GEOLOGY AND QUICKSILVER DEPOSITS OF THE COSO HOT SPRINGS AREA INYO COUNTY, CALIFORNIA

by

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Requirements for the Degree of Master of Science

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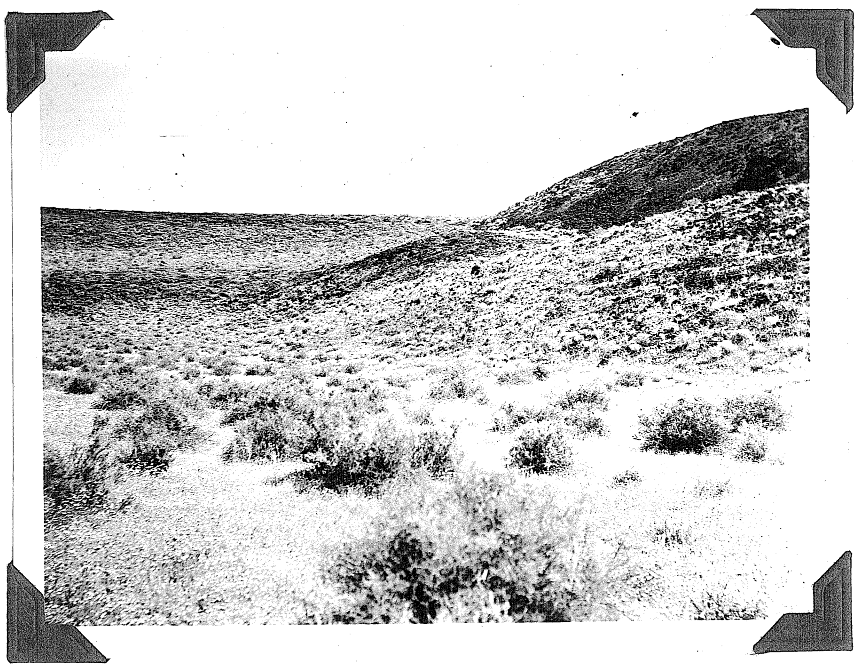
A



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GEOLOGY AND QUICKSILVER DEPOSITS
OF THE COSO HOT SPRINGS AREA

Introduction

This thesis presents the results of a geological examination of the Coso Hot Springs region, including a discussion of the areal geology and a description of the hot springs and mercury deposits in the area.

The thesis is presented as a partial fulfillment of the requirements for the degree of Master of Science at the California Institute of Technology. The field work on which the report is based covered parts of the academic year of 1938-39. A topographic map of the area was prepared by means of a plane-table survey. The geologic features were mapped with the use of a plane-table and a Brunton compass.

Early reconnaissance work was done in the Coso Mountains by H. W. Fairbanks[1], G. K. Gilbert[2],

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1. H. W. Fairbanks, The Mineral Deposits of Eastern California, Amer. Geologist, Vol. XVII, pp. 144-158, 1896. Geology of California, Amer. Geol., Vol. XVII, pp. 63-76, 1896.
2. G. K. Gilbert, U. S. G. S., West of One Hundredth Meridian, Vol. III, p. 124.

J. E. Spurr[1], and J. R. Schultz[2]. The mercury deposits

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1. J. E. Spurr, Descriptive Geology of Nevada South of the Fortieth Parallel and Adjacent Portions of California, U. S. G. S. Bull. 208, 1903.
2. J. R. Schultz, A Late Cenozoic Vertebrate Fauna from the Coso Mountains, Inyo County, California; Carnegie Inst. of Wash. Publication #487, pp. 75-109, 1937.

Appreciation is expressed to Dr. J. H. Fraser of the California Institute of Technology for critical reading of the manuscript, and to Dr. Fraser and Mr. R. M. Dreyer for helpful suggestions in the field work. It is a pleasure to acknowledge the hospitality of Mr. M. U. Daly and to thank Mr. Daly and the owners of the Coso Mercury Mine for access to their properties.

GEOGRAPHY

LOCATION

The area under investigation is in the southwest corner of the Ballarat quadrangle, Inyo County, California. It can be reached over either of two graded gravel roads which run easterly from U. S. Interstate Highway #6. The Coso Hot Springs lie within the Coso Basin in the Coso Mountain Range, about ten miles east of Coso Junction, a station on the Southern Pacific Railroad in Owen's Valley. The area described in detail is approximately one by two miles in extent and extends in a southwesterly direction from Coso Hot Springs.

The mercury deposits in the region are designated by the terms "Devil's Kitchen", "Basin deposit", and "Coso Basin deposit." Devil's Kitchen is in the southwest corner of the map area. The Basin deposit lies on both sides of the main road through the area and approximately 2000 feet east of Devil's Kitchen. The Coso Basin deposit is about two miles south of Coso Hot Springs and outside of the map area.

ELEVATION AND RELIEF

The Coso Mountains are in the basin and range province. The elevation of the block varies from an average of 3700 feet in Owen's Valley to a maximum of 8156 feet at the summit of Coso Peak. The elevation of the map area varies from a minimum of 3635 feet at Coso Hot Springs to a maximum of about 4700 feet.

The relief is not extreme. Although slopes of the mountains and canyons in the eastern half of the area are steep, in the western part the slopes are moderate and a rolling topography prevails. Partly dissected volcanic cones are numerous to the west of the map area.

CLIMATE

The Coso Mountains are cut off from the supply of moisture on the east and south by long stretches of desert, and on the west by the high mountains of the Sierra Nevada with the result that desert conditions prevail in this region. The annual precipitation varies from less than two inches in dry years to ten inches in wet years. Precipitation, concentrated mainly between December to March, usually occurs as snowfall with occasional cloudbursts. The humidity is characteristically very low during most of the year. The temperature ranges from about 10° Fahrenheit in the winter to 100° Fahrenheit during the summer months. The winds are variable in direction and usually quite strong.

DRAINAGE

The area drains to the eastward into the valley around Coso Hot Springs and thence southward to Indian Wells Valley. A few small interior drainage basins remain but these are being cut into by the drainage to the east. The streams are all of the intermittent type.

VEGETATION

Vegetation is sparse and the flora is typical of the desert. Sage and creosote are the most common shrubs but small cacti and other desert plants are numerous. Joshua trees are present but not abundant, while pine forests grow in the higher parts of the range to the north.

ROCK EXPOSURES

The rock exposures are typical of the desert country. The surface is usually covered with boulders, and contacts and contact relations are obscured. The only bedrock outcrops are in the steep canyons where the rock has been laid bare by actively cutting streams.

GENERAL GEOLOGY

The central portion of the Coso Mountains consists of granite and gneissoidal rocks. In the area studied the core of the range is a coarse, easily decomposed rock with the composition of a true granite. According to Fairbanks[1] this granite is continuous with

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1. H. W. Fairbanks, Amer. Geol, Vol. XVII, 1896, p. 45.

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the granite of the Sierra Nevada and hence is of late Jurassic Age.

Masses of diorite, hornblende gabbro, and other closely related rocks are found in the granite. Many of these basic rocks are gneissoid and schistose and are intruded by the granite. Other basic masses appear very fresh and may possibly be intruded into the granite as suggested by Knopf.[1]

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1. Adolph Knopf, A Geologic Reconnaissance of the Inyo Range and the Eastern Slope of the Southern Sierra Nevada, California; U. S. G. S. Prof. Paper 110, 1918.

The only truly sedimentary rocks in the vicinity occur three miles south of Coso Hot Springs. They consist of angular alluvial material derived from the preexisting granite and basic rocks. This alluvial material is firmly cemented in places by aragonite and calcite, probably of hot spring origin.

Late extrusive rocks of Pleistocene age are a prominent feature near Coso Hot Springs although the flows are not abundant in the map area. The earliest flows are basaltic in composition and some of the old basaltic cinder cones are still present. The latest flows are rhyolitic in composition. The cinder cones from which the lavas were extruded lie in a general north-south line about three miles west of Coso Hot Springs. A large proportion of the mapped and surrounding areas is covered with ash and volcanic tuffs, some of which are cemented by silica while some still remain as an unconsolidated mantle over the granite.

Hot springs and fumaroles are found in many places throughout the map area and in places the rocks are still undergoing alteration by these hot vapors and thermal solutions.

Recent active faulting, as shown by scarps in recent alluvium, earthquakes, and seismic evidence indicate that the area is undergoing intense structural deformation.

DESCRIPTION OF THE ROCKS

INTRUSIVE ROCKS

The rocks that are referred to the main period of batholithic intrusion may be most conveniently described under two separate headings: first, granite, and second, the more basic phases such as diorite and hornblende gabbro which occur as small, irregular masses in the granite.

GRANITE

The granite occupies about two-thirds of the map area and is typical of the type which composes the greater part of the Coso Mountains.

In general the granite is coarse, light colored, and homogeneous in composition and texture over the map area. It is composed essentially of an aggregate of albite, andesine feldspar and quartz, its only mafic constituents being biotite, which generally comprises less than ten per cent of the total mineral content.

The granite is comparatively unaltered, but readily disintegrates when exposed to erosion. Many of the slopes are covered with a fine granitic detritus. The outcrops assume a light orange tint.

The granite is traversed by a number of systems of jointing, but these are not constant in strike and dip over the area as a whole ; nor are they equally strongly developed from place to place. The most pronounced system of jointing strikes between south 20° to 50° west with a dip of 70° to the northwest.

PETROGRAPHY

Specimens of the granite taken from different points in the map area prove under the microscope to be very uniform in composition and texture. The feldspars are found to consist of andesine, albite and microcline; they do not show zoning. The albite is notably antiperthitic. In all cases the andesine crystals are much more highly altered to sericite and kaolin than are the other feldspars. Also the contact relations of the andesine crystals with the other feldspars are such as would indicate that the former crystallized early from a more calcic magma. The andesine composes about ten per cent of the rock. The remainder of the rock consists of fifteen per cent albite, thirty percent antiperthite, fifteen per cent microcline and thirty per cent quartz. Biotite is a minor constituent; magnetite and apatite are accessory minerals. The antiperthitic structure is very common and gives the feldspar a wavy extinction. The structure is present in grains between three and four millimeters in length. Albite shows no twin lamellae. Quartz occurs in subhedral grains and shows wavy extinction; many of the grains show sutured borders as the result of recrystallization. Where biotite is present it shows evidence of having been bleached with the separation of iron along lines parallel to the cleavage of the flakes. Some of the flakes have been bent and broken.

The correct composition for this rock could only be obtained from a chemical analysis, but an estimate of the constituents classify it as sodaclase granite. However, it may be more correctly an orthoclase-albite granite.

DIORITE AND HORNBLENDE GABBRO

Small masses of diorite and hornblende gabbro occur as inclusions in the granite. The hornblende gabbro bodies vary from twenty to seventy-five feet in diameter and are of roughly circular or oval shape. They are most numerous in the vicinity of Devil's Kitchen, and are rarely found on the north side of the Coso road in the map area.

The diorite inclusions vary in shape and size, from elongate forms 1000 feet lone and 50 feet wide to small roughly circular outcrops some 50 feet across.

They are most abundant on the north side of the Coso road. Beyond the map area both to the north and south these bodies are larger and in certain localities compose the main rock type, the granite occupying only small and irregular areas. This condition is local, however; further again to the north and south granite becomes the dominant rock type.

DIORITE

The diorite inclusions vary in appearance from a fine-grained brownish tc black variety to a medium grained, light grey type. Both are characterized by abundant biotite and hornblende, these minerals composing about fifty per cent of the rocks.

Microscopically the various types are found to be relatively uniform in composition. Andesine is the only feldspar present and composes from forty to fifty per cent of the rock, varying slightly in the different bodies. Hornblende and biotite are present in nearly equal amounts and make up practically the remainder of the rock. Quartz is absent in most of the types though in some it is present in amounts up to ten per cent. Magnetite, titanite, apatite, and zircon are the accessory minerals.

In general, the rock has undergone little metamorphism. In some types the hornblende is partially altered to chlorite, but this is the exception and usually the hornblende appears as fresh, unbroken crystals. The plagioclase crystals show no indication of any crushing action but most of them are partly altered to sericite. The alteration process is taking place b oth along the twinning planes and from the center of the crystals outwards. This latter type probably indicates that the central portions of some of the plagioclase crystals are more calcic than the margins, and hence are more readily altered.

Some of the diorite bodies appear to possess a schistose or gneissic structure in hand specimen and have the appearance of having undergone extensive metamorphism. When examined under the microscope, however, no evidence of gneissic of schistose structure can be found and the constituent minerals are all quite fresh. Apparently the pseudo schistosity is due to weathering.

HORNBLENDE GABBRO

The hornblende gabbro is characterized by the presence of large crystals of hornblende, some of which are over an inch long. In general, these crystals form ragged patches which enclose patches of a fine grained, light grey ground mass, and it is this feature which gives the rock its mottled appearance. In hand specimen the hornblende crystals possess a fresh appearance, whereas the groundmass is composed of an altered mass of a variety of minerals.

Under the microscope the rock is seen to be composed of 42 per cent hornblende, 28 per cent augite, 25 per cent labradorite together with the accessory minerals, apatite, titanite, magnetite and zircon. The hornblende occurs in the form of large crystals and irregular masses. These all contain inclusions of augite which are in various stages of alteration to hornblende. In some cases the hornblende is found to grade into augite, both minerals being in parallel position with respect to the cleavage directions. It is apparent from these relations that the original

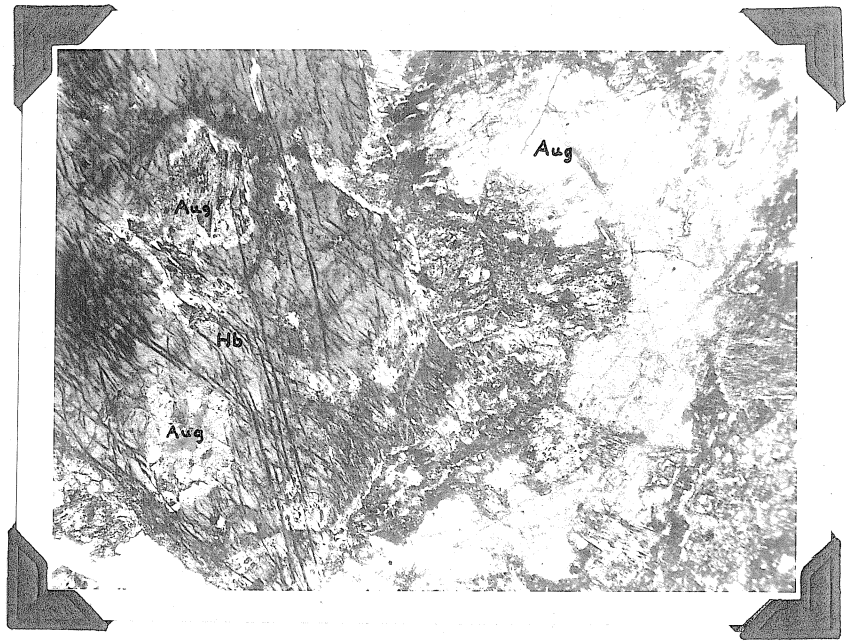
PLATE II

A. A portion of the hornbkende gabbro intrusive rock type. Augite (Aug) is partially altered to hornblende (Hblende) in this picture. Small inclusions of partially altered augite are present in the main hornblende crystal.

X 30

B. A portion of an original granite which has undergone "moderate" alteration as a result of the action of hot gases and solutions. The andesine (And) is partially altered to clay (dickite or nacrite) and the quartz (Qtz) shows signs of corrosion.

X 110



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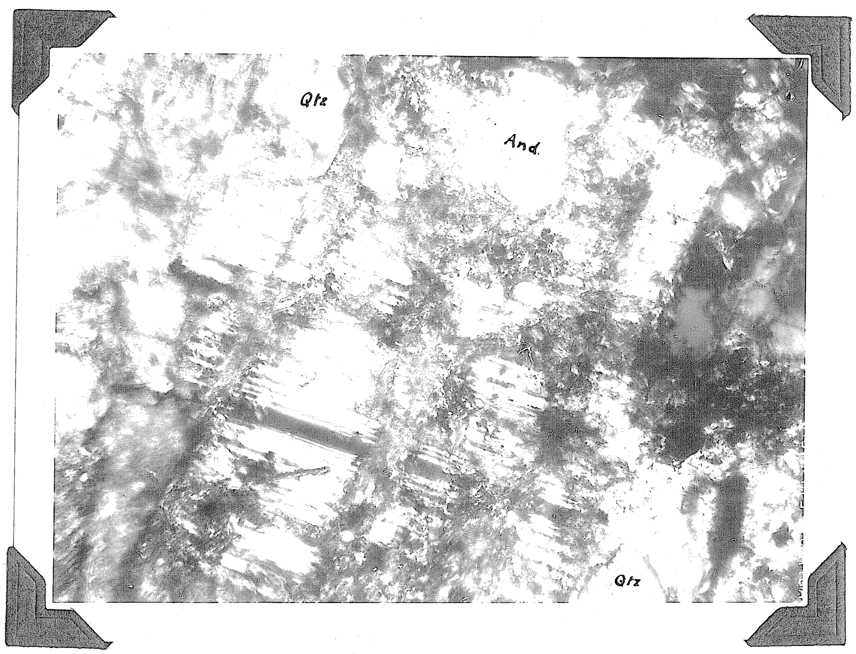

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phenocrysts of augite have been almost completely altered to hornblende as a result of late magmatic reaction. Augite composes about half the groundmass and appears in thin section both as irregular prismatic forms and well developed eight-sided cross sections. They may be present as complex aggregates or as single crystals. In all cases these crystals of augite have been partially altered to hornblende though this mineral is not nearly as prominent as in the larger crystals. Titanite occurs remarkably abundantly both as anhedral crystals and irregular grains. The plagioclase, in some places, shows very marked zoning; the zones are different in composition and so sharply defined that the difference in indices is noticeable. Apparently the successive layers become more sodic outwards. The plagioclase has been only slightly altered to sericite and kaolin. Myrmekitic intergrowths are common.

It is not improbable that the diorite and hornblende gabbro represent the complementary differentiates of a common magma. Moreover, the poverty of the granite in ferromagnesian minerals may have resulted from the previous segregation of these constituents into diorites and gabbros. Contact relationships between the granite and the more basic types are generally obscured by overburden. It was observed, however, that in many cases aplite dykes, which are thought to have originated from the same magma as the granite, cut across the diorite bodies. This would indicate that the diorite was older than the granite. In the case of the gabbro no such relationship was observed.

APLITE

Aplite is fairly common as dykes in the plutonic complexes. It occurs as a white to greyish, fine grained rock containing small amounts of biotite; its texture is typically phaneritic.

Under the microscope the rock is seen to be composed of 40 per cent quartz, 30 per cent orthoclase, 23 per cent albite and 5 per cent microcline. Biotite, apatite and magnetite compose the remainder of the constituents. Myrmekite intergrowths are common in the rock. The feldspars show only slight alteration to kaolin and sericite.

ALTERED PHASES OF THE GRANITE

Under normal conditions of weathering the constituent minerals of the granitic rocks show only slight indication of alteration; the main feature is a moderate conversion of the more calcic feldspars to sericite and kaolin. In the vicinity of the hot springs, however, alteration processes have been very extensive and in some cases complete alteration of the original constituents has taken place. For purposes of description the altered types will be divided into three groups, in order of the degree of alteration:

1. MODERATE

This type of alteration is representative of the granite at the "Basin" deposit, both in the tunnel and from the road cut on the southwest end of the deposit. At these points the granite has not been exposed directly to hot solutions and large quantities of hot gases, but instead has been maintained at a constant temperature (probably about 100^0 Fahrenheit) and has been exposed, probably, to only small amounts of hot gases.

The rock has greatly increased in porosity but has decreased in specific gravity. It consists of a light buff, poorly consolidated type, composed chiefly of clay, but retains its mafic constituents in only a slightly altered state.

Under the microscope the rock is seen to consist chiefly of clay (dickite or nacrite). Quartz comprises about 25 per cent, andesine 2 per cent, bleached biotite 10 per cent, calcite 10 per cent, and magnetite 5 per cent of the rock. Chalcedony is present in minor amounts. The quartz occurs as fractured grains, which, in some cases, have a corroded appearance around their margins. The biotite, in general, has been highly bleached and iron has separated out as a result of this reaction. Only small fragments of the original andesine crystals remain; these are highly altered but twinning can still be recognized.

2. HIGH

A sample illustrating this type of alteration was taken from the rim of a vent from which hot solutions and gases were emanating, at the extreme southwest end of the line of springs which extend past the village of Coso.

The rock is composed chiefly of clay (dickite or nacrite) and quartz phenocrysts are readily seen in hand specimen. No mafic minerals are present. The rock, held together only by clay, disintegrates easily. It is a dirty greyish white in appearance.

Under the microscope the quartz is seen to compose about 30 per cent of the rock, the remainder being clay and magnetite. The quartz occurs as irregular grains and shows no corrosive effects around the margins. Magnetite is fairly abundant and occurs as very fine aggregates and individual grains in the clay.

There has been a large volume loss as a result of the alteration processes.

3. EXTREME

This type of alteration is present in the "Basin" deposit. At this locality, situated at the southwest side of the deposit and revealed by a road cut, a small area of the granite has been replaced by opal and none of the original minerals are present.

The rock is chalky in appearance and white to buff in color. The "high" type of altered granite grades within six inches to a buff, altered type and then to the white chalky type.

The index of the material was found to be 1.46 which would indicate that it is opal. Very fine particles of what may have been original quartz are present in the fine groundmass and can only be seen under the microscope. None of the original minerals of the granite are present and apparently they have all been replaced by opal.

It is interesting to note that this zone of extreme alteration extends several feet on either side of a small, steeply dipping fault. The zone of alteration grades rapidly into the "high" type of altered granite on both sides. Apparently, then, hot solutions and gases rich in silica, ascended by means of this open fracture, altered the constituent minerals of the granite and finally replaced them entirely.

In all three types alteration has been brought about by hydrothermal processes and has resulted in an increase in porosity and a large decrease in specific gravity.

SEDIMENTARY ROCKS

The only sedimentary rocks found near Coso Hot Springs were in an exposure a few acres in extent, about three miles south of the town. These rocks are exposed on a platform which lies at the base of the foothills of the mountains to the west, and rises above the general drainage floor of Coso Basin. The platform has been cut through by an easterly flowing stream and the sediments are well exposed in a steep sided canyon.

The sediments are composed of angular fragments varying from very fine monominerallic grains to large boulders a foot or more in diameter. The fragments are composed of granite and more basic material similar to that found in the mountains to the west, which apparently were the source of the material. The fragments are poorly sorted and do not appear to have undergone much transportation, hence were probably deposited in fans at the mountain front. The fanglomerate is cemented by aragonite and calcite. Carbonates also occur as veins and veinlets throughout, and in many cases appear to be interbedded with the breccia. These carbonate beds, generally composed of aragonite, are as much as three or four feet in thickness. They show a cross-fibre structure and grade outwards from the center as though they were deposited between two existing beds of breccia. This origin is clearly shown by the vuggy centers of many of the smaller veins and beds. In other places the carbonate appears to have been deposited in pools in the breccia as the carbonate is in flat thin beds which sometimes contain fairly large breccia boulders. In places the matrix of the breccia is almost pure carbonate, so there may have been some replacement of the breccia by the carbonate bearing solutions. It seems very probable that the carbonate was derived from hot springs that at one time flowed out over this region.

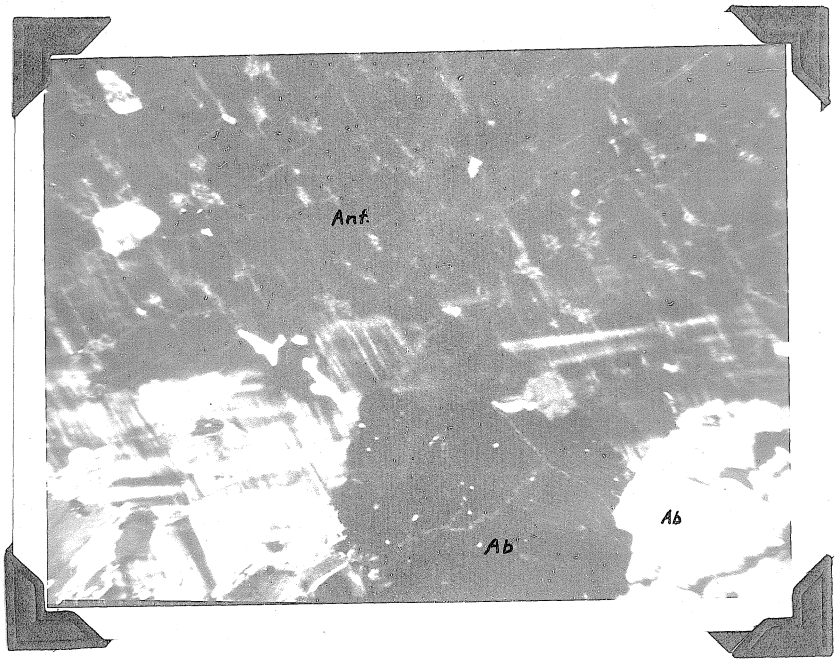
The beds in the canyon are at least fifty feet thick but neither the top nor the bottom of the series is exposed. No fossils were found in the beds. The sediments are probably older than the basaltic flows as they contain no basaltic fragments and there is a basaltic flow which should have contributed fragments if it predated the sediments.

The beds are nearly flat lying but strike N 60°E and dip about 2°SE. The basalt flow about 1000 yards to the north and west is at a higher elevation

PLATE III

A. A microphotograph of the granite. Antiperthite (Ant) is shown in the main portion of the photograph with two grains of untwinned albite (Ab). (X 30)

B. Basalt lava showing alignment of feldspar phenocrysts. The groundmass is largely magnetite and feldspar. Augite (A), Labradorite (L). X 30.



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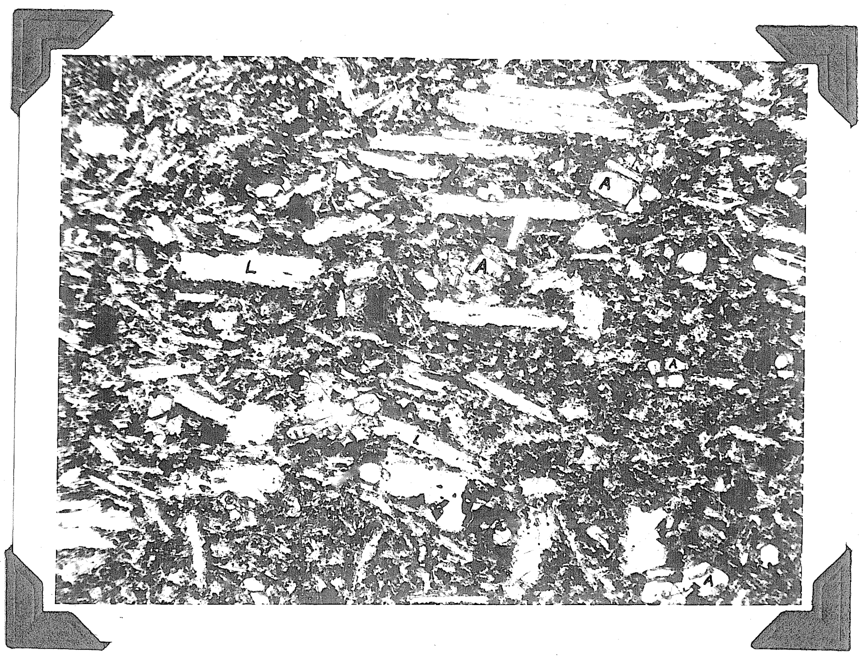


B

and should overlie these beds. Since the fanglomerate contains no fragments of basalt, it appears that the basalt is probably later than the fanglomerate.

EXTRUSIVE ROCKS

BASALT

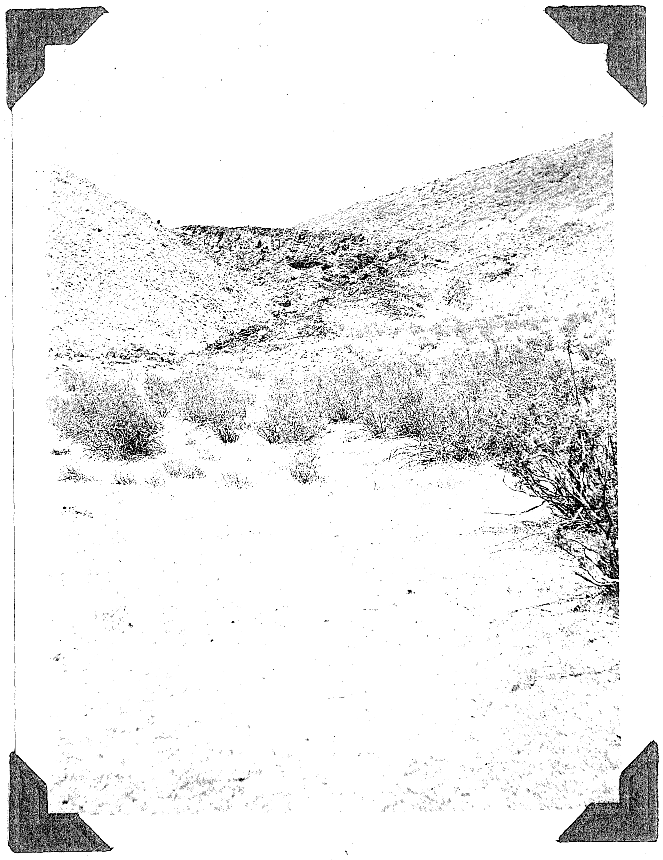
A considerable number of finely preserved basaltic cinder cones and associated lava flows form prominent features of the Coso Range. The cones are well preserved and the lava can be seen to have flowed through the breaks in the cones and on down the nearby slopes.

One of these cones rises up from the granite about two miles south of Coso Hot Springs. The cone is a horseshoe shaped amphitheater that has been cut through on the south side. The lava probably broke through the cone at this opening then turned and flowed eastward down a preexisting stream canyon. Most of the lava flow still remains, although it has been cut through in places by erosion. The cone consists largely of scoriaceous cinders and oddly shaped fragments of ropy lava. The extruded material does not seem to have been a single flow as layers of basaltic ash lie between the different lava flows. The top of the uppermost flow is exceedingly rough and vesicular but within a few

PLATE IV

C. A basic lava flow to the south-east of the map area, just west of Coso Basin. The lava has flowed down a narrow canyon in the granite.

D. A view from the top of Devil's Kitchen to the north-west. In the foreground are pits in the altered tuff. Several volcanic cones can be seen in the background.



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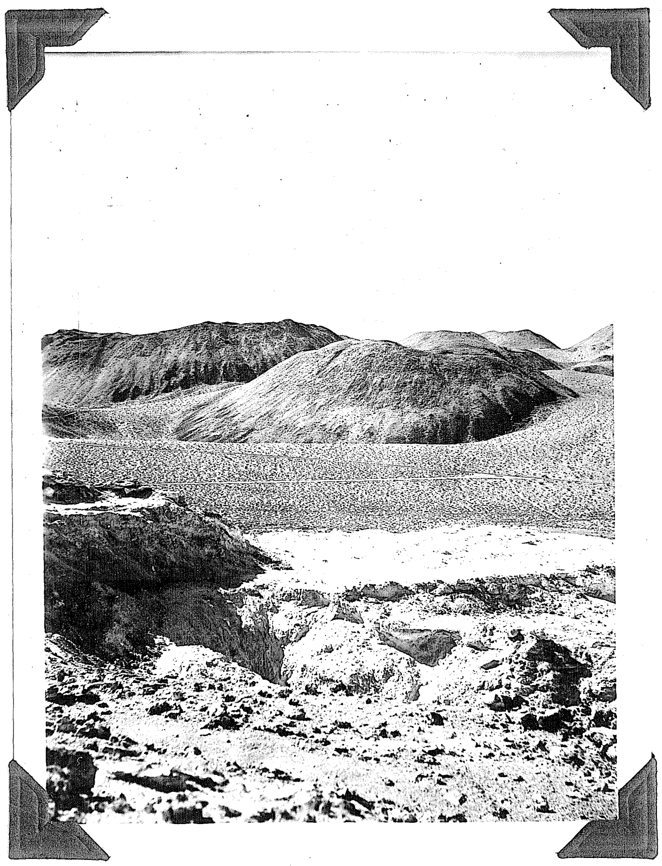


D

feet of the surface the flow becomes quite massive and finely cyrstalline with very few vesicles. The lava is at least a hundred feet thick near the crater and the flow extends for about half a mile east of the crater although its thickness rapidly diminishes.

Petrographically, the rock consists of numerous long, narrow blades of labradorite and rounded, anhedral augite crystals in an exceedingly fine grained groundmass consisting largely of basic feldspar and magnetite. The labradorite blades make up approximately 25 per cent, and the augite 10 per cent, of the section, while the rest of the section consists of the fine & grained groundmass. Nearly one third of the groundmass or about 20 per cent of the whole section is composed of the small magnetite grains. There is a very small amount of biotite in the groundmass and some of the augite is somewhat altered to biotite. The labradorite prisms show some alighment and thus reflect the flow structure of the lava.

This basalt cone is probably of Quaternary age as the cone is fairly well preserved and the lava seems to have flowed out over essentially the same topography as that of today.

The only basaltic lava in the map area is a small patch about three hundred feet long and a hundred and fifty feet wide. This patch is on the top of one of the higher hills about 2000 feet south of the main road in the central part of the map area. The lava, which shows excellent flow structure, consists mostly of large boulders about ten feet in diameter. The origin of this lava is doubtful and even the relative age is uncertain. It may be very closely related to the late lava just described although its high topographic position and isolation might suggest that it is part of an earlier flow that has been isolated by erosion and that much of the granitic surface of the area was once covered by more extensive basalt flows.

The east side of Coso Basin as well as the narrow gap extending to the north is covered with basaltic lava flows. These lavas have apparently come from that part of the Coso Range which lies to the east of Coso Basin.

RHYOLITE AND RHYOLITIC TUFFS

Rhyolite flows, obsidian and associated tuffs and volcanic breccias occur at many places in the Coso Hot Springs region. The volcanic material is derived from a nearly north-south line of volcanic craters which lie to the west of the map area. The largest of these craters, nearly a mile in diameter and over 700 feet high, lies about half a mile west of Devil's Kitchen. The nearly circular cones are composed of glassy lava fragments which almost always show good flow structure. The tops of the cones show depressions within an outer rim and in most cases this rim has not been dissected by erosion. On a fresh surface these fragments are almost white, but on their outer surface they are dark brown as a result of desert varnish. The large quantity of volcanic ash and breccia attests to the explosive character of these old volcanoes.

A number of lava flows overlie the region, though very little lava lies within the area itself. Rhyolitic lava outcrops over a large area just south of Devil's Kitchen and flows of rhyolite are at least 300 feet thick just north of the largest crater where the road crosses the summit of the Coso Range west of the hot springs. The only shyolite flows known in the map area are relatively thin, and are interbedded with volcanic tuff and breccia in Devil's Kitchen.

Rhyolitic tuff and breccia are very widespread throughout the area and occur extensively in the western part near the mercury deposits. The breccia and ash are of two types: a consolidated type which is well indurated and lies in definite beds, and an unconsolidated type that mantles many of the hills and valleys in the area. Part of this latter type was probably washed down into the valleys from the hills, and its position is therefore determined by alluvial rather than pyroclastic processes.

The unconsolidated ash and breccia cover the tops of most of the hills in the southwest portion of the map area, with the exception of that part immediately surrounding Devil's Kitchen. At this point the breccia is in well cemented beds. The ash from these higher levels can be traced down the bottoms of the canyons to the main valley in the western part of the area. It appears as though the ash is being washed down these canyons by streams and deposited in the valley below. The ash and breccia in the open cuts in the Basin deposit are well cemented although the bedding is not very apparent. This breccia, with the exception of the top layer, was probably deposited directly after volcanic explosions. The top layer probably represents alluvial ash and breccia washed down from the higher elevations after the volcanic activity ceased.

As mentioned before, the rocks in Devil's Kitchen consist of indurated ash beds with some interbedded acidic lava flows. Nearly a hundred feet of ash and lava are exposed in the deeply excavated canyon of the Kitchen. Well indurated beds of volcanic breccia outcrop along the main road just east of the Basin deposit, and again about 1200 feet further east along the road. The breccia is in contact with the granite at the latter outcrop.

Bedded volcanics are exposed near the southeast corner of the area. These beds are in a small canyon and were apparently deposited by the stream which descends from a valley of unconsolidated volcanic material which lies just outside the map area.

The dip of the volcanic beds varies, but it conforms in general to the present topography of the area.

The only exposed contact of the breccia and underlying granite occurs along the main road about 2000 feet east of the Basin deposit. The breccia lies on an uneven surface which in places slopes as high as 45°. Sand and granitic pebbles predominate in the lowermost bed. However, with a few exceptions, volcanic material is more abundant in the majority of the beds. The series of thin beds has a total thickness of approximately twelve feet and strikes N 55° E and dips

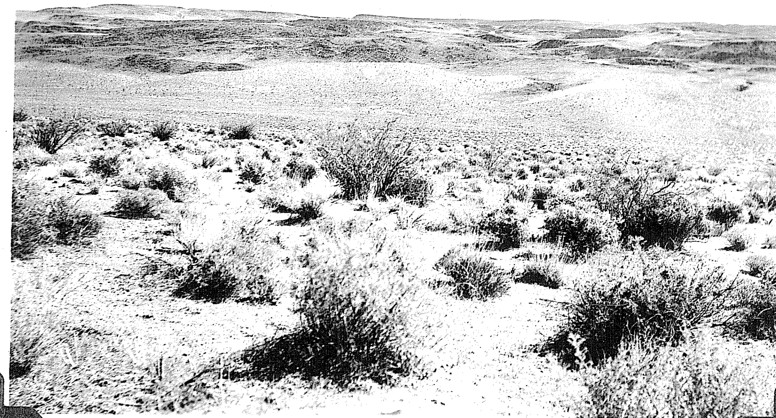
17° N. The intermixture of granitic and volcanic material indicates that they were laid down in the canyon by a stream. The stream has since been rejuvenated and the sediments are being removed. The volcanic material did not come down from the two canyons to the south, as these canyons are composed of granite. The granitic alluvium from these canyons partially covers the volcanic breccia beds. The volcanic material must have been carried down the main canyon from the large valley to the west.

AGE OF THE RHYOLITE

The rhyolite lavas are thought to be of Recent or late Pleistocene age. The cones show very little erosion and give the impression of recent activity. Fragments of basalt were incorporated in the lava flow to the south of Devil's Kitchen. This suggests that the rhyolites are later than the basalts in the region; however, it is not certain that these fragments are from the late basalt. The perfect cones and the fragments, however, suggest that the rhyolite is very recent. It is also believed that the hot springs and fumaroles are related to, and represent the end stages of the rhyolitic volcanic activity.

E. A view to the east from Coso Basin. The mountains in the background are cut by a series of step faults. Basic lava covers a large portion of these mountains.

F. A view of a well preserved volcanic cone, northwest of the map area.



E

F

PETROGRAPHY OF THE LAVAS AND VOLCANIC BRECCIA

In thin section the lava from the rhyolitic volcanic cones is largely composed of glass and small needlelike crystals which are aligned with the flow texture of the glass. These acicular crystals cannot be identified, but some very small grains of quartz and fine biotite plates can be recognized. Some fine grained crystalline aggregates are yellow in transmitted light but colorless in reflected light. These have been explained by Pirsson[1] as due to the unequal

1. L. V. Pirsson, Artificial Lava Flow and its Spherulitic Crystallization; Amer. Jour. Sci., Vol. XXX., p. 101. 1910.

refraction and internal reflection of light in passing through aggregated fibres and particles, whereby the blue rays are absorbed and the red-orange ones are transmitted. These aggregates, therefore, are probably quartz or feldspar, although many of the fine acicular crystals may well be other minerals. The clusters are not devitrification products as the flow lines go around them.

The lava was probably ejected in a liquid state or perhaps with these aggregates already crystallized, and cooling was sufficiently rapid to prevent the formation of large crystals.

A light brown, porous, flow fragment from the Basin deposit was also examined in thin section. The fragment, which is composed wholly of volcanic glass, shows excellent flow structure. Under the microscope the vesicles are elongate and the glass is in the form of long fibres which bend around the vesicles. The glass is usually colorless and isotropic, but grades into a yellowish, anisotropic variety in places. This latter variety is probably palagonite, an alteration form of volcanic glass.

The composition of these two glasses was determined by the refractive index method of W. O. George.[1]

1. W. O. George, Physical Properties of Natural Glass; Jour. Geol., pp. 353-372; 1924.

The compositions as determined are compared in Table I with the average composition of a type rhyolite.

TABLE I

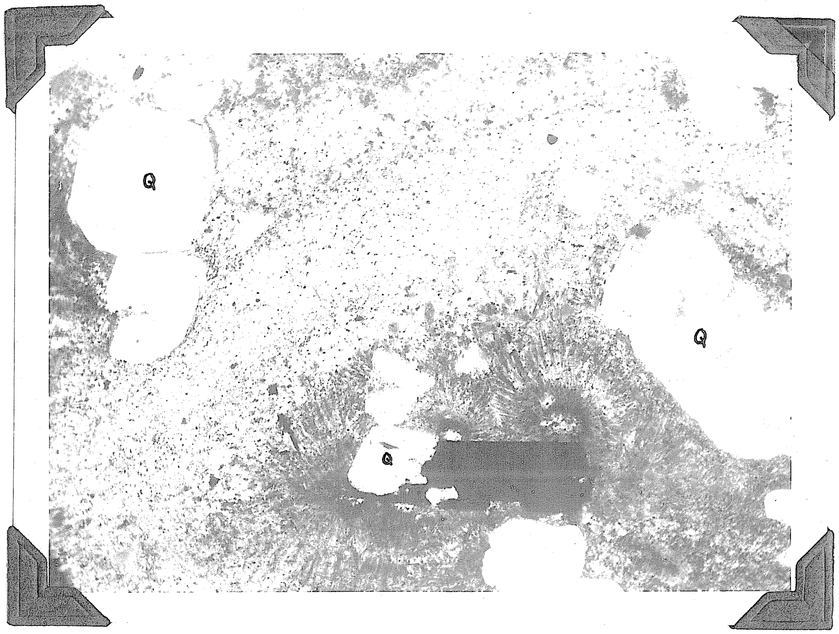
	Type Rhyolite	1	2
SiO_2	73.7	73.5	70.0
K_2O	3.4	4.2	4.0
Iron Oxide	2.3	2.2	2.5
CaO	1.3	2.4	2.0
MgO	.4	.3	.7
Na_2O	3.6	3.7	3.7
Al_2O	14.1	14.0	16.0

1. Lava from volcanic cone one half mile northwest of Devil's Kitchen.
2. Breccia fragment from Basin deposit.

PLATE VI

A. Rhyolitic lava south of Devil's Kitchen showing phenocrysts of quartz and spherulites in the fine grained groundmass of quartz and feldspar. Quartz (Q). X 50.

B. Cemented volcanic breccia. Opal deposited in open spaces between fragments of glass, quartz and biotite. Opal (Op), Quartz (Qu), Glass (Gl), Biotite (Bi), Andesine (An). X 110.



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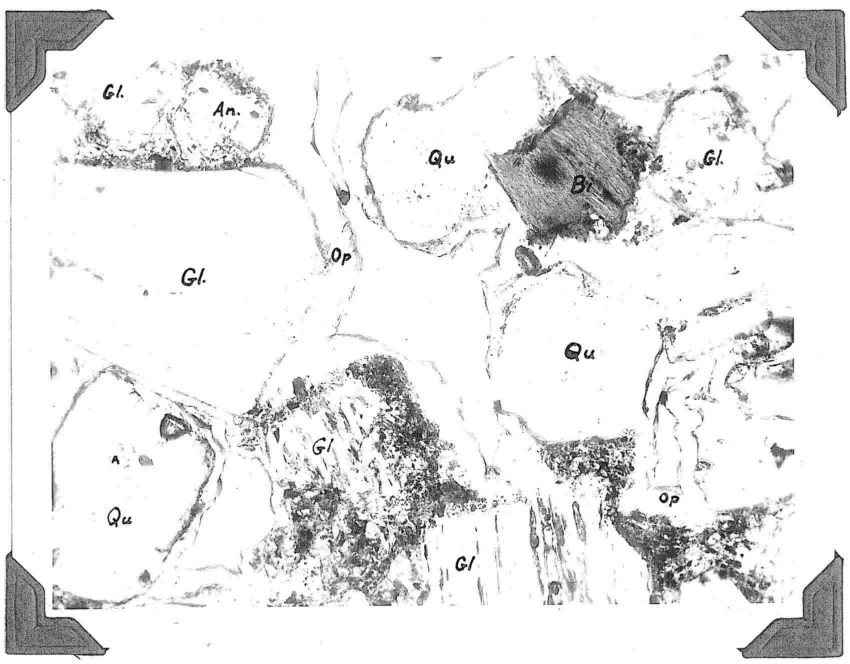


B

The lava south of Devil's Kitchen is fairly dense, fine grained, and light grey in color, with small phenocrysts of quartz and feldspar. In places this lava contains fragments of dark brown vesicular and amygdaloidal basalt.

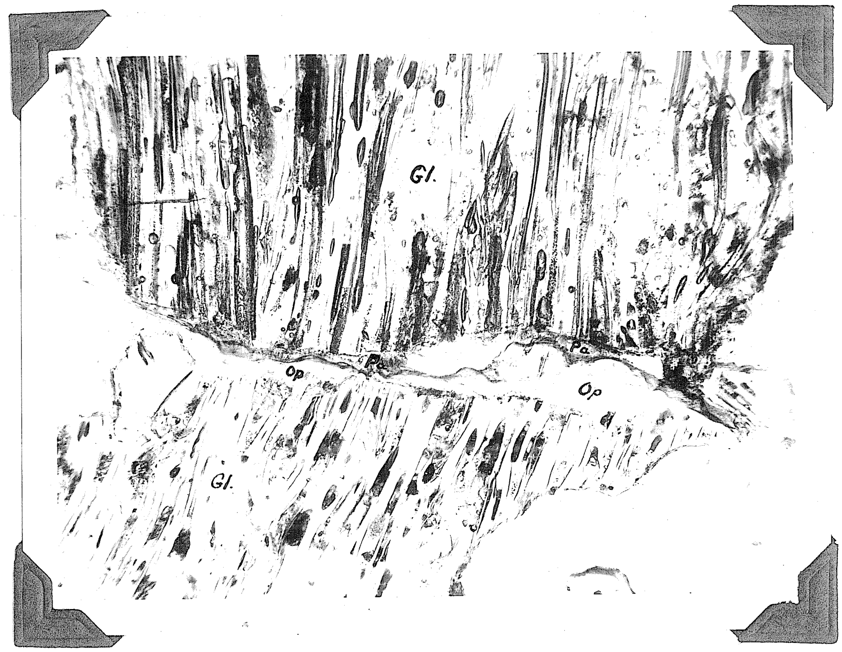
Under the microscope the lava consists of about 25 per cent of phenocrysts, with a diameter of two millimeters, in a fine grained groundmass. The groundmass is probably composed largely of quartz and feldspar although the grains are too small to make accurate determinations. Quartz is by far the most abundant phenocryst, and in this form probably amounts to about 20 per cent of the whole section, the remainder of the phenocrysts being largely orthoclase and andesine. Biotite and muscovite are minor accessories. Some secondary quartz veins parts of the section as well as veining one of the primary quartz phenocrysts. Spherulites are abundant in the section and usually have a small crystal core.

It is apparent that the crystallization of the lava was interrupted by quick cooling. The shape of some of the quartz crystals suggests the hexagonal bipyramids of beta quartz, so the phenocrysts may have been present in the lava before it was extruded. The spherulites and the texture of the groundmass also

PLATE VII

A. Cemented volcanic tuff. Two glass fragments (Gl) cemented by opal (Op) and palagonite (Pa), the darker cementing material.
X 110.

B. Slightly altered volcanic breccia from Devil's Kitchen. Two small fragments of quartz (Qtz). Large fragments are glass, matrix is largely glassy but with a small amount of clay (C)
X110



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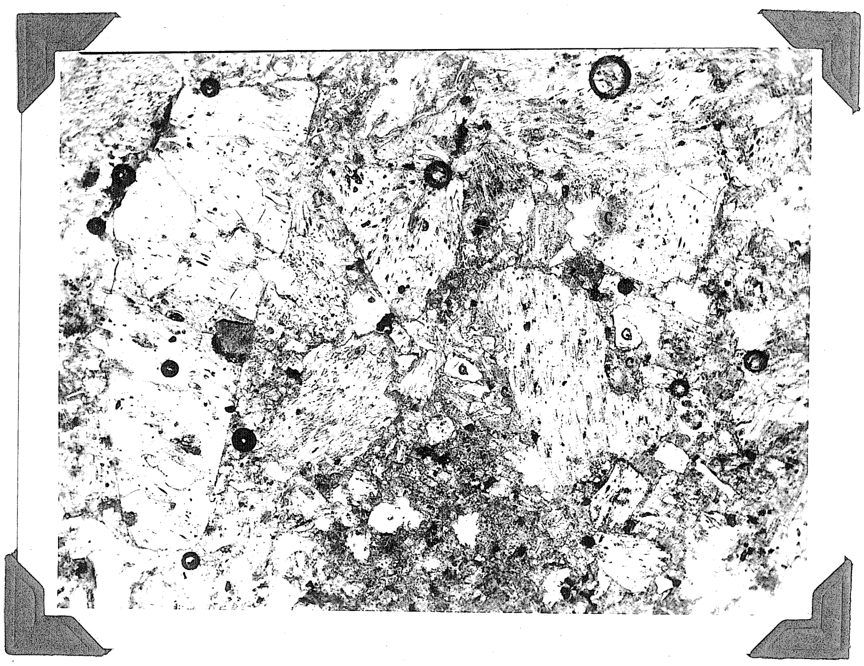

B

point to the fact that the phenocrysts were already in the lava before extrusion, as these textures indicate quick cooling, and it is doubtful if such large phenocrysts would have had time to form.

Under the microscope, the volcanic tuffs and breccias are composed largely of fresh unaltered volcanic glass. The amount of glass in different tuffs varies considerably. Some were evidently deposited by water and contain many sand grains picked up by the streams and deposited along with the volcanic material. Due to the nature of deposition the relative amounts of volcanic material and sand varies a great deal. Where the volcanic tuff beds are relatively fine grained they seem to carry a high percentage of other mineral grains.

Other beds of tuff are domposed almost entirely of glass. These were probably deposited by settling from the air after a volcanic explosion. The few crystallized grains in these tuffs are minerals which had already crystallized before eruption, or else are small explosive fragments torn from the sides of the volcano. Quartz is the most abundant fragmental material, but orthoclase, sanidine, and andesine are also common. Microcline, hornblende, biotite, muscovite and sericite are found in minor amounts. Limonite and hematite sometimes occur as coatings on other grains. The state of alteration of the feldspars varies a great deal; at times they are very fresh; at others, they are highly altered to sericite.

The indurated tuffs are usually cemented with opal, which in some places forms as much as 20 per cent of the rock. This opal, when present in large amounts, makes the tuff extremely hard and gives it a shiny, siliceous appearance. Occasionally the cement is in part chalcedony and iron oxides. The silica cement probably originated from the hot springs of the region. A yellow amorphous cement, probably palagonite from alteration of the glass, has also been observed.

ALTERATION OF THE TUFF

The tuffs appear to be highly altered in the areas of hot spring and fumarole action in Devil's Kitchen and the Basin deposit. Instead of the usual buff color, the tuffs are white, except within a few feet of the surface where they may be colored red by hematite.

The types of alteration which take place are silicification, kaolinization and sericitization.

Silicification is very common around the hot springs. As mentioned above, most of the cementing material of the tuffs consists of opal and chalcedony. Secondary silica, either as chalcedony or quartz, is found in aggregates in many of the sections. Opal, besides occurring as a cement, is found in numerous small veinlets cutting the tuff in the altered portions of Devil's Kitchen.

Kaolinization is one of the most important processes of alteration near the hot springs. The clay minerals seem to occur as alteration products on the surface of the glass fragments. The very fine ash is attacked first, as shown by the fact that in some sections this ash is almost completely altered to clay, while the larger fragments are unattacked. This is probably due to the fact that the larger the ratio of surface area exposed, the more rapid the alteration, and the surface area ratio is greater in the smaller grains. The alteration of the tuff is clearly due to hydrothermal action as clay minerals do not occur in the top beds of Devil's Kitchen, nor do they occur in the tuff at any distance from the other heated zones in the area. The clay is one of the kaolin group as shown by its refractive index. It is probably nacrite or dickite as kaolin is supposedly only produced by weathering.

Sericite is found in only a few of the sections and always in very minor amounts. It is probably due to the alteration of small feldspar fragments, though some may be the result of alteration of the glass.

The fact that ferric oxides are found only near the surface in the altered zones, probably indicates that reducing conditions prevail until the solutions and gases almost reach the surface, where the oxygen of the air begins to exert its influence.

The white color of the highly altered tuffs is probably not only due to the clay minerals but also to the fact that the iron is reduced, with the result that the tuffs are bleached.

SUMMARY OF ALTERATION

Regional alteration of the granite has not been great. In general, the only indication of alteration is shown when the rocks are observed in thin section by the presence of small amounts of sericite and kaolinite. The mafic minerals of the rocks are characteristically unaltered.

In areas of hot spring activity, however, the alteration of the rocks has been intense. In all cases the granite has decreased in specific gravity and has greatly increased in porosity. In some cases none of the original minerals are present but have been altered and replaced by opal. In others only irregular quartz grains and particles of feldspar crystals are left, the remainder of the rock being composed of clay and opal. Where the granite has not been exposed directly to the action of hot gases and solutions, the original texture can be recognized, and biotite and quartz have not been altered. However, the more directly the rock is exposed to these solutions and gases, the greater becomes the percentage of opal and the less the original constituents and the clay.

The rhyolitic lavas and tuffs, like the granite, show little chemical weathering. They are so recent that devitrification of the glass has not taken place in areas that have not been attacked by thermal solution.

These rocks show the first signs of alteration at some distance from the springs and fumaroles. This is due to the addition of silica, usually in the form of opal, or sometimes chalcedony. The silica is deposited between the fragments of the tuff and apparently acts only as a cementing material with no replacement or alteration of the glass.

The alteration becomes more intense as the heated areas are approached. Silica is still deposited

PLATE VIII

K. A view of the Coso fault, the scarp can be seen in the alluvium. The fenced area is a zone of active springs.

L. A view of active springs at Coso village. This is the fenced area shown above.

K

L

in open spaces but the heat and hot solutions cause devitrification of the glass with the formation of clay minerals and secondary silica. The iron and magnesia in the glass probably becomes hydrated and forms palagonite. Cinnabar, metacinnabarite, sulfur, alum, and siliceous sinter are deposited near the fumaroles and hot springs.

The tuff, unlike the granite, was not found completely altered to opal. Fragments of glass are found in even the most highly altered areas and only the smallest fragments are completely altered to clay. The clay never seems to be removed to leave a rock composed wholly of opal, as in the case of some of the altered granite.

The apparent difference in the degree of alteration of the tuffs and granite may be due to the fact that the alteration of the granite began before the deposition of the tuffs.

HOT SPRINGS AND FUMAROLES

Hot springs and fumaroles occur in three princiapl areas. The main area is in Coso Basin along a fault which strikes N 30° E, while the other two areas are in Devil's Kitchen and the Basin deposit. Hot springs and altered zones are found in some of the canyons west of the Coso basin, and the Coso Basin mercury deposit is still quite hot, with steam emanating from holes which are only a few feet in depth.

The springs in Coso Basin all occur along the east side of the fault which runs through the basin. The location of the springs and of the fault are shown both on the map of the area and on an enlarged map of the fault. Flowing springs occur in only two places, but many fumaroles and vents along the fault contain bubbling water and mud.

At the principal spring, which is in a pit about 150 feet by 100 feet in diameter and 15 feet deep, vapor and hot sour water rise through a white mud that has been formed from the granite material around the pit. In summer the water in this pit is low, but in winter the water is five or six feet deep, due to the increased precipitation and lower evaporation rate.

The water in this pit has been analysed and reported by Waring[1].

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1. G. A. Waring, Springs of California; U. S. G. S. Water Supply Paper 338, pp. 149-151. 1915.

ANALYSES OF WATER FROM COSO HOT SPRINGS,

INYO COUNTY, CALIFORNIA

(Constituents are in parts per million)

Properties of reaction:			1	2
Primary Salinity			5	13
Secondary Salinity			5	18
Tertiary Salinity			90	69
Primary Alkalinity			0	0
Secondary Alkalinity			0	0
Tertiary Alakalinity			(?)	45

Constituents	By Weight	Reacting Values	By Weight	Reacting Values
Sodium (Na)	49	2.13	81	3.52
Potassium (K)	11	.29	12	.31
Lithium (Li)	Trace	Trace	..	...
Ammonium (NH_4)	Trace	Trace	..	...
Calcium (Ca)	45	2.25	59	2.84
Magnesium (Mg)	2.4	.20	34	2.80
Iron (Fe)	122	4.98	83	2.97
Aluminum (Al)	201	22.22	56	6.20
Hydrogen (H)	16	15.98	12	11.67
Sulphate (SO_4)	2,308	48.05	1,400	29.18
Nitrate (NO_3)	Trace	Trace	0	.00
Chloride (Cl)	Trace	Trace	40	1.13
Carbonate (CO_3)	0	.00	0	.00
Metaborate (BO_2)	..	...	0	.00
Phosphate (PO_4)	Trace	Trace	Trace	Trace
Silica (SiO_2)	..	...	411	13.59
	2.754.4	...	2,188	...

1. Main Spring. Analyst, Oscar Loew (1876). Authority, Wheeler report.
2. Main Spring. Analyst and Authority, F. M. Eaton (1910).

These analyses show that the water contains unusually large amounts of sulphate and of iron, aluminum and silica. The most remarkable feature, however, is the high tertiary salinity. The discordance of the two analyses is apparently due, in part at lest, to a change in the character of the water.

The steaming vents are usually filled with a bubbling mud. This mud varies from white to deep reddish brown in color. The color change from red to white may be complete in vents that are only three or four feet apart. Such jets probably are fed from independent sources in depth which maintain non-connecting channelways to the surface in spite of their juxtaposition. The supposition that the vents are not in close connection is also borne out by the fact the water in two springs stands at entirely different levels, often differing by as much as two feet in large wells which are not more than twenty feet apart.

In many places along the fault the springs have deposited a very fine clay which has long been used as a bath mud. The clay is essentially composed of one of the kaolin group of minerals, probably nacrite or dickite. This clay is very pure and contains less than one quarter of one per cent of extremely fine quartz grains. The clay in the bubbling steam vents is very similar to that in the deposits used for mud baths, and hence these "mud" deposits are pbobably due to deposition from springs and not from the alteration of a granitic body in place.

Large quantities of vapor issue from the cuts in Devil's Kitchen. Numerous fumaroles are active and one hot spring is flowing in the central part of the kitchen. A temperature of 203° Fahrenheit, which is the boiling point at this elevation (about 4300 feet), was recorded in the vapor vents by Waring.[1]

1. Waring, ibid., p. 36.

The rocks of the basin deposit are also in a heated condition but there are no naturally active fumaroles or flowing wells. Where holes have been drilled, however, steam, and in some cases water, come to the surface and are used for heating and drinking purposes.

In addition to the clay, the various fumaroles and springs deposit other salts. At Devil's Kitchen and the wells along the fault, green and yellow iron sulphate, realgar and orpiment are deposited close to the springs, and at the Kitchen and the Basin deposit the ground is impregnated with sulfur and alum along with the ore minerals cinnabar and metacinnabarite. In addition to the opal and chalcedony already mentioned, siliceous sinter has been deposited in large amounts in Devil's Kitchen. The gases emanating from the fumaroles include sulfur dioxide, hydrogen sulfide, and carbon dioxide, in addition to the steam. Pyrite has been observed floating in the scum in the main spring along the fault, and is occasionally seen in small grains in some of the rock in the mercury deposits.

STRUCTURE

The Coso Mountains have been described as a fault block range of the horst type. It is also very probable that the Coso Basin is of structural origin and represents a depressed block, or graben, within the Coso Range.

The Coso fault, which is the principal fault in the map area, is shown in detail on a structural contour map. The fault trace, which strikes N 30° E, is marked by a scarp in the alluvium of Coso basin. This scarp, which varies from a few feet to about twelve feet in height, indicates that the western block was uplifted relatively to the eastern block. The fault must be active to produce such a scarp in recent alluvium.

The dip of the fault is not positively known but the fact that all the springs are on the east side of the fault would indicate that the dip is to the east, as the springs should come up on the hanging wall side of the fault. If heat is being conducted to the surface along the fault zone, the ground water which is flowing from the west, on reaching the fault would be heated; and if the fault was dipping to the west, the springs should be on the west side of the fault. However, the fact that the east side has a lower elevation may influence the location of the springs.

Another fault zone is exposed in one of the pits at the Coso Basin deposit. The pit is about five feet in width and is cut by a series of faults and gouge zones, with different types of rock between the small faults. The faults strike N 25° W and dip 70° NE. This is probably a part of a zone of fairly large displacement. The slickensides all show that the last displacement was largely vertical, although there was a small horizontal component of movement.

Physiographic evidence also indicates an uplift of the western side of the basin. The streams draining into the basin have been rejuvenated and are eroding headward with the formation of steep canyons. To the west of these headward eroding streams, the high land surface is of a rolling mature nature.

Rejuvenation of the streams is also shown by the fact that they have cut through the cemented tuffs and breccias along the main road on the map area, and the sedimentary rocks to the south of Coso Hot Springs. The trunk stream in Coso Basin shows no sign of entrenchment, so it seems probable that the mountains west of the basin were uplifted in relation to the basin.

The eastern side of the basin is covered by a series of lava flows which appear to be step faulted, with the eastern blocks being uplifted relatively to the western blocks.

From the above evidence it seems quite probable that Coso Basin is a graben, delimited on the east and west sides by a number of nearly parallel, normal faults.

Faulting has also been observed in the Basin deposit. These faults are numerous, but generally are small and show no definite trend or direction of movement. The many faults are probably instrumental in the localization of the altered zone, as they would provide an easy means of access for the solutions.

GEOLOGIC HISTORY

During the late Jurassic time a huge batholith was intruded into the region. No trace of the intruded rocks remains, unless some of the diorite bodies represent roof pendants of an older intrusion. However, the magma may have differentiated at depth to give a more basic diorite and hornblende gabbro phase with the granitic phase being intruded into these more basic rocks.

Subsequent to the intrusion the land was uplifted and the erosion of the older, intruded rocks took place and the granite was exposed. From the end of the Jurassic, no sedimentation or extrusion of lavas is known in this restricted area until the late Tertiary or Pleistocene, when the sediments were deposited in Coso Basin.

In the Pleistocene, numerous volcanoes burst through the granitic range which must have had a rugged topography because the basaltic lavas may be seen flowing down steep canyons and over small cliffs.

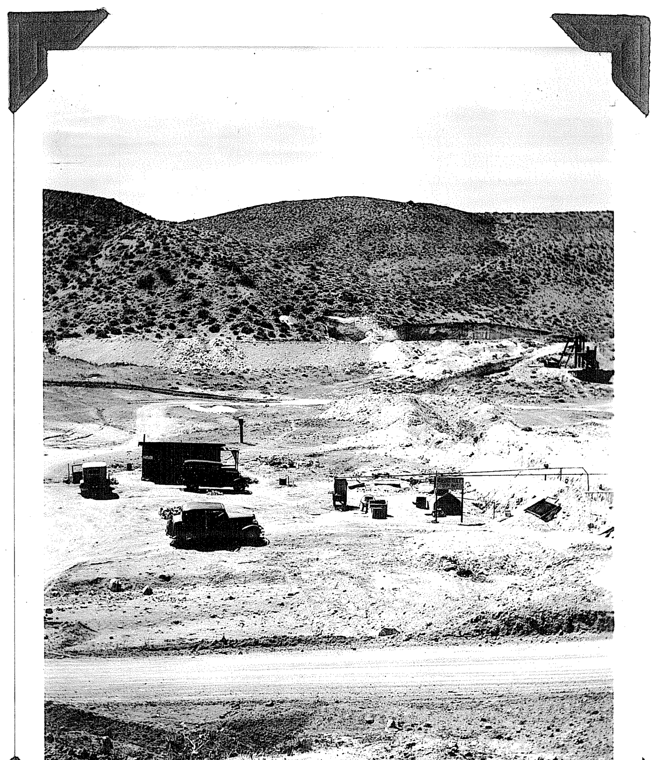
These volcanoes had probably not long subsided before the rhyolitic lavas came to the surface and poured forth amid violent explosive activity, with ash and cinders being blown out and deposited as a mantle

PLATE IX

G. A view of a portion of the Basin Deposit and the Coso Quicksilver mill. A large volcanic cone can be seen in the background.

H. A view of the Basin Deposit, showing several pits and trenches. The headframe of the 30 foot shaft can be seen to the right. The light colored material is highly altered volcanic tuff.

G



H

over much of the surrounding country. The rhyolitic volcanoes only recently became inactive and the hot springs and fumaroles in the area probably represent the last cooling stages of a consolidated, or nearly consolidated magma below. The solutions are now altering the rocks in the area and depositing late magmatic minerals.

The range is still being uplifted along a complex series of faults and this uplift was probably taking place all during the deposition of the sediments and the extrusion of the various lavas.

ECONOMIC GEOLOGY

Deposits of Quicksilver

GENERAL HISTORY OF QUICKSILVER

Quicksilver has been mined for many centuries. As early as 415 B. C. a reduction process had been invented for treating quicksilver ores and was used in Spain, Italy and China where the first production of quicksilver is recorded. This early production was used mainly for treating skin diseases, and in later years its principal use was in the recovery of precious metals. Today there are a great many uses for quicksilver a few of which are explosives; drugs and chemicals.

A few large mines have produced the bulk of the quicksilver used thus far in the world. The leading producing mines at the present time in order of greatest production are Almaden, Spain, Idria, Italy, Huancavelica, Peru, New Idria, United States and Monte Amiata, Italy.

Quicksilver occurrences are definitely associated with volcanism and most of the deposits are found in regions of Tertiary and Quarternary volcanic activity where there has not been much erosion; long continued erosion to great depths would have removed many of the deposits, most of which were deposited near the surface.

Quicksilver, in the form of its common ores, is a rare metal. It is also one of the most volatile of metals. This latter characteristic would seem to be responsible for the scarcity of its ore bodies, because, if special conditions do not obtain, the metal, upon escape from the parent magma, quickly reaches the surface and escapes.

It is generally considered that quicksilver ore deposits are formed by a concentration of the primary mineralization during deposition, and that the usual causes that induce such a concentration are largely structural features of the geology, at the point of deposition.

"At Sulphur Bank, in California, and Steamboat Springs, in Nevada, there are alkaline solutions escaping, which are depositing cinnabar and sulphur at the surface. These are mineralizing solutions which have great pressure and temperature at depth, both of which become less as the solutions ascend toward the surface."

"The 'cap' rock, above escaping solutions, traps these solutions, and thus determines the location of the deposit. The receptacle rock determines the grade and shape of the ore deposited in it. Tight receptacle rocks, such as shales and schists, give little room for deposition, hence only low grade ore can be deposited in such rocks. On the other hand, an open textured sandstone, or a coarse breccia yields generous space for deposition and high gradeore bodies are often found in them." [1]

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1. C. N. Schuette, Quicksilver in Oregon; State of Oregon Dept. of Geol. and Min. Ind. Bull. No. 4. 1938.

The most important ore mineral of quicksilver is cinnabar; other minerals include native quicksilver, metacinnabarite.

In general cinnabar is formed under alkaline conditions, while metacinnabarite is formed under acid conditions.

World production of quicksilver is from 2000 to 3500 tons per year. At the present time it is worth about $90 per flask of 76 pounds.

QUICKSILVER DEPOSITS AT COSO HOT SPRINGS

INTRODUCTION

The examination of the Coso Hot Springs quicksilver deposits is of especial interest in that it offers an opportunity of studying processes of mineral deposition which are taking place at the present time and also of studying the types of alteration which accompany this mineralization.

Very little geological work has been done on the quicksilver deposits. Although many geologists and mining engineers have visited the property in the past, they have done little more than sample the deposits. The only article which has been published and which describes the geology of the deposits is by Thor Warner.[1]

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1. *Op. cit.*

GEOGRAPHY

Location

There are three separate deposits in the general area of the springs. One is located beyond the map area about one mile southeast from the main springs. This deposit can be reached in about twenty minutes by automobile along a road which trends nearly due east and then turns southeasterly, along Coso Valley.

The other two deposits are located one and one quarter and two miles, respectively, southwesterly from the springs. The first ("Basin" deposit) is situated on, and the second (Devil's Kitchen) about half a mile from the main road between Coso Springs and Coso Junction.

HISTORY AND PRODUCTION

The deposits of quicksilver "Devil's Kitchen" and the "Basin" in the Coso Hot Springs area were discovered prior to 1925. Up to this time, however, the economic aspects of the deposits were not recognized. In 1925 Sanders, of Santa Barbara, staked the deposits and subsequently interested a Salt Lake City company in them. After taking a large mumber of samples this company did no further work and as a result Sanders raised some money himself and proceeded to work the property. This work was continued intermittently until May 1935 when Leege, also of Santa Barbara, took over the property. A four ton retort was built in 1935 and 96 flasks of mercury were recovered in that year. A 25 ton mill was constructed in the same year. No further work was done until 1937 when development and mining were resumed, and continued until April 1939, at which time the operation was closed down.

A total of 200 flasks of quicksilver have been recovered from the deposits.

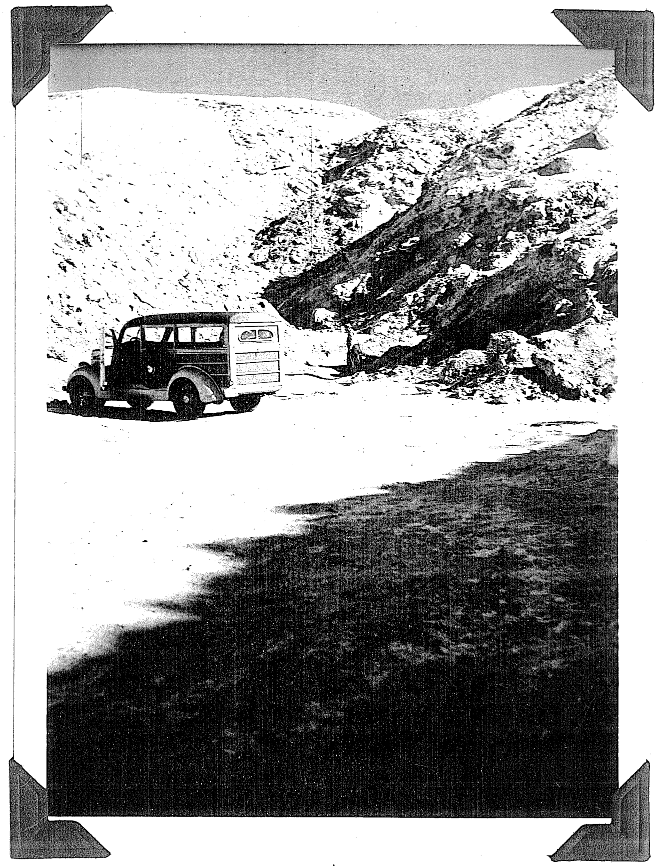
The history of the small mining operation located in Coso Valley is not known. A small type retort has been built, but very little development work has been done. It is not thought that any quicksilver has been recovered from this locality.

The main development work done on the deposits takes the form of pits, trenches and large open cuts. In addition there are several adits, a tunnel, which has been drived about 100 feet, and a 30-foot shaft. The locations of these are shown on the map of the "Basin" deposit.

PLATE X

I. A view of a large canyon cut on the west side of Devil's Kitchen. The rock is highly altered volcanic tuff. Hot gases and solutions are emanating from many points in this canyon.

J. A view of a large cut on the west side of Devil's Kitchen. The bedding of the tuffaceous rocks can be seen in the upper part of the picture. This a very active part of the Kitchen.



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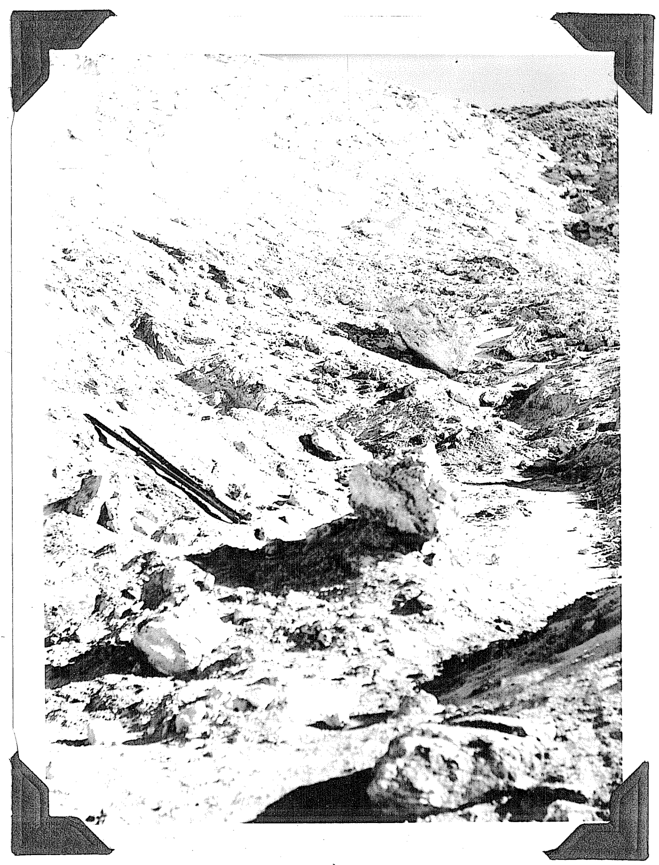

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MINERAL DEPOSITS

GENERAL CHARACTER OF THE DEPOSITS

The quicksilver deposits of the Coso region occur in an area of hot spring activity. Such areas are characteristic of regions of Tertiary formations and especially of those of very recent volcanic activity. Theprincipal element of economic interest that occurs in the deposits is quicksilver. It occurs chiefly as cinnabar, though the secondary sulfide of mercury, metacinnabarite, is also present. In detail, however, quicksilver is not the only mineral occurence, for sulphur is present in these same areas of hot springs activity, and some recovery of sulphur has been recorded. Altered granite and volcanic tuff occur in large amounts and might possibly find some use as a ceramic product.

For purposes of general description it is convenient to divide the deposits as follows:

1. Devil's Kitchen -- A considerable amount of material has been taken from this deposit and run through the mill and the retort. The principal minerals are cinnabar, metacinnabarite, sulphur, both the black and yellow varieties, hematite and various mineral salts which are being deposited by springs and fumaroles.

These include alum, iron sulphate, and possibly several others.

2. Basin Deposit -- A great deal of development work has been done at this locality though it is doubtful if as much of the material has been put through the mill as at Devil's Kitchen. Cinnabar, metacinnabarite and hematite are the most abundant minerals, though sulphur is present at various points. The various salts mentioned above occur in minor amounts.

3. Coso Valley Deposit -- Only about half a dozen pits have been dug in this vicinity and a very small amount of material has been put through the retort. The only mineral observed to be present was hematite. No cinnabar or metacinnabarite was seen though they are present in very minor amounts as shown by assay returns. No sulphur or mineral salts were observed to be present.

GENERAL MINERALOGY

CINNABAR: Small quantities of cinnabar occur in the altered granite and tuffaceous rocks while larger amounts are present along irregular, iron rich seams in the altered rocks. It occurs as irregular, platy particles. It is one of the recent minerals of primary, hypogene origin.

METACINNABARITE: This mineral occurs in very much the same way as cinnabar, though it is not nearly so common. It occurs mainly as fine, black disseminations in irregular seams in the altered rock types.

HEMATITE: This mineral is abundant in narrow seams in the altered rocks. In color it resembles cinnabar and might easily be mistaken for that mineral. It usually occurs as a thin coating over parts of the altered rock types and this is especially true along cracks or seams. The mineral is probably a product of the solutions and gases which emanate from the deposits.

SULPHUR: Sulphur is abundant in Devil's Kitchen where it occurs in yellow crystals and as a black amorphous surface coating. Both types have been deposited directly from the gases being discharged. The yellow, crystalline type which forms both on the surface and in cavities below the surface, is being deposited at the present time in large quantities.

MINERAL SALTS: These salts include alum, iron sulphate and possibly several other types. They are to be found around vents where hot solutions or gases are being discharged. The alum occurs in a white, fibrous state as a surface coating. These fibres are very delicate and have a distinctly sour taste. Iron sulphate occurs as a green precipitate around the borders of the springs.

OPAL: This mineral is a constituent of the rocks in which the cinnabar and metacinnabarite occur. Opal occurs as a replacement product of the minerals of both the tuffaceous and granitic rock types. It is being deposited from silica bearing waters and gases at low temperature.

CHALCEDONY: Chalcedony occurs in much the same way as opal but is not nearly as abundant. It is being deposited from silica bearing waters.

KAOLINITE: Present as a common constituent of those granitic rocks which have undergone only moderate metamorphism. Upon being subjected directly to hot gases and solutions, however, the kaolinite is apparently replaced by opal.

ZIRCON: This mineral occurs in the altered tuffs and granitic rocks in considerable amounts. It is present usually as euhedral crystals. Since zircon is also a constituent of the granitic rocks, its presence may be assumed to be a result of the disintegration of these same rocks.

All the minerals listed above, except zircon, and probably cinnabar, are being deposited at the present time from hot solutions and gases emanating at many points in the deposits. Thus, there is no definite mineral paragenesis. The temperature at which these minerals are being deposited is quite low, probably not exceeding 200° Centigrade.

DESCRIPTION OF DEPOSITS

The deposits are of the extreme low temperature or telethermal type, being associated with the final stages of volcanic activity in the region. All the minerals are to be found at, or near the surface.

From west to east the deposits are known as Devil's Kitchen, Basin and Coso Basin.

In each deposit the ore minerals (cinnabar and metacinnabarite) occur as disseminated grains through the altered granite and volcanic tuffs. These minerals are also present in larger quantities along seams in these same rocks. The seams are usually quite narrow, rarely being over two or three inches in width. They are irregular in both strike and dip, some being horizontal or nearly so, while others are nearly vertical. They cannot be traced except by a great deal of detailed development work for any distance. In addition to these disseminations and stringers numerous small patches of "kidneys" of altered rock contain small amounts of cinnabar. In general, however, these have no definite arrangement and are found by accidmnt during development work.

In part, the character of the altered rock may have some influence in causing the precipitation of cinnabar from the solutions and this fact may be the reason for the presence of the patches of mineralized rock. The formation of the steeply dipping seams, however, is thought to be due to pre-mineral faults of small magnitude which are especially abundant in the Basin deposit. It is possible that narrow gouge seams resulted from this faulting and this gouge partly obstructed the upward flow of the gases or solutions along these fractures, causing a more rapid precipitation at these points than would otherwise have been the case. Due to the fact that the gases and solutions were not completely obstructed, only a small amount of their mineral content was deposited, the remainder on reaching the surface escaped into the atmosphere. In part, too, the gouge may have caused precipitation by chemical action. In regard to this Schuette[1] writes:

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1. C. N. Schuette, Quicksilver in Oregon; State of Oregon, Dept. of Geol. and Min. Ind. Bull. No. 4. 1938.

"Quicksilver has its origin in rock magmas. When a fracture in the earth's crust breaks through to such a magma, or is opened by pressure from such a magma, the ore minerals escape and ascend through the fracture toward the surface. These solutions often reach the surface quickly through large open fissures and emanate as hot springs without depositing any ore bodies. In many cases, however, these solutions are slowed down or partially obstructed by impervious gouges of fault slips. In such cases the ore minerals are deposited by cooling, by loss of pressure, or by precipitating agents."

More numerous, perhaps, than the steeply dipping seams, are those of moderate or no dip. This type is to be found both in Devil's Kitchen and the "Basin" deposit. These seams are much more irregular than those of steep dip. In places they appear to follow contacts between the layers of tuffaceous material and their irregularity is the result of the irregularity in the bedding of the tuffs. Again the seams follow the irregular contacts between the granite and the tuffs.

The presence of metacinnabarite in the deposits, and the absence of any native mercury, indicates that acidification has played a role in the precipitation of cinnabar. Likewise, a major role has probably been played by the decrease in pressure to which the solutions must have been submitted on nearing and after reaching the surface. The fact that cinnabar often occurs as a coating over the component grains of the altered rock in which it is found indicates that the mineralization must have, in general, been past alteration. The relatively porous nature of the altered rock permitted widespread dissemination of the mineralizing solutions. In the absence of any evident structural traps, with only a few minor exceptions, the result was the formation of a generally low grade deposit.

At the Coso Basin deposit none of these types of mineralization were observed. However, this may be mainly due to the fact that very little development work has been done. The main structural feature at this locality is a fault zone which strikes north 25° west, and dips 70° northeast. Apparently the hot solutions and gases ascended along this fault, as evidenced by the high degree of alteration of the rocks which border it. Very little cinnabar occurs as impregnations in this altered rock but cinnabar bearing seams may exist.

GENESIS OF THE DEPOSITS

There is little doubt that the cinnabar is a product of the hot gases and solutions in the area. It is a proven fact that where the rocks have been highly altered by these same gases and solutions, cinnabar is to be found. It is true that in most cases the amount of cinnabar present is very small, but this is thought to be due to the lack of suitable structural conditions rather than the absence of cinnabar in the gases and solutions. However, the presence of narrow seams containing fairly large amounts of cinnabar is considered to be direct evidence as to its deposition from hot solutions and gases.

It is possible that cinnabar is not being deposited everywhere at the present time as no mercury was deposited on a copper plate which was placed over a vent. Also some of the solutions which are being given off are acidic. However, these solutions and gases might differ in composition in different parts of the deposit and it is probable that small amounts of cinnabar are now being deposited in some zones.

ROCK ALTERATION

The hot solutions and gases, of hydrothermal origin, have produced extensive alteration of the different rock types. In the areas of greatest hot spring activity the original rock types are difficult to identify. However, the altered tuffaceous rocks still retain their banded appearance and in most places still contain fragments of obsidian. By recognizing these features it is possible to identify the different types in their highly altered condition.

The original granite is a relatively fresh, holocrystalline rock composed chiefly of quartz, albite, orthoclase, microcline, biotite and various accessory minerals such as apatite, titanite, zircon and magnetite. In the areas of greatest hot spring activity none of these minerals is present in the rock. There has been a large loss in specific gravity in the original rock and all of the above minerals have been replaced by clay, chalcedony and opal.

In areas of less severe alteration the original texture of the granite can still be recognized though there has been a large loss in specific gravity. The only original constituents left in the rock are quartz, some biotite and fragments of andesine. Even the quartz is somewhat corroded and partly replaced by clay (probably dickite). Calcite, chalcedony, and possibly some opal have been introduced into the rock.

The tuffaceous rocks have undergone silicification when in close proximity to vents where hot gases or solutions are emanating. The degree of silification varies greatly at different points. This silica is a low temperature variety and is probably largely opal with smaller amounts of chalcedony.

SAMPLING AND ASSAYING

A total of eighteen samples was taken from different points in the three deposits. Over half of these samples were picked from supposedly high grade seams and pockets in the altered tuff and granite. The remainder were taken from the various pits and open cuts from which material has been taken and put through the mill.

The results of the assays are as follows:

Sample number	Location	Per cent Mercury	Pounds of Mercury per ton
1	Large open cut in east part of "Basin" deposit from 2 ft. seam in altered granite.	.94	18.7
3	Large open cut in east part of "Basin" deposit --oxidized rock below brown capping material --above 4-5 ft. below surface.	.002	0.05
5	Small odit below opal bed-block seam 2 inches wide. ("Basin" deposit)	.11	2.2
7	Tunnel (100 ft.) beside shaft. "Basin" deposit, seam 2 inches wide between granite and breccia.	.36	7.2
9	Tunnel (100 ft.) beside shaft, "Basin" deposit, breccia above granite contact.	.22	4.3
11	Tunnel (100 ft.) beside shaft, "Basin" deposit, 2 ft. seam of red material above granite contact.	.68	13.5
12	Large open cut on west side of "Basin" deposit --altered breccia.	1.11	22.3
13	Large basin near top of Devil's Kitchen--below chute--narrow black seam in breccia.	0.0	0.0
14	Devil's Kitchen deposit --at top of chute-- pink colored altered breccia.	0.32	6.5

Sample number	Location	Per cent Mercury	Pounds of Mercury per ton
15	Devil's Kitchen deposit--altered breccia 100 ft. south of chute.	0.025	0.5
16	Devil's Kitchen deposit--altered breccia 125 ft. west of top of chute.	0.06	1.2
A	Coso Basin deposit--small pit east of basic lava flow--altered granite.	0.05	0.9

AGE OF MINERALIZATION

The mineralization in the region is very recent. In fact, such minerals as sulphur, opal, various mineral salts, hematite, and probably cinnabar and metacinnabarite, are being deposited at the present time in various parts of the deposit.

The beginning of the mineralization period can possibly be dated from the time of large scale volcanic activity in the region when the acid rhyolitic cones were formed. These cones are considered to be very recent. The emanations of hot solutions and gases, then, represent the final stages of volcanic activity.

ECONOMIC FUTURE OF THE DISTRICT

Although there is a considerable tonnage of potential cinnabar bearing material both in Devil's Kitchen and the "Basin" deposit, it is in average too low a grade to be considered economic. Again, there are many seams and pockets of fairly high grade material which in themselves can be classed as ore. However, the very nature of these seams and pockets makes the mining of them economically impossible. They are most erratic, can be followed only with difficulty and at considerable expense, and are found generally by accident in the course of other development work.

On the other hand, a small tonnage operation might prove successful. Selective mining and hand picking of the altered material would have to be resorted to. The returns from such an operation would not be high but might provide a living for a few men.