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Title RHYOLITIC EPITHERMAL MINERALIZATION OF THE BOULDER BATHOLITH, MONTANA

Abstract Approved: [redacted]
(Major Professor)

The Boulder Batholith is one of the richest mining areas in the world. Among its many types of deposits is an epithermal phase which is being mined at many localities.

In spite of the fact that active mining has been in progress for over half a century, such fundamental considerations as post-rhyolite erosion, exact association of rocks and ores, and the exact mechanics involved in the formation of these epithermal deposits are not available in the literature.

The purpose of this paper is to present some evidence found in the rhyolite-covered area five miles south of Rimini in the northwest corner of the batholith. Here the mineralization is definitely known to be epithermal, and here also the conditions seem favorable for determining the relationship of the epithermal mineralization and the rhyolite.

Viscous rhyolites were pushed up to the surface and oozed forth on a steeply rolling relief very similar to that of the present. Flow planes were developed by the upward movement of the rhyolites as they were squeezed through inverted funnel-like outlets. These flow planes were followed by the mineralizing fluids.

Two closely related stages of mineralization have occurred and are exposed by the mining operations of the Porphyry Dike mine. The first mineralization consisted entirely of pyrite and gold and is distributed along the flow planes. The second stage is primarily confined to cross-flow-line fractures or small gash veins and is composed of drusy quartz with insignificant amounts of pyrite and uncertain but small amounts of gold. Both stages of mineralization occurred while the rhyolite retained a sufficient degree of plasticity to allow drag folding along the flow planes.

Because the rhyolite and the mineralization are essentially contemporaneous, they are either both derived from the same source, or the mineral forming fluids were derived from the rhyolite at depth.

The majority of the vents were on or near the hills and higher elevations. At the vents the rhyolite built mounds and flowed down into the valleys. The surface of the rhyolite in the valleys was probably not increased any more in elevation than were the mounds from which the rhyolite flowed.

The rhyolite in the valleys has undergone rapid stream erosion due to underlying ash or residual arkose which permitted undersapping. Approximately 500 feet has been removed from the valleys and not over 100 feet and perhaps almost nothing from the hills.

Authorities do not agree on the age of these rhyolites, but it is the author's conclusion that they are younger than any age previously assigned to them. These rhyolites are younger than the dacites with which they have been confused and to which they have often been compared in age. At least they are so young that they are all present except in the valleys.

This mineralization is typically epithermal and definitely associated with the rhyolite. The facts disclosed in this study relative to their associations and the amount of post-rhyolite erosion is directly applicable to all related epithermal mineralization in the region.

RHYOLITIC EPITHERMAL MINERALIZATION OF THE BOULDER BATHOLITH, MONTANA

by

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INTRODUCTION

The Boulder Batholith is one of the richest mining areas in the world. Among the many types of deposits represented is an epithermal phase which is being mined at many localities.

Although the records of the first recognition of the epithermal character of these deposits may now lie only in the memory of the early miner, we know it was definitely recognized over 40 years ago by Weed. Since then it has been widely recognized.

In view of these facts the paucity of detailed literature available on the subject is surprising. Such fundamental considerations as elevation of the original surface, depth of erosion, exact association with certain igneous rocks, causes of association of rocks and ores, depths to which one may expect the deposits to descend, and more exactly the exact mechanics involved in the formation of the veins, which are all so essential to the development of the mines, are described in less than one page by Pardee and Schrader in the latest and most complete report available on the area.

The purpose of this paper is to present some evidence found in the rhyolite covered area five miles south of Rimini in the northwest corner of the batholith. Here

the mineralization is definitely known to be epithermal, and here also the conditions seem favorable for determining the relationship of the epithermal mineralization and the rhyolite.

SUMMARY

Viscous rhyolites were pushed up to the surface and oozed forth on a steeply rolling relief very similar to that of the present. Flow planes were developed by the upward movement of the rhyolites as they were squeezed through inverted funnel-like outlets. These flow planes were followed by the mineralizing fluids.

Two closely related stages of mineralization have occurred and are exposed by the mining operations of the Porphyry Dike mine. The first mineralization consisted entirely of pyrite and gold and is distributed along the flow planes. The second stage is primarily confined to cross-flow-line fractures or small gash veins and is composed of drusy quartz with insignificant amounts of pyrite and uncertain but small amounts of gold. Both stages of mineralization occurred while the rhyolite retained a sufficient degree of plasticity to allow drag folding along the flow planes.

Because the rhyolite and the mineralization are essentially contemporaneous, they are either both derived from the same source, or the mineral forming fluids were derived from the rhyolite at depth.

The rhyolite in the valleys has undergone rapid stream erosion due to underlying ash or residual arkose which permitted undersapping. Approximately 500 feet has

been removed from the valleys and not over 100 feet and perhaps almost nothing from the hills.

Authorities do not agree on the age of these rhyolites, but it is the author's conclusion that they are younger than any age previously assigned to them. These rhyolites are younger than the dacites with which they have been confused and to which they have been often compared in age. At least they are so young that they are all present except in the valleys.

This mineralization is typically epithermal and definitely associated with the rhyolite. The facts disclosed in this study relative to their associations and the amount of post-rhyolite erosion is directly applicable to all related epithermal mineralization in the region. Briefly, any ore deposit of this region that has a relatively recent stage of mineralization consisting essentially of silica and pyrite might be of related occurrence. The amount of erosion relative to any mineralization that is found to be related to the rhyolites can be closely approximated when its local physiographic features are also taken into consideration. Generally speaking, the nearer to the rhyolite covered summits that a mineral deposit of this age occurs, the less post-mineral erosion has taken place. At the very summits the erosion is

negligible. Even at the very bottoms of the valleys, erosion in excess of 500 feet would occur only in exceptional cases.

On the basis of the above reasoning one might expect to find 1000 to 1500 feet of an epithermal vein available below the present surface in any mine in the district.

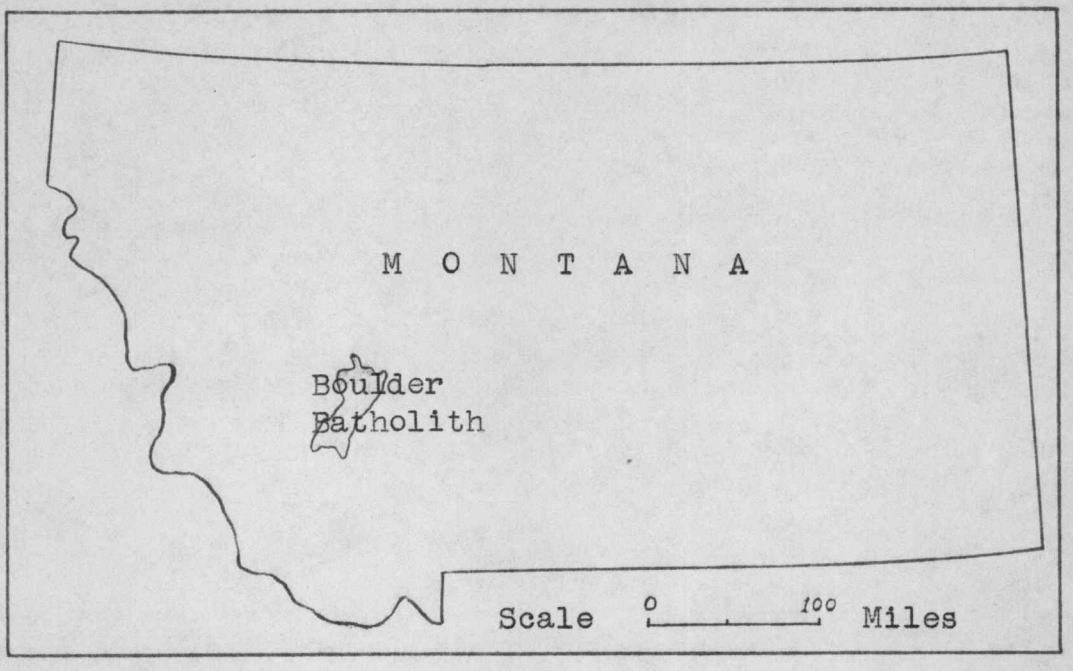
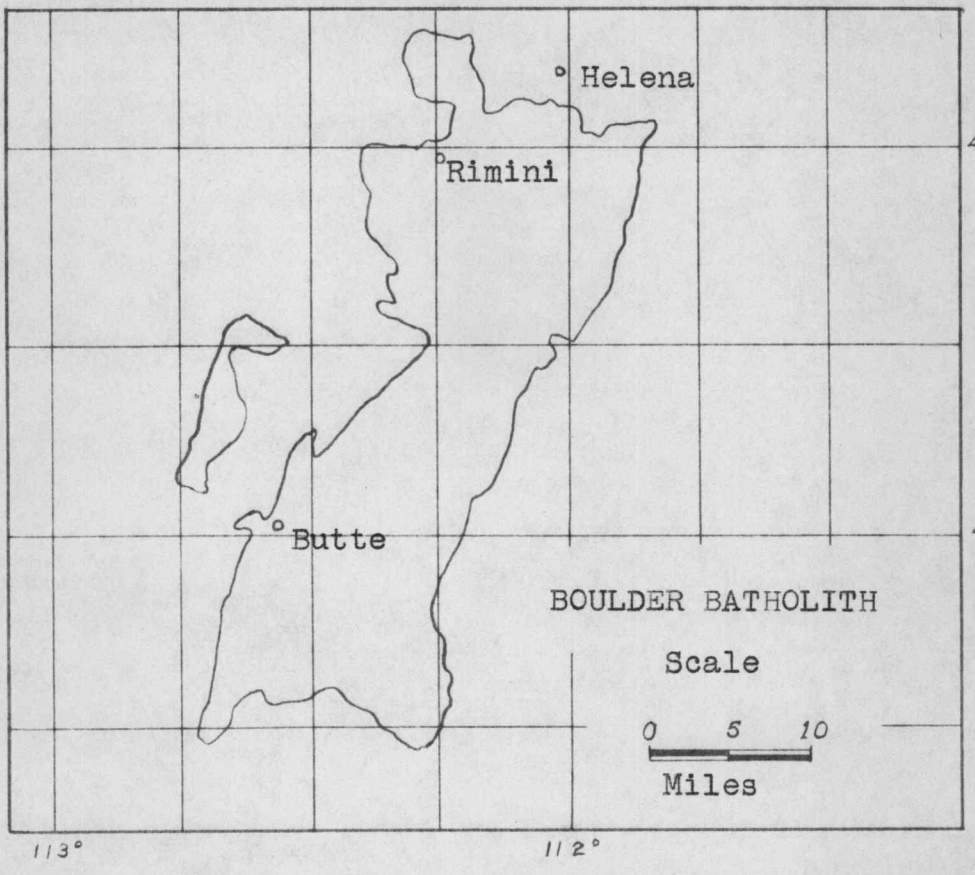

M O N T A N A
Boulder
Batholith
Scale
0
100
Miles

PLATE 1


Helena
Rimini
Butte
46°30'
46°
BOULDER BATHOLITH
Scale
0
5
10
Miles
113°
112°

TOPOGRAPHY

The Boulder batholith lies approximately between 45°42' and 46°40' north latitude, and 111°48' and 112°50' west longitude.

The area that is covered in this paper (part of the Rimini district) is located on the northwest corner of the batholith and lies mainly to the south of the town of Rimini. This area straddles the Continental Divide which here maintains an average elevation of about 7000 feet.

The Rimini area, which is topographically typical of much of the batholith, may be considered mountainous with considerable relief. The mature topography is characterized by smoothly rounded profiles, due in general to the large areas of exposed granite whose uniform texture controls the erosion. Although the area has a "velvety" profile because of the dome-like summits, considerable and often rather abrupt relief is fairly typical. Remnants of a formerly flat and gently rounded surface are found at an elevation of from 7000 to 7500 feet.

Although late Tertiary rhyolites are locally conspicuous, they were erupted on an already mature relief, were apparently too viscous to concentrate in the depressions, and are therefore of little influence on the present topography except for adding some slight height.

PLATE 2

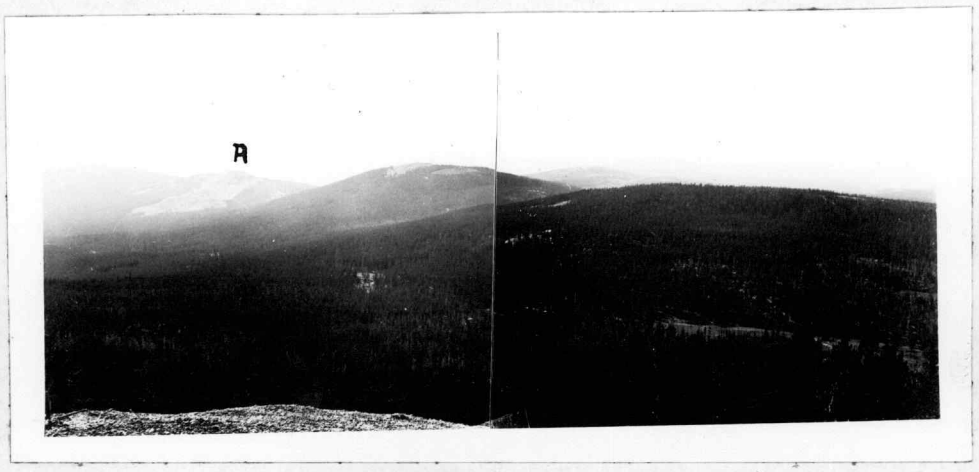


Figure 1

Looking westerly from Baldy Mt. The rounded, bare knob (R) is "Round Mt." with the Josephine mine to its right.

Figure 2

Looking westward from the Porphyry Dike mine. The white area in the center foreground is a tailings catchment basin.

GENERAL GEOLOGY

Large areas bordering the northern and eastern part of the batholith and smaller areas along the western, southwestern, and southeastern side are underlain by sedimentary rocks of the Belt series of Algonkian age. These are exposed to a total thickness of 15,000 feet or more.

In part they are overlain by Paleozoic and later sedimentaries in the northeast and, to a lesser degree, in the southwest.

Tertiary sediments, composed chiefly of sands, clays, tuffs, and conglomerates, occupy large areas in the intermontane valleys and compose the so-called lake beds.

Quaternary alluvium forms a thin veneer in all favorable situations. Glaciation is poorly represented except for some of the morainal deposits in the valleys of the northern part of the region and a few peaks that exhibit cirques.

The principal igneous rock of the region is the large granitic mass known as the Boulder batholith, probably of Late Cretacious or early Eocene Age. Around this granitic exposure, which extends southwesterly from Helena, are clustered many smaller exposures of a lithologically similar rock, which has been defined as a quartz monzonite.[1]

[1] Barrell, Joseph, Microscopical Petrography of the Elkhorn Mining District, Jefferson Co., Montana, U. S. Geol. Surv. Twenty-second Ann. Rept., Pt. 2, 1901, p. 535.

Igneous rocks of the region older than the batholith include gabbros, diorite dikes and sills, and andesite-latite flows and breccias. Post-batholithic igneous rocks are represented by the rhyolite-dacite series. The later rhyolites are almost entirely confined to an area of approximately 150 square miles, mostly south of the town of Rimini.

All the Mesozoic and older rocks are involved in a series of northwesterly-trending folds. Paralleling these folds across the northeastern part of the region, overthrust faults related to the great Lewis overthrust, have superimposed the older Belt rocks upon Paleozoic and Mesozoic formations in an easterly direction.

Billingsly and Grimes[1] fix the relation of the igneous rocks of the Boulder batholith to the general mountain structure as follows:

1. Upper Cretaceous.--Andesite eruption. Deposition of extrusive lavas and breccias west of Rocky Mountain front and formation of tuffs and andesitic sediments on the plains.

2. Upper Cretaceous.--Local intense erosion and formation of coarse andesite conglomerates.

3. Upper Cretaceous.--Thrust faulting along northwest lines, and local intensification of folding.

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[1] Billingsly, Paul, and Grimes, J. A., Ore Deposits of the Boulder Batholith of Montana, Am. Inst. Min. Eng. Trans., vol. 58, 1917, p. 288.

4. Eocene (?).--Intrusion of Boulder Granite Batholith.

5. Eocene.--Extensive erosion, approximating peneplanation.

6. Oligocene, Miocene.--Normal faulting; accumulation of river gravels and lake silts; early rhyolite.

7. Pliocene.--Same conditions with extrusion of later rhyolite and dacite.

8. Pleistocene.--Two or more glacial stages in the mountains.

RHYOLITES

General Description

Lying on the eroded surface of the batholith and capping or partially capping many of the peaks of the area, such as Luttrell Peak, Red Mountain, Baldy Mountain and others, are rhyolitic lavas, tuffs, and breccias.

These rocks are in general light colored, but an unusual variety in color and texture may be observed in a comparatively small area. The changes take place not only vertically but also horizontally or parallel to the generally supposed direction of flow. The colors vary from a purplish tinge through blue, gray, white, and pink. The texture ranges from tuffaceous to very dense almost flinty massive, to highly laminated typically flow banded. Much of the banding is highly folded, distorted, and irregular in direction. Phenocrysts of smoky quartz and glassy sanidine are common in the denser rhyolites.

The commonest rhyolites are mainly lithoidal flows, which in some localities offer an excellent development of lithophysae. The better developed and larger lithophysae, seemingly, are mostly confined to the portions showing the best flow structure, although they are not always associated with flow banding, as much well banded rhyolite is free of them. Parting by weathering along the flow lines has apparently been most effective in releasing

the concretionary-like lithophysae which may be found scattered over the surface in large numbers in restricted areas. This flow-line parting is also the cause of the great masses of almost slaty-like slabs on the talus slopes. The very small lithophysae, if not associated with the larger ones, are commonly confined to the more massive rock which breaks in blocks. This phase of the lithophysae gives the rock an oolitic appearance (Plate 3, Figure 1).

In places these rhyolites have a pronounced columnar structure as seen on the round topped hill approximately 1 mile southwest of the Josephine mine. This knob was designated as "Round Mountain" in the field and will be so spoken of in this report since it is nameless on all maps of the region.

Tuff breccias containing pumiceous fragments were found on the top of the Luttrell Peak ridge above the Porphyry Dike mine. Much of the ridge 1¼ miles southwest of Luttrell Peak is also composed of a blocky, massive tuff-breccia (Plate 3, Figure 2).

Indurated tuffs and ash were found over a distance of approximately ½ mile in the saddle between the Luttrell Peak ridge and "Round Mountain", but their lower extremities could not be ascertained due to talus material and overburden. They apparently extend down the southeast side of this saddle-ridge for a vertical extent of at

PLATE 3

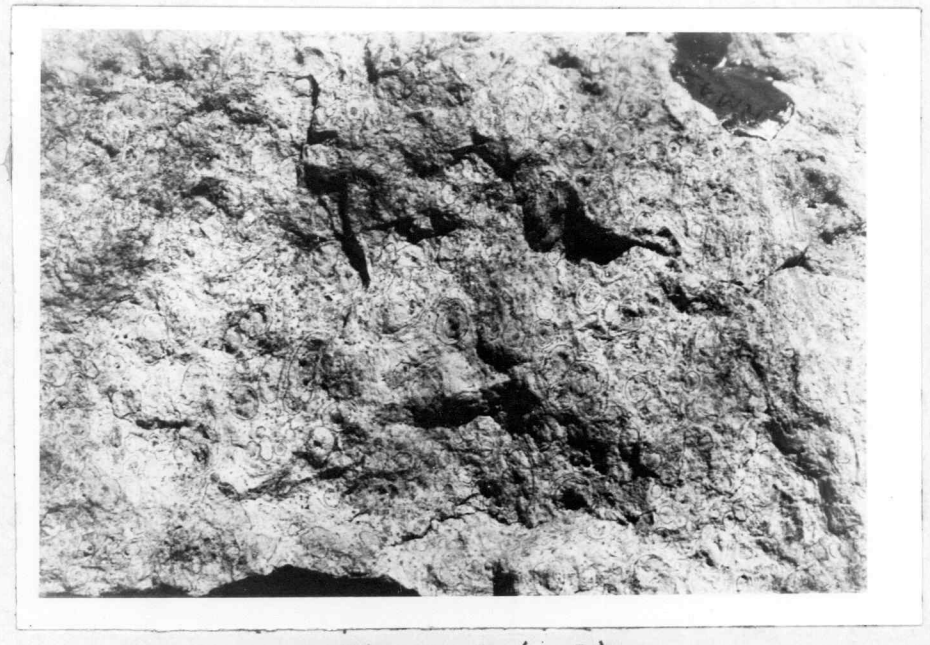


Figure 1 (x 1)

Massive rhyolite with an oolitic appearance due to the numerous small lithophysae.

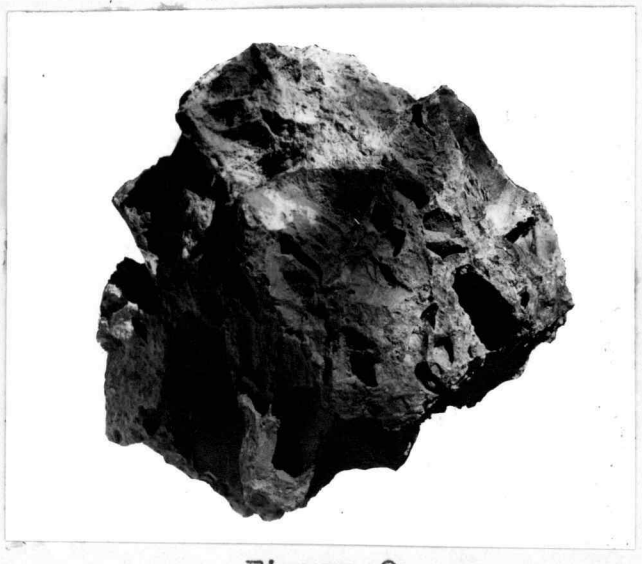


Figure 2

Tuff-breccia (agglomeritic) with large pumice fragments removed by weathering.

least 100 feet. The exact contact between these tuffs and the later rhyolite flows from "Round Mountain" could not be uncovered; but it is believed that they underlie these flows, at least on the north and northeast side, as no evidence was found to disprove their apparent stratigraphic position.

On the northeast side of "Round Mountain" at the approximate contact of the tuff and the rhyolite, as judged by the vegetation and topsoil, numerous pieces of dark, highly fractured obsidian are scattered about. Much of the obsidian is in the form of rounded and semi-rounded pebbles. In numerous specimens the outside is slick to the touch, due to a very thin veneer of whitish, kaolinitic material. This material also fills the fractures and hold the much fractured pebbles together. The fractured pieces are not displaced and all the seams are very tight.

The south end of Baldy Mountain, lying 1½ miles southeast of Luttrell Peak, is also capped by rhyolite, lithologically similar to that of Luttrell Peak and "Round Mountain". Talus slopes of the light-colored rhyolite are distributed along the south, the southwest, and the southeast slopes of Baldy Mountain; but the flat surface on the top of the mountain is a highly weathered quartz monzonite.

Although the conduit was not observed, the outbreak of lava on Baldy Mountain appears to have been on the southern end and perhaps along the southwestern brow of

this elongated dome.

From field observations it seems apparent that each rhyolite capping on each individual prominence or hill had its own local source of extrusion, at least in this specific area. The 1400 foot[1] tunnel of the Porphyry Dike mine commences in the quartz monzonite upon which the rhyolites rest and through which they had penetrated on their way to the surface. The quartz monzonite is also exposed on the surface about 200 feet down slope from the open pit in the mineralized rhyolite. That the source of exit should be at Luttrell Peak seems most reasonable as there is no other apparent nearby (or distant) source with an elevation sufficient to allow an acidic lava flow to accumulate to this height.

On "Round Mountain" there is much evidence of another source of an extrusion as indicated by its columnar structure. Columns with diameters of two to three feet and of indeterminable lengths dip southeast at angles of about 30° to 40°. This direction is at right angles to the greater dimension of the entire mass of rhyolite. The flow lines almost invariably stand vertical (Plate 4, Figure 2), but vary in strike from southeast (parallel to direction of columns) to about 10° south of east. In the

[1]Pardee, J. T., and Schrader, F. C., Metalliferous Deposits of the Greater Helena Mining Region, Montana, U. S. Geol. Survey Bull. 842, 1933, p. 259.

latter case, which is a more common tendency, the flow lines cut across the columns at an angle of about 30° (Plate 4, Figure 3). This evidence seems conclusive proof that the rock had cooled between steeply dipping walls unless the orientation of the columns had been altered after formation. A close field examination could not produce any signs that would indicate movements of a type and proportion necessary to orient originally vertical columns to this position.

Further evidence of the localized sources of extrusions is brought forth under the discussions of age, viscosity, relief, and erosion to which several of these facts happen to be more closely related.

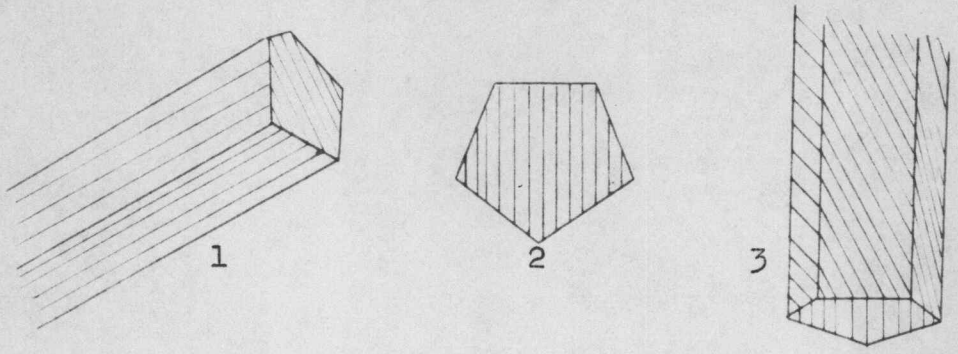
Age and Amount of Rhyolite

An agreement as to the age of the rhyolites does not seem to have been arrived at by the various geologists who have examined the numerous mining regions of the Boulder batholith.

Knopf[1] says, "The rhyolite series seems, because of its general petrographic homogeneity, to represent an outburst of volcanic activity distinct from that of the dacitic eruptions which are known to have taken place in upper Miocene time. However, as the rhyolites have not

[1]Knopf, Adolph, Ore Deposits of the Helena Mining Region, Montana; U. S. Geol. Survey Bull. 527, 1913, p. 41.

PLATE 4



Relation of flow lines to columns as seen on "Round Mt." Fig. 1 shows approximate dip of columns with vertical flow lines parallel to direction of dip. Fig. 2 is an end view of a column showing vertical flow lines. Fig. 3 shows vertical flow lines forming an angle of approximately 30° with the direction of dip.

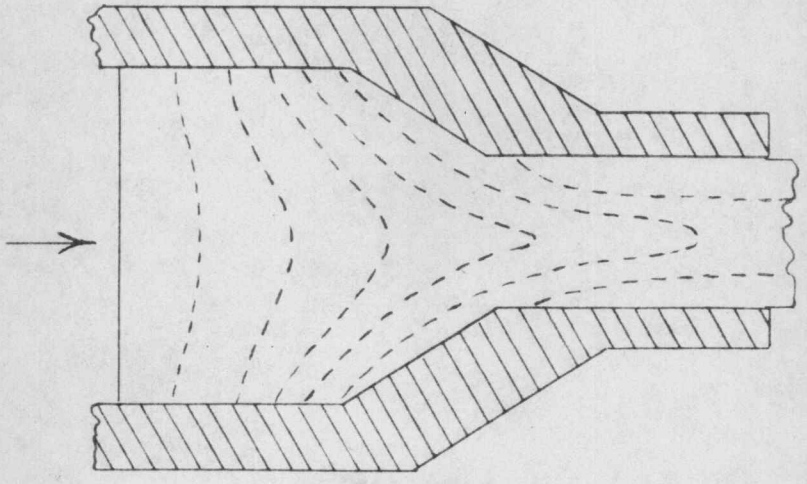


Figure 4

Drawn after Becker to show the formation of the so-called fluxion structure formed when a plastic substance is forced through an opening.

been found in contact with the dacites, their relation to the dacites is not known. If they were not contemporaneous with the dacites, they probably represent a somewhat younger period of volcanism, as they were erupted upon a surface broadly similar to that of the present."

Billingsley[1], in figure 6 on page 38, illustrates a section near Avon across Day Creek, Trout Creek, and the Little Blackfoot River which clearly show considerable planation, and is labeled, "Section showing Occurrence of Early Rhyolite near Avon." On top of this surface lie considerable Tertiary gravels. The three streams have cut through these gravels and into the rhyolite. On his reconnaisance map opposite page 56, he indicates the rhyolite south of Rimini as being this early rhyolite.

Billingsly and Grimes in their chronological table (p. 288) date the early rhyolites and the normal faulting as "Oligocene, Miocene", and show the Pliocene period to have had the same conditions with the extrusion of later rhyolite and dacite. They also state, "There is much evidence, especially in the Rimini region that the early rhyolite antedated the period of block faulting that initiated the upper Tertiary. It is definitely known that the later rhyolite dacite series comes late in the Neocene, as its tuffs and gravels, with leaf impressions are

[1]Billingsly, Paul, The Boulder Batholith of Montana; Am. Inst. Min. Eng. Trans., vol 51, 1915, p. 38.

interbedded with Miocene and Pliocene gravels."[1]

It is presumed that the last sentence refers to Weed's findings, that the rhyolite-dacite eruptions were contemporaneous with the deposition of the lake beds west of Butte.[2] These are upper Miocene in age.

The rhyolites of the Butte area were found to be liparitic (rhyolitic) dacites, characterized by the dominance of biotite as a porphyritic constituent. These have been termed rhyolite-dacites by Weed.[3]

Pardee and Schrader[4] state that the rhyolites which erupted on a surface about a rough as that of the present and form the cap of Red Mountain and the bed rock of the "porphyry dike", are "probably younger than the dacite, though their relationship to it is not shown".

Summing up the statements and the evidence offered concerning the ages of rhyolites and related rocks in the area of the Boulder Batholith, two facts seem to be outstanding and definite. First, the rhyolite of the northern part of the area in the vicinity of Avon and Elliston is undoubtedly earlier, either Oligocene or Miocene. Second, the dacites from Basin west and south are apparently upper Miocene in age and perhaps lower Pliocene.

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[1] Billingsly, Paul, and Grimes, J. A., Op. cit., p. 290.
[2] Weed, W. H., Geology and Ore Deposits of the Butte District, Mont.: Prof. Paper U. S. Geol. Surv., No. 74, 1912, p. 46.
[3] Ibid., p. 43.
[4] Pardee, J. T., and Schrader, F. C., Op. cit., p. 192.

Concerning the Rimini region, where the rhyolites cap Red Mountain, Luttrell Peak, Baldy Mountain and other lesser summits, the deciding factors are not so clean-cut. Billingsly and Grimes consider them as belonging to the early stage of eruptions. Pardee and Schrader believe that they are probably younger than the dacites. Knopf believes that if they were not contemporaneous with the dacites, they are probably somewhat younger.

In view of the above discussion and the lithologic difference, especially in the amount of weathering, between these south Rimini rhyolites and the much more highly decomposed rhyolites west of Elliston, it would seem more favorable to conclude that they are not of the same age. Pardee and Schrader, the most recent of the papers quoted, seem in agreement with this statement by the fact that they consider these rhyolites as probably younger than the dacites whose age is known.

Perhaps the fact that the rhyolite south of Rimini is greatly limited to cappings on the higher ridges and hills has influenced the age decision, since definite proof seems to have been otherwise lacking. The valleys are comparatively free of rhyolite, and superficial evidence indicated that great amounts of this material had been removed.

If the area as a whole had been covered with a single large rhyolitic lava flow, the present topography of high

relief would demand the removal of great amounts of material. In places it would easily demand a removal in excess of 1500 to 2000 feet of material. For an extreme example, the west slope of Red Mountain now drops over 2200 feet to the valley below in less than 1½ miles, map (horizontal) distance.

Several facts were observed that seem to indicate that such great quantities have not been removed. For example, the cone-shaped elevation on the south end of Baldy Mountain extends for some distance above the nearby flattened surface of the rest of the top. Less than ¼ mile away the shaft of the May Lillie mine begins in quartz monzonite immediately below 1 to 2 feet of arkosic top soil. Not over 100 feet from the shaft, at the brow of the hill and over the side below, is a talus-like deposit of comparatively fresh-looking rhyolite (Plate 5, Figure 2). Suppose the irregular terrain was completely covered by a single thick rhyolite flow which is now entirely removed in the valleys; then, during this valley removal, of a thousand or more feet of material, surely the area where the cone now stands must have been lowered at least a few hundred feet.

If this cone ever stood at a much higher elevation than at the present, then much of the flat topped surface of the mountain should have been covered with rhyolite. Yet this had never happened as the surface rock at the

PLATE 5

Figure 1

Scale 1 in.=400 ft. (approx.)

ROUND MT. SLIDE

The orientation of the columnar structure at "A" suggests that the bench "B" has been dropped and rotated in the typical cycloid curve. This event took place long before the slide as judged by the state of the rock surfaces. (See the photographs on page 32.)

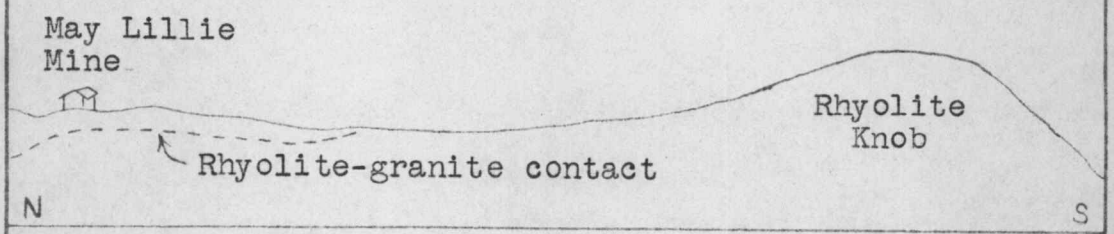


Figure 2

Scale 1 in.=300 ft. (approx.)

SOUTH END OF BALDY MOUNTAIN

If the rhyolite knob had ever stood much higher, then lava should have covered the quartz monzonite exposed at the Mine where two feet of residual arkosic soil now bears vegetation on the flat top.

May Lillie is weathered quartz monzonite. There is no apparent way of completely removing a comparatively resistant rhyolite flow from such a flat surface without adjoining highlands, without leaving a single clue to its former presence, and yet leave large amounts of a similar rock reclining on the adjoining slopes.

If the cone doesn't represent an extrusive exit, then the expulsion must have taken place somewhere to the south. Such a hypothesis would only make the situation more difficult. It would demand the total filling of a basin which is 2½ miles wide and slopes southward for 10 miles or more to Boulder River. This basin would have to be filled with over 1200 feet of lavas in order to suppose the cone in question to be the edge of a flow. Even though this was the case, the problem still is, - why is the flat top of Baldy Mountain not covered with rhyolite at present since the edge of a flow would have succumbed to erosion also, thereby, demanding at least several hundred feet more height than now exists. In either case, appreciable additional height on this point would have caused even a viscous lava to encroach on more of the flat top.

The only apparent answer is, that it never was covered by a lava of the same age as that which caps its southern tip and forms the southwestern and southeastern flanks.

These facts seem to eliminate any thought that the

entire area was covered by a great thickness of rhyolite, which has been removed from all except the present peaks. If it remained on these other peaks then it should have remained on the flat top of Baldy Mountain, if it was ever there. It was never there; therefore, the cone to the south has never been much higher.

This seems conclusive proof that the rhyolite is comparatively young, at least younger than an age which would allow thousands of feet to be removed from the now existent valleys.

The evidence just offered strongly suggests that a vent existed below this cone. The nearly flat lying columns on "Round Mountain" discussed on pages 16-17 are good proof that a vent also existed on that elevated area. Just why this condition should exist is not entirely clear, but the fact that most of the eruptions took place on elevated areas will materially help to explain the positions of the present rhyolite remnants.

The fact that several of these high areas are mineralized is still further evidence that the vents must be nearby. The Porphyry Dike, the Pauper's Dream, and the so-called "M and M" property on the south end of Baldy Mountain are all mineralized rhyolite areas at elevations of 7000 feet or more. Lindgren[1] says that epithermal

[1]Lindgren, Waldemar, Mineral Deposits, 3rd Edition, McGraw-Hill Co., New York, 1928, p. 529.

veins are confined mainly to volcanic necks or centers of eruption and not to the great wide flows. Although none of these deposits deal with veins in the common concept of the term, yet they may be considered as of a similar origin and differing only in form.

With local vents possible, it removes the necessity of having had the area covered by one solid flow, which by necessity would have had to exceed 2000 feet in numerous places. Consideration of the acidic nature of the lava also indicates that it would be highly improbable that all this material came from one vent, or even from two vents, as it would demand a tremendous height to overcome its greater viscosity sufficiently to cover an area of about 10 by 15 miles. No vestige of such a built-up height remains.

Viscosity of the Rhyolite

A brief reconstruction of the eruptions as based on the field evidence would be as follows:

The magma was squeezed out upon the surface of the batholith. The high viscosity did not allow its rapid removal by flowage. As has often been shown in other regions, the viscous lava quickly crusted over by cooling. The quickly solidified surface was twisted, fractured, and cracked by the uneven upward thrust of more lava, or the down grade movement of the still plastic lava beneath.

Instead of a molten mass flowing rapidly down the slopes and filling the valleys, the majority stayed at or near the point of exit. As more lava was added to the mass from below, the entire mass was forced upward and outward, perhaps piling the rhyolite to a higher elevation than the exit in those cases where it appears that the exit fracture was on the side of a hill as at the south end of Baldy Mountain. The greater viscosity of this acidic lava decreased its down-slope movement and allowed it to freeze at higher angles of rest.

While this type of a flow is perhaps not as common as the flat basaltic flows, nevertheless, descriptions are to be found in the literature. Hodge[1], in describing the trachytic Newberry Flow on the south slope of the South Sister in the Cascades, states, "The vent through which this lava issued must have been a sort of slit in the mountain side extending southeastward. It is apparent that the lava squeezed out through this slit at an elevation of 8000 feet and even more abundantly at about 7700 feet, and oozed slowly upward and outward, and then downward. The pressure of lava from below and the viscosity made possible the piling up of the lava to an elevation of 8,100 feet."

[1]Hodge, Edwin T., Mount Multnomah, Ancient Ancestor of the Three Sisters, University of Oregon Press, Eugene, Oregon, 1925, p. 56.

A more recent illustration of a very similar type of extrusion and quick surface cooling with the resultant fracturing is from the now 18 year-old Santiaguito, a recent edifice of the supposedly extinct Santa Maria in Quatemala.

Although this appears to be an extreme case, it is best to show the possibilities present by quoting their description, which is as follows:

"Up to the present time (1939) there has not been any well-defined flow of lava, but, instead, the freezing of the viscous rock-forming material has permitted the extrusion of ridges, spines, and hot fragmental material. The ridges and spines are often broken down by the pressure exerted against them from below, and as a result the outer surface of Santiaguito consists largely of loosely piled-up rocks, which are often at their angles of repose (about 32°)."[1]

That the surfaces of these talus-like rhyolite slopes generally contain fewer large blocks than might be expected, such as those seen on the somewhat similar but perhaps younger flows in the Cascades, is not unusual when their lithologic structure is considered. The majority of these rocks are well flow-banded. With but a minor degree of weathering these flow lines become lines of easy cleavage.

[1]Report of Geophysical Laboratory, Carnegie Inst. of Washington, Yearbook No. 38, 1939, pp. 47-8.

Weathering, plus the shifting and differential contacts that would be prevalent in the jumbled and jagged surface of such a mass of rock, has broken down the rhyolite to flat, slabby pieces that in places take on a shaly appearance (Plate 6).

The excellently developed flow lines are perhaps not truly flow lines in the common sense, but could be more fittingly called "stretch lines". At no place has this banding been observed in a horizontal position for any distance. Generally it stands vertically or dips at high angles. The banding is very often twisted, jumbled, and folded into both small and large features. This is especially so over certain areas.

Imagination will not conceive nor permit any method by which a lava could be so highly unoriented in flow banding if this banding was caused by surface flowage. The presumption is that this banding was developed in the supposedly great distance traveled by the magma in reaching the surface. A material perhaps not entirely homogenious, that began its ascension in a wide passage which gradually narrowed as it approached the surface, would undoubtedly develop a series of bands that could perhaps be referred to as "stretch bands or lines" for the sake of differentiation.

Becker recognized this possibility when he said, "When a plastic mass is extruded through a small opening,

whether circular or rectangular, the action is very similar to that involved in drawing a wire, excepting that the external force is a pressure instead of a tension. The friction on the moulding surface delays the motion of the external layers relatively to the internal layers, and so-called fluxion structure results"[1] (Plate 4, Figure 4).

The vertically standing flow lines, as observed on "Round Mountain" where the nearly horizontal columnar structure indicates cooling between vertical walls, lend valuable indications as to the worth of the suggestions just offered.

If this banding was formed previous to the extrusion, then the jumbled and highly folded bands are good proof of a high viscosity which caused the folding and surface fracturing by a simple piling up of the lava after it was extruded.

"Round Mountain" Slide

Certain conditions portrayed in this slide may have some diagnostic value when considering the relative age of the rhyolite or the amount of erosion that has taken place. Therefore, it is described at what may seem unnecessary length.

On the east side of "Round Mountain" is a rhyolite

[1] Becker, G. F., Finite Homogeneous Strain, Flow and Rupture of Rocks, Bull. Geol. Soc. Am., vol. 4, 1893, p. 81.

slide that is recent enough to be dated by the dead trees, not yet entirely decayed. It has an approximate length of 2000 feet and a width of 1000 feet. The surface of the slide is highly undulating. The pattern is of a knob and kettle type, varied by numerous ridges which are generally oriented with their longer axes normal to the directions of movement of the slide (Plate 6, Figure 3).

The kettles or holes vary in depth from about 6 feet to 30 feet measured from a mean base level. Their width varies from 15 feet to approximately 200 feet. The knobs could be considered inverted holes, from both the point of size and shape. Their symmetry is as identical as the eye can discern, and the heights and depths measured from the same mean base line are approximately identical. An area of small kettles contains knobs of a similar dimension. Large knobs are accompanied by large holes. The largest knob, on the "prow" of the slide, exceeds 35 feet in height. The extreme relief when measured to an adjoining large hole would exceed 70 feet.

The ridges, which are at right angles to the slide, average from 5 to 8 feet in height. The distance between crests is approximately two and one-half times the height. Any single ridge is not continuous, but runs out only to be replaced by two more that seem to rise from the adjoining trough areas. The pattern is identical to that formed by waves on a disturbed surface of water when the

PLATE 6

Figure 1

Look across the slide near the back end. Note the dead and the living trees.

Figure 2

Near the front of the slide. A large knob to the left and an equivalent hole in the center.

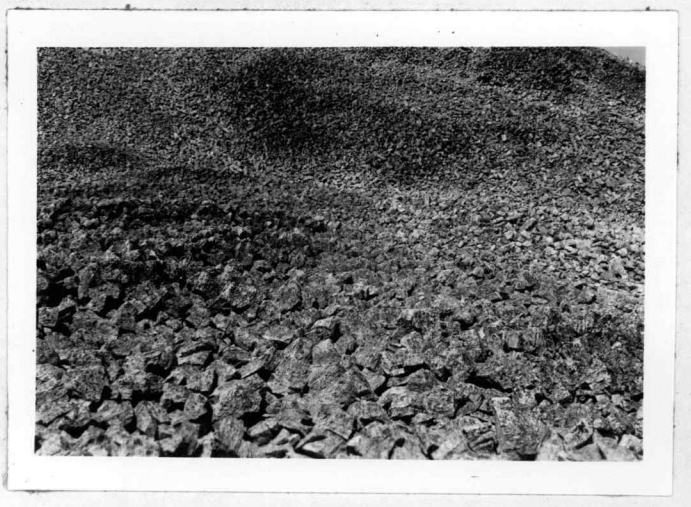


Figure 3

The cross-slide ridges or swells that are a prominent feature.

disturbing agency is beneath the surface and not directed in any particular direction.

Many of the accompanying features point to the relative youthfulness of the slide. Dead trees are to be observed along both sides of the slide and at the head of the cirque, on the comparatively undisturbed surfaces. The cause of their death was undoubtedly the removal of nearby material allowing a local lowering of the ground water table. New trees have since grown up among the dead trees, but it must have required a few years to allow natural grouting of this disturbed material so as to again raise the water table. The living trees have a 6 to 8 inch maximum diameter. Evidence that the dead trees did not die of old age is offered by their variance in size, from 8 inches to 4 feet in diameter. They all appear to be the same specie.

The largest living trees (8 inch diameter) are not over 50 years old. Apparently the hiatus in the tree growth records the date of the slide. Since many of the dead trees are still standing (all show about the same degree of deterioration) the slide must be comparatively young, perhaps 50 and not over 100 years old.

The high degree of instability, even on the comparatively flat surfaces, which makes traversing of the slide rather precarious, also attests its youthfulness. The front end shows a higher degree of stability and more

lichen on the surface rocks. Judging by the ease with which rock movements could be promoted, all but the front end of the slide seem to be still in a state of readjustment or movement. This state is definitely noticeable in the middle section which is flat or nearly flat, if one disregards the undulations. The source end is definitely not stabilized.

The slide came with great velocity in order to carry 2000 feet out (mostly flat) since it possessed a "gravity head" of less than 400 feet. The head of the cirque is less than 200 feet high.

The comparatively steep hill or cliff must have collasped all at once. The movement was probably determined by an earthquake. The inherent cause and also the source of a lubricated plane of movement was undoubtedly a layer of soft, ashy or pumiceous-like underlying material. A slightly indurated ash which could well promote such a movement is seen stratigraphically below the rhyolite along the saddle to the northeast.

Over the edge or break of the bench, columnar jointing can be seen as if in place (Plate 5, Figure 1). These columns have a slight dip westerly into the mountain, while all the columns observed at other places on "Round Mountain" dip fairly steeply in a southeasterly direction. If these westerly-dipping columns were originally oriented the same as the rest, then they could have assumed this

new angle by the entire block being dropped and rotated. Such an action would have created the bench as it is seen at present. This bench has a definitely older surface than the slide, being covered with small erosion fragments and slight soil. Furthermore, the bench surface also shows greater rock weathering than does the top of the mountain, but no greater than the weathering seen on the north slopes of the mountain.

The rock freshness on the rounded top almost suggests a younger rock, but must be attributed to a more effective wind removal of the decomposed material and to a higher degree of coarse mechanical breakdown which effectively hides the chemical effects since no evidence to the contrary was found.

Relief and Erosion of the Rhyolite

The rhyolite flowed out on a surface with a relief very similar to that of the present, although perhaps not quite as much. The majority of the vents were on or near the hills and higher elevations. At the vents the rhyolite built mounds and flowed down into the valleys. The surface of the rhyolite in the valleys was probably not increased any more in elevation than were the mounds from which the lava flowed.

The new drainage followed the partially filled valleys. This allowed the streams to go back to work immediately

and as effectively as if they had spent many years in concentrating their erosive efforts on an otherwise flat terrain. The erosion and down-cutting of these lava-formed valleys was increased by the ash underlying the lavas. Where volcanic ash was not present, the thick arkosic residual deposits from the batholith were effective in providing a means of undersapping and rapid headward erosion.

The questions now remaining are how thick were these flows and how much erosion has since taken place.

The contact profile of the probably minimum area that was covered, or mostly covered, with rhyolite is shown in section 1-2 on plate 8. This profile line follows the outside contact of the rhyolite bodies and takes the shortest distance between such bodies, inclosing all the rhyolite bodies in the area except one small patch 3 miles due north of Red Mountain. Since this patch was off the base map, the profile was carried across on the map and the distance that was altered is indicated by dots and dashes.

This outline section cuts only two deep valleys in its entire circumference. Both of these are young, narrow valleys. Compare this relief with the noticeably greater relief outside the area as shown in Sections I-J and K-L and near the headwaters of Jack Creek. Although not striking, there is obviously a difference.

On these sections the vertical scale is approximately ten times greater than the horizontal scale (except sections M'-N' and O-P where it is five times greater) so as to exaggerate the relief. Comparisons of relief are made in comparable 2-mile sections or less.

A comparison shows that most of the relief inside the area seldom exceeds 700 to 900 feet with much of it around 500 feet. In the adjacent areas reliefs of from 1500 to 1800 feet are found with the most of it around 1000 feet. This shows a difference of about 500 feet in the reliefs of the two areas. In this comparison the two deep valleys in the first section, and a similar proportion of the deepest valleys in the second section are ignored.

In other words this 500 feet is the amount of relief acquired since the rhyolites were layed down. In the time necessary to gain this additional relief the higher rhyolite-covered areas were not cut down as much as the valleys. Also, because of the greater height of the local eruptive vents, a certain amount of this relief was due to them. Exactly how much of the original relief was from this source can not be accurately determined, but in any case it must have been less than at present. The greater it was the more favorable picture it would present for a minimum amount of necessary erosion to reach the present stage. It appears that returning 500 feet of materials to the valleys (with possibly a few exceptions) and not over

100 feet to the higher areas would reestablish the original post-rhyolite topography. (See section M'-N' and O-P; dotted lines represent a probably pre-rhyolite relief.)

The readjustment of streams within the rhyolite area should leave some traceable effects in the adjacent areas that would have values corresponding to the amount of erosion since that time. Sections G-H and Q-R show features that might be considered as two stages of erosion. (Section G-H lies 3 miles east of the northeast corner of the map.) Jack Creek in section Q-R was perhaps pirated at that time, and the present Jack Creek has been enlarged from a side gulley since then. The second stage has cut new valleys from 500 to 600 feet deep in these areas. This stage of erosion conforms in amount with that noticed in the rhyolite areas and also with the amount of difference noted between the rhyolite areas and the adjacent areas.

In view of the material just presented, and since there is a valley between each rhyolite covered area, it is safe to assume that the area indicated was largely covered with rhyolite. Also it seems reasonable to assume that the rhyolite had attained no great thicknesses except in the vicinity of Red Mountain, and that in certain spots the approximate original surface still remains.

Although the various types of evidence just given, such as numerous elevated vents, high viscosity of the

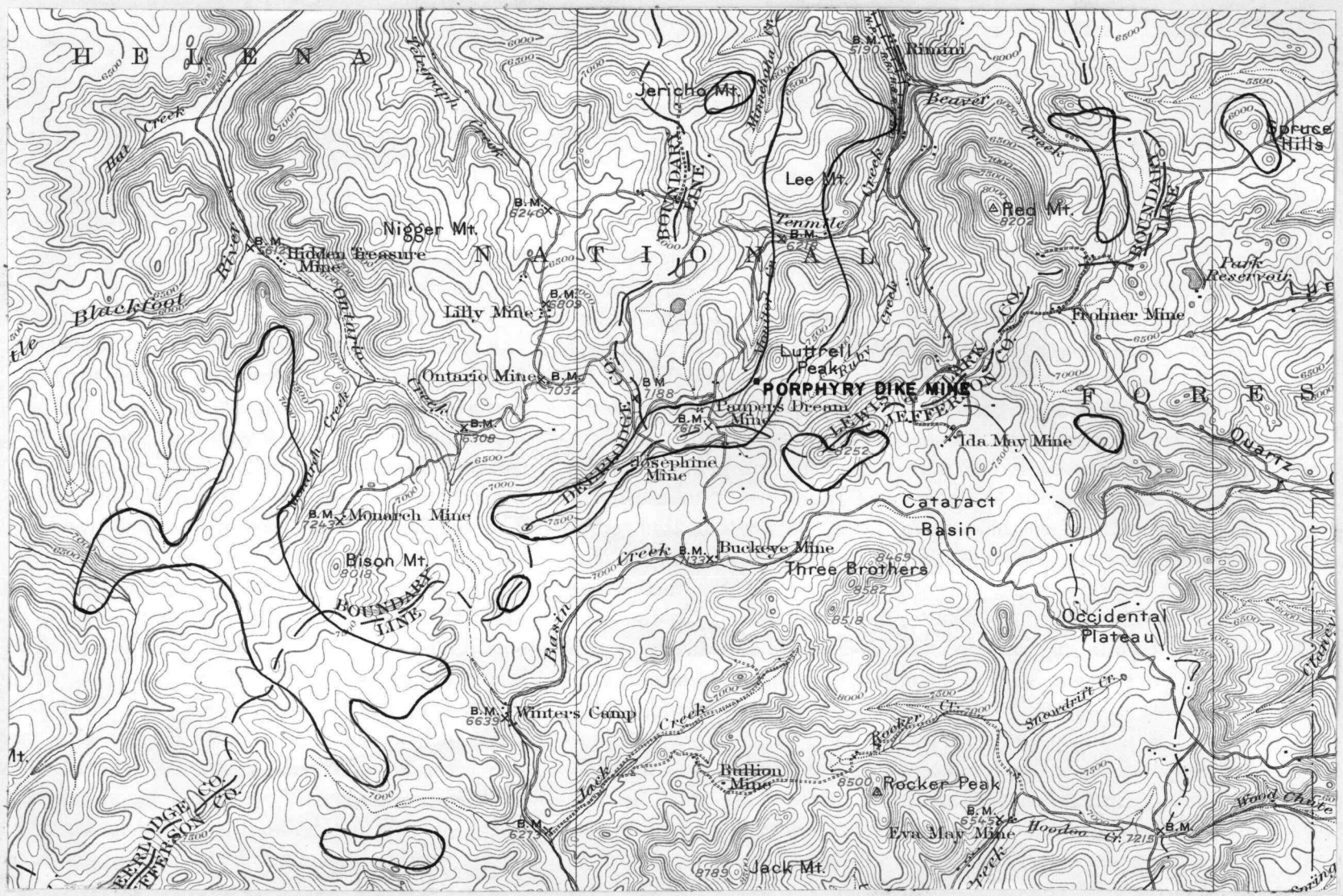
eruptive material, less erosion of the higher areas as shown at Baldy Mountain, and the apparent amount of erosion necessary to reach the present stage does not establish a definite age as relative to time, it does seem to indicate that the rhyolite is younger than has been generally suggested. However, the facts brought forth are vital in determining the relative amount of post-rhyolitic erosion in any part of the area. In order to apply this knowledge to any one definite locality in the area, the local variables such as elevation, amount of remaining rhyolite, and the size and gradient of the nearby streams must also be taken into consideration.

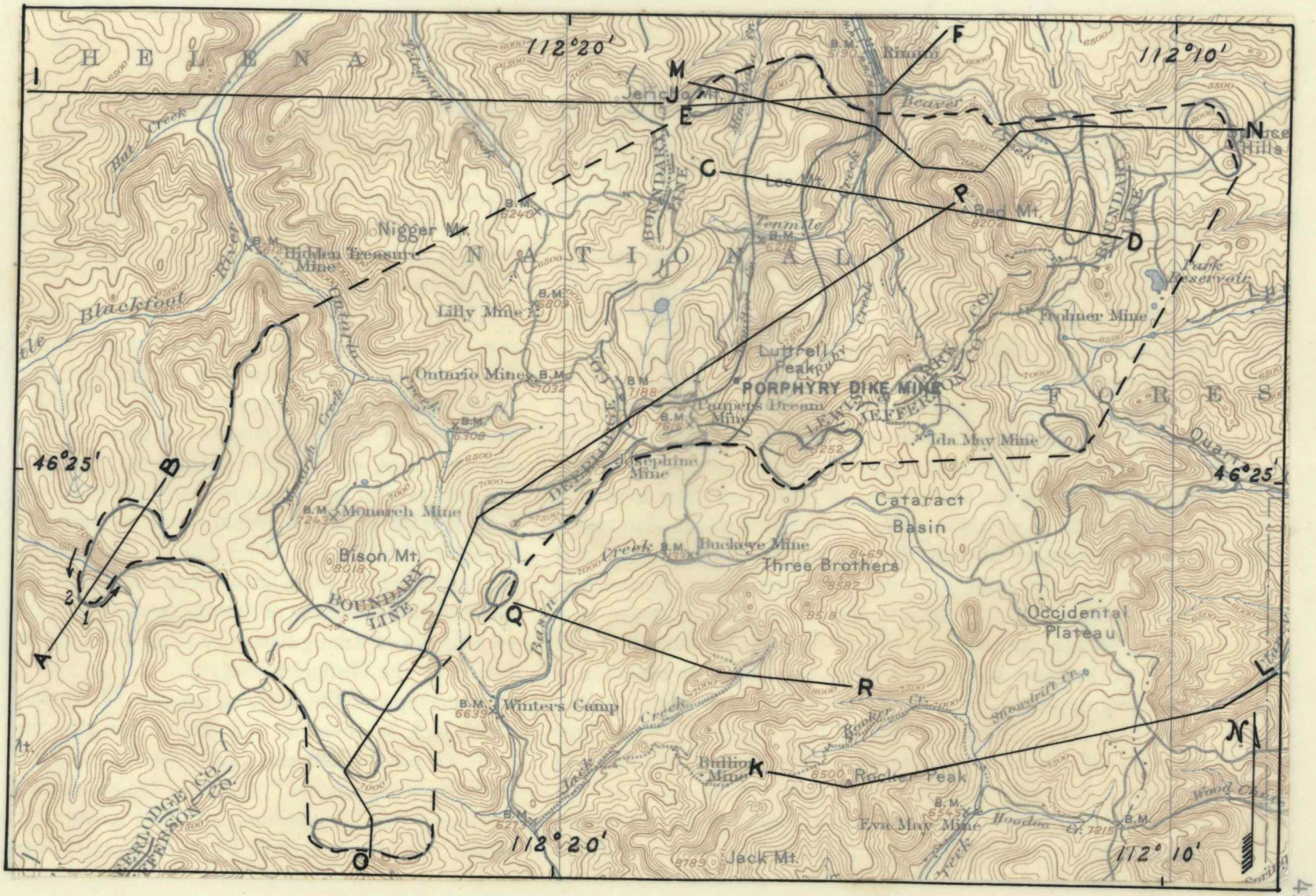
KEY TO MAP OF AREA

The base of the map used on the following page is a part of the Boulder quadrangle topographic sheet issued by the United States Geological Survey. The triangulations are by R. H. Chapman and the topography by W. J. Lloyd and R. H. Chapman. The area was surveyed in 1896-97. The scale is $\frac{1}{250,000}$ with 1 inch equalling approximately 2 miles. The contour interval is 100 feet, and the datum is mean sea level. (Readjustment indicates that elevations on this map should be increased 4 feet). The culture, relief, and drainage are expressed in the conventional signs of the United States Geological Survey.

The mapped rhyolite areas are taken from the "Geologic Map of the Greater Helena Mining District, U. S. Geological Survey, Bulletin 842, Plate 2", with alterations and additions by L. T. Teir.

There are certain mapping facts that might be in error due to the talus slopes and should therefore be called to the attention of anyone who wishes to study the cross sections critically. In section A-B across the Little Blackfoot River and in the section showing the north-south ridge line of Luttrell Peak there is some doubt that the rhyolite extends across beneath the deep valleys.


HELENA
NATIONAL
FOREST
Jericho Mt.
Rimini
Beaver Creek
Spruce Hills
Lee Mt.
Red Mt.
Nigger Mt.
Hidden Treasure Mine
Hat Creek
Blackfoot River
Lilly Mine
Ontario Mine
Ontario Creek
Frohner Mine
Park Reservoir
Luttrell Peak
PORPHYRY DIKE MINE
Tenmile Creek
Tampers Dream Mine
Ida May Mine
Josephine Mine
Dry Gulch
Cataract Basin
Monarch Mine
Monarch Creek
Bison Mt.
Buckeye Mine
Three Brothers
Basin Creek
Occidental Plateau
Winters Camp
Jack Creek
Bullion Mine
Rocker Peak
Rocker Cr.
Moundrift Cr.
Eva May Mine
Hoodoo Cr.
Wood Chute
Jack Mt.
BOUNDARY LINE
LEWIS & CLARK CO.
JEFFERSON CO.
BROADWATER CO.
JEFFERSON CO.
Quarry

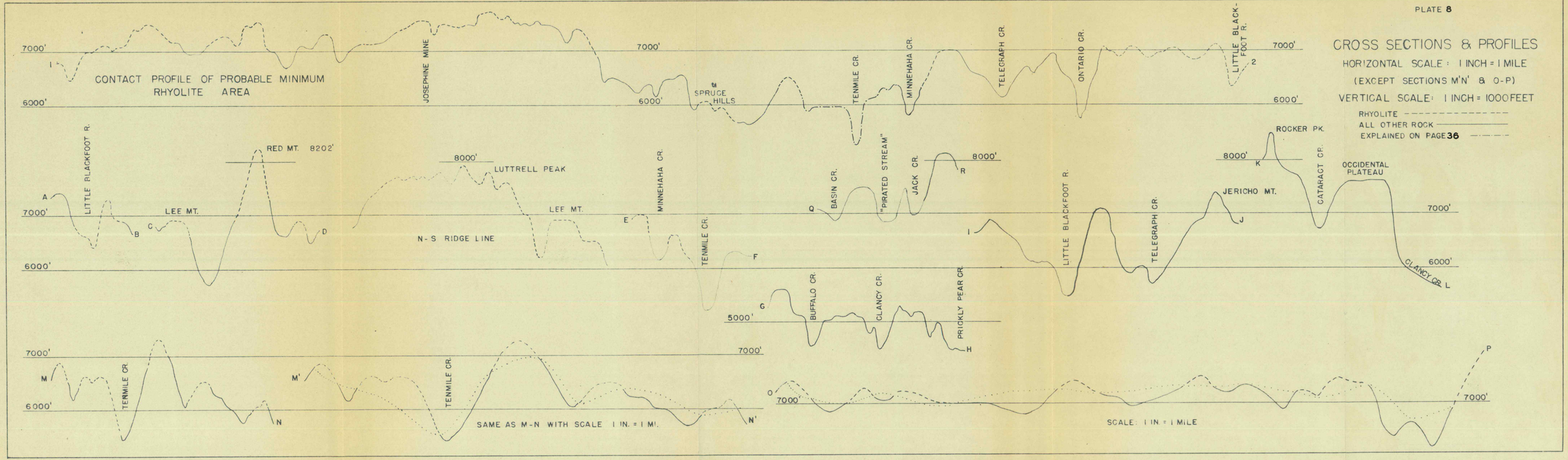


Page 41 with Overlay

CROSS SECTIONS & PROFILES

HORIZONTAL SCALE: 1 INCH = 1 MILE
(EXCEPT SECTIONS M'N' & O-P)
VERTICAL SCALE: 1 INCH = 1000 FEET

RHYOLITE - - - - - - - - - - - - -
ALL OTHER ROCK ————————
EXPLAINED ON PAGE 36 —·—·—



RHYOLITE ORE

The rhyolitic gold ores are very ordinary appearing rhyolites until examined closely, and are either dense lithoidal flows or light-colored consolidated tuffs and tuff-breccias. If appreciable mineralization is present in the dense well-banded flows they may, upon inspection, be recognizable as ores. The most common features to be noted are tiny quartz veinlets generally cutting across the flow banding and slightly wider dark-gray lines paralleling the flow lines. These slightly wider and darker lines are sulphide replacements composed largely or almost wholly of very fine-grained pyrite.

The tuff-breccias are generally not so easily identified as gold ores. Their typical kaolinization may be easily recognized but this is also present in the surrounding unmineralized country rock. The only outstanding feature common to the tuffaceous gold-bearing phases is the rusty seams. Except for the rusty seams this type resembles any other rhyolitic consolidated tuff or tuff-breccia of the area. This statement is equally true microscopically, as thin sections show only considerable sericitiztion and extensive kaolinization in an otherwise ordinary texture.

Because the tuff breccias offered an easy access, equal in all directions, to the mineralizing fluids, the

channels of their movements cannot be easily traced. The opposite is true of the denser, more lithoidal phases where the path of the mineralizing fluids was largely confined to flow planes and fractures. The discussion henceforth will be concerned only with the denser, commonly flow-banded rhyolite ores on which a greater amount of work was done, and from which the conclusions were largely drawn.

The only easily available exposure of this type of rhyolite mineralization is the large mass of material exposed by the open pit workings of the Porphyry Dike mine. The following description will essentially be a description of the mineralization of that part of the Luttrell Peak rhyolites.

The rhyolite ore seems to be much more durable than the other rhyolite and stains rather easily to a yellowish olive-green when exposed to the weather for a short time. The rock itself is commonly of a light greenish-gray color, but varies to a dull white. In general, the light, greenish-gray color is not due to a solid color, but to finely lammellar alternating greenish-gray and dirty-white flow lines. The darker colored rock has proportionately thicker, dark flow lines and thinner, light-gray flow lines. These flow lines are highly variable in direction and often folded. The flow lines dip at fairly high degrees, but a preference for a westerly dip of about 60°

is noticeable.

The major part of the mineralization is dispersed as gray or dark-gray streaks paralleling the flow lines (Plate 9, Figures 1, 2). These streaks are composed of very tiny pyrite grains in replacement deposits. The color of the streaks depends on the intensity of replacement. The lighter colored streaks are composed of not more than one-fourth pyrite and the darker streaks contain one-half or more pyrite. The mineralized streaks that are almost pure pyrite, assume a true metallic luster, but are still rather grayish in color because of the very small individual crystals.

The pyrite bands are commonly about 0.5 to 2 mm. thick, although short bands up to 3 mm. thick are not unusual in the richer specimens. A band is generally at maximum thickness for a distance of 1 to 3 inches and then continues for several inches at the thickness of a single flow line before thickening again. The richest specimens seldom have the pyrite bands more closely spaced than ½ inch apart, although 1½ to 2 inches is a more common distance of separation. Between these rather easily seen mineralized bands the ordinary appearing rhyolite is often seen to carry a sprinkling of very fine sulphides.

Small, disseminated patches of pyrite are scattered throughout the rhyolite. While these often appear to be solid masses, magnification generally shows them to be

PLATE 9

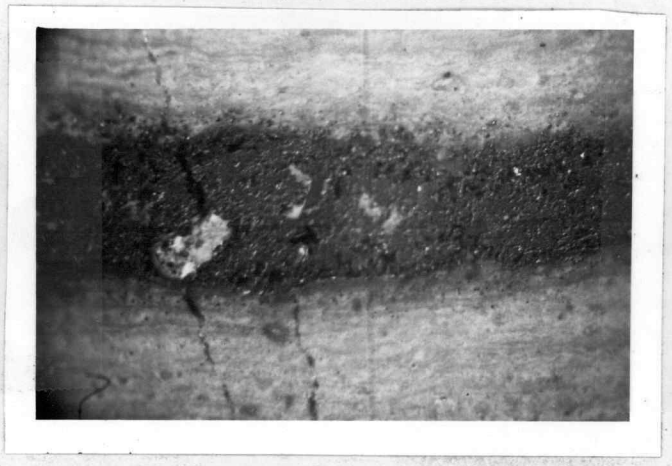


Figure 1 (x 12)

Pyrite has been introduced parallel to the flow lines. This band is almost pure pyrite. The white spots are altered phenocrysts of feldspar. One quartz veinlet is seen distinctly cutting through the pyrite.

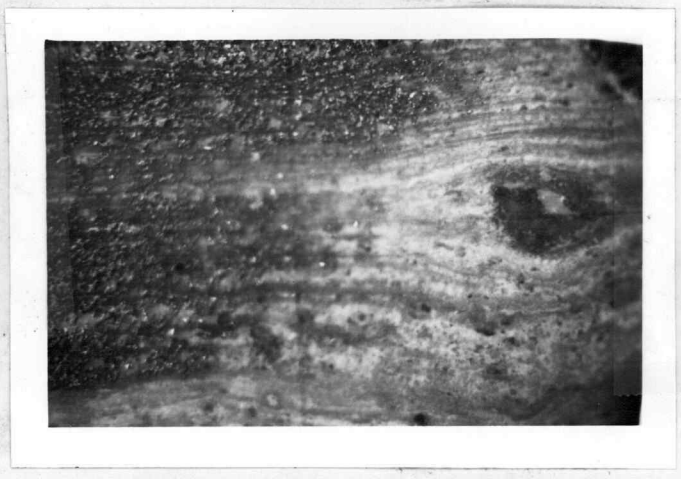


Figure 2 (x 20)

The end of a band of pyrite showing replacement. Note that some flow lines were more easily replaced than others.

composed of numerous very small crystals identical in appearance to the pyrite found along the flow lines. There are a few disseminated, larger single pyrite crystals ranging up to ½ mm. in diameter that can be detected upon careful inspection.

Although the pyrite bands or streaks that are dispersed parallel to the flow lines are spoken of as seen in two dimensions, actually the pyrite mineralization lies in sheets between the flow sheets.

In seeking to prove that the gold values were actually brought in with the pyrite, several pieces of the mineralized rhyolite were split along the pyrite bands. A cold chisel and a small hammer was used to chip away the heavily mineralized layers. The removed material was pulverized and examined under a microscope to estimate the amount of pyrite present. Approximately 40 per cent to 50 percent was pyrite, and the gangue appeared to be almost entirely country rock with some small pieces of quartz. This material gave assays of from .50 to .72 ounces of gold per ton. The adjoining rock having but a very small amount of disseminated pyrite (less than 0.1 per cent) was also assayed with varying results, sometimes a trace; sometimes none.

An attempt was also made to remove and assay the disseminated patches of pyrite, but the small quantity procurable was not sufficient to assure accurate results. A

trace of gold was obtained; but the quantity was so small that accurate calculations were not possible, and also it may have been introduced by other factors. However, as already stated, it is believed that this disseminated pyrite is associated with the flow band deposits because of its similarity in appearance.

It would be impossible to accurately estimate the percentage of pyrite in the ore because of its unusual distribution. Therefore, no safe estimates of total value can be determined from these assays. However, it seems safe to assume that at least a large proportion, and perhaps all of the gold values, are associated with the pyrite. Miscellaneous "grab" specimens of the ore often gave values from .01 to .03 ounces of gold per ton, and selected material gave values up to .10 and .11 ounces. No attempts were made to obtain a true representative value of the entire deposit or of any part of it on a major scale. The assay results offered should not be so construed as their primary purpose was to determine where the gold was, and not necessarily what the commercial values were.

The hydrothermal alteration effects which accompanied the mineralization are neither unusual nor of great intensity. Sericitization and kaolinization with some silicification are present. The sericite is outstandingly noticeable in small cream-colored masses that are scattered

through the rhyolite. Most of these masses have irregular outlines, but several have rectangular or square-like outlines indicating that they may be altered phenocrysts of feldspar. In general, the flow lines pass around them, suggesting that they are phenocrysts which were formed in the magma previous to the flow lines. Microscopically sericite is plentiful in the groundmass and no feldspar remains unaltered.

Kaolinization is not dominant, but was always present in all rock specimens sectioned and may be easily noted by its odor when moistened.

Although the pyrite is mainly confined to certain flow lines the entire rock seems to have undergone varying degrees of silicification. This is evidenced in several ways. The rhyolite ores are more durable than the ordinary flow rock. The rock as a whole is but very slightly altered by weathering, remaining hard and quartzy out to the very edge of the old fractures. In some specimens the distinct flow lines are partly obliterated or end in massive material that appears to be high in quartz. Other specimens show a somewhat churned, structureless complex as if brecciated material had been partially replaced by quartz.

The pyrite bands are cut by minute, glassy quartz veinlets (Plate 9, Figure 1). These veinlets always cut across the flow lines, generally at almost right angles

(Plate 10, Figure 1). They never parallel the flow lines for any appreciable distance. They may make rather small angles with the flow lines for a short distance as in the case of a few veins that form a zigzag pattern. Their thickness ranges from microscopic to 1 mm. Exceptions may attain 2 mm. in thickness. They are generally barren of mineralization, but in rare instances will have a crystal or two of pyrite. Magnification shows an interlacing comb structure in some of the larger veinlets and sometimes an open center space.

There is also a later set of quartz-filled fractures which are often very hard to differentiate from the earlier set except where the two sets happen to cross. These in general also favor cutting across the flow lines, but may also strike parallel to them. They are commonly larger than the earlier set, attaining widths of 8 to 10 mm. Drusy quartz crystals often coat the walls, and there are generally some open spaces in the center. Larger quartz crystals up to 8 to 10 mm. may be found lying parallel in the veins. No sulphide or other mineralization has been found in this later set.

Augen-like structures are fairly common in the rhyolite ore (Plate 10, Figure 2). They are composed of slightly rounded grains of smoky quartz with interstitial kaolinitic material and some sericite. The outlines are often irregular and cornered. The flow lines pass around

PLATE 10

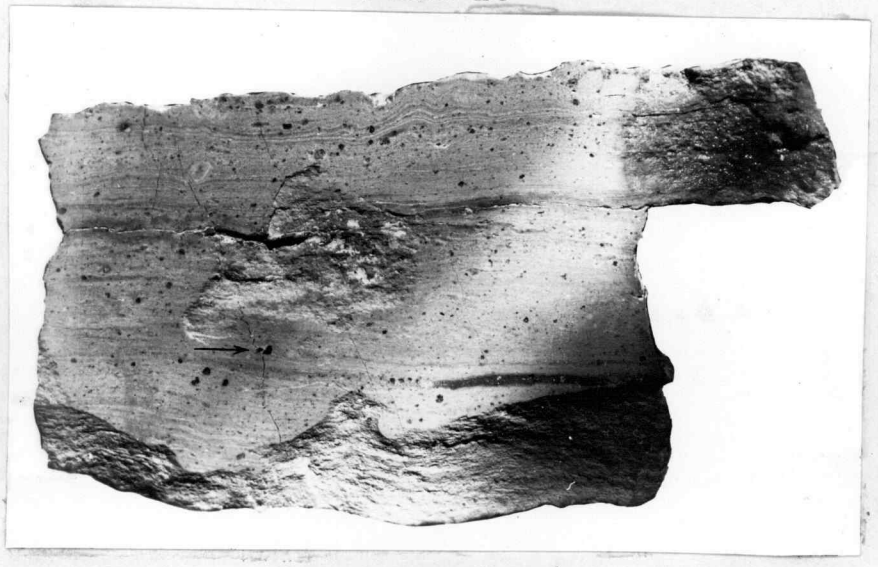


Figure 1 (x 1)

A quartz vein is cutting across the flow banding and is later than the lean pyrite band immediately below the fractured phenocryst. A photomicrograph of this phenocryst is shown on Plate 11.

Figure 2 (x 1)

An augen structure which is believed to be a highly altered inclusion of quartz monzonite. The tail-like appendage is broken off on this piece.

them proving that they are at least previous to the flow lines. Generally one end has a short comet-like appendage of kaolinitic material. The appearance thereby attained is as if a liquid had solidified during its passage around an obstruction and the flow lines had not completely closed in the wake of the obstruction.

The augen structures are quite commonly shot full of coarser pyrite particles similar to the disseminated sulphides. The strung out tail-like part also may carry pyrite. It is believed that these structures represent included fragments of quartz monzonite. The ferro-magnesium constituents have been entirely removed. The feldspars have been altered to kaolinitic material and sericite. The slightly smoky quartz, typical of the quartz monzonite, has remained essentially the same. The pyrite was perhaps more easily deposited in these inclusions because of their slightly more basic content.

In addition to being highly fractured and otherwise folded and distorted, a peculiarity in certain of the smaller folds is noticeable. Small but rather unusual drag folds are to be found. Variable intensities of these drag folds are expressed, and those of slighter movement or of a more gently rounded type would not perhaps be recognized as unusual or due to drag if it were not for the few excellently developed ones that were found. The sketch on Plate 12 (Figure 3) is an illustrative

enlargement and shows most significantly the mechanics involved.

These drag folds indicate slipping along the flowage plane with subsequent folding of the rock on one side of the plane of movement. The fact that there is no apparent present plane of weakness or fracturing along the plane of movement suggests that the magma had not entirely cooled at the time of movement. Nor was this slippage plane sealed by later quartz as the rock texture is homogeneous throughout. It would be difficult to account for the ability of a dense, siliceous type of rock like a rhyolite to respond to either shearing or compressive stresses by folding unless that rock still retained some degree of plasticity. Ordinarily the resulting expressions of such stresses would be planes of shear. Neither is it feasible to appeal to a sufficient overhead load to allow such expression in a completely solidified crystalline rock. This evidence seems sufficient proof that the drag folds were formed before the complete solidification of the rhyolite.

The earlier set of quartz-filled fractures is offset by the movements that took place parallel to the flow lines and created the drag folds (Plate 11, Figure 1). This statement demands that the sulphides were present and that the quartz veinlets were formed before the rhyolite had completely cooled, in fact so shortly afterward that

PLATE 11

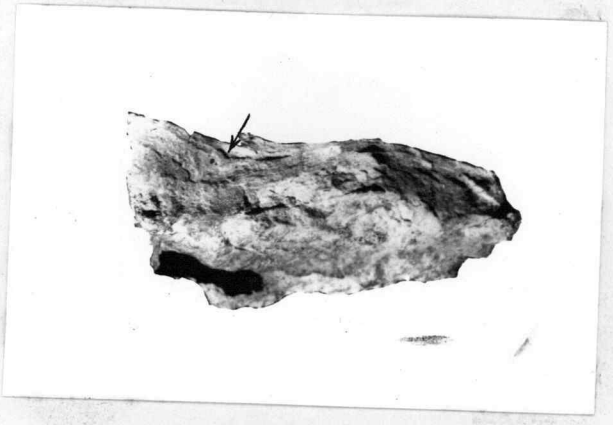


Figure 1 (x 1)

A small inter-flow-line drag fold formed by the movement that displaced the quartz vein in the photograph below. This fold is illustrated in a simplified drawing on Plate 12.

Figure 2

Quartz vein is displaced. Phenocryst is fractured and one piece rotated. A natural size photograph of this is shown on page 51, Figure 1. A diagrammatic illustration to show flow lines is shown on page 56, Figure 2.

they still retained some plasticity. Literature produces at least one somewhat analogous case. Quoting Ries as to the origin of the siliceous ledge deposits of Gold Field, Nevada, he states, "Ransom's theory is that after the dacite had solidified, but not perhaps entirely cooled, the subjection of the rocks to stresses of unknown origin developed a complicated system of fractures. Hot waters --- rose along these fissures;----"[1]

If both of these cases have been correctly analyzed then the elapsing time between the extrusion and fracturing in the two cases need not have differed greatly.

The ideal conditions required for these events to take place would be such that the rhyolites had reached a stage of viscosity where tensile stresses were expressible by fractures yet sufficient plasticity remained for the shearing stresses to be recorded by drag folds. That such a condition could exist is recognizable since a rock fails in tension more easily than under any other type of stress. Nevin says, "The resistance of rocks to shearing couples and rotational shearing stresses is roughly one-tenth that of their resistance to compressive stresses, and about twice that of their resistance to direct tensile stresses. Presumably the tensile elastic limit is reached in ductile

[1] Reis, Heinrich, Economic Geology, 7th Edition, John Wiley & Sons, New York, 1937, p. 605.

PLATE 12

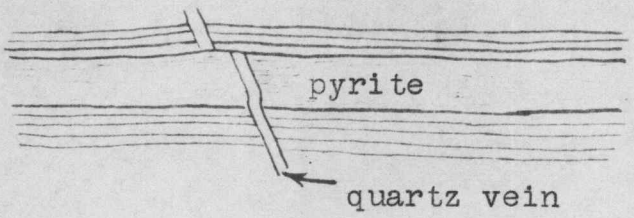


Figure 1

Quartz vein cutting flow plane pyrite. This vein is a continuation of the vein in Figure 2 and shows displacement in the same direction.

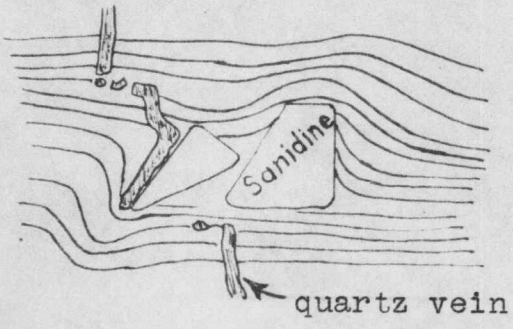


Figure 2

Diagrammatic illustration of displacement of quartz vein and rotation of a part of a phenocryst as shown in photographs on pages 51 and 54.

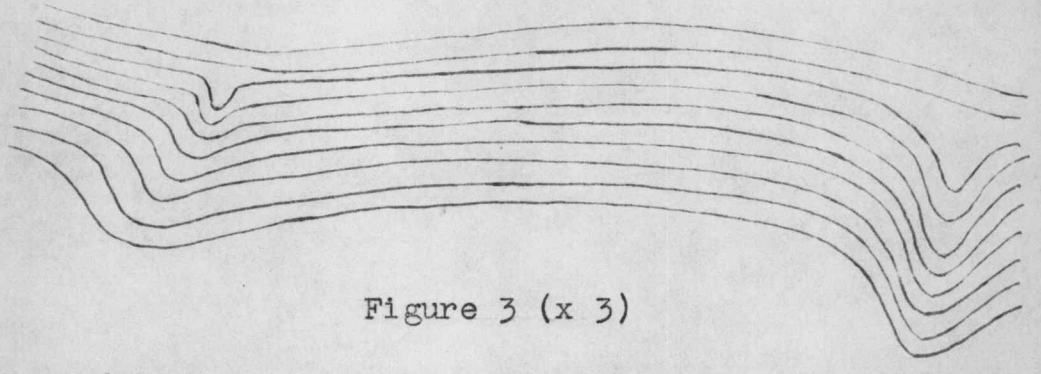


Figure 3 (x 3)

Drag fold formed by the same stress or stresses that displaced the quartz veinlets. The rhyolite still retained some plasticity at this stage. A photograph of this fold is shown on page 54.

materials when the shearing stress on any plane reaches the shearing elastic limit. That is, in ductile materials the failure is in shear rather than in tension, even though the deforming force may be tensile."[1]

Plastic material will flow without showing any other visible indication of failure when subject to shearing stresses as has often been illustrated by drag folds formed in the less competent sedimentary beds involved in larger folds. That a dense crystalline rock might react similarly to stresses when under the influence of a high temperature was suggested by Hawkes[2] in discussing the flow of ice when he said, "The processes by which ice suffers deformation are those which operate in the flow of all crystalline masses. The comparative ease with which it is deformed being an instance of weakness of rocks near their melting temperatures." Should this comparison be thought invalid on the basis that ice flow is assisted by melting and recrystallization then we may quote Beilby[3] who has shown that in the fine polishing of metals and minerals liquification occurs. He concludes, "that molecular flow, which in polishing is a purely surface effect, also takes place at all the internal surfaces at

[1] Nevin, Charles M., Principles of Structural Geology, John Wiley & Sons, New York, 1936, pp. 15-16.
[2] Hawkes, L., Some Notes on the Structure and Flow of Ice, Geol. Mag., vol. 67, 1930, p. 123.
[3] Beilby, G., Aggregation and Flow of Solids, MacMillian Co., New York, 1921, p. 189.

which deformation and slips occur." This seems to be saying that all rock flow is shear. Perhaps it is; Becker says, "Flow is thus continuous shear. The shearing must take place along certain lines, and these must be the lines which are just strained beyond the limit of solidity."[1]

The exact theoretics of flow or drag folding are not important here, and these quotations were drawn upon only to illustrate some possibilities that do exist and to show the practicalness of the observations previously noted.

A brief review of the assembled facts will consolidate the picture.

The rhyolite was extruded upon the granitic surface. Immediately afterwards while the rhyolite was still hot and somewhat plastic, gold-bearing pyrite was introduced. Quartz veinlets that cut the pyrite were formed in the fractures caused by tensile stresses. Rotational or possibly local compressive stresses were exerted causing movements along the flow lines which formed the drag folds and displaced the quartz veinlets. It is also possible that the second set of quartz veinlets were formed at this time. These events all took place in a comparatively short time and very shortly after the rhyolites were expelled.

[1] Becker, G. F., Op. cit., p. 46.

Structural Relations

As previously stated these studies were made from specimens gathered at the pit of the Porphyry Dike mine and in its vicinity; therefore, the following discussion also has to do with this area.

The flow banding is often much twisted and warped. A rather steep to vertical dip of the banding is common, ranging anywhere from 45° to 90°. The western and northwestern sides of the pit show the most consistancy in direction and angle of dip. Here the flow lines dip in a westerly direction at angles varying but slightly from 60°.

The 40 foot wide vertical brecciated zone on the easterly side of the open pit represents a zone of repeated faulting. The movement has taken place along an easterly or slightly south easterly strike. The first movement is registered along the north side of the zone where drag folding indicates that the north block has been dropped with respect to the south block. This movement took place while the rhyolite still retained some plasticity, thereby allowing the drag as shown on Plate 13 to be registered. That this was possible only in a plastic phase of the rhyolite seems evident as sufficient overburden can not be appealed to, to otherwise permit these mechanics. Nevin[1]

[1]Nevin, Charles M., Op. cit., pp. 142-3.

PLATE 13

Drag formed by the first movements along the easterly striking fault as seen on the east side of the Porphyry Dike pit. This took place while the rhyolite still retained some plasticity. Later movements are expressed in shear. The block on the north (left) side has dropped in relative position.

says, "However, if rocks are not very brittle, or if the overburden is large (the overburden could not have been large), readjustments may occur in a local zone bordering the fault by plastic distortion and bending, even though the major deformation along the fault itself is a true shear.---- It is very possible that a considerable portion of the dragging occurs during accumulation of the strain, rather than at the time of slip along the fault surface."

It was during this time of accumulation of strain that the inter-flow-line dragging was accomplished which has enabled the exact time determination of the mineralization. The varied orientation of the flow banding permitted certain areas to be oriented so as to best register this strain in the minute drag folds along the flow lines.

Later movements along the same zone after the rhyolite had reached a greater degree of solidification has caused the 40 to 50 feet of brecciated material.

This entire zone seems to carry more mineralization than does the adjoining rock. Since a greater part of the mineralization and perhaps all of the mineralization preceded these movements, it is believed that the conditions that predetermined the location of the faulting were also favorable for the upward movement of the mineralizing solutions. Then again it is possible that the first slight strains expressed in this area preceded the mineralization and created conditions favorable for the movement of the

mineralizers, but were not of sufficient magnitude to be registered, or if registered, were of such a general nature that their significance was lost in the already jumbled flow lines.

Two northerly striking high angle, clean-cut planes of shear, varying about 35° in direction, are traceable on the face of the pit. These planes cut across the major faulted zone. They perhaps do not mark the exact line of faulting, but are merely planes of sympathetic shear as they seem to show very little movement.

Many of the fracture planes of this brecciated zone are stained with limonite and a little manganese oxide. Along the south side of the brecciated zone, a 2 inch limonitic vein material bordering fault gouge gave only a trace of gold. On the other hand a similar appearing gossan-like material that fills a fracture in chalky-appearing massive rhyolite on the west side gave assays exceeding $3 per ton. It is believed that these values are due to secondard mechanical and chemical enrichment caused by the downward moving atmospheric waters.

PROPERTIES AND MINES OF THE AREA

Brief descriptions of other properties in the area and such material on the Porphyry Dike mine that is not given elsewhere are included below. Practically every patch of rhyolite in the area has been staked and prospected at some time or other in the past and much of that around Luttrell Peak is patented. Most of these rhyolite claims were perhaps founded on hope rather than on knowledge or observation. Of these, other than the Porphry Dike and the Pauper's Dream, the only one worthy of mention is the so-called "M and M" property. This is located on the south end of Baldy Mountain. The tunnels and shafts are all caved and inaccessible. The material on the dump shows some mineralization which is very much like that of the Porphyry Dike mine.

Porphyry Dike Mine

The Porphyry Dike mine is located on the west side of Luttrell Peak at an elevation of about 7,500 feet. The mine is now inoperative although the mill still remains on the property.

The sketch on Plate 14 was drawn from the description given by a miner who has been in the last tunnel many times. Knopf[1] states a 1400 foot tunnel was driven approximately

[1]Knopf, Adolph, Op. cit., p. 85.

125 feet below the pit. The first tunnel started was entirely in quartz monzonite and therefore evidently too low, so a second tunnel was started. The portals of the second tunnel are in quartz monzonite and thereafter encounter it only as if in waves. At present the tunnel is not open except for a short distance.

Pauper's Dream

The location of the Pauper's Dream Mining and Milling Company's activities lies about 3000 feet southwest of the Porphyry Dike mine at an elevation of about 7000 feet. It consists of two pits and 500 or 600 feet of tunnels and drifts. No recent operations have taken place and no equipment remains on the property.

The excavations and the drifts are in massive, blocky rhyolite tuff-breccia that shows little or no crushing as is evident at the Porphyry Dike pit. The drifts which appear to be merely prospects have apparently been driven along zones of rusty seams. Ore from these workings is said to have yielded $2 a ton.[1] Assays by the author on "grab" specimens indicate a concentration of gold in the rusty areas. The rusty seams were chipped away from the country rock and both materials assayed under carefully controlled conditions. The rusty areas assayed

[1]Pardee, J. T., and Schrader, F. C., Op. cit., p. 260.

approximately $.50 in gold and the adjoining rock produced only a neligible trace. While "grab" specimens can't be used for true-value assays the relative difference observed in the rusty seams and the adjoining rock can be accepted as an indication of the existance of a difference of gold content.

The May Lillie Mine

The May Lillie mine is located at an approximate elevation of 8000 feet on the west edge of the flat top of Baldy Mountain. Rhyolite flows which lie below the edge of the table-topped mountain are within 100 feet of the west shaft, hence the area seemed critical. The property was examined with a view as to what light it could cast upon the rhyolite mineralization. All the workings are in quartz monzonite from the surface down. In the rhyolite talus a short distance to the north, much bluish-gray quartz float was found which is identical to the ore exposed in the upper 50 feet of the mine. One piece of float was found that had rhyolite wall rock attached.

The specimen, when ground at right angles to the contact, exposed in the rhyolite an inclusion of the bluish quartz ore 1.2 cm. away from the contact (Plate 14, Figure 1). No quartz veining or other channels were present to suggest other means of transportation.

Thin-section and polished-section examinations of the

PLATE 14

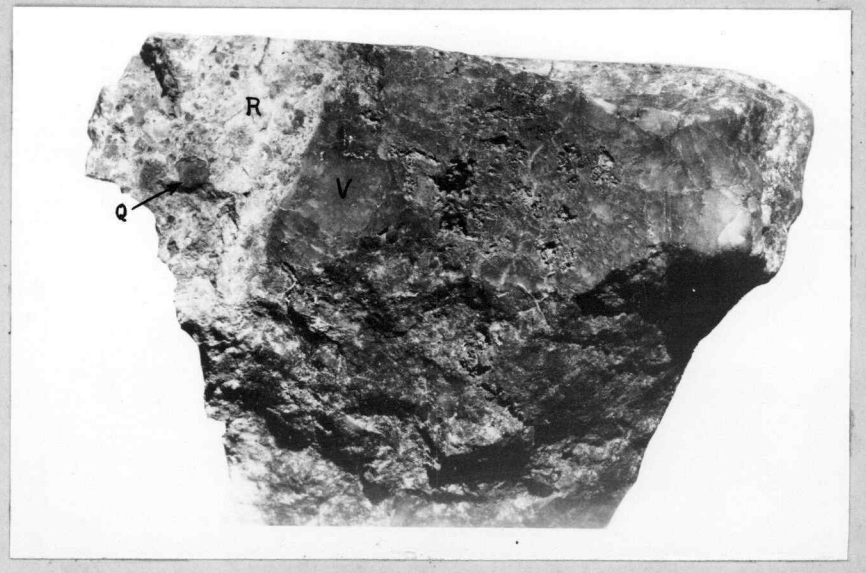


Figure 1

Piece of float from talus slope near the May Lillie mine which shows an inclusion of blue quartz ore (Q) in rhyolite (R) that has flowed against the more resistant "reef" of blue quartz ore (V).

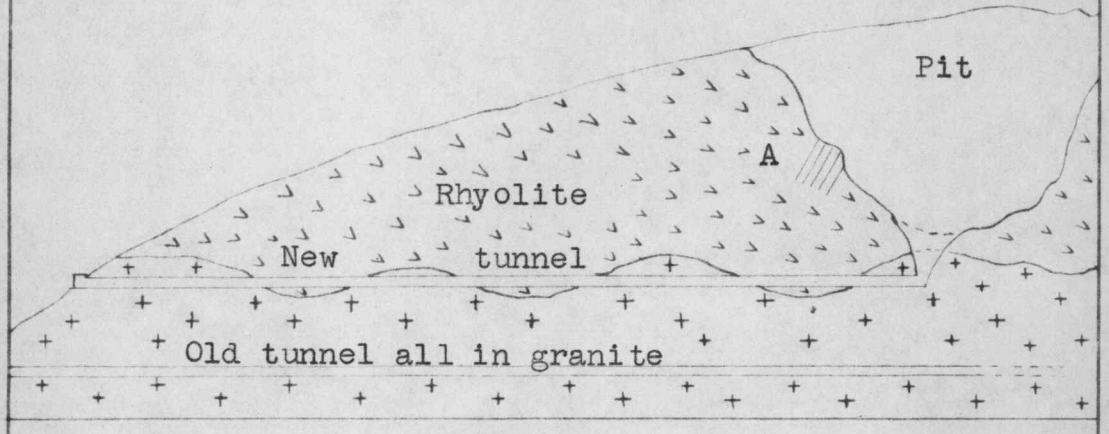


Figure 2

Diagrammatic illustration of the Porphyry Dike open pit mining operations. Lines at (A) show the attitude of the most constant dip as seen along the west side of the pit. Tunnels drawn from description by local miner.

rhyolite and quartz contact showed the rhyolite to be finer grained and denser next to the quartz. The rhyolite had flowed against an irregular quartz surface filling the embayments and penetrating small fractures. Megascopically this fracture penetration is discernable on polished sections as limonite stained, small, crooked apophyses ranging from .5 to 2 cm. in length.

This evidence indicates that the rhyolite flowed against a more resistant outcropping reef or boulders of quartz ore. In either event the mineralization is pre-rhyolitic in age.

The only other conclusion that might be drawn from this area is highly hypothetical. The nearby small rhyolite flow seems to have been extruded from a fracture, that roughly parallels the three veins of the May Lillie mine. Since this flow assays approximately $1.50[1], it might be expected that possible enrichment could have taken place at depth in the nearby and undoubtedly related fractures that form the veins of the May Lillie mine.

The Josephine Mine

The Josephine mine is located about 2 miles southwest of the Porphyry Dike mine. The property is abandoned, the machinery removed, and much of the workings are caved.

[1] Mannuel, E., Basin, Montana, Oral Communication.

This mine was of interest to this paper only to such an extent as it was related to epithermal rhyolite mineralization.

Some of the ore greatly resembled the bluish-gray quartz ore in the May Lillie. Much of the ore appeared to be dark-gray and black quartz. A piece of this black quartz was thin-sectioned and found to be well filled by acicular tourmaline crystals in radiating groups. Samples taken from a surface cut on what was apparently one of the main veins, proved to be a highly altered country rock with numerous sulphide disseminations surrounded by reddish iron oxide halos.

The wall rock in the lowest drift has suffered much hydrothermal alteration at the portals and in for the 100 feet of accessible tunnel. A hand specimen examination of this rock showed much resemblance to the wall rock from the May Lillie mine, which can be definitely proven a quartz monzonite by following it outward to a less altered and more recognizable phase. Thin sections of the two specimens showed a similar mineral content (mainly quartz and sericite) and great similarity in texture and granularity. The rock with the haloed sulphides appeared very similar in a thin section study to the altered quartz monzonite. To further check these specimens they were compared under the microscope with unaltered quartz monzonite for granularity and general texture and were found to be

identical.

Apparently the Josephine as well as the May Lillie mineralization is pre-rhyolitic in age. No data or assays were obtained on the Josephine ore, but both of these mines could perhaps have been enriched by gold bearing solutions related to the rhyolite because of their proximity and the common practice of later solutions often seeking the same channels as the earlier ones.

APPENDIX

APPENDIX

LITHOPHYSAE

The lithophysae were studied in an attempt to determine what their relation might be to the mineralization. No relationship was recognized, but as they are a common constituent of much of this rhyolite and also show definite evidence of the mechanics of their origin, a general physical description is included in this appendix.

Description

There are three main locations in which lithophysae are found more or less abundantly in the Porphyry Dike area. The largest and best preserved specimens come from the north slopes of "Round Mountain". A smaller, more variable, but perhaps more numerous type is found on Luttrell Peak near the open pit of the Porphyry Dike mine. On the southwest slopes of Baldy Mountain a type similar to those of Luttrell Peak is to be found but in lesser quantities and varieties.

The shapes of these lithophysae are best observed in weathered-out specimens. Their shapes are not due to the spherical growth of crystals, nor does any theory known to the writer adequately explain their origin. They are due to an outward impregnation of an endurating solution which

spread from a centrally located point along a favored flow line into common flow-banded rhyolite.

Very few of these lithophysae attain perfect spherical shapes. The smaller ones approach more closely to perfect spheres than do the larger specimens, but an oblate ellipsoid is the most common shape. Oblate spheroids are also quite numerous, while elongated loaf-shaped structures are comparatively rare. In a majority of specimens, especially the larger ones, one side is always more or less flattened.

The specimens from "Round Mountain" always show a concentrically striated exterior (Plate 15, Figure 1). Many of those from Luttrell Peak lack these narrow encircling ridges. Specimens from both areas favor a slightly keeled equatorial zone, but the keel or belt is more pronounced in the smaller and rounder varieties, especially those from Luttrell Peak.

The larger specimens often have a smaller parasitic lithophysae attached and slightly buried in the surface, generally on the rounded side, very seldom on the flattened side. The parasitic lithophysae are commonly much smaller but sometimes attain equality in size to the host. An intergrowth of equal-sized specimens is more common among the smaller sizes.

Their size is highly variable, as they range from giants, 14 and 15 cm. in diameter, to tiny, pinhead sizes. Undoubtedly even larger specimens could be found, but the

PLATE 15

Figure 1

The large specimen is from "Round Mountain". The smaller specimens are from Luttrell Peak.

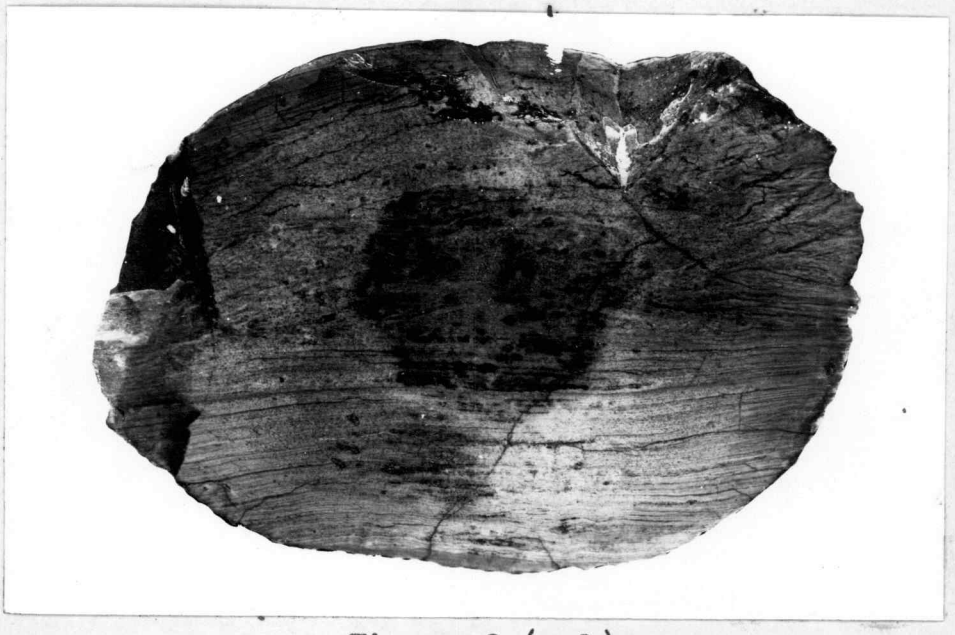


Figure 2 (x 1)

A "Round Mountain" specimen showing flow lines passing directly through. The more siliceous center in this specimen has a purplish color.

very large ones are generally fractured or broken when found. Pieces were found that must have been broken from specimens larger than 1 foot in diameter.

The exterior color is commonly a light greenish-gray. This color is unanimously present in all the specimens from "Round Mountain". Specimens from Luttrell Peak range in exterior color from the common greenish-gray to a bleached buff which is slightly discolored by limonite stain. The lighter colored specimens are covered by a thin veneer of fairly soft kaolinized material and lack the prominent outside concentric striations of the darker specimens.

Phenocrysts are studded in the outside surfaces of the specimens from both type localities and are common to all varieties. They appear to favor the Luttrell Peak specimens slightly in abundance. It is megascopically difficult to ascertain whether sanidine or quartz is more common, but both are represented. Only those quartz phenocrysts which are of a slightly smokey hue can be positively identified as such without resorting to optical means or careful removal.

A more solid internal structure is common of the lithophysae from the "Round Mountain" area. In these the relation of the matrix to the lithophysae also is best shown. These specimens have the best developed internal flow lines. The internal flow lines are continuations of

the flow lines in the rhyolite matrix. Approximately 40 percent of the "Round Mountain" specimens have flow lines that pass straight through the lithophysae without any doming, and are entirely without central cavities (Plate 15, Figure 2). The remainder have a central interior doming of the flow lines. The majority of these have but a slight lenticular cavity, the diameter of which is approximately one-half of the diameter of the specimen involved. The thickness of the lenticular cavity in the average domed specimen ranges from 1/10 to 1/5 the distance across the cavity. A very few from this locality have excessively rounded interior cavities such as in comparatively common in the specimens from the Luttrell Peak area.

The internal structures of the specimens from the Luttrell Peak locality are more variable. The strength, consistancy, and direction of flow lines show a greater range of variation. The cavities vary in size, orientation and outline. Not a single specimen was found in this area which did not have at least a slight doming of flow lines. That is, every specimen has a cavity, although the cavity, especially if of the smaller more lenticular type, is often filled solidly with quartz crystals. These crystals are sometimes packed so solidly as to practically lose their individual identity.

In perhaps half of the Luttrell Peak variety the flow lines are merely domed to compensate for the cavity. In

others they are warped and folded. Oftentimes this folding seems to be in excess of that displayed by the matrix. In still others, flow lines which are essentially parallel on both sides are swelled in part and in part compressed in the interior. Also more than one cavity is common. Several specimens have as many as three. These may be directly aligned above each other, or displaced. The dual cavities seem to be primarily confined to those which appear to be the intergrowth of two or three very close specimens which have later assumed the general outline of one individual.

Lithophysae from both type localities show, in rare instances, what appears to be a higher degree of silicification or a later replacement. The flow lines remain distinct near the edges but fade out and sometimes entirely disappear near the center. In the case of the "Round Mountain" specimens this material is a light reddish brown color. The lighter colored interior flow lines seem to have given place to this light brownish color more easily than the darker colored lines. In no single case had it altered the color so completely to the edges that the outside color was materially changed. The texture remains essentially the same. The greater, centrally interior alteration in the Luttrell Peak specimens was essentially the same, except that the color was a light milky-gray. The loaf structures mentioned show this higher degree of

silicification the most. One has a core that is composed of glassy almost transparent quartz. This core grades into the normal appearing walls by such slow degrees as to obviate the belief that it was only a cavity filling.

About one-tenth of the Luttrell Peak specimens have all semblance of flow lines obliterated and exhibit only what appears like concentric rings in a cross-section. Actually they are repeated spheres as if several hollow rubber balls were built, each outside the last. This type when broken and much weathered presents a typical, textbook rose-petal structure (Plate 16, Figure 2). Without an intermediate or connecting variety, that is fortunately present, these would appear to bear no relationship to the more common varieties. Several excellent specimens show both the repeated sphere structure and the flow lines, which intersect and cross each other (Plate 16, Figure 1).

The "rose petal" type is comparatively frail. Many have open spaces edged with quartz crystals which partly conform to the spherical pattern, being bridged here and there. These concentric cavities are also somewhat limonite stained and in part contain kaolinitic material. This makes the cavities appear as if they are definitely secondary or of later origin by weathering.

The true central cavities, as expressed by flat lenses in the "Round Mountain" variety and the variable shaped openings of the Luttrell Peak forms, have essentially two

PLATE 16

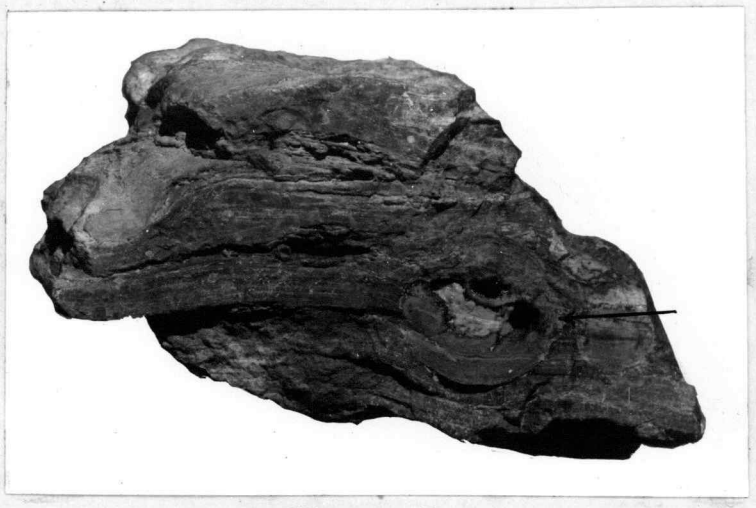


Figure 1

A transition stage between the ordinary lithophysae and the "rose petal" varieties is shown here. Arrow indicates the beginning of concentric rings that pass through the flow lines just above it.

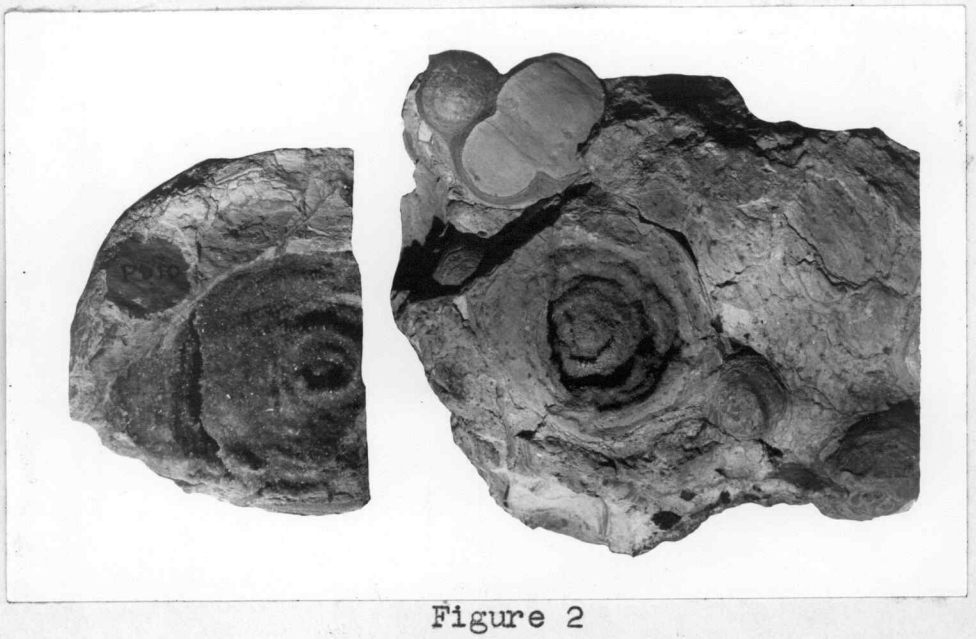


Figure 2

Two "rose petal" types showing the remaining sphericals shells coated with ferruginous quartz crystals.

types of filling or lining. A lining of the walls of the cavity is more common than a complete filling of the void. In the "Round Mountain" specimens the cavity-occupying material is entirely of chalcedonic or opal-like silica, commonly milky white. No crystalline outlines or faces are observable. The surface of the material might be described as "semi-botryoidal", as the rounded prominences are low and flat. Several from this area also have tabular plates or floors of a chalcedonic material. The plates are as much as ½ inch thick and often variegated or of a banded onyx-like structure. The bands vary from milky-white to shades of medium-brown or reddish-brown.

The orientation of these plates indicates that the flow lines were dipping at angles generally greater than 45° at the time of their formation. One specimen has two plates with a difference in orientation of approximately 30°. The position of repose of this specimen, and we must infer its now lost matrix, was suddenly altered during the deposition of the chalcedonic filling.

The highly variable shaped cavities observed in the Luttrell Peak lithophysae never carry chalcedonic quartz. These always have clean-cut quartz crystals lining the openings. The crystals show even and symmetrical development in the majority of cases. Most of the quartz crystals are clear and transparent but some have a deep, brilliant brown ferruginous color. The ferruginous quartz crystals

are always smaller and also seem limited to the smaller specimens. These cavities also have been found containing kaolinitic material. In some specimens the less resistant, lighter-colored flow lines seem to have suffered weathering and subsequent removal, thereby exhibiting a porosity such as is common to well weathered surface rhyolites.

Relation of Flow Lines to Lithophysae

The relation of the flow lines in the rhyolite matrix to the lithophysae is best shown in the specimens from the "Round Mountain" area. A similar relationship is exhibited by the specimens from Luttrell Peak but to a much smaller degree.

As previously stated the flow lines of the matrix invariable pass directly through the lithophysae. Even in those with excessive compensation for a large cavity, the lines resume their proper places upon exit. The compensation or doming is almost always entirely accounted for inside the lithophysae, if not always. The few that appear to be exceptions generally exhibit a wavy phase of flowage thereby practically eliminating them consideration.

The flow lines themselves, in all rhyolite that exhibits good flowage structure, are a repetition of very light gray and greenish-gray lines. In the average rock each line is generally less than 1 mm. thick. Either color may be thicker; the resistance to weathering as well

as the color of the rock seemingly is governed by whichever type predominates.

A thicker flow line of the greenish-gray variety almost invariably forms a plane through the centers of the lithophysae at the equatorial zone, or zone of greatest circumference. This fact can be seen in all specimens from the "Round Mountain" location and is noticeable in a majority of the others.

In case of the larger well developed adjoining specimens they seem to invariably have sought common levels for their equatorial belts. Apparently their sources of material were from the same zone.

The color assumed inside the lithophysae by the previously lighter colored lines approximates the color of the darker lines of the matrix. The originally greenish-gray lines are also slightly darker inside the specimens, thereby preserving the flowage appearance throughout. The color of the lithophysae as a whole is therefore almost identical to that of the greenish-gray flow lines.

Not only is there a great similarity in color, there is also much similarity of both the greenish-gray flow lines and the lithophysae in their ability to resist erosion by weathering. (These resistive flow lines also seem to account for the unusual fragmental shapes of the "pseudo-wood" rhyolite by exercising a certain control of the direction of variation of necessary breaking stresses

through selective weathering.)

The encircling ridges, typical of the "Round Mountain" specimens and common to all, are an outward expression of the comparatively more resistant darker internal flow lines. Examination of these ridges in association with the internal flow lines offered a method whereby the approximate amount of internal doming could be estimated. When these ridges continue toward the top and the bottom as if the object was built up with properly decreasing sizes of coins from a center both ways, there is very little or no doming of flow lines. If the "coins" failed to decrease sufficiently fast and the last pole-ward "coins" were rather large and slightly convex then the interior may be expected to have well domed flow lines.

Time Relationship

The lithophysae are definitely later than the flow lines as the flow lines pass uninterruptedly through them. That they were formed while the lava was still plastic seems most reasonable as the specimens with domed flow lines show no fracturing. An examination of many specimens demands the belief that the indurating materials spread spherically from a central point on a certain flow line that acted as a feeder. It seems entirely possible that the last active stages of the magmatic material caused the introduction of the required solutions.

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