GEOLOGY AND ORE DEPOSITS OF THE BODIE MINING DISTRICT

MONO COUNTY, CALIFORNIA

BULLETIN 206

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To
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ABSTRACT

The Bodie mining district, located in the northeastern part of Mono County, California, was the source of gold and silver valued at more than $34,000,000 between 1860 and 1942.

The district is underlain by volcanic rocks, including flows, plugs, and pyroclastic deposits, principally of dacitic composition. The oldest rocks are those of the Silver Hill Volcanic Series, which consists of lava flows, plugs, and tuff breccia with minor layers of welded tuff. This sequence is overlain unconformably by lava flows and pyroclastic deposits of the Murphy Spring Tuff Breccia, which, in the southern part of the district, are intruded by several plugs of porphyritic dacite. Flows and pyroclastic deposits of the Potato Peak Formation unconformably lie upon units of the Silver Hill Volcanic Series in the northern part of the district.

Investigations of the geochronology of the rocks of the Bodie mining district, using the K-Ar method, indicate that the several units of the Silver Hill Volcanic Series were emplaced 8.6 to 9.4 m.y. ago and, furthermore, that they are a local phase of an extensive suite of calc-alkaline volcanic rocks (including basalt, andesite, dacite, and rhyolite) that were erupted 7.8 to 9.5 m.y. ago in the region surrounding the Bodie mining district. Volcanism ceased in the district and in the region surrounding it, following ore deposition in the district, and did not resume until 5 m.y. ago, when rhyolite plugs intruded rocks of dacitic composition west of the district.

Four plugs in the district were emplaced into vents from which the lava flows and pyroclastic deposits of the Silver Hill Volcanic Series evolved. The largest plug, comprising Bodie Bluff and Standard Hill, is the host rock for the quartz veins from which more than 90 percent of the total production of gold and silver was obtained. The other plugs at the Red Cloud mine, Queen Bee Hill, and Sugarloaf are smaller in size and contain fewer quartz veins.

The two major faults, the Moyle Footwall and the Standard Vein, along which movement was both pre- and post-mineral, were responsible for the formation of the graben in the Bodie Bluff-Standard Hill plug. Other pre-mineral faults are the sites of vein deposition. The post-mineral faults, especially the Mono and the Tioga, did much to offset the veins.

Hydrothermal alteration of the rocks was widespread in the district. Propylitic alteration, which is characteristic of the margins of the district, occurred first; argillic and potassic alteration sequences occurred later and were more pervasive. Propylitically altered rocks are greenish in color and contain chlorite, epidote, various clay minerals, albite, pyrite, and minor quartz. The argillically altered rocks are usually light colored and contain montmorillonite, illite, sericite, quartz, and pyrite. They weather easily and form sparse croppings. The potassically altered rocks are only locally light colored, and tend to resemble the original rock in color and texture. They show extensive development of adularia, quartz, sericite, and pervasive, irregular veins of quartz-adularia, with or without calcite. The silicic alteration generally occurred last. Silica-altered rock is light colored, hard, and forms a capping on argillically altered rocks.

K-Ar dating of adularia in the gold-bearing quartz veins and in the hydrothermally altered rocks indicates that the alteration-mineralization occurred between 7.2 and 8.6 m.y. ago and that the hydrothermal system responsible for the mineralization lasted for about 1.4 m.y.

Principal gold-silver production in the Bodie mining district came from several systems of quartz veins in the intrusive dacite plug of the Bodie Bluff-Standard Hill area. Farther south, in the Silver Hill area, the mineralization was pervasive, and the gold and silver were recovered from quartz veins and irregular silicified zones in dacite flows and tuff breccio. The ore minerals include native gold, pyrargyrite, tetrahedrite, stephanite, and pyrite. The ratio of gold to silver by weight in the northern part of the district was about 1:12, whereas in the southern part of the district the ratio was about 1:40.

Mining activities ceased in the district in 1942, but interest in the mineral deposits in the district has not relaxed. The intensely mineralized and mined bonanza zone of the Bodie Bluff-Standard Hill area contains numerous narrow, gold-bearing quartz veins that, collectively, may constitute a large, low-grade deposit that would be a fair target for further exploration and development.

Photo 1. View of Bodie in 1932 from Standard Hill. *Photograph by Francis H. Frederick.*

INTRODUCTION

Location

The Bodie mining district (Figures 1 and 2), in which the mines and the now famous ghost town of Bodie are situated, is in the southern part of the Bodie Hills in northeastern Mono County. The two routes leading to the Bodie mining district from State Highway 31 and U.S. Highway 395 are graded dirt roads that are usually closed during the winter.

The Bodie mining district, as originally defined in 1860, "shall extend in each direction from the Bodie claim, north, south, east and west, five miles" (Hakes, 1902). For many years, however, the Bodie mining district (Plate 1) has been confined to a narrow tract of mountainous land which measures about 3 miles long and one mile wide, roughly encompassing a north-trending, ridge-like feature. At the northern end, Bodie Bluff, the highest peak in the district at 9,000 feet in elevation, stands some 600 feet above the Bodie townsite. The southern end of the district is about one mile south of Sugarloaf, a conical shaped peak which is a prominent landmark of the area. Bodie Creek drains the area and flows throughout the year down Bodie Canyon.

Field Work and Acknowledgments

Most of the 1968 field season was spent by Chesterman and Gray making a detailed geologic study of the Bodie mining district. R.H. Chapman made detailed magnetic and gravity surveys. Fortunately, several of the long-inaccessible mine tunnels had been reopened in 1968 for prospecting, making it possible for the writers to make limited observations underground and to collect samples of rock and ore for laboratory study. All geologic field work was plotted upon enlarged aerial photographs and transferred to a topographic base, scale 1:4,800, which had been compiled in 1931 from a survey made by D.W. Ormsbee.

M.L. Silberman of the U.S. Geological Survey assisted in the collection of rock and mineral samples for age dating and geochemical studies, and to him are tendered special thanks for making readily available all analytical data from the laboratories of the U.S. Geological Survey. The writers are especially grateful to the late E.W. Billeb of the J.S. Cain Company for making available unpublished notes and maps and for his many helpful suggestions and discussions. The late F.H. Frederick permitted the use of his maps as part of his long-continued interest in the district.

Previous Work

The Bodie mining district was organized in 1860, and several reports about it have appeared in various technical journals since that time. The earliest, perhaps, of the published reports is by Joseph Wasson (1879), who obtained much of his information from visits to the district and from early investigations made by Blake (1863, p. 17), Silliman (1864, p. 13-15), and Browne (1864, p. 17-18). Wasson's report was made for members of the New York Bullion Club and received limited circulation. Melville Atwood (1879, p. 169) examined wall rocks from the mines

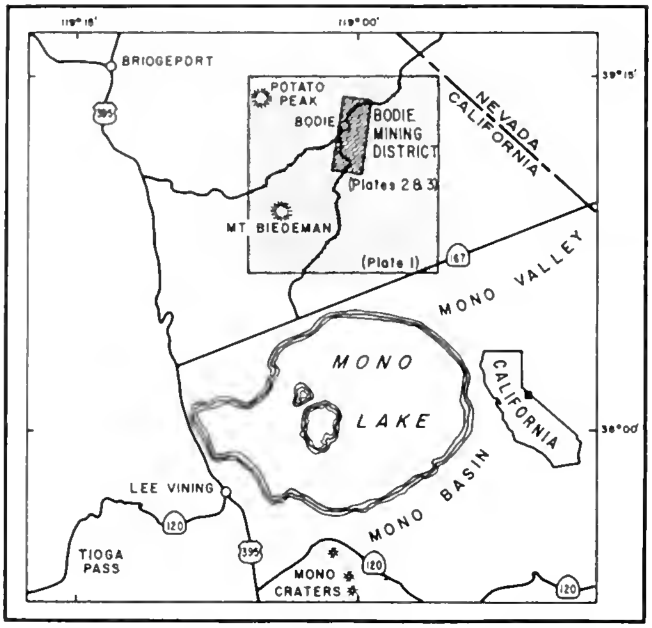

Figure 1. Index map of east-central California showing location of the Bodie mining district.

at Bodie and reported his findings before the California State Geological Society.

Toward the middle of the 1880s, H.A. Whiting, superintendent of the Bodie Consolidated Mining Company, made an extensive study of the mines at Bodie and published his report in 1888 (Whiting, 1888, p. 382-401). In the early 1900s, several investigations were made of the district; notable among these are studies by R.P. McLaughlin (1907, p. 795), R. Gilman Brown (1907, p. 343-357), and A.S. Eakle and R.P. McLaughlin (1917, p. 143-160). Much later still, Al-Rawi, then a graduate student at the University of California, reported upon the age of mineralization at Bodie (1968, p. 30).

REGIONAL GEOLOGIC SETTING

The Bodie Hills (Plate 1) comprise a complex mass of late Tertiary volcanic rocks (Kleinhampl and others, 1975) which consists of lava flows, tuff breccia, and intrusive dikes, plugs and domes that were erupted from well-defined vent areas. The rocks range in composition from rhyolite to basalt, and those of dacitic and andesitic compositions are most widespread and voluminous. The oldest volcanic rocks in the Bodie Hills, range in age from 11 to 29 m.y., consist of andesite, dacite, and rhyolite, and occur principally in the northeastern part of the area. These older volcanic rocks are overlain unconformably by ash flow tuff units that are mildly to intensely welded, but locally non-welded, and include conspicuous black to dark brown vitric zones. They are trachyandesitic in composition and have an average age of 9.4 m.y.

Pre-Tertiary Basement

Rocks older than Tertiary are not exposed in the immediate area surrounding the Bodie mining district, but in adjacent areas

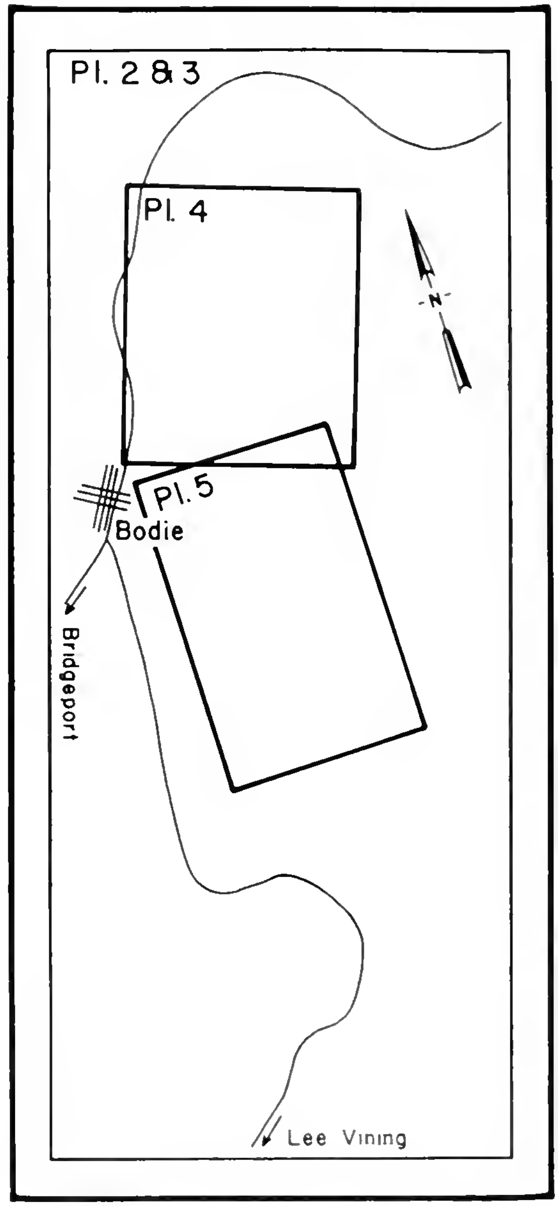

Figure 2. Index map showing location of plates 3, 4, and 5.

to the west and northwest, the Tertiary volcanic rocks rest unconformably upon pre-Tertiary metamorphic and granitic rocks that crop out usually as islands in the lava flows and pyroclastic deposits (Chesterman and Gray, 1966; Chesterman, 1968; and Chesterman and Gray, 1975). The metamorphic rocks include gneiss and schist of pre-Cretaceous age (Koenig, 1963) at Masonic Mountain, 12 miles northwest of Bodie, and quartzofeldspathic hornfels and greenstones of Paleozoic(?) and Mesozoic(?) age (Chesterman, 1968) east and northeast of Conway Summit, 12 miles southwest of Bodie.

Granitic bodies occur in the Bodie Hills and are generally found intrusive into the pre-Cretaceous metamorphic rocks. East of Conway Summit, there is a body consisting principally of biotite granite which has a Cretaceous age of 93.4 m.y. (Chesterman, 1968). Masonic Mountain, that is at the northern end of

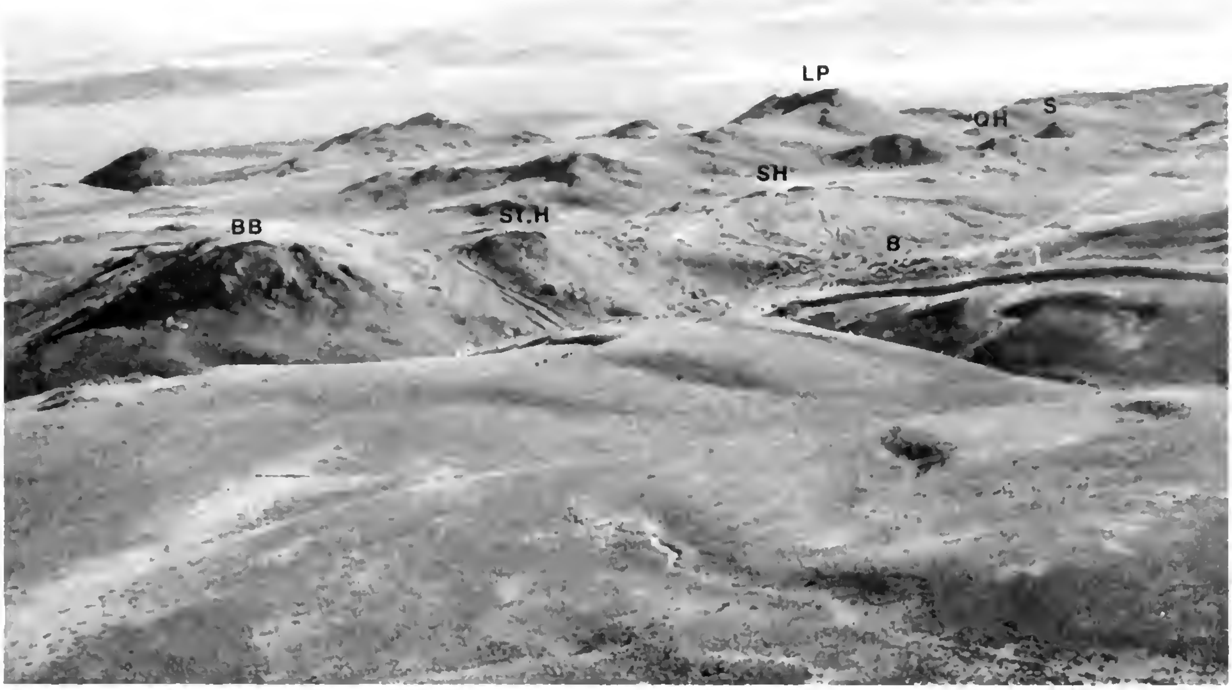

Photo 2. View looking southeastward, with the White Mountains in left distance, Glass Mountain in middle distance, and the Sierra Nevada on the right distance. In the middle-ground are Bodie Townsite (B), Bodie Bluff (BB), Standard Hill (St.H), Silver Hill (SH), Lookout Peak (LP), Queen Bee Hill (QH) and Sugarloaf (S). *Photograph by Norman F. Prine, U.S. Geological Survey.*

the Bodie Hills, is underlain by a body of granitic rock whose composition ranges from granodiorite to quartz monzonite. This body is presumed to be pre-Cretaceous in age (Koenig, 1963).

A sample, referred to as black chert possibly altered from some underlying sedimentary formation, is said to have been collected at a depth of about 500 feet in mine workings near the Lent shaft (McLaughlin, 1907, p. 795) (Plate 2). Specimens of a fine-grained, dense, dark gray to black rock were collected from the waste dump of the Dudley shaft. Presumably this is the underground workings to which McLaughlin referred. A microscopic examination of specimens of this material collected by the writers indicates that the rock is a well-indurated, fine-grained phase of welded tuff. There are several outcrops of the welded-tuff phase of the Silver Hill Volcanic Series in the district, and it seems most likely that the material from the Dudley shaft is from a layer of this welded tuff that was encountered underground in the Dudley mine.

Tertiary Rocks

The most widespread volcanic rocks of the Bodie Hills consist largely of lava flows, tuff breccia, and intrusive plugs of dacitic composition, although lava flows, tuff breccia, and intrusive bodies of rhyolitic, andesitic, and basaltic compositions are present. Several small plugs of rhyodacitic composition occur near the mining district. These rocks form a blanket-like deposit and include the Mount Biedeman and Potato Peak Formations, the Murphy Spring Tuff Breccia, and the Silver Hill Volcanic Series (Chesterman and Gray, 1966). Their range in age is approximately 8.6 to 9.4 m.y.

Lying unconformably upon the late Miocene volcanic rocks are lava flows of andesitic and basaltic composition of the Cedar Hill-Trench Canyon complex (Al-Rawi, 1969). Their range in age is 2.2 to 3.6 m.y.

GEOLOGY OF THE BODIE MINING DISTRICT

Rocks of the Bodie mining district (Plate 2) include extrusive and intrusive lavas and pyroclastic deposits of the Potato Peak Formation and Murphy Spring Tuff Breccia (Chesterman, 1968, p. 51-60) and of a unit referred to as the Silver Hill Volcanic Series (Chesterman and Gray, 1966, p. 14), all of which appear to range in age from 8.6 to 9.4 m.y. (Silberman and others, 1972, p. 601).

Silver Hill Volcanic Series

The rocks of the Silver Hill Volcanic Series (Chesterman and Gray, 1966, p. 14) crop out extensively in the Bodie mining district. They consist of interlayered lava flows and tuff breccia, and intrusive plugs, and are named after Silver Hill, a small hill near the center of the district (Plate 2). Outcrops of these rocks that show contacts are not common, but their relationships are well exposed in underground mine workings. It appears that tuff

Photo 3. View westward toward Sugarloaf, a plug of dacite of the Silver Hill Volcanic Series at the southern end of the district. Snowcapped Sierra Nevada in distance.

breccia layers were deposited and are overlain by lava flows and more layers of tuff breccia. The principal tuff breccia layer, which underlies a large portion of the district, is about 400 feet thick. Remnants of a thinner tuff breccia layer caps Silver Hill and occupies the small graben near Standard Hill; it has been extensively altered and probably is no more than 150 feet thick.

Several flows are exposed on the surface, and some are exposed in mine workings, especially the deeper ones. One composite flow in particular, which underlies much of the district, is between 500 and 700 feet thick and appears to be composed of two units. The upper unit is biotite-rich dacite and the lower unit is hornblende-rich dacite. The contact between the two was not observed.

Four plugs of dacite intrude the tuff breccia layers and flows of the Silver Hill Volcanic Series. The largest plug occurs at the northern end of the district and makes up the bulk of the rocks that form Bodie Bluff and Standard Hill (Plate 2). The other plugs are near the Red Cloud mine, at Queen Bee Hill and at Sugarloaf (Plate 2). These plugs are composed of hornblende dacite and are probably connected at depth.

In general, the sequence of pyroclastic deposits and interlayered lava flows dips from 5 to 15 degrees in a southerly direction except near the plugs where they dip outward at steeper angles.

TUFF BRECCIA

Throughout much of the Bodie mining district the rocks of the Silver Hill Volcanic Series are difficult to discern because they have undergone alteration. The tuff breccia is best exposed in scattered exposures at the north end of the district, where a stratigraphic section consisting of about 200 feet of pyroclastic rocks was studied and measured. The basal unit is gray tuff breccia which is massive and sufficiently indurated to form low cliffs. It has indistinct layering and consists of angular and subangular blocks of dark- and light-colored dacite from a few inches to several feet across enclosed in a matrix of volcanic ash and mineral grains. At least 125 feet of this basal unit is exposed. The basal, gray tuff breccia is overlain unconformably by a layer, from one to 60 feet thick, of well-indurated, buff-colored tuff breccia which is massive, poorly layered, and consists of angular fragments of tan-colored tuff breccia. Grading into it is a layer of black welded tuff, which ranges in thickness from 4 to 6 feet. The welded tuff has been referred to by various people as obsidian, and in color, texture, structure, and mode of occurrence it resembles other layers of welded tuff that occur in several of the volcanic formations in the Bodie Hills (Chesterman, 1968, p. 49-53). At its contact with the underlying tuff breccia the welded tuff is dark brown, and the color transition from dark welded tuff to buff-colored tuff breccia is gradual.

The welded tuff is dense, has a well-developed vitroclastic texture, and consists of angular and rounded fragments of light to dark gray and dark brown porphyritic dacite enclosed in a dark gray, fine-grained groundmass streaked with black glass. The lithic fragments rarely exceed several inches in diameter, and the average size is less than one-half an inch. The dacite clasts contain euhedral phenocrysts of glassy white plagioclase

(An_{35-40}), black hornblende, and deep-brown biotite. A small mass of dark gray to black welded tuff crops out in the eastern part of the district, about 700 feet southeast of the Defiance shaft (Plate 2). It is completely enclosed in tuff breccia overlain by hornblende-rich dacite, all in a triangularly shaped fault block. Still larger and more prominent outcrops of the welded tuff are exposed in the walls of Milk Ranch Canyon in the northwestern part of the study area. Although outcrops of the black welded tuff are neither very large nor abundant, it is apparent from their distribution that the rock covered much of the Bodie mining district.

Much of the pyroclastic rock of the district probably was derived from vents in the district, which are now sites of plugs, and because of the lack of sorting and layering, they suggest a lahar mode of deposition.

Lying above the black welded tuff in what appears to be a conformable relationship is a sequence of weakly indurated tuff breccia layers. Because of scarce and inadequate exposures of this sequence of tuff breccia layers, it was not possible to ascertain its thickness or structural characteristics. It is composed of angular and subangular blocks and fragments of medium-gray dacite, ranging in diameter from a few inches to one foot and enclosed in a matrix of fine-grained volcanic ash and mineral grains. The sequence of upper tuff breccia layers is unconformably overlain by moderately indurated and layered tuff breccia of the Potato Peak Formation.

The clasts in all of the tuff breccia layers, except the black welded tuff, range in color from light and medium gray to brown and tan. The rock is principally hornblende dacite in composition and contains phenocrysts of black hornblende and glassy white plagioclase enclosed in a fine-grained, light gray groundmass of plagioclase, hornblende, minor biotite, and devitrified volcanic glass.

DACITE FLOWS

Based on sparse information from records of extensive mining operations in the district, several flows of dacite, separated by relatively thin interlayers of tuff breccia, were encountered in shafts. In the Lent shaft (Plate 2), which extended to a depth of 1,200 feet below its collar elevation of 8,422 feet, a layer of dacite about 8 feet thick was encountered at a depth of 650 feet.

Composite Flow

A composite flow covers much of the district and is exposed in many of the mine workings. The composite flow is made up of two rather distinct units. The upper unit is biotite-rich dacite and the lower unit is hornblende-rich dacite. Because of the lack of adequate exposures, it was not possible to ascertain the thickness of the composite flow or to delineate its individual units and their contact relationships, but it is estimated that the thickness of the flow is between 500 and 700 feet. The interrelationship of the two units is constant throughout the district.

Exposures of unaltered units of the composite flow are uncommon, primarily because of extensive hydrothermal alteration of the rocks, but relatively unaltered samples were obtained on the south side of Queen Bee Hill and in the underground workings of the Red Cloud mine (Plate 2).

The lower hornblende-rich unit has well-developed platy jointing and conspicuous needle-like, black crystals of hornblende. The upper biotite-rich unit lacks the platy structure but shows blocky jointing, conspicuous black crystals of biotite, and an equigranular appearance of the plagioclase phenocrysts.

LOWER UNIT. The hornblende-rich dacite is light gray, porphyritic, and contains phenocrysts of plagioclase and hornblende enclosed in a fine-grained groundmass of mineral grains, microphenocrysts of biotite, and partly devitrified volcanic glass. The plagioclase, with phenocrysts of euhedral and subhedral grains, ranges in composition between intermediate and calcic andesine (An_{40-45}), and shows multiple twinning and oscillatory zoning. It is remarkably fresh in spite of the generally slightly altered condition of the rock, and it constitutes about 60 percent of the phenocrysts.

The hornblende is light brown and greenish-brown, is weakly pleochroic, and occurs in euhedral and subhedral grains, of which the larger are partly resorbed and the smaller are completely resorbed, leaving residues of tiny grains of black iron oxide. The hornblende constitutes about 30 percent of the phenocrysts. Biotite is dark brown in color and strongly pleochroic from tan to dark brown. It is in euhedral and subhedral grains, all of which are resorbed to varying degrees. The biotite constitutes about 10 percent of the phenocrysts.

The groundmass constitutes about 30 percent of the rock. It consists of plagioclase microlites which show simple polysynthetic twinning and are probably sodic andesine in composition. They are unaltered and occur with microphenocrysts of hornblende and biotite in partly devitrified volcanic glass.

Samples of altered hornblende-rich dacite from the underground workings of the Red Cloud mine (Plate 2) and from outcrops elsewhere in the district illustrate very well the types and degrees of hydrothermal alteration to which the rock has been subjected.

UPPER UNIT. The biotite-rich dacite of the upper unit ranges in color from pale gray to pinkish gray. It is porphyritic and contains phenocrysts of dark brown biotite, scarce black hornblende, and glassy-white plagioclase enclosed in a fine-grained groundmass. Phenocrysts make up about 60 to 65 percent of the rock. The plagioclase phenocrysts are in euhedral and subhedral grains, which occur singly or in clusters. They show multiple twinning, oscillatory zoning, and range in composition between sodic and intermediate andesine (An_{35-40}). Alteration is present in the large phenocrysts and manifests itself as a narrow zone immediately beneath a clear glassy rim on the grain. The plagioclase phenocrysts constitute from 40 to 50 percent of the phenocrysts. The groundmass plagioclase is in small microlites that show simple polysynthetic twinning, and has a composition of sodic andesine.

Sanidine occurs as small rectangular-shaped euhedral grains which show simple carlsbad twinning. The grains are skeletal and have dark shadowy interiors. They are not altered and constitute about 5 percent of the rock.

The femic minerals are generally resorbed. Relatively fresh biotite occurs in dark brown, strongly pleochroic euhedral grains which constitute about 30 to 40 percent of the phenocrysts. Hornblende is subordinate to the biotite, and where it is incompletely resorbed it occurs as deep-green euhedral and subhedral grains which are weakly pleochroic.

The groundmass glass is usually pinkish-tan in color and somewhat devitrified. It constitutes about 35 to 40 percent of the rock.

INTRUSIVE DACITE

Aside from dikes, which crop out rarely but were encountered in mines, the bulk of the intrusive dacite occurs in plugs. The dacite shows well developed flow banding, especially near contacts with wall rocks, and shows a range in color from pale gray

Photo 4. Intrusive dacite of the Silver Hill Volcanic Series as exposed in the face of the Roseklip cut, on the south side of Standard Hill. *Photograph by M.L. Silberman, U.S. Geological Survey.*

to medium gray, rarely pinkish (Photo 4). The dacite is porphyritic with phenocrysts of hornblende occasionally up to 10 mm in length and plagioclase as much as 5 mm across; biotite, when abundant, tends to form euhedral plates as much as 3 mm across. The phenocrysts range in amount from 40 to 80 percent of the rock. The groundmass is fine grained and generally contains from 10 to 15 percent volcanic glass that is more or less devitrified.

The plagioclase, which constitutes 40 to 60 percent of the phenocrysts, occurs as euhedral to subhedral grains which show multiple twinning and complex oscillatory zoning. Their composition range is from sodic to intermediate andesine (An_{35-40}). Many of the larger euhedral-shaped grains show considerable alteration, generally as a narrow zone of calcite and sericite surrounding an unaltered core and rimmed by a narrow zone of clear, glassy feldspar which lacks twinning and has an extinction position different from the interior feldspar. Inclusions of volcanic glass commonly form a narrow zone immediately beneath the clear glassy rim of the grain. Other inclusions include femic minerals and magnetite.

Sanidine phenocrysts, as much as 3 mm across, are common in the dacite that forms the eastern part of the plug at Bodie Bluff, and constitute about 40 percent of the phenocrysts. They are euhedral, glassy where unaltered, and show carlsbad twins. Altered sanidine phenocrysts contain carbonate and sericite.

Feldspar in the groundmass, which constitutes about 20 percent of the rock, is sodic andesine and sanidine. The sodic andesine occurs as small lath-shaped grains and as microlites which show simple polysynthetic twinning and are generally unaltered. The sanidine is in rectangular-shaped crystals which are commonly untwinned and generally unaltered.

Phenocrysts and microphenocrysts of biotite and hornblende are largely resorbed and altered, but unaltered phenocrysts are dark brown in color and strongly pleochroic. The strongly resorbed femic phenocrysts are represented by residual accumulations of small black grains of iron oxide. Partly resorbed grains contain the residual iron oxide grains, calcite, and the unaltered mineral. Apatite and magnetite occur as inclusions in the unaltered biotite. The femic minerals comprise generally 10 to 40 percent of the total phenocrysts. Apatite and sphene are accessory minerals.

The volcanic glass is usually completely devitrified to cryptocrystalline and microcrystalline aggregates. Tridymite occurs as small, wedge-shaped, twinned crystals, but it is rare.

The intrusive dacite of the Bodie Bluff-Standard Hill plug (Plate 2) has undergone potassic alteration as well as locally intense argillic alteration (see section on hydrothermal alteration).

CHEMICAL COMPOSITION

The lava flows of the Silver Hill Volcanic Series in the Bodie mining district have a range in composition from latite-andesite through latite and dacite to rhyodacite. Fourteen chemical analyses, available through the U.S. Geological Survey, are given in Table 1. Norms were calculated for these rocks and plotted on a Streckeisen diagram (Figure 3). The spread of points on the diagram reflects the alteration effects on the rocks. Rocks of the plug at Bodie Bluff-Standard Hill, in spite of their apparent freshness, have undergone considerable potassic alteration; the added potassium shows up principally in the groundmass. The composite flow, of which analysis 12 is from the upper biotite-rich unit and analysis 13 is from the lower hornblende-rich unit, appears to be fairly constant in chemical composition, regardless of its two-phase division on a basis of mineralogical composition.

AGE OF THE SILVER HILL VOLCANIC SERIES

Biotite and hornblende separated from plugs and flows of the Silver Hill Volcanic Series have been dated by the K-Ar method. The flows have ages ranging from 8.8 ± .2 m.y. to 9.1 ± .5 m.y., and the plugs have a range of 8.3 ± .4 m.y. to 9.2 ± .5 m.y. (Silberman and others, 1972, p. 601).

Murphy Spring Tuff Breccia

Lava flows and pyroclastic deposits of the Murphy Springs Tuff Breccia (Chesterman, 1966, p. 51-52) crop out extensively in the southern part of the Bodie mining district. The formation consists of flows and plugs of dacite and tuff breccia of dacitic composition.

The pyroclastic member of the Murphy Springs Tuff Breccia in the district consists principally of tuff breccia and minor tuff layers. The tuff breccia in the vicinity of Sugarloaf (Plate 2) has a maximum thickness of about 750 feet. The source vents for much of the pyroclastic deposits in the district are at the southern end of the district, where the tuff breccia dips steeply away from central plugs of dacite. The dip of the layering in the tuff breccia flattens greatly and is generally in a westerly direction.

Individual lava flows cannot be traced for more than a few hundred feet because of poor exposures, but they tend to range in thickness from a few feet to several tens of feet. Several flows in the low hill west of Sugarloaf, which contain very little interlayered fragmental or pyroclastic material, have an aggregate thickness of about 375 feet; on the northwest slope of Lookout Peak, just within the district, the dacite lava flows have an aggregate thickness of at least 450 feet. Flow banding within the flows locally dips in many directions, but in general the flows tend to have a low to moderate dip to the west and southwest.

PYROCLASTIC DEPOSITS

The tuff breccia is a massive rock in which layering is most distinct near the source vents. Exposures of tuff breccia are scarce, principally because of removal by erosion, but the presence of the rock can easily be ascertained by the large number of small rock fragments and angular boulders up to 5 feet across lying on the surface.

Tuff breccia exposed west of Sugarloaf can be divided into a gray tuff breccia unit and an underlying brown tuff breccia. The color of the clasts contained in the two units is the basis for the division. The gray tuff breccia appears to be restricted to this small area, whereas the brown tuff breccia is widely distributed.

The gray tuff breccia lies unconformably upon the brown tuff breccia, and is estimated to be approximately 170 feet thick. Layering is indistinct in the rock, but indications are that the general dip of the unit is toward the southwest at a low angle. The clasts are pale to medium gray in color and occur as angular to subangular boulders and fragments that range in size from a few inches to several feet across, enclosed in a matrix of pale gray rock, mineral fragments, and volcanic ash. The clasts are composed of porphyritic hornblende dacite, in which phenocrysts of black hornblende, glassy feldspar, and scarce black biotite are enclosed in a fine-grained matrix of plagioclase and partly devitrified volcanic glass. Hornblende comprises about 40 percent of the phenocrysts. It occurs in euhedral grains which are pleochroic from dark brown to greenish brown. A few of the grains are partly resorbed and contain granules of iron oxide concentrated at the central part of the host grain. Plagioclase (An_{35-40}) constitutes about 40 percent of the phenocrysts. It occurs as euhedral to subhedral grains which show multiple zoning, inclusions of volcanic glass, and evidence of re-solution during a complex cooling history. The interior part of some of the larger plagioclase phenocrysts are altered to carbonate and kaolin, which are surrounded by a rim of glassy feldspar. Black biotite is in euhedral phenocrysts that are strongly pleochroic and partly resorbed.

The groundmass plagioclase is in the form of small euhedral and subhedral lath-shaped grains which are more sodic in composition than the plagioclase phenocrysts. Except for the groundmass plagioclase and microphenocrysts of hornblende and minor biotite, the remainder of the groundmass is cloudy, partly devitrified volcanic glass.

The clasts in the brown tuff breccia unit are hornblende dacite, angular and subangular, and range in size and shape from sharp angular fragments several inches across to large angular blocks as much as 5 feet in diameter. The average clast size is about one foot. Near the source vents, this tuff breccia unit has distinct, massive layering with individual layers that range in thickness from several feet to several tens of feet.

The clasts range in color from dark reddish-brown to pale pinkish-brown. The rock, similar petrographically to the dacite in the gray tuff breccia, is porphyritic and contains phenocrysts of basaltic hornblende and plagioclase enclosed in a fine-grained, microcrystalline and glassy groundmass. The basaltic hornblende is strongly pleochroic, from pale yellowish- to deep golden-brown, and is the principal contributor to the color distinction between the clasts in the two tuff breccia units. The groundmass has a pale pinkish-yellow color due to the secondary limonite which contributes to the overall color of the rock. The color of the scarce biotite is deep golden brown, identical to that of the basaltic hornblende.

Because the clasts in the two tuff breccia units are hornblende dacite and differ only in the type of hornblende, one can assume that the brown dacite was extruded at a higher temperature than was the gray dacite, and that the color differences are due principally to the presence of brown basaltic hornblende and brown colored glass in the brown dacite. The pyroclastic deposits of the Murphy Spring Tuff Breccia lie unconformably upon units of the Silver Hill Volcanic Series.

DACITE FLOWS AND PLUGS

Lava flows of the Murphy Spring Tuff Breccia are dacitic in composition and crop out principally in the southern and southeastern parts of the Bodie mining district. The thickness of individual flows within the district could not be measured, but several flows outside the district on the south flank of Lookout Peak (name applied by local residents), the west flank of which lies within the district, range in thickness from 10 to 20 feet

Table 1. Chemical analyses and normative compositions, in percent, of the dacite flows and intrusives from the Silver Hill Volcanic Series in the Bodie mining district.

CHEMICAL ANALYSES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	63.67	68.66	62.11	63.83	62.66	62.14	61.52	60.30	62.44	61.15	66.23	64.15	64.20	64.07
Al_2O_3	16.02	14.53	17.10	16.21	16.92	17.21	16.59	16.78	17.44	17.33	16.31	16.49	17.38	16.62
Fe_2O_3	2.60	3.61	4.70	2.80	3.00	3.60	2.33	3.42	3.31	3.32	2.80	4.00	4.22	3.50
FeO	1.80	0.32	0.20	1.40	1.50	1.60	2.33	1.61	1.20	1.71	1.00	0.52	0.36	0.68
MgO	2.20	0.52	1.30	2.20	2.40	2.00	2.63	2.81	1.90	2.22	1.60	1.90	0.95	1.20
CaO	3.30	0.76	0.19	2.50	4.10	4.30	4.76	5.33	3.21	4.63	3.40	3.80	3.42	4.00
Na_2O	3.00	2.31	0.31	3.50	3.80	4.50	3.64	3.22	4.01	4.03	3.50	3.60	3.92	4.00
K_2O	5.11	7.32	10.91	4.60	3.10	2.30	2.73	2.51	2.61	2.72	3.40	3.00	3.21	3.40
H_2O	1.35	1.20	2.40	2.01	1.42	1.11	1.29	2.81	2.81	1.71	0.85	1.50	1.21	1.40
TiO_2	0.62	0.53	0.56	0.56	0.71	0.80	0.70	0.73	0.67	0.74	0.50	0.62	0.71	0.69
P_2O_5	0.26	0.23	0.19	0.25	0.29	0.35	0.30	0.34	0.31	0.33	0.25	0.26	0.38	0.32
MnO	0.06		0.04	0.09	0.09	0.04	0.07	0.13	0.09	0.10	0.10	0.10	0.04	0.04
ZrO_2	0.00													0.00
CO_2	0.00			0.05		0.04	1.11				0.06	0.08		0.06
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

NORMATIVE COMPOSITIONS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Quartz	16.923	25.492		18.051	17.104	16.034	19.056	17.390	20.316	15.007	24.039	21.739	21.438	18.465
Corundum	0.167	1.989		1.633	0.534	0.421	2.304		2.936	0.125	1.419	1.229	2.159	
Orthoclase	30.170	43.421		27.193	18.335	13.599	16.144	14.847	15.400	16.074	20.100	17.714	18.997	20.114
Albite	25.413	19.508		29.628	32.183	38.101	30.823	27.214	33.925	34.099	29.628	30.438	33.153	33.884
Anorthite	14.689	2.273		10.457	18.462	18.804	14.574	23.940	13.882	20.819	14.861	16.634	14.451	17.317
Wollastonite								0.106						0.032
Enstatite	5.485	1.298		5.481	5.983	4.984	6.552	7.008	4.743	5.520	3.986	4.728	2.377	2.992
Ferrosilite	0.245						1.330							
Magnetite	3.774			3.184	3.073	2.070	3.374							
Hematite		3.609		0.605	0.883	1.554		3.483	2.225	3.717	2.101	0.205		0.323
Ilmenite	1.179	0.677		1.064	1.350	1.520	1.326	1.015	1.773	0.761	1.352	3.855	4.219	3.281
Rutile		0.175						1.393	1.275	1.397	0.950	1.177	0.850	1.312
Apatite	0.616	0.546		0.592	0.688	0.830	0.719	0.809	0.736	0.787	0.592	0.615	0.266	0.759
Calcite				0.114		0.091	2.531				0.137	0.182	0.904	0.137
Total	98.662	98.808		98.003	98.595	98.908	98.731	97.205	97.211	98.306	99.164	98.516	98.815	98.615
Salic	87.363	92.504		86.936	86.619	86.959	82.899	83.391	86.459	86.124	90.045	87.753	90.198	89.781
Femic	11.299	6.305		11.040	11.976	11.949	15.832	13.815	10.752	12.192	9.118	10.762	8.616	8.835

1 (BH-271*) Hornblende-biotite dacite from the intrusive dacite of the Silver Hill Volcanic Series of the Bodie Bluff-Standard Hill plug, collected from the dump of the New Standard shaft in the south central part of Sec 9, T4N, R27E.

2 (BH-272) Hornblende biotite dacite from the intrusive dacite of the Silver Hill Volcanic Series of the Bodie Bluff-Standard Hill plug, collected from a shallow prospect pit at the summit of Bodie Bluff in the central part of Sec 9, T4N, R27E.

3 (814G 1) Biotite-hornblende dacite from the intrusive dacite of the Silver Hill Volcanic Series of the Bodie Bluff Standard Hill plug, collected from a tunnel near the southern margin of Sec 10, T4N R27E, about one-quarter mile southwest of the Gray Mill

4 (856G 8) Hornblende dacite from the intrusive dacite of the Silver Hill Volcanic Series of the Bodie Bluff-Standard Hill plug, collected from the so-called Roseklip cut in south central part of Sec 9, T4N, R27E

5 (BH 17) Hornblende dacite from the intrusive dacite of the Silver Hill Volcanic Series of the Queen Bee Hill plug collected near the summit of Queen Bee Hill in the west central part of Sec 21, T4N R27E

6 (BH 30) Hornblende biotite dacite from the hornblende-rich unit of the composite flow of the Silver Hill Volcanic Series, collected near the eastern boundary of Sec 20, T4N, R27E.

7 (BH-273) Hornblende-biotite dacite from the intrusive dacite of the Silver Hill Volcanic Series of the Queen Bee Hill plug, collected on the north side of Queen Bee Hill in the west central part of Sec 21, T4N, R27E

8 (BH-15) Biotite-hornblende dacite from a lava flow of the Silver Hill Volcanic Series, collected in the north central part of Sec 21, T4N, R27E, about 500 feet southeasterly from the Red Cloud shaft

9 (S#1) Hornblende-biotite dacite from the intrusive Silver Hill Volcanic Series of the Sugarloaf plug, collected at the summit of Sugarloaf in the southwest quarter of Sec 21, T4N, R27E.

10 (BH-26) Hornblende-biotite dacite from the intrusive Silver Hill Volcanic Series of the Sugarloaf plug, collected from the north slope of Sugarloaf in the southwest quarter of Sec 21, T4N, R27E.

11 (85610) Biotite-hornblende dacite of the Silver Hill Volcanic Series from a small intrusive plug, collected just outside the Bodie mining district in the west central part of Sec 17, T4N, R27E. On the basis of chemical composition and abundance of biotite, the rock might be considered as rhyodacite.

12 (Lilac) Hornblende dacite from the hornblende-rich unit of the composite flow of dacite of the Silver Hill Volcanic Series, collected from a small hill in the northeast quarter of Sec 16, T4N, R27E, about 1,000 feet easterly from the Dudley shaft

13 (BH-16) Biotite-hornblende dacite from the biotite-rich unit of the composite dacite flow of the Silver Hill Volcanic Series, collected from a prominent cropping in the southeast quarter of Sec. 16, T4N, R27E.

14 (BH-32) Biotite-hornblende dacite from the biotite-rich unit of the composite dacite flow of the Silver Hill Volcanic Series, collected near the top of a small hill in the center of Sec 21, T4N, R27E.

For samples 6 and 14, method of analysis used is the single solution procedure described in U S Geological Survey Professional Paper 575-B, p 187-191 (1967) Analysts P Elmore, S Botts, L Artis, J Kelsey, H Smith and J Glenn For samples 1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, and 13, methods of analysis used are described in U S Geological Survey Bulletin 1144-A, supplemented by atomic absorption Analysts P Elmore, S Botts, G Chloe, H Smith, J Kelsey, L Artis and J Glenn

* Indicates field number

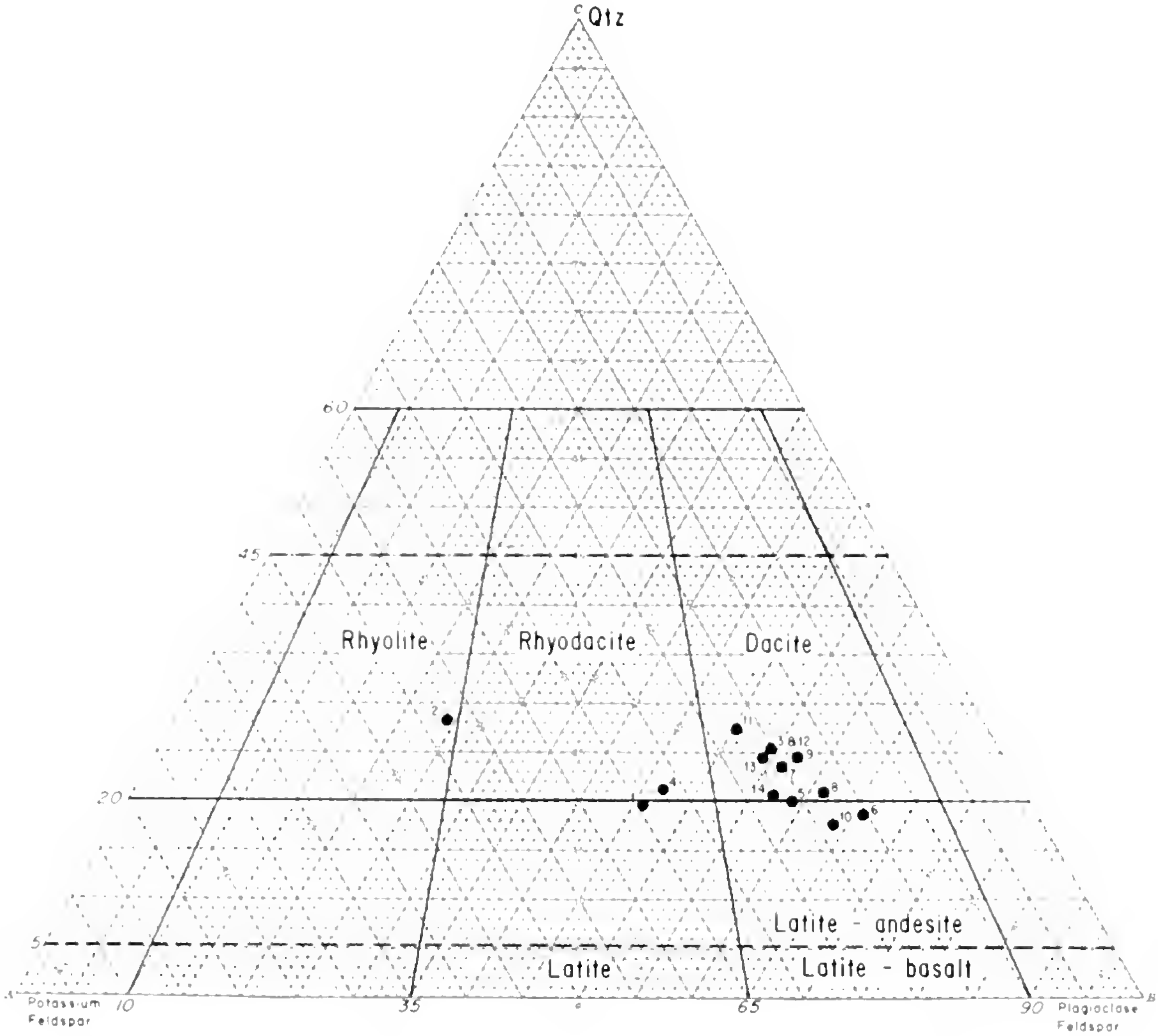

Figure 3 Normative compositions of rocks of the Silver Hill Volcanic Series in the Bodie mining district plotted on a Streckeisen diagram. Numbers refer to analyses in Table 1. *Diagram adapted from Streckeisen (1967, p. 161).*

Individual flows wedge out laterally, and the thickest section of them (about 450 feet) is in the vicinity of Lookout Peak—one of the local vents for much of the material for the Murphy Spring Tuff Breccia. The plug at Lookout Peak is somewhat circular in plan and is about half a mile in diameter. Another plug lies about one mile south of Sugarloaf. It has a circular plan and is about one quarter of a mile in diameter (Plate 2).

The dacite in the plugs and flows is dense, shows flow banding, and ranges in color from pale to dark gray and medium brown. Brown is the predominant color, especially in the plugs. The dacite is porphyritic, and 30 to 40 percent of the rock is made up of phenocrysts enclosed in a fine-grained groundmass composed of mineral grains and volcanic glass.

About 50 to 60 percent of the phenocrysts are plagioclase. They occur in euhedral and subhedral grains which show multiple twinning and oscillatory zoning. The interiors of a few larger phenocrysts are altered to calcite and kaolin and have glassy clear rims of more sodic plagioclase. The unaltered plagioclase phenocrysts range in composition from sodic andesine to calcic andesine (An_{30-46}), and the average composition is intermediate andesine (An_{40}). Inclusions of volcanic glass are common, especially in the rims of the larger phenocrysts.

About 30 to 35 percent of the phenocrysts are hornblende and biotite. The biotite, usually less abundant than the hornblende, is pleochroic and ranges from pale yellow to dark brown, but where associated with basaltic hornblende, it is reddish- to golden-brown and strongly pleochroic. Many of the biotite grains have undergone resorption, which leaves a residue of black iron oxide grains at their rims. Hornblende in the gray dacite occurs in euhedral and subhedral grains that are moderately pleochroic and range from pale yellowish-green to deep yellowish-brown. Many of the grains are partly to completely resorbed and leave dark rims around unaltered hornblende or residues of dark iron oxide grains. The amphibole in the brown dacite is basaltic hornblende. It is strongly pleochroic and ranges in color from pale yellowish- to deep reddish-golden brown. Those grains that are strongly resorbed show subhedral form, whereas those that are weakly resorbed show euhedral form.

The groundmass of the dacite, regardless of the color of the rock, appears to consist of an aggregate of microlites of plagioclase, microphenocrysts of short prismatic plagioclase, euhedral hornblende and biotite, and partly devitrified volcanic glass. The plagioclase is probably sodic andesine or calcic oligoclase in composition The mafic minerals in the groundmass are generally partly to completely resorbed. The groundmass of the brown dacite has a pale buff color due to secondary limonite. The partly devitrified glass is cloudy and contains minor carbonate and kaolin.

CHEMICAL COMPOSITION

Four new chemical analyses, all by the U.S. Geological Survey, are given in Table 2 for the dacite of the Murphy Spring Tuff Breccia. Three of these analyses are of samples collected in the Bodie mining district, and the fourth is from a prominent outcrop of dacite near Murphy Spring, about 2.5 miles west of the district (Plate 1). Norms for these analyses are plotted in Figure 4. The spread of the points on the diagram indicates a change of composition due to different source vents for the samples. Points 2, 3, and 4 represent samples from the flows near the large plug at Lookout Peak and Point 1 represents the sample from a flow whose source is near Murphy Spring (Plate 1).

AGE OF THE MURPHY SPRING TUFF BRECCIA

Biotites separated from dacite samples from the plug at Lookout Peak give identical K-Ar age dates of 8.7 ± 0.2 m.y.

Potato Peak Formation

Several hundred feet of Potato Peak Formation, consisting of interlayered dacite flows and layers of tuff breccia of dacitic composition, are exposed in the northwestern corner of the Bodie mining district (Plate 2).

DACITE FLOWS

Individual flows of dacite are not well defined in the district, but their aggregate thickness is estimated to be approximately 350 feet. The dacite lies unconformably upon tuff breccia.

The dacite is medium- to coarse-grained, is medium gray colored, and shows well-developed flow banding. It is porphyritic and contains phenocrysts of andesine, black biotite, and dark greenish-brown hornblende enclosed in a fine-grained crystalline to semi-crystalline groundmass composed of andesine, biotite, hornblende, deep-green diopsidic augite, and devitrified glass. The feldspar phenocrysts are generally euhedral, show well-developed twinning and oscillatory zoning, and are in the composition range of intermediate to calcic andesine (An[illegible]) The groundmass feldspar is in small lath-shaped crystals whose composition ranges from sodic to intermediate andesine (An[illegible]). Biotite is generally more common than the hornblende. It occurs in dark brown to golden brown euhedral plates, the hornblende is in dark brownish-green euhedral grains Both, when altered, show black borders consisting of dust-like magnetite.

Diopsidic-augite is not common, but usually occurs in deep-green, weakly pleochroic euhedral grains in those dacite flows with hornblende content exceeding that of the biotite Quartz is rare and generally occurs in anhedral grains

Petrographic examinations of the lava flows in the Potato Peak Formation indicate that the flow rocks are andesitic in composition Chemical analyses, on the other hand, indicate a dacitic composition (Table 3, Figure 5)

Table 2. Chemical analyses and normative composition, in percent, of the dacite flows from the Murphy Spring Tuff Breccia of the Bodie mining district and adjacent area.

CHEMICAL ANALYSES

	1	2	3	4
SiO_2	60.34	61.54	63.56	64.36
Al_2O_3	18.30	17.71	17.52	16.94
Fe_2O_3	3.32	4.50	4.20	3.19
FeO	1.61	0.68	0.36	1.30
MgO	1.81	2.00	1.30	1.20
CaO	4.93	5.10	3.50	3.98
Na_2O	3.82	3.90	3.70	4.28
K_2O	2.92	2.40	3.00	2.79
H_2O	1.79	0.84	1.80	1.00
TiO_2	0.70	0.82	0.58	0.61
P_2O_5	0.37	0.33	0.30	0.32
MnO	0.08	0.08	0.07	0.04
ZrO_2	0.00	0.00	0.00	0.00
CO_2	0.00	0.08	0.09	0.01
Total	100.00	100.00	100.00	100.00

NORMATIVE COMPOSITIONS

	1	2	3	4
Quartz	14.744	16.883	22.175	19.370
Corundum	0.791	0.390	2.732	0.411
Orthoclase	17.235	14.192	17.746	16.483
Albite	32.339	33.024	31.340	36.248
Wollastonite				
Enstatite	4.509	4.985	3.241	2.977
Ferrosilite				
Magnetite	3.408	0.076		2.543
Hematite	0.968	4.451	4.204	1.434
Ilmenite	1.337	1 5580 911	1.154	
Rutile			0.101	
Apatite	0.881	0.782	0.711	0.755
Calcite		0.182	0.205	0.023
Total	98.230	99.177	98.214	99.021
Salic	87.126	87.143	88.841	90.135
Femic	11.104	12.034	9.373	8.886

1. (BH-14*) Biotite-hornblende dacite from near the top of one of the latest lava flows in the Murphy Spring Tuff Breccia, collected from the west edge of Sec. 24, T4N, R26E, MDM, about three-quarters mile westerly of Murphy Spring.
2. (BH-18) Biotite-hornblende dacite from a lava flow in the Murphy Spring Tuff Breccia, collected in the northeast corner of Sec. 21, T4N, R27E, MDM, about one and one-quarter miles northeasterly of Sugarloaf.
3. (854G-1) Biotite dacite from lava flow in Murphy Spring Tuff Breccia, collected in the central part of Sec. 28, T4N, R27E, MDM, about 300 feet southeast of Sugarloaf
4. (BH-20) Biotite-hornblend dacite from a lava flow in an easternmost exposure of Murphy Spring Tuff Breccia, collected at an abandoned railroad cut in the northeast quarter of Sec. 23, T4N, R27E, MDM

For samples 1, 2 and 4, methods of analysis used are described in U.S Geological Survey Bulletin 1144-A, supplemented by atomic absorption. Analysts P. Elmore, S. Botts, G Chloe, H Smith, J Kelsey, L Artis and J Glenn. For sample 3, method of analysis used is the single solution procedure described in U.S Geological Survey Professional Paper 575-B, p. 187-191 Analysts: P Elmore, S Botts, L. Artis, J Kelsey, H Smith and J Glenn

* Indicates field number

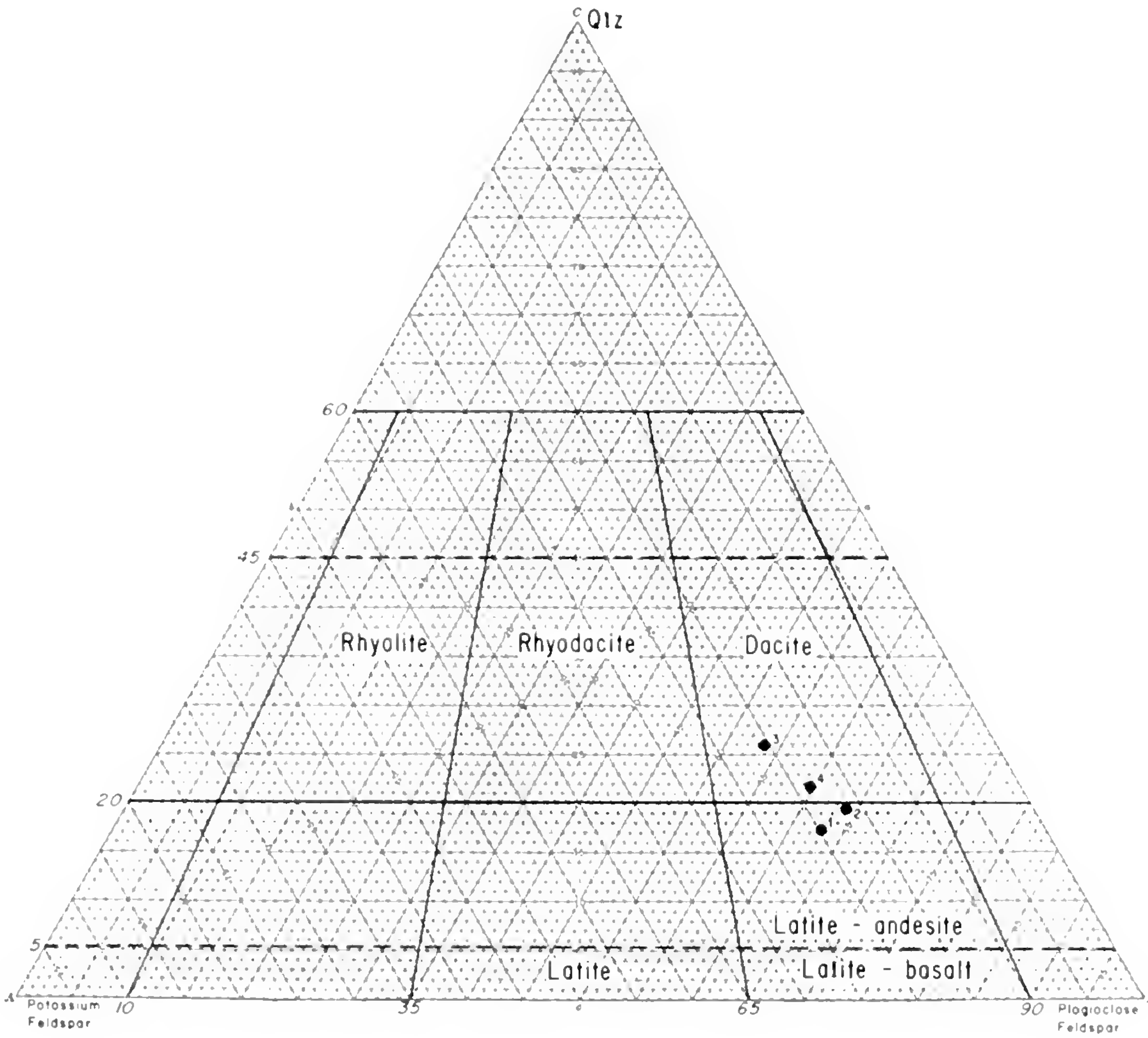

Figure 4. Normative compositions of dacite lavas from the Murphy Spring Tuff Breccia of the Bodie mining district and adjacent area plotted on a Streckeisen diagram. Numbers refer to analyses in Table 2. *Diagram adopted from Streckeisen (1967, p. 161).*

TUFF BRECCIA

Tuff breccia of the Potato Peak Formation is a massive rock unit whose actual thickness in the Bodie mining district is not known, but whose exposed thickness is estimated to be about 150 feet. Exposures of the tuff breccia are scarce; but, where observed, it is medium gray in color and firmly indurated, and contains minor interbeds of tuffaceous sandstone and conglomerate. The tuff breccia is poorly bedded and consists of angular fragments and blocks of light gray biotite dacite, as much as 6 feet across, enclosed in a matrix of small rock fragments and volcanic ash. The average size of blocks in the tuff breccia is approximately one foot.

The tuffaceous sandstone and conglomerate layers are lens-like and generally range in thickness from 6 inches to 2 feet. The tuffaceous sandstone is well bedded, medium to fine grained, light gray in color, and firmly indurated. The tuffaceous conglomerate, too, is light colored, and firmly indurated, and consists of subangular and well-rounded clasts that range in size from pea-size fragments to boulders ten inches across. Volcanic ash makes up at least 40 percent of the matrix material, and the clasts consist largely of light gray biotite dacite and minor brown-colored hornblende andesite.

The tuff breccia unit rests unconformably upon tuff breccia of the Silver Hill Volcanic Series and is unconformably overlain by dacite flows of the Potato Peak Formation.

AGE OF THE POTATO PEAK FORMATION

Based upon K-Ar age determinations of biotite from flows of dacite, the age of the Potato Peak Formation ranges between 9.1 and 8.4 m.y.

STRUCTURE

Whiting (1888, p. 383) favored a structural picture for the Bodie mining district consisting of inter-layered lava flows and tuff breccia layers dipping gently toward the south. The irregular outcrop pattern of the hydrothermally altered rocks and their disturbed condition, due principally to faulting, may have contributed much to this thesis. F.H. Frederick (written communication, 1960) carried on a systematic geologic investigation of the district in the early 1930s, and many of his thoughts and maps were the basis of some of the conclusions expressed by Wisser (1960, p. 70), who considered the structure to be an irregular northeastward-trending anticline, upon which are superimposed several domes.

Table 3. Chemical analyses and normative composition, in percent, of the dacite flows of the Potato Peak Formation of the Potato Peak-Bodie Mountain area.

CHEMICAL ANALYSES

	1	2	3	4	5
SiO_2	61.70	61.81	61.47	62.53	61.40
Al_2O_3	17.63	16.93	17.49	17.74	17.53
Fe_2O_3	4.01	3.81	4.30	3.31	4.21
FeO	1.30	1.20	0.72	1.50	0.96
MgO	1.30	2.40	1.90	1.30	2.20
CaO	5.01	4.81	4.90	4.31	4.91
Na_2O	3.91	3.61	4.00	3.91	3.91
K_2O	2.50	2.60	2.60	3.01	2.30
H_2O	1.50	1.60	1.50	1.30	0.83
TiO_2	0.73	0.62	0.64	0.68	0.88
P_2O_5	0.34	0.40	0.47	0.34	0.73
MnO	0.07	0.21	0.02	0.08	0.14
ZrO_2	0.00	0.00	0.00	0.00	0.00
CO_2	0.00	0.00	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00

NORMATIVE COMPOSITIONS

	1	2	3	4	5
Quartz	17.684	18.107	16.270	18.078	18.123
Corundum	0.202	0.395	0.322	1.035	1.436
Orthoclase	14.797	15.390	15.356	17.763	13.613
Albite	33.054	30.514	33.830	33.067	33.054
Anorthite	22.620	21.236	21.228	19.149	19.571
Wollastonite					
Enstatite	3.243	5.987	4.730	3.244	5.488
Ferrosilite					
Magnetite	2.306	2.761	0.531	3.131	1.002
Hematite	2.416	1.902	3.932	1.147	3.516
Ilmenite	1.389	1.180	1.215	1.294	1.674
Rutile					
Apatite	0.807	0.949	1.113	0.807	1.732
Calcite					
Total	98.516	98.421	98.525	98.716	99.208
Salic	88.356	85.641	87.005	89.093	85.797
Femic	10.160	12.779	11.520	9.623	13.411

1. (48101*) Biotite-hornglende dacite from a lava flow in the Potato Peak Formation, collected from a peak in the western part of Sec. 4, T4N, R26E, MDM, about two miles west of Potato Peak.
2. (48102) Biotite-hornblende dacite from a lava flow in the Potato Peak Formation, collected from the southeast flank of Potato Peak in the eastern part of Sec. 3, T4N, R26E, MDM.
3. (48103) Biotite-hornblende dacite from a lava flow in the Potato Peak Formation, collected from the southeast corner of Sec. 3, T4N, R26E, MDM.
4. (BH-13) Biotite-hornblende dacite from a lava flow in the Potato Peak Formation, collected from a small hill in Sec. 23, T4N, R26E, MDM, about three-quarters mile northwest of Murphy Spring.
5. (BM-2) Biotite dacite flow of the Potato Peak Formation, collected from the center of Sec. 12, T4N, R26E, MDM, about two and one-half miles northwest of Bodie townsite.

For analyses 1, 2, 3 and 5, method of analysis used is the single solution procedure described in U.S. Geological Survey Professional Paper 575-B, p. 187-191 (1967). Analysts: P. Elmore, S. Botts, L. Artis, J. Kelsey, H. Smith and J. Glenn. For sample 4, methods of analysis used are described in U.S. Geological Survey Bulletin 1144-A, supplemented by atomic absorption. Analysts: P. Elmore, S. Botts, G. Chloe, H. Smith, J. Kelsey, L. Artis and J. Glenn.

*Field numbers shown on plate 2

Faults

The main faults, the Moyle Footwall fault and the Standard Vein fault, are parallel in general to the axial plane of the anticlinal upfold (Plate 2) mentioned by Wisser. Both faults are normal with very little strike-slip movement. The Moyle Footwall fault has a fairly constant strike of N 38° E and dips eastward from 60 to 70 degrees. It can be traced intermittently along its strike for a distance of about 4,000 feet. It was encountered underground in the Bodie and Standard mines and supposedly in the Syndicate mine at the north, but no evidence could be found to indicate whether it was cut by the later Mono fault (Plate 2). Where seen in the Roseklip cut, underground near the Standard New shaft, the Moyle Footwall fault has a well-defined breccia zone about 2 feet wide that contains quartz fragments. It appears from the character of the gouge and the off-setting of veins formed later that activity on the Moyle Footwall fault extended from pre-mineral into post-mineral time.

The Standard Vein fault, so called because it contains the Main Standard vein, has about the same magnitude as the Moyle Footwall fault. It strikes N 18-20° E, has a 60 to 70 degree westerly dip, and can be traced intermittently along its strike for a distance of about 3,500 feet. The fault was encountered in the Standard and Syndicate mines and in small intervening mine workings, but apparently not in the workings from the Lent shaft. It is pre-mineral in age, but with sustained post-mineral movement which produced a saccharoidal or granular condition in large sections of the Main Standard vein.

As the direct result of extensive stoping in the Standard mine, a relatively large block of rock principally altered tuff breccia of the Silver Hill Volcanic Series, dropped. At the surface, this produced an eastward-facing escarpment 3 to 5 feet high and 800 feet long at the Moyle Footwall fault and a westward-facing escarpment from one to 4 feet high and 150 feet in length along a segment of the Standard Vein fault.

A third major fault, which also is roughly parallel to the axial plane of the anticlinal upfold (Plate 2), is in the valley occupied by the Bodie townsite, where it is overlain by alluvium. The position of the northern trace of the fault is indicated by several springs. The fault strikes N 18° E for much of its studied length, but strikes N 30° E at its northern end. It is a steep, normal fault whose dip could not be measured, and it appears to have downdropped the block on the east by at least several hundred feet.

There are several cross faults in the district: the Tioga, the Mono, and the Jupiter. The Tioga and Mono help define what has been referred to as the Bonanza zone. Brown (1907, p. 356) pointed out that the rocks underground between these faults are highly altered but contain no ore.

The Tioga fault, which forms the northern boundary of the Bonanza zone, strikes N 62° E. It crosses the canyon west of Bodie Bluff and follows Milk Ranch Canyon in a westerly direction (Plate 2). The fault is clearly marked on the surface by depressions and gulches, especially on the west slope of Bodie Bluff. It is a normal fault in which the block on the south has dropped, probably in a near-vertical direction, by perhaps as much as 500 feet. It is a pre-mineral fault, as veins pass through altered, brecciated rock in its fault zone and reappear on the

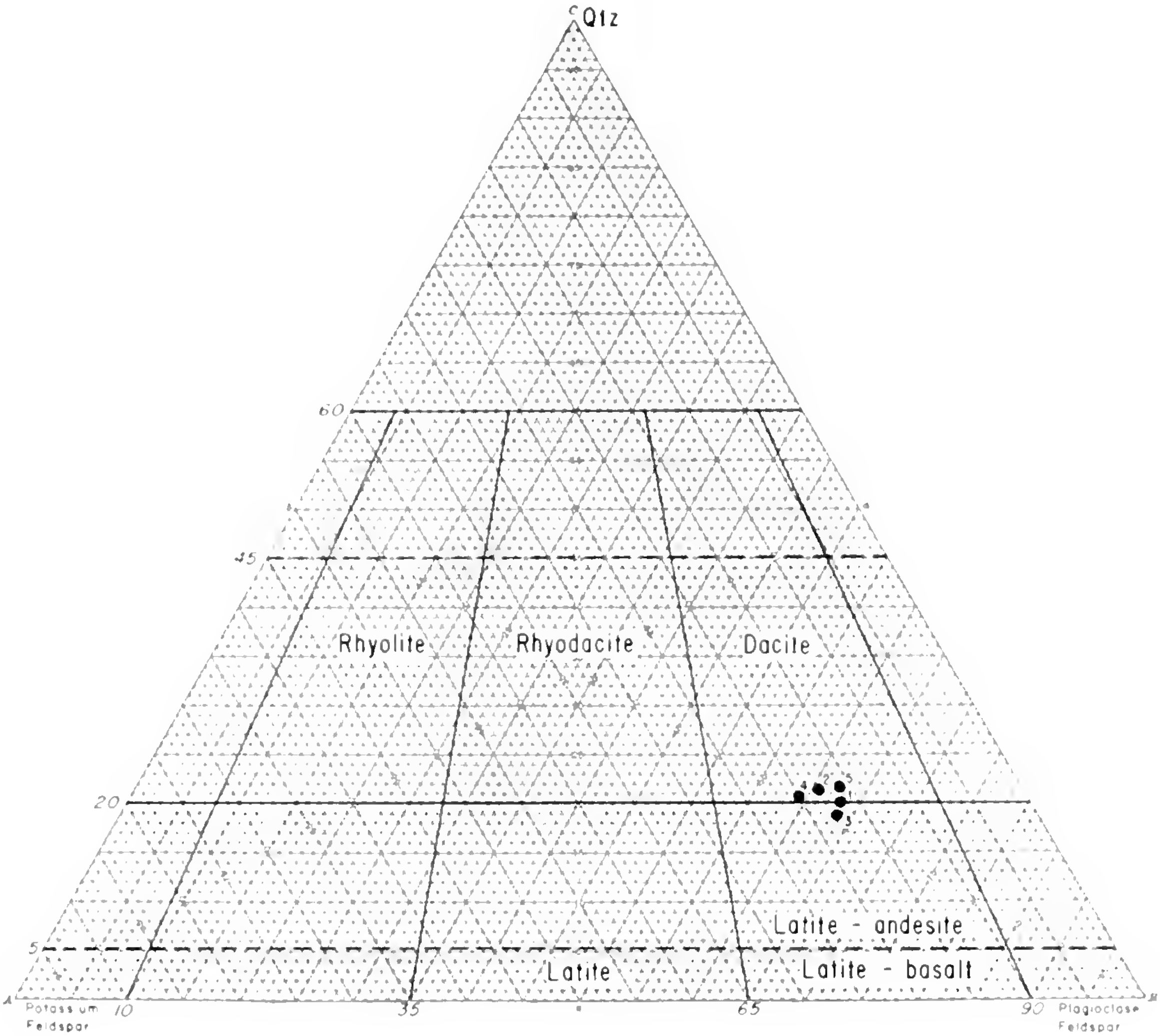

Figure 5. Normative compositions of dacite lavas of the Potato Peak Formation of the Bodie Mountain-Potato Peak area plotted on a Streckeisen diagram. Numbers refer to analyses given in Table 3. *Diagram adapted from Streckeisen (1967, p. 161)*

other side. Post-mineral movement along the Tioga fault was relatively small, probably no more than several tens of feet at the most.

The Mono fault forms the southern boundary of the Bonanza zone. This fault strikes N 66° W and, like the Tioga fault, is marked at the surface by topographic expression as well as by displacement of rock units. It, too, is a normal fault with a horizontal right lateral displacement of about 500 feet, the extent of vertical displacement, down on the south, is not known. The Mono fault zone, about 100 feet wide, is visible on the surface and in mine workings. The water storage tank for the Bodie State Historic Park is situated in the Mono fault zone, and during the excavation for the tank's foundation, relatively pure montmorillonite and altered dacite were encountered.

Major movement on the Mono fault was pre-mineral, as no quartz veins were offset in the fault zone. The Fortuna vein fracture was traced into the Mono fault zone and its presence was indicated by vein material consisting essentially of coarsely crystalline gypsum.

Faulting in the Middle mines and Southern mines areas of the district has done much toward dislocating various units of the Silver Hill Volcanic Series and opening them to mineralization and alteration. The principal fault in the Southern mines area extends in a northwesterly direction through the Queen Bee shaft, across the northern flank of Queen Bee Hill, and through the University and Spaulding shafts (Plate 2). Beyond the latter shaft, it dies out at or along the contact between tuff breccia and dacite lava flows of the Silver Hill Volcanic Series. This is a normal fault which dips eastward 60° in the Booker workings, and whose principal movement was pre-mineral. The amount of downward movement is not known, but an andesite dike on Queen Bee Hill was cut and its segments were displaced by as much as 200 feet by strike-slip movement. Quartz veins along the fault have been crushed as the result of post-mineral movement, which apparently was not great.

A fault whose strike ranges from N 75° W to S 60° W trends across the district just north of Sugarloaf (Plate 2). It is a normal fault whose upward movement on the south side brings the lower hornblende-rich dacite unit of the composite flow into contact with the upper biotite-rich unit of the flow. This fault is cut off on the east by what appears to be one of the youngest faults in the district, which trends approximately north, dips steeply toward the west, and forms for some distance the contact between units of the Murphy Spring Tuff Breccia and rocks of the Silver Hill Volcanic Series.

Numerous small faults occur in the district. Although some of them can be found at the surface, others are identified only in mine workings where they have displaced veins or are fracture zones along which veins were deposited and were avenues for the migration of hydrothermal fluids. A polar plot (Figure 6) of the

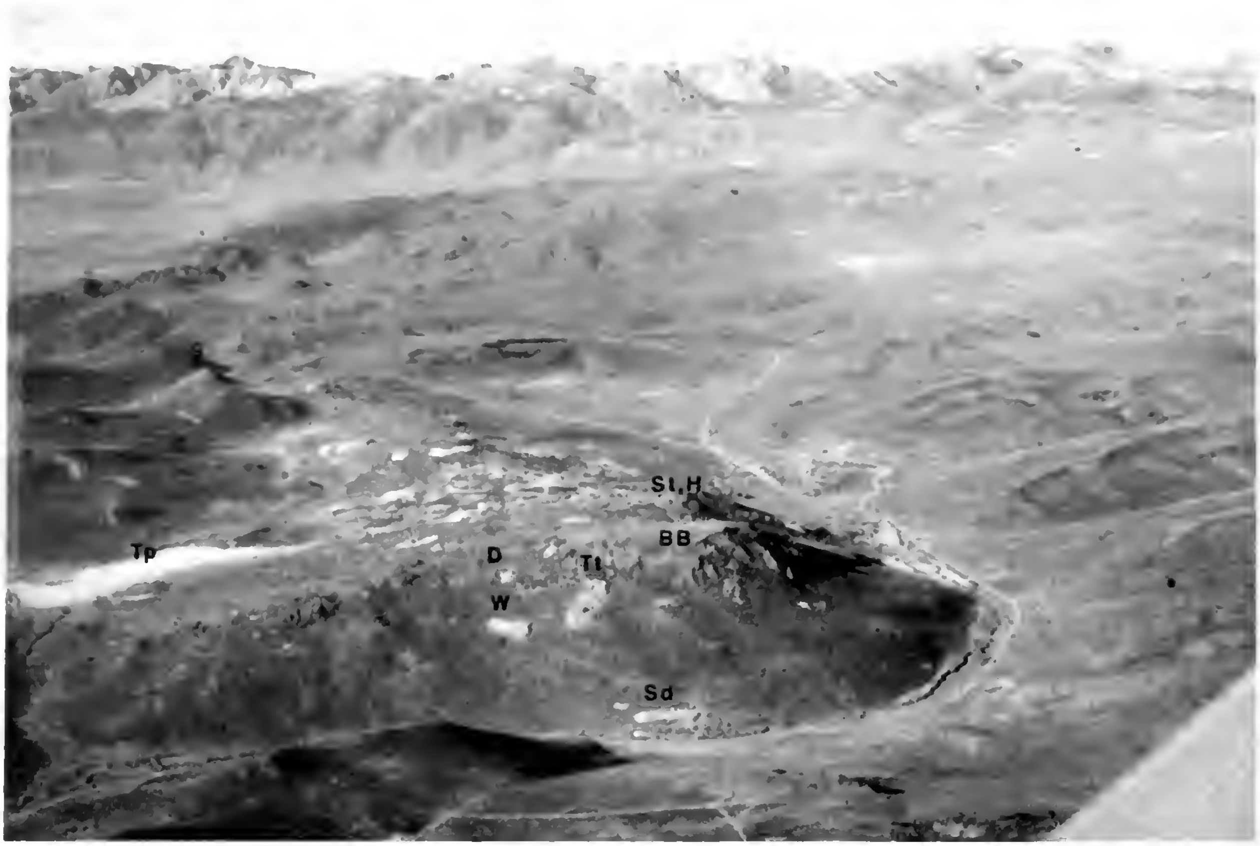

Photo 5. View to southwest of the Bodie mining district, showing the Syndicate mine (Sd), Whitney tunnel (W), Davis tunnel (D), Tioga tunnel (Tt), Bodie Bluff (BB), Standard Hill (St.H), Tailings pond (Tp) and Sugarloaf (S), Sierra Nevada on skyline. *Photograph by Bennie W. Troxel.*

principal faults encountered underground in the Red Cloud mine indicates that the faults here essentially trend north and are parallel in large measure to the trend of the shear zones and vein system.

Jointing and Sheeting

Studies of the outcrops of the intrusive dacite and flows in the Bodie mining district failed to reveal any joint patterns or systems that might help to decipher the structural history of the rocks. In the mines, especially those in the Standard Hill area, early investigators found closely spaced parallel fractures called "sheeting" in the wall rocks, generally parallel to the so-called fissures which contained the quartz veins in the Standard and Bodie mines. Whiting (1888, p. 387) states: "Even in the minuter structure of the rock this effect of compression is no less strikingly evidenced by a schistose foliation along now one, now the other, wall of a fissure; and, as a peculiar feature of these ore bodies such foliated portions have invariably been found to be very rich in gold and silver; as though this structure, originally due to compression, had affected in the innumerable, though minute, fault fissures thus formed, such retardation to the flow of the mineral bearing solutions and such virtual increase of deposition surface as to have caused a more abundant mineralization of the veins at such localities."

The development of sheeting and tension fissures in the intrusive dacite of the Bodie Bluff-Standard Hill plug has been attributed to up-arching of the rocks to form the Bodie anticline (Wisser, 1960, p. 73). Certain sheeting planes became the Moyle Footwall and the Standard Vein faults, which produced the graben in the Standard Hill mines area. The fan pattern of longitudinal sheeting, which is said to show up so well in cross section in the vicinity of the Syndicate mine (Whiting, 1888, p. 387), is related to the same dynamics that produced the longitudinal sheeting in the Bodie and Standard mines. This same fan pattern is said to occur in the mines near Silver Hill and Red Cloud mine, where the tension fractures and sheeting are in lava flows of the Silver Hill Volcanic Series and are related directly to the formation of the anticlinal upfold.

Farther south at Queen Bee Hill and at Sugarloaf, evidence of sheeting is scarce, although the flows and intrusive bodies are highly jointed.

Plugs

The largest plug in the district underlies Bodie Bluff and Standard Hill. In plan, it is elongate in an easterly direction, with its greatest development at Bodie Bluff and Standard Hill, where it is approximately 3,500 feet across. At the surface, the plug is divided into two sections by a narrow septum of brecciated, propylitized tuff breccia of the Silver Hill Volcanic Series; the eastern mass is potassically altered dacite, but the main body of the plug has undergone strong propylitic alteration and mild potassic alteration.

Internal structures in the plug are not abundantly evident, but flow-banding, where observed, is generally steep. Contacts

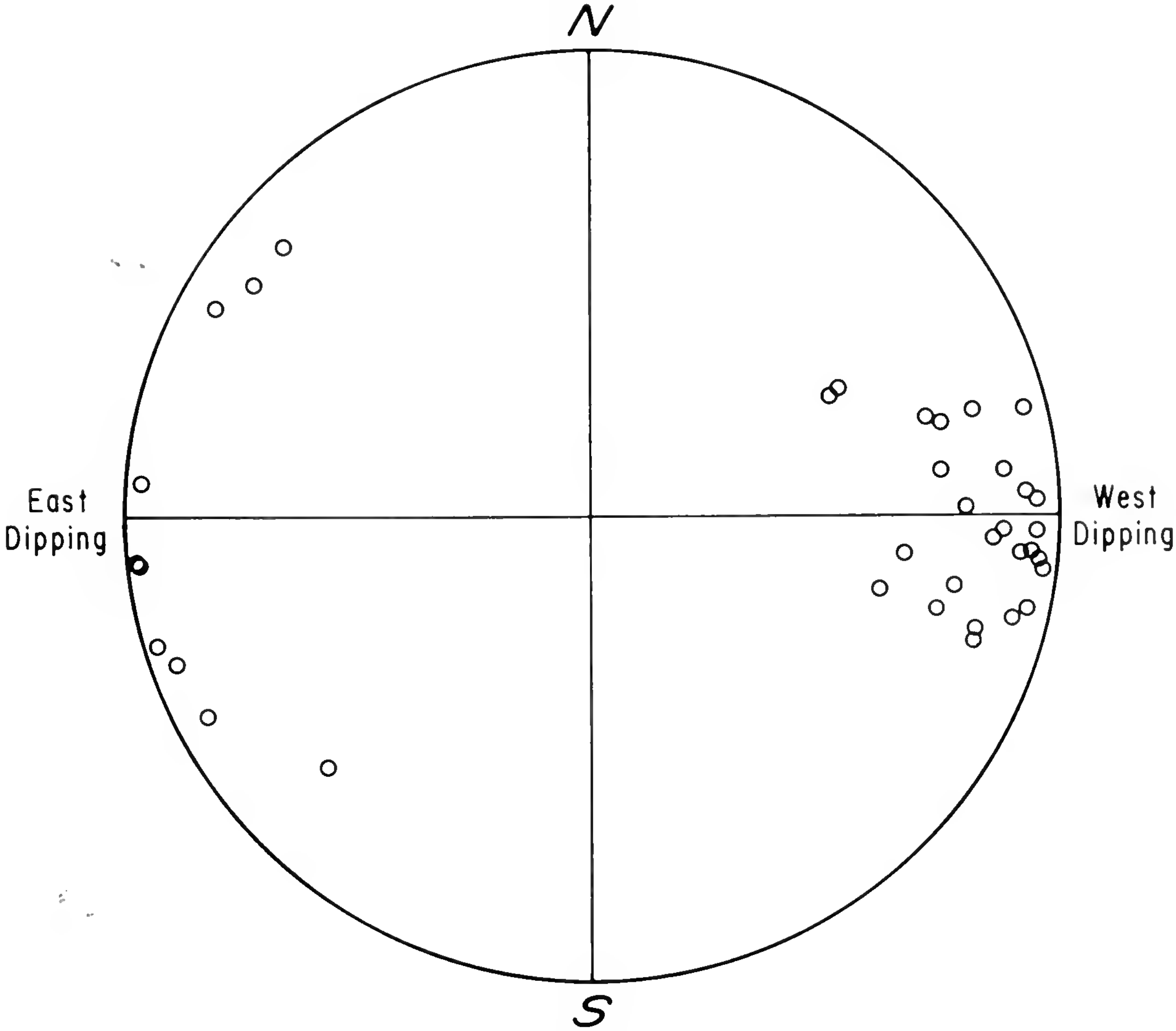

Figure 6. Polar plot of faults in the Red Cloud mine. Plotted on upper hemisphere.

between the plug and the wall rock are steep and generally accompanied by intense argillization of both the plug rock and the wall rock and by local shearing in the walls of the plug.

Based upon exposures of the plug in the field and the sequence in which the several types of hydrothermal alteration occurred, it is reasonable to assume that the plug was emplaced in two separate yet overlapping pulses of volcanic activity. The main body of the plug at Bodie Bluff was formed first, as the dacite of which it is composed was subjected to early propylitic alteration, and later the plug dacite east of the septum in the plug was emplaced at a time when potassic alteration was taking place.

The plug at Queen Bee Hill, which was emplaced at about the same time as was the Bodie Bluff-Standard Hill plug, is small and elongated in a northwesterly direction, and has a maximum dimension of about 1,000 feet. Flow-banding is vertical or dips steeply, generally inward toward the central part of the plug. Lack of access to mine workings at Queen Bee Hill made it impossible to observe the contact between the plug dacite and the wall rock, but the nature of the flow-banding in the plug indicates that the contact is steep. The dacite of the plug has undergone argillic alteration, which extends outward from the plug into the wall rock for only a few tens of feet. The wall rock consists principally of units of the composite flow that have undergone propylitic alteration.

The plugs at Sugarloaf and near the Red Cloud mine were emplaced between 8.3 and 8.9 m.y. ago, and are later than the other plugs in the district (Silberman and others, 1972, p. 601). The plug at Sugarloaf forms a symmetrical cone when viewed from ground level and has an ellipsoidal shape whose north-trending axis measures approximately 1,300 feet. Flow-banding and the principal joint pattern in the plug dip very steeply to vertically. The Gorman tunnel (Plate 2), on the west side of Sugarloaf, passes first through the lower hornblende-rich dacite unit of the composite flow, then penetrates the intrusive dacite of the plug at a point about 100 feet from the portal, which is now caved (Frederick, 1960, written communication). The contact between the plug and the wall rock is steep and marked by a zone about 4 feet wide, of clay and sheared rock. Inward from the contact, a zone of propylitized intrusive dacite about 150 feet wide is uniformly developed around the circumference of the plug. The interior of the plug is relatively unaltered hornblende dacite.

The smallest plug in the district lies a few hundred feet south of the Red Cloud mine. It is roughly circular in plan and has a diameter of approximately 500 feet. Unlike the other intrusive bodies, this plug has no distinctive topographic expression. The contact between the plug and the wall rock is concealed by soil. Flow-banding is scarce, but where found it is steeply inclined

Photo 6. View to northwest of the central and northern sections of the Bodie mining district, showing Red Cloud mine (RC), Silver Hill (SH), Standard Hill (St.H) and Bodie Bluff (BB).

inward. The plug is composed of hornblende-biotite dacite, which is relatively unaltered at the interior but argillically altered near the margins. The biotite-rich dacite unit of the composite flow, which forms the wall rock of the plug at the surface, also has been argillically altered.

Silver Hill is considered by Wisser (1960, p. 70) to be underlain by an anticline at whose core is a dome, but no evidence could be found to support this hypothesis. Instead, the topographic high at Silver Hill is capped by a mass of intensely silicified tuff breccia of the Silver Hill Volcanic Series that lies upon the biotite-rich dacite unit of the composite flow.

GEOLOGIC HISTORY

Structure Interpretation

The interpretation of the structure of the Bodie mining district by the present writers is based on detailed geological mapping of the district and of the area immediately surrounding it, a great deal of which lies in the Bodie quadrangle (Chesterman and Gray, 1975).

The writers concur in general with the anticlinal suggestion of Wisser, but the structure of the district is complex and can be perhaps best understood through a discussion of its history.

Tertiary Rocks

The extrusive rocks of the Silver Hill Volcanic Series are considered to be the oldest exposed volcanic rocks in the Bodie mining district. The distribution of the pyroclastic deposits of the Silver Hill Volcanic Series indicates that the principal eruptive vents for the materials were what are known as Bodie Bluff, Queen Bee Hill, and Sugarloaf (Plate 2). The pyroclastic deposits in the vicinity of Bodie Bluff are thickest north of the peak of Bodie Bluff. Because of the lack of adequate exposures, the thickness of the series in the district can only be estimated at between 800 and 1,000 feet. That there were several explosive periods in the volcanoes of the district is indicated by the occurrence of several thin tuff breccia layers among dacite flows in the vicinity of Silver Hill.

The deposition of the main (lowermost) layer of tuff breccia was followed by flows of dacite, the first of which, from the vent near Silver Hill, was interrupted by brief periods of explosive activity. The emplacement of the composite flow at Bodie Bluff some 9.4 to 8.8 m.y. ago was near the closing phase of volcanic activity in the district. The emplacement of the plugs at Bodie Bluff, near the Red Cloud mine, at Queen Bee Hill, and at Sugarloaf represents the intrusion of dacite into the several vents following the last outpouring of lavas as flows. It seems most likely that these plugs were connected with the same magma chamber, the activity at each vent, however, was not necessarily contemporaneous with that of the others, although their overall range in age from 8.3 ± .4 m.y. to 9.2 ± 0.5 m.y. indicates a relatively brief time interval within which these plugs could have been emplaced. The chemical analyses and petrographic studies indicate that no appreciable differentiation has taken place within the magma chamber.

The emplacement of the plugs was accompanied by a general anticlinal upfolding of the earlier deposited interlayered lava flows and pyroclastic layers. Bedding in the tuff breccia and flow banding in the lava flows in the immediate vicinity of the plugs is steeply dipping, especially around the plug at Bodie Bluff and Standard Hill, where contacts were observed in the mines. The evidence supports the assumption that the plugs are apophyses of a larger intrusive body of volcanic rock, probably dacite, at depth, and that the shape of this body is elongated in a generally north-south direction. Both magnetic and gravity data support this concept. The axis of the anticlinal upfold is parallel to the general alignment of the plugs. The major fractures, faults (other than the cross faults), and veins are parallel to the axis of this upfold and dip generally toward its axial plane.

The fracture systems which opened the rocks to alteration and mineralization were developed in the intrusive bodies following their emplacement and the formation of the anticlinal upfold.

The Fortuna vein fracture is perhaps the oldest in the district. It strikes approximately N 10° E. In the upper levels of the Bodie and Standard mines, the fracture dips 30° toward the east and, in the lower levels of these mines, steepens to as much as 45° E. Where it steepens, the fracture contains very little vein material and appears principally as a zone of thinly sheeted and highly altered dacite and gouge showing slickensides and striations (Whiting, 1888, p. 392).

The Fortuna fracture (Figures 7, 8, 9, and 10) is cut by later veins and fractures, and its origin may be related more to the emplacement of the plug at Bodie Bluff than to the general anticlinal upfolding in the district. Wisser (1960, p. 73) related the Fortuna fracture to a period of uplift which was supposed to have occurred east of the Bodie anticline and developed before the extrusion of lava from the vents at Bodie Mountain.

Lava flows of the Potato Peak Formation overlap the pyroclastic deposits and flows of the Silver Hill Volcanic Series at the northern and northwestern parts of the Bodie mining district, but nowhere could any evidence be found to support Wisser's thesis that units of the Potato Peak Formation covered the entire area now encompassing the Bodie anticline. Tension fractures would have been developed in the flows and pyroclastic layers in the development of the anticlinal upfold, but what dynamics are required to produce linear fractures and sheeting in the intrusive dacite plugs themselves, which should have been marked by radial and concentric fracture systems?

Although the K-Ar age data indicate a continuous process of emplacement of the intrusive bodies in the district, specific age dating indicates that the plugs at Bodie Bluff-Standard Hill and Queen Bee Hill were emplaced about 9.2 ± 0.5 m.y. ago (Silberman and others, 1972, p. 602)—older than those at Sugarloaf Peak and near the Red Cloud mine, which were emplaced at 8.3 and 8.9 m.y. ago, respectively.

Partial withdrawal of the magma from the plug at Bodie Bluff to form the plugs at Sugarloaf and near the Red Cloud mine resulted in the development of the faults and graben structure in the Bodie Bluff-Standard Hill area.

Mineralization in the Bodie mining district seems to have commenced shortly after the emplacement of the plugs. K-Ar age determinations made on adularia obtained from a vein in the Moyle Footwall fault zone gave an age of 7.0 ± 0.2 m.y. to 7.0 ± 0.1 m.y. Adularia from the waste dump of the McClinton shaft, either from the Burgess or Incline vein series, gave an age of 8.0 ± 0.2 m.y. (Silberman and Chesterman, 1972, p. 17).

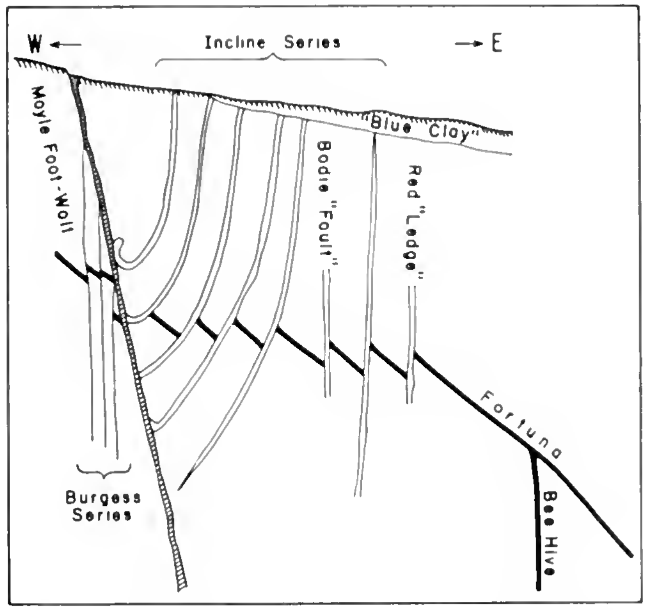

Figure 7. Cross section of the vein system of the Standard mine. *Modified from Brown, 1907.*

Adularia from the vein specimen, of coarse-grained calcite and intergrown fine-grained quartz and adularia from the Red Cloud mine, gave an age of 7.7 ± 0.1 m.y. (Silberman and Chesterman, 1972, p. 17).

ALTERED AND MINERALIZED ROCKS

Hydrothermal alteration (Plate 2) has been widespread in the Bodie mining district. The type of hydrothermal alteration has determined to a considerable degree the color of the altered rock. Propylitic alteration has given a greenish color to lava flows and tuff breccia; argillic and silicic alteration generally results in white and pale gray rocks, with fracture surfaces thinly coated by reddish, reddish-brown, and yellow hydrous iron oxide stains. Rocks that have been affected principally by potassic alteration do not appear to have suffered significant color changes; where these rocks have not been affected by additional argillic alteration, they are dense and firm and have the general appearance of unaltered rock.

Hydrothermal alteration in the district commenced during or soon after the closing stages of volcanism (Silberman and others, 1972, p. 602). Detailed field mapping in the district indicates that there were four stages of hydrothermal activity, commencing with propylitic and followed in succession by argillic, potassic, and silicic.

The propylitic alteration was widespread and seems to have affected all rock types regardless of composition and structure. The resulting mineral assemblage includes chlorite, sericite, epidote, quartz, pyrite, and hematite, in addition to the feldspar and other minerals characteristic of the original rock (Photos 7 and 8).

Argillic alteration resulted in formation of rocks characterized by quartz, chalcedonic and opaline silica, montmorillonite, kaolin, limited sericite, carbonate, and pyrite (see Photo 14). The altered rock is usually soft and friable, and forms smooth slopes. The pyrite is irregularly distributed in the argillically altered rocks and appears to be more concentrated along joints and fractures and occasionally sparsely disseminated throughout lo-

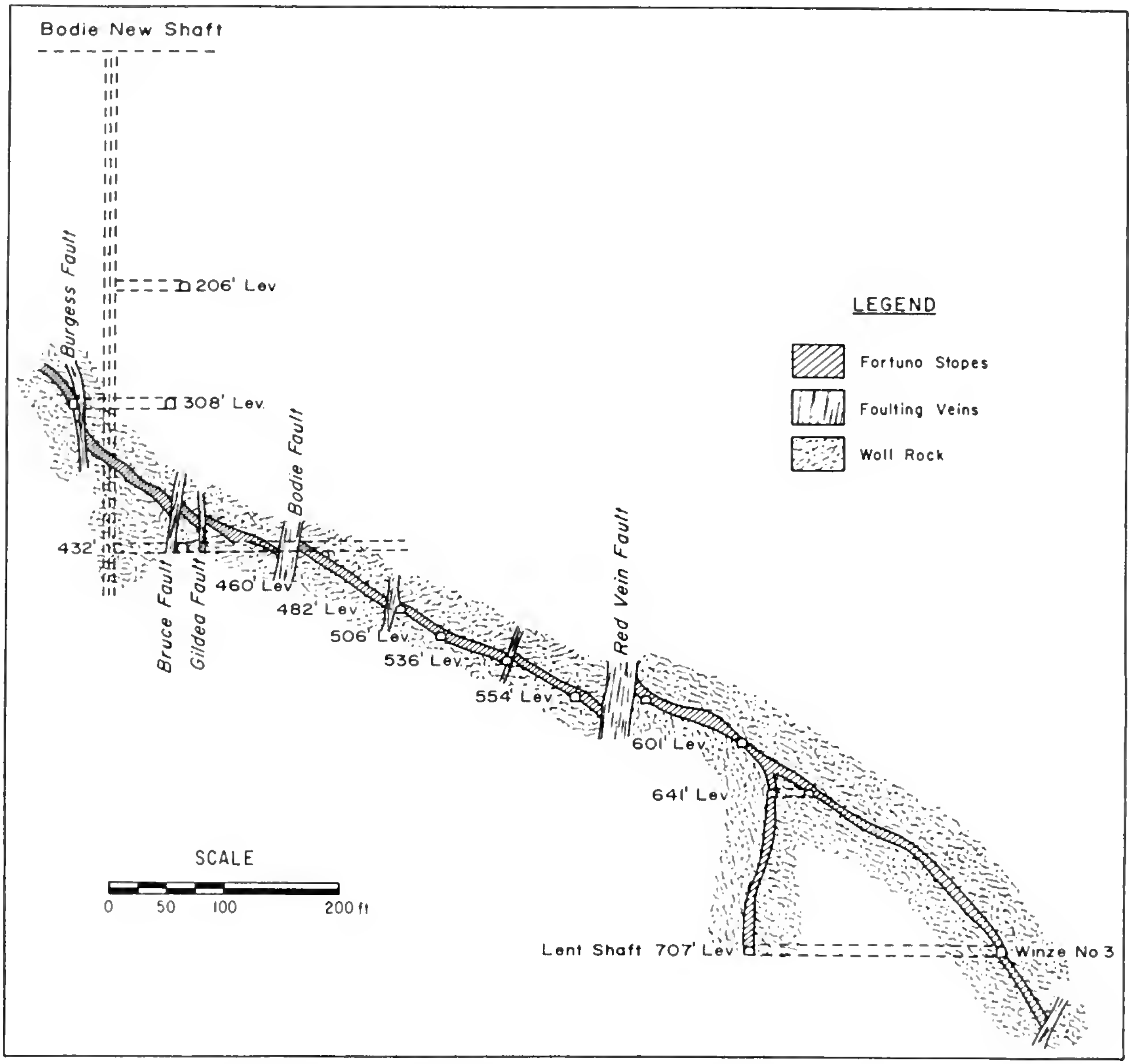

Figure 8. Vertical section through Fortuna stopes, Bodie mine. *Modified from Whiting, 1888.*

cal areas. Oxidation of the pyrite has given outcrops of the rock a blotchy brown and reddish-brown color.

Potassic alteration appears to be confined to the rocks in and surrounding the Bodie Bluff-Standard Hill plug, where it is obviously later than the propylitic alteration. The relationship of potassic to argillic alteration is not well known, but exposures in the Bulwer tunnel suggest that the potassic alteration is later. Dacite that has undergone potassic alteration is firm, appears unaltered in hand specimens, and forms bold outcrops, especially on and near crests of ridges and hills. It is porphyritic; a microscopic examination revealed small rectangular microphenocrysts of sanidine and fine-grained adularia in the groundmass.

Analyses 1, 2, 3, and 4 (Table 1) on rocks from the Bodie Bluff-Standard Hill plug show abnormally high K_2O content in comparison to the analyses (nos. 5, 7, 9, 10, and 11) of dacite from the plugs at Queen Bee Hill and Sugarloaf.

Potassic alteration undoubtedly occurred over a considerable span of time, even into the formation of quartz veins in rocks which had potassic alteration superimposed upon earlier propylitic and argillic alteration processes. Adularia is a common constituent in some of the quartz veins, especially those of the Burgess series, which are clearly later than those of the early Fortuna series, and which have been dated as being between 7.1 and 8.0 m.y. old.

Silicic alteration, the last stage of hydrothermal activity and perhaps a factor in the formation of the quartz veins, is evident on the surface at several areas but is localized in the central part of the district on Silver Hill (Plate 2), in an area surrounding the Noonday mine and near the portal of the Aurora tunnel. Two rock types are involved in silicic alteration, the biotite-rich dacite unit of the composite flow and a tuff breccia layer that lies above the composite flow.

The silicically altered rock is pale gray to white in color and dense, and appears to consist largely of quartz and chalcedonic silica. A sample of silicified tuff breccia, which forms the cap on Silver Hill, contains 91.14 percent SiO_2, 0.11 percent CaO, 0.06 percent Na_2O, and 0.72 percent K_2O, the remainder consists principally of iron and sulfur and minor amounts of aluminum (Majmundar, written communication, 1973). Where the alteration has affected the dacite lava flows, textures and structures of the original rock are visible but not common. However, the original clastic structure is plainly visible in silicified tuff breccia. A structural control for selective silicification can be deduced from the fact that the pyroclastic materials, because of their lower bulk density and high porosity, are more readily and completely silicified and pervasively mineralized than are the denser flow rocks.

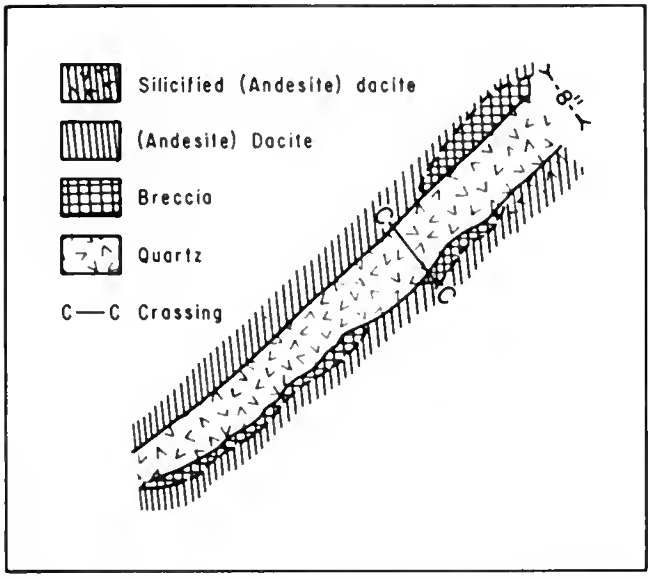

Figure 9. Face in stope on the Fortuno vein, Bodie mine. *Modified from Brown, 1907.*

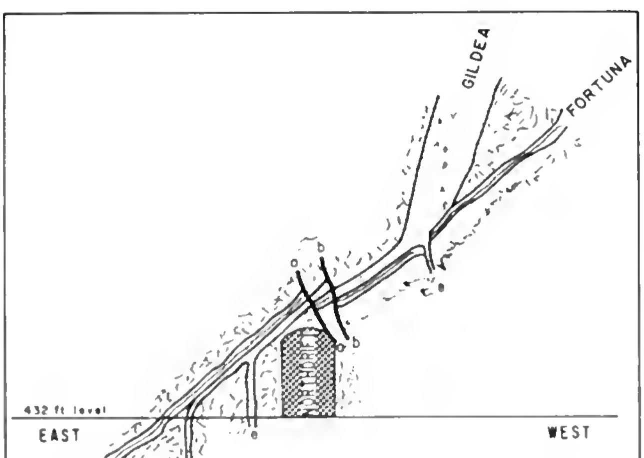

Figure 10 East west section through the Fortuna slope in the north drift No. 1 of the 432 foot level of the Bodie mine, showing the cross-cutting age relationships of the Fortuna and Gildea veins *Modified from Whiting 1888*

GEOPHYSICAL INVESTIGATIONS

Regional Gravity and Magnetic Data

The results of regional aeromagnetic and gravity studies in the Bodie Hills area of California and Nevada by the U.S. Geological Survey and the California Division of Mines and Geology have been discussed by Kleinhampl and others (1975). The aeromagnetic and gravity data presented by Kleinhampl and others (Plate 1 and Figure 4) include anomalies that have a significant bearing on the interpretation of the geology of the Bodie mining district. The features of greatest importance shown by these may be two nearly coincident, north-trending anomalies: a negative aeromagnetic anomaly and a positive gravity anomaly, both of which are centered near the mining district. Plate 1 shows a comparison of the regional aeromagnetic and gravity data along Profile R-S across the Bodie mining district near Queen Bee Hill (location shown on Plate 2). This profile illustrates the close association of the aeromagnetic and gravity anomalies here and suggests the possibility that both anomalies may reflect the same source or closely related sources.

The local gravity anomaly is a part of a more extensive positive anomaly trend that extends through the Bodie Hills area. This major feature trends northeastward from near Lundy Canyon, north of Mono Lake, to Cottonwood Canyon, where it turns almost directly north and passes through the Bodie mining district (Kleinhampl and others, 1975, Figure 4; Plate 1 of this report). Near Bodie the anomaly turns northeastward again and continues to the vicinity of Aurora Peak in Nevada. The anomaly is essentially continuous except for a possible interruption near the change in trend east of Cottonwood Canyon

Pre-Tertiary basement rocks are closely associated with the gravity anomaly in the northeastern and southwestern parts of the Bodie Hills, but in the intervening area, which includes the Bodie mining district, only younger extrusive and intrusive rocks are exposed. Thus, a possible explanation for this anomaly may be relief on the basement rock surface. An alternative explanation for the gravity high, which would be reasonable at least in the Bodie mining district, is suggested by the series of dacite plugs that have been mapped in the area (Plate 1). These plugs are believed to be apophyses of a larger intrusive mass at depth (this report, page 17). Either of these possible explanations, basement reiief or intrusive rocks, assumes a higher average density for the anomaly source than for the surrounding rocks

The cause of the local aeromagnetic anomaly in the vicinity of the Bodie mining district might be either the extensive hydrothermal alteration, which has resulted in destruction of magnetite in some of the extrusive and intrusive rocks underlying the district (this report, page 17), or simply a contrast in magnetic properties between two or more rock types The results of measurements of the magnetic susceptibility of a number of samples (Table 4) suggests that the average value (0.0012 emu/cm) for extrusive dacite from the Bodie mining district is only slightly less that that (0.0014-0.0017 emu/cm) for similar rocks (dacite and andesite) from the surrounding areas in the Bodie Hills. Nevertheless, it is possible that the sampling did not give proper weight to the relatively altered extrusive rocks in the mining district

The average value (0.0008 emu/cm , Table 4) of magnetic susceptibility obtained for intrusive dacite from the Bodie mining district is distinctly lower than that (0.0012-0.0017 emu/cm) for the extrusive rocks given above Although this apparent difference may be large enough to cause the observed anomaly considering the possible size of the intrusive mass at depth it is not known whether these results are truly representative of the mass of the rock The relatively low magnetic susceptibilities of the intrusive rocks sampled may, however, be the result of the intense hydrothermal alteration which characterizes these rocks in surface exposures throughout most of the Bodie mining district

The loss of magnetite during alteration of the rocks in the mining district also would reduce the effect on the magnetic field caused by remanent magnetism This, or the presence of reverse

Photo 7. Veined and propylitically altered tuff breccia of the Silver Hill Volcanic Series, as exposed underground in the Bulwer tunnel, about 150 feet west of the contact with the intrusive dacite. Scale is 6 inches long and rests against a pyroclast of argillically altered dacite.

ly magnetized rocks, might also help account for the negative aeromagnetic anomaly, but no measurements of the intensity of remanent magnetism of samples were made during this study. The direction of remanent magnetism was determined in the field for a number of intrusive and extrusive rock samples from the Bodie Hills (see Chesterman and Gray, 1975). In the Bodie mining district, these measurements showed normal and reversed directions of remanent magnetism for approximately equal numbers of both intrusive and extrusive rocks. Thus, it was not determined whether the direction of remanent magnetism contributes significantly to the observed anomalies in the Bodie area. A more detailed and extensive study would be required to resolve this question.

Detailed Gravity and Magnetic Data

While the regional geophysical work for this report was in progress, relatively detailed gravity and ground magnetic surveys were also undertaken in the Bodie mining district. Approximately 180 gravity and magnetic stations were occupied at points of known location and elevation in the district. A Worden gravity meter and a Jalander fluxgate magnetometer were used. These points include a few bench marks established by the U.S. Coast and Geodetic Survey and the U.S. Geological Survey and spot elevations from U.S. Geological Survey topographic maps, but most are spot elevations that had been established by surveying in the district. In addition to these stations, a few lines of closely spaced magnetic values were added in parts of the area

Table 4. Magnetic susceptibility measurements of rocks of the Bodie mining district and surrounding area.

Rock Type	No. of Samples	Range in Magnetic Susceptibility (emu cm³)	Average Magnetic Susceptibility (emu cm³)
Intrusive rocks of the Bodie Hills area			
dacite	2	0001 0020	[illegible]
rhyolite	2	0004 0006	0005
Intrusive rocks of the Bodie mining district only			
dacite	16	[illegible] 0021	0008
Extrusive rocks of the Bodie Hills area			
andesite	4	0006 0025	0017
dacite	5	0006 0021	0014
basalt	1	-	[illegible]
welded tuff	1		[illegible]
Extrusive rocks of the Bodie mining district only			
dacite	9	[illegible] [illegible]	0012
tuff breccia	3	[illegible] [illegible]	0003

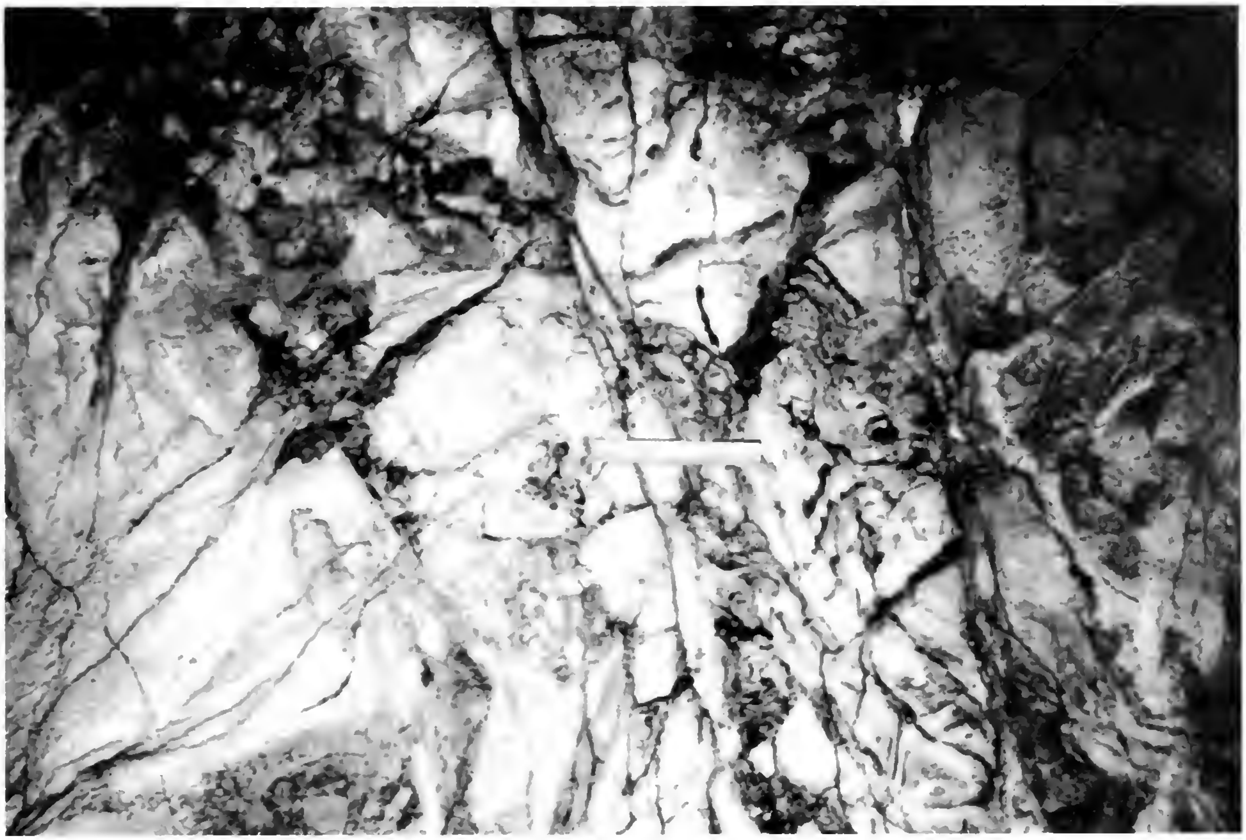

Photo 8. Fractured and propylitically altered intrusive dacite of the Silver Hill Volcanic Series, as exposed underground in the Bulwer tunnel, about 50 feet from the contact between the intrusive dacite and tuff breccia. Scale is 6 inches long and lies across a quartz vein that dips steeply to the right.

Values of observed gravity were tied to a local station in Bodie which was referenced to a California Division of Mines and Geology base station in Bridgeport (Chapman, 1966, p. 46). Terrain corrections were calculated for all stations; these include inner zone corrections out to 2.29 km, estimated from topographic maps by using Hayford zones A-F and subzones (Oliver and others, 1969, p. 20-21). The remaining terrain corrections, out to a distance of 166.7 km, were obtained by the use of a U.S. Geological Survey computer program (Plouff, 1966). The terrain corrections calculated for stations in the Bodie mining district range from about 3 mgal in the flat area south of the townsite of Bodie to more than 9 mgal for a station on top of Bodie Bluff. Gravity values were reduced to complete Bouguer anomalies for densities of 2.67 g/cm^3 and 2.50 g/cm^3 using a U.S. Geological Survey reduction program.

Values of the vertical intensity of the magnetic field were determined at each of the gravity stations and on a few separate profiles, as mentioned above. These values are on an arbitrary datum but were tied to a base in the Bodie townsite. Repeated readings at this base were used to remove drift and diurnal effects.

RESULTS OF THE GRAVITY SURVEY

The Bodie Hills, including the Bodie mining district, are located near the axis of a large regional gravity minimum (Woollard and Joesting, 1964). Although the Bodie mining district is on the eastern side of this minimum, there is apparently only a relatively gentle regional gradient in this area. Therefore, a flat regional anomaly surface was assumed for purposes of constructing a residual gravity map of the Bodie mining district area. Gravity values calculated for a density of 2.50 g/cm^3 were used because the density measurements given in Table 5 indicate that this should be close to the average for the Tertiary intrusive and extrusive rocks of the Bodie Hills. The value of density used is important, because local elevation changes, which are as much as 600 feet in this area, will greatly influence the results if an incorrect density is assumed.

After subtracting the estimated regional gravity gradient from the values at individual stations, the resulting residual values were plotted and contoured using a 1 mgal interval. The resulting gravity map, Plate 2, shows a north-trending gravity high with an amplitude of 7 mgal in the south part of the district near Queen Bee Hill which decreases to an amplitude of about 5 mgal near the north end of the mining district. In the southern end of the district, the axis of the anomaly passes close to Sugarloaf, Queen Bee Hill, and Silver Hill, but to the north this axis turns northeast and passes east of Bodie Bluff. The southern end of the anomaly in Plate 2 appears to consist of two parts: a relatively broad high with an amplitude of a few mgal, upon which is superimposed a second anomaly of short-wavelength with an amplitude of 2 or 3 mgal.

Although the positive residual gravity anomaly in the Bodie mining district is larger in areal extent than the district, the anomaly appears to be spatially related to the mining district, particularly in the southern part. This can also be seen in the regional gravity map (Plate 1). Furthermore, the steepness of the gravity gradients, especially in the southern part of the district, suggests that at least part of the source of the anomaly should be close to the ground surface.

As mentioned above, the Bodie gravity anomaly could be caused by relief on the basement rock surface if these rocks have a sufficiently high density and if they are at a relatively shallow depth beneath the mining district. Measured values of densities for pre-Tertiary rocks from the Bodie Hills area, given in Table 5, show a range from an average of 2.60 g/cm^3 for plutonic (granitic) rocks to an average of 2.82 g/cm^3 for a sample of greenstone (altered basic volcanic rock). For comparison, the most common Tertiary extrusive and intrusive rocks range from averages of 2.39 g/cm^3 for samples of dacite to 2.60 g/cm^3 for samples of andesite. Samples of basalt (2.79 g/cm^3) and Quaternary tuff and pumice (1.36 and 1.14 g/cm^3, respectively) represent extreme values for rocks which are not quantitatively significant in the Bodie mining district. Thus, density measurements confirm the possibility that the anomaly could be related to the underlying basement rock surface, considering the fact that dacitic intrusive and extrusive rocks are probably the most common of the Tertiary rock units in the area. However, this would require that a basement topographic high coincide in position with the mining district. The fact that no basement rocks crop out in this area and that mining operations to a maximum depth of about 1,000 feet apparently have not encountered any such rocks does not tend to support this explanation.

The other possibility is that the gravity anomaly in the Bodie mining district might be caused by an intrusive mass, which is believed to underlie and extend beyond the district. The average density of a suite of samples of the dacitic intrusive rocks from the mining district is 2.41 g/cm^3 (Table 5). This value is not significantly different than those for the extrusive dacite and tuff breccia measured (2.39 and 2.41 g/cm^3, respectively) and is decidely low for intrusive igneous rocks of this composition. Both the extrusive and intrusive rocks in the Bodie mining district are commonly affected by argillic, potassic, or prophylitic alteration, however, which may account for these lower than normal density values. The intrusive rocks exposed near the Red Cloud shaft, Queen Bee Hill, and Sugarloaf appear to be less affected by alteration than those in most of the rest of the mining district. Density values obtained from samples of these rocks average approximately 2.59 g/cm^3, in sharp contrast to the overall average. Thus, the density contrast between these intrusive rocks and the surrounding extrusive rocks is nearly 0.20 g/cm^3 in this part of the area. This may explain at least the local, short-wavelength part of the anomaly which is closely associated with the exposures of intrusive rocks in the south end of the district. The remaining part of the gravity anomaly might be caused by a large mass of intrusive rocks at depth. These deeper rocks might be less affected by alteration and thus have a higher average value of density than those measured at the surface. The intrusive mass at depth may also have a different, possibly more basic, composition, which could also result in a higher average density.

In the north end of the Bodie mining district, the axis of the gravity anomaly turns northeastward, away from the surface exposures of intrusive rocks at Bodie Bluff and also eastward from the location of the apparent northern extension of the aeromagnetic low. This fact is puzzling if the positive gravity anomaly is caused by the exposed intrusive rocks of the area. It may suggest, however, that the principal intrusive mass does not underlie Bodie Bluff, but instead is located about ½ mile to the east. An incorrect density used for reduction of the data or failure to obtain complete terrain corrections in the area of high local relief near Bodie Bluff may affect the gravity map, but errors of the magnitude required to shift the location of the anomaly appear unlikely.

Table 5. Rock density measurements of rocks of the Bodie mining district and surrounding area.

Age	*Rock Type*	*Source of Data*	*No. of Samples*	*Density Range (g/cm^3)*	*Average Density (g/cm^3)*
Quaternary					
	Coarse lake gravels	Pakiser, and others (1964, p. 22)	—	—	2.27
	Tuff	Pakiser, and others (1964, p. 22)	—	—	1.36
	Pumice	This report	1	—	1.14
	Basalt	Pakiser, and others (1964, p. 22)	6	2.59-2.73	2.66
Tertiary					
	Intrusive rocks of the Bodie Hills area				
	Dacite	This report	2	2.34-2.55	2.45
	Chyolite	This report	2	2.24-2.36	2.30
	Intrusive rocks of the Bodie mining district only				
	Dacite	This report	25	2.03-2.68	2.41
	Extrusive rocks of the Bodie Hills area				
	Andesite	This report	4	2.54-2.64	2.60
	Dacite	This report	7	2.20-2.56	2.49
	Basalt	This report	1	—	2.79
	Welded tuff	This report	1	—	2.31
	Extrusive rocks of the Bodie Mining District only				
	Dacite	This report	15	2.25-2.59	2.39
	Tuff breccias	This report	7	2.18-2.59	2.41
Pre-Tertiary	Plutonic rocks	Pakiser, and others (1964, p. 22)	10	2.42-2.69	2.60
	Metamorphic rocks	Pakiser, and others (1964, p. 22)	—	2.63-2.94	2.78
	Greenstone	This report	1	—	2.82
	Metatuff	This report	1	—	2.65

RESULTS OF THE GROUND MAGNETIC SURVEY

Possible causes for the aeromagnetic low associated with the Bodie mining district are discussed earlier in this report. Measurements of values of the magnetic susceptibility of samples from the Bodie mining district (Table 4) did not provide a conclusive answer to the question of the cause of the magnetic anomaly, but did suggest that the cause might be related to rock alteration, particularly of the intrusive rocks.

Plate 2 is a vertical intensity magnetic map of the Bodie mining district with a contour interval of 200 gammas, based on an arbitrary datum. Magnetic values shown for most stations are the average of approximately 3 or 4 separate observations taken around each station site. The resulting map of the magnetic field varies in magnitude from a low east of Queen Bee Hill (zero contour), to a high exceeding 1200 gammas southeast of the Red Cloud shaft. Because of the irregular station interval and possible rapid local variations in the magnetic field, this magnetic contour map may not show many of the local features that would be detected in a more detailed survey.

In contrast to the relationships shown by the regional anomalies, there is little apparent correlation between the gravity and

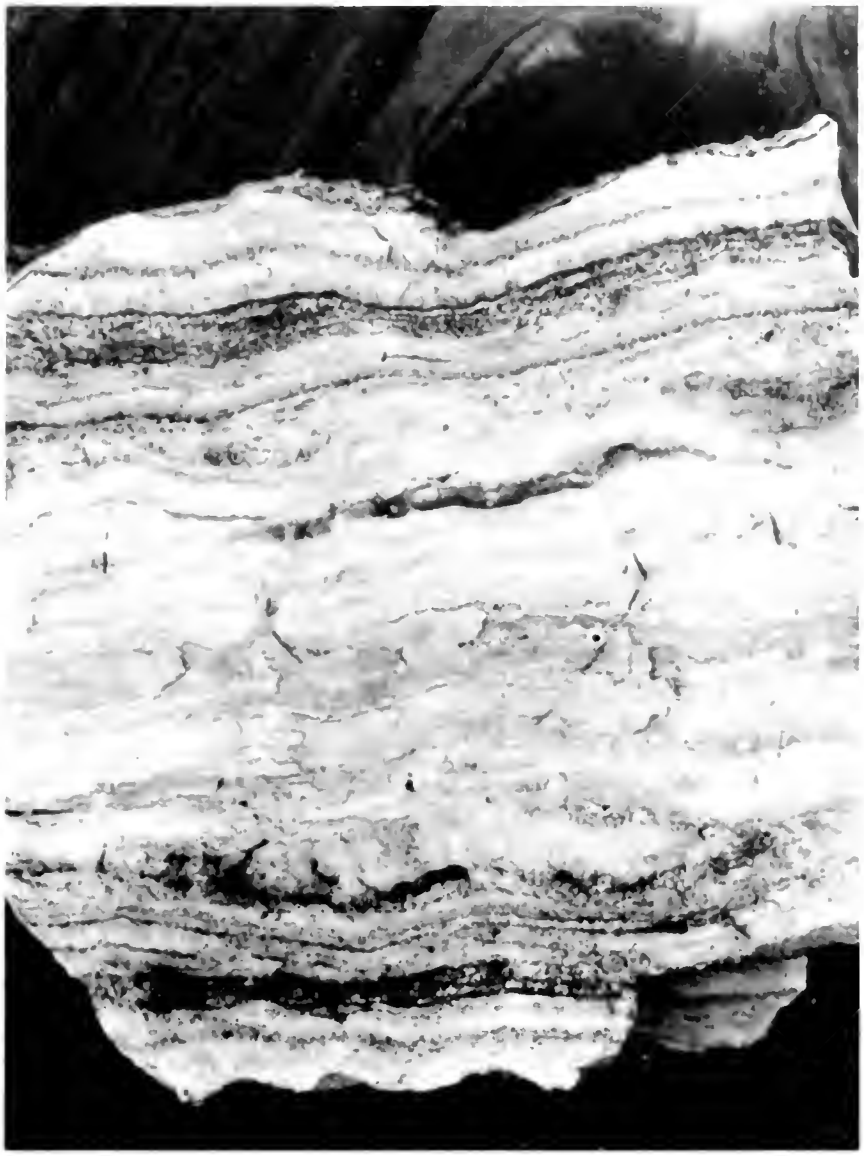

Photo 9. Ribbon quartz, containing fine-grained free gold. Typical of the veins mined in the Bodie Bluff area. *Photograph by Francis H. Frederick.*

ground magnetic maps of the Bodie mining district (Plate 2). Furthermore, the negative aeromagnetic anomaly which characterizes this area is difficult to identify in Plate 2, but this is probably because of the relatively small area studied on the ground (a part of this negative anomaly can be seen in profile X-Y, Plate 1). The observed variations in the magnetic field shown in Plate 2 are relatively minor features which probably are all within the major regional magnetic low. It would be expected, however, that these minor features might show some general correlation on the map with local geology within the area of the mining district.

The highest magnetic values observed in the ground survey are generally, but not exclusively, associated with the intrusive dacites and tuff breccias of the Silver Hill Volcanic Series. The intermediate and low values are associated with the dacite flows of the Silver Hill Volcanic Series. This is contrary to what might be expected, in general, from values of magnetic susceptibility given in Table 4, which suggest that the intrusive dacites and the tuff breccias might even cause magnetic lows. It is probable that local magnetic values actually are more related to the degree of rock alteration than to specific rock type. However, no consistent relationships between the magnetic map and mineralization or a map showing rock alteration (Plate 2) could be determined.

Of interest in this regard is profile X-Y which traverses the mining district just south of the Red Cloud shaft, where it crosses the northern edge of a small dacite intrusive plug, shown on the geologic map (Plate 2). This profile shows a sharp, local, positive anomaly, with an amplitude of about 500 gammas, which is closely associated with the intrusive rocks. In contrast with many of the other intrusive rocks in the Bodie mining district, the Red Cloud intrusive is believed to be relatively unaffected by alteration. The results of magnetic susceptibility measurements of samples of these rocks yielded a relatively high average value of 0.0021 emu/cc. Thus, the susceptibility measurements tend to confirm the apparent association of the intrusive plug and the magnetic anomaly in this area. Therefore, it appears that rela-

Photo 10. Ribbon quartz veins in intrusive dacite near summit of Bodie Bluff. *Photograph by Francis H. Frederick*

tively unaltered intrusive rocks in the Bodie mining district might be more likely to cause magnetic highs, or normal background values, than magnetic lows.

Summary

Evidence from the regional and local geophysical data in the Bodie mining district and measurements of some of the rock properties suggests the following. (1) the negative aeromagnetic anomaly is probably caused by extensive hydrothermal alteration of the intrusive and extrusive rocks in this area, which has removed a large part of the normal magnetic content of these rocks, (2) the positive gravity anomaly is most likely caused by an intrusive mass underlying the Bodie mining district, (3) hydrothermal solutions responsible for the rock alteration were probably closely related to the emplacement of the intrusive body, thus explaining the close spatial relationship of the major gravity and magnetic anomalies, (4) some of the minor magnetic and gravity anomalies are associated with the relatively unaltered intrusive rocks of the Bodie mining district—otherwise there is little apparent relationship on a local scale between these anomalies and rock types, types of alteration, or mineralization, and (5) the extensions of the gravity anomaly beyond the mining district suggest additional areas as possible targets for mineral exploration.

ECONOMIC GEOLOGY

The mines of the Bodie mining district have been divided, principally upon the basis of their geographic distribution, into three groups (Plate 3): (1) Standard Hill area, centering essentially around Standard Hill and Bodie Bluff; (2) Middle mines area, occupying the low saddle-like area between Standard Hill and Silver Hill; and (3) the Southern mines area, which lies between Silver Hill and Sugarloaf.

More than 90 percent of the ore from lode deposits has come from mines in the Standard Hill area, where the ore occurs in quartz veins, principally in the intrusive dacite of the Standard Hill-Bodie Bluff plug, and to a lesser extent in tuff breccia of the Silver Hill Volcanic Series (Photos 9, 10, and 11). A substantial lode production came from several mines in the Southern mines area, where veins occur in flows and tuff breccia units of the Silver Hill Volcanic Series. Lode production in the Middle mines area was small and is not known, but it, too, was from veins in the rocks of the Silver Hill Volcanic Series.

Placer operations were conducted at sites centered principally in a small area in the eastern part of the Middle mines area, where gold was first discovered in the district. The production of gold from the Placer area is not known but was not great.

Because accessibility of many of the mines in the district was limited during these investigations, it was necessary to make extensive use of published reports and private reports for subsurface information on the mines and ore deposits. Brown (1907), McLaughlin (1907), and Whiting (1888) have been the sources of published data, and the extensive personal files of Francis H. Frederick (deceased in 1968) provided much valuable data that were obtained in the district between 1929 and 1931.

These published and unpublished data, plus our detailed field investigations, provide an outline of the general features of the mines and ore deposits.

Photo 11. Quartz-breccia zone, containing free gold, 436 level Bodie mine. Pencil is 5 inches in length. *Photograph by Francis H. Frederick*

Standard Hill Area

Brown (1907) called attention to the Fortuna, Incline, and Burgess series of veins, all of which appear to occur only in the Standard and Bodie mines of Standard Hill. Before the mines had become inaccessible, the relationships of these three vein series had been mapped and clearly deciphered. The Fortuna is the oldest and the Burgess the youngest. In order of decreasing productivity, the Incline is followed by the Fortuna and the Burgess.

Several prominent faults, of which only the Moyle Footwall fault and the Standard Vein fault are observable at the surface, have cut the veins into segments. The Incline series occurs in the hanging wall segment of the Moyle Footwall fault and the Burgess series is in the footwall segment of this fault. The Fortuna series is cut and displaced by all other veins and fractures it meets (Figures 7, 8, 9, and 10). In spite of the close juxtaposition of the three vein series and the fact that they interesect one another, each series has distinguishable features.

FORTUNA SERIES

The Fortuna vein series yielded the richest ore in the Bodie mine. The series consists principally of the Fortuna and the Beehive veins, which are fissure veins. The Fortuna vein did not crop out at the surface and was first encountered in 1878 in the Bodie new shaft about 340 feet below the collar. Early in 1879, the vein was again cut in a crosscut on the 430-foot level of the Bodie mine, about 125 feet east of the Bodie new shaft, and its apparent richness was quickly determined. The Fortuna vein had a strike around N 10° W and a variable dip, ranging from 30 degrees toward the east, where first encountered in the Bodie new shaft, to 45 degrees in the workings below the 600-foot incline level of the Bodie mine. The average width of the vein was no more than 2 feet (Figure 9, Photo 12), and in many places it was only a few inches. The strike length of the Fortuna vein is not known, but it was encountered in the east crosscut of the 1,000-foot level and at points above in the Standard mine, followed for several hundred feet southward into the Mono claim, and encountered in the lower levels of the Lent shaft workings. The Fortuna bonanza, the zone from which the greatest value was produced, extended down the dip of the vein in the Bodie mine for some 1,000 feet. It had its maximum horizontal development of 350 feet on the 600-foot level of that mine and an average length of 200 feet.

The quartz in the Fortuna vein is hard, flint-like, white, and adhered tightly to the walls. Drusy cavities and comb structures are common. The ore minerals include native gold and silver, argentite, pyrite, and sphalerite. The sphalerite content increased

Photo 12. Fortuna vein, 400 level Bodie mine looking south. Vein is approximately one foot maximum width at this place. *Photograph by Francis H. Frederick.*

with depth as the gold content decreased. Minor amounts of pyragyrite were encountered in drusy cavities in the vein below the 670-foot incline level of the Bodie mine.

At the bottom of the Fortuna bonanza, near the 600-foot level in the Bodie mine where the dip of the Fortuna vein starts to steepen, a very narrow vein, referred to as the Beehive, left the footwall of the fortuna vein at a high angle (Figures 7 and 8). The Beehive vein ranged in thickness from one inch to one foot and extended downward from its junction with the Fortuna vein to the 707-foot level of the Lent shaft, a distance of about 180 feet; below there it disappears as narrow seams and thin veinlets of weakly mineralized quartz.

The Beehive vein was rich in silver and was mined extensively throughout its length and depth.

The Fortuna vein was observed on the 1,200-foot level of the Lent shaft, where it appears to occupy a fissure whose dip steepens to an angle greater than that observed at higher levels in the Standard mine. The vein had dwindled down to small isolated bunches of quartz veinlets which were occasionally rich in gold and silver. The Fortuna vein was not prospected below the 1,200-foot level of the Lent shaft workings.

INCLINE VEIN SERIES

The veins of the Incline series (Figure 11) were said to be gash veins by Brown (1907, p. 350), although the evidence does not always support this designation. All of the veins of this series, except the Gildea in the Bodie mine, terminate at or above the Moyle Footwall fault in the Standard mine. Important veins of the Incline series include the Main Standard vein, the Gildea vein, the Bullion vein, the Incline vein, and the Bruce vein.

Most of the veins of the Incline series dip to the west at high angles, from near vertical to 65 degrees; the main Standard vein, however, had a dip of only 40 degrees. At their contact with the Moyle Footwall fault, which is a normal fault, the dip of the veins flattens and many of the veins seem to curl up into masses of broken quartz (Figures 7 and 11). Most of the veins range in width from 14 inches to 6 feet, but on the 380-foot level of the Standard mine, the Main Standard vein, the largest in the district, was 90 feet wide and averaged about 20 feet. The general strike of the veins of the Incline series is from north to N 20° E. The Main Standard vein follows closely to the strike trend of the Standard vein fault, which is generally N 15° E.

The Incline vein series can be subdivided (Brown, 1907, p. 351) into two distinct groups of veins of different ages. The older group, which includes the Main Standard and Incline veins, is characterized by massive, well-banded, flint-like quartz, which is usually firm, but in places highly fractured, and is associated with red ferruginous clay that was derived through attrition and alteration of the wall rock. The walls of the older group of veins are well defined.

The veins of the Incline series that were formed later, including the Bullion vein, are characterized by well-banded, porous quartz which is crumbly and contains scarce black manganese oxide and minor amounts of clay.

Post-mineral movement in the oldest group of veins accounts for the fractured condition of the quartz and the development of the clay, whereas simple crushing action is said to account for the crumbly condition of the quartz and small clay content of the later group of veins (Brown, 1907, p. 351).

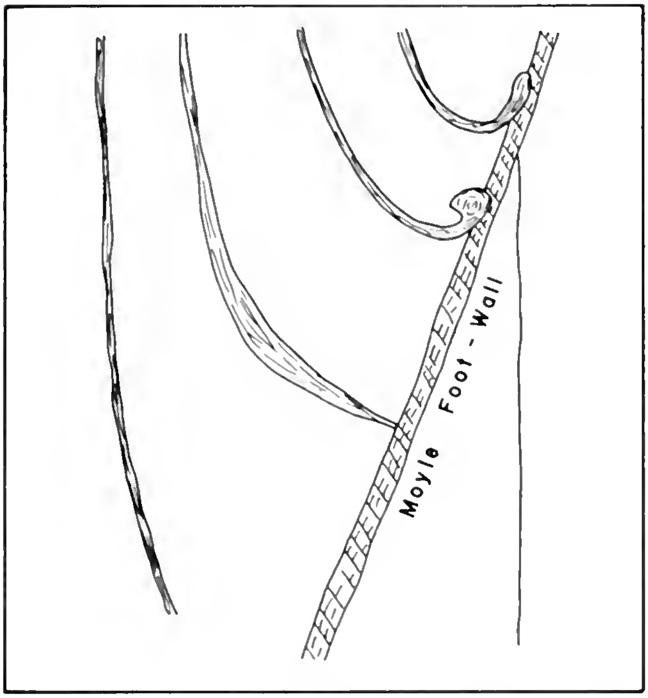

Figure 11. Cross section of the veins of the Incline series showing their relationships to the Moyle Footwall fault, Standard mine. *From Brown, 1907.*

The precious metal content of the Incline veins, which were mined profitably along a strike length of 3,000 feet, seems to have dropped off greatly at about the 500-foot level in the Standard mine. Gold content was uneven in the veins of the younger group of this series, and it was soon discovered that small veins (called "enrichers" by the miners), which branch off generally into the footwall, carried fabulously rich gold ore, assaying several hundreds of dollars per ton. These enricher veins, the latest of the series, were thought to be related to the Burgess vein series, but the character of the quartz and the coarseness of the gold indicate that the enricher veins are more likely a third group of the Incline series (Brown, 1907, p. 352-353).

Although the walls of the Incline series of veins are well defined, the dacite adjacent to the veins is highly altered and contains considerable limonite, derived from pyrite. Adularia occurs in the veins of this series, especially on the 260-foot level of the Standard mine, and the entire width of the Bullion vein was composed of coarse quartz.

BURGESS VEIN SERIES

The Burgess series makes up the youngest veins in this part of the district, and includes the Ralston vein in the Standard mine (Photo 13). These veins are reported to lie in the footwall below the Moyle Footwall fault, and very few of them reached the surface. Their strike trend is from north to N 20° E and their dip is at high angles toward the east. They are rarely a foot in thickness and are characterized by weakly banded, white quartz with a comb-like structure, generally at the center of the vein. It was common to find a thin layer of high-grade, gold-bearing quartz, referred to as "scale", adhering to one of the vein walls. An unfailing indication of rich ore was a layer, up to [illegible]-inch thick, called "shale," composed of ground wall-rock and quartz particles in clay. Brown (1907, p. 354) suggested that the "shale" indicates movement along the vein.

The dacite adjacent to the veins is altered, but limonite is not abundant. Some of the veins were rich in gold, so much so that veins no more than ½-inch thick were stoped. Not only were the veins rich, but the wall rock on both sides of the vein for as much as several feet contained sufficient gold to make the vein zones worth mining. The so-called Burgess bonanza, which was some 12 feet in width on the 300-foot level of the Bodie mine, consisted of mineralized wall rock and numerous, rich, narrow quartz veins. The length of the Burgess vein series is not known, but the Ralston vein was prospected and mined for a distance of more than 500 feet.

Middle and Southern Mines Areas

Many of the mines in the Middle mines and Southern mines areas have been under water since 1882 and hence were not accessible to the early investigators who provided so much of the useful data on the veins in the Standard Hill area. Work done in the early 1930s by Treadwell-Yukon Company, Ltd., especially in the Red Cloud mine, provides a limited amount of information on the Concordia, Red Cloud, and Booker veins, all of which appear to have provided the principal lode production in the Southern mines area.

CONCORDIA VEIN

The Concordia vein was the principal producer of silver and gold in the Noonday mine and was encountered on several levels in the western part of the Red Cloud mine. On the 402-foot level of the Red Cloud mine west of the Red Cloud shaft, the Concordia vein dips 60° E and has a strike of about N 5° W. Farther south, this vein changed to a south strike and a dip of 65° E. The vein ranged in width from a few inches to as much as 12 feet. It consists of vuggy white quartz, coarse-grained calcite, pseudomorphs of quartz after calcite, and clayey gouge. The ore minerals are tetrahedrite, pyrargyrite, and pyrite.

Several ore shoots were encountered and stoped in the Concordia vein in the Noonday mine. The largest and most important of these shoots was encountered between the 450-foot level and the 700-foot level. It raked to the south, measured 400 feet in length on the upper levels, and bottomed on the 700-foot level. The best ore mined from this shoot in the Concordia vein was more than 3 feet wide and had an average per-ton content of about 6 ounces of gold at the 1931 price of $20.6718 per ounce) and 53 ounces of silver. It was presumably from this ore shoot that most of the total production of $1,200,000 was realized for the Noonday mine.

RED CLOUD VEIN

In most places where the Red Cloud vein was encountered and developed, it was accompanied by gouge and crushed quartz. Its strike is generally to the north and its dip to the east ranges from near vertical to 45 degrees. The vein ranges in width from a few inches to 4 feet. On the 256-foot level of the Red Cloud mine north of the shaft, the vein consists of a zone of numerous narrow, parallel, and anastomizing quartz veins and gouge. Farther south on the same level, the vein became a definite band of yellowish ribbon quartz and calcite. One ore shoot, stoped between the 256-foot level and the 592-foot level, was 120 feet in length, 4 feet in width, and raked to the south. The total value of the ore, in gold and silver, was $10.05 per ton at 1931 prices.

Photo 13. Ralston vein, just off Bulwer tunnel, looking south. *Photograph by Francis H. Frederick*

At deeper levels in the Red Cloud mine (Photo 14), the Red Cloud vein was consistently better defined and contained, in addition to quartz and pseudomorphs of quartz after calcite, coarse-grained calcite and fine-grained adularia. Ore minerals included tetrahedrite, pyrite, galena, chalcopyrite, and minor sphalerite. Pyrargyrite was reported to be present in the Red Cloud vein by O.H. Hershey (written communication, 1929).

ORO VEIN

The Oro vein, the principal vein developed and mined in the Oro mine, has a general strike from N 10° E to north and a dip of 50° E (locally steeper). The length of the vein is not known, but mine maps show at least 400 feet. It ranges in thickness from 2 to 6 feet. Most of the ore was obtained from a north-raking shoot which assayed as high as $340 per ton at 1931 values for gold and silver. Ore minerals included tetrahedrite, stephenite, pyrargyrite, pyrite, and galena.

BASE METAL VEIN

Hershey, in his study of the mines of the Bodie mining district (written communication to Treadwell-Yukon Co., Inc., 1929), applied the name of "Base Metal vein" to a mineralized zone which he maintained extended discontinuously from the Bulwer tunnel in the Standard Hill area to the King Bee shaft on Queen Bee Hill (Plate 2), a distance of about 8,000 feet. According to O.H. Hershey (written communication to Treadwell-Yukon Co., Inc., 1929) this vein's maximum development in grade and width in the Silver Hill area ranged from 12 to 250 feet in the Red Cloud mine. No zone corresponding to the Base Metal vein could be found on the surface. In the Red Cloud mine, a zone was encountered. This zone consisted principally of intensely brecciated wall rock that had been bleached and replaced in part by veins of comb quartz and irregular bodies composed of quartz, calcite, and adularia. The quartz is generally fine grained but developed into glassy, needle-like crystals lining vugs and as

Photo 14. Argillically altered tuff breccia of the Silver Hill Volcanic Series, cemented by dark gray, pyrite-rich chalcedony. 700 level of the Red Cloud mine. *Photograph by Francis H. Frederick.*

pseudomorphs after calcite. Calcite commonly occurs as fine-grained intergrowths with quartz, and lamallar plates up to one inch across are not uncommon. The adularia is fine grained and occurs largely in the fine-grained, quartz-calcite intergrowths. Pyrite is abundant and occurs as small crystals, usually less than ¼ inch across, disseminated throughout the bleached and altered dacite fragments. The largest pyrite crystals occur in vugs in quartz masses and veins. Other ore minerals include tetrahedrite, pyrargyrite, galena, chalcopyrite, and sphalerite; azurite and malachite are rare and principally represent alteration of chalcopyrite.

According to E.W. Billeb (oral communication to the authors, 1965), a small ore shoot in the Base Metal vein was developed and stoped in the 622-A raise of the Red Cloud mine. This shoot was about 50 feet long and 3 feet wide, it had an average per-ton content of about one ounce of gold ($20.55 at the 1931 price of $20.6718 per ounce) and 32.27 ounces of silver

BOOKER VEIN

Several prominent veins were prospected in the area between the Noonday mine and Queen Bee Hill. The Booker vein (Plates 2 and 5) seems to have been the largest and most promising of these and the one that was developed the most. In the vicinity of the Noonday mine, the Booker vein strikes north, but farther south it bends to the east, strikes S 30° E and dips 40° E. The thickness of the vein is not known, but near the Booker shaft it is less than one foot. The vein appears to consist of quartz and calcite, and much of the quartz is pseudomorphous after calcite. Pyrite is present, usually as small crystals in the quartz.

Distribution of Metals in the Veins

A characteristic feature of the veins in the Southern mines area is the direct relationships between their silver and gold

Photo 15. Lent shaft hoist house and office, as it appeared in 1895. Photographer unkown (Frederick, 1960, private communication).

content and the amount of quartz present. Those veins that had the highest quartz content had the highest content in silver and gold, both contained in minerals such as tetrahedrite, pyrargyrite, and pyrite.

Because of the inaccessibility of the underground workings of the mines (Plate 4) in the Standard Hill area, it was not possible for the writers to obtain first-hand information regarding the distribution of metals and the grade of ore.

Whiting (1888, p. 389), from whom much of the data about the veins in the Standard Hill area was obtained, made the following comment regarding the metal distribution in the Incline and Burgess vein systems: "In all of these younger series of lodes the gold content largely exceeds in value that of the silver, though in the relative proportions of the two metals by weight, the silver is somewhat in excess of the gold tenor. In the average assay value of the Standard ore, as given in its Superintendent's report for the fiscal year ending February 1, 1883, the gold content was stated at $34.28 per ton, the silver at $4.07, in a total of $38.35 per ton of two thousand pounds. Its silver value was calculated at $1 2929 per troy ounce, the gold at $20.6718 per ounce In weights, therefore, the average gold contents of the ore for the year were 1.65 troy ounces per ton; while the silver tenure amounted to 3 14 ounces per ton, furnishing 65.6 percent by weight of the precious metals in the ore of these so-called gold mines The native gold of these Bodie veins, moreover, is itself an alloy with silver in the proportion of about six hundred and ninty-five thousandths gold and three hundred and five thousandths silver. Apart from this occurrence of the silver, however, these veins also carry that metal in flakes and wires, and mineralized as argentite and kerargyrite..." Further along in his report, Whiting (p. 392) states, "As is the case along all of the Bodie fault fissures the andesite on either wall of the rich vein is more or less thinly sheeted, and along such structural planes, to the depth of a foot or more from this narrow quartz vein, native silver was often found in the wall-rock, in small fronds and wires, so that where the quartz of the vein did not exceed six inches in width, from eighteen inches to two feet could be profitably mined."

Brown (1907, p. 347), in his analysis of the veins in the Bodie mining district, stated, "The Fortuna is the only vein with marked easterly dip. It is also the only one presenting the characteristics of a strong, deep-reaching zone of fissuring. Unfortunately, this permanency is of structure alone, and does not extend to the contents; for in the lower portions the vein rapidly becomes impoverished; sphalerite, from being almost absent, increases to a large percentage; gold values weaken and almost die out; and silver diminished to a few sparse patches of wire in masses of impure, bluish kaolin "

Wisser (1960, p. 76) summed up the relation of structure to metallization at the Bodie mining district as follows: "All Bodie

Photo 16. View of Bodie looking southwest from Standard Hill. Excavation in foreground is part of large scale sampling conducted by Yukon-Treadwell Company, Inc. in the Spring of 1931. *Photograph by Francis H. Frederick.*

veins carried both silver and gold, but some were relatively high in silver, some in gold. Where earlier vein matter was fractured and later vein minerals deposited in the openings created, the later vein matter was invariably richer in gold than the earlier. Solutions, therefore, changed in time from relatively silver-rich to relatively gold-rich."

Depth of Mineralization

As was brought out in the discussion of the veins, mineralization in the district appears to be shallow, and the precious metals values rarely extended much lower than the 500-foot level in any mine. This is especially true in the Standard Hill area for the Incline and Burgess vein series. The Fortuna vein, an exception to the general depth rule, was mined down dip for 1,000 feet, or to a depth of about 600 feet below the surface.

Mineralization in the Southern mines area appears to have extended at least 800 feet below the surface. Below this depth, veins continue but consist almost wholly of calcite with an occasional small irregular body of quartz pseudomorphous after calcite.

The depth to which precious metal mineralization extends in the Middle mines area is not known, although the Dudley shaft (Plate 2) is said to have been sunk 500 feet below its collar (O.H. Hershey, written communication to Treadwell-Yukon Co., Inc., 1929), and no veins of any significance were encountered in either of the long crosscuts extending east and west from the bottom of the shaft.

A study (O'Neil and others, 1973, p. 780) of the stable isotopes of hydrogen, oxygen, potassium, rubidium, and strontium in the quartz veins and their unaltered and altered host rocks, and alteration clay, fluid inclusions, and modern spring waters in the district indicates that alteration and ore deposition occurred over the approximate temperature interval of 215-240° C. The study also indicates that the source of the ore constituents is probably magmatic and perhaps from the same source as was postulated for the dacite plugs of the district.

HISTORY OF MINING AND PRODUCTION

The discovery and early development of the mines in the Bodie mining district have been described by Cain (1956, 196 p.), Billeb (1968, 229 p.), and Wedertz (1969, 211 p.), all former residents of Bodie. The account by Wedertz goes into considerable detail on the mines of the district. Early accounts on the mines of the district are by Browne (1865, p. 274-284) and Wasson (1879, 46 p.). Other accounts have been published in the past 10 years, but they deal primarily with events that took place in the town of Bodie and only incidentally with the mines of the district (Johnson, 1967, 119 p; Calhoun, 1967, 172 p.). These reports and information obtained from discussions with Emil W. Billeb and others who have been closely associated with the mining activities of the district were the sources for preparation of this historical sketch.

Gold was discovered in the Bodie mining district in mid-summer of 1859 in shallow placer deposits situated in the east-central part of the district. Later that summer, gold-bearing quartz veins were discovered on a claim, then known as the Montauk (Plate 3) but now called the Goodshaw. In 1860, the mining district was organized and named Bodey; in 1862 the spelling was changed to Bodie. The first mining company was formed in 1863 when owners of several adjacent mines consolidated their claims and holdings to form the Bodie Bluff Consolidated Mining Company with Governor Leland Stanford as president and Judge F. T. Bechtel as secretary.

Between 1859 and 1876, sporadic development was carried on in the district with moderate production, no statistics on this development are available. Rich ore found on the Bullion location in 1872 was milled in arrastras on Rough Creek, about 5 miles northwestward from the district. In April 1877 the Standard Mining Company was incorporated, and the first ore mined by the new company was milled in the Syndicate mill, which was situated on Bodie Creek at the north end of the district. Soon thereafter, however, the Standard Mining Company constructed its own mill.

Rich ore found in the Standard mine in 1878 sparked a boom which lasted for about 10 years, during which period as many as 50 companies were operating simultaneously in the district.

Costs of mining and milling of the ores were very high in the district, owing principally to the high cost of firewood for the generation of steam. In the early 1890s, the Standard Mining Company brought in electrical power for mining and milling purposes from its hydroelectric power plant on Green Creek, some 13 miles to the west of the district. The introduction of electrical power into the district dramatically reduced mining and milling costs, and this, in turn, stimulated new interest in developing the mines.

The bonanza in the Standard mine was exhausted in the late 1880s and the district was faced once more with drastic decline in production, activity, and interest. In 1915, the Standard Consolidated Mining Company was dissolved and its properties were acquired by the J.S. Cain Company, which still retains title to them. Small-scale lease operations continued for about 15 years on high-grade ore in place and on tailings and mine dumps.

The first systematic development of the Bodie mining district was undertaken between 1928 and 1931 by the Treadwell-Yukon Company, Ltd. Extensive, deep exploration were conducted in the Noonday and Red Cloud mines of the Southern Consolidated Company. A total of 18,000 feet of drifting and crosscutting resulted from these exploration attempts to locate a southern extension of the Fortuna vein. Although the results were encouraging, the search was eventually abandoned. Treadwell-Yukon also examined the Standard Hill mines area, by systematically sampling underground and surface exposures (Photo 15) and by a large-scale pilot plant investigation of treatment of mine dumps and surface ore in place.

Treadwell-Yukon discontinued its investigations in 1931. In 1935, the Roseklip Mines Company, organized by John Rosekranz and Henry Klipstein, obtained a lease from the J.S. Cain Company and constructed a mill and cyanide plant of 500-ton-per-day capacity. It was operated continuously until 1942, at which time most gold mining ceased in the United States. During this period, the mill treated 346,000 tons of material from dumps and 55,000 tons of ore mined by mechanical shovel from surface cuts.

In 1945 the J.S. Cain Company leased the mines to Sierra Mines Incorporated. This company proposed to continue operations to confirm the existence of a large quantity of marginal ore in the Standard Hill mines area. This operation, however, was short-lived, for on April 3, 1946, a fire of accidental origin destroyed the mill and cyanide plant, which at the time were being enlarged to a capacity of 20,000 tons per month.

Since 1946, sporadic interest has been shown in the district. The American Smelting and Refining Company acquired most of the properties in the district in 1967 through lease and option, and in the summer and fall of 1968 carried on a brief extensive program of sampling both underground and on the surface, and the testing of ores. In 1970, the Phelps Dodge Corporation acquired a lease on the properties in the district and immediately commenced a detailed, systematic sampling of veins exposed at the surface and in mine workings that could be made easily accessible. By 1972, prospecting by core drilling was started, particularly in areas where previous mining activities had not been extensive.

Table 6. Production of gold and silver of the Bodie mining district, Mono County, California, from 1860 to 1941.

Year	Gold Value	Silver Value	Total Value
1860-1876* (1)			4 000 000 00
1877	731 083 02	67 867 28	798 950 30
1878	1 890 531 18	239 669 14	2 130 200 32
1879	2 371 984 36	298 137 13	2 670 121 49
1880	2 333 590 86	636 663 86	2 970.253 87
1881	2 743.391 77	416 675 74	3 160 067 51
1882	1 751.152 07	466 628 17	2 217 780 24
1883			1 582 6[illegible] 08
1884			1 123 56[illegible]
1885			449 [illegible]
1886			526 [illegible]
1887			341 78[illegible]
1888			126 294 [illegible]
1889**			193 264 [illegible]
1890			144 160 [illegible]
1891			302 514 [illegible]
1892			39[illegible] 29[illegible]
1893			293 637 [illegible]
1894			358 824 [illegible]
1895			552 6[illegible]
1896			451 5[illegible]
1897			520 10[illegible]
1898			446 [illegible]
1899			697 0[illegible]
1900			670 20[illegible]
1901			493 355 [illegible]
1902			510 5[illegible]
1903			334 [illegible]
1904			[illegible]
1905			[illegible]
1906			33[illegible]
1907			383 [illegible]
1908			4[illegible]
1909			354 409 [illegible]
1910			4[illegible]
1911			[illegible]
1912			[illegible]
1913			14[illegible]
1914 (2)			6 6[illegible]
1915			107 30[illegible]
1916			[illegible]37 064 [illegible]
1917			209 04[illegible]
1918			[illegible]
1919			[illegible]
1920			144 [illegible]
1921			37 754 [illegible]
1922			65 7[illegible]
1923			34 6[illegible]
1924			[illegible]
1925			5 [illegible]
1926			20 [illegible]
1927			3 [illegible]
1928			[illegible]
1929			
1930			
1931	[illegible] 34		[illegible] 34
1932			
1933			
1934			
1935			
1936***	[illegible]	[illegible]	43 [illegible]
1937	[illegible] 481 00	[illegible] 688 00	168 [illegible]
1938	100 [illegible]	[illegible] 335 00	[illegible]
1939	150 [illegible]	[illegible]	[illegible]
1940	13[illegible]	84 658 86	[illegible]
1941	[illegible] 551 [illegible]	[illegible]	[illegible]
Totals	[illegible]	[illegible]	33 [illegible]

* Estimate based upon sparse reporting of annual production value.

** Between 1889 and 1918 total value includes $[illegible] 480 000 00 in gold and $4 [illegible] in silver reported from other districts in Mono County.

*** Gold calculated at $35.00 per fine ounce and silver at $0.[illegible] per fine ounce for period from 1936-1941.

(1) Between 1860 and 1935 gold was calculated at $20.6718 per fine ounce and silver at $1.2929 per fine ounce.

[illegible]

Table 7. Production, dividends and operations of the Standard Consolidated Mining Company, Bodie mining district, Mono County, California (Eakle & McLaughlin, 1917, p. 151).

Year	Production Value	Dividends	Tons of ore	Value per ton	Tons of waste	Development in feet	Cost mill per ton	Cost mining per ton	Percent saved in mill	Total percent saved	Remarks
1877*	78 4522 80	890,000 00	†	—	†						
1878*	1,025 383 35					†	—	—	—	—	
1879*	1 448 854 47	550,000 00	†	—	†	†	—	—	—	—	
1880	1,398 864 62	950,000 00	†	—	†	†	-	—	—	—	
1881	1,952 843 55	975,000 00	†	—	†	†	—	—	—	—	
1882	2,049,521 53	675 000 00	†	—	†	†	—	—	—	—	
1883	1,175,728 01	375 000 00	†	—	†	†	—	—	—	—	Assessment of $25 000 00
1884	1,084 934 46	50 000 00	†	—	†	†	—	—	—	—	
1885	242,093 74	—	†	—	†	†	—	—	—	—	
1886	226,988 86	—	†	—	†	†	-	—	—	—	
1887	228 821 00	50,000 00	†	—	†	†	—	—	—	—	
1888	202 207 80	40,000 00	†	—	†	†	—	—	—	—	
1889	127,340 94	—	†	—	†	†	—	—	—	—	Assessment of $75,000 00
1890	134,900 82	-	†	—	†	†	—	—	—	—	
1891	846,22 26	18 902 80	†	—	†	†	—	—	—	—	
1892	23 7993 78	28 354 20	17,420	—	7,017	†	3 78	6 02	74	—	Electric power introduced
1893	239,381 70	18,902 80	6,950	28 46	8,094	5363	4 92	9 85	79	—	
1894	171 535 59	37,803 60	10,111	16 63	7,342	4334	3 42	7 31	70	—	
1895	195,907 50	18,902 80	10,160	20 40	13,057	4413	3 12	8 90	65	—	
1896	234 617 99	35,678 80	12,967	22 57	9,327	6407	2 92	7 56	66	—	
1897	294,278 97	35,678 80	—	—	—	6026	—	—	—	—	
1898	261,750 43	53,518 20	12,358	38 71	10,605	5282	2 22	8 11	72	—	
1899	445,179 98	71,357 60	17,883	26 06	15 928	6761	1 80	8 08	67	—	
1900	425,613 78	71 357 60	20,673	19 14	16,775	7961	2 17	7 48	66	—	
1901	351,804 05	71,357 60	18,047	18 48	18,353	7504	1 98	7 93	68	—	
1902	360,775 40	53,518 20	14,738	20 70	16,863	6106	2 59	9 05	66	—	
1903	309 425 56	—	17,734	18 26	20,954	6049	2 24	8 33	62	—	
1904	221,870 03	17 839 40	10,210	—	—	—	1 69	5 97	—	—	Slime, cyanide plant began operation
1905	273,048 91	44 598 50	18,240	19 77	—	5437	1 60	6 26	—	—	
1906	323 069 05	35,678 80	16,021	17 15	9,167	3654	1 43	6 92	42	—	
1907	284,047 36	35,678 80	14 229	16 36	8,179	3282	1 35	7 22	28	90	
1908	253,252 02	—	11,732	14 16	14 784	6087	1 63	8 79	28	88	
1909	226,404 08	17,839 40	13,138	14 38	13,432	4460	1 28	7 55	38	88	
1910	267,935 39	17,839 40	†† 8,798	14 14	15,077	6254	2 02	12 67	41	91	
1911	235,476 81	—	8,150	11 72	14,749	6216	1 92	10 71	46	90	
1912	188,902 34	44 598 50	6,342	13 08	—	2846	1 64	10 50	48	90	Mill and slime plant closed, October to end of year
1913	132,943 69	5,264 407 80	260,901	—	219 905						
Total	$18,204 798 62										

*From Whiting 1888 p 296
†Earlier figures unavailable
††Dry tonnage from 1911, wet tonnage previously

This apparently was the first core drilling in the Bodie mining district. Mine records fail to indicate whether any long-hole percussion drilling had been done in the mine workings. Because many of the veins that were profitably mined underground have not been found at the surface, especially in the bonanza zone, core drilling from underground mine workings may disclose new veins or extensions of veins that had been dislocated by faulting but not found by crosscutting and drifting.

During the productive life of the Standard Consolidated mines from 1877 to 1915, the group accounted for more than 90 percent of the bullion produced in the district, which exceeded $18,000,000 in value at prices prevailing at that time (see Tables 6 and 7).

In the course of mining and milling ore from the bonanza zone, an estimated 527,000 tons of waste material was hoisted to the surface and placed as waste dumps. An estimated 150,000 tons of waste material remains underground as stope filling.

The Bodie Historic State Park was created in 1956 to preserve a ghost town of a colorful past. It encompasses the townsite of Bodie but does not include the mining properties in the Bodie mining district.

Milling

The first ore mined in the Bodie mining district was milled in arrastras on Rough Creek, about 5 miles northwestward from the district, and some ore was hauled 13 miles to Aurora, Nevada, and processed in stamp mills.

About 1863 a mill was established low at the western base of Bodie Bluff (Wedertz, 1969, p. 178). By 1882, eight mills were operating in the district; they contained 140 stamps, all powered by steam engines.

The Bodie ores were characterized as "free-milling." A large percentage of the gold was recoverable in the free and relatively pure state by amalgamation or strake (shaking table) concentration. The silver occurs in the gold and as sulfides or as the chloride-cerargyrite. In the early 1900s, it was found that the Bodie ores were amenable to simple cyanidation; the process yielded high extraction with relatively low costs and low consumption of reagents.

SUGGESTIONS FOR PROSPECTING

On the basis of sampling by Treadwell-Yukon Company, Inc., during the early 1930s, the bonanza zone (a highly productive block bound by the Mono, Tioga, Moyle Footwall, and Standard Vein faults) offers the best possibilities for new exploration and development. This conclusion is based upon several factors: (1) the character and widespread distribution of innumerable veins in the bonanza zone, of which many yielded high-grade ore, (2) productive history of the mines in this zone, and (3) detailed sampling of some of the underground workings in the margins of the bonanza zone.

The bonanza zone yielded more than 633,000 ounces of gold and as many as 800,000 ounces of silver from approximately 380,000 tons of ore (S.B. McCluskey, written communication, Report to Sierra Mines, Inc., 1947). It has been estimated that the bonanza zone still contains as much as 25,000,000 tons of ore whose average value in 1947 was reported to be $1.86 per ton. Furthermore, this value might be increased substantially (to perhaps $2.10 per ton) from enrichment due to fills, pillars, and veinlets of high-grade ore that were undiscovered or rejected because of the high costs of operating the mines.

Photo 17. View north toward Standard Mill. High peak is standard Hill.

Zones of marginal ore lie in the footwalls of the Moyle Footwall and Standard Vein faults adjacent to and on the west and east sides of the bonanza zone and on Bodie Bluff on the north side of the Tioga fault. The marginal ore zones contain many quartz veins, barren and ore-bearing, and an intervening lattice of veinlets, stringers, and seams which form a stockwork in the firm intrusive dacite.

Underground workings in these zones are, in a majority of cases, accessible, and from them drilling can be done in many directions, even into the bonanza zone, where mine workings have been inaccessible for many years.

Only a few of the veins south of the Mono fault were productive, but those that were apparently barren or too low in grade to be considered at the time were not explored along their length or to any significant depth. These veins occur in highly altered tuff breccia and dacite flows, and, as most of them are also highly mineralized, none should be overlooked.

Because of extensive surficial debris at the southern end of the Bodie mining district, especially in the areas surrounding Sugarloaf and underlain by units of the Silver Hill Volcanic Series, very few quartz veins and zones of mineralized rock were found at the surface.

Samples of mineralized rock containing significant amounts of pyrargyrite and pyrite were collected from the waste dump of a shaft that is located about 2,000 feet south of Sugarloaf and were found to contain 18 ounces in silver and 0.2 ounces in gold. Pyrargyrite and pyrite were found on the waste dumps of other prospects in this particular area, thus indicating widespread mineralization worthy of consideration and/or testing.

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APPENDIX:

K-Ar Sample Description and Locations*

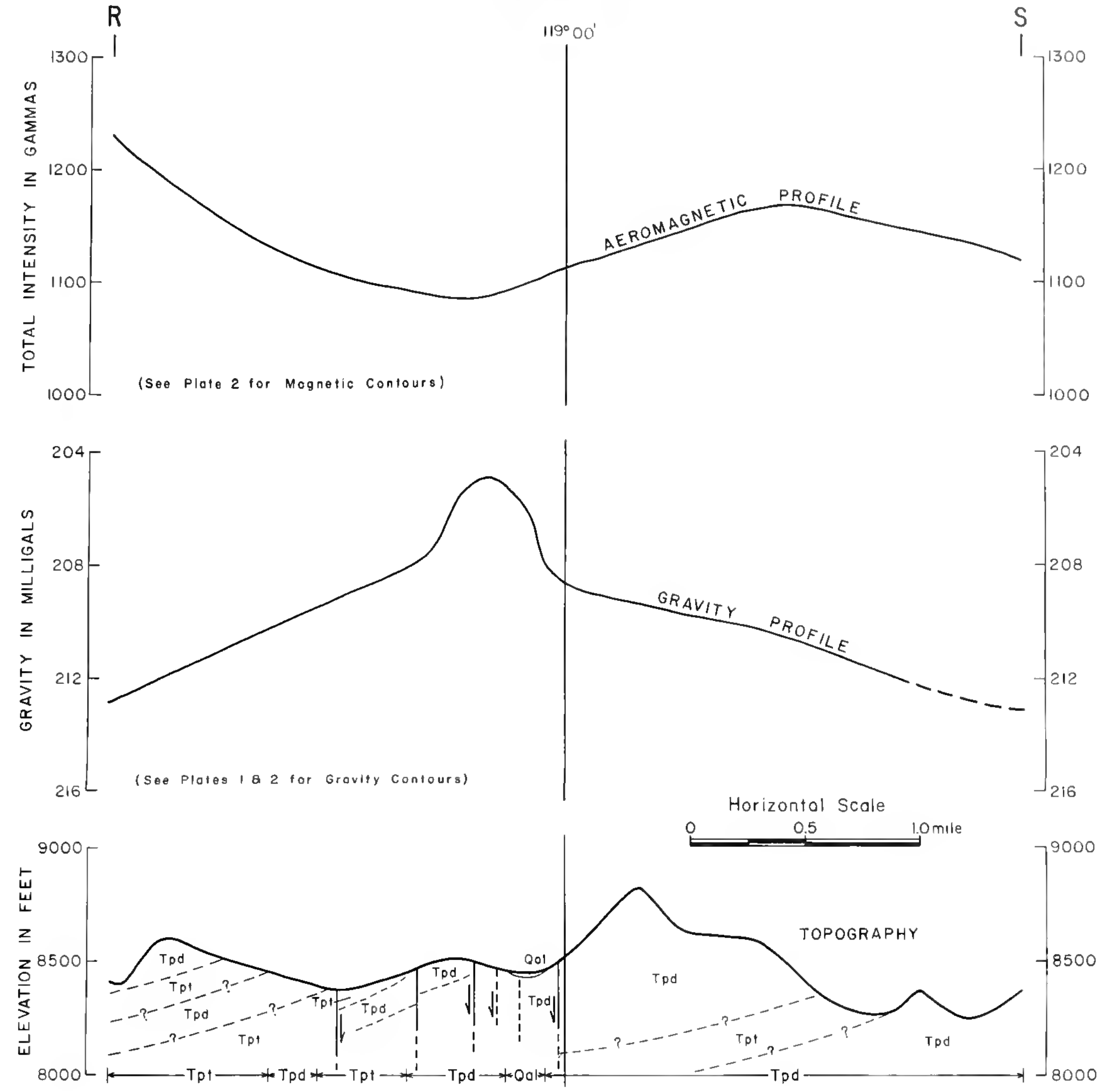
1. Adularia-quartz vein (S-central Sec. 9, T4N, R27E, on south side of Standard Hill, Mono County, California) USGS(M)-7346-1
2. Adularia-calcite-quartz vein (S-central Sec. 16, T4N, R27E, waste dump of Red Cloud mine, Mono County, California). USGS(M) RCD1B
3. Adularia-quartz vein (S-central Sec. 9, T4N, R27E, waste dump of McClinton shaft, Mono County, California). USGS(M) B270.
4. Porphyritic biotite hornblende dacite intrusive (NW ¼, Sec. 21, T4N, R27E, about 500 feet south of Red Cloud shaft, Mono County, California) USGS(M)-BH15
5. Porphyritic hornblende dacite intrusive (SW ¼ Sec. 21, T4N, R27E, on top of Sugarloaf, Mono County, California) USGS(M)-S1
6. Altered porphyritic hornblende dacite intrusive of Bodie Bluff (S central Sec. 9, T4N, R27E, cut west of Standard shaft, Mono County, California) USGS(M) B271
7. Porphyritic hornblende dacite intrusive at Queen Bee Hill (NW ¼ Sec 21, T4N, R27E, Mono County, California) USGS(M) BH17
8. Porphyritic hornblende pyroxene andesite flow, "Wall Andesite" (SE ¼ Sec. 10, T4N, R27E, Mono County, California) USGS(M) 7346-3 Locality off map
9. Porphyritic biotite-hornblende dacite (NE ¼ Sec. 21, T4N, R27E, Mono County, California). USGS(M) BH32 Locality off map
10. Porphyritic biotite-hornblende dacite (E-central Sec. 16, T4N, R27E, old quarry near dismantled railroad, Mono County, California) USGS(M) 856-32
11. Porphyritic biotite hornblende rhyodacite intrusive (W central Sec. 16, T4N, R27E, 1 mile southwest of Bodie, Mono County California) USGS(M) 856-10 Locality off map
12. Porphyritic biotite hornblende dacite flow, lower unit of composite flow (NE ¼ Sec. 16, T4N, R27E, about 2000 feet east of Red Cloud mine Mono County, California) USGS(M) BH16
13. Porphyritic biotite dacite flow (N central Sec. 28, T4N, R27E, Mono County, California) USGS(M) 854-1
14. Porphyritic biotite dacite flow (center Sec. 12, T4N, R26E, Mono County, California) USGS(M) BM2 Locality off map
15. Porphyritic biotite hornblende dacite intrusive (NE ¼ Sec. 23, T4N, R27E, near dismantled railroad, Mono County California) USGS(M) BH29 Locality off map
16. Porphyritic rhyolite (SW ¼ Sec. 7, T3N, R26E, Mono County, California) USGS(M) BH27 Locality off map

*Field numbers shown on plate 2

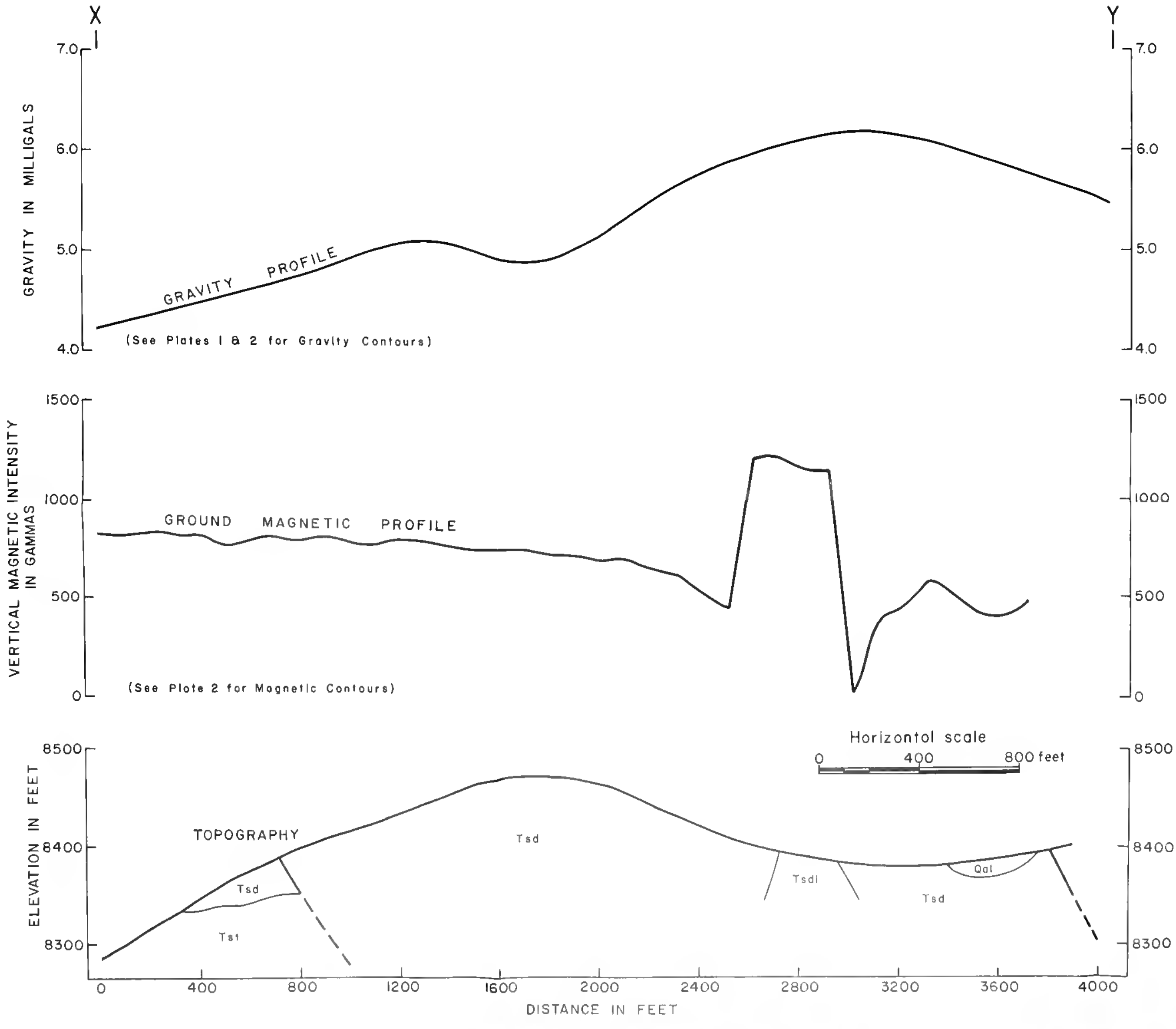
86 81685

COLLATE: 5 pieces

AEROMAGNETIC AND GRAVITY PROFILE R-S



GROUND MAGNETIC AND GRAVITY PROFILE X - Y



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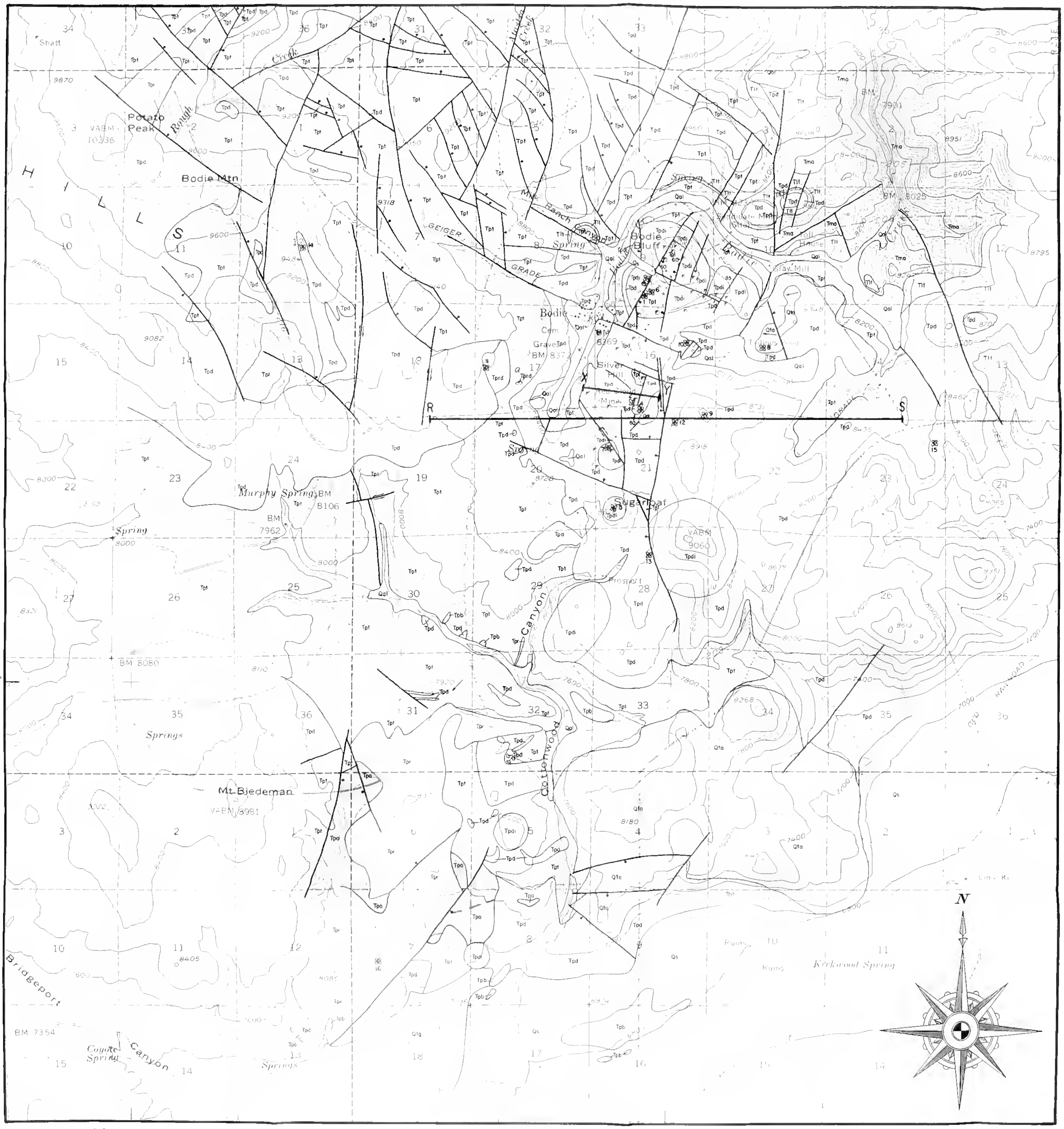
DEPARTMENT OF CONSERVATION - RANDALL M WARD, DIRECTOR



Base map enlarged from a portion of the Bodie and Trench Canyon 15' quadrangle series

GENERALIZED GEOLOGIC MAP

BODIE MINING DISTRICT
Mono County, California

Geologic Map compiled by Charles W. Chesterman
Geophysics by Rodger H. Chapman

SCALE

0 0.5 1.0 1.5 2.0 Miles

LEGEND

GEOLOGIC EXPLANATION

Symbol	Description
Qal	Soil and alluvial cover
Qtg	Unsorted, poorly bedded, well-rounded boulder, gravel and sand deposits
Qs	Unconsolidated lacustral deposits, volcanic ash, fan and talus deposits
Qta	Andesitic and basaltic rocks of the Cedar Hill-Trench Canyon complex (Al-Rawi, 1969). Range of age from 2.5 to 4.5 m y
Tpd	Dacite flows and minor tuff breccia layers Range of age from 8.8 to 9.4 m y
Tpdi	Dacite plugs. Range of age from 8.2 to 8.7 m y
Tpr	Rhyolite plugs, dikes and flows. Average age of 9.1 m y
Tprd	Rhyodacite plugs and flow Average age of 8.9 m y
Tpb	Basalt flows Average age of 9.3 m y
Tpa	Andesite flows Average age of 9.5 m y
Tpt	Tuff breccia of dacitic composition. Locally includes minor layers of dark-brown to black welded tuff. Range of age from 8.7 to 8.9 m y
Tlt	Ash flows of trachyandesitic composition, locally non-welded; includes conspicuous dark brown to black vitric zones. Average age of 9.4 m y
Tma	Andesitic rocks, porphyritic to non-porphyritic Flows, breccias and minor intrusions Range of age from 9.5 to 11.2 m.y

GRAVITY EXPLANATION

Gravity Station

Contour interval: 4 milligals
with supplementary contours at 2 milligals

Reduction density: 2.50 g/cm³

GEOLOGIC SYMBOLS

Contact, dashed where probable, queried where uncertain.

40

Fault, dashed where probable, dotted where concealed
Bar and ball on downthrown side

General direction of dip of flow banding and layering

13

Specimen locality for rock sampled for K-Ar age dating.

INDEX TO GEOLOGIC MAPPING

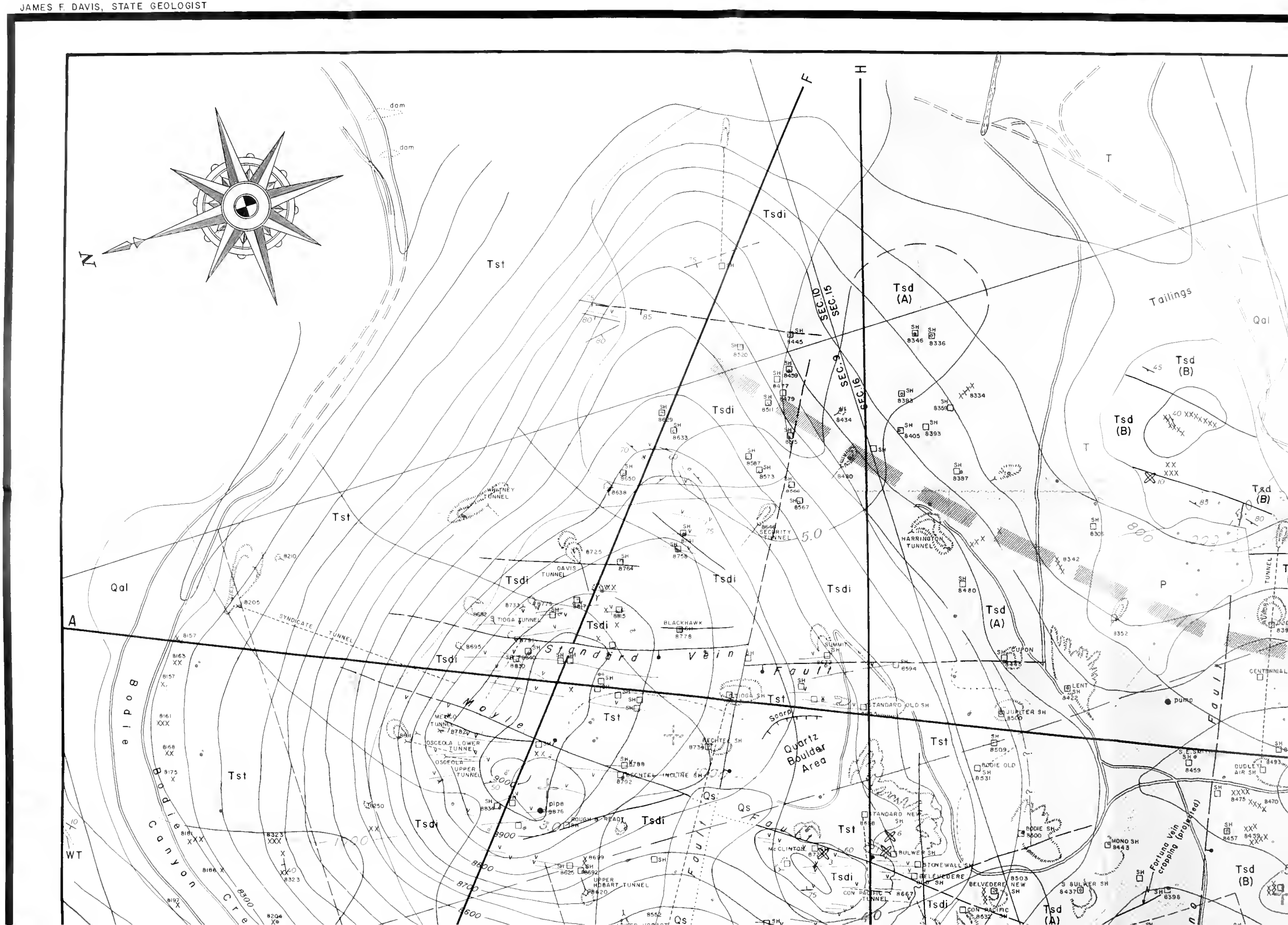
Chesterman, C.W. and Gray, C.H., in press

Kleinhampl, F.J and others, U.S.G.S Bulletin 1384

Al-Rawi, Y.T., unpublished

DRAFTING AND LAYOUT BY C.A. ALLEN

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, STATE GEOLOGIST



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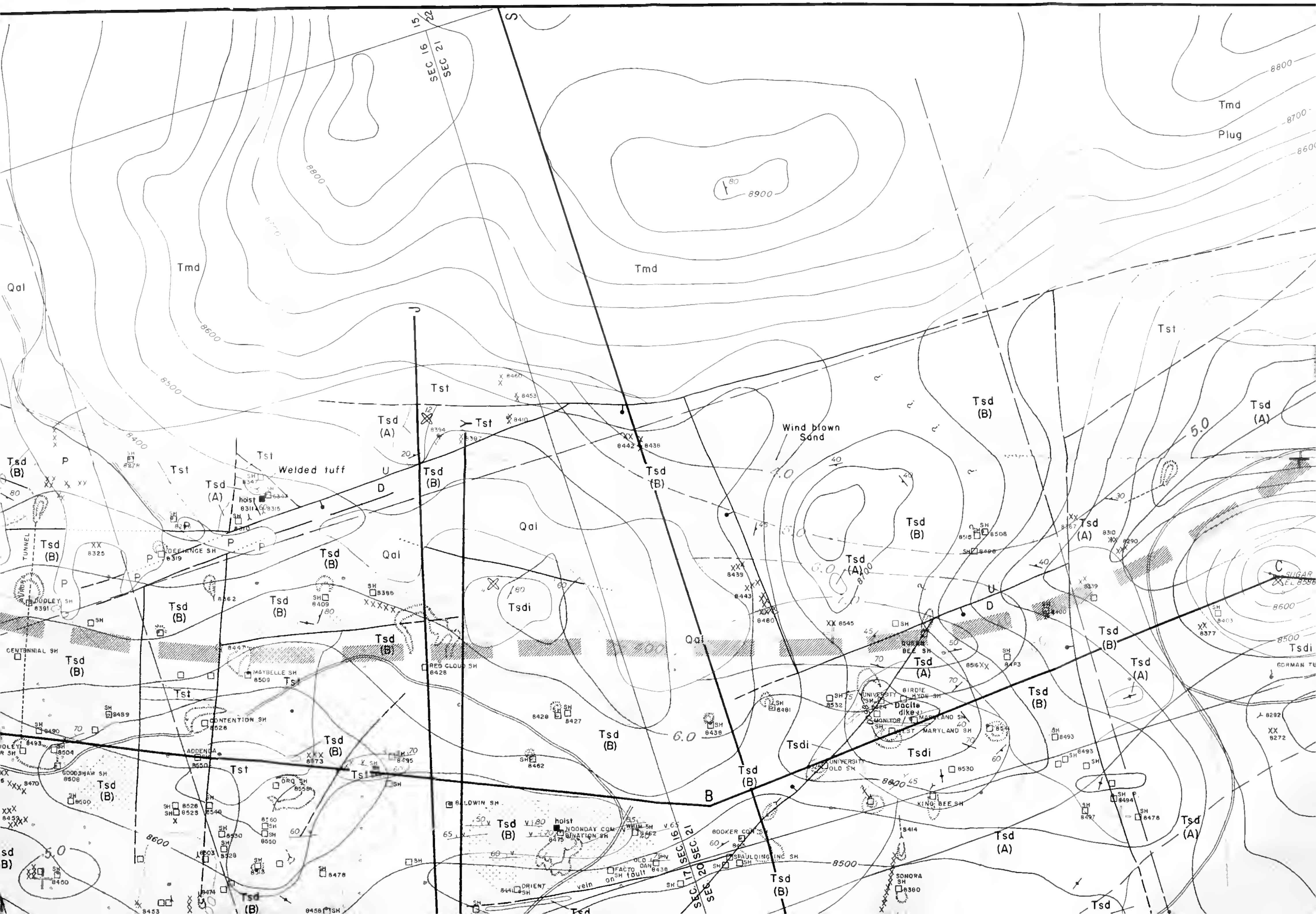
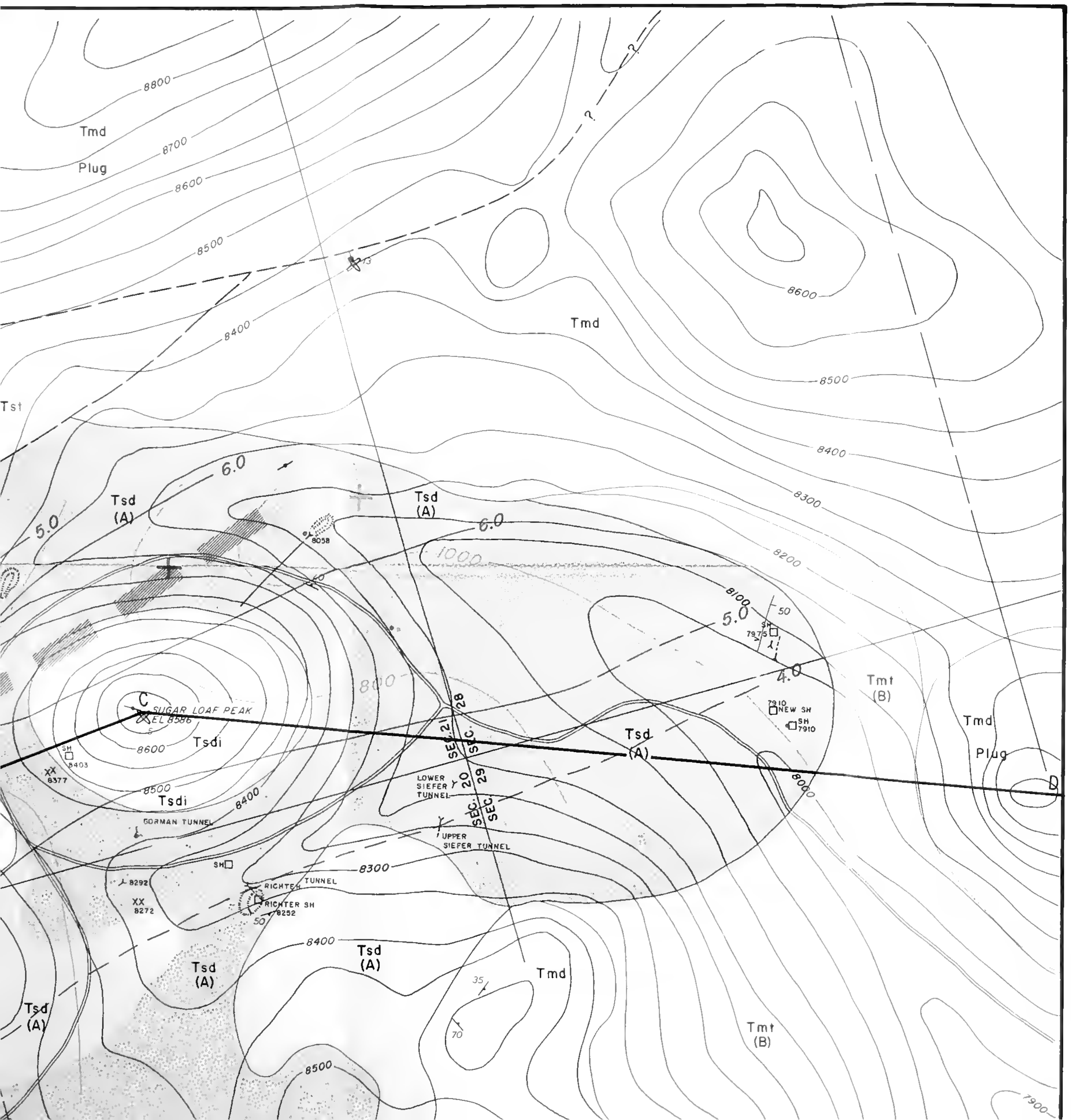




GEOLOGIC MAP

SHOWING MAGNETICS, GRAVITY, AND ROCK ALTERATIONS

BODIE MINING DISTRICT
Mono County, California

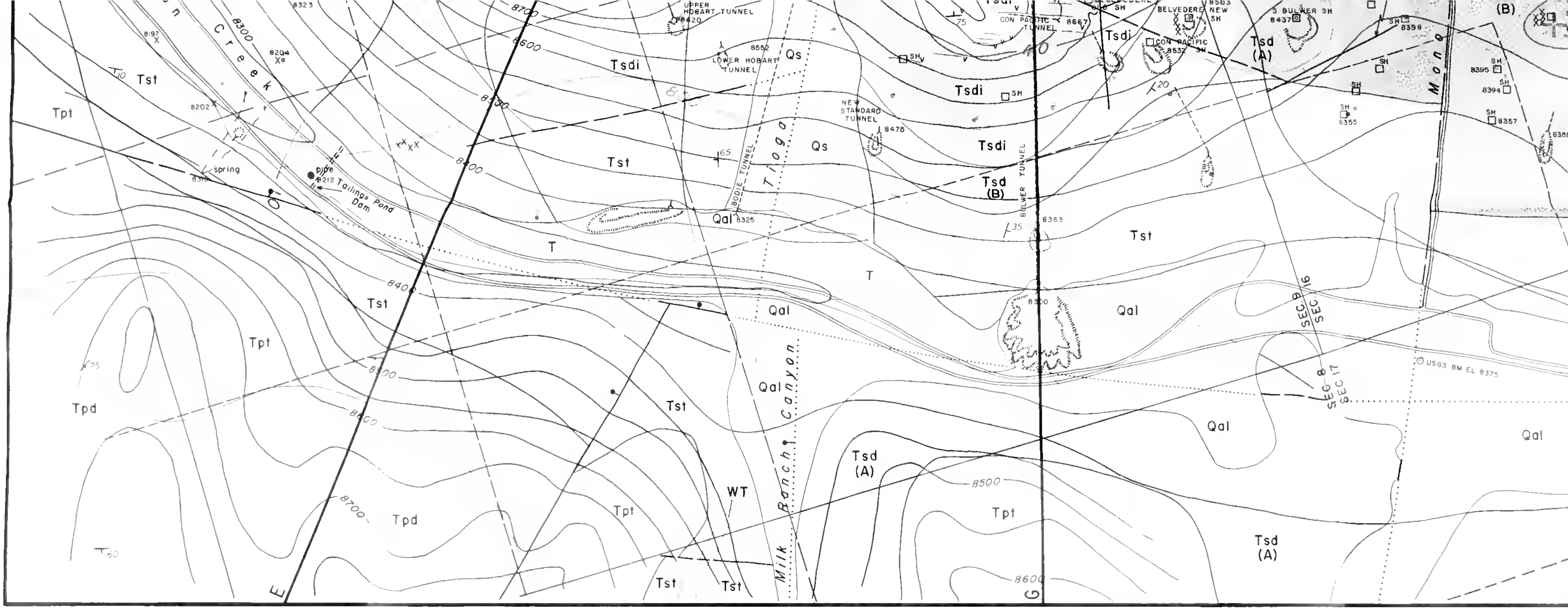
Geology by
Charles W. Chesterman & Cliffton H. Gray

Geophysics by
Rodger H. Chapman

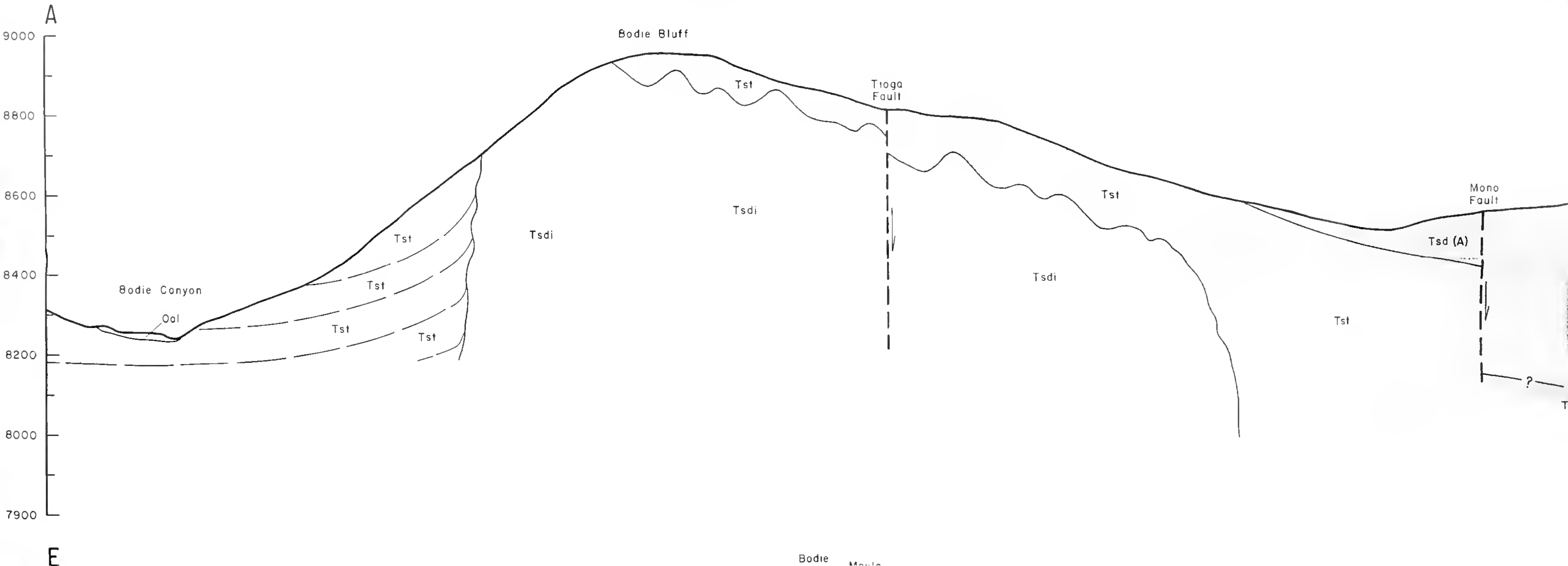
CONTOUR INTERVAL 50'

SCALE
0 500 1000ft.

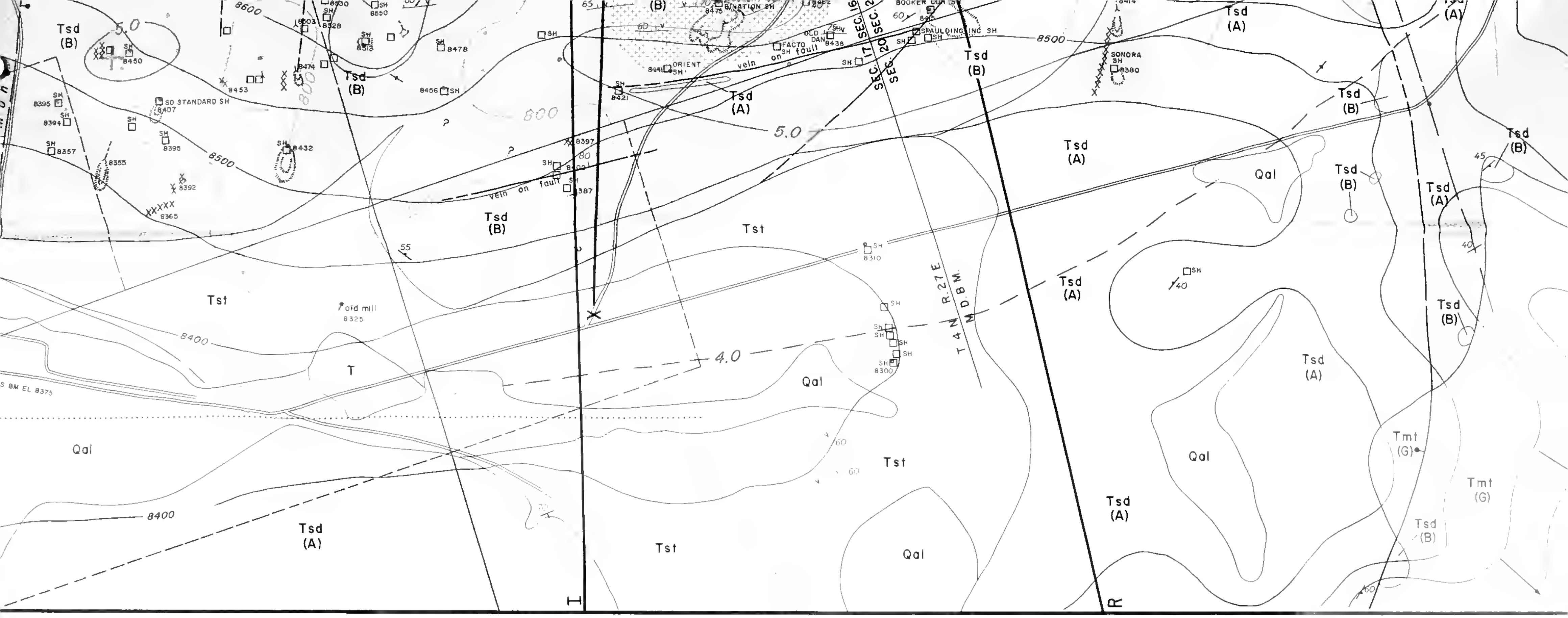
Note: Refer to Plate I for gravity and ground magnetic profile X-Y and aeromagnetic and gravity profile R-S.

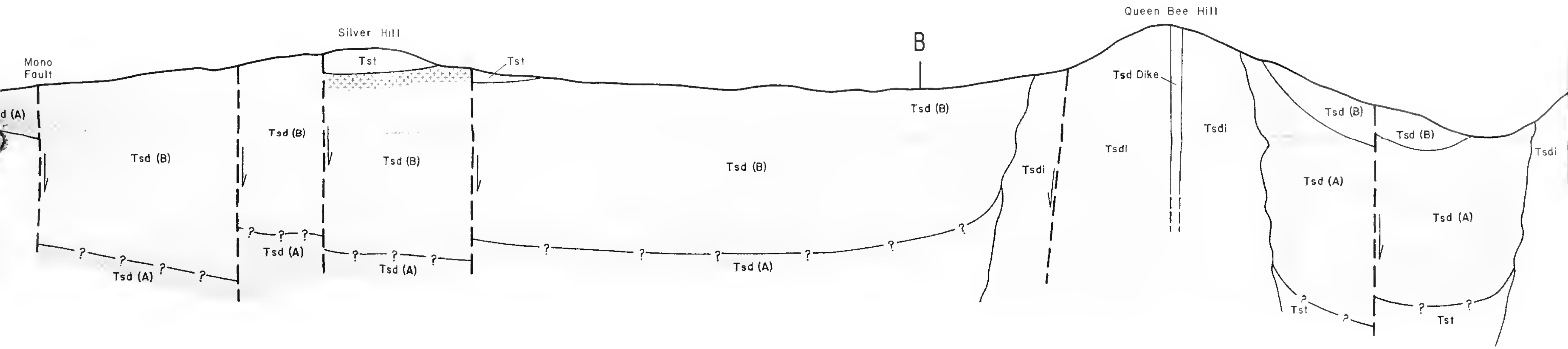


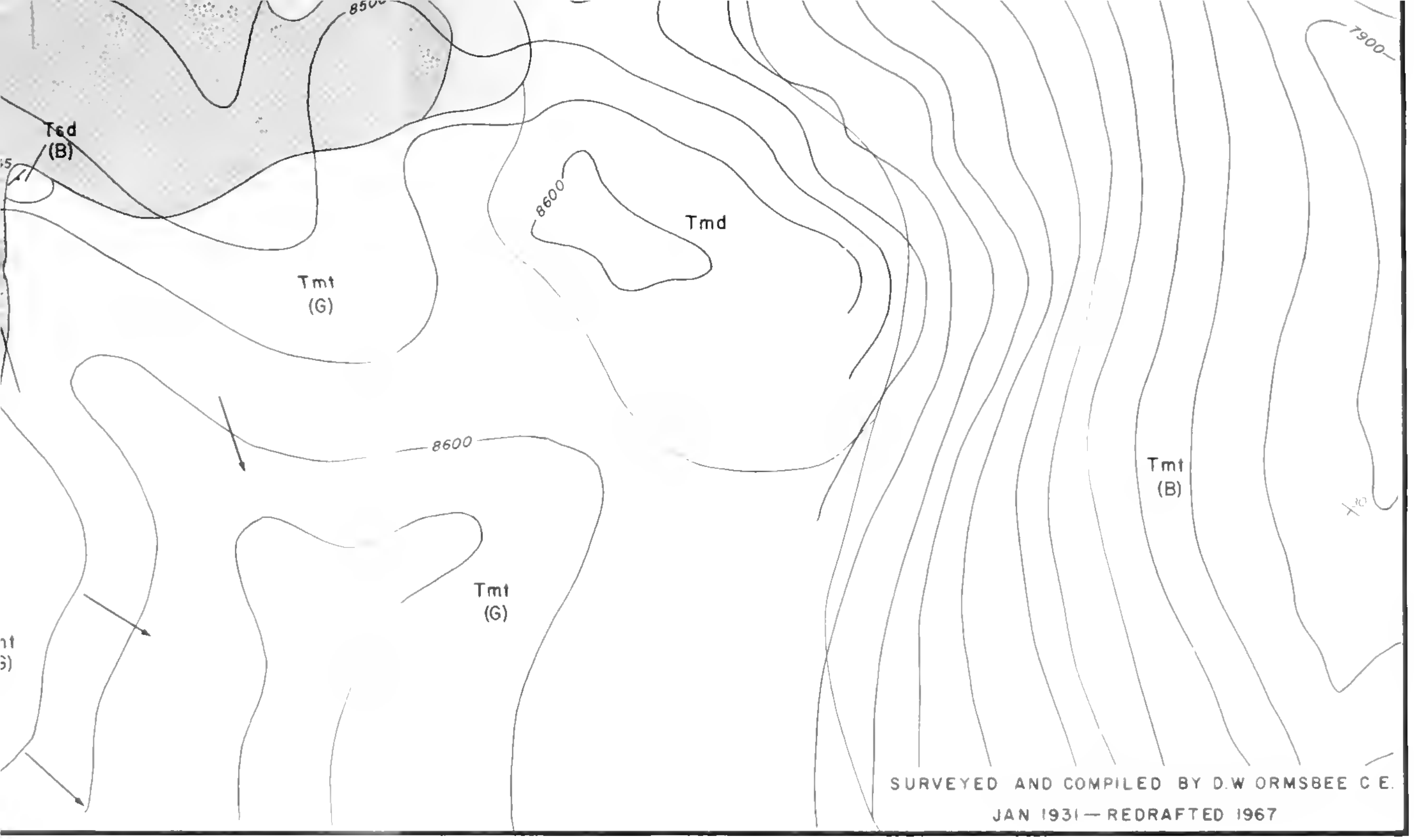
UPPER HOBART TUNNEL
LOWER HOBART TUNNEL
CON PACIFIC TUNNEL
CON PACIFIC SH
BELVEDERE NEW SH
S BULWER SH
NEW STANDARD TUNNEL
BODIE TUNNEL
BULWER TUNNEL
Creek
Tioga
Milk Ranch Canyon
Mono
Tailings Pond Dam
spring
Pipe
Tst
Tpt
Tpd
Tsdi
Tsd (A)
Tsd (B)
Qs
Qal
T
WT
SEC 9
SEC 16
SEC 8
SEC 17
USGS BM EL 8375
8300
8400
8500
8600
8700
E
G



A
9000
8800
8600
8400
8200
8000
7900
Bodie Bluff
Tioga Fault
Mono Fault
Bodie Canyon
Qal
Tst
Tsdi
Tsd (A)
?
E
Bodie


Tsd (B)
Tsd (A)
Tst
T
Qal
Tmt (G)
old mill 8325
SO STANDARD SH
ORIENT SH
SPAULDING INC SH
SONORA SH
OLD DAN
vein on fault
SEC. 16
SEC. 17
SEC. 20
T 4 N R. 27 E M. D. B. M.
8600
8500
8400
5.0
4.0
BM EL 8375
I
R


Mono Fault
Silver Hill
Queen Bee Hill
B
Tst
Tsd Dike
Tsd (B)
Tsd (A)
Tsdi



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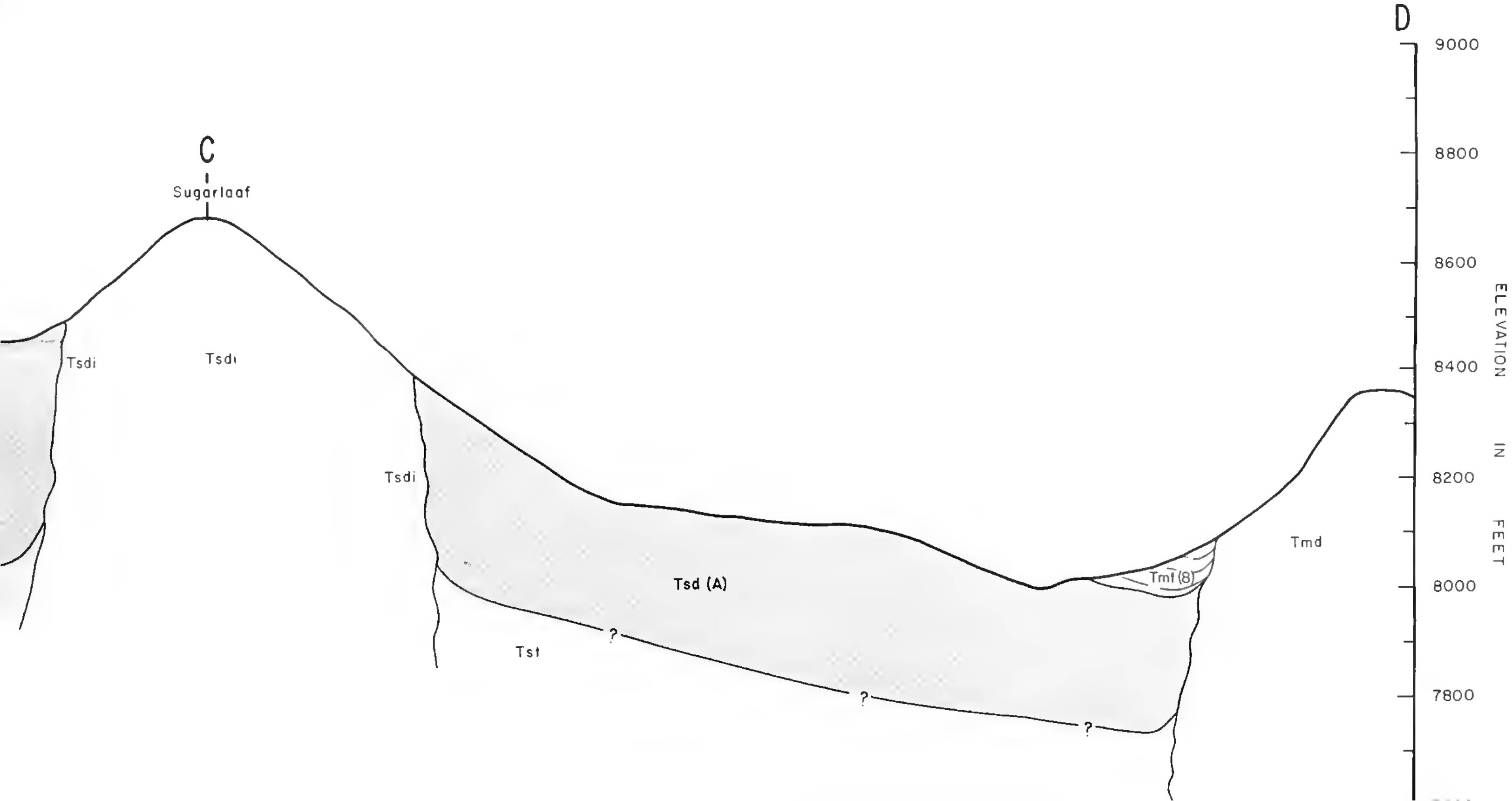
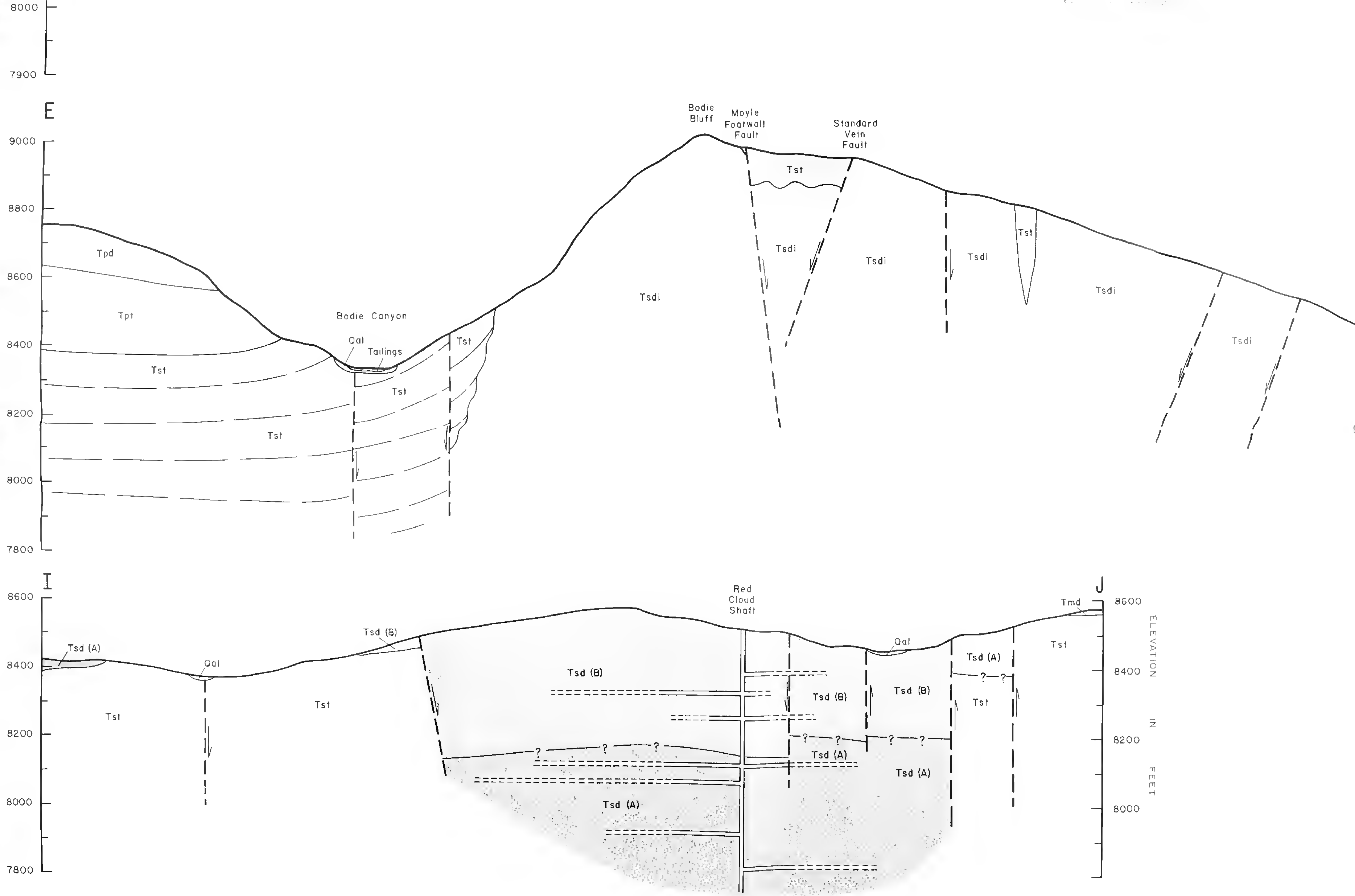
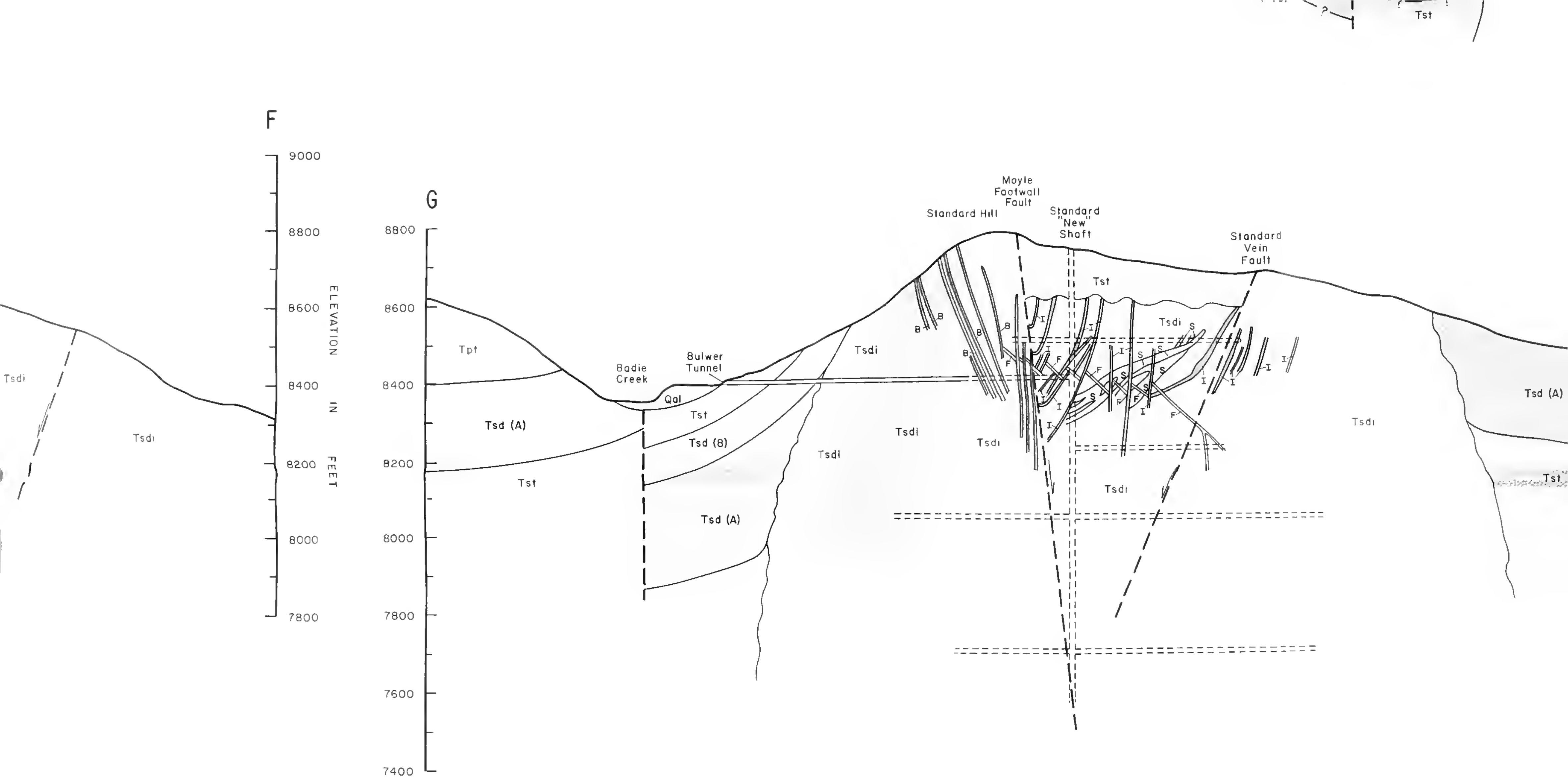
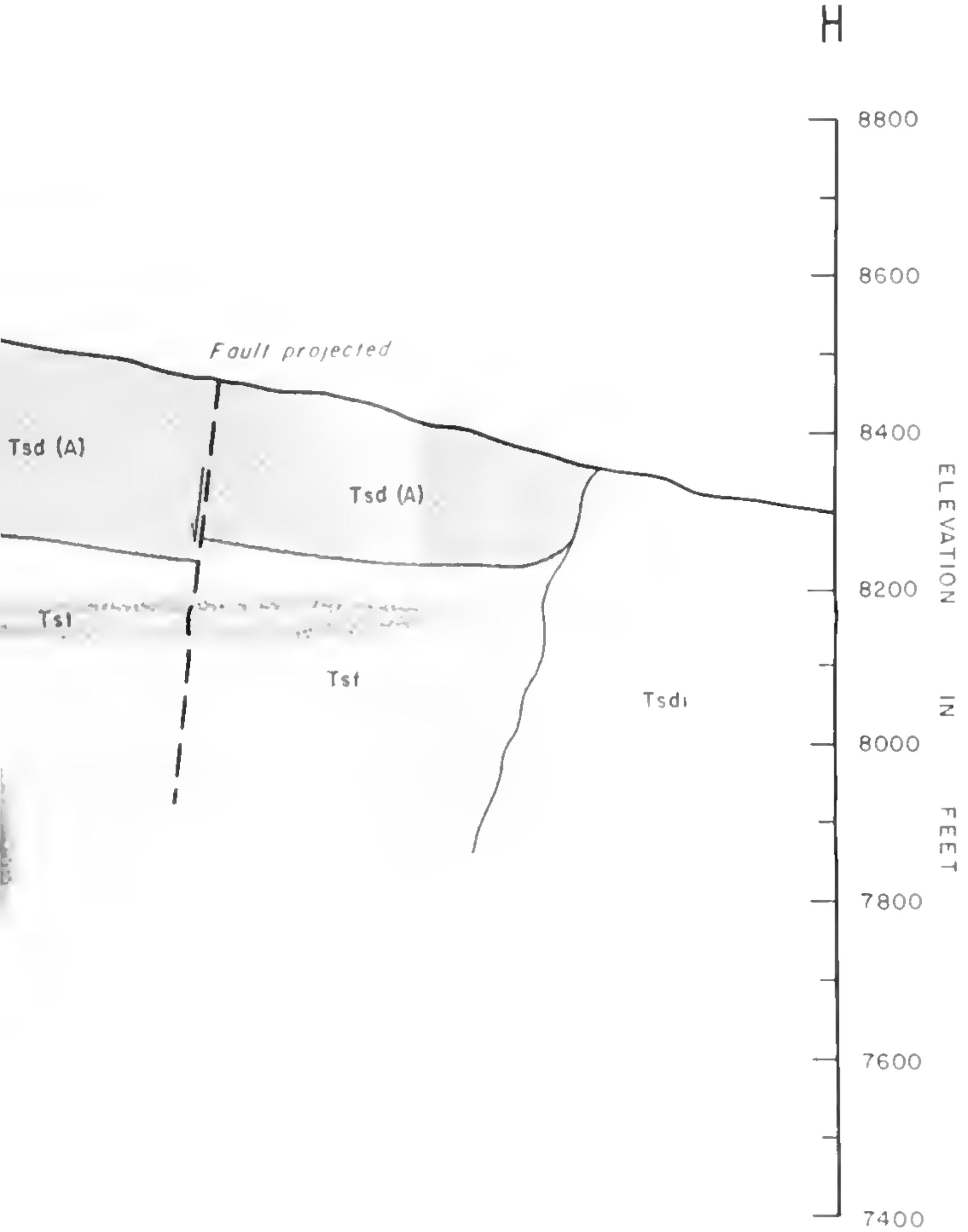




8000
7900
E
9000
8800
8600
8400
8200
8000
7800
Bodie Bluff
Moyle Footwall Fault
Standard Vein Fault
Tst
Tsdi
Tpd
Tpt
Bodie Canyon
Qal
Tailings
Tst
Tsdi
I
J
8600
8400
8200
8000
7800
Red Cloud Shaft
Tsd (A)
Qal
Tsd (B)
Tst
Tsd (B)
Tsd (A)
Tmd
Qal
Tsd (A)
Tsd (B)
Tst
?
8600
8400
8200
8000
ELEVATION IN FEET



F
G
ELEVATION IN FEET
9000
8800
8600
8400
8200
8000
7800
7600
7400
Tsdi
Tpt
Tsd (A)
Tst
Badie Creek
Bulwer Tunnel
Qal
Tsd (B)
Standard Hill
Moyle Footwall Fault
Standard "New" Shaft
Standard Vein Fault
Tsdi



LEGEND

GEOLOGIC EXPLANATION

Symbol	Explanation
T	Mill tailings
P	Placered area
Qal	Alluvium
Qs	Slope Wash
Potato Peak Formation	
Tpd	Dacite flows
Tpt	Tuff breccia
Murphy Spring Tuff Breccia	
Tmd	Dacite flows and plugs
Tmt (G) / Tmt (B)	Tuff breccia; (G) gray, (B) brown
Silver Hill Volcanic Series	
Tsdi	Dacite plugs
Tsd (B) / Tsd (A)	Dacite composite flow; (A) hornblende-rich, (B) biotite-rich
Tst	Tuff breccia, includes vitric zones (WT)
	Silicic alteration
	Potassic alteration
	Argillic alteration
	Propylitic alteration
I	Incline vein series, various veins
S	Incline vein series, main Standard
B	Burgess vein series
F	Fortuna vein

GEOLOGIC SYMBOLS

Contact; dashed where probable, queried where uncertain.

Fault, dashed where uncertain, dotted where concealed. Bar and bell on downthrown block

Vein; showing strike and dip, dashed where uncertain.

Strike and dip of bedding

Strike and dip of flow banding

Strike of vertical flow banding.

Strike and dip of joints

General direction of dip.

Specimen locality of rock sampled for K-Ar age dating

GRAVITY EXPLANATION

Gravity Station

Contour interval: 1.0 milligals

Reduction density: 2.50 g/cm³

Axis of positive anomaly trend

MAGNETIC EXPLANATION

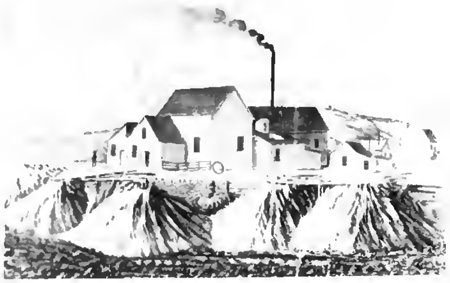
Magnetometer station

800

Contour interval: 200 gammas

Arbitrary datum

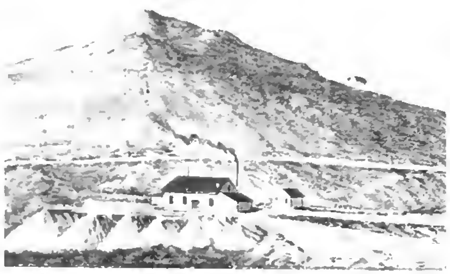
DRAFTING AND LAYOUT BY C.A. ALLEN



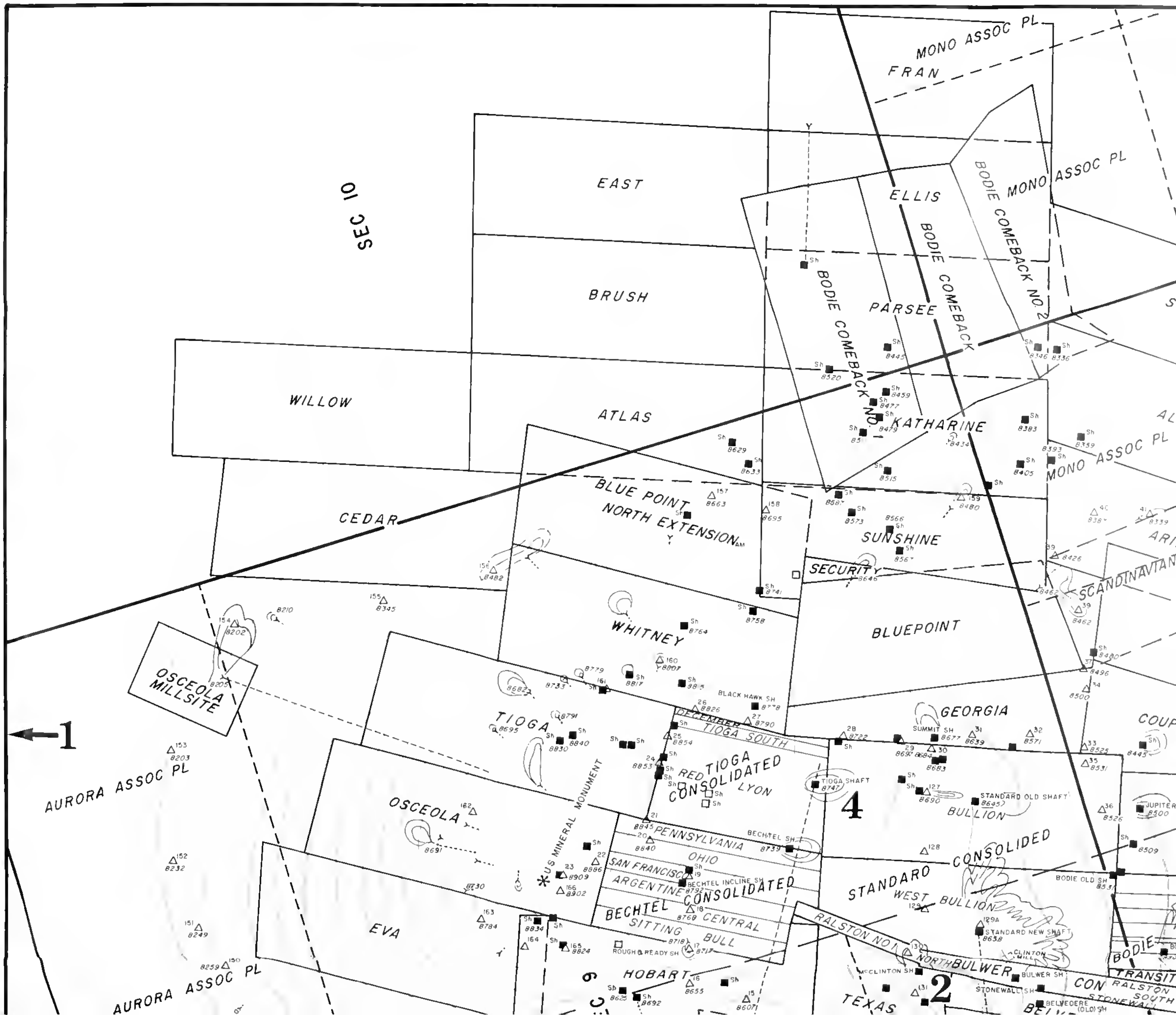
4. Tioga Mine

5. Con Pacific Mine

6. Bel



3. The Bodie Tunnel



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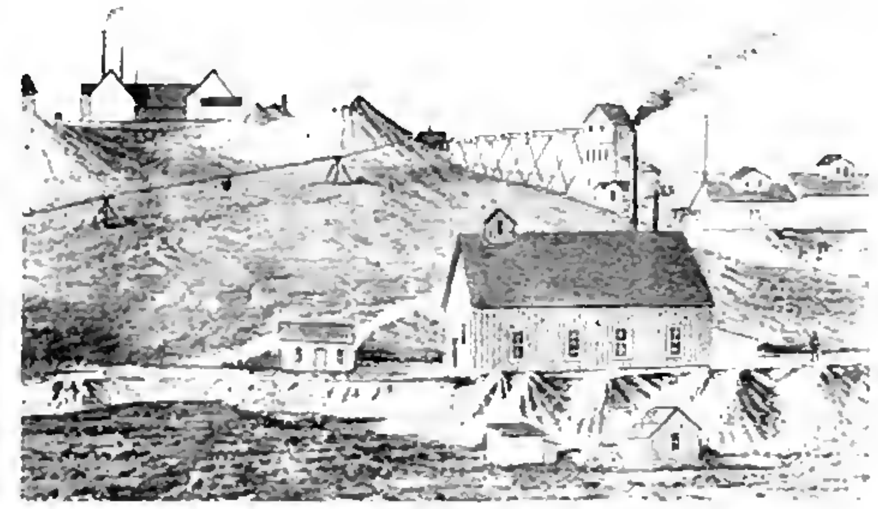
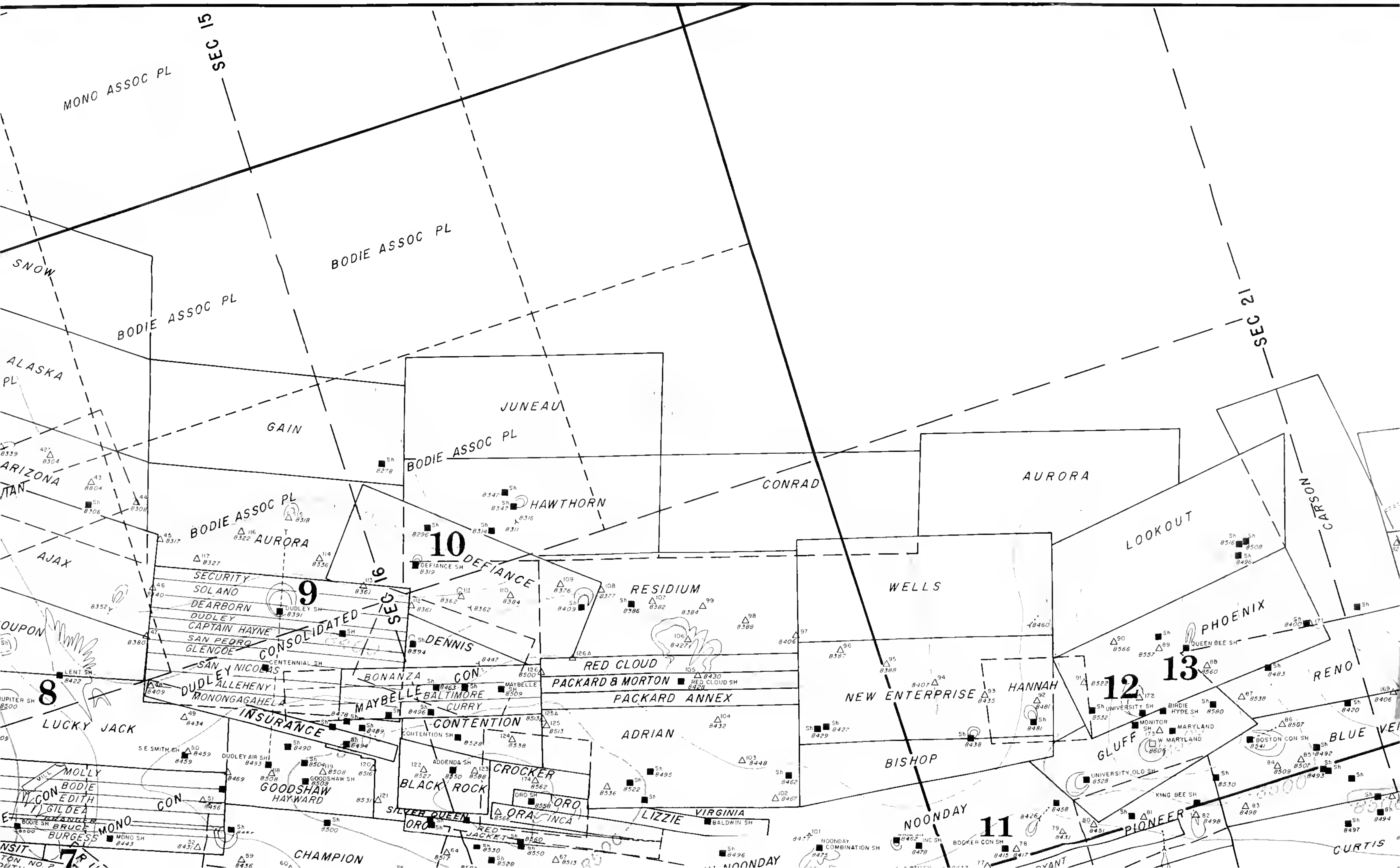
Belvedere Mine



7. South Bulwer Hoisting Works

8. Jupiter Hoisting Works



ng Works

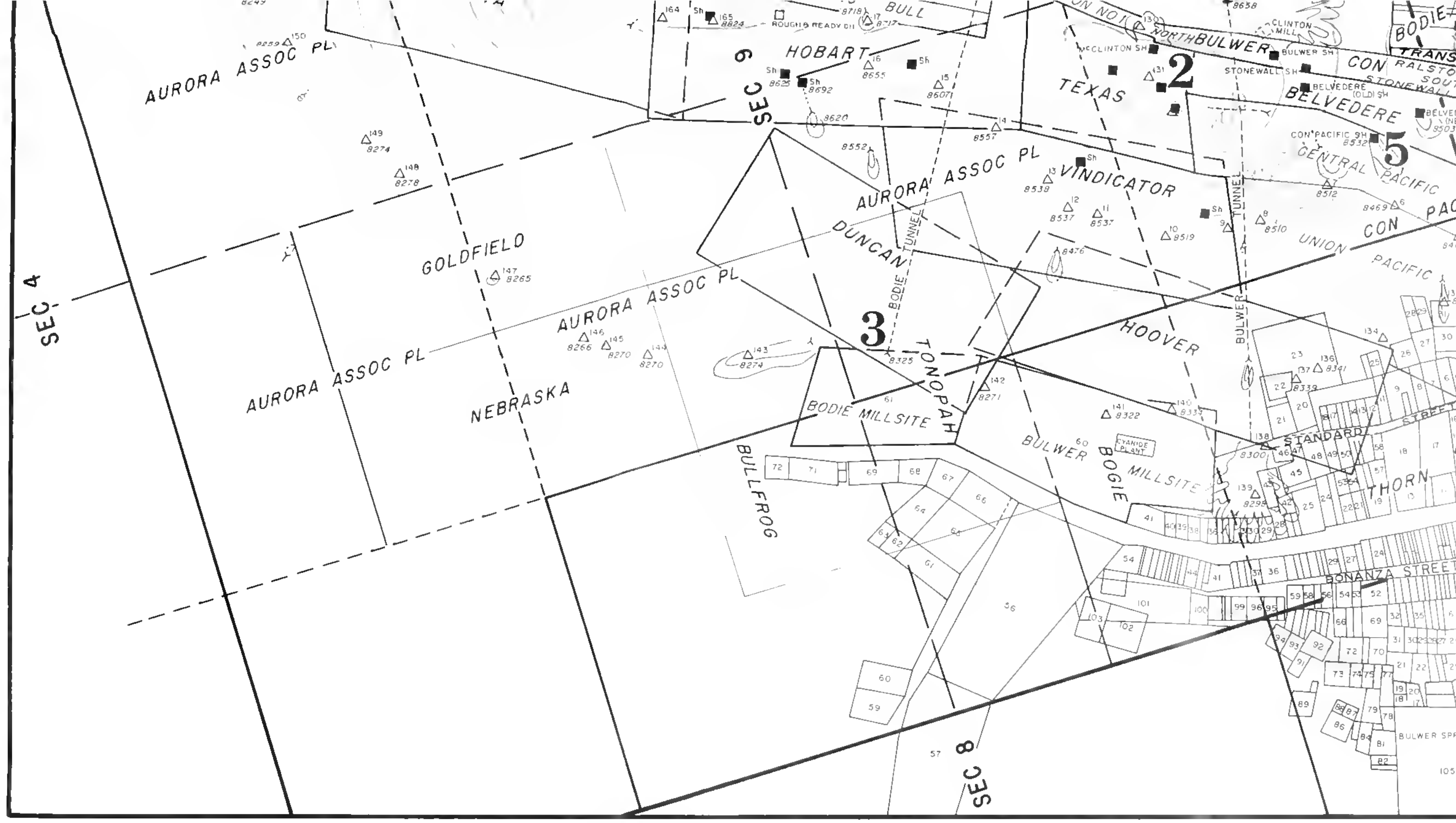
9. Dudley Hoisting Works

10. Defiance Hoisting Works

11. Booker Mine

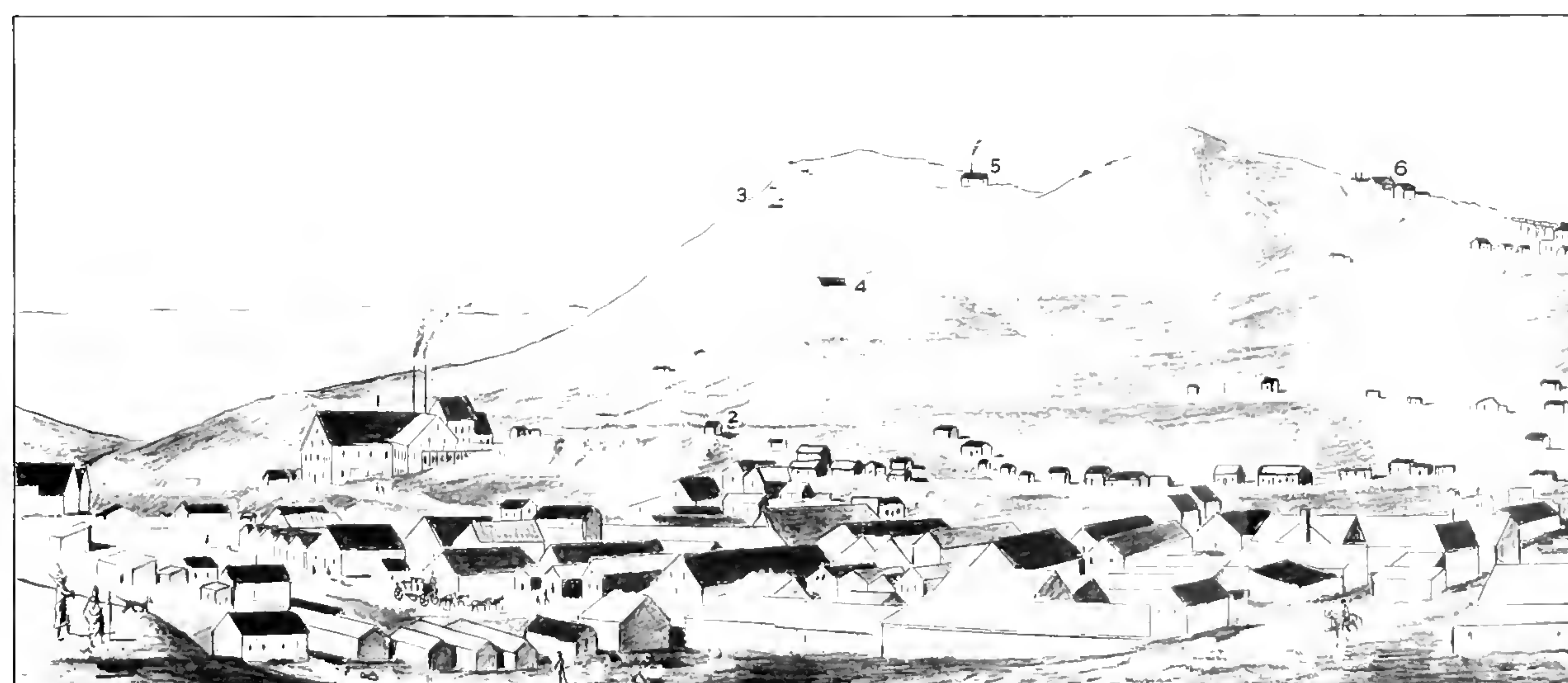
2. McClinton Mine

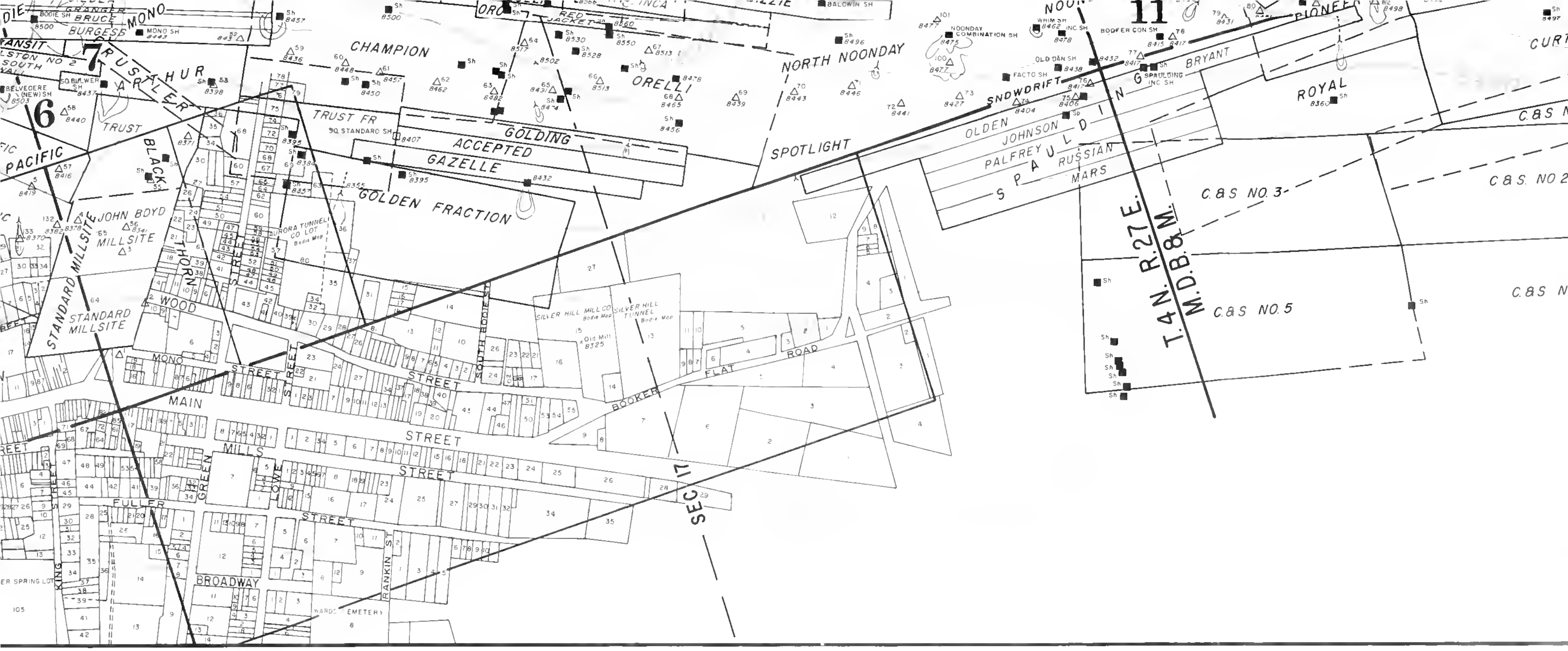
1. Syndicate Mine

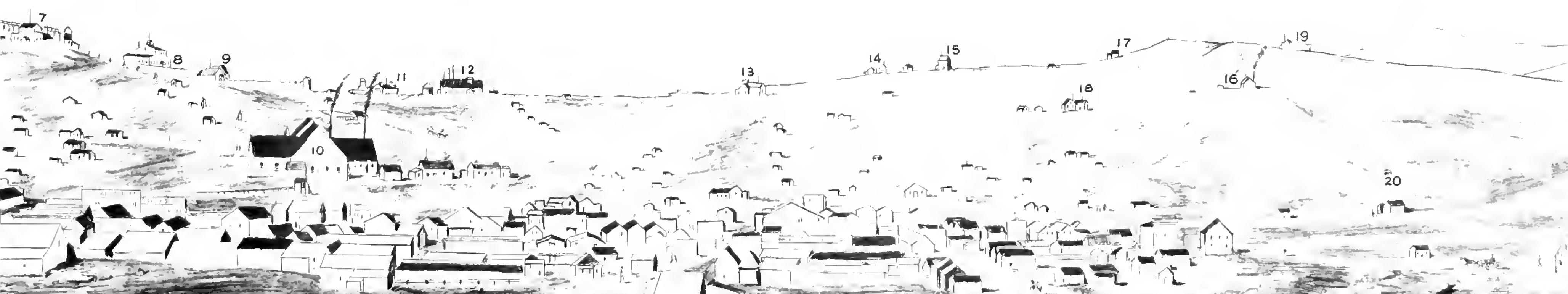


REFERENCES

1 STANDARD-BULWER MILL
2 MOUTH OF BULWER TUNNEL
3 ORIGINAL SUMMIT MINE.
4 BODIE BLUFF MINE
5 BECHTEL MINE
6 STANDARD MINE
7 CON PACIFIC MINE
8 BELVIDERE MINE
9 BODIE MINE.
10 STANDARD MILL.
11 SOUTH BULWER MINE.
12 MONO MINE
13 CHAMPION MINE
14 GOODSHAW MINE.



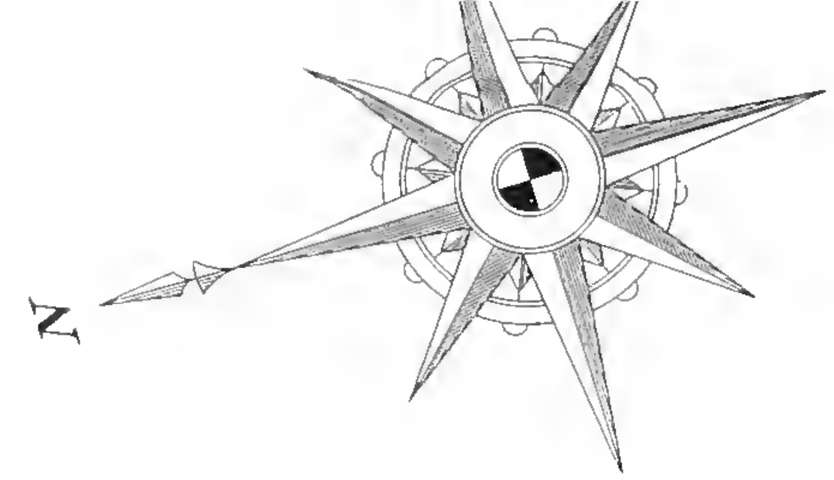




GENERAL VIEW OF BODIE MINING DISTRICT

SHOWING THE WESTERN SLOPE OF THE MAIN RANGE FROM NORTH TO SOUTH

1880



CLAIM MAP

BODIE MINING DISTRICT
Mono County, California

Surveyed and compiled
by
D.W. ORMSBEE - G.E.

January, 1931

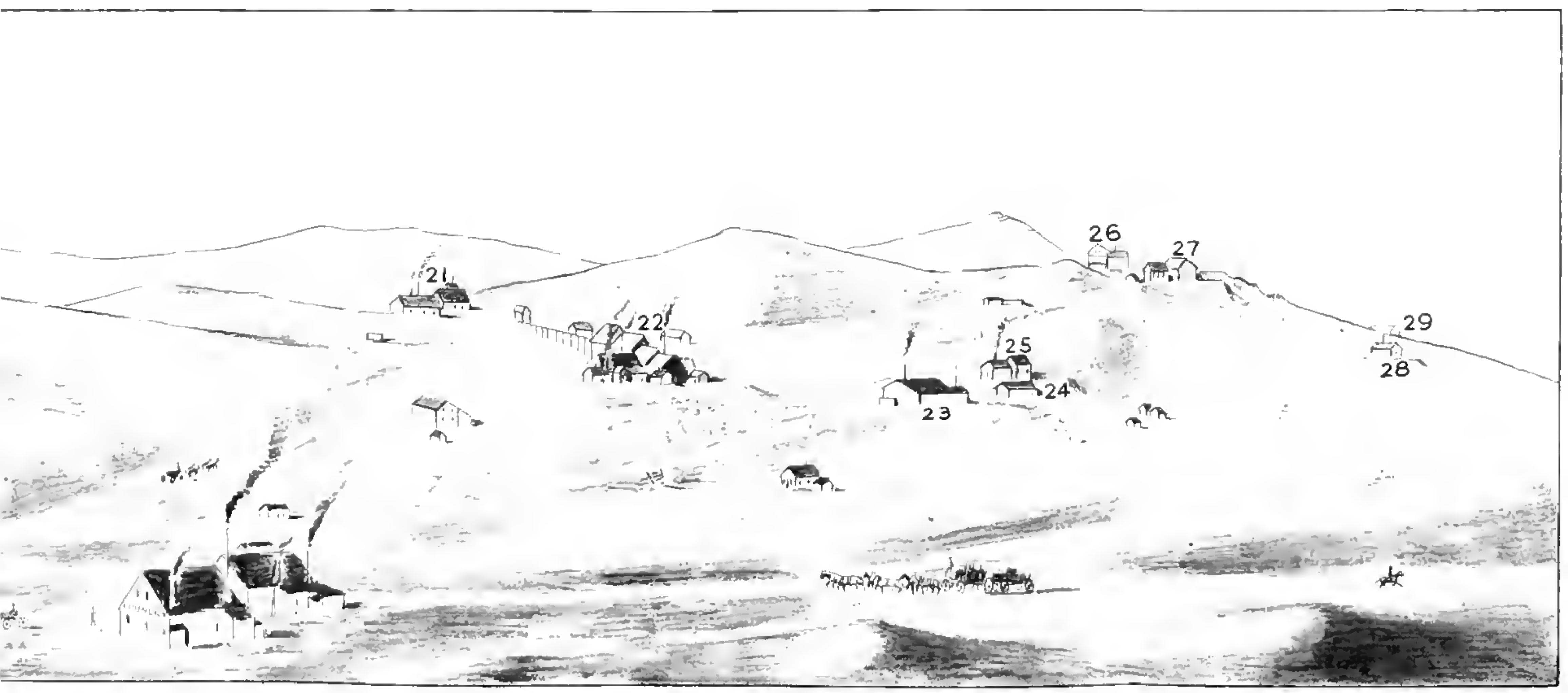
Contour Interval: 50 ft.

SCALE

0 500 1000 ft.

12. University and Maryland Mines

13. Queen Bee Mine



FROM ORIGINAL ILLUSTRATION BY EDWARD EYSEN

REFERENCES.

15 GIPSY QUEEN MINE
16 SOUTH BODIE MINE
17 ADDENDA MINE
18 SOUTH STANDARD MINE
19 ORO MINE
20 SILVER HILL TUNNEL
21 NOONDAY MINE
22 NOONDAY MILL
23 SPAULDING MILL
24 SPAULDING MINE
25 BOOKER MINE
26 UNIVERSITY MINE
27 MARYLAND MINE
28 BOSTON CON. MINE
29 KING BEE MINE

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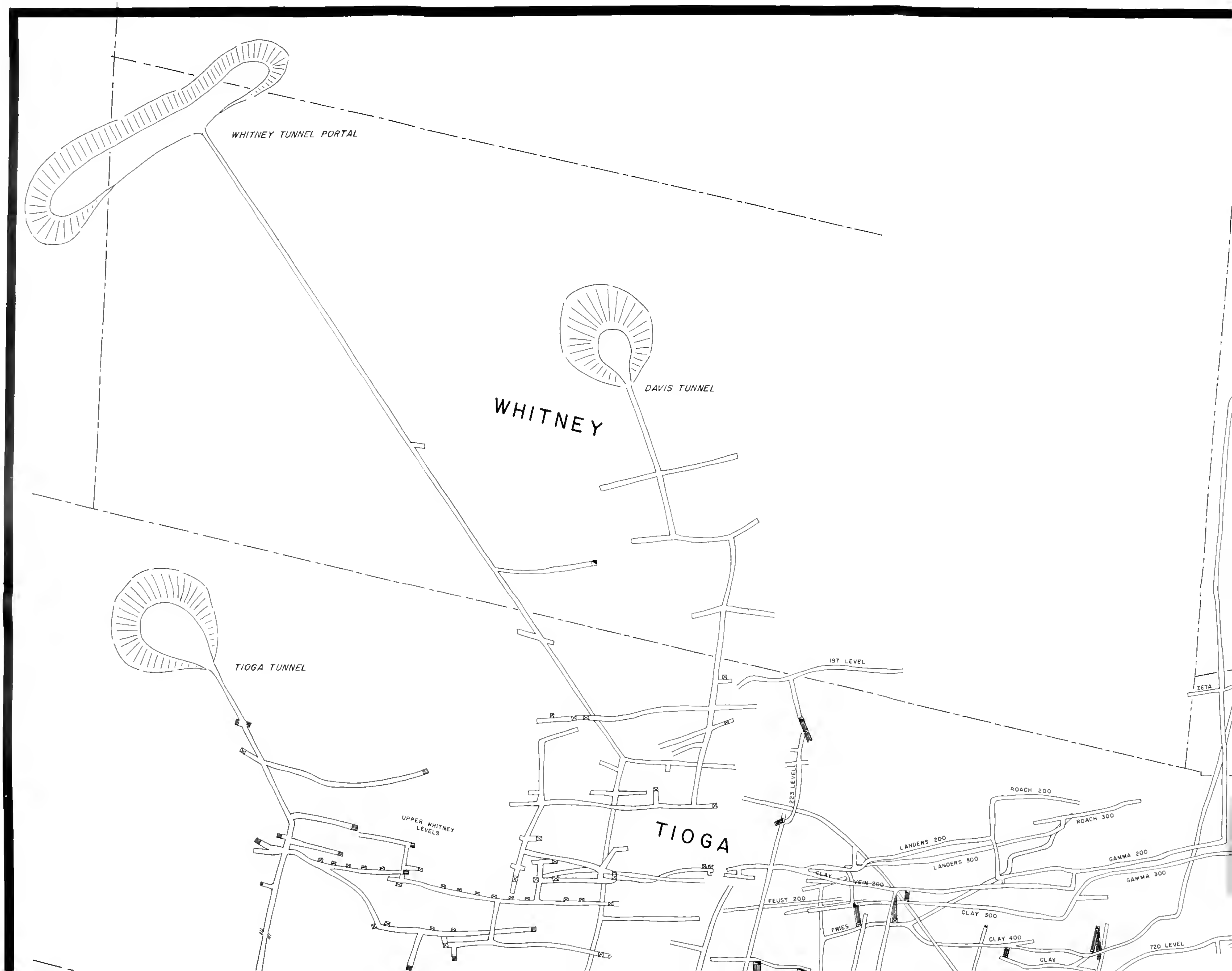
Drafting and layout by C.A. Allen

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, STATE GEOLOGIST



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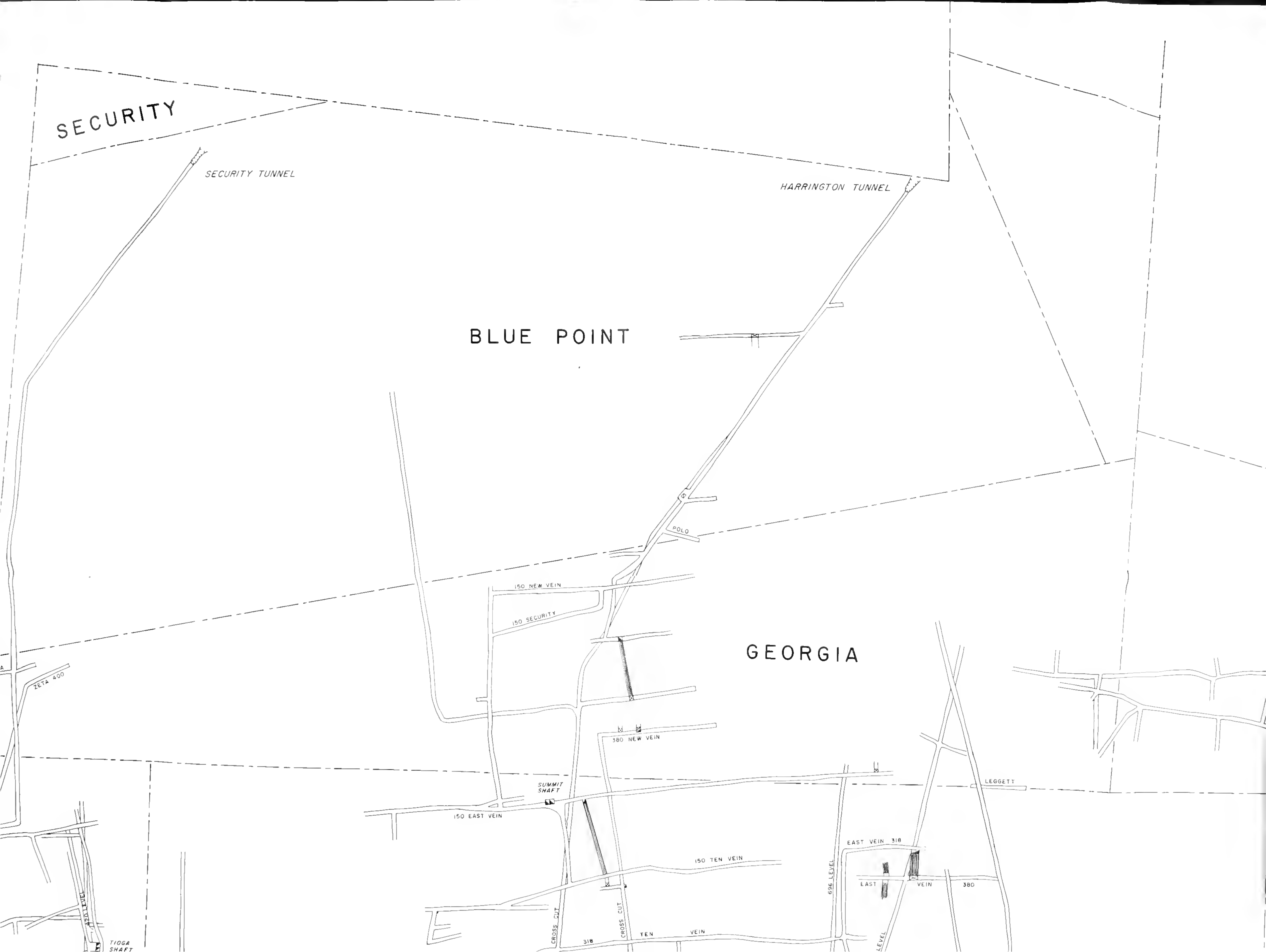
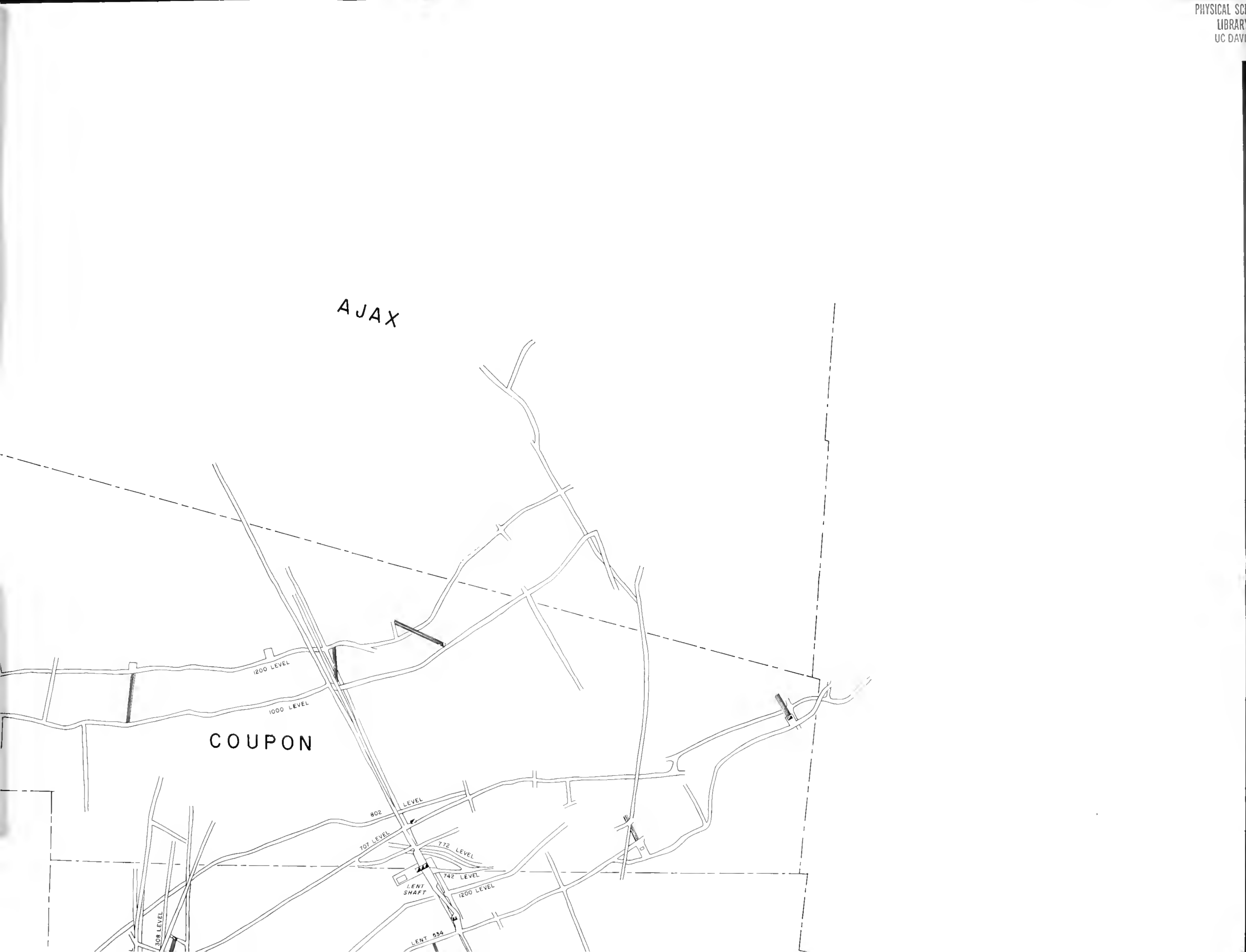
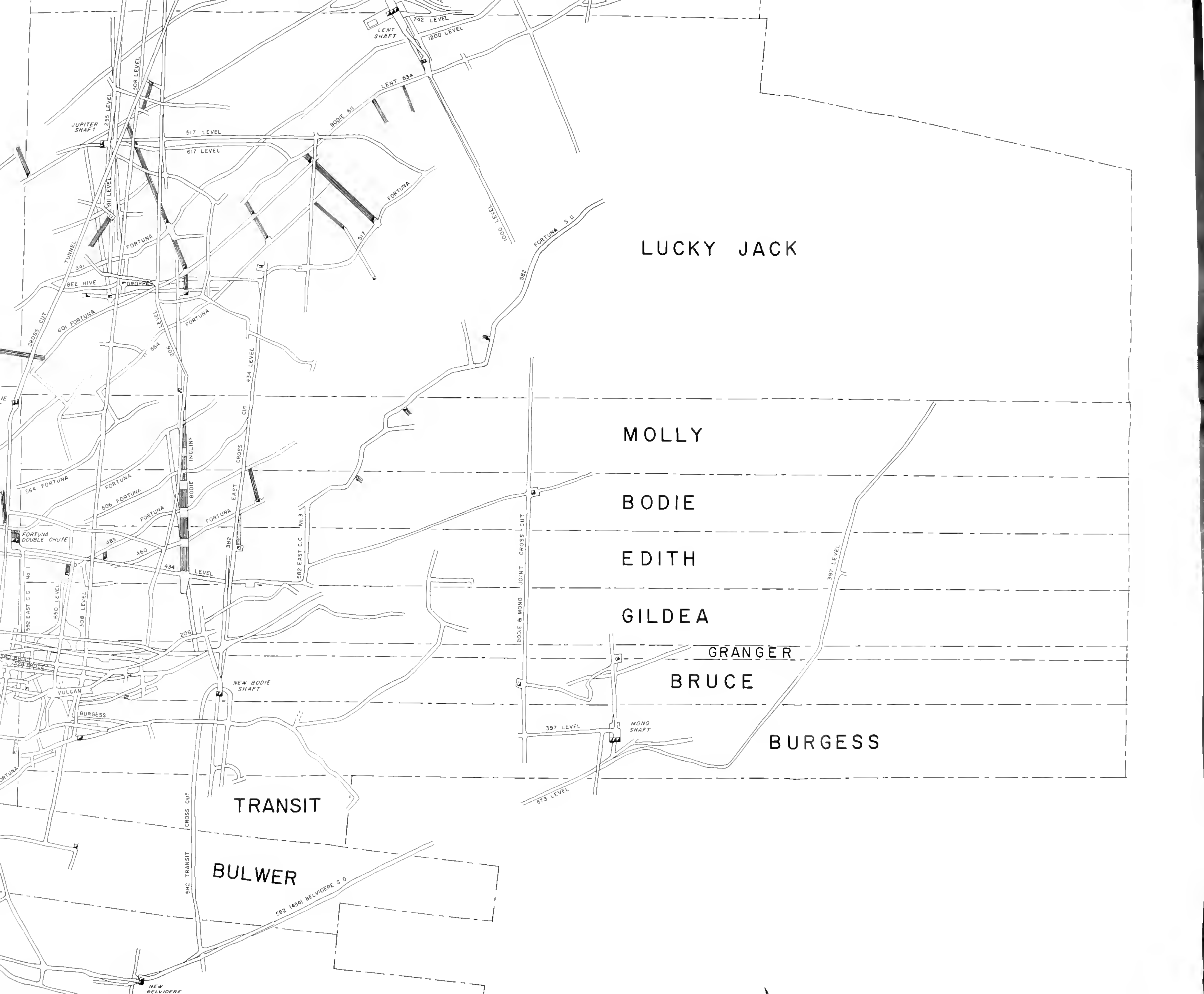
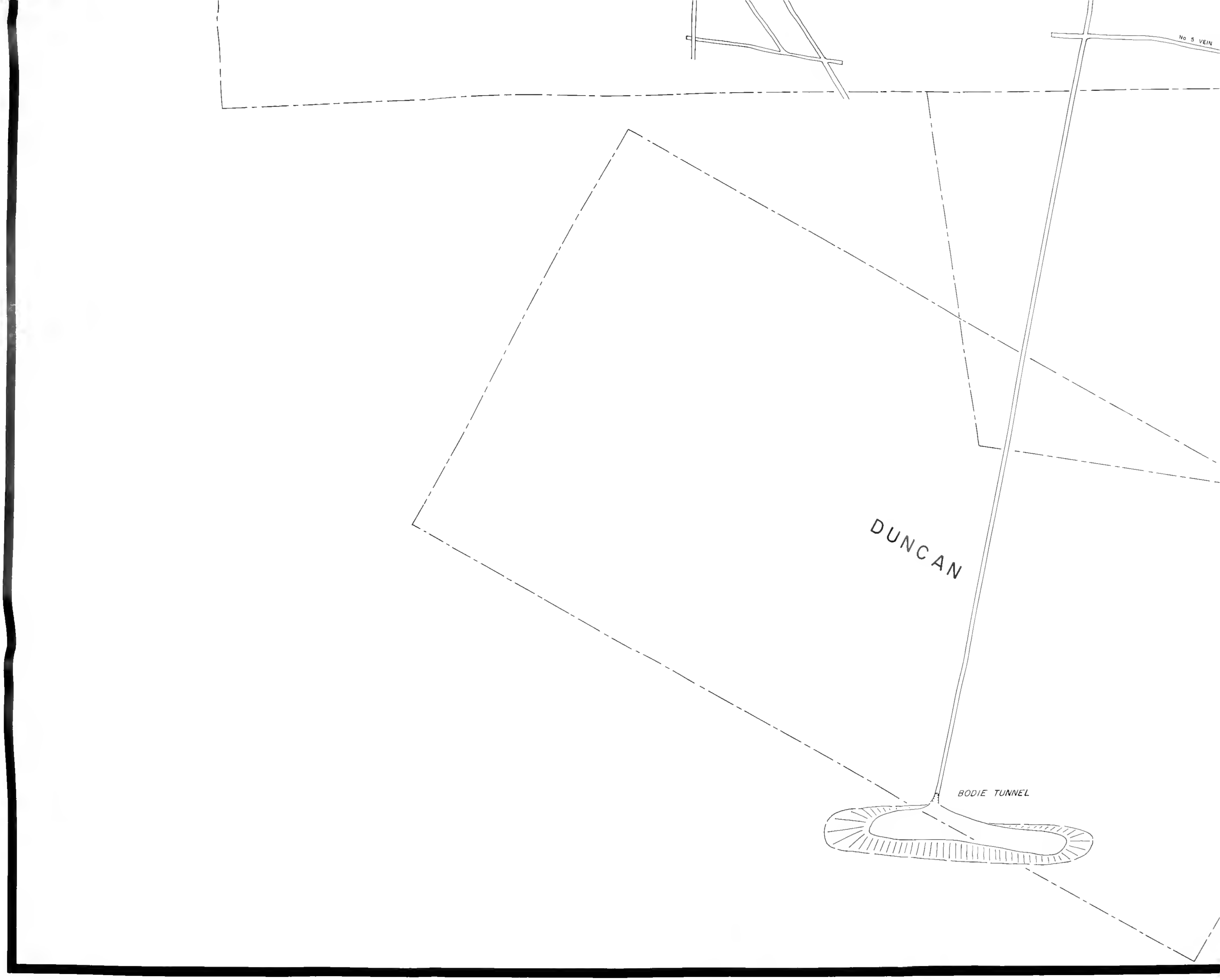


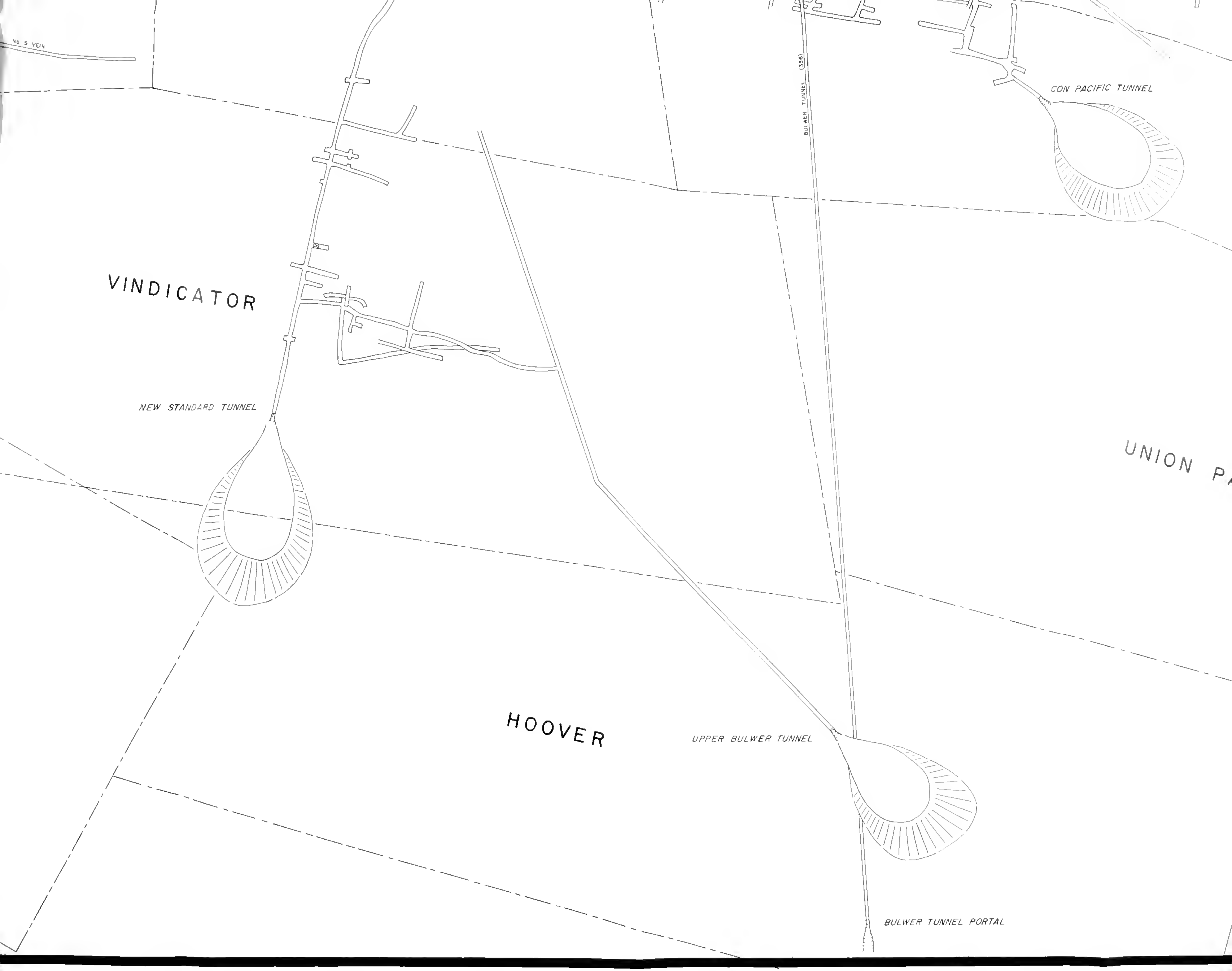

AJAX
COUPON
1200 LEVEL
1000 LEVEL
802 LEVEL
707 LEVEL
772 LEVEL
742 LEVEL
LENT SHAFT
1200 LEVEL
308 LEVEL
LENT 534

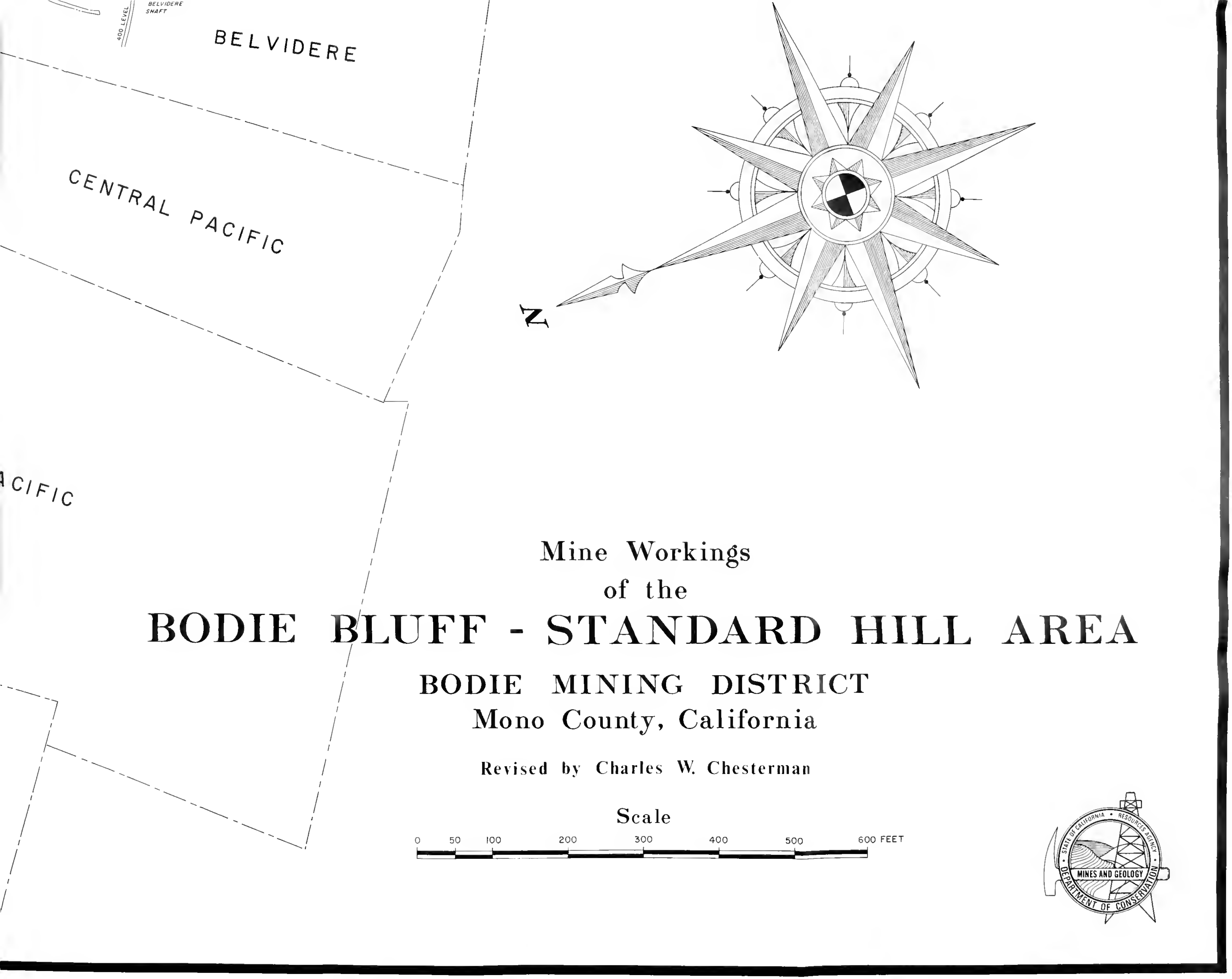
720 LEVEL
CLAY
BUSTER 200
TIOGA 370
BUSTER
TIOGA 400
TIOGA WINZE
320 LEVEL
TIOGA 400
BOWDEN
BUSTER 370
SAN ANTONE EAST CROSS CUT
BECHTEL EAST CROSS CUT
DELTA
BETA 400
ALPHA 400
ALPHA 300
BETA 200
ALPHA 200
OSCEOLA
GALE 255
BECHTEL 300
NEW BECHTEL SHAFT
B 400 LEVEL
BECHTEL 200
GALE 200
EAST LEDGE 400
SAN ANTONE
400 LEVEL
EAST LEDGE 300
EAST LEDGE 200
150 LEVEL
SAN ANTONE
OLD BECHTEL SHAFT
BECHTEL
KAPPA 400
WEST LEDGE 300
WEST LEDGE 200
ROUGH & READY 200
HOBART TUNNEL
BELL 200
HOBART
HOBART 300
HOBART 200
HOBART TUNNEL No 2
BODIE TUNNEL
No 5 VEIN


BULLION
WEST BULLION
BULWER
TEXAS
TIOGA SHAFT
OLD INCLINE SHAFT
TEN VEIN
318 WEST GRAHAM
GRAHAM
MAIN EAST
CROSS CUT
318 SUMMIT
380 SUMMIT
BULLION
380 BULLION
INCLINE
BLACK LEDGE EAST CROSS CUT
520 LEVEL
620 LEVEL
323 LEVEL
200 LEVEL
318 MAIN STANDARD
380 MAIN STANDARD
650 LEVEL
420 MAIN STANDARD
M S WINZE
528 MAIN STANDARD
318 BLACK LEDGE
ANTONE
EAST BRANCH M S
MAIN STANDARD
STICKNEY
380 STICKNEY
318 MAIN EAST
RED LEDGE
OLD BODIE SHAFT
601 FORTUNA
564 FORTUNA
FORTUNA DOUBLE
436 STANDARD
GRANT
380 4th SOUTH
MULE CANYON
BLACK LEDGE
WEST STANDARD
MAIN STANDARD
No 7 VEIN
No 5 VEIN
No 4 VEIN
No 3 VEIN
3rd SOUTH
380 BRUCE
380 GILDEA
OLD BODIE
582 EAST C C
STANDARD SHAFT
DOLAN 200
W DOLAN
318 S VEIN
380 BURGESS
GHOST ALLEY
696 LEVEL
RALSTON
A VEIN
100 LEVEL
FOOT-WALL DRIFT
RALSTON 200
No 1 VEIN
A VEIN
BULWER C C
528 FORTUNA
582 FORTUNA
McCLINTON SHAFT
BULWER SHAFT
RALSTON No 1
C VEIN
RALSTON 336
STONEWALL SHAFT
D VEIN
WASHINGTON
E VEIN STONEWALL
OLD BELVIDERE SHAFT
BELVIDERE 200 LEVEL
997 LEVEL
(336)


LUCKY JACK
MOLLY
BODIE
EDITH
GILDEA
GRANGER
BRUCE
BURGESS
TRANSIT
BULWER
LENT SHAFT
742 LEVEL
1200 LEVEL
LENT 534
BODIE 611
JUPITER SHAFT
255 LEVEL
308 LEVEL
517 LEVEL
617 LEVEL
411 LEVEL
FORTUNA
517
1000 LEVEL
FORTUNA S.D.
582
TUNNEL
541
BEE HIVE
DROPPER
CROSS CUT
601 FORTUNA
206 LEVEL
564
434 LEVEL
CUT
CROSS
EAST
INCLINE
BODIE
564 FORTUNA
506 FORTUNA
FORTUNA DOUBLE CHUTE
483
460
434
LEVEL
382
582 EAST C.C. No. 3
JOINT CROSS CUT
BODIE & MONO
397 LEVEL
582 EAST C.C. No.
650 LEVEL
308 LEVEL
206
VULCAN
BURGESS
NEW BODIE SHAFT
MONO SHAFT
573 LEVEL
582 TRANSIT CROSS CUT
582 (434) BELVIDERE S.D.
NEW BELVIDERE


No 5 VEIN
DUNCAN
BODIE TUNNEL


No 5 VEIN
CON PACIFIC TUNNEL
BULWER TUNNEL (336)
VINDICATOR
NEW STANDARD TUNNEL
UNION PA
HOOVER
UPPER BULWER TUNNEL
BULWER TUNNEL PORTAL



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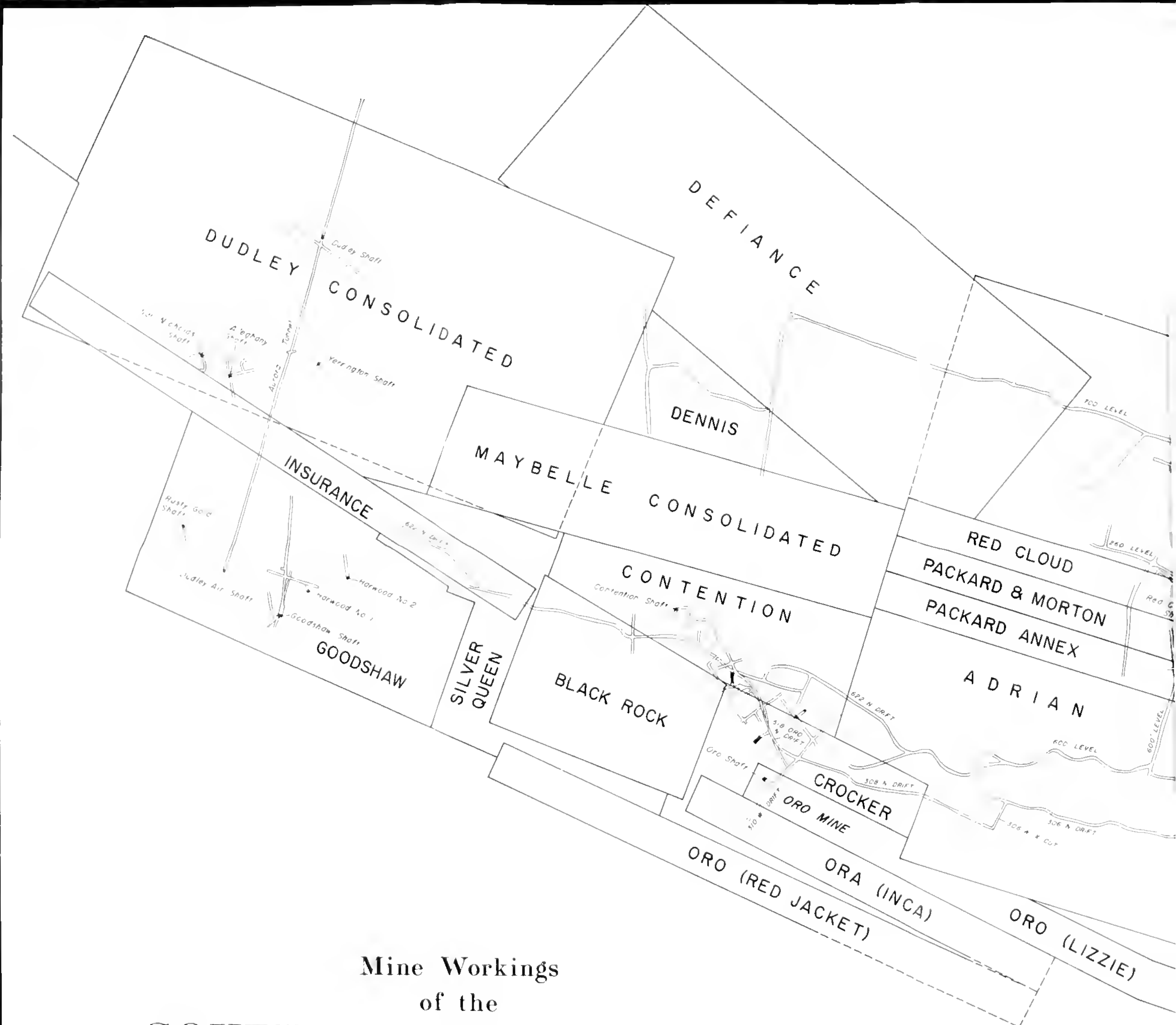
DIVISION OF MINES AND GEOLOGY
JAMES F DAVIS, STATE GEOLOGIST

STATE OF CALIFORNIA – GEORG
THE RESOURCES AGENCY – GORDON K VAN
DEPARTMENT OF CONSERVATION –



Mine Workings of the SOUTHERN MINES AREA

BODIE MINING DISTRICT
Mono County, California

Compiled by Charles W. Chesterman

Scale

0 50 100 200 300 400 500 600 700 800 900 1000 FEET

MINES AND GEOLOGY
STATE OF CALIFORNIA • RESOURCES AGENCY
DEPARTMENT OF CONSERVATION

- GEORGE DEUKMEJIAN, GOVERNOR
N K VAN VLECK, SECRETARY FOR RESOURCES
VATION - RANDALL M WARD, DIRECTOR

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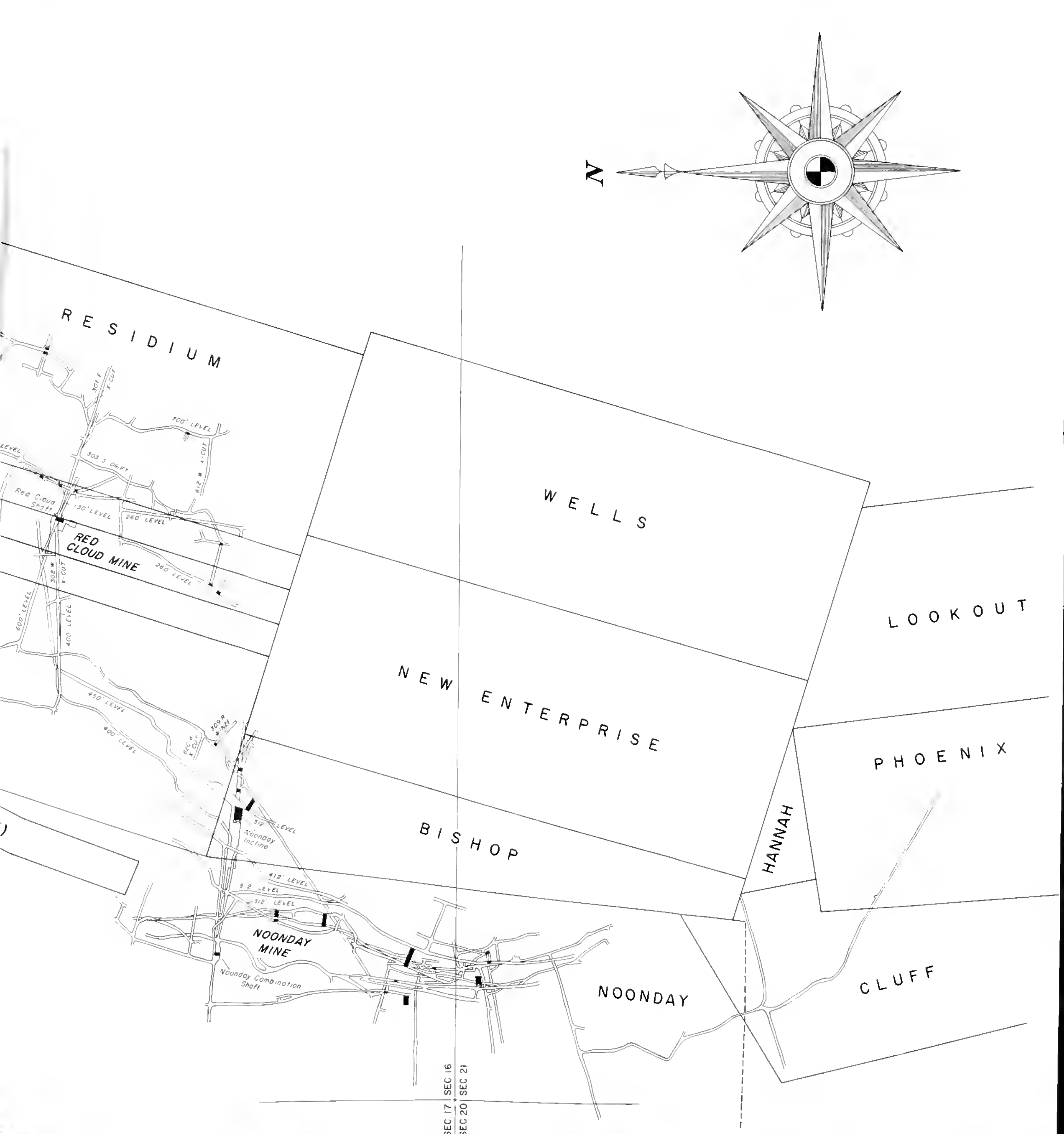
PLATE 5



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GEOLOGY AND ORE DEPOSITS OF THE BODIE MINING DISTRICT - BULLETIN 206