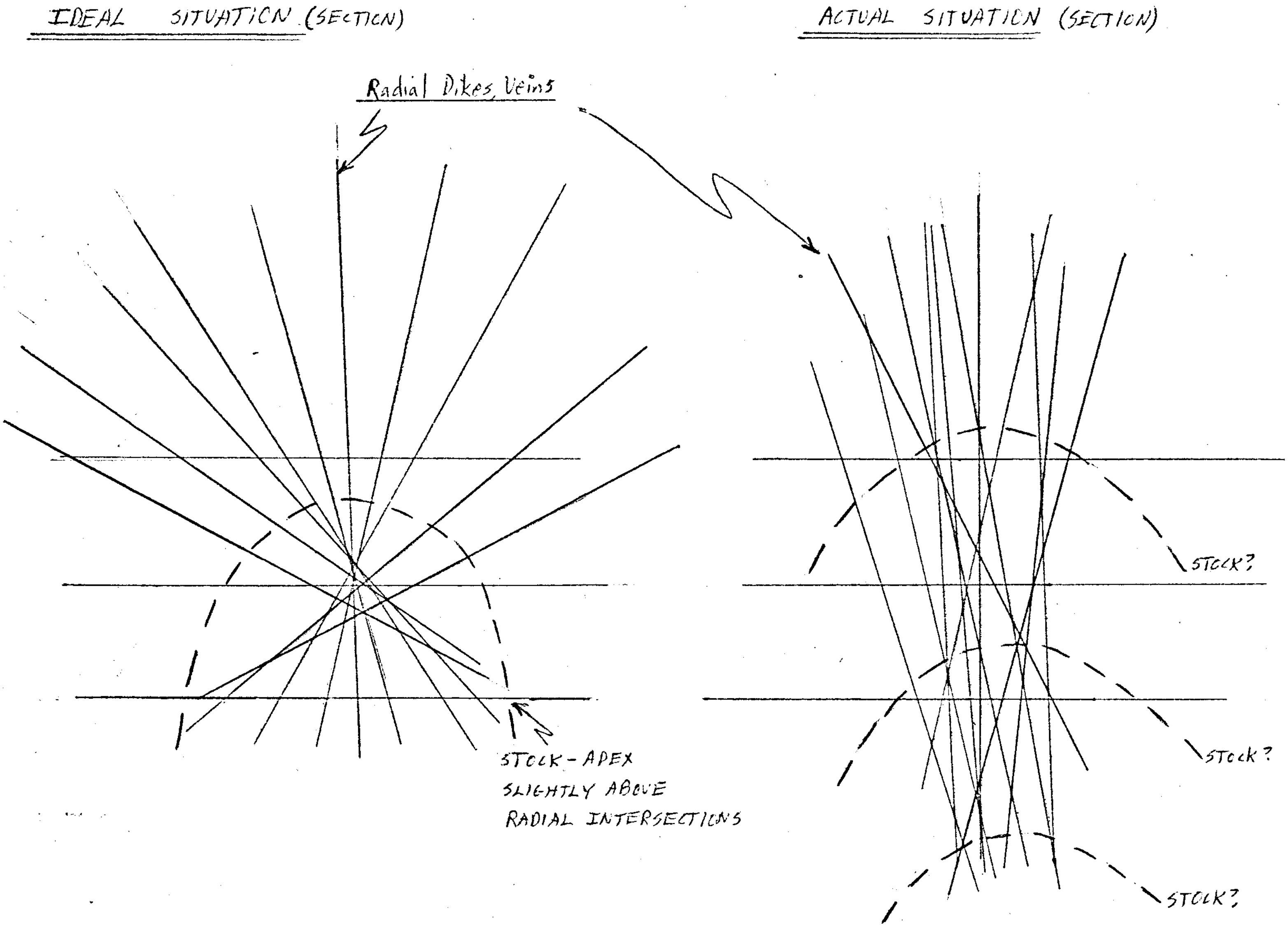
Dike Intrusion - do

Oldest Event

Stock Intrusion - do

Although we are searching for another moly ore body under the glacier, we shall need considerable luck to hit ore on the first drill hole. The hole may be "a geologic success and an economic failure" - a) Moly mineralization, strongly dispersed over an enormous area on the surface, may also be dispersed at depth; b) the hole might encounter weak mineralization above, below or to one side of a possible ore body; c) strong, closely-spaced quartz veins may be encountered, but with little moly; d) the hole may penetrate the interior of the stock where veining and mineralization would be expected to be weak to nonexistent. (If the stock is composite, additional mineralization might be encountered along an interior contact, however.)

It's assumed that mineralization will be strongest slightly above, or straddling, the apex of the stock. But the elevation of the top of the stock cannot be postulated from projections of either the radial dikes or the radial veins. The dikes and veins dip so steeply that a presumed stock apex, slightly above their common point of intersection, cannot be accurately located:



II. Probable Origin of the Thrust Fault by Stock Intrusion (and Possible Doming)

The attached paper by Wisser* describes the Columbia Mountain fault in the Goldfield, Nevada, district, a normal fault which is remarkably similar in its structural setting to the thrust fault on the west side of H. B. Mtn.

Wisser says, "The (Columbia Mountain) fault completes a belt of intense minor fracturing which almost encircles the dome, but in the arc occupied by the fault minor fracturing is almost lacking." A similar condition exists on H. B. Mtn. where intensity of fracturing and veining is strongly asymmetrical around the presumed stock under the glacier.

On the north, east and south sides of the icefall, fractures, veins and alteration extend two to four miles and die out quite gradually.

West of the icefall area, in contrast, fracturing, veining and alteration abruptly terminate. Radial dikes are absent on the cliffs west of the icefall. Radial fractures are also very weak in this area, concentric fractures are absent and because of the lack of fracturing the iron-stained halo is also absent. (Very little detailed mapping has been completed west of the summit of the mountain near the thrust but traverses across the area show that porphyry dikes, strong fracturing, quartz veins and alteration are absent; the rocks are essentially fresh.) Wisser's conclusion could be applied to H. B. Mtn. - "The abundant discontinuous fractures which characterize the circular zone elsewhere are lacking where the Columbia Mountain fault reaches the surface because the strain of doming was relieved simply by movement along the fault."

Although gently-dipping on the surface, the H. B. Mtn. thrust may be a steep reverse fault at depth. On the north and south "ends" of the thrust, where it disappears under alluvium and ice, the fault is believed to dip steeply. On an east-west section through the mountain the thrust projects quite nicely toward the bottom of the granodiorite sheet if the dip is quite gentle, but although there is some minor fracturing along the bottom of the sheet a major gently-dipping fault has yet to be located. (The assumption had been previously made that the granodiorite sheet, of igneous origin, was intruded along the thrust, or the sheet, of either igneous or metasomatic origin, was truncated by the thrust prior to intrusion of the surface dike swarm.)

The H. B. Mtn. thrust-reverse fault may therefore be related to upward movement of a stock, or stocks, in the hanging wall block east of the thrust. One or more strong north-trending faults lie west of the thrust on the back side of the mountain and may have considerable displacement. Sedimentary rocks on the north side of the mountain dip steeply north, and on the east side of the mountain dip gently to steeply east. The sediments are uncomformable with underlying volcanics but the contact is locally a strong fault, as along the base of the north wall in Glacier Gulch. General uplift of the center of the mountain relative to the north, east and west sides, at least, is not an unreasonable possibility, related to upward movement of the quartz monzonite and quartz porphyry stocks.

The amount of true doming is unknown. Layering in the volcanics is known to flatten at high elevations on the south wall, but this warping may be part of a regional fold, as pointed out by D. Davidson.

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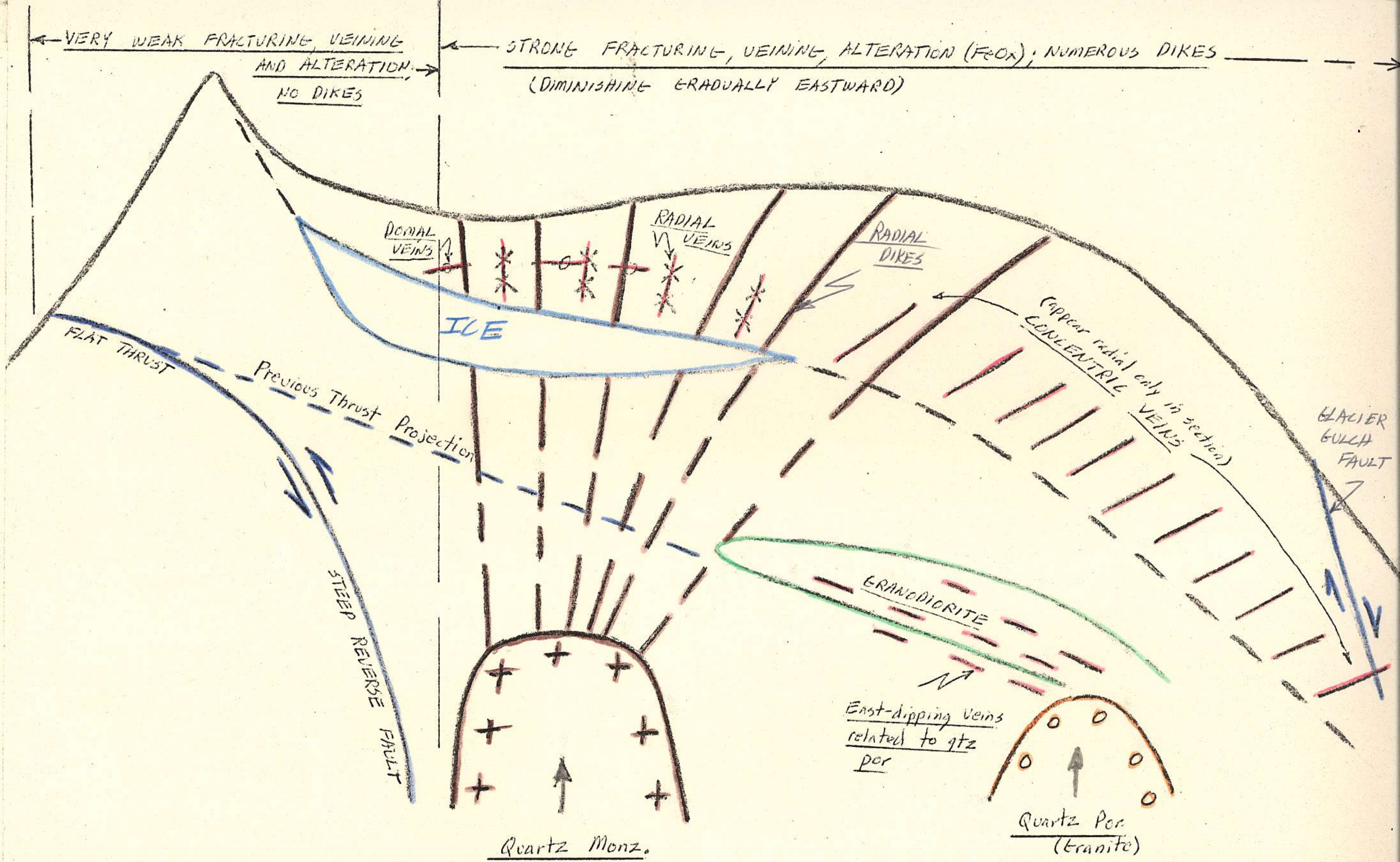

SECTION - LOOK NORTH NO SCALE

ings guided and localized ore deposition by fluids rising along the north-northwestward-trending cross joints and penetrating the blanket where they deposited ore by a combination of replacement and open-space filling. The ore solutions were "sucked up" into the blanket to form mantos. No ore was deposited in the feeding fissures, because owing to the permeable nature of the blanket overlying the feeders no "damming" action to back the solutions down into the feeders took place. After formation of the mantos renewed movement opened the feeders to receive late barren quartz, which was shattered by still later movements.

In the case of the east-northeastward-trending or longitudinal feeders there was but a single gaping of the fissure walls to receive vein matter of the rich ore surge. These movements created much less shattering of the weak blanket than did the recurrent minor fault movements along the north-northwestward-trending feeders. Ascending solutions found few openings in the blanket above the feeder. They formed inferior mantos and backed down the feeder, depositing ore that sealed it against further movement.

The Newman Hill feeders and mantos are in the central arch connecting the two half domes of the plunging anticline. The Union Carbonate blanket ore bodies occurred in the eastern half dome. The feeders there are radial fractures which parallel those of the graben wedge southeast of the mine. The feeders resemble the radial fractures in the right-hand sketch of Figure 1F. They veer northwestward toward a westerly strike which is that of the longitudinal fractures of the central arch.

The fact that the radial veins around the western portion of the Rico dome resemble in their mineralogy the veins in the cross joints of Newman Hill suggests that these vein fissures, like the cross joints, opened too late to receive the rich ore.

SOURCES FOR RICO: Collins (1931); Cross and Spencer (1900); Hubbell (1927); Ransome (1901a)

GOLDFIELD, NEVADA

REGIONAL SETTING: This late Tertiary gold district is near the southwest edge of the Great Basin (Pl. 1). Although the axis of the geosyncline traversing Nevada in Paleozoic time passed not far east of the Goldfield area, the crystalline basement is now elevated in a series of structural highs, most of which trend roughly northward. Goldfield lies above a platform in the basement between two marked structural highs.

ROCK FORMATIONS: Tertiary latite, rhyolite, dacite, and andesite extrusives rest upon Cambrian shale intruded, before the volcanism, by alaskite. The prevolcanic surface was one of low relief.

STRUCTURE: The dominant structure is that of a dome about 6 miles in diameter (Fig. 13). The ratio of vertical rise to diameter seems to be on the order of 1:20, so that the dome is somewhat flatter than those of Rico and La Plata. Several satellitic domes lie on the southwest flank of the main dome.

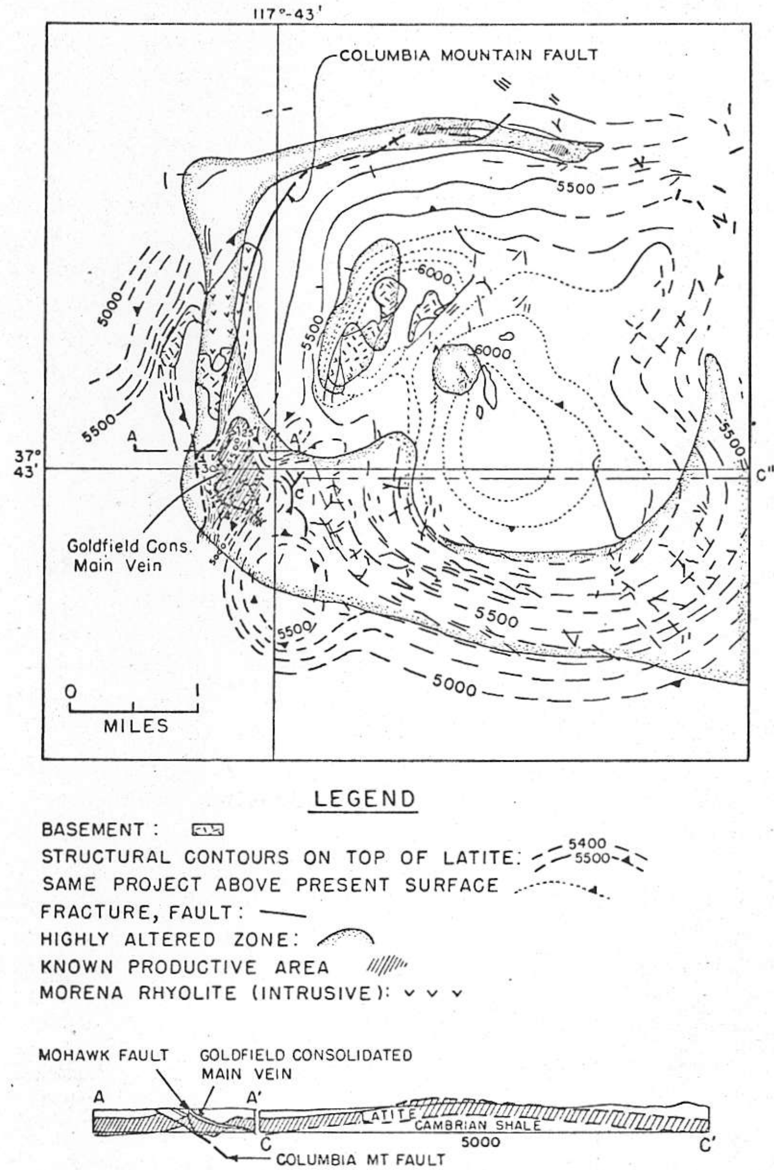

FIGURE 13.—*Structural map and section, Goldfield district, Nevada*

A remarkable concentric normal fault, the Columbia Mountain fault, follows the structural contours of the dome in the northwest quadrant. The fault dips inward toward the apex of the dome. The fault completes a belt of intense minor fracturing and alteration which almost encircles the dome, but in the arc occupied by the fault minor fracturing is almost lacking.

The fractures within this annular belt fall into a concentric and a radial set, but concentric fractures predominate.

Mine workings in the productive area on the southwest flank of the dome (Fig. 13) have shown that the many irregular fractures at and near the surface coalesce at depth into a few strong concentric fractures which dip, like the Columbia Mountain fault, toward the apex of the dome. One such fracture is the Goldfield Consolidated Main vein (Fig. 13, Plan and Section A-C′); several more are shown in the detailed section of Searls (1948, Pl. II).

The uniform course of the Columbia Mountain fault over most of its known length is broken in the productive area by two sharp southwest jogs. The Goldfield Consolidated Main vein lies in the prolongation of the Columbia Mountain fault south of the first southwestward jog, but unlike the smooth course of the Columbia Mountain fault north of the jog the Main vein has a sinuous course (Fig. 13).

ANALYSIS OF STRUCTURE: The fact that the discontinuous fractures near the surface in the productive area merge at depth into fewer but more regular and continuous fractures makes it reasonable to assume that this holds for the entire fracture zone encircling the Goldfield dome. In that case the discontinuous fractures throughout the zone coalesce at depth into a group of ring faults which dip toward the apex of the dome. The strong, continuous alteration, and the ore deposits, both of which are confined to the circular belt of fractures, suggest a continuous solution channel at depth.

Such a continuous concentric break or zone of breaks would resemble the fractures occupied by the cone sheets of western Scotland, and Sunlight. Cone-sheet fractures originate as tension fissures caused by radial stretching of a doming plate (Fig. 1E).

Whereas the Columbia Mountain concentric break probably encircles the dome at depth, it reaches the surface only in the northwest quadrant. Here it broke the dome into two blocks. Had the uplifting force been centered sharply beneath the apex of the dome, reverse faulting might have taken place along this break. At Goldfield, however, the uplifting force was distributed throughout the domed area. (Figure 13, Section A-C′, shows that the west flank of the dome in the footwall of the Columbia Mountain fault has been strongly uplifted.) Under such conditions the hanging-wall block, toward the apex of the dome, dropped as a normal gravity fault.

The abundant discontinuous fractures which characterize the circular zone elsewhere are lacking where the Columbia Mountain fault reaches the surface because the strain of doming was relieved simply by movement along the fault. Where the fault failed to reach the surface, strain was relieved by minor radial and concentric fracturing in which concentric fractures dominate because they reflect the master fracturing below.

The discontinuous fractures in the circular belt suggest deformation of brittle rock, but they lie now within a zone of rock softened by hydrothermal alteration which would deform today by flow rather than fracture. Plainly the fractures formed before the rock was softened. The belt of alteration coincides with that of fracturing which suggests that the softening solutions rose along the fractures which offered a fine-scale mesh of channels from which to permeate the rock.

The softening process consisted of alunitization and kaolinization and was followed by silicification which formed the striking Goldfield "ledges." Silicification of the walls of channel fractures formed the underlying, tabular "keels" of these ledges, whereas toward the surface silica spread outward from its channels to produce the nontabular and highly irregular "blow-outs," the ledges themselves.

Blankets of gouge surround the brittle ledges and are found throughout the soft matrix which flowed under stress, whereas the ledges could not flow but had to fracture. They were repeatedly shattered and even pulverized in places.

The exaggerated tendency to fracture shown by brittle bodies encased in soft material is discussed by Balk (1937, p. 32):

"Experiments have been made by A. Föppl, E. Seidl and Hans Cloos. Tear cracks, or tension joints formed, if a block was squeezed so that its compressed surfaces were free to move at right angles to the direction of maximum compression. . . . The better the compressed block was lubricated . . . the better is the development of the tension joints. The more the compressed block and its surrounding soft material differ in brittleness the sooner the cracks appear."

If the solutions that softened the rock ascended the postulated ring fault dipping inward, the softened body had the shape of a thick cone sheet. Under doming, compression and shortening would occur in directions normal to the doming strata; since the cone sheet lies also normal to the strata, these directions correspond, in terms of mathematics, to elements of the cone. Tension and stretching would operate in two directions, one radial with respect to the dome and normal to the surface of the cone, the other concentric both with respect to the apex of the dome and to the axis of the cone. In other words, the "cone sheet" would tend to shorten vertically but would thicken, and its diameter in horizontal section would increase.

Under such deformation the soft material would flow, but the brittle ledges would shatter.

Mine development in the productive area on the southwest flank of the dome has thrown light on the mechanics of deformation there. The Goldfield Consolidated Main vein fracture is genetically connected to the Columbia Mountain fault.

". . . the lode-like Goldfield Consolidated vein is almost exactly in the prolongation of the plane of the Columbia Mountain fault north of this [sudden westward] turn. It evidently represents a sheer zone or series of cracks, formed in extenso, as it were, of the northerly part of the great fault, without sharing appreciably in the movement that occurred on the fault itself," (Searls, 1948, p. 19).

Movement on the Columbia Mountain fault was normal, and so was that on its offspring, the Goldfield Consolidated vein fracture; but dip slip on the latter was slight.

The Combination ledge is a vertical dip split extending upward from the hanging-wall side of the flat-dipping Goldfield Consolidated Main vein and paralleling that vein in strike. Where it leaves the Main vein the split is a vein also, but above it expands to a fat, irregular ledge and resembles the ore-bearing dip splits in the hanging wall of the Comstock main lode (Ransome, 1909a, Pl. XVII, XVIII, p. 155).

The main vein in depth follows the dacite-latite contact (Fig. 13, Section A-C′). Just where the Combination dip split leaves the Main vein, the contact is warped into an anticlinal wrinkle.

The Columbia Mountain fault, in the area of its two westward jogs, is also an irregular surface. Underground exploration by Searls found three vertical dip splits in the hanging wall of the fault. One of them was a wide vein carrying rich ore. This vein could "actually be seen departing from the low-grade pyritic mineralization of the Columbia Mountain fault, like a branch from a tree trunk" (Searls, 1948, p. 21). This dip split leaves the Columbia Mountain fault at a pronounced irregularity in the surface.

"Feather joints" (E. Cloos, 1932; Hills, 1941, p. 122-124) are acute-angle branches of major fractures. They are so called because, with respect to the fault or fracture from which they spring, they are arranged like the barbs of a feather with respect to its shaft. The acute angle between the branch and the main fracture points in the direction of relative movement (or tendency toward movement) of the blocks on either side of the main fracture.

The origin of feather joints has been suggested by Wisser (1939, p. 318). Where faulting occurs

> "Completely free movement of one fault block past another involves no strain in the parts of the blocks adjoining the fault. The case is that of one brick shoved past an adjoining brick . . . with no pressing of the bricks together as they slide. But if high friction opposes the movement, a given force will displace one block with respect to the other less than with free movement. The parts of the blocks next to the fault will be intensely strained in the effort of the force to overcome the high friction opposing the movement. A shearing stress is set up and the rock on both sides of the fault is stretched in a direction crossing the fault obliquely. . . . If this tensional stress exceeds the tensional breaking strength of the deformed rock, 'feather joints' or tension fissures form perpendicular to the direction of stretching."

Actual fault displacements need not take place to produce feather joints because as movement is impeded the shearing strain increases.

These considerations suggest that the steep dip splits off the flat-dipping main fractures in the Goldfield productive area are feather joints; they are oriented to conform with normal-fault movements and they leave their parent fractures where these are locally distorted in a manner to hinder fault movements and strain the adjoining rock.

The Columbia Mountain fault in its straight northern segment was adapted toward free-slipping fault movements with a minimum of strain in the fault walls. No feather joints are known there.

The origin of the irregularities in the Columbia Mountain fault and the Goldfield Main vein is not clear. Searls (1948, p. 14) attributes the main jog in the Columbia Mountain fault to a combination of a sharp bend to the west and westerly displacement by "subsequent east-west faults." Such eastward-trending faults would lie radially with respect to the main dome.

Radial and concentric fractures often form simultaneously during doming. The Columbia Mountain fault is only one of several concentric fractures in this area (Main vein, Clermont, Sheets-Ish, and others). All originated as tension fissures; but, as doming continued, the strongest, the Columbia Mountain fault, may have acted as a normal gravity fault. It could do so without complications as far south as the first important radial break it encountered, and here it may have ended.

On reaching the break, the Columbia Mountain fault would tend to cross the radial break and extend itself southward. It succeeded only in producing the Main vein fracture, formed "in extenso . . . of the northerly part of the great fault," to quote again the analysis of Searls.

The Columbia Mountain fault movement then may have followed the eastward-trending radial break westward until a concentric fracture south of the radial break was encountered; the concentric fracture would then become the southern extension of the Columbia Mountain fault.

Such an origin can hardly apply to the wavy Main vein. Figure 13 shows two satellitic domes, separated by a trough, in the area of the Main vein. The vein follows roughly the structural contours of the northern dome but bulges westward in the basin, where it ends. These structural relations suggest that the Main vein may have been folded by the rise of the northern dome and sag of the basin. Such folding, if it occurred, presumably preceded the slight normal-fault movements on the vein fracture which were associated with formation of the steep feather joints. That faulting could well have been connected with rise of the northern minor dome because the Main vein fracture stands in the same relation to that dome as the Columbia Mountain fault does to the main dome.

An en echelon southeast prolongation of the Main vein fracture looks like a radial fracture on the southern satellitic dome. If so, it bolsters the notion that these minor domes were forming during fracturing and faulting in this area.

METALLIZATION: Most of the Goldfield silica ledges are barren of gold; but the upper and principal portion of nearly all the ore bodies lay within such ledges. Most production was from the small area on the southwest flank of the dome discussed above (cross-hatched area, Fig. 13).

Primary ore consisted of native gold in fine-grained quartz and very minor amounts of pyrite, sphalerite, and complex sulfides of antimony, arsenic, bismuth, and tellurium.

I have shown that the irregular ledges or "blowouts" commonly possess a tabular "keel" of silica on their lower sides. In barren ledges the silica keel disappears with depth and is absent from the soft matrix enclosing the ledges. Mine workings show that productive ledges have maintained connection with such major fractures as the Main vein by downward persistence of their silica keels.

RELATION OF STRUCTURE TO METALLIZATION: Both productive and barren ledges were fractured persistently; fracturing of productive ledges took place before, during, and after formation of the ore shoots. The silica keels maintaining connection between productive ledges and trunk solution channels at depth were shattered and kept permeable by slight movements which triggered the influx of ore-bearing solutions up the keel and into the "blowout" above, which was shattered also to permit entry and deposition of ore. Ideal conditions for ore localization were supplied by a loose, open shattering unaccompanied by any movement tending to compact the shattered material. Apparently even this kind of shattering, however, unless it took place at the precise time of ore invasion, localized no ore.

The barren ledges, although they shattered like the ore ledges, lacked continuous keels beneath them to serve as channels for ore solutions. The soft matrix prevented access of such solutions.

It is evident that the trunk channels for solutions that softened the rock were identical with those that silicified it and with those that brought in the ore at Goldfield. According to Searls (1948, p. 21) the trunk channel was the ring fault or zone of ring faults of which the Columbia Mountain fault is a part.

The Columbia Mountain fault, south of its westward jog, fed ore to the three dip-split feather-joint veins found by Searls. Ore solutions which used the Goldfield Consolidated Main vein as a channel probably reached it via the Columbia Mountain fault and left that fault at its westward jog. The Main vein in turn fed ore to the Combination feather joint in its hanging wall, up which the solutions moved to the ledge, where they deposited their load. The Jumbo and January ledges were supplied with ore in the same way. Some ore ledges were not fed by steep feather-joint branches of the Main vein but were fed directly by concentric fractures which parallel the Main vein in strike and dip (Red, Top, Mohawk, Clermont, and Sheets-Ish ledges).

Whereas conditions at Goldfield are in some respects unique, tectonic control of ore deposition there by persistent doming during metallization was not essentially different from that manifested at Rico, La Plata, Silverton, and other districts associated with domes.

Sources for Goldfield: E. F. Lambert (1948, unpublished report); Locke (1912); Ransome (1909a); Searls (1948)