SPATIAL RELATION OF MINERAL DEPOSITS TO TERTIARY VOLCANIC CENTERS IN NEVADA

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Abstract.—About 80 major Tertiary volcanic centers have ..n recognized in Nevada. Some 17 are either certain or pos- ..le calderas ranging in diameter from 3 to 25 miles. Associated ..th 35 of the 80 centers are spatially related mineral deposits. ..e more important ones are in the following districts: Bull- ..g (gold, silver), Daisy (fluorspar), Goldfield (gold, silver), ..nopah (silver), Silver Peak (silver), Bodie and Aurora (gold ..d silver), Comstock (silver, gold), and Opalite (mercury). ..ologic settings typical of deposits associated with volcanic ..nters include: (1) rim fracture zones of calderas; (2) areas .. local uplift that may reflect the intrusion of an igneous ..dy; and (3) groups of veins, breccia pipes, and breccia zones ..ar the heart of a volcanic center, which may dip inward ..ward the presumed center.

A program of geologic mapping of counties in ..vada by geologists of the U.S. Geological Survey and ..e Nevada Bureau of Mines, underway since the 1950's, ..s led to the recognition of about 80 Tertiary volcanic ..nters from which a large volume of rhyolitic to ande- ..ic material has been erupted (fig. 1). These 80 centers ..e, for the purpose of this discussion,[1] regarded as the ..jor ones. Their number does not include the hundreds, ..rhaps thousands, of small rhyolitic domes and plugs ..d basaltic vents. Of the major centers, about 17 are ..ieved to be calderas ranging in diameter from 3 to .. miles. Some of the centers have been described in the ..erature by geologists working at the Nevada Test ..e and by other geologists. Most of the 80 centers, ..wever, have not been described in publication. We are ..ebted to our colleagues, all members of the Geological ..rvey except where otherwise noted, for locating them ..many of the counties: R. R. Coats, Elko County; Ronald Willden, R. G. Yates, and G. W. Walker, Humboldt County; Ronald Willden, Churchill County; Harold Bonham, of the Nevada Bureau of Mines, Washoe and Churchill Counties; J. G. Moore, Lyon, Douglas, and

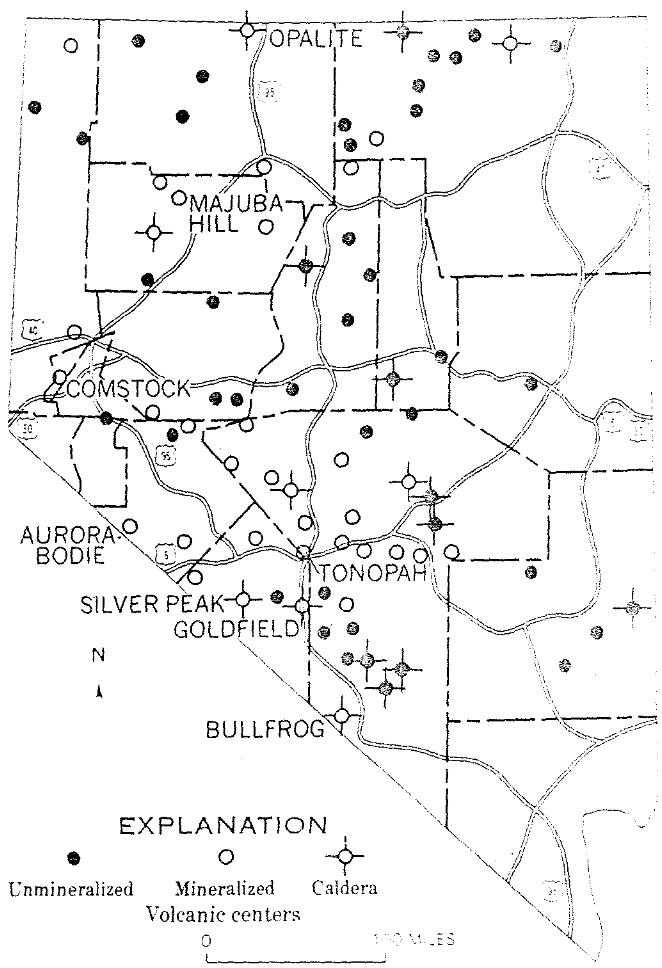


FIGURE 1.—Tertiary volcanic centers, Nevada.

[1] ..his paper is a somewhat revised version of one presented in Feb- ..y 1968 at the annual meeting of the American Institute of Mining ..neers in New York (Albers and Kleinhampl, 1967). Interest at that .. and continuing requests for copies of the paper have led to this ..cation.

Ormsby Counties; E. H. Pampeyan, Lincoln County; D. B. Tatlock, Pershing County; E. H. McKee, J. H. Stewart, and H. G. Masursky, Lander County; R. J. Roberts and H. G. Masursky, Eureka County; R. O. Fournier and M. C. Blake, White Pine County; and H. R. Cornwall, southern Nye County. In addition, we have obtained information on the Bodie district in several field conferences with C. W. Chesterman and Clifford Gray, of the California Division of Mines, and information on the region encompassed by the U.S. Atomic Energy Commission testing facilities in conference with E. B. Ekren, R. A. Anderson, and other geologists working at the Nevada Test Site, and from their publications. Responsibility for the identification of most of the centers shown in Esmeralda and Mineral Counties rests with Albers; that for those shown in northern Nye County with Kleinhampl.

Although the recognition of most of the 80 centers looks plausible in our present state of reconnaissance, it should be stressed that the nature of a few is speculative and may be disproved in time; no doubt centers not known now will be recognized. The reader should note that most of the centers are in the central and western parts of the State; only a very few are in the eastern and southern parts.

Published maps by Schilling (1964), of the Nevada Bureau of Mines, show 344 established metal mining districts in Nevada. Of these, about 75 are in Tertiary volcanic host rocks; the remaining ... of pre-Tertiary age. Of the 80 major ... mentioned above, 35 have spatially r... posits, chiefly mercury, gold, silver, ... and possibly manganese. The close s... suggests a possible genetic relations... useful guide to exploration.

Some of the more important dist... be spatially related to volcanic cente... (gold, silver), Daisy (fluorspar, ... silver), Tonopah (silver), Silver Pe... and Aurora (gold), Comstock (silv... (mercury), and Majuba Hill (gold, ... these are discussed in some detail ... tions of this report, and data co... tabulated in table 1.

Some typical geologic settings of de... with volcanic centers include: (1) rim ... calderas (Bullfrog, Daisy, Opalite, G... areas of local uplift that may reflect ... an igneous body (Tonopah, Goldfield ... Bodie and Aurora); and (3) groups of ... pipes, and breccia zones near the hear... center that may dip inward toward the ... Peak, Majuba Hill, Bodie). As seen fro... cation, the deposits in some districts, such ... Goldfield, appear to have composite set...

TABLE 1.—*Brief description and age of mineralization at major mining districts associated with volcanic c...*

District	Type of center	Type of deposit	Age of mineralization [1] (millions of years)	Sou...
Aurora	Volcanic center, undifferentiated.	Veins	>12.5	Gilbert and oth... Yehya Al-Raw... 1968).
Bodie	Intrusion, with uplift(?).	do	7.9 (adulária)	M. L. Silberman 1969).
Bullfrog	Caldera	Deposits along rim fracture zones (veins and bonanza ore).	<11	H. R. Cornwall (o... 1969).
Comstock	Intrusion, with uplift(?).	Veins	13 (adularia)	D. H. Whitebrea... 1968).
Goldfield	Caldera(?) and (or) intrusion, with local uplift.	do	±21	H. R. Cornwall ... 1969).
Majuba Hill	Intrusive complex (heart of volcanic center).	Veins, some replacement of rhyolite and breccia.	Tertiary(?)	Trites and Thur... 200–201).
Opalite	Caldera	Deposits along rim fracture zones.	<13	G. W. Walker (o... 1968).
Silver Peak	do	Veins	<5.9	Robinson, McK... (1968, p. 598) ... Albers and J. ... Unpublished ...
Tonopah	Intrusion, with uplift	do	>17.5, probably >22.	[2].

[1] Primary age control, except for Majuba Hill, is based on K-Ar dating techniques, with the age of mineralization, except where given as an ad... ages of volcanic host rock or rocks adjacent to the host and obtained from sources given. The Majuba Hill age is based on geologic deduction, not on ...

[2] Age based on dates obtained by E. B. Ekren (oral commun., 1965) for the Fraction Tuff in the Kawich Range and by R. W. Kistler (see Klei... for the Toyabe Quartz Latite in the Toiyabe Range.

SITS RELATED TO CALDERAS

most clearly related to calderas include rog, possibly Goldfield, Opalite, and

Hills caldera in the Bullfrog district, fig. 2, table 1), measures 10–13 miles ornwall and Kleinhampl, 1964). The ra is underlain principally by rhyolitic welded tuffs that form a broad faulted tward toward the peripheral fault zone era rim. Displacement on the peripheral is exposed along the southeast rim is the northwest or inner side being down- well known mineral deposits and most eposits in the Bullfrog area are located faults of the caldera, or near the related ture that extends outward from the f the caldera. Three of the deposits, ines, are on the east rim of the caldera: -Shoshone (*1*, fig. 2), the Mayflower (*2*, Pioneer (*3*, fig. 2). The fourth, the mine (*4*, fig. 2), is in Paleozoic rocks southern margin of the subsidence zone angentially outward from the caldera . In addition to these deposits, a concentration of small deposits, mostly gold and silver, occurs along the east rim of the caldera, and several other gold deposits occur within the caldera along the north margin of the area of pre-Tertiary basement rocks that have been pushed up into the tuffs and ash flows (see Original Bullfrog mine, *5*, fig. 2).

Goldfield

The Goldfield district, where the U.S. Geological Survey currently has a project, is at the site of a volcanic center that may be a resurgent caldera (table 1, fig. 3). That a volcanic center exists is indicated by the unique pile of volcanic rocks—quartz latites, andesites, and dacites—that thin out away from the area and are not found elsewhere in the region. These rocks are mostly early to middle Miocene in age and are extensively kaolinized, alunitized, and silicified. The silicified and alunitized rocks commonly form tabular ledges that in the aggregate make an eastward-elongate elliptical pattern several miles in diameter (fig. 3) and open on the east. The pattern reflects a concentric fracture system that suggests a collapse structure. However, the presence of the older Tertiary and pre-Tertiary rocks in the central and western parts of the ellipse is not consistent with the idea of collapse and, instead, suggests uplift or doming, possibly by a resurgent igneous body at depth. Modifications of a resurgent caldera by Basin and Range faulting may account for the distribution of

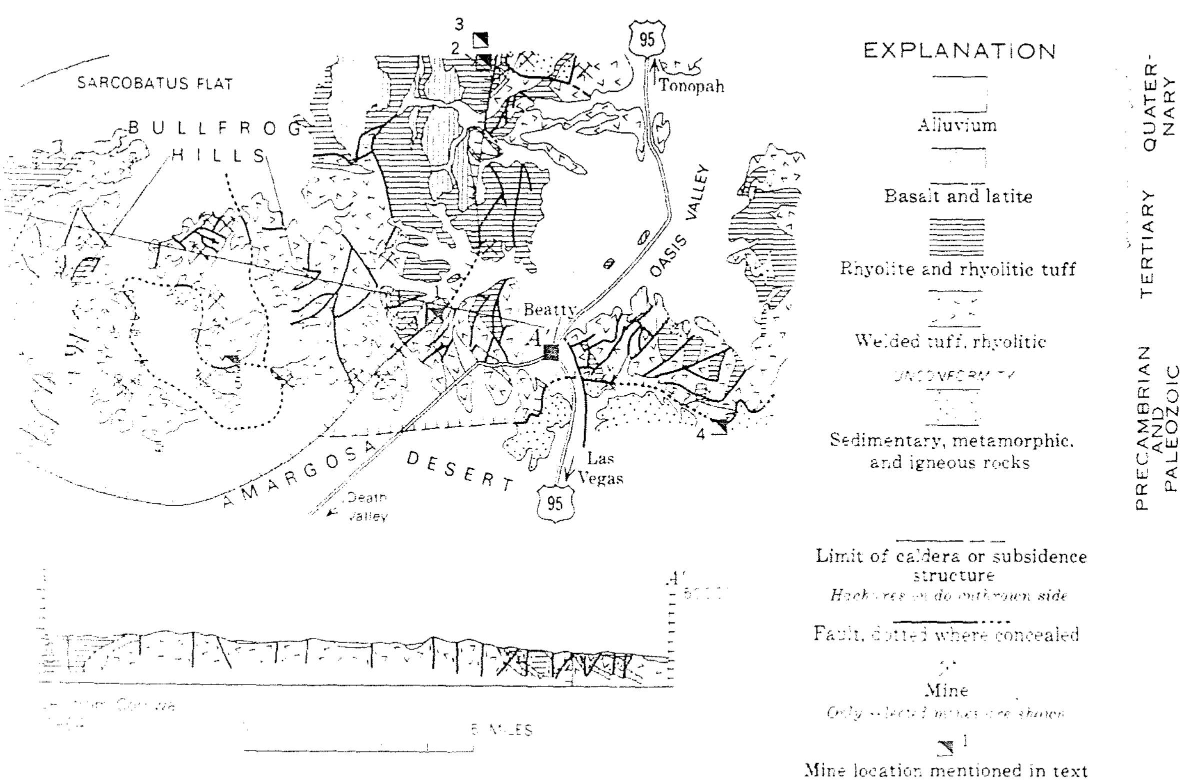


FIGURE 2.—Bullfrog district, Nevada.

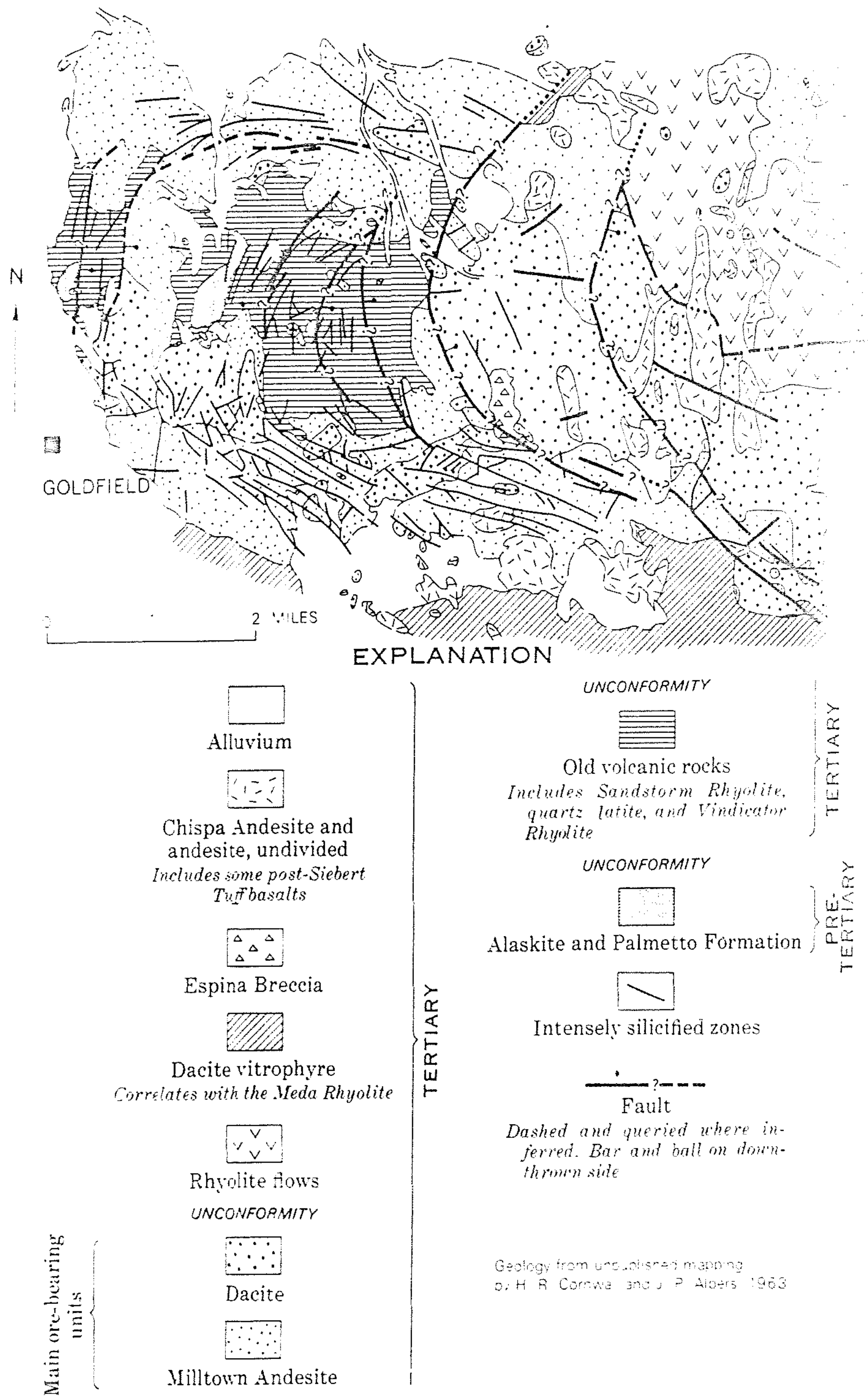


FIGURE 3.—Goldfield district, Nevada.

...ary rocks. The known gold and silver deposits ... to the western and northern sides of the ... structure; 98 percent of the production has ... segment about three-fourths of a mile long ... side. The dip of the main mineralized ... surface is about 35° eastward, toward the ... ellipse.

...palite district (table 1, fig. 4), located along ... between Nevada and Oregon, was studied ... R. G. Yates, who found four quicksilver de-... the Cordero, to lie in steep fault zones ... ular area about 20 miles in length. The ... in places marked by inward-facing ... feet high. In this area, Tertiary vol-... andesitic to basaltic lavas at the base of ... followed by extensive welded tuffs, are over-... Miocene tuffaceous lakebeds. The andesite ... flows may be about 14.5 million years old; ... welded tuffs are about 13 million years old ... Walker, oral commun., 1968).

The kinds of rocks, their distribution, and structural relations suggest that the lakebeds fill a calderalike collapse feature. Lake sediments commonly fill such depressions, as shown for example by Smith, Bailey, and Ross (1961, p. D146, D147), at the Valles Caldera, N. Mex. Evidence presented by Yates (1942, p. N326–N328), however, places the major collapse after the deposition of the lakebeds in the Opalite area. More recently, R. G. Yates (oral commun., 1968) states that as caldera structures were not generally recognized in the early 1940's, he only suspected the presence of some kind of a collapsed volcanic structure, and further that the evidence in the Opalite area does not conclusively prove deposition of lacustrine beds prior to faulting. In recent years, workers in the area have recognized it to be underlain by a calderalike structure, with many of the known mercury deposits lying along the northern segment of the rim fracture zone and the large Cordero mine near or on the inferred southeastern rim.

Silver Peak

A volcanic center 5–6 miles in diameter forms the highest part of the Silver Peak Range in Esmeralda

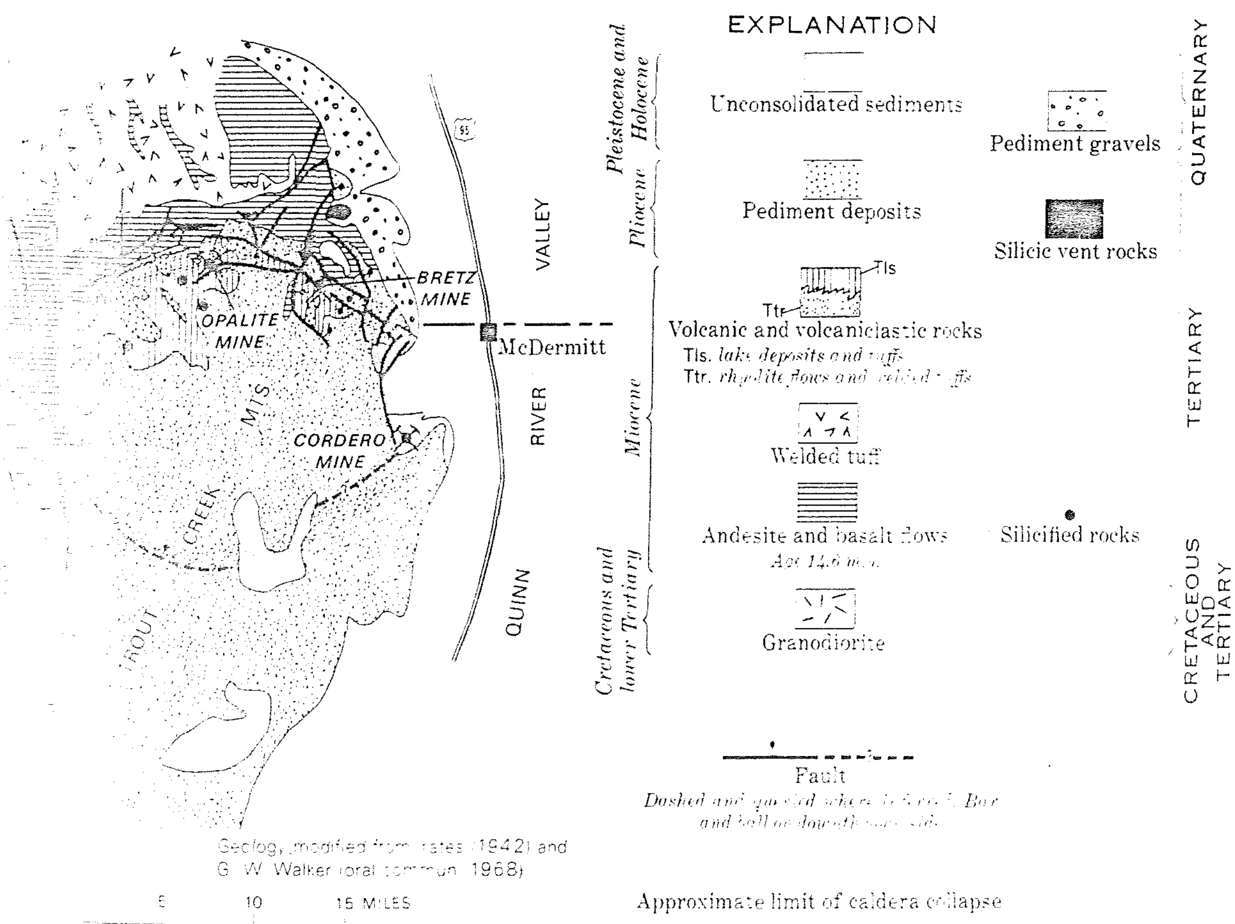


FIGURE 4.—Opalite quicksilver district, Oregon-Nevada.

County (table 1, fig. 5). This center is marked by a thick body of trachyandesite that is the youngest volcanic unit except basalt and appears to fill a calderalike depression. The age of the trachyandesite is only 5.9 m.y., making this center one of the youngest major volcanic centers in Nevada. Cutting the eastern part of the mass of trachyandesite are a group of northeast-striking veins bearing silver chiefly as argentite; barite and calcite are principal gangue minerals. The westernmost veins, including the Mohawk and Sanger, dip northwest toward the presumed center of the caldera (fig. 5). The mineralogically similar veins farther southeast dip steeply either northwest or southeast and cut a complex of volcanic rocks that are older than the trachyandesite and range from andesite to rhyolite in composition. The very youthful age of these rocks and deposits and their close spatial relation are highly suggestive of a genetic relationship.

DEPOSITS RELATED TO INTRUSION AND UPLIFT(?)

Deposits related at least in part to intrusion with possible uplift include those in the districts of Bodie and Aurora, Comstock, and possibly Goldfield and Tonopah.

Aurora-Bodie

Gold- and silver-bearing quartz veins cutting Tertiary propylitized andesitic rocks were the source of ore at Bodie, Calif., and at Aurora, Nev. Aurora lie northeast of Bodie and is separated structura it, but both districts are related to a volcanic that forms an elongate, northeast-trending top high, 25 miles long, bordering the north rin Mono Lake basin (table 1, fig. 6). Several discr tive centers have been recognized within the highland complex from which rhyolites, quart dacites, andesites, and basalts have been erup

The Bodie district is more or less centrally within the highland complex in propylitized a fied volcanic rocks of intermediate composition. mined from several systems of north-striking dipping veins, many of which cut an andesi that underlies the main part of the district k the Bonanza zone. Chesterman, Silberman, a (1969, p. 10–11) indicate that andesite intrus emplaced into andesitic flows and tuff brecc bearing solutions, apparently related to a late the intrusion, are considered to have deposi metals approximately 7.9 m.y. ago, the age ob M. L. Silberman on four adularia samples, each of two veins in the district.

At Aurora, veins with major production a ated with steeply dipping silicified "reefs" th northeast within intensely propylitized and loc

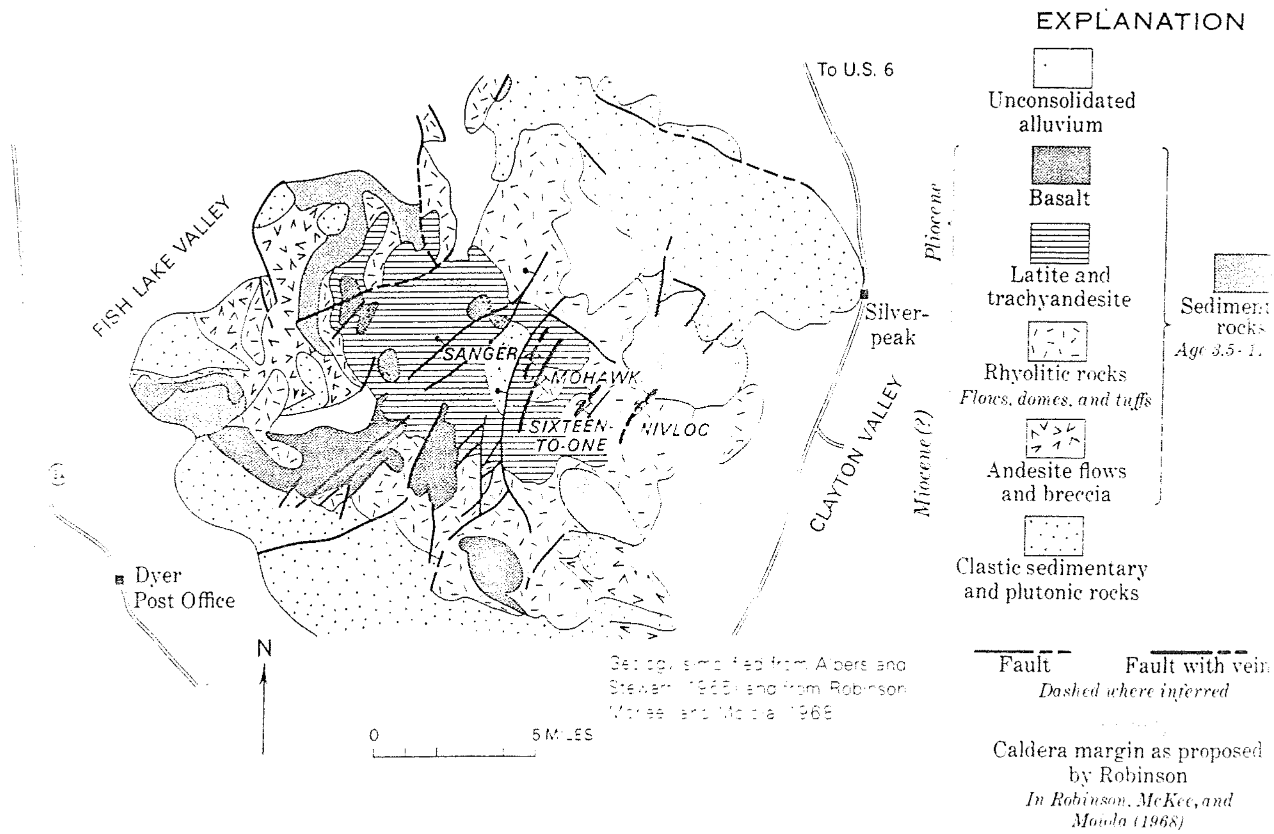


FIGURE 5.—Silver Peak Range, Esmeralda County, Nev.

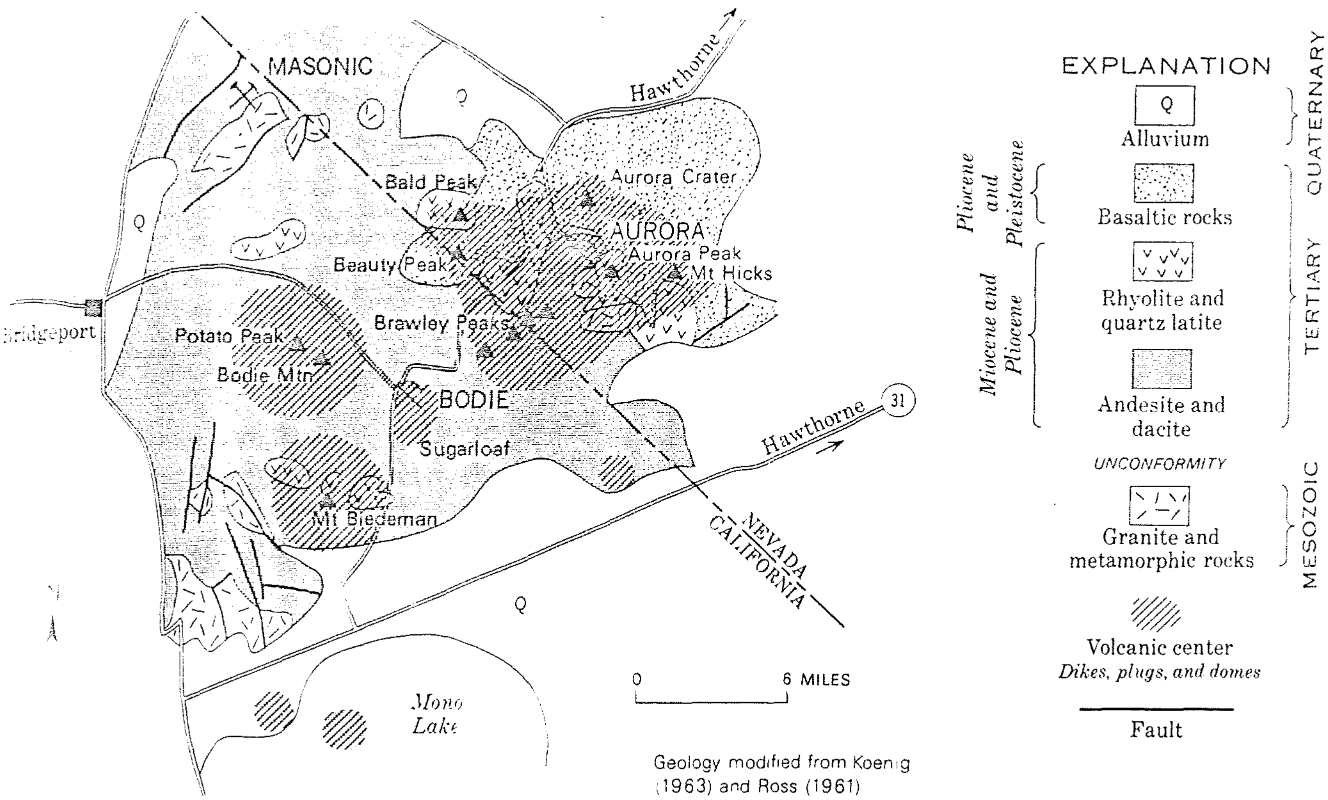


FIGURE 6.—Aurora-Bodie area, California-Nevada.

...d andesitic flows and breccias. Rhyolitic to andesitic ...rusives are common in the district. Some are clearly ...nger than ore mineralization; for others, genetic ...tionships to the ore deposits is unknown.

...omstock

A strong argument can be made for a large Tertiary ...anic center in the Comstock lode district (table 1, ... 7). Thompson (1956) points out that the distribu...n and thickness of the Alta Formation indicates that ...least one of the centers from which it was erupted ...st have been in the Comstock district, and that the ...nger Kate Peak Formation came from vents in the ...rginia Range and nearby areas. Whitebread and ...hoover (1968, p. 4–5) also mention intrusive Kate Peak ... the Comstock district. Moreover, it is tempting to ...eculate that the Davidson Granodiorite, which is ...ounger than the Alta and may be in part contempo...aneous with the Kate Peak, could mark one of the prin...pal centers from which one or both of the andestic ...nits were derived.

The heart of the Comstock lies directly east of the Davidson Granodiorite, and the principal vein system ...ong the Comstock fault dips eastward away from the ...ock at about 45°. Ideally, if we subscribe to the classi...al hypothesis that ore fluids are derived from bodies of cooling magma, we might prefer that the dip of the Comstock fault be westward toward the granodiorite stock. However, the eastward dip is certainly not a flaw in the argument of spatial relationship to a large center in the Comstock area. Nor is it incompatible with the concept of a genetic relationship with the Davidson stock, as little is known of the routes and processes involved in the migration of the ore-forming fluids.

Tonopah

The Tonopah silver district is on the northwestern side of a volcanic center characterized by numerous domes, plugs, and flows of rhyolite quartz latite, and andesite that are of middle Miocene age and mostly younger than the mineral deposits (table 1, fig. 8). The Mizpah Trachyte (andesite) is the host for the ore deposits and is intruded by the other rock types. Part of the same, or a similar, volcanic center is present at the Divide district, several miles south of Tonopah (fig. 8). Here the mineral deposits are younger than those at Tonopah and occur in rocks that overlie or intrude the host andesite there. The abundance of the younger small intrusive bodies in an area otherwise underlain by tuff and andesite lava shows that the general Tonopah area was the site of considerable volcanic activity in Mio-

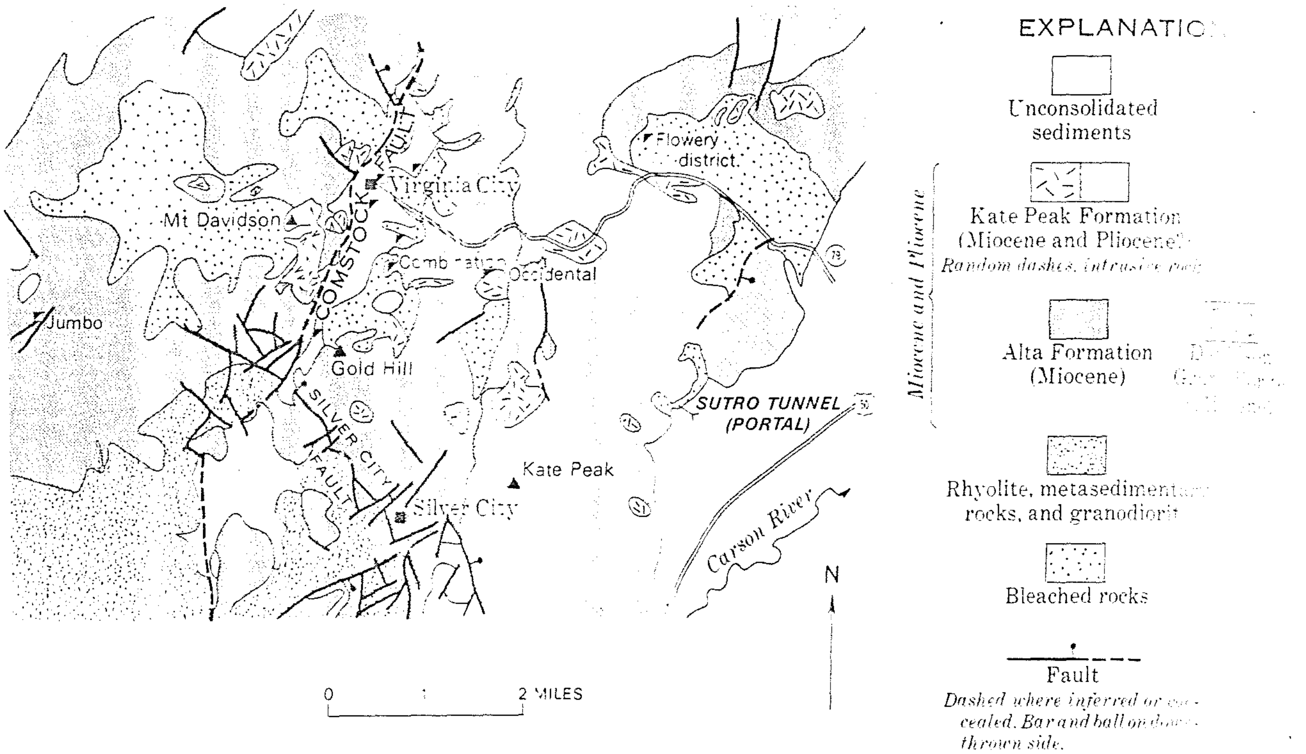


FIGURE 7.—Comstock district, Nevada.

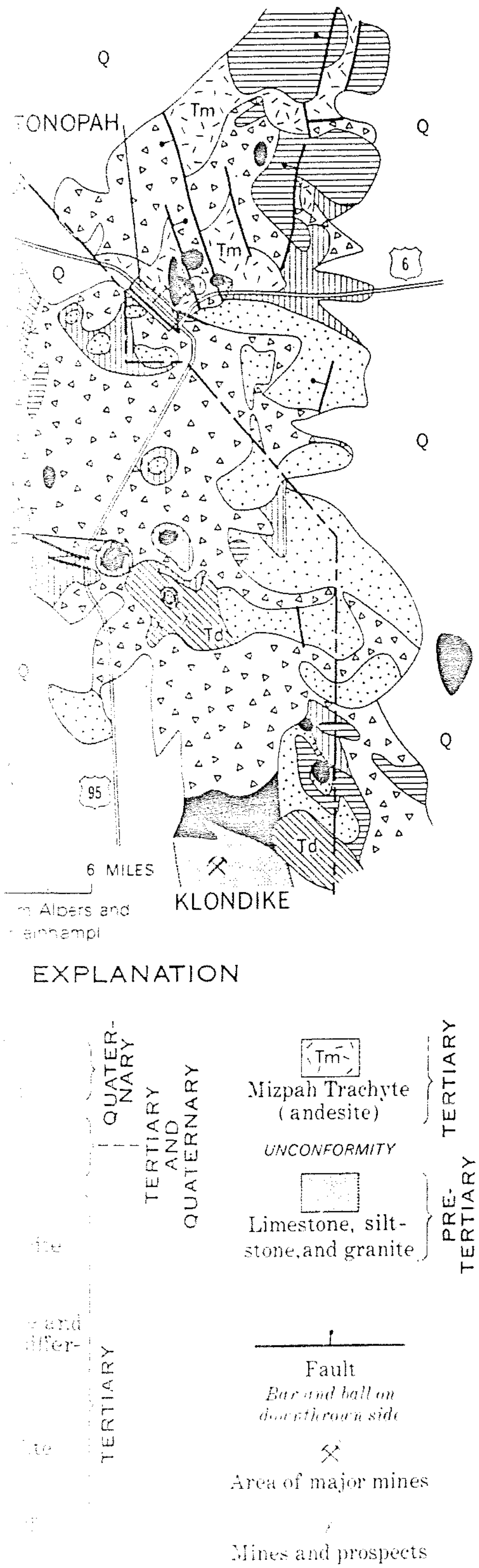
cene time. Upward doming of the Halifax and Tonopah faults, alteration and ore zones, and zones defined by gold-silver ratios led Nolan (1935) to suggest that the Tonopah mine area was domed, possibly above an igneous intrusion prior to deposition of the Esmeralda or Siebert Formations. Inasmuch as several plugs (Oddie Rhyolite, Brougher Dacite) younger than the Siebert are known in the immediate area, this conclusion is certainly reasonable. Quite possibly still another pluglike or stocklike mass representing the intrusive episode is not far beneath the Tonopah workings.

The ore deposits at Tonopah appear to rank about with those at Goldfield as the oldest in the districts herein described (table 1). At Tonopah, the ore is pre-Fraction Breccia where the Fraction overlies the Mizpah Trachyte host. The age of the ore must be greater than 17.5 m.y. if one accepts this as the age of the Fraction Breccia as extrapolated into Tonopah from the dated correlative unit about 45 miles to the east in the Kawich Range (E. B. Ekren, oral commun., 1965).

In addition, the Mizpah Trachyte may be coeval with thin andesite flows that underlie the approximately 22-m.y.-old Toyabe Quartz Latite (Kleinhampl and Ziony, 1967), a welded tuff in the Toiyabe Range about 45 miles north of Tonopah. A lower limit for the age of the Mizpah cannot be set, but the basal Mizpah intertongues (Nolan, 1935, p. 16) with volcanic str[illegible] have affinities with, and may grossly correlate [illegible] rhyolitic volcanic sequence that underlies the [illegible] flows in the Toiyabe Range. These rhyolitic rocks are believed to be early Miocene in age.

OTHER DEPOSITS ASSOCIATED WITH VOLCANIC CENTERS, BRECCIA ZONES, AND PIPES

Deposits belonging to this geologic [illegible] Majuba Hill in Pershing County, commonly [illegible] tures found in deposits related to calderas [illegible] of igneous intrusion and uplift, such as [illegible] Bodie. But Majuba Hill is clearly not [illegible] dera, nor is it obviously related to uplift [illegible] Majuba Hill is a complex plug of Tertiary [illegible] rocks, about 5,000 feet in diameter, cutting [illegible] sedimentary strata (table 1, fig. 9). [illegible] varieties of intrusive breccia form [illegible] and irregular masses cutting the rhyolitic [illegible] latter include an earlier and later rhyolite [illegible] a rhyolite porphyry. The rhyolitic rocks, [illegible] intruded sedimentary strata, are silicified [illegible] and tourmalinized (Trites and Thurston, [illegible] and tin are the principal ore minerals. [illegible] paragenetic sequence is tourmaline [illegible] and tin (youngest), and all are [illegible]



8.—Tonopah area, Nevada.

Majuba fault, which is the principal fracture in the area.

The mineralization of all the deposits discussed here and of others as well occurred after the volcanism and indeed after the volcanic rocks were solidfied. How long afterward is not known. The presently available evidence seems to allow the speculation that many, if not most, of the ore deposits spatially associated with volcanic centers are also genetically related to the centers. Whether or not this is a valid inference, the fact that many deposits are located close to known volcanic centers may be a useful concept in exploration.

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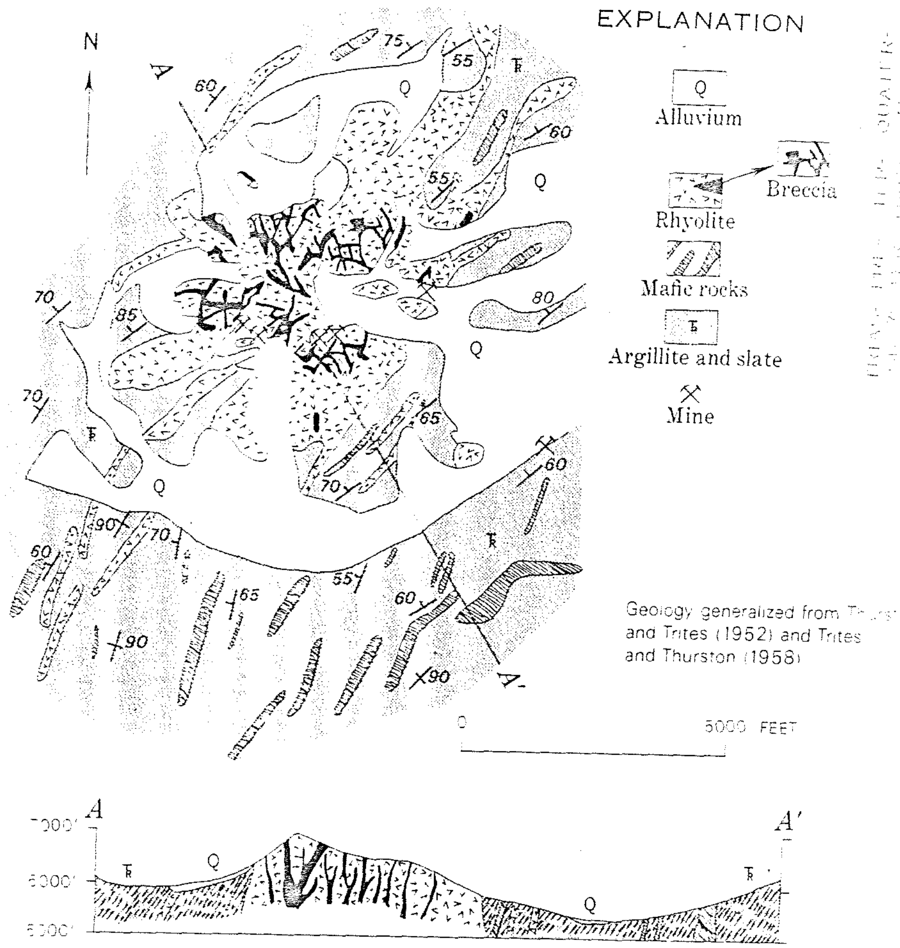

FIGURE 9.—Majuba Hill, Nev.

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