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GEOLOGY AND MINERALOGY

PRELIMINARY REPORT ON THE GEOLOGY AND URANIUM DEPOSITS OF HAIWEE RIDGE, INYO COUNTY, CALIFORNIA

By
W. Robert Power

March 1958

Salt Lake Branch Office, AEC
Grand Junction Operations Office
Salt Lake City, Utah

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SALT LAKE BRANCH

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ABSTRACT

The Coso formation of Plio-Pleistocene age, consisting of rhyolitic volcanics, fanglomerates, and lake beds, overlies granite unconformably. It records a period of repeated volcanism and faulting on Haiwee Ridge and almost continuous deposition in Owens Valley that began in late Pliocene or early Pleistocene time. It is overlain unconformably by andesites. Recent normal faults cut the andesites. Uranium minerals believed to be hydrothermal in origin are found along pre-Coso formation fault zones at the unconformity between the granite and Coso formation. Other uranium minerals are disseminated in the Coso formation.

INTRODUCTION

This study concerns the geology and occurrence of some uranium deposits on the west flank of the Coso Mountains near Olancha, California (fig. 1). The area lies within the Haiwee Reservoir quadrangle of the U. S. Geological Survey topographic quadrangle map series.

The uranium deposits occur on a north-south ridge that is separated from the main Coso Mountain range by a wide valley called Cactus Flat. The ridge is about 6 miles long and lies between Cactus Flat and the Haiwee Reservoir of the Los Angeles Water and Power Company. Owens Lake is about 8 miles to the northwest.

The ridge has been intensely prospected and most of it is staked out for uranium claims. It is easily accessible by dirt roads from Olancha, California, and from the south dam of Haiwee Reservoir. The ridge will be referred to in this report as Haiwee Ridge.

Haiwee Ridge is in a region of arid climate. There are no permanent streams and the chief vegetation is sagebrush, cactus, and a few Joshua trees.

Haiwee Ridge is asymmetric with a gentle west slope and a steep east escarpment. It rises from 3,759 feet at Haiwee Reservoir to 5,970 feet at the crest in a distance of 2 miles. From here it drops slightly over 1,000 feet to Cactus Flat in a distance of about a quarter of a mile. The ridge is limited on the south by a dry gully that drains a

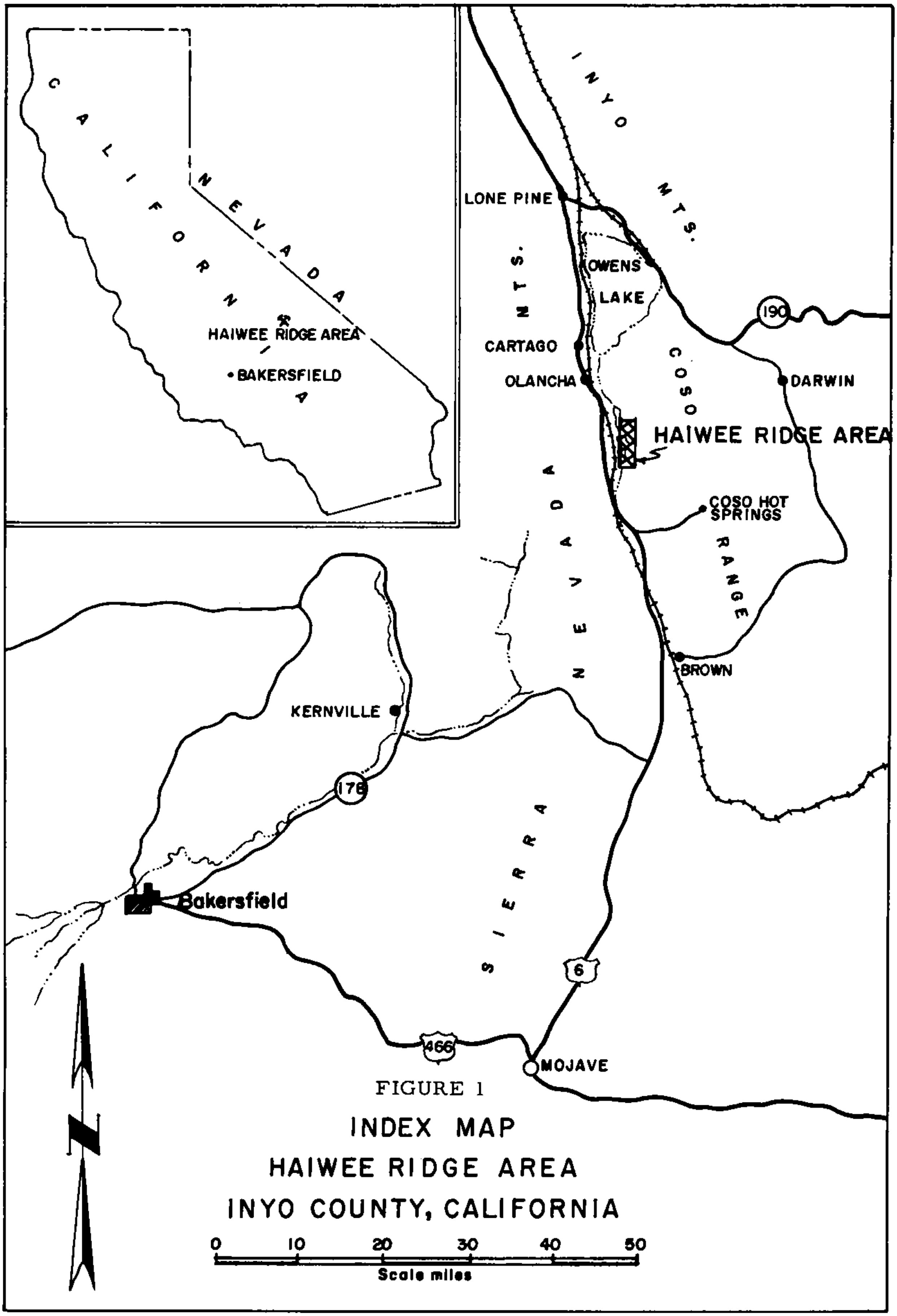

FIGURE 1

INDEX MAP
HAIWEE RIDGE AREA
INYO COUNTY, CALIFORNIA

southward extension of Cactus Flat. It is limited on the north by a dry gully just south of Cactus Flat road that drains the central portion of Cactus Flat. The central part of the ridge is highest. At the northern tip, the ridge crest drops to an elevation of about 4,800 feet; at the southern tip, it is approximately 5,800 feet. The eastern escarpment ranges from slightly over 1,000 feet high to about 300 feet at the northern tip and to about 800 feet at the southern tip.

Cactus Flat is a short broad valley about 2 miles wide with a narrow southern extension that parallels the southern part of Haiwee Ridge. It has a flat floor except in the southern extension which is a valley separating Haiwee Ridge from the rest of the Coso Mountains.

Haiwee Reservoir separates Haiwee Ridge from alluvial fans of the Sierra Nevada to the west.

The area mapped includes all of Haiwee Ridge and a narrow strip of the Coso Mountains immediately east of the southern extension of Cactus Flat.

GENERAL GEOLOGY

Nine geologic units of four general age groups have been mapped in the Haiwee Ridge area. They are from youngest to oldest:

- Recent deposits
  - Talus and alluvium
  - Wind-blown silt
- Younger volcanics - Pleistocene or younger
  - Andesite
  - Biotite tuff
- Coso formation - upper Pliocene and Pleistocene to Recent?
  - Lake beds
  - Rhyolite tuff
  - Fanglomerate
- Older crystalline rocks - Jurassic?
  - Granite
  - Hornblende gabbro

The Coso formation rests unconformably on the older crystalline rocks. It has been dated as upper Pliocene or early Pleistocene but may continue into the Recent. Younger volcanics rest unconformably on it. The Coso formation and younger volcanics record a history of repeated faulting and uplift accompanied by volcanism and sedimentation. This report is primarily concerned with the post-granite geologic history of the area.

Pre-Tertiary crystalline rocks

The oldest rocks are granite and hornblende gabbro. They are lithologically similar to rocks described by Knopf and Kirk (1918) in the Sierra Nevada. Hopper (1947, p. 412) has suggested that they are probably of the same age as the Jurassic Sierra Nevada pluton. No evidence bearing on their age was found in the present study.

Granite

The granite is medium- to coarse-grained, subhedral, and composed chiefly of quartz, microcline, and microperthite. It contains less than 10 percent albite-oligoclase. Biotite is the most abundant mafic mineral but only near basic inclusions does it exceed about 3 percent of the rock. In many outcrops biotite is absent, but small flaky "rust" spots suggest that it may only have weathered out.

The grain size of the granite varies. Normally it is medium- to coarse-grained, but along the crest of Haiwee Ridge it is almost pegmatitic. The changes are gradational.

Aplite dikes are locally common, but in most of the granite they are rare. Pegmatite dikes are extremely rare.

Sparse inclusions of feldspathic biotite schist reach a diameter of 15 feet. The contacts between inclusions and granite are generally sharp, but the granite tends to be richer in biotite near the inclusions. Some contacts near large inclusions are completely gradational. The inclusions show no preferred orientation either of their greatest length or of their internal structure.

The most striking feature of the granite is the intense jointing (fig. 2) which will be more thoroughly discussed in a later section. There are three principal joint sets. The first trends about N. 10° E. and dips steeply to the east; the second trends roughly east and dips steeply south; and the third trends about N. 15° E. and dips about 30° W. Erosion of the granite is controlled by these joints. The greatest erosion is along the east-west joints, but the first set is most intense.

Figure 2. Looking north at jointed granite overlain by Coso formation. Haiwee Reservoir and Owens Valley in background. Note that the jointing extends from the granite into the Coso formation.

The first two sets parallel joints in the Sierra Nevada west of Haiwee Ridge (Mayo, 1947, fig. 2, p. 497).

Just east of the map area at the Beebe mine, the granite invades a body of feldspathic biotite schist which may be a roof pendant. The contacts are generally sharp, but in places are gradational; they cut across the structure of the schist. Apophyses of the granite extend into the schist. These features plus the general uniformity of the granite indicate that the granite was formed by the intrusion and solidification of a magma.

Hornblende gabbro

Small bodies of hornblende gabbro occur about 1 mile north of the Ontario mine and just east of the Inland Oil claims at the base of the east escarpment of Haiwee Ridge. The gabbro is composed chiefly of zoned plagioclase (An_{30-55}) and hornblende with lesser amounts of sphene, biotite, and magnetite. The texture is extremely variable and ranges from fine grained to coarse pegmatitic. The fine-grained rock has subhedral plagioclase laths with intersertal hornblende. The coarse pegmatitic rock has large euhedral hornblende crystals ranging up to 2 inches long. Irregular pods of the coarse pegmatitic material are found within the generally fine- to medium-grained rock.

The hornblende gabbro is poorly exposed and, although outcrops of the gabbro were found within a few feet of granite outcrops, no contacts between the two were seen.

Knopf and Kirk (1918, p. 69, 70) describe similar hornblende gabbros in the Sierra Nevada. They found conflicting evidence as to their age relationship to granites but thought that the more basic rocks were older than the granites (1918, p. 72).

Coso formation

The Coso formation was named by Schultz (1937, p. 79). It consists of sediments and associated pyroclastics on the east flank of the Coso Mountains south of Keeler, California. Earlier workers had described these rocks without giving them a formational name (Fairbanks, 1896; Campbell, 1902; W. T. Lee, 1906; C. H. Lee, 1912; Knopf and Kirk, 1918). Fairbanks assigned the rocks to the Miocene (1896, p. 67). Knopf and Kirk found ostracods in the sediments near South Dam of the Haiwee Reservoir. The ostracods were examined by E. O. Ulrich who was unable to make specific determination, but thought that some were marine to brackish-water forms while others resembled fresh- to brackish-water genera. Ulrich thought the age to be Tertiary or younger (Knopf and Kirk, 1918, p. 51). Charles D. Walcott found fresh-water fauna in similar lake beds near Big Pine, California. The fresh-water fauna were examined by W. H. Dall who identified them as Pliocene to Recent forms and thought the whole assemblage was most likely Pleistocene (Walcott, 1897, p. 342).

Schultz examined vertebrates from alluvial gravels that lie on granite and are overlain by tuffs about 8 miles north of Haiwee Ridge (Schultz, 1937, p. 78-80). He dated the fauna as upper Pliocene or early Pleistocene and thought that they represented a time of cool humid climate (1937, p. 81). After discussing the difficulties of establishing the Pliocene-Pleistocene border, Schultz (p. 95-98) favored a first glacial or Nebraskan age for the fauna of the Coso formation on the basis that they and related fauna in Europe represented the first climatic change toward glacial conditions.

The alluvial material in which the vertebrate fauna were found is reported to be about 300 feet thick (Schultz, 1937, p. 80), and Hopper (1947, p. 415) found it to be overlain by about 200 feet of thin-bedded, white and light-buff lake beds with interbedded white rhyolite tuffs. The lake beds reported by Hopper are the same as those mapped by this writer. The area that Hopper mapped is mostly north of, but includes part of, the area mapped by the present writer.

The Coso formation includes fanglomerates, lake beds, and rhyolitic tuffs. The fanglomerates lie on the east flank of Haiwee Ridge; they grade into, interfinger with, and are overlain by lake beds. The lake beds occupy Owens Valley and extend around the northern end of Haiwee Ridge into Cactus Flat. Rhyolite tuffs predominate in the southern part of the map area and are interbedded with the lake beds and fanglomerates elsewhere.

In Owens Valley, the Coso formation is essentially a conformable sequence of lake beds and tuff that dips about 10° W. On the flank of Haiwee Ridge, the formation changes to fanglomerates, the dips become steeper, and unconformities are common. The lake beds and fanglomerates are derived from both the underlying granite and the rhyolite tuffs. The Coso formation is thus a heterogeneous assemblage of rock types which records repeated volcanism, uplift, and erosion on Haiwee Ridge, and almost continuous deposition in Owens Valley.

The Coso formation rests unconformably on an uneven and blocky erosion surface cut on the granite. Deep open cracks along joint surfaces in the granite were filled with arkosic and pyroclastic material (fig. 3) from the basal bed of the Coso formation. The erosion surface was cut at least in part while the fanglomerate of the Coso formation was being deposited because coarse conglomerates of the fanglomerate can be traced to granite ledges and they surround outliers of the granite.

Fanglomerate

The arkosic fanglomerate is wedge shaped and has its source at and slightly east of Haiwee Ridge. It is extremely coarse at its source (fig. 3) and it grades westward into fine-grained, thin-bedded, and ripple-marked sands of the lake beds. Wedges of boulder conglomerate that grade within a few hundred feet to pebble conglomerate and coarse sand can be traced to granite ledges that are believed to be exhumed fault scarps.

Near the Ontario mine, two units of the fanglomerate are separated by beds of crystal-ash tuff and vitric-ash tuff. The lower unit is a coarse arkosic sand and pebble conglomerate that is exposed in the bottom of gullies to the west of the Ontario mine. Its source is presumed to be buried granite ledges at the Ontario mine.

The upper unit is a coarse arkose. Near the crest of Haiwee Ridge, it rests on granite except for small intervening patches of tuff. In places, it extends to the east escarpment of Haiwee Ridge and in the southeast corner of the map area similar conglomerate was found on the next ridge east of Haiwee Ridge.

At its source, the fanglomerate is composed predominantly of granite fragments, but it contains small amounts of pyroclastic material in the finer fractions. To the west, as the grain size becomes finer and the sorting better, the proportion of volcanic material increases. About 1 mile north of the Ontario mine the fanglomerate covers a body of hornblende gabbro. The mafic minerals of the gabbro weather so rapidly that recognizable fragments of gabbro in the conglomerate are found only within a few feet of the actual gabbro outcrops. However, west of the gabbro the amount of fine material in the conglomerate increases and the color changes from gray to deep brown. This color change extends over half a mile north and south of the gabbro outcrops suggesting that the gabbro may be more extensive than is indicated by its outcrops.

The fanglomerate is cemented with cryptocrystalline silica near its source at the exhumed fault scarps. The silicified zone is limited to a long narrow strip parallel to Haiwee Ridge. Elsewhere the rock is

Figure 3. Coarse arkosic conglomerate at base of the Coso formation.

cemented with calcite. The amount and firmness of the cementation decreases to the west. Near the source where cementation is strongest, the fanglomerate is very resistant and dip slopes have formed on it near the crest of Haiwee Ridge (fig. 3). To the west where cementation is weaker, the fanglomerate is generally less resistant than interbedded tuffs.

<u>Lake beds</u>

The lake beds of the Coso formation are thin-bedded, white to buff silts and fine-grained sandstones. They interfinger with and overlie the fanglomerate on Haiwee Ridge and they extend westward across Owens Valley where they are covered by alluvial fans of the Sierra Nevada. North of Haiwee Ridge they are warped into an anticline along the axis of the ridge (fig. 4). They are covered by recent alluvium in Cactus Flat.

The lake beds are composed mostly of reworked volcanic debris, but the sandy beds contain arkosic material as well. Ripple marks are common. Tuff is interbedded with the silts and sands. The amount of interbedded tuff is greatest in the southern part of the area.

The dip of bedding planes is generally 6° to 10° W., but becomes steeper along the flank of Haiwee Ridge. Gentle west-plunging anticlines and synclines are superposed on the general west-dipping structure along the west flank of Haiwee Ridge near South Dam.

Evidence of subaqueous sliding is common in the lake beds. In places, sliding along bedding planes has produced decollement-type folds. Convolutions and crinkling of beds are common. In all cases the fold axes parallel the axis of Haiwee Ridge.

The total thickness of the lake beds is unknown. Over 350 feet are exposed. Willis T. Lee (1906, p. 7) reported a well boring 1,028 feet deep in "Haway Meadows" (the present site of Haiwee Reservoir) that did not reach the bottom of the formation.

<u>Rhyolite tuff</u>

Interstratified massive beds of rhyolite tuff are common throughout the Coso formation, and they predominate in the southern part of the map area. They include vitric-ash tuff, pumice-lapilli tuff, and crystal-ash tuff. Fragments of granite and metamorphic rock are common in all of the tuff beds. Individual beds range from 1 foot to over 50 feet thick.

Figure 4. Vertical flow structures in andesite.

Vitric-ash tuff and pumice-lapilli tuff are the most common types. Pumice is intermittently mined near the southern margin of the map area and to the southeast.

The crystal-ash tuffs are composed predominantly of quartz, feldspar, and granite fragments. The quartz and feldspar are identical with those of the granite basement. The crystals and rock fragments are cemented with a matrix of fine white ash.

None of the tuffs are fused, but nonetheless they form compact resistant beds.

Tuffs in the bottom of a shallow west-plunging syncline between South Dam and the Ontario mine are partially silicified. They are light buff to brown in contrast to the generally white unsilicified beds. They are mostly pumice-lapilli tuffs with walnut-size pumice fragments imbedded in an ash matrix. The matrix only has been silicified and on exposed surface the pumice fragments weather out giving the rock a spongy appearance. This silicification was general over an area about 1 mile square and the beds are overlain by unsilicified beds of the same or similar composition. Elsewhere the tuffs are unsilicified except along linear zones which are believed to mark the trace of old fault zones.

The total thickness of the tuffs is at least 400 feet and probably considerably more. One massive bed of pumice-lapilli tuff was traced for a distance of 3 miles from the Ontario mine to the Coso mine. This is probably only a fraction of the total extent of the bed.

The lateral extent and the composition of the tuffs suggest that they resulted from the ultravulcanian or nuée ardente-type explosions. The greater predominance of tuff in the southern part of the area and known pumice deposits being mined to the southeast suggest that the vents may be in that general area.

Younger volcanics

Biotite tuffs

Pumice-lapilli tuff, distinguished from the rhyolite tuff by the abundance of biotite in the pumice fragments, overlies the Coso formation unconformably in the southern part of Haiwee Ridge. It forms a more or less even mantle on top of an erosion surface on the Coso formation. A few-hundred yards west-southwest of the Ontario mine this tuff is separated from underlying rhyolite tuff by a very coarse breccia conglomerate composed of fragments of arkose and tuff. In places, the tuff is well sorted and stratified indicating that it was in part reworked by water; but for the most part, it is poorly sorted and contains many fragments of granite and metasediments. It ranges from a few feet to over 40 feet thick. The thickest accumulations tend to be in valleys or hollows. This tuff is not found in the northern half of the map area except as tiny unmappable patches between the andesite and the Coso formation. It is moderately well indurated and tends to form ledges in modern gullies. It is not, however, fused or welded. It is believed to have formed as volcanic showers, with only local reworking by running water.

Andesite

Andesite flows cover much of the northern and southern parts of Haiwee Ridge. The surface on which the flows were extruded was youthfully dissected with steep gullies separated by relatively plain undissected areas. The andesites spilled over these surfaces, filled the gullies, and spread out thinly over the undissected intergully areas. The thickness of the andesites thus varies with the underlying surface. The total exposed thickness ranges from slightly over 400 feet near the pumice mine at the southern margin of the area to less than 5 feet at the lower end of some flows in the northern part of the area.

The andesite is a perlitic, glassy rock that contains phenocrysts of plagioclase, biotite, and hornblende and traces of magnetite and pyroxene. The plagioclase is mainly andesine, but has complex oscillatory zoning. The biotite occurs as euhedral crystals that are almost black from exsolved magnetite. Hornblende similarly has exsolved magnetite and it forms reaction rims around rare pyroxene crystals. The groundmass contains abundant microlites, most of which are indeterminable, but many take a yellow stain when treated with hydrofluoric acid and sodium cobaltinitrate. They are probably potash feldspar. Potash feldspar also occurs with exsolved magnetite in the biotite crystals. Although the mineralogy of the phenocrysts indicates that the rock is an andesite, the abundant biotite and indications of potash feldspar suggest it is much more potassic, possibly a latite or trachyte.

The andesite has a strongly developed internal layering caused by parting planes and color changes. The color differences are in the glassy matrix of the rock; phenocrysts do not vary from layer to layer. On fresh surfaces, the colors vary from light and dark gray to almost black; on weathered surfaces, some layers are red. The layers range in thickness from 1 mm to over 30 mm. Parting planes are along the planes of color change. In the interior of thick massive flows, the layering is generally parallel to the underlying surface; it is interpreted as flow structure.

The surface of the flows is extremely blocky. They resemble talus accumulations with loose jumbles of disoriented blocks. This blocky character extends throughout the entire thickness of many of the thinner flows. Near the surface of some flows, blocks of andesite showing layered structure are imbedded in massive andesite of the same composition. These blocks are oriented parallel to the surface of the flow. Near the base of flows, blocks of underlying tuff have been caught up and mixed with disoriented blocks of andesite. This mixture has been cemented with a matrix of more or less massive andesite.

Columnar jointing developed in a flow that came down a gully about three-quarters of a mile east-southeast of the South Dam of the Haiwee Reservoir. The columns average about 8 inches in diameter. They extend nearly to the bottom of the flow, but near the surface they pass into a blocky zone. The columns are straight and inclined toward the side of the gully. The orientation is a result of cooling from both the upper and lower surfaces of the flow. The exposed thickness of this flow is about 80 feet, but part of the top has been eroded away.

Superposed flows were not recognized. Just north of the pumice mine in the southern part of the map area, the thickness of the andesite is over 400 feet. Throughout this thickness,the composition is very uniform and layered flow structure is well developed. This is apparently one very thick flow.

Feeder dikes are indicated at several localities by vertical flow structure (fig. 4). The largest of these is exposed in an east gully at the northern end of Haiwee Ridge. North-trending flow structures are vertical in the central part of the dike and fan out along the sides. Blocky flows extend both east and west. At the west margin, a block of the Coso formation is tilted steeply toward the dike.

An oval body of andesite just southwest of the Coso mine shows predominantly vertical structure. Around its margin,beds of the Coso formation are tilted steeply toward the andesite. Figure 5 is a photograph taken in the gully just north of the andesite body. The beds that are dipping east (left) in this photograph appear to have been thrust up and over the west-dipping beds as the andesite magma forced its way through the Coso formation.

Figure 5. Looking south at tilted sediments on the west margin of an andesite dome. The east (left) dipping beds are believed to have been thrust over the west dipping beds.

Figure 6 illustrates how the andesites were probably extruded. They came out as domelike masses which repeatedly crusted over. The frozen crusts broke up as the still liquid interior of the mass continued to move. The lava carried blocks of the frozen crust in places orienting them parallel to the direction of flow. As the domes spread upward and outward, blocks of the country rock were thrust upward and outward. The internal part of the domelike masses retains flow structure, but, where the flows spread out, they are predominantly blocky and retain little or no internal structures.

Isolated bodies of andesite lying in the tuff in the southern part of the area show similar vertical flow structure and are probably feeder dikes.

Talus and alluvium

Talus has accumulated at the base of recent faults and alluvium covers much of the lowlands and valley bottoms. In many places, slope wash on hill sides forms thin deposits with internal stratification parallel to the slope and with a marked angular discordance with the underlying material. The same deposits are essentially conformable with the underlying material in valley bottoms. This is best illustrated at the south end of Haiwee Ridge where recent deposits which are essentially conformable with the Coso formation in the flat floor of Owens Valley are continuous with material showing marked angular discordance on the side of Haiwee Ridge.

These recent deposits illustrate a process that was probably going on throughout the deposition of the Coso formation. It would be very difficult to distinguish the recent conformable deposits in the floor of Owens Valley from many of the sandy beds of the Coso formation.

Windblown deposits

Most of the Coso formation is covered by a discontinuous thin veneer of windblown material. Thicker deposits of fine silt and sand, probably wind-deposited, are found in hollows and protected areas along the west flank of Haiwee Ridge. These have been mapped separately. Joshua trees invariably grow in these areas, but generally not elsewhere. Bulldozer cuts made by uranium prospectors reveal these deposits to be as much as 15 feet thick and to be composed only of silt and very fine sand. They are unstratified and unconsolidated.

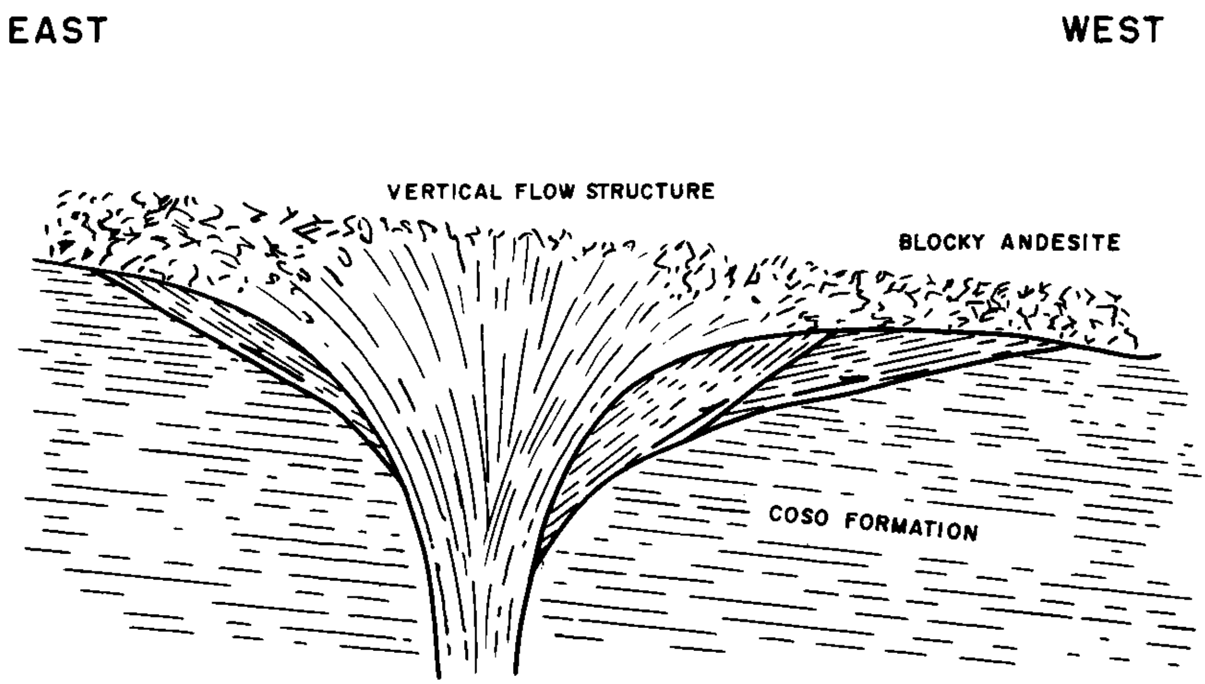

FIGURE 6

Diagramatic section across andesite dome showing manner of extrusion. The top of the dome has been eroded away.

Structural geology

Geologic structures are described under three subheadings--joints and shear zones, faults, and folds--but all are probably interrelated. Faulting in the general area during late Tertiary and Quaternary time has long been recognized by geologists. Walcott (1897) found evidence of uplift by faulting of 3,000 feet or more in the Inyo (White) Mountains. Late Tertiary and Quaternary movements along the Sierra Nevada fault block have long been known (King, 1878; LeConte, 1886; Turner, 1903; and others). The violent earthquake of 1872 in Owens Valley produced east-facing scarps as high as 20 feet (Whitney, 1872, and Gilbert, 1890).

Post-Pleistocene faulting on Haiwee Ridge is proved by offsets of the Coso formation. Planes of movement are believed to be parallel to and controlled by joints in the granite. Sharp flexures in the Coso formation probably reflect faults in the basement.

Joints and shear zones

The granite is intensely jointed. Three hundred joints were plotted on a Schmidt net and contoured (fig. 7). The results show what is also readily apparent in the field--there are three principal sets of which the first trends about N. 10° E. and dips about 65° E.; the second trends about east-west and the average dip is about 70° S.; and the third trends about N. 15° E. and dips about 30° W.

The first set is the most intense (figs. 2 and 8). The joint planes are generally less than 1 foot apart and in many places less than 1 inch. In places fracture planes that are parallel to the joint surfaces cut across individual mineral grains. Locally the rock is brecciated with anastomosing fracture planes that in general trend parallel to the joint surfaces. Zones of very intense jointing grade into brecciated and partially mylonitized zones.

In some places, slightly divergent joints are present. The most persistent joints dip steeply to the east and others cross between them at a slightly lower dip.

It was generally impossible to determine any offset along these joints but locally small aplite dikes are displaced a fraction of an inch along the joints. The displacements indicate that the east side moved upward or northward.

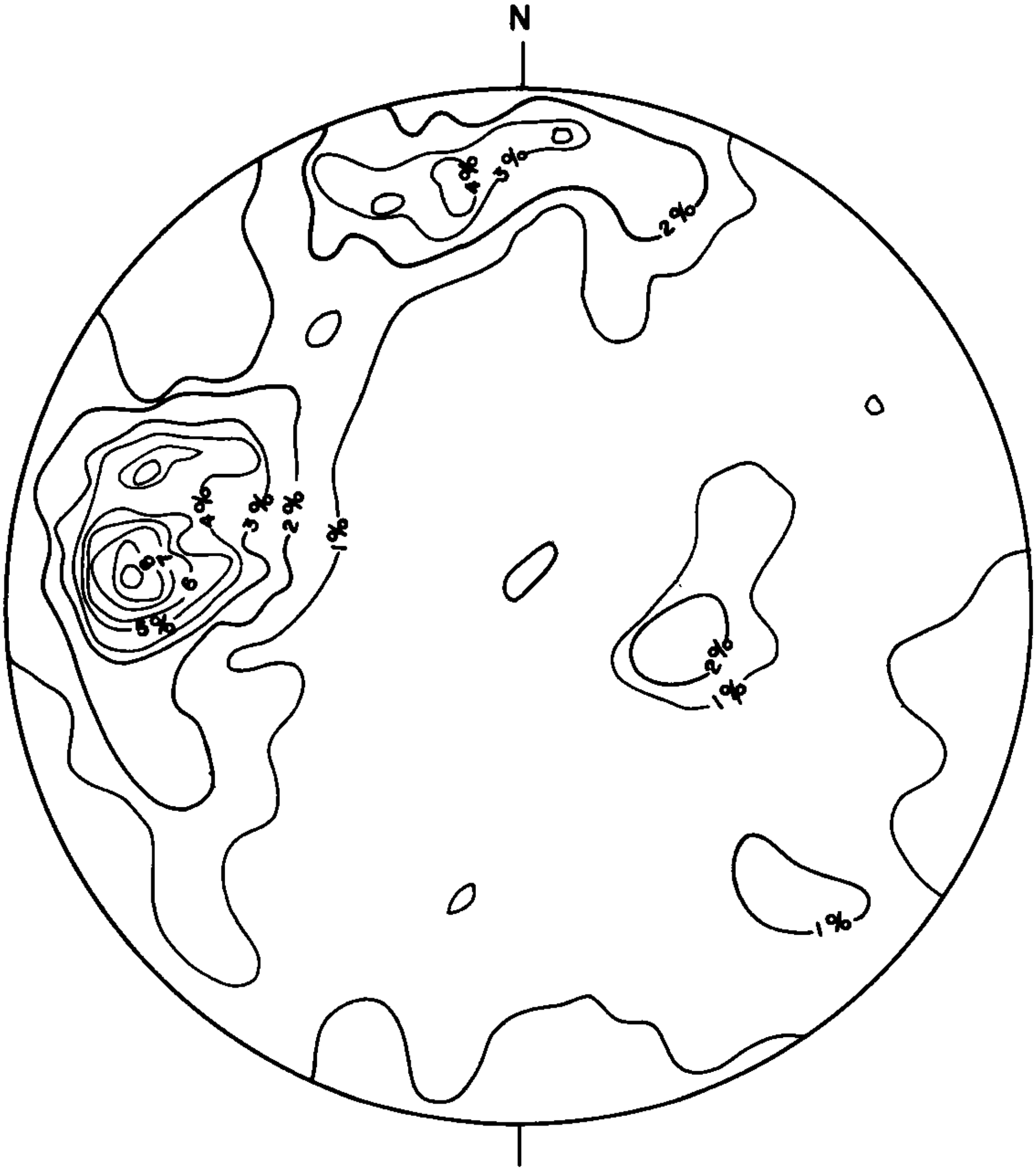

FIGURE 7

Orientation diagram of 300 joint measurments. Contours drawn on 1% intervals.

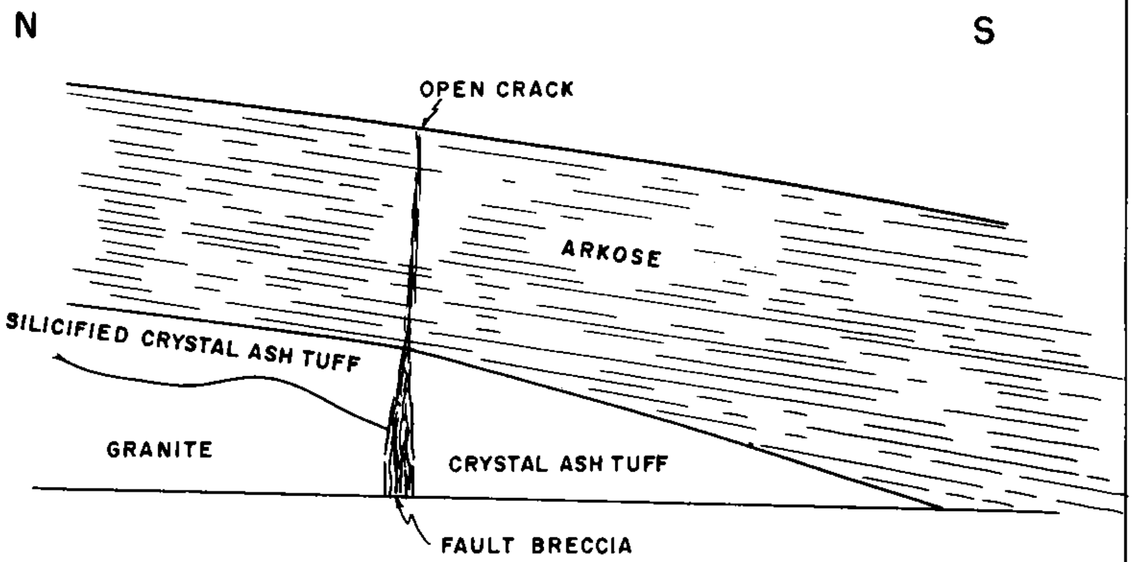

FIGURE 8

East - West fault near Ontario mine shows crystal ash tuff brought into vertical contact with granite. Main fault movement was pre-arkose.

The second joint set is slightly less well developed than the first, but due to erosion it shows up most strikingly on air photos. In general the characteristics of these joints are similar to those of the first set. The joints grade into shear zones where the rock is intensely brecciated, fracture planes cut across mineral grains, and zones of brecciation grade into zones of mylonitization.

Both joint sets extend weakly into the overlying Coso formation (fig. 1), but in the sediments jointing is less intense and more variable.

Mayo (1947) reported joint sets in the Sierra Nevada directly west of Haiwee Reservoir that are parallel to the first two sets on Haiwee Ridge. He believed that the fracture systems predated and controlled the intrusion of granite (1941, p. 1073-1074; 1947, p. 498) and that Tertiary-Pleistocene faulting has followed the old pre-Jurassic fracture patterns (1941, p. 1061-1069, 1080; 1947, p. 500). No evidence of pregranite structure patterns was found on Haiwee Ridge, but postgranite movement along the first two joint sets is indicated by fractures that cut individual mineral grains, offset aplite dikes, and by joints that extend into the Coso formation.

The third joint set is generally parallel to the surface of granite outcrops. It is less well developed than the other two and shows no evidence of shearing or brecciation. It is a sheeting essentially parallel to the granite surface, and is probably, therefore, an exfoliation effect.

Faults

The earliest recognized faults in the area occurred before the deposition of fanglomerate. The main faulting was north trending with the east side uplifted, but some faults cut across the main zone in a west to northwesterly direction.

The best evidence for the north-trending fault zone is the fanglomerate which for much of the length of Haiwee Ridge can be traced to but not beyond a nearly continuous ledge of granite that forms a west-facing scarp. Immediately below this scarp the fanglomerate is composed of coarse, angular fragments of rock identical with the granite. The fanglomerate is silicified near the source at the granite ledge, but not elsewhere. The scarp can be traced almost continuously from slightly south of the Ontario mine to the Coso Uranium Company properties, a distance of nearly 3 miles.

West and northwest of the Ontario mine the fanglomerate extends eastward beyond the line of the scarp as tongues that in places reach the east face of Haiwee Ridge. The tongues of fanglomerate are not faulted along the line of the scarp, but about one-half mile northeast of the Ontario mine they and overlying rhyolite tuff are strongly silicified along linear zones in line with the scarp. These silicified zones stand out as parallel north-trending ridges about 15 feet high. The silicified zones probably mark the trace of the old fault zone that is now overlain unconformably by the fanglomerate and tuff.

At the Ontario mine a second scarp about 400 feet west of the one described above is partially buried by younger rocks. It is exposed in a cliff at the Ontario mine where material to the west has slumped exposing a granite ledge. The granite ledge is overlain by an arkosic bed of the fanglomerate. Thin discontinuous patches of rhyolite tuff lie between the arkose and the granite. West of the granite ledge the same bed of arkose overlies over 100 feet of rhyolite tuff and sediment. This underlying tuff and sediment probably abuts against a steep buried ledge of granite, but the contact is not well exposed (fig. 9).

Along the crest and west flank of Haiwee Ridge there are numerous zones of intense jointing and brecciation in the granite, that trend parallel to the fault scarps described above. The dip of these brecciated zones is steeply to the east. The uplift was probably along these east-dipping shear zones.

Mineralized zones are found at several places along the exhumed fault scarp. At the Ontario mine, uranium and pyrite occur in silicified zones at the contact between granite and fanglomerate. The Seneca claims and two prospects of the Coso Uranium Company are on or within a few feet of the main exhumed fault scarp. The radioactivity of the silicified zones that cross the arkose in line with the major north-trending fault scarp is, at the surface, about two to three times the normal background in the area.

Prefanglomerate west- to west-northwest-trending faults are exposed along the crest of Haiwee Ridge and in the cliff at the Ontario mine. Most of these faults are zones of brecciation and in places mylonitization of the granite. The shear zones grade into the east-trending joint set. The prefanglomerate age of the faults is shown by the lack of any offset of the overlying Coso formation where that formation overlies on the granite.

Some of these fault zones are silicified and mineralized at their contact with the overlying Coso formation. They have a central zone of

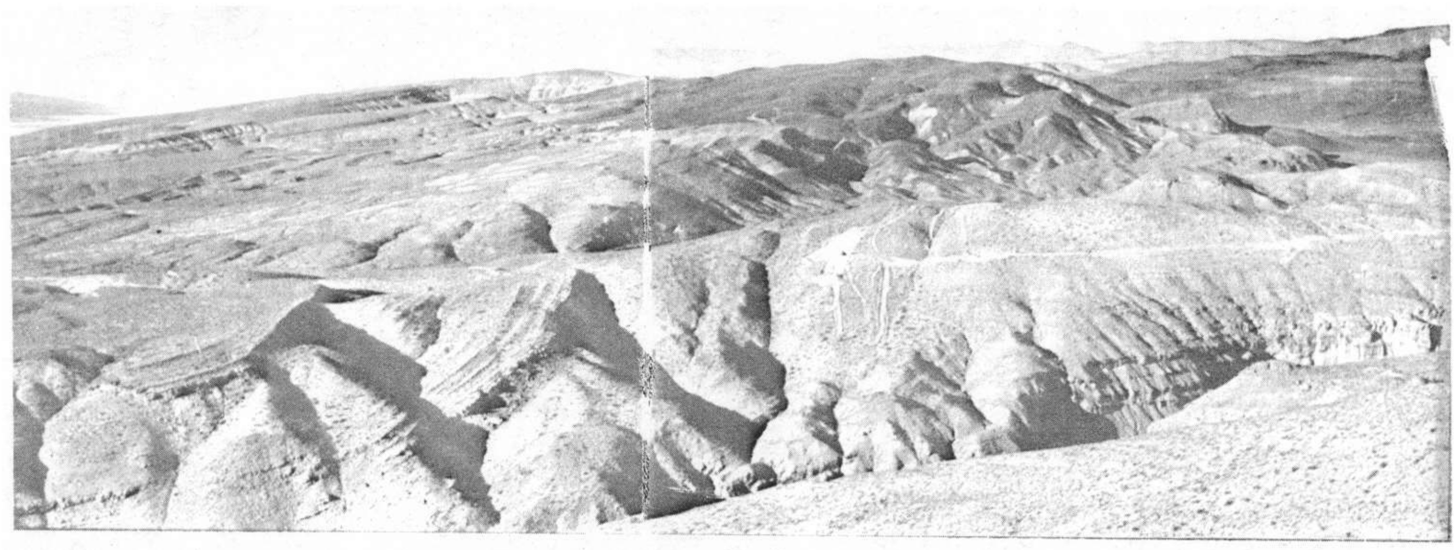

Figure 9. Looking north from Haiwee Ridge. The Coso formation is warped into an asymmetric anticline.

fragmented granite and pyroclastic material that is cemented with secondary silica. Within this zone vein and podlike masses of black mineralized rock contain pyrite and uranium minerals. On weathered surfaces much of the pyrite is altered to limonite. Horizontal drifts at the Ontario mine and the Coso Uranium Company property show that the silicification and mineralization were limited to a narrow zone at the contact between the granite and overlying Coso formation. Within the granite there is only a central zone of brecciated or mylonitized granite bordered by 1 inch to several feet of cataclastic granite.

The presence of pyroclastic material in the fragmented zone of faults seems to indicate that the fault zones had been eroded before the Coso formation was deposited. When the pyroclastics of the Coso formation were deposited, tuffaceous material was dropped into the eroded fault zones and mixed with fragmented granite. The mixture must have been silicified later because the silicification extended into the overlying fanglomerate.

A prefanglomerate fault that brought crystal ash tuff into vertical contact with granite is exposed in the cliff at the Ontario mine (fig. 8). A fracture extends from this fault through the overlying arkosic bed of the fanglomerate, but the arkose is not offset along it.

Normal faults of small displacement (up to 20 feet) that cut the Coso formation but not the younger biotite-rich tuff and andesite occur west of the Ontario mine and at the northern end of Haiwee Ridge. Some of these faults dip to the west, others to the east. The dips vary from about 40 to 60 degrees. Similar faults were found in the Coso formation along the central part of Haiwee Ridge between the Ontario and Coso properties, but in this region only east-dipping faults were seen and it is not known whether they are pre- or postandesite. No mineralized zones were observed along these faults.

The most recent faults have cut the andesite. They are predominantly east- or southeast-dipping normal faults, but in the northern part of the area some are west-dipping normal faults. The east-dipping normal faults are responsible for the eastern escarpment of Haiwee Ridge and the maximum dip-slip displacement along that escarpment is at least 2,000 feet.

North of the Ontario mine the faults strike about N. 15° to 20° E. and are arranged en echelon in a zone that strikes about N. 5° E. The great bulk of the displacement is along single faults (or narrow fault zones) which form the east escarpment of Haiwee Ridge. Many small faults with displacement of 25 feet or less and with the same general strike and dip of the main faults occur along the west flank of Haiwee Ridge.

South of the Ontario mine the general strike of the postandesite faults is about N. 60° E. and the displacement is more evenly divided among three main faults, but further west other normal faults of the same general strike and dip show small displacement.

Some secondary silica has formed along the most recent faults. It generally forms cockscomb encrustations along fractures. It does not permeate the rock. Shattered vein quartz is found in the granite along some of the most recent faults.

Calcite has filled fracture planes in the sediments and is more widespread than the silicified zones. In places it is found in close association with silica, but more typically it is found either higher in the section or surrounding the silicified zones.

Folds

At the north end of the map area the Coso formation is warped into an asymmetric fold (fig. 9). The beds which generally dip about 10° W. on the western flank of Haiwee Ridge are warped up sharply and within a distance of about 300 feet change from 10 to 40 degrees and then flatten out to no dip. To the east of this sharp flexure the beds dip very gently east and disappear under recent alluvium of Cactus Flat.

The sharp flexure is north of and in line with steep, west-dipping normal faults on the west flank of Haiwee Ridge. The same forces that produced the normal, west-dipping faults must have produced the sharp west-dipping flexure and there are probably basement faults under the flexure.

On the west flank of Haiwee Ridge near the Ontario mine the Coso formation is warped into gentle west-plunging anticlines and synclines. The overall dip remains west. These gentle west-dipping structures may reflect movements in the basement granite along the east-trending faults.

Geologic history 1/

The earliest postgranite event recorded in the Haiwee Ridge area is the formation of the Plio-Pleistocene Coso formation fanglomerates. Although arkosic conglomerates are the oldest postgranite rocks seen in the area, older rhyolite tuffs are not precluded because they may have been eroded away from the present summit area of Haiwee Ridge during the first uplift that caused the fanglomerate to form.

The first uplift included areas to the east of Haiwee Ridge as well as the ridge itself. The uplift was relative to Owens Valley and from evidence in the Haiwee Ridge area it is not known whether Owens Valley was absolutely depressed or the area east absolutely raised. Hudson (1955, p. 869) cites evidence to indicate that "the deeper grabens east of the summit (of the Sierra Nevada) have suffered absolute depression".

After cessation of rhyolite volcanism in the Haiwee Ridge area there was more relative uplift along Haiwee Ridge and moderate erosion of the Coso formation. This erosion was followed by eruption of the younger volcanics. First biotite-rich tuffs were laid down and partially eroded. This was followed by extrusion of the andesites. Large-scale faulting along the eastern side of Haiwee Ridge followed extrusion of the andesites.

1/ Following is a brief summary of the Cenozoic history of the Sierra Nevada region as compiled from Lindgren (1911, p. 9-11), Matthes (1930, p. 28-30), Hudson (1955, p. 859), and Axelrod (1957, p. 37-40). Although the various authors disagree on details of the time and intensity of successive geologic events, there is general agreement on the sequence of events.

After general beveling of the Nevadan mountains in Cretaceous time there was general broad, epiorogenic uplift of the Sierra Nevada and adjacent parts of the Great Basin. This was accompanied in early Tertiary time by rhyolitic volcanism. The rhyolites were eroded and followed by a period of andesitic volcanism. Finally in early Quaternary time block faulting formed the present eastern scarp of the Sierra Nevada. Hudson's correlation chart (1955, p. 837) shows rhyolite tuff in the Middle Eocene, overlain unconformably by Oligocene or Eocene andesite tuff that is in turn overlain unconformably by Miocene-Pliocene andesites. Axelrod (1957, p. 28) places the Valley Springs formation "which contains as much as 500 feet of rhyolite tuff and associated fluviatile material" at the Mio-Pliocene border. The Valley Springs formation is overlain by the andesitic Mehrten formation (Axelrod, 1957, p. 27).

Cactus Flat formed as a graben. There was some uplift of Haiwee Ridge relative to Owens Valley at this time as shown by west-dipping normal faults that cut the andesite at the northern end of Haiwee Ridge. Erosion of Haiwee Ridge continued to the present and alluvial deposits formed in Owens Valley and Cactus Flat.

The silicification along prefanglomerate fault zones affected the rhyolite tuffs. Hyaline silica is common as encrustations in the andesites. No similar silicified zones were seen along the most recent faults. The silicification probably occurred during or after the eruption of the younger volcanics, but before the youngest faulting that cuts the andesites. A genetic connection between the eruption of the younger volcanics and the silicification is suggested. Hydrothermal solutions either emanating directly from the andesitic magma, or heated by it, probably followed the prefanglomerate fault zones in the granite and were "trapped" at the unconformity overlain by the Coso formation.

URANIUM MINERALIZATION

Two types of uranium mineralization took place on Haiwee Ridge. They were: (1) associated with silicified zones in prefanglomerate fault zones, and (2) associated with disseminated deposits in the Coso formation. They will be discussed separately.

Uranium deposits in silicified zones

The best example of this type of deposit is at the Ontario mine. The silicified zones are at the contact between granite and a gritty arkose of the Coso formation. Brecciated fault zones cut the granite, but not the arkose. Cryptocrystalline silica has permeated the brecciated zones near the contact and has extended into the sediments for a distance of 10 to 15 feet. Irregular podlike and veinlike black material extends through the silicified zone in an anastomosing network. Under highest power of the microscope the black material is either completely opaque or it is faintly birefringent and shows an aggregate structure resembling the cryptocrystalline silica. The black color comes from tiny opaque particles most of which are barely resolvable by the microscope, but some of which can be identified as pyrite. The black material has the highest radioactivity. The uranium mineral is probably uraninite, but positive identification has been impossible. The silicified rock surrounding the black material is slightly less radioactive than the black and contains a yellow, micaceous mineral tentatively identified as autunite.

A 40-foot horizontal tunnel has been driven on the fault zone removing most of the black material which was concentrated in the fault zone. The silicified zone is limited to the first 10 to 15 feet of the tunnel (fig. 10). The rest of the tunnel follows a zone of brecciated granite with a thin seam of clayey gouge in the center. No secondary silica or uranium minerals are present, except at the contact between the granite and sediment.

Figure 10 is a diagrammatic east-west cross section at the Ontario mine and shows the general relationships of the granite, arkose, and silicified zones. One of several prospect pits dug through the arkose on the dip slope above the tunnel is shown in the diagram. The prospect pit shows granite overlain by a friable, weathered zone and a thin layer of arkose. The friable weathered zone is partially cemented by black material similar to that at the mouth of the tunnel. The black material is altered to iron oxide along cracks and fractures, and it gives a strong sulfide odor when struck by a hammer. This prospect pit does not expose the fault zone in the granite, but it is very close to a projected extension of the fault zone underneath the arkose.

Similar occurrences of black mineralized rock within silicified zones occur at the Seneca claims and on the Coso Uranium Company properties. In each case the mineralization was limited to the upper surface of the granite and the granite-Coso formation contact. The Coso Uranium Company has explored black veinlike deposits similar to those at the Ontario mine in two places. At one place they tunneled into the rock about 25 feet. Silicified sediment and fault breccia are exposed at the portal of the tunnel, but within the tunnel there is only brecciated unmineralized granite. At the second locality pitchblende veins were reported (personal communication from the Coso Uranium Company geologist), but they are completely removed. The material was reported to be veins of finely disseminated pyrite with uraninite. None was found more than 10 feet from the granite surface. In the small open pit that remains irregular patches of dark granite with "smoky" quartz can be seen in the normally white granite.

At a third locality the Coso Uranium Company found autunite disseminated along fracture planes in the granite. Again, the mineralization was limited to the upper few feet of the granite surface.

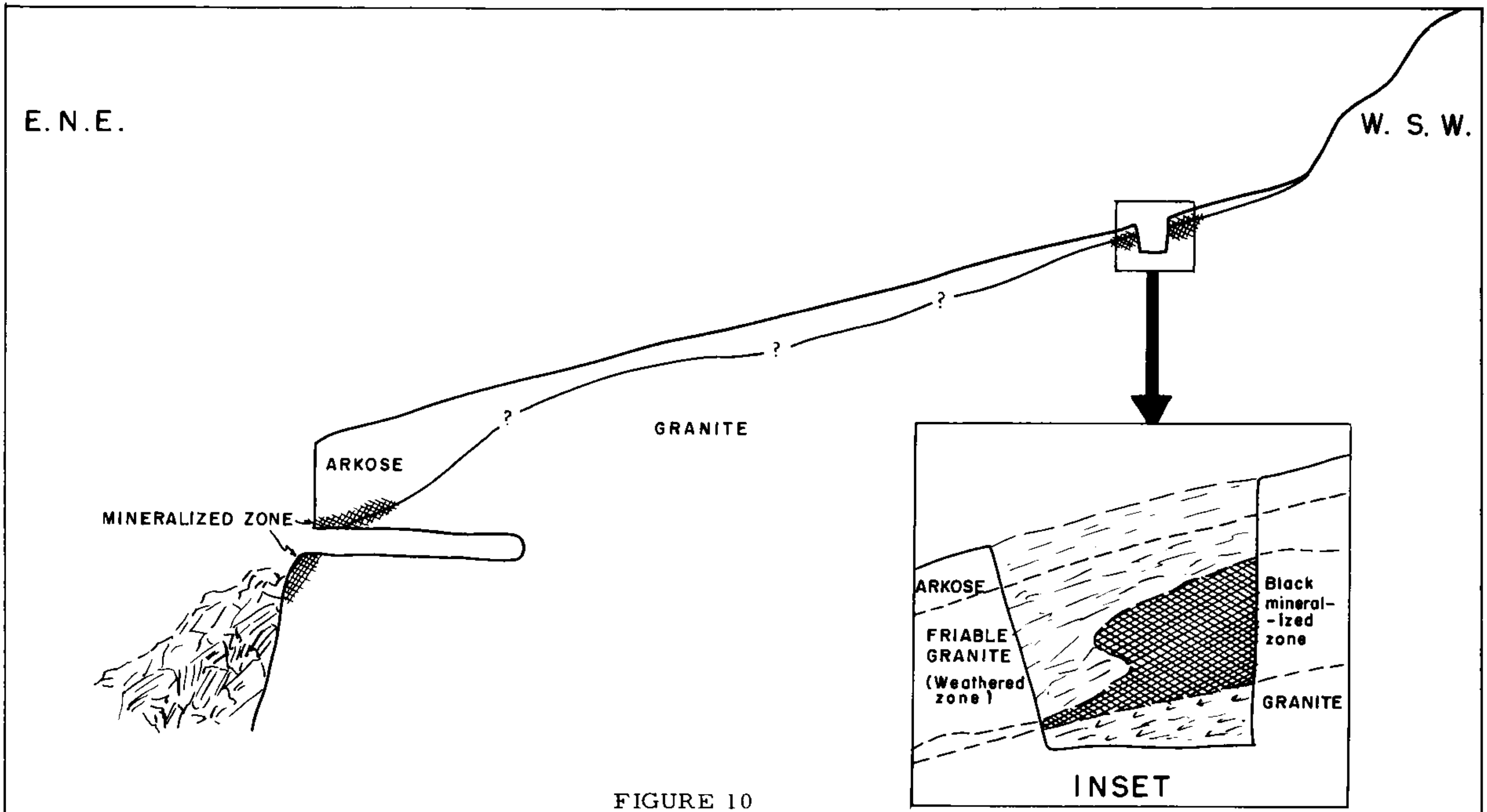

FIGURE 10

GENERALIZED CROSS SECTION
THROUGH
ONTARIO MINE

Origin of the uranium

The uranium-bearing silicified zones are limited to the contact between granite and Coso formation where the contact is met by prefanglomerate faults in the granite. They are limited to a narrow belt along the major prefanglomerate north-trending fault and the "hottest spots" are the intersection of this fault zone with prefanglomerate east-trending faults. This areal distribution suggests a genetic connection between prefanglomerate faults and mineralization. The writer believes that hydrothermal solutions rising along the old fault zones were trapped at the unconformity by the overlying Coso formation. The hydrothermal solutions carried silica, iron sulfide, and uranium. Reducing conditions at the contact with the Coso formation are indicated by the presence of pyrite and the uranium was deposited as uraninite. Some of the uranium was carried, perhaps in a volatile state, beyond the silicified zone into the overlying Coso formation.

Gruner (1951) found similar mineralized and silicified zones at Marysvale, Utah. At Marysvale, the mineralization was near the contact between quartz monzonite and rhyolite. Gruner attributed the silicification and mineralization to a rapid decrease in vapor pressure when hydrothermal solutions reached more porous zones in the rhyolite.

The abundance of rhyolite tuff in the Coso formation and the sporadic occurrence of autunite at various zones in the lake beds of the Coso formation suggest the possibility of ash leaching as the origin of the uranium. Ash leaching, however, seems inadequate to account for the localization of deposits along prefanglomerate faults and for the association with pyrite.

Disseminated deposits

Disseminated autunite is found in the basal fanglomerate at the Coso Uranium Company properties, the Seneca claims, and in some of the gullies below the Ontario mine. At the Coso properties, which have been most thoroughly explored, the uranium is in the lower 60 feet or so of the fanglomerate. In this area the fanglomerate is a coarse, gritty arkosic sandstone that contains much volcanic material in the finer fractions. It is buff to reddish buff and contains streaks of iron and manganese-oxide stain. The autunite is distributed more or less evenly throughout the rock as tiny disseminated crystals. An inclined shaft was sunk along an east-dipping normal fault in the fanglomerate. Autunite crystals were found along the unconformity at the granite surface and in the uppermost part of the fault zone in the granite.

Exploration work under a Defense Minerals Exploration Administration contract was done on the Coso properties during the winter of 1956-57, but the results were not available for this report.

At the Seneca claims disseminated autunite was found in a coarse basal arkosic conglomerate. The mineralization is about 500 feet downslope from a silicified and mineralized area at the contact between granite shear zones and Coso formation.

At the Inland Oil Company claims autunite was found on tiny fracture planes in clay and disseminated in overlying sandstones. The sandstones are composed predominantly of volcanic material. The clay layers range from a few inches to several feet in thickness and are in large part stained to a deep purple color.

Similar deposits of autunite in the Coso lake beds have been found north of Haiwee Ridge (see, for example, Hetland, D. L., 1955, Preliminary report on the uranium occurrence of the Green Velvet claims, Inyo County, California: U. S. Atomic Energy Comm. RME-2045).

SUMMARY AND CONCLUSIONS

Uranium minerals are locally concentrated at the unconformity between the Coso formation and granite where pre-Coso faults intersect the unconformity. There is no indication that they extend at depth into the granite. They are not high-grade deposits and it seems doubtful that they will be of much commercial importance.

Other uranium minerals are disseminated in fanglomerates near the base of the Coso formation. They are now being explored under a Defense Minerals Exploration Administration contract, and their commercial value appears to depend on whether there is enough volume of mineralized rock to warrant upgrading to commercial values.

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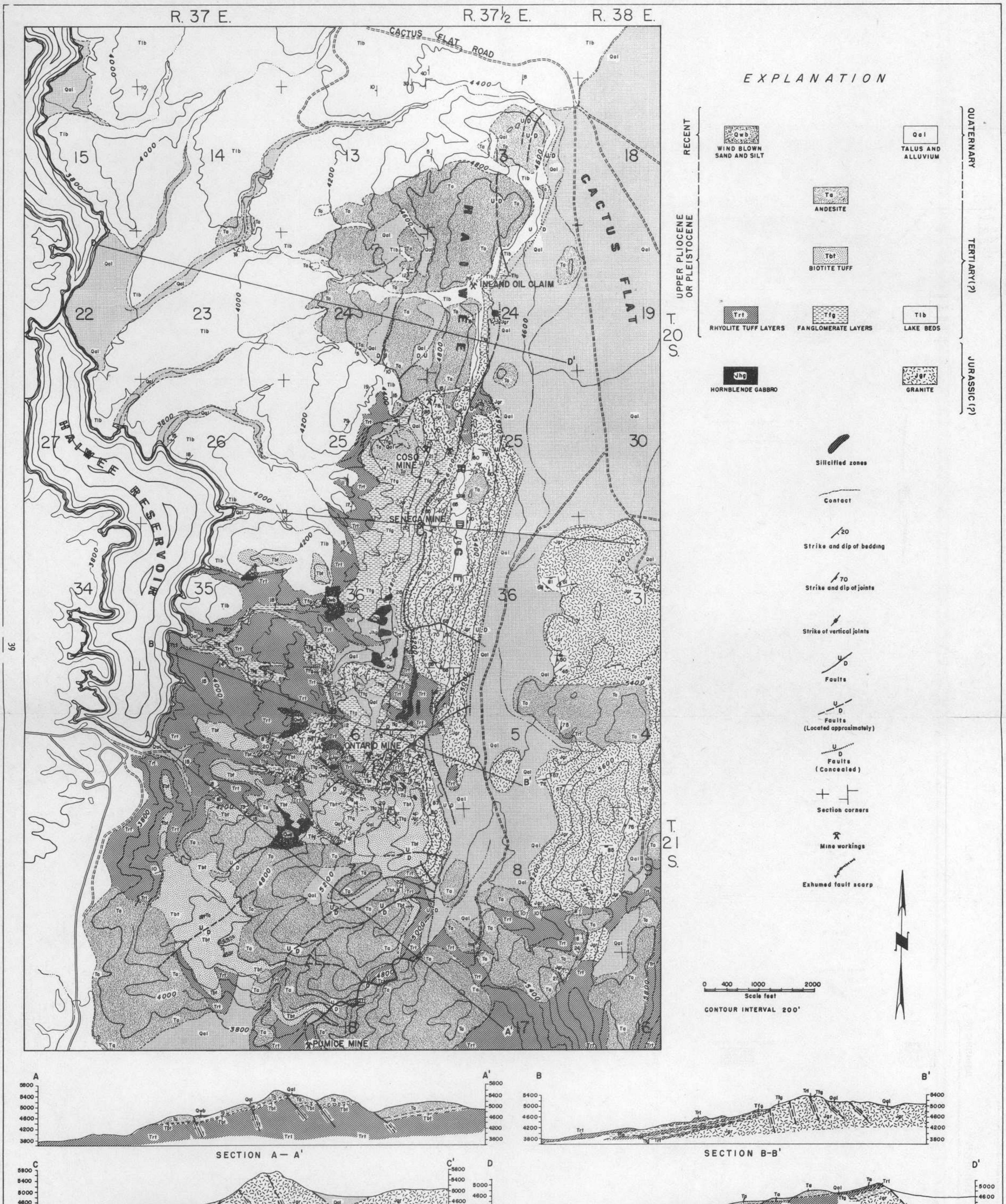

PLATE I

GEOLOGIC MAP AND SECTIONS

OF HAIWEE RIDGE, INYO COUNTY, CALIFORNIA