Aeromagnetic and Limited Gravity Studies and Generalized Geology of the Bodie Hills Region, Nevada and California

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By F. J. KLEINHAMPL, W. E. DAVIS, M. L. SILBERMAN, C. W. CHESTERMAN,[1] R. H. CHAPMAN,[1] and C. H. GRAY, JR.

ABSTRACT

The Bodie Hills region is characterized geomorphically by a variety of land forms — rugged high-relief mountains, such as the Wassuk Range and Sierra Nevada; broad volcanic massifs and tablelands, such as the Bodie Hills, Anchorite Hills, and southern Excelsior Mountains; and wide alluviated valleys, such as northern Mono Valley and Bridgeport Valley.

The present report is in large part a synthesis of published and unpublished data of the authors and other workers. It describes very briefly the Paleozoic and Mesozoic metamorphic, sedimentary, and plutonic rocks underlying about 15 percent of the mapped area and exposed mainly in the cores of the uplifted mountain ranges. It concentrates on the aeromagnetics and the Tertiary geology and their relationships to mineral deposits. About one-half of the area is underlain by an assemblage of Tertiary and Quaternary volcanic rocks of varied composition and mode of emplacement. These volcanic rocks can be divided into two suites and several groups on the basis of age, dominant chemical composition, and location. Tertiary and Quaternary sedimentary strata occur in scattered areas, some township size, and most commonly crop out in the valleys or on the lower slopes of the mountains. Most of the remainder of the area is covered by unconsolidated Quaternary deposits consisting largely of alluvium, fanglomerate, volcanic ash, eolian sand, and glacial deposits.

Major Tertiary structural elements in the mapped area include Basin and Range faults that tilted and uplifted large mountain blocks, such as the Wassuk Range and Sierra Nevada. Most faults in the area are steep northwest- to northeast-trending normal faults. A major zone of northeast-striking left-lateral faults cutting across the region in the area east of Mono Lake has been postulated by C. M. Gilbert, M. N. Christensen, Yehya Al-Rawi, and K. R. Lajoie. These authors have concluded that Mono Basin was formed by broad regional warping within the last 4 million years. Warping was accompanied by volcanism around the margins of the basin. Simple and complex vents and volcanic centers of Tertiary and Quaternary age form constructional upland features throughout the mapped area, and nearly all the features have been modified by faults. Generally, only the youngest basaltic volcanoes remain unfaulted.

Mineral deposits occur in both pre-Tertiary and Tertiary rocks. Copper, tungsten, and gold-bearing ore deposits in the Paleozoic and Mesozoic rocks are found within or near the Mesozoic granitic rocks. Gold, silver, and mercury in Miocene epithermal deposits occur in predominantly andesitic to rhyolitic volcanic rocks, and the largest known ore deposits consist of gold- and silver-bearing quartz veins in Miocene volcanic rocks at Bodie, Calif., and Aurora, Nev. Metalliferous mineral deposits have not been found in Tertiary sedimentary strata or in the Pliocene and younger volcanic rocks.

[1]California Division of Mines and Geology

Magnetic anomalies coincide with all or parts of each major mining district; elsewhere the magnetic pattern tends to reflect the gross aspects of the geology. Gravity data reflect mainly the thick accumulations of low-density valley-fill deposits. In most places the gravity and magnetic data bear little relation to one another, but they probably correlate in the Bodie mining district. Some of the major aeromagnetic anomalies delineate areas where additional geologic or geophysical studies would enhance the definition of postulated major geologic features, such as structural lineaments, and might lead to discovery of additional ore deposits.

INTRODUCTION

An aeromagnetic survey of the Bodie Hills region (fig. 1) was made as part of a geologic investigation of mineral deposits undertaken in the U.S. Geological Survey's Mineral Resources program. This region is near the Virginia City–Tonopah (Walker Lane) mineral belt hypothesized by Roberts (1966) and contains a variety of metallic mineral deposits, including rich silver and gold deposits once mined at Aurora, Nev., and Bodie, Calif. Tertiary volcanic rocks were examined critically because they are host rocks for the ore in the Aurora and Bodie districts and their widespread distribution appeared to enhance the possibility of finding additional deposits. The magnetic work was done primarily to define intrusive rock masses and volcanic sources and to determine their proximity and relation to known ore deposits.

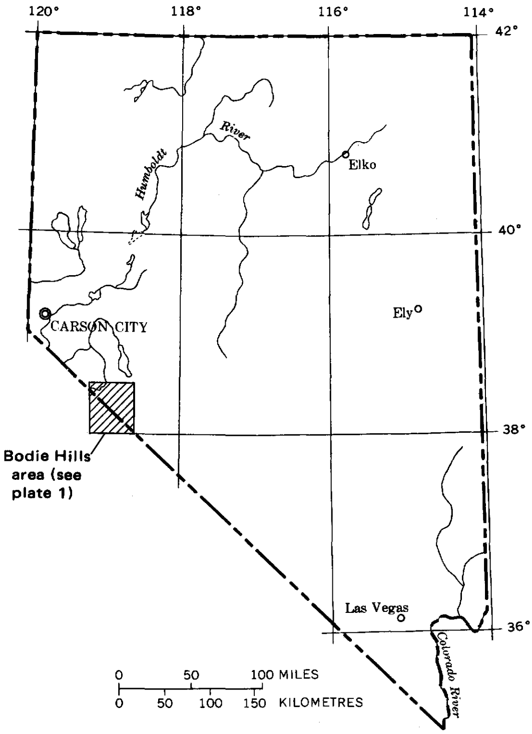

FIGURE 1. — Map of Nevada and California, showing location of the Bodie Hills region.

The area surveyed is between lat 38°00′ N. and 38°30′ N. and long 118°35′ W. and 119°15′ W. in Lyon and Mineral Counties, Nev., and Mono County, Calif. (pl. 1). It includes elements of the Sierra Nevada on the west and the Great Basin on the east. Alluviated valleys of irregular shape make up about one-third of the region; the largest, Mono Valley, is the site of the extensive saline Mono Lake in the southern part of the area. Several mountain ranges, including the Sierra Nevada and Sweetwater Mountains on the west and the Wassuk Range on the northeast, rise precipitously above the adjacent valleys; maximum relief is about 4,000 feet. In contrast, the Bodie Hills in the west-central part of the area and the Anchorite Hills in the east-central part form mountain masses with relief of 1,000 to 3,000 feet and rise more gradually and irregularly above the adjacent valleys, except north of Mono Lake, where the Bodie Hills rise abruptly. The mountainous Pine Grove Hills in the extreme north-northwest part of the area are about 2,000 feet higher than the lowland along East Walker River. Bridgeport, the county seat of Mono County, is in Bridgeport Valley, of the Bodie Hills; the old mining towns of Bodie, Calif., and Aurora, Nev., famous in the past for their gold and silver production, are in the central part of the mapped area.

Drainage in the region is internal; the local base levels are Mono Lake at 6,400 feet in the southern part of the mapped area and Walker Lake at about 4,000 feet just northeast of the area. The main courses of the East Walker River and its major tributaries, Bodie and Rough Creeks, are distinguished from the other streams in the mapped area by their meandering incised gorges.

GEOLOGY

The geology of the region is summarized from work by several investigators whose names are listed on the map (pl. 1). The data were compiled for reference in interpreting the aeromagnetic features and are intended to serve as a basis for further study of the environments of mineralization.

The region is characterized geologically by pre-Tertiary metamorphic, sedimentary, and granitic plutonic rocks and Tertiary volcanic and minor sedimentary rocks. Pre-Tertiary metamorphic and sedimentary rocks are about as widely scattered as the granitic rocks that intrude them, but they are only about one-fifth as extensive as the plutonic bodies, which form about 10 percent of all outcrops and appear chiefly in the Sierra Nevada and Wassuk Range. Small scattered bodies crop out north of Mono Lake in the Bodie and Pine Grove Hills and the Sweetwater Mountains. Tertiary rocks are more abundant than pre-Tertiary rocks and form about one-half of the entire cover; the volcanic component of the Tertiary exceeds the sedimentary component by about 10 to 1.

Areas underlain by volcanic rocks are distinguished from the starkly high relief pre-Tertiary areas of the Sierra Nevada and Wassuk Range by a generally more subdued terrain resulting in part from a constructional origin and in part from weathering of volcanic rocks that include a large amount of easily eroded tuffaceous material and volcanic breccia. Ubiquitous unconsolidated late Quaternary volcanic ash, probably from the eruptions of the Mono Craters, further softens the upland surfaces, as do glacial deposits in limited areas south of Bridgeport. Eolian sand fills vast stretches of Mono Valley and partly covers the lower foothills of the surrounding mountains. The sand was derived in part from beaches exposed by receding Mono Lake and receding stages of glacial Lake Russell (Putnam, 1949, p. 1285, 1295-1296) and perhaps in part from exhumed scattered Pliocene lake beds.

The age assignments of the rocks described are based on the epoch boundaries given in the Geological Society of London's (1964) Phanerozoic time scale.

PRE-TERTIARY ROCKS

METAMORPHIC AND SEDIMENTARY ROCKS

Pre-Tertiary metamorphic and sedimentary rocks are grouped together for some of the map units. The metamorphic rocks include a variety of types. Gneiss and schist are found at Masonic and in the extreme southwestern part of the mapped area. Hornfelsed metasedimentary rocks (metagraywackes and others), minor marble, and metavolcanic rocks (greenstones) occur east of Conway Summit in the southwestern Bodie Hills but are more abundant along the Sierran front and in the Pine Grove Hills. Metarhyolites and meta-andesites, including pyroclastic deposits (C. W. Chesterman and C. H. Gray, unpub. data, 1972), crop out in the Sierra Nevada. Marble is restricted primarily to the Sierra Nevada and to some of the pendants in the Wassuk Range. Porphyroblastic rocks, perhaps originally volcanic, crop out adjacent to the granitic bodies south of Aurora. A little skarn float partly surrounds the rhyolite plug of Martinez Hill, where the pre-Tertiary basement is inferred to lie at shallow depth. Pieces of the pre-Tertiary may have been carried upward during emplacement of the plug. Sedimentary rocks include fine-grained clastic strata and, in the southern Excelsior Mountains, conglomeratic beds.

The pre-Tertiary strata north and east of the Bodie Hills, in the Pine Grove Hills and Wassuk Range, are Mesozoic according to Moore (1969, p. 3, 5) and Ross (1961, pl. 2). Mesozoic and possibly Paleozoic rocks crop out in the Excelsior Mountains (Ross, 1961, p. 16, 20-21, pl. 2). Rocks of Paleozoic and Mesozoic age crop out near Conway Summit (Kistler, 1966a, b; Koenig, 1963; Chesterman, 1968). Metarhyolites and meta-andesites of the Sierra Nevada are assigned to the Jurassic. The metamorphic rocks at Masonic are pre-Cretaceous (Koenig, 1963), possibly pre-Late Jurassic (Johnson, 1951, p. 13 and pl. 1); other metamorphic and sedimentary strata in the Bodie Hills have been variously assigned to the Paleozoic or Mesozoic (Chesterman, 1968; Al-Rawi, 1970).

PLUTONIC ROCKS

Numerous granitic bodies lie within the region mapped, and most crop out peripheral to the Bodie Hills. Southwest of the Bodie Hills, the Sierran Jurassic and Cretaceous plutonic complex has been differentiated into five units ranging from diorite to granite by C. W. Chesterman and C. H. Gray (unpub. data, including a map of the Bodie quadrangle). An age of 93 m.y. (million years) (Cretaceous) was reported for the granite at Conway Summit (Chesterman, 1968). We obtained an age of 90 m.y. (Cretaceous) for quartz monzonite porphyry at Copper Mountain, west of Mono Lake (tables 1 and 2, sample 1). To the north, in the Pine Grove Hills, Moore (1969) mapped Cretaceous plutons that range in composition from quartz monzonite to granodiorite and hybrid mafic rocks. The most extensive granitic rocks in the region crop out northeast of the Bodie Hills, in the Wassuk Range, where Ross (1961, p. 29-36) described them as chiefly quartz monzonite and lesser granodiorite of Cretaceous (?) age. Evernden and Kistler (1970, pl. 2) reported two ages of 75 m.y. (Cretaceous) for rocks from two separate granitic localities in the southern Wassuk Range. Ross (1961, p. 28) mentioned dioritic bodies there that he believes to be partly the result of contaminating metavolcanic material assimilated into granitic magma. Quartz monzonite (?) porphyry with pegmatitic facies crops out south of Aurora Peak, southeast of Aurora, where much of the rock is argillized and oxidized. Masonic Mountain, about 13 miles west-northwest of Aurora, is underlain by a granodioritic to alaskitic quartz monzonite. Argillized (kaolin) and sericitized zones and quartz-veined quartz monzonite constitute the northeastern exposures of the granitic rocks at Masonic Mountain; zoned, commonly clustered feldspar phenocrysts as much as several inches long are conspicuous in parts of the plutonic complex.

TERTIARY AND QUATERNARY ROCKS

VOLCANIC ROCKS

The Bodie Hills region is underlain by two suites of Tertiary and Quaternary volcanic rocks; each appears to represent a separate petrochemical province that is a function of age. A calc-alkaline suite is the older (Oligocene and Miocene); an alkalic-calcic suite is the younger (Pliocene and Pleistocene). Another separation of the Tertiary and Quaternary volcanic rocks into six divisions based on age, location, and dominant chemical composition is useful for preliminary discussion (fig. 2). The divisions, numbered from oldest to youngest, are based mainly on the K-Ar ages reported in Gilbert, Christensen, Al-Rawi, and Lajoie (1968) and in this report (table 1). The oldest division, unit 1, is chiefly andesite, dacite, and minor rhyolite; latite welded ash-flow tuff about 11 to 12 m.y. old east of Mono Lake is included. Unit 1 is the most widely distributed and may contain some rocks correlative throughout the area, but ages are not well

TABLE 1. — *Potassium-argon ages of plutonic and volcanic rocks*[1]

Sample	Rock type and map unit (pl. 1)	Location	Mineral	Age (m.y.)	Reference
		Granitic rocks of the Sierra Nevada			
1	Quartz monzonite porphyry, Ptg	SW¼ sec. 11, T. 2N., R. 25 E.	Biotite	90 ± 2	This work.[2]
		Volcanic rocks of the Bodie Hills and the Bodie mining district			
2	Rhyolite plug, QTr	NW¼ sec. 31, T. 4 N., R. 26 E.	Biotite	5.7 ±0.2	Silberman and Chesterman (1972).
3	Rhyodacite plug, QTr	Center sec. 7, T. 4 N., R. 26 E.	do	5.2 ± .3	Do.
			Hornblende	5.4 ± .6	
4	Dacite flow, Tvb	West-central sec. 12, T. 4 N., R. 25 E.	Biotite	8.0 ± .2	Do.
5	Porphyritic andesite flow, Tvb	NW¼ sec. 30, T. 3 N., R. 26 E.	Hornblende	13.3 ± .4	This work.[2]
6	Basalt flow, Tvb	North border sec. 13, T. 3 N., R. 25 E.	Whole rock	11.3 ± .9	This work.[2]
7	do	NW¼ sec. 4, T. 3 N., R. 26 E.	do	9.3 ± .3	Silberman and Chesterman (1972).
8	Andesite flow, Tvb	SE¼ sec. 2, T. 3 N., R. 26 E.	Hornblende	9.5 ± .2	Do.
9	Rhyolite, QTr	NE¼ sec. 12, T. 3N., R. 26 E.	Biotite	9.1 ± .2	Do.
10	Dacite flow, Tvb	Center sec. 12, T. 4 N., R. 26 E.	do	9.1 ± .1	Do.
11	Dacite plug, Tvb	South-central sec. 16, T. 4 N., R. 27 E.	Hornblende	8.6 ± .4	Do.
			Biotite	8.7 ± .2	Do.
12	do	SW¼ sec. 21, T. 4 N., R. 27 E.	Whole rock	8.5 ± .4	Do.
			Plagioclase	8.3 ± .4	Do.
			Do.	8.9 ± .4	Do.
13	do	South-central sec. 9, T. 4 N., R. 27 E.	Hornblende	9.2 ± .5	Do.
14	do	West-central sec. 21, T. 4 N., R. 27 E.	do	9.2 ± .5	Do.
15	Andesite flow, QTa	SE¼ sec. 10, T. 4 N., R. 27 E.	Whole rock	2.7 ± .1	Do.
16	Dacite flow, Tvb	Center sec. 21, T. 4 N., R. 27 E.	Biotite	8.8 ± .2	Do.
17	do	East-central sec. 16, T. 4 N., R. 27 E.	do	8.9 ± .3	Do.
18	Rhyodacite plug, Tvb	West-central sec. 17, T. 4 N., R. 27 E.	do	8.9 ± .2	Do.
			Hornblende	9.0 ± .2	Do.
19	Dacite flow, Tvb	NW¼ sec. 21, T. 4 N., R. 27 E.	do	9.1 ± .5	Do.
20	do	SE¼ sec. 16, T. 4 N., R. 27 E.	Biotite	9.4 ± .2	Do.
21	do	North-central sec. 28, T. 4 N., R. 27 E.	do	8.7 ± .2	Do.
22	Dacite plug, Tvb	NE¼ sec. 23, T. 4 N., R. 27 E.	do	8.7 ± .2	Do.
		Volcanic rocks of the Aurora mining district and vicinity			
23	Andesite flow, Toa	East border sec. 13, T. 5 N., R. 27 E.	Hornblende	13.5 ±0.3	Silberman and McKee (1973).
24	do	NE¼ sec. 6, T. 4 N., R. 28 E.	do	14.4 ± .3	Do.
25	Andesite plug, Toa	NE¼ sec. 30, T. 5 N., R. 28 E.	Plagioclase	15.4 ± .3	Do.
26	Andesite porphyry plug, Tpmv	North-central sec. 36, T. 5 N., R. 27 E.	Biotite	11.2 ± .2	Do.
27	Rhyolite porphyry flow, Tpmv	NE¼ sec. 23, T. 5 N., R. 27 E.	do	11.2 ± .2	Do.
28	Rhylite flow, QTr	SE¼ sec. 7, T. 5 N., R. 28 E.	do	10.9 ± .2	Do.
			Sanidine	11.0 ± .2	Do.

29	Rhyolite plug, QTr	East-central sec. 22, T. 5 N., R. 27 E.	Plagioclase	10.2 ± .4	Do.
			Sanidine	9.9 ± .3	Do.
30	do	NW¼ sec. 20, T. 5 N., R. 28 E.	Biotite	2.5 ± .1	Do.
31	Dacite plug, QTa	NE¼ sec. 21, T. 5 N., R. 28 E.	do	2.5 ± .2	Do.
			Hornblende	2.7 ± .2	Do.
32	Basaltic andesite flow, Qby	NW¼ sec. 8, T. 5 N., R. 28 E.	Whole rock	.25± .05	Do.
33	Andesite flow, QTa	SE¼ sec. 28, T. 5 N., R. 28 E.	do	2.2 ± .1	Do.
			Hornblende	2.5 ± .2	Do.
	Gold- and silver-bearing veins of the Bodie and Aurora mining districts				
34	Adularia-quartz vein, Bodie district	South-central sec. 9, T. 4 N., R. 27 E.	Adularia	7.2 ±0.1	Silberman and Chesterman (1972).
35	do	South-central sec. 16, T. 4 N., R. 27 E.	do	7.7 ± .1	Do.
36	do	South-central sec. 9, T. 4 N., R. 27 E.	do	8.0 ± .2	Do.
37	Adularia-quartz vein, Aurora district	SW¼ sec. 17, T. 5 N., R. 28 E.	do	10.3 ± .2	This work.[2]

[1]Refer also to the list of potassium-argon ages in Gilbert, Christensen, Al-Rawi, and Lajoie (1968, p. 302–307) for volcanic rocks and Evernden and Kistler (1970, pl. 2) for granitic rocks.

[2]See table 2 for analytical data.

TABLE 2. — *Potassium-argon analytical data for previously unpublished age determinations*

[Potassium analyses by flame photometer using lithium metaborate fusion method (Suhr and Ingamells, 1966); analyst: Lois Schlocker. Argon analyses by standard isotope dilution techniques (Dalrymple and Lanphere, 1969); analyst; Miles L. Silberman. Analytical precision 2 to 3 percent for samples with radiogenic argon contents >30 percent. For samples of lower radiogenic argon contents, precision estimated from curves of Dalrymple and Lanphere (1969) based on amount of atmospheric argon. Constants: $\lambda e = 0.585 \times 10^{-10}$ yr^{-1}; $\lambda \beta = 4.72 \times 10^{-10}$ yr^{-1}; K^{40}/K tot $= 1.22 \times 10^{-4}$ g/g]

Sample	Rock type and map unit (pl. 1)	Mineral	K_2O (percent)	Ar^{40}rad. (mole/g$\times 10^{-10}$)	Ar^{40}rad./Ar^{40}tot (percent)	Age (m.y.)
1	Quartz monzonite porphyry, Ptg	Biotite	8.28	11.29	87.7	90.2±1.8
5	Porphyritic andesite flow, Tvb	Hornblende	.643	.1264	38.2	13.3± .4
6	Basalt flow, Tvb	Whole rock	1.58	2.655	11.3	11.3± .9
37	Adularia-quartz vein, Aurora district	Adularia	11.4	1.768	61.6	10.3± .2
				1.716	47.8	10.3± .2

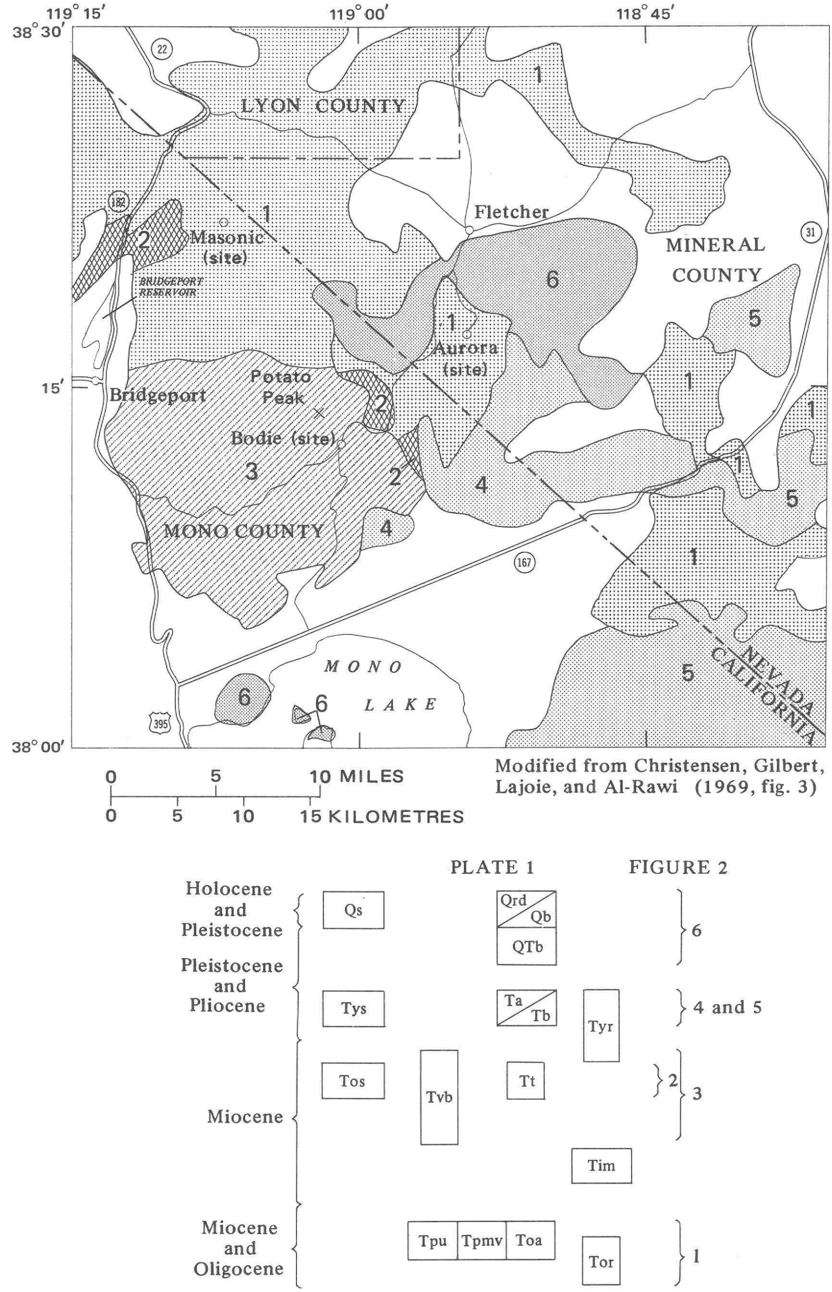

FIGURE 2 (above and right) — Generalized distribution of six major types of Tertiary volcanic rocks divided on the basis of age, location, and dominant chemical composition.

EXPLANATION

6

Basaltic andesite

Includes some olivine-bearing basalts, several thousand years to about 3 m.y. old. Also includes rhyolites not shown separately, some of which are about 3½ m.y. old

4

Andesitic and dacitic lavas, domes, and minor tuffs

Approximately 2-4 m.y. old

5

Olivine basalt

2½-4½ m.y. old

3

Dacitic and andesitic lavas, and tuff breccias

Approximately 8-13 m.y. old. Also include some younger rhyolites

2

Trachyandesitic welded tuff

9-10 m.y. old

1

Andesite and dacite lavas, intrusive bodies, and breccias with oldest absolute ages known

13.5-15.4 m.y. old at Aurora. Also include numerous rhyolitic flows and associated intrusive bodies and welded tuffs that are separated into older and younger rhyolites on plate 1, consisting of rocks possibly 22-29 m.y. old in southeastern and extreme northwestern part of map, rhyolitic welded tuff 11-12 m.y. old east of Mono Lake, and rhyolites in the vicinity of Aurora with ages of 2.5-11 m.y.

Contact

enough known for certain correlation. Late Oligocene rocks, 29 m.y. old, are included. Unit 2, consisting of trachyandesite welded ash-flow tuffs about 9 to 10 m.y. old, forms generally small outcrops, but its geographic distribution nearly equals that for unit 1, which is quantitatively much more abundant. The remaining units, 3 through 6, appear to reflect a greater clustering of eruptive centers as compared with the older units, whose centers are not well known.

Chemically the rocks in all six divisions range from rhyolite to basalt. Rocks of units 1 and 3, except for the latite ash-flow tuffs in unit 1, are part of a calc-alkaline province (Ross, 1961, p. 50-51; Al-Rawi, 1970, p. 106; Silberman and others, 1972), whereas rocks of units 2, 4, 5, and 6, chiefly trachyandesite to andesite, are part of an alkalic-calcic province. The six-fold separation of Tertiary volcanic rocks exclusive of rhyolitic bodies into crude age groupings has limitations owing to incomplete age data and the inability, with present knowledge, to correlate between similar rocks in some isolated outcrops, such as those in the Pine Grove Hills and Wassuk

Range. Nevertheless, this grouping permits a quicker understanding of the aeromagnetic and geologic map (pl. 1), which was largely synthesized from numerous sources.

OLDER RHYOLITE AND YOUNGER RHYOLITE

Rhyolites are described and mapped to include lesser amounts of rhyodacites and are considered separately from the six divisions. The rhyolites have a relatively small volume but are scattered widely throughout the region in welded tuffs, dikes, plugs, and cumulodomes. They have considerable range in age and are separated on the map into older rhyolite and younger rhyolite.

The older rhyolite in and near the Pine Grove Hills is probably Oligocene and Miocene in age (Eastwood, 1969, p. 63, 75), and some rhyolitic or dacitic ash-flow tuffs that crop out east of Mono Valley are 22 to 28.5 m.y. old (Gilbert and others, 1968, p. 280, 283). These ages represent the oldest known for the Tertiary in the mapped region. Similar ages obtained for rhyolitic tuffs and welded ash-flow material in Nye Canyon, Pine Grove Hills, just north of the mapped area (Eastwood, 1969, p. 63, 75), are extrapolated to the rhyolitic rocks cropping out nearby around Sweetwater Flat, in the extreme northwestern part of the mapped area.

The younger rhyolite unit includes several ages of rhyolites. The oldest rhyolites may be those northwest of Aurora, which have K-Ar ages of about 10 and 11 m.y. (table 1, samples 28 and 29). Gilbert, Christensen, Al-Rawi, and Lajoie (1968, p. 305) reported an age of 9.4 m.y. for rhyolite west of Mount Biedeman, in the Bodie Hills; a sample of rhyolite south of Mount Biedeman gave an age of 9.1 m.y. (table 1, sample 9). Many rhyolites are Pliocene in age: the 5.3-m.y.-old plug in Warm Spring Flat, in the western Bodie Hills (table 1, sample 3, chemically a rhyodacite); the 5.7-m.y.-old rhyolite plug in Clearwater Canyon (table 1, sample 2); the 3.6-m.y.-old rhyolites of Mount Hicks (Gilbert and others, 1968, p. 293); and a 2.5-m.y.-old glassy rhyolite plug of Martinez Hill, at Aurora (table 1, sample 30).

OLDER VOLCANIC ROCKS

Lavas, tuffs, minor agglomerate, and breccia of intermediate composition, predominantly andesitic and dacitic, make up the bulk of the older Tertiary rocks, which are mapped as unit 1 in figure 2. Pervasively to locally altered areas, especially propylitized zones, are common. Argillized and silicified masses, though less abundant, locally form conspicuous geomorphic features. The lavas are presumed to have had mainly local sources, as shown in figure 3; source areas are discussed under "Structure."

A Miocene age for part of the older volcanic rocks is based on data from Aldrich Station (north-central margin of pl. 1), Aurora, and east of Mono Lake. At Aldrich Station, andesite is overlain by tuffs that range in age from 10.5 to 11.2 m.y. (Evernden and others, 1964, p. 178-180). At Aurora, the oldest andesitic rocks have ages of 13.5 to 15.4 m.y. (table 1, samples 23-

25) and are intruded by a rhyolite porphyry and andesite porphyry plug and flow complex dated at 11 to 12.5 m.y. (Gilbert and others, 1968, p. 307; table 1, samples 26 and 27). The intermediate lavas east of Mono Lake underlie welded ash-flow tuffs dated at about 11 to 12 m.y. and in a few places overlie the older rhyolite that here includes rhyolitic ash-flow tuffs dated at about 22 to 29 m.y. (Gilbert and others, 1968, p. 283, 285, 300-301, 307). The predominantly andesitic rocks mapped in Masonic Gulch and in Red Wash by Johnson (1951, p. 16–25) are considered by us as part of the older volcanic rocks. Their ages have not been determined by isotopic methods but are inferred to be Miocene.

As mapped, the older volcanic rocks also include intrusive bodies, which have been recognized in only a few areas where detailed mapping was done, as at Aurora and Brawley Peaks. Less well mapped areas may have more intrusive rocks than shown (fig. 3). Because the bodies are generally similar in composition and appearance to the andesitic lavas, a common source is suggested for both. The older intrusive rocks at Aurora are in general slightly fresher in appearance than those seen elsewhere. One intrusive andesite at Aurora gave a K-Ar age of 15.4 m.y. (table 1, sample 25).

INTERMEDIATE INTRUSIVE BODIES OF THE MASONIC MOUNTAIN AREA

Numerous equant to elliptical intrusive bodies, ranging in diameter from 100 to about 2,500 feet, have been mapped in the vicinity of Masonic Mountain and especially near Masonic (pl. 1). Most of the bodies are andesitic, and several are leucophyric (Johnson, 1951, p. 25–27; Stanford Univ., unpub. data; Al-Rawi, 1970, pl. 1). One basalt plug was described by Johnson (1951, p. 26-27), and accessory magnetite was found in it and in all the other intrusive volcanic rocks examined. The presence of magnetite may not serve to distinguish them magnetically, because much of the andesitic country rock they intrude also contains accessory magnetite. The intrusive bodies have pluglike or cumulodome forms and, according to Johnson (1951, p. 25), cut all rock types older than welded tuff. (See "Ash-Flow Tuffs" section of the present report.) Johnson (1951, p. 19-25, 27) also stated that these bodies are in part contemporaneous with the andesite lavas and agglomerates that he mapped in Masonic Gulch and may have been a source for some of them.

VOLCANIC ROCKS OF THE BODIE AREA

Andesitic to dacitic tuff breccia, tuff, and lava, mapped as unit 3 in figure 2, underlie the central and southwestern parts of the Bodie Hills, making up one of the greatest outpourings of calc-alkaline rocks within the mapped area. The volcanic pile covers about 80 km^2 and has a volume of 35 km^3 (Gilbert and others, 1968, p. 281; Al-Rawi, 1970, p. 43); it includes units that range in age from about 13 to 8 m.y. (Miocene) (table 1, samples 4-22;

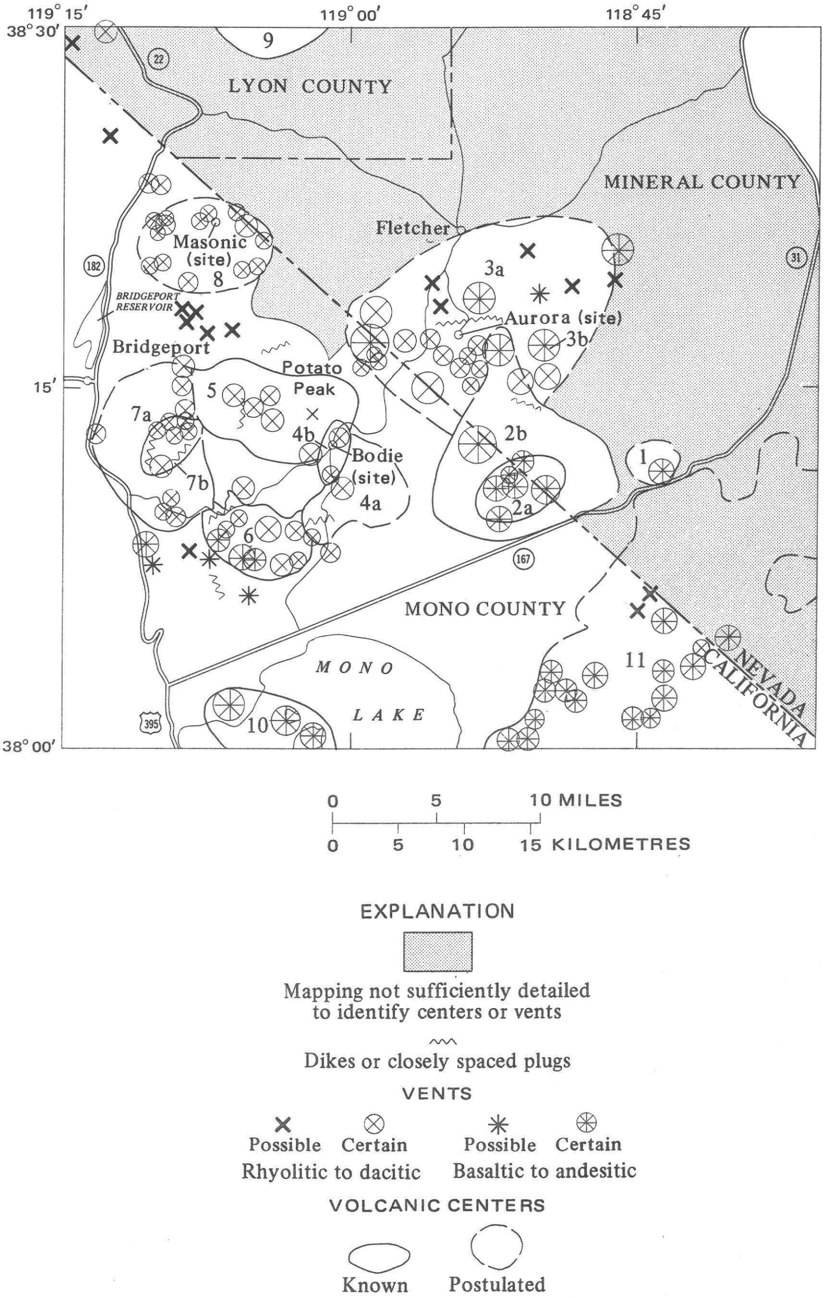

FIGURE 3 (above and right). — Known or postulated major Tertiary volcanic or instrusive centers. Interpretations modified from data of workers listed on plate 1.

VOLCANIC CENTERS—continued

Relatively simple(?)		Relatively complex
Anchorite Pass	1	
	2a,2b	Cedar Hill - Trench Canyon
	3a,3b	Aurora, Mount Hicks
Bodie	4a,4b	Lookout Mountain
	5	Bodie Mountain
	6	Mount Biedeman
	7a,7b	Willow Springs, Big Alkali
	8	Masonic
	9	Bald Mtn. (Pine Grove Hills)
Northwestern Mono Lake	10	
	11	Adobe and Anchorite Hills and Excelsior Mountains

Gilbert and others, 1968, p. 305). Chesterman and Gray (1966) and Chesterman (1968, p. 45, 49-60) divided the pile into five formations, each of which has a limited areal extent and its own eruptive centers (fig. 3).

ASH-FLOW TUFFS

Geographically extensive but relatively small exposures of thin trachyandesitic and latitic welded ash-flow tuffs dot the region discussed in this report (Al-Rawi, 1970, p. 29–37) and provide excellent marker beds. Conspicuous black vitric zones, locally devitrified, form the best and often the only exposures of the welded tuffs. The tuffs fit into two age groups: the younger and thinner group (up to 250 ft thick) is about 9 to 10 m.y. old; the older and thicker group (700 ft thick at one place) is about 11 to 12 m.y. old (Gilbert and others, 1968, p. 285–286). The younger group, mapped as unit 2 in figure 2, lies north of Mono Lake; its source presumably is west of the mapped area, near Sonora Pass, where the correlative Eureka Valley Member of the Stanislaus Formation of Slemmons (1966, p. 203–205) crops out and extends down the western slope of the Sierra Nevada (Gilbert and others, 1968, p. 285–286; Al-Rawi, 1970, fig. 5). Noble, Dickinson, and Clark (1968, p. 87–88) described a collapse caldera about 12 miles northwest of Bridgeport, Calif. (also west of the mapped area) that may have been the source for these trachyandesite ash-flow tuffs. Local sources, such as in the Bodie Hills themselves, have been suggested by Chesterman (1968, p. 61). The older group of ash-flow tuffs, not examined by the authors, is mapped with unit 1 in figure 2 and lies east of Mono Lake and south of Nevada Highway 31. Gilbert, Christensen, Al-Rawi, and Lajoie (1968, p. 284–285) indicated that these latite ignimbrites may have their sources partly in the southwestern Anchorite Hills (fig. 3). Both groups lie unconformably on older volcanic rocks.

As many as four flows compose the younger group of ash-flow tuffs, although all four are very rarely found at any one locality. The earliest and latest of the four exhibit a reversal of paleomagnetic polarity (Al-Rawi, 1970, p. 33–34, fig. 5), but because the earliest is best preserved and most extensive, it shows the most pronounced aeromagnetic response.

YOUNGER VOLCANIC ROCKS

The younger volcanic rocks of the region are of Pliocene to Holocene age and belong to an alkalic-calcic suite, unlike most of the Tertiary rocks discussed previously, which belong to the calc-alkaline suite. The younger volcanic rocks are divided into two main groups. One, the volcanic rocks east and northeast of Mono Lake, is of Pliocene age and is subdivided into two lithologic units: (1) andesitic and basaltic andesite rocks of Cedar Hill and Trench Canyon, and (2) alkali (?)-olivine basalt and basaltic rocks. The other group, miscellaneous rhyolitic to basaltic rocks (unit 6, fig. 2), is, as far as has been determined, late Pliocene, Pleistocene, and Holocene in age and is subdivided into two units: (1) andesitic and basaltic rocks (late Pliocene and Pleistocene), and (2) rhyolitic to dacitic rocks in Mono Lake (Holocene).

VOLCANIC ROCKS EAST AND NORTHEAST OF MONO LAKE

Alkalic-calcic rocks predominate east and northeast of Mono Lake and are of two lithologic groups, each with ages clustered mostly in the 2- to 4.5-m.y. range (units 4 and 5, fig. 2). One group (unit 4, fig. 2) forms a complex of pyroxene and hornblende andesite domes and flows that crop out primarily in the Cedar Hill and Trench Canyon area (Gilbert and others, 1968, p. 295; Al-Rawi, 1970, p. 52–60). Both normal and reversed polarity were observed in different parts of the complex by Al-Rawi (1970, p. 58), who noted, for example, a reversed polarity for the conspicuous biotite-hornblende andesite dome of Tal al Arab, northwest of Cedar Hill. Cedar Hill itself is a composite dome composed chiefly of intrusive rocks, flows, and minor pumice and ash flows.

The second group (unit 5, fig. 2), alkali (?)-olivine basalt and basaltic rocks, crops out chiefly as lavas over a wide area east of Mono Lake. The lavas are considered to have issued from vents within the areas of outcrop (Gilbert and others, 1968, p. 291–293). As expected, magnetite is one of the minerals in the microcrystalline lavas and has a bearing on interpretation of the aeromagnetic map.

MISCELLANEOUS RHYOLITIC TO BASALTIC ROCKS

Andesitic and Basaltic Rocks

Basaltic andesites near Aurora have a typically basaltic appearance in the field, but analysis shows 53 to 60 percent SiO_2 (M. L. Silberman and F. J. Kleinhampl, unpub. data, 1970; Al-Rawi, 1970, p. 108). These rocks form conspicuous volcanoes in the vicinity of Aurora and cover about 40 square miles, with nearly equal areas assignable to separate volcanoes at Aurora Crater, Beauty Peak, and Mount Hicks and to two unnamed vents east of Aurora Crater.

The basaltic volcano at Beauty Peak now forms a symmetrical volcanic cone and is clearly less voluminous than that at Aurora Crater. Broad thin basaltic lavas extending outward for several miles from the vent area erupted about 2.8 m.y. ago (Al-Rawi, 1970, p. 52) in the vicinity of older rhyolitic eruptions (10 m.y. old, table 1, sample 29) and are considered to be the oldest of the basaltic andesites near Aurora.

Similarly, at Mount Hicks, basaltic andesite vents formed on the site of a large, partly eruptive rhyolitic mass whose age is 3.6 m.y. (Gilbert and others, 1968, p. 293). The basaltic andesite vent rocks are less voluminous than those at Beauty Peak unless one includes the basaltic hill with 8,000-foot closure located about 2½ miles north-northwest of Mount Hicks. An age of about 1.6 m.y. was obtained by Al-Rawi (1970, p. 52) for the basaltic andesite at Mount Hicks. The hill with 8,000-foot closure may represent a separate, slightly older center of eruption.

Aurora Crater is the most voluminous basaltic andesite volcano (about 2 km^3 according to Al-Rawi, 1970, p. 60) and is a composite volcanic cone with dikes and a partly collapsed central core through which small cinder cones have been extruded. An age of 250,000 years was obtained from a sample of lava from Aurora Crater (table 1, sample 32). The Aurora Crater volcano and another to the east, here named the Mud Spring volcano, abut or lap onto the other basaltic andesite vent rocks in the vicinity. Both the Aurora Crater and the Mud Spring volcanoes show minimal erosion effects and beautifully retain geomorphic features common to very young volcanic vents. These observations are borne out by the young age of the lava at Aurora Crater, but the studies on rates of erosion by Christensen, Gilbert, Al-Rawi, and Lajoie (1970, p. 81) indicate that landforms developed on basalts, especially in this semiarid region, may retain their characteristic features for as long as several million years because the average rate of denudation is only about 0.1 cm per 1,000 years for basalts.

Black Point, a basaltic volcano that erupted under water and that is part of the present shoreline of Mono Lake since being exposed by post-Wisconsin recession of lake waters in the Mono Basin, has been dated at 9,500 to 13,000 years B.P. (Christensen and Gilbert, 1964, p. 240–242; Lajoie and Carmichael, 1967, p. 127; and Gilbert and others, 1968, p. 298).

Rhyolitic to Dacitic Rocks in Mono Lake

Rhyolitic to dacitic rocks in cones, plugs, and flows form part or all of the islands in Mono Lake, including Paoha and Negit Islands. Lajoie and Carmichael (1967, p. 127), who studied these bodies, stated that volcanoes on Negit and Paoha were active during post-Tioga time. On Paoha, the oldest exposed volcanic rock, a rhyolite, has uplifted 9,500-year-old lake beds and is overlain by dacite. A small Pleistocene andesite body postdating lake beds and Tioga till (Kistler, 1966a) also crops out on the island but lies south of the area mapped.

SEDIMENTARY ROCKS

Sedimentary rocks, including fluvial and lacustrine deposits, are widely scattered in the region. Some are so thin and discontinuous that they are mapped with the volcanic rocks, as are the Miocene andesitic sandstone and fine conglomerate in the older andesitic rocks on the west wall of Bodie Canyon near its mouth. The better developed sedimentary strata are mapped separately, like the older sedimentary rocks of Miocene age that form conspicuous outcrops peripheral to the Bodie Hills on the north and that occur in deposits flanking the Wassuk Range. The younger sedimentary rocks, Pliocene in age, form discontinuous outcrops of similar lithology and are scattered in the hills east of Mono Valley.

OLDER SEDIMENTARY ROCKS

Well-bedded partly tuffaceous fluviatile and lacustrine deposits, including diatomite, shale, siltstone, sandstone, and conglomerate, are of Miocene age. Ash layers and volcanic breccias are intercalated in many of the sections. Land mammal and plant fossils and trace-element assemblages in ash beds are useful for correlation between discontinuous outcrops. Eastwood (1969, p. 55–62) showed that ash layers at Rough Creek and near the dam at Bridgeport Reservoir are associated in time with ashes in the upper part of the well-known Aldrich Station section, indicating partial contemporaneity of the enclosing sedimentary rocks. These ashes are also contemporaneous with 9-to 10 m.y.-old trachyandesite welded tuffs ("latite ignimbrites" of Eastwood, 1969, p. 58, 61) in the Bodie Hills. The basal strata at Aldrich Station are late Barstovian (late Miocene) according to Axelrod (1956, p. 63–64, 68); an intercalated tuff layer yields the oldest K-Ar age yet obtained here, 11.2 m.y. (Evernden and others, 1964, p. 163–164). Some of the older ash layers in these strata may have originated from eruptions east of Mono Lake, where the previously described 11- to 12-m.y.-old welded ash-flow tuffs occur (Eastwood, 1969, p. 66).

YOUNGER SEDIMENTARY ROCKS

Gilbert, Christensen, Al-Rawi, and Lajoie (1968, p. 289–291) described the younger sedimentary rocks in and near the east end of Mono Valley. These beds have a maximum thickness of about 300 feet and include partly tuffaceous fine-grained clastic deposits and diatomite, all intercalated with rhyolitic and basaltic tuffs. An age between 3 and 4 m.y. (Pliocene) is deduced from stratigraphic relations of the beds to K-Ar-dated rhyolitic and basaltic rocks. The kinds and relations of sedimentary rocks led Gilbert and his coworkers to infer the former presence of a fresh-water lake that may have been terminated by filling with stream deposits.

UNCONSOLIDATED SEDIMENTARY DEPOSITS

Nearly one-third of the mapped region is underlain by unconsolidated sedimentary deposits. Such deposits primarily cover Mono Valley, where they probably are thickest, but also cover the smaller intermontane valleys, including the one north of Aurora Crater, where they may be chiefly a veneer on Tertiary volcanic and sedimentary rocks.

The coarsest unconsolidated material lies peripheral to steep range fronts and constitutes talus and alluvial fan deposits and morainal and outwash deposits associated with the glaciated Sierra Nevada. Coarse gravel and sand rim the Mono Valley and form beaches that are arranged concentrically and at successively lower elevations down to the present level of Mono Lake. Medium to fine sand forms dune fields east and northeast of Mono Lake and locally obliterates old beach levels and partly buries the adjacent hills. Some of the sand has been reworked from the old lake deposits; much of it, such as the fine material festooning the highest parts of the Bodie Hills, is derived from ash that settled across the region, perhaps during eruptions at the Mono Craters and other localities to the south (off the map). The sand has a high percentage of feldspar, glass, and pumiceous material suggestive of derivation from settling of air-fall tuffs as well as from erosion of surrounding volcanic rocks. The latest explosive volcanism, which occured only several thousand years ago (Gilbert and others, 1968, p. 298–299), readily accounts for the extensive thin veneer of unconsolidated ashy material blanketing the region.

STRUCTURE

The major structural elements of the mapped region are those common to the Great Basin and the Sierra Nevada—warps, tilted blocks, Basin and Range faults, and elements related to Mesozoic intrusive activity and to Tertiary volcanism. The Sierra Nevada, Pine Grove Hills, and Wassuk Range represent in part tilted upraised fault blocks that have been eroded to expose cores of Mesozoic plutonic rocks. Several mountainous areas in the region are chiefly constructional upland features developed on the sites of volcanic vents and intrusive complexes of Tertiary age. They include the Bodie Hills, Anchorite Hills, and southern Excelsior Mountains. Ash-flow tuff sheets, tumescent upwellings of lava, and subsequent Basin and Range faults have been the chief contributors to the form of the Anchorite Hills and Excelsior Mountains. Bald Mountain, in the southern Pine Grove Hills, appears to be a major complex volcano with a partial central collapse zone (Moore, 1969, pl. 1; fig. 3, this report).

Major Tertiary centers of volcanism or intrusion are common in the region; some are well defined, and others are postulated. Relatively simple centers, such as at Anchorite Pass (No. 1, fig. 3), are separated from relatively complex ones, such as at Aurora (No. 3a), on the basis of areal extent and diversity of vent or intrusive features. Such features include vent rocks or near-surface intrusive bodies (plugs, domes, and dikes) and associated structures. The separation into simple and complex centers is arbitrary in some cases and is a function of having more data on some centers than on others, but it does serve to differentiate between small centers and larger, less well understood centers. Numerous volcanic centers and vents are scattered throughout the Bodie Hills and may be abundant in the volcanic parts of adjacent ranges, but no areas were as carefully examined as the Bodie Hills. Big Alkali caldera, low on the southwest flank of Potato Peak, is a collapse feature from which pyroclastic materials and lavas issued and into whose interior and rim zone plugs of rhyodacite and rhyolite (Chesterman, 1968, p. 63–64) were later emplaced. Other clustered plugs and dikes form discrete composite centers, such as at Cedar Hill, Mount Biedeman, and Mount Hicks. Potato Peak and Bodie Mountain represent a major complex volcano composed mainly of dacitic to andesitic lava and tuff breccia intruded by plugs and dikes of andesitic to rhyolitic composition. The Bodie mining district lies near the east edge of the Potato Peak center, within an area of altered andesitic flows and tuffs that have been intruded by several andesitic bodies (Silberman and Chesterman, 1972). The Aurora mining district lies within an irregularly shaped complex center in which volcanism was sporadic throughout a long period beginning in the Miocene and ending with the formation of Aurora Crater about 250,000 years ago. The latter event may more properly reflect a late stage in the evolution of an ancillary and overlapping center, Mount Hicks (No. 3b, fig 3), and indicates the complex relations to be found in the region.

Most observed Basin and Range structure probably predates the development of the basaltic andesite volcanoes of Beauty Peak and Mount Hicks, which are late Pliocene and Pleistocene in age, respectively, and most certainly predates Aurora Crater and Mud Spring volcano, which are Holocene. The Basin and Range structure has modified some of the older volcanic upland, such as the Excelsior Mountains, which is a block tilted westward along a range-front fault. Numerous faults with normal and possible left-lateral (Gilbert and others, 1968, p. 309–310) displacements cut the Anchorite Hills and Excelsior Mountains into slightly disarticulated blocks, and the overall structure is related to regional distension and buckling along a west-northwest axis between Mono Lake on the west and Montgomery Pass (off the map) on the east (Gilbert and others, 1968, p. 275–276, 313–314).

Faults in the Bodie Hills trend mostly north and northwest and are clustered in some localities, as at Bodie and Aurora. The apparent scarcity of faults in the older volcanic rocks of the region probably does not accurately reflect the density of faults and is most likely due to either less detailed mapping or greater difficulty in distinguishing mappable features in the older volcanic rocks as compared with the younger rocks. Short arcuate faults are common on the north, east, and south flanks of the Potato Peak–Bodie Mountain massif, where they reflect gravity slumping in a thick pile of tuff and tuff breccias (C. W. Chesterman and C.H. Gray, Jr., unpub. data, 1972). Other arcuate faults between Beauty Peak and the westernmost of the Brawley Peaks outline a crudely circular collapse feature in which landslide topography is well developed. Divergent major faults with more easterly strikes are conspicuous locally, as at Bodie, at

Masonic, and in the south end of the Wassuk Range. Strike-slip left-lateral displacements predominate on N. 60° E.-striking faults in the area east of Mono Lake (Gilbert and others, 1968, p. 313–314). The north-trending faults at Aurora are also said to have had strike-slip movement, predominantly in a right-lateral sense (Green, 1964, p. 21). Arcuate north-trending faults that cut the high part of the southern Pine Grove Hills appear by their shape and distribution to be the surficial manifestation of major collapse during the late developmental stage of a volcano.

Mono Basin is a structural depression that is bounded partly by faults and contains considerable low-density material. Interpretation of geophysical and geologic data indicates that the basin was formed by subsidence and warping. From results of gravity and seismic studies, Pakiser and coworkers concluded that Mono Basin may be a subsidence structure that developed incrementally beginning in the early or middle Pliocene as magma was withdrawn from a magma chamber at depth and extruded (Pakiser and others, 1960, p. 440–441, 445–446; Pakiser and others, 1964, p. 49, 60–62; Pakiser, 1968, p. 1835–1837; 1970, p. 4077–4080). Using an assumed density contrast of -0.4 g cm $^{-3}$ between basin fill and bedrock, they interpreted the gravity pattern of the basin as representing a broad triangular block that subsided about 5.5 ± 1.5 km to form a depression in which sedimentary and volcanic material accumulated. High gravity gradients suggest that near-vertical faults are somewhat inside the basin margins and partly under Mono Lake, which lies over the deepest part of the structure. Kistler (1966b, p. E49) suggested a lesser amount of subsidence. Gilbert and coworkers supported Kistler and treated Pakiser's data differently, primarily by using a lower density and velocity for the basin-fill deposits (Gilbert and others, 1968, p. 316–323; Christensen and others, 1969, p. 5221–5238; Christensen and Gilbert, 1970, p. 4081–4082). By combining this information with an interpretation of regional structure between the Sierra Nevada and the White Mountains, they concluded that the basin is about 1 to 1.5 km deep and has been formed within the last 4 m.y. by regional warping and faulting, accompanied by some volcanism. Recent seismic data (March 1971) interpreted by L. C. Pakiser and Cecelia Borcherdt (L. C. Pakiser, written commun., 1971) indicate that the maximum depth to crystalline basement in the western part of Mono Lake is 2.2 to 2.4 km and that volcanic rocks exposed north of the lake extend southward and thin beneath valley fill to form a layer of higher seismic velocity above the basement rocks. Fault zones north and southwest of the lake that were indicated by steep gravity gradients are confirmed by the seismic data.

A broad gentle upwarp was found by Al-Rawi (1970, p. 87–89) to underlie the Bodie Hills. He presented evidence that dates the warp as probably early or middle Pleistocene, and he placed the warp axis along a N. 60°–65° E. trend from near Conway Summit, and passing just north of

Bodie, to the vicinity of Aurora. The Pliocene basalts east of Mono Lake also have been deformed by warping as well as faulting (Gilbert and others, 1968, p. 293, 311–313). Compilation of regional gravity data in the area (fig. 4) reveals several anomalies that seem to be related to geologic structures. The most prominent anomaly is an extensive gravity low over Mono Basin (Pakiser and others, 1960) that has an estimated maximum residual amplitude of about −50 mgal and is bounded by high gravity gradients. The large amplitude and the gradients strongly suggest that the low represents a major structural feature such as a faulted depression or downwarp. Straight-line northeast-trending gravity contour lines bordering this anomaly near the south edge of the Bodie Hills appear to indicate a fault.

Another broad gravity low, whose axis lies west of the area, includes a large part of the Bodie Hills. Within the low are pronounced minimums over Bridgeport Valley and Potato Peak. The Bridgeport Valley minimum has an amplitude of at least −10 mgal and is associated mostly with Tertiary extrusive and intrusive rocks and Quaternary alluvium and glacial deposits. An eastward extension of the minimum almost encloses the nearly circular Big Alkali Flat, where a small caldera is characterized by arcuate faults, rhyolitic plugs, and hot springs (Chesterman, 1968, p. 63). Steep gravity gradients on the south and southeast flanks of the main anomaly suggest the presence of faults, but no east- and northeast-trending faults have been observed in this part of the area. Very likely the gravity low is the expression of low-density Tertiary sedimentary and volcanic deposits that fill a broad shallow depression in the pre-Tertiary basement rocks. The Potato Peak minimum extends northward from near Mount Biedeman to Masonic Mountain. It is a comparatively narrow feature of about −5 to −10 mgal amplitude and, except for exposed granitic rocks near Masonic Mountain, lies mainly over Tertiary volcanic rocks that crop out in the central part of the Bodie Hills. The central and southern parts of the minimum seem to be associated with the complex volcanic centers of Potato Peak, Bodie Mountain, and Mount Biedeman. This minimum is separated from the Bridgeport Valley minimum by a gravity ridge that occurs mostly over Tertiary volcanic rocks but also over pre-Tertiary basement rocks exposed west of Masonic Mountain and in Bridgeport Canyon west of Mount Biedeman. Near the canyon several north-trending faults occur in rocks marked by the ridge. The gravity pattern and steep gradients associated with the ridge and adjoining low suggest that the Potato Peak minimum represents a constructional volcanic upland underlain chiefly by low-density tuff breccias. A northeastward extension of the minimum that may be related to warping is centered over Quaternary basalt and alluvium north of Aurora Crater near Fletcher. Owing to the lack of data, this feature is not well defined; it may be caused at least in part by Quaternary alluvium and Tertiary sedimentary rocks in the lowland north of Fletcher but is probably also related to a local depression in the Tertiary volcanic rocks.

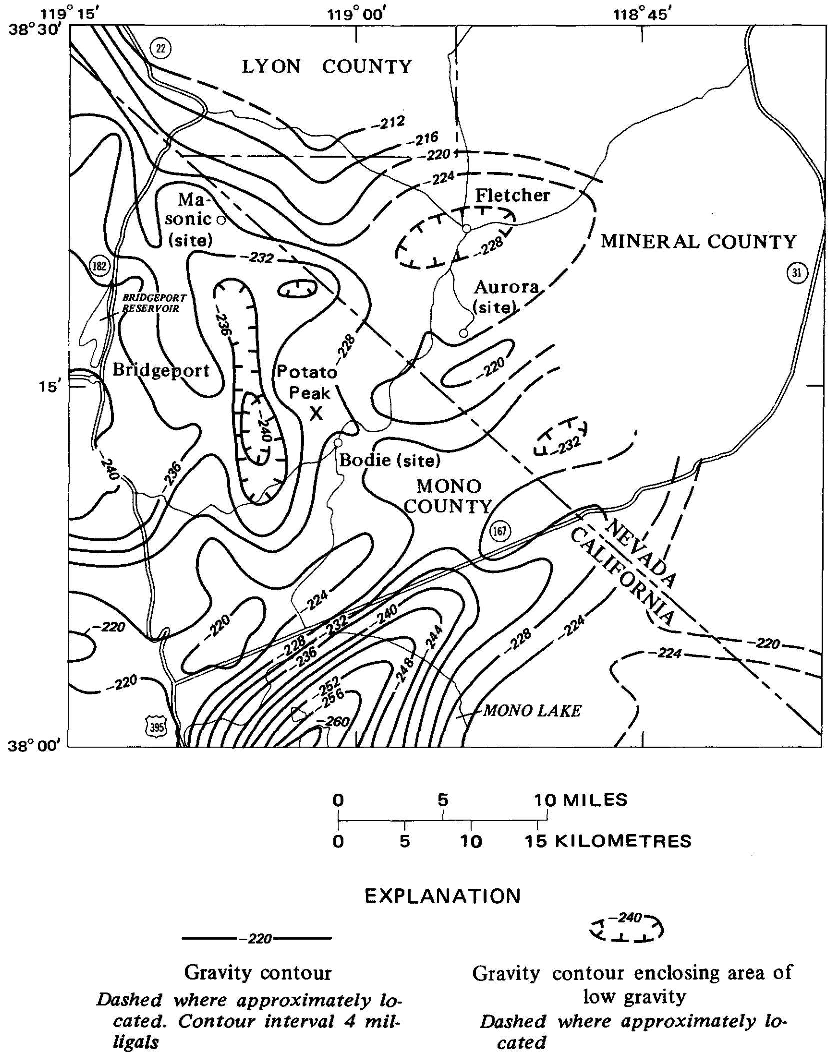

FIGURE 4. — Bouger gravity map. Compiled from gravity data in northern Mono Basin by Pakiser and others (1960), data from surveys in Nevada by Mabey (1960), unpublished detailed data in the Bodie mining district by the California Division of Mines and Geology, and regional gravity data obtained by both the U.S. Geological Survey and the California Division of Mines and Geology.

Near the front of the hills north of Mono Lake, a narrow positive anomaly trends northeastward from Lundy Canyon to Cottonwood Canyon, where it turns directly north and continues through the Bodie mining district. The anomaly trend turns northeast near Bodie, where there is a distinct saddle, and continues to the vicinity of Aurora Peak. Pre-Tertiary metamorphic and plutonic rocks crop out in the southwestern and northeastern parts of the feature, but elsewhere younger volcanic rocks are exposed. The pre-Tertiary rocks near the anomaly maximums, at its extremities, strongly suggest that the feature may be caused by relief on the underlying basement rock surface, even though the basement rocks are not exposed in the intervening area. Near Bodie, mining operations, even to a depth of 1,000 feet, have not revealed the presence of significant amounts of basement rocks. The small quantities of metamorphic rocks that have been reported in the mine workings at Bodie may be pieces brought near the surface by intrusive bodies. If pre-Tertiary basement rocks are not the source of the moderately high gravity near Bodie and Aurora, an alternative source might be the series of dacitic and andesitic plugs that occur in these areas. The overall northeastward trend of the gravity anomaly corresponds to the axis of the broad, probably Pleistocene upwarp mentioned by Al-Rawi (1970, p. 87–89). However, the width and shape of the high do not necessarily suggest a broad upwarp.

ALTERATION

Alteration has affected both the pre-Tertiary and the Tertiary rocks of the region; the effects are best treated separately. Pre-Tertiary rocks invaded by Mesozoic (?) plutons locally have been altered near the intrusive contacts by pneumatolytic and contact metamorphic processes. The effects of such processes are noted, for example, at Copper Mountain in the Sierra Nevada and, similarly, near Lucky Boy Pass in the Wassuk Range; Mesozoic roof pendants are commonly argillized, epidotized, and hornfelsed and locally sericitized. Limestones have been converted to marble at both localities, and skarn zones are conspicuous in places.

Broad areas of Tertiary and Quaternary volcanic rocks, especially the Pliocene and Pleistocene sequences, are relatively fresh and exhibit only incipient chloritic alteration or oxidation of mafic constituents. Equally broad expanses of the Miocene sequences, such as the andesitic rocks north of Masonic and at Aurora, have been propylitically altered. Argillized, silicified, and bleached zones are common in the middle Miocene or older volcanic rocks, even away from known metalliferous deposits, whereas similar zones in the younger Tertiary rocks are perhaps less common and more likely to be associated with metallic mineral deposits, such as at Bodie and west of Potato Peak. West of Potato Peak, some cinnabar was found in a zone of intensely hydrothermally altered rocks. The zone extends northwestward across the east half of T. 4 N., R. 25 E., from Cinnabar Canyon to the Travertine hot springs and consists largely of opaline silica

(Chesterman, 1968, p. 55). Altered zones in the Bodie and Aurora mining districts carry mineral assemblages characteristic of potassic, argillic, and propylitic alteration. Pyrite is commonly disseminated in the veined wallrock at both Aurora and Bodie. The pervasive conspicuous reddish-brown coloration of some lavas within the older volcanic rocks in the Red Wash drainage north of Masonic described by Johnson (1951, p. 16) may have had its origin in oxidation of both mafic minerals and broadly disseminated pyrite. Johnson (1951, p. 41) thought that "early heavy sulphide concentrations" in the older Tertiary volcanic rocks at Masonic were unlikely, because the mineral assemblage and fractured open structure of the ore bodies indicate "near-surface deposition" and little or no erosional stripping since mineral formation that would account for the absence of the sulfides today. A better explanation for the absence of sulfides may be near-surface oxidation of sulfides that could lead to the development of massive silicified bodies such as those at the Serita and Pittsburg-Liberty mines. These bodies appear to be similar to the silicified "ledges" at Goldfield, Nev., where quartz-kaolinite-alunite alteration has been well documented (R. P. Ashley, oral commun., 1969). The silicified masses at Masonic and to the southeast at the Paramount mine are hosts to metalliferous deposits. Some of the masses or "ledges" at Masonic were in part mistaken for altered rhyolites by other workers (Stanford Univ., Geology Dept., unpub. data, 1966), and the presence of rhyolite in the area makes identification difficult. A part of the large tabulate silicified mass at the Paramount mine closely resembles large silicified areas farther southeast of the eastern Brawley Peaks, where broad tabulatelike zones of silicified andesite and andesitic breccia underlie most of the crestal area of the eastern peaks and may represent part of a massive breccia-pipe complex. These silicified zones also closely resemble in type of alteration and character of original rock other zones found between Masonic and the East Walker River, especially the large mass at The Elbow along the river.

ECONOMIC GEOLOGY

The Aurora, Nev., and Bodie, Calif., mining districts lie within the mapped region. Each has yielded about $30 million in gold and silver (at time-of-sale prices) from precious-metal-bearing quartz veins in altered intermediate Tertiary volcanic rocks. The main part of each district is crudely rectangular in outline, about 0.5 by 1.5 miles, elongated northeastward at Aurora and northward at Bodie. Aurora has not produced steadily since about 1950, when the Chesco Mining Co. ceased operation. Bodie has had no reported production since 1942, when the Roseklip Mines Co. stopped work (S. B. McCluskey, unpub. reports, the Siskon Corp., Reno, Nev.). Intermittent exploration is still carried on in both districts.

Gold- and silver-bearing quartz veins at Bodie cut andesitic intrusives, lavas, and tuff breccias that are similar in petrography and age to the Potato Peak Formation of Chesterman (1968, p. 59). The age of the Miocene volcanic host rocks of the Bodie district ranges from 9.4 to 8.6 m.y. (table 1). Two sets of steeply dipping north-striking veins were mined for precious-metal deposits; these veins cut a moderately eastward-dipping vein, the Fortuna, that yielded gold- and silver-bearing base-metal ore. Adularia from several veins yielded K-Ar ages of 7.2 to 8.0 m.y. (table 1, samples 34–36), indicating that vein emplacement occurred slightly later than or at the end stages of andesitic intrusive activity (Silberman and Chesterman, 1972).

Major production of silver and gold at Aurora came from conspicuous north- and northeast-striking steeply dipping quartz-filled fissure veins that cut 13.5- to 15.4-m.y.-old Miocene andesitic lavas and breccias (table 1, samples 23–25). The high-grade ore generally lies within 200 feet of the surface; the richest ore appears to have developed along the veins where cut by north-striking faults (Green, 1964, p. 29–33). Adularia from one of the largest and most productive veins gave a 10.3-m.y. age (table 1, sample 37).

Other mining districts within the region are less important when gaged by their past production, and few, if any, metal mines are active today. Other localities within the Bodie Hills that exhibit large obviously altered or mineralized zones include the Masonic mining district, Paramount mine, and Cinnabar Canyon. At Masonic, the major gold and silver deposits formed in fissure veins and veinlets that fill fractures cutting parallel to and across silicified "ledges" that developed in the oldest Tertiary volcanic rocks and in Mesozoic granitic rocks (Johnson, 1951, p. 36–40). A major fault zone along the northwest flank of Masonic Mountain served as a channelway for solutions that localized the main ore-bearing "ledges" and subsequently formed the ore deposits. North of Masonic, cinnabar is exposed in minor prospects in bleached and silicified andesitic lavas and associated rhyolite; southeast of the Masonic district, there are similar occurrences at the Paramount mine, the west flank of Potato Peak, and Cinnabar Canyon. Placer gold was mined in the Bodie Hills from Bodie Creek, Virginia Creek (south of Bridgeport), and near Conway Summit at the Sinnamon Cut and the Mono Diggings. Minor secondary copper minerals are exposed in prospects in sheared and deformed pre-Tertiary metamorphic rocks of the Rancheria Gulch area. Sparse secondary copper minerals are also present near the west end of the large gougy fault zone that cuts the granitic pluton south of Aurora Peak. A little tungsten ore was mined in 1953 (Ross, 1961, table 6.8) at the Homestead (Hefler) mine in the extreme northern Bodie Hills.

A major mining company explored copper deposits in 1968–69 by drilling and excavation at Copper Mountain in the Sierra Nevada, where there is a record of past minor production of gold from the Goleta mine. The May Lundy mine south of Lundy Canyon also produced some gold.

In the Wassuk Range, precious and base metals were produced in moderate to appreciable quantities from the Big Indian and Lucky Boy mines, Hawthorne district; the Lucky Boy mine was active to 1911 (Ross, 1961, table 6.3). These deposits, as well as some tungsten occurrences, are found in and adjacent to partly altered pendants of Mesozoic rocks in granitic plutons. Silica was being mined in 1972 from a silicified mass south of and near Lucky Boy Pass at what may be the only active nonmetallic mine in the region (Silicone group of claims when described by Archbold, 1966, p. 31).

Some mining properties in the Excelsior Mountains on the northwest side of Huntoon Valley are presumed to be inactive but have not been visited by the authors. Mines and prospects in that part of the Sweetwater Mountains and Pine Grove Hills within the region of this study are not well known to the authors. Such workings are believed to be few and minor. Large but presumably inactive (?) precious-metal mines lie just off the northwest corner of the mapped region, near Sweetwater, in the Patterson mining district, Sweetwater Mountains.

AEROMAGNETIC SURVEY

The aeromagnetic survey (pl. 1) was flown in 1967 by Lockwood, Kessler and Bartlett, Inc., for the U.S. Geological Survey (U.S. Geol. Survey, 1971). Total intensity magnetic data were obtained with a continuously recording Gulf Mark III fluxgate magnetometer installed in a fixed-wing aircraft. The flight paths were east-west, about 1 mile apart, and were flown at barometric altitudes of 11,000 feet above sea level north of lat 38°11′N. and west of long 118°37′W. and at 9,000 feet above sea level elsewhere. Topographic maps were used for guidance, and the flight paths were recorded by a 35-mm camera. Ground clearance ranged from less than 1,000 feet over the highest mountains to as much as 5,000 feet over the lowlands.

MAGNETIC FEATURES

Magnetic intensity values were greater in the block flown at an altitude of 9,000 feet than in the block flown at 11,000 feet. This difference in values can be accounted for by the difference in flight altitude. Although the difference in values results in contour-line irregularities along the junction of the blocks, the shape and amplitude of overlapping anomalies are readily apparent.

Over the Bodie Hills is a group of discontinuous magnetic anomalies dominated by maximums and related minimums over Bodie Mountain, the upland south of Bodie, and Aurora Crater. Magnetic lows occur over the lowland north and east of the Bodie Hills, and extensive zones of low intensity lie over the east front of the Sweetwater Mountains, the Bridgeport Valley, and the northern part of Mono Valley. Broad magnetic highs occur over the Pine Grove Hills and Wassuk Range. Prominent highs lie over the upland east of Mono Lake. The magnetic features are augmented by topography and are superimposed on a positive northeastward regional gradient of about 9 gammas per mile.

The pattern of the aeromagnetic map is much more complex than that of the regional gravity map. Except for magnetic lows partly coincident with gravity lows over parts of the lowlands, there seems to be little relation between magnetic and gravity features. Correlation between such features may not be expected in this region. The gravity data reflect mainly the thick accumulations of low-density valley-fill deposits, whereas the magnetic data show magnetic contrasts in these materials and in the country rock. The lack of definition of local anomalies inherent in wide spacing of gravity data as compared with the more definitive coverage of the aeromagnetic survey partly accounts for discrepancies between the map patterns.

INTERPRETATION

The interpretation of magnetic features is based on results of geologic mapping and general knowledge of the magnetic properties of rocks involved. Anomalies are assumed to be caused by magnetic contrasts between rock masses that are exposed or lie in the subsurface. Expression of these masses depends mostly upon their size and shape, intensity and direction of magnetization, and positions relative to the observation level. Intensities of magnetization in igneous rocks are inferred from results of laboratory examination of samples collected at some of the anomalous localities. The sedimentary rocks and unconsolidated deposits generally possess relatively low magnetic susceptibility and negligible remanent magnetization and are considered to be essentially nonmagnetic.

BODIE HILLS

The magnetic high over Bodie Mountain is associated with Miocene andesitic lavas and tuff breccias of the Potato Peak Formation of Chesterman (1968, p. 59) and probably represents the source of these rocks. The anomaly has a relief of more than 300 gammas, as indicated by maximums near the mountain peak and over the lower slopes about 3 miles to the west. A study of the magnetic gradients suggests that the source of the anomaly is an elongate, partly steep walled mass whose top lies near the ground surface. Oriented samples of rocks collected on Bodie Mountain and Potato Peak have induced magnetization intensities of 0.54×10^{-3} to 0.99×10^{-3} emu/cc (electromagnetic units per cubic centimeter) and remanent intensities of 8.37×10^{-3} to 1.22×10^{-1} emu/cc. The strong remanent magnetization in these samples suggests that the anomaly is produced mainly by the remanence in a thick accumulation of the andesitic flows.

On the north flank of the Bodie Mountain anomaly are minor magnetic lows indicated by a negative closure near Potato Peak and a contoured reentrant about a mile to the west. The negative closure lies over rhyolite and andesite along part of a northwest-trending fault zone and may represent altered rocks near the structure. The reentrant to the west lies over a zone of highly altered rhyolitic and andesitic rocks. Mercury deposits occur at shallow depths in rhyolite in the northern part of this zone. The east-trending magnetic low north of these features is considered to be a counterpart of the Bodie Mountain anomaly. It is part of an arcuate narrow zone of low intensity that extends southeastward from Aurora Canyon to a junction of jeep trails about 2 miles west of the mouth of Trench Canyon on the north side of Mono Valley. Locally this zone is associated with altered rocks and faults, which suggests that it marks a concealed structure.

South of Bodie Mountain, narrow anomalies are associated with rocks of the Mount Biedeman Formation of Chesterman (1968). A small elongate magnetic high that is probably caused by dacite or rhyolite occurs over a ridge and the eastern slopes of Mount Biedeman. Present data are insufficient, if contoured conservatively, to permit including Mount Biedeman in the anomaly, because flight lines straddle the mountain peak. Two samples of dacite tuff collected near the anomaly maximum have induced magnetization intensities of 0.04×10^{-3} and 0.16×10^{-3} emu/cc and remanent magnetization intensities of 0.74×10^{-3} and 2.12×10^{-3} emu/cc. The remanent magnetization could account for the anomaly.

A narrow northwest-trending magnetic low lies over andesitic rocks in the central part of Mount Biedeman. Two samples of andesite from the saddle between the main peaks have weak induced magnetization intensities of 0.12×10^{-3} and 0.16×10^{-3} emu/cc and negligible remanent magnetization. Another sample collected about half a mile to the south shows a moderately strong reversed remanent magnetization of 3.64×10^{-3} emu/cc and an induced magnetization of 1.37×10^{-3} emu/ cc. These data suggest that the anomaly is caused by the andesitic rocks, which apparently may vary in composition locally. Higher magnetic intensity values over andesite to the west indicate that the low represents a zone of thinner or more siliceous flows. The shape of the low and its association with springs in the northern slope of the mountain also suggest that the anomaly could be caused in part by rocks in the northwest-trending fault zones.

Near the mouth of Cottonwood Canyon is a high-intensity anomaly of about 700 gammas that was observed in earlier work (Pakiser and others, 1960, p. 440) and attributed to a mass of intrusive rock. The magnetic maximum indicates that the main part of the body lies beneath the upland on the east side of the canyon, and the magnetic gradients indicate that the body is elliptical and dips steeply to the southeast. A sample of andesitic rock from the locality has an induced magnetization intensity of 0.76×10^{-3} emu/cc and a remanent magnetization intensity of 6.78×10^{-3} emu/cc, which suggests that the anomaly is produced by an intrusive body of andesite. From the shape of the anomaly, we infer that parts of the intrusive mass underlie the upland on the west side of the canyon and the lowland near the old railroad grade east of the hills and that flows extend a few miles northward from the western and eastern parts of the body. The anomaly may be the expression of a source of the discrete andesitic flows in this part of the Bodie Hills.

To the north is a pronounced magnetic low, in part related to the high-intensity anomaly. The low extends northward over the Bodie mining district and terminates near Bodie Bluff. According to geology by C. W. Chesterman and C. H. Gray, Jr. (unpub. data, 1968), the low is associated with altered andesite flows, tuff, and dacite; and it seems to coincide with a north-trending fault zone, within which blocks are broken by cross faults. Much of the volcanic rock of intermediate composition that underlies the district has undergone potassic, argillic, and propylitic alteration, and the destruction of magnetite during alteration may account in part for the magnetic low. The andesite flows may be inversely polarized and thus would contribute to the low magnetic response of rocks in the district. Brief examination of the rocks indicates that the widespread altered andesite lavas and tuff breccias are weakly magnetized by induction, whereas the intrusive andesites at Bodie Bluff and Sugarloaf have weak and strong remanent magnetization intensities, respectively. The dacite northeast of Sugarloaf displays moderate remanent magnetization, and the rhyodacite (not shown on pl. 1 because of small size) west of the district has low intensities of induced and remanent magnetization. The magnetic low corresponds in general with the location and trend of the positive gravity anomaly in the Bodie mining district. This apparent correlation suggests that these anomalies may have the same source or be closely related.

In the southeastern part of the Bodie Hills, positive anomalies occur over andesitic rocks on Cedar Hill and near the mouth of Trench Canyon. The Cedar Hill anomaly, observed at an altitude of 9,000 feet and apparently augmented by topography, has an amplitude of 180 gammas. It is centered over the crest of the hill and probably represents a thick accumulation of andesite. Andesite samples collected from the northwest slopes near the canyon have induced magnetization intensities of 0.72×10^{-3} and 0.79×10^{-3} emu/cc and remanent magnetization intensities of 0.72×10^{-3} and 1.68×10^{-3} emu/cc. The Trench Canyon anomaly has a much smaller amplitude, 80 gammas, and lies over andesitic rocks exposed on both sides of the canyon and a small extrusive feature at the base of Cedar Hill. The anomaly is attributed to a thin andesite flow partly concealed by alluvium in the canyon.

South of Aurora, a positive anomaly with two maximums and an associated minimum to the north occurs over the Brawley Peaks and their southeast slopes. The magnetic gradients indicate that the source of the anomaly may be exposed near the central and southwest peaks but is probably concealed elsewhere. Rocks coincident with the anomaly range from rhyolite to andesite; an 11-m.y.-old andesite porphyry is the major rock type in the vicinity of the western maximum. Silicified andesite and silicified andesite breccia crop out over much of the northeast peak, as shown by contour undulations in the bordering magnetic low. Granitic and metamorphic rocks are exposed off the northeast flank of the anomaly, but the anomaly is probably caused mostly by andesitic rocks whose magnetic expression is dominated by remanent magnetization. Six samples of andesite from the anomalous area have induced magnetization intensities of 0.41×10^{-3} to 1.10×10^{-3} emu/cc and remanent intensities of 0.37×10^{-3} to 2.28×10^{-3} emu/cc. A few of these rocks are inversely polarized. Latite near the base of the southeast slopes also has reversed remanent magnetization, 0.98×10^{-3} emu/cc, and has an induced magnetization of 0.40×10^{-3} emu/cc. A sample of the rhyolite was found to be virtually nonmagnetic. The granitic rocks probably are not very magnetic; one sample has 0.60×10^{-3} emu/cc induced magnetization and 0.14×10^{-3} emu/cc remanent magnetization. A sample of the metavolcanic rocks displays induced and remanent magnetization intensities of 1.25×10^{-3} and 0.56×10^{-3} emu/cc, respectively.

Southeast of Aurora, minimums in a broad zone of low magnetic intensity are associated with andesitic rocks on Aurora Peak, rhyolite on the slopes of Mount Hicks, and alluvium in the western part of Alkali Valley. The minimum over Aurora Peak is attributed to the andesitic rocks, which on the south slopes display reversed remanent magnetization, 0.24×10^{-3} emu/cc, and have an induced magnetization of 0.49×10^{-3} emu/ cc. The minimum near Mount Hicks probably is caused by the thinness of basalt flows that locally cover the relatively nonmagnetic rhyolite and may in places possess appreciable reversed remanent magnetization. These flows cap much of the upland to the south and may extend into Alkali Valley, as suggested by the southern magnetic minimum, which may be due partly to a possible deepening of Alkali Valley caused by a down-dropped fault block.

A prominent positive anomaly of nearly 400 gammas amplitude occurs over Aurora Crater and has a negative counterpart north of the crater. The positive anomaly, though enhanced by the magnetic effect of basaltic andesite flows, is interpreted as being caused mainly by a volcanic plug that lies beneath the crater. Nose-shaped highs extending eastward and southward from the flanks of the anomaly indicate that concealed thick flows or other feeder mafic rocks locally extend more than a mile from the foot of the crater. Samples of basaltic andesitic rocks near the crater contain appreciable remanent magnetization, 3.86×10^{-2} to 7.27×10^{-2} emu/cc, which suggests that the main source of the anomaly is intrusive basaltic andesite.

The elongate northwest-trending negative anomaly north of Aurora Crater probably is associated partly with thick deposits of unconsolidated sediments. Its southeast end lies over mafic volcanic rocks, suggesting that these rocks are comparatively thin lava flows, possibly overlying relatively nonmagnetic pyroclastic material or altered (oxidized) lavas. This anomaly has several intriguing aspects of possible structural significance: (1) size and amplitude of the feature gradually decrease northwestward from Fletcher to just northwest of the Ninemile Ranch; (2) trend of the low coincides with a

4-mile-long segment of the combined Bodie and Rough Creeks; and (3) a transverse lobate magnetic high cuts off the low at its northwest end, upstream from where the creeks empty into the East Walker River. The extent (about 7 miles) and linearity of the anomaly suggest that the anomaly marks a sharp structural downwarp or downfaulted bedrock.

Near Beauty Peak, west of Bodie Creek, is a circular small-amplitude magnetic high that lies partly over basalt flows. The shape of the anomaly suggests that its source may be a concealed feeder for the basalt, perhaps related to the Beauty Peak volcano.

A triangular positive anomaly near the Paramount mine coincides with an upland underlain chiefly by hornblende andesite west of Rough Creek. The anomaly probably is caused by the andesite or by similar near-surface volcanic rocks. A few oriented samples indicate that the andesite has appreciable induced and remanent magnetization and in places is reversely magnetized; rhyolite tuff in the southern part of the upland seems to be essentially nonmagnetic. The south flank of the anomaly near the Paramount mine exhibits high gradients, indicating that this side of the source is steep. These gradients form part of the north flank of the major arcuate belt of magnetic lows that extends around the north side of Bodie Mountain, to the Bodie district, and thence southeastward.

An elongate, lobate positive anomaly of low amplitude near Logan Spring, south of Masonic Mountain, may be caused by locally thickened andesitic rocks. Remanent magnetization intensities of 2.58×10^{-3} to 8.26×10^{-3} emu/cc and induced intensities of 0.75×10^{-3} to 1.25×10^{-3} emu/cc were observed in samples of these rocks. The easternmost part of the anomaly is a lobe nearly separated from the main body by a reentrant in the contour lines on the southeast flank. The reentrant could be caused by a topographic feature, but it occurs partly over rhyolite and corresponds with the northern part of an inferred fault. Another lobe of the anomaly is inferred to reflect andesitic rocks extending northwestward from Logan Spring toward East Walker River. This extension is bordered on the north by volcanic and metamorphic rocks and is probably cut by a northeast-trending fault (Koenig, 1963). Springs and magnetic gradients mark the fault zone and suggest that it continues southwestward beneath a narrow magnetic low which forms a contoured reentrant on the west side of the upland. Another inferred fault enters the low from the east. A magnetic maximum that appears to be a part of the positive anomaly and may be caused by the same source occurs over the north end of Bridgeport Reservoir. The source rock is not exposed near the dam, although it could be under water. Perhaps the maximum represents a volcanic center.

A zone of low magnetic intensity lies along the north side of the Logan Spring anomaly and its related magnetic maximums. The zone probably is a counterpart of the positive anomaly and includes rocks of low magnetic susceptibility and some that possess reversed remanent magnetization.

Along the southeast slopes of the Sweetwater Mountains, north of the Bridgeport Reservoir, is an extensive complex magnetic low that occupies the western part of the zone. The low is associated with landslide debris and colluvium bordered on the west by highly faulted granitic and pyroclastic rocks that apparently have a weak magnetic response. To the east, thin latite flows crop out along East Walker River. A sample of these rocks indicates that the flows are reversely magnetized and probably contribute to the magnetic low. Mesozoic quartz monzonite and Tertiary andesite occur beneath an arcuate part of the low intensity zone that lies over Masonic Mountain and extends southeastward beyond the National Forest boundary. A sample of the quartz monzonite displays weak induced magnetization, 0.33×10^{-3} emu/cc, and an appreciable component of reversed remanent magnetization, 1.01×10^{-2} emu/c, which accounts for part of the magnetic minimum. Altered andesites north and west of the exposed monzonite contribute to the magnetic low.

Over the upland east of East Canyon and the slopes northwest of China Camp are two magnetic maximums that are associated with Mesozoic basement rocks. These features are parts of a broad magnetic high of moderate intensity that extends northwestward from Aurora Crater and whose southwest flank is formed by steep gradients trending southeastward form the Masonic Mountain magnetic low. The source of the magnetic high is probably exposed in the vicinities of the maximums and may consist of mafic metavolcanic basement rocks. Fine-grained metavolcanic rocks, whose combined induced and remanent magnetizations could account for the anomaly, crop out beneath the west maximum. A narrow concealed part of the source, indicated by a nose in the contour lines, extends southwestward to about a mile beyond the California-Nevada State line. The central part of the magnetic high is probably caused by Tertiary intermediate volcanic rocks that underlie the upland near Rough Creek. To the west, a minor low near China Camp may represent an altered zone in the intermediate volcanic rocks.

The Homestead (Hefler) mine and prospect pits lie between the magnetic maximums east of East Canyon. Here, minor amounts of scheelite occur in tactite associated with meta-andesite (Ross, 1961, table 6.8) near the inferred source of the magnetic high.

A magnetic minimum occurs over a hill about 2 miles north of the Homestead mine. The anomaly conforms with topography and suggests that the hill may be covered by reversely magnetized andesitic or basaltic material associated with a volcanic center or vent.

PINE GROVE HILLS

The southern part of the Pine Grove Hills coincides with a zone of high magnetic intensity that is believed to be associated with rocks of a major collapsed andesitic vent centered southeast of Bald Mountain summit (north of pl. 1). Only a small part of the high extends into the mapped region (north margin of pl. 1). The low-amplitude positive anomalies along Sweetwater Creek and over the upland northwest of East Walker River are attributed to andesitic rocks that lie in the southern part of the structure. A magnetic low south of the summit probably is caused by porphyritic quartz monzonite underlying part of the feature and may be augmented by the effect of a canyon on the east side of the exposed intrusive body.

WASSUK RANGE

Positive and negative anomalies occur over granitic rocks and intermediate volcanic rocks in the southern part of the Wassuk Range. A positive anomaly lies over the south slopes of Corey Peak and extends southeastward toward Buller Mountain. It probably represents a more magnetic part of the granitic rocks, perhaps a discrete pluton, which crop out near the peak and underlie the southern part of the mountain. The southeast extension could be caused by a thick accumulation of Tertiary volcanic rocks exposed along the lower slopes. On the southwest flank of the anomaly, a nose in the contour lines suggests that volcanic rocks, or possibly granitic rocks, extend southwestward beneath alluvium into the bordering lowland. A less prominent positive anomaly attributed to granitic rocks occurs over the ridge west of Baldwin Canyon. Along the north sides of the positive anomalies is an extensive narrow zone of low intensity with magnetic minimums near Big Indian Mountain and north of Corey Peak. This zone continues several miles eastward beyond the mapped area and includes minimums near Powell Creek and over the Lucky Boy mine near Garfield Creek in the east part of the range. The zone is probably related to the positive anomalies, but magnetic gradients and the scattered alined minimums suggest that a major west-northwest-tranding fault zone passes transversely across the Wassuk Range. The Corey Peak and Big Indian Mountain minimums in the granitic terrain are sufficiently broad to suggest that they are partly related to material of low magnetic susceptibility. Prospect pits near these features indicate that mineralized rock is present, and extensive alteration at depth might account for the local magnetic lows.

Along the western foothills of the Wassuk Range is a belt of magnetic gradients that form the west flank of a high-intensity zone associated with volcanic and granitic rocks in the mountains. The belt probably coincides with the west edge of the intrusive mass that underlies the range. South of Mud Spring Canyon, a small magnetic high occurs over low hills that are underlain by Tertiary rhyolite and basaltic andesite. Local sources are inferred for these rocks, so the anomaly may be caused by volcanic plugs. The Borealis mine and several prospect pits north of Mud Spring Canyon seem to lie along the inferred margin of the granitic intrusive mass that underlies intermediate volcanic rocks exposed on Buller Mountain to the east. Near the mine, a weak magnetic low associated with alluvium in the valley extends into the mountain front. The extension of the low may mark a change in character of the volcanic rocks on the western slopes of the mountain or may reflect alteration in the underlying granitic rocks. Positive anomalies are associated with Tertiary volcanic rocks on Buller Mountain and with granitic rocks on Powell Mountain and on the spur north of Johnson Canyon in the east part of the range.

In the Anchorite Hills, at the south end of the range, magnetic maximums mark andesite flows or near-surface intrusive bodies. Southwest of Anchorite Pass, a pronounced magnetic low indicates younger andesitic rocks.

Over the Excelsior Mountains, at the east margin of the mapped area, are positive anomalies that seem to be caused by exposed Tertiary andesitic and pre-Tertiary metamorphic rocks.

MONO VALLEY

Thick accumulations of unconsolidated Quaternary lake deposits probably are the source of low-intensity zones over Mono Valley. The broad minimum on the northeast side of Mono Lake may be related to a positive anomaly observed over the lake in earlier work (Pakiser and others, 1960, p. 435). In the low-intensity zone to the east are several magnetic minimums associated with unconsolidated deposits containing large amounts of tuffaceous debris and volcanic ash. Near the old railroad grade east of Mono Lake is a positive anomaly whose eastern part coincides with cinder cones and basalt flows; the anomaly is attributed to remanent magnetization in the flows. Westward, these flows are concealed but extend almost to the lake shore. Positive anomalies coincide with a basaltic field in the Adobe Hills along the southeast edge of the mapped area.

MAGNETIC FEATURES AND MINERAL DEPOSITS

Host rocks in several of the mining localities seem to be expressed in the magnetic pattern. Those in the principal mining districts are marked by magnetic lows and zones of high magnetic gradients. Some of the features associated with zones of alteration, faults, and lithologic contacts may serve as favorable targets for exploration.

Most of the mines in the Bodie district occur in a magnetic low. At the north end of the feature, the "bonanza zone" is underlain by intrusive andesite. Mines near Silver Hill and Queen Bee Hill (Silberman and Chesterman, 1972, fig. 1), the southern limit of productivity from the district, are in fault blocks in the central part of the feature. Volcanic rocks underlying the district are intensely altered and probably are expressed by the low. The southern part of the anomaly, south of the district, may reflect an area favorable for mineralization. High gradients at the south end of the low suggest a fault. Perhaps the low is associated with rocks in a fault intersection. One might infer that because the "bonanza zone" occurs near intrusive andesite, the rocks near the source of the positive anomaly just south of the low might also be mineralized. However, the andesitic rocks associated with this positive anomaly are younger than the ore of the Bodie district (Silberman and Chesterman, 1972, p. 13–17), and correlative rocks in the region are not metallized.

Parts of the Aurora Crater positive anomaly, which is caused mainly by a volcanic plug and associated basaltic andesite flows, lie over mineralized areas in the Aurora mining district. Several major mines and prospects are along the west flank of the anomaly's south extension in veins that cut propylitized and more intensely altered Tertiary intermediate volcanic rocks. The vein complex in the Chesco mine seems to be associated with a divergence in magnetic gradients over Gregory Flats. A few prospects are beneath the east extension of the main anomaly. Several of the major mineralized zones and the north-striking faults in the heart of the Aurora district coincide with the west flank of the south extension of the Aurora Crater anomaly. This extension, however, lies athwart the vein system of the district, which generally forms a northeast-striking zone that ends approximately at the crest of the anomaly. The south extension is believed to be caused by rocks in part of the conduit system that fed the Aurora Crater volcano or by a dike that extends southward from the conduit. The rock concealed beneath the extension could have been intruded into either a newly formed or a reactivated old fracture or fault. Because the ore deposits predate the basaltic andesite of Aurora Crater by about 10 m.y., clearly the south extension of the Aurora Crater anomaly is not caused by rocks genetically related to the ore deposits. Magnetic gradients northeast and south of the Chesco mine indicate a sharp contact that may be a fault between the postore andesitic rocks of Aurora Crater and those of Aurora Peak. Mines and prospects in the southern part of the district are on the north flank of a weak magnetic low indicated by a reentrant in the contour lines. The low, apparently associated with altered rocks, extends southward into the minimum over silicified rocks in the northern part of the Brawley Peaks. The silicified rocks represent a southwestward extension of the zone of alteration that underlies the mining district.

The elongate northwest-trending magnetic low north of Aurora Crater, described previously as extending for several miles to just northwest of the Ninemile Ranch, is not associated with known ore deposits but demarcates an area in which placer deposits might be found. The shape and direction of the low, its abrupt termination on the northwest, and its coincidence with parts of Bodie and Rough Creeks all suggest a structural feature in the bedrock beneath unconsolidated valley fill. There is a strong likelihood that streams draining the Bodie and Aurora mining districts during Pliocene and Pleistocene time partly followed the same course as the present drainages, and thus a possibility that gold and silver placer deposits, originally derived from bedrock in the Bodie and Aurora mining districts, lie at or near the base of the unconsolidated valley-fill deposits along the trace of this elongate magnetic low. A structural and geomorphic trend, probably extant by at least the Pleistocene, and perhaps the late Pliocene, is inferred from the geology and the narrow magnetic low and may take the form of either a narrow downwarp or a fault zone which partly controlled the main drainage from Bodie and Aurora and along which the thickest unconsolidated valley-fill deposits may be localized. Exploration by gravity or seismic geophysical techniques could probably verify the existence of the feature as a major topographic low in the bedrock surface. Special attention should be directed toward that part of the feature extending to about 1½ miles northwest of the Ninemile Ranch, where an abrupt change in either direction or grade of the pre-Holocene main drainage could have enhanced the likelihood of formation of a major placer deposit.

The north flank and west end of the Masonic Mountain magnetic low is coincident with the Masonic mining district. Main mines occur in highly silicified volcanic rocks that in part are spatially related to major northeast-trending faults. The northern gradients of the low are part of a northwest-trending belt that may be the reflection of a structural lineation. Mines between New York Hill and Dome Hill (Bridgeport, Calif.-Nev., 15-min. quad., 1958) appear to be associated with this lineation. The Chemung and Success mines in the southwestern part of the district are in a fault zone that joins another zone or bifurcates south of the Success mine, one branch continuing southwestward across the upland and another swinging southeastward along the southwest flank of Masonic Mountain. Near McMillan Spring the southeast branch of the fault zone coincides with a divergence in trend of a belt of steep magnetic gradients that may be related to a structural complex. Very likely the locality of divergence is a favorable target for prospecting. Another locality of probable alteration and ore potential is near the southwest branch of the fault zone, about 2 miles west of Logan Spring. Here, strands of the fault zone, partly marked by springs, separate Tertiary andesitic rocks from pre-Tertiary metamorphic rocks and possibly from Tertiary welded tuff at the northeast end of a magnetic low that may be associated with altered rocks.

About a mile northwest of Potato Peak, in the central part of the Bodie Hills, mercury deposits in rhyolite occur at shallow depths in a zone of altered rocks marked by a magnetic low that forms a reentrant in the contour lines. The magnetic pattern suggests that the low continues southward from the mercury mines toward Warm Spring, where extension of the altered zone may intersect a northwest-trending fault. Altered rocks in the low and springs along it, such as Warm Spring and another spring near the mines, indicate a fault zone that passes through the western slopes of Bodie Mountain. Rocks within this belt of low magnetic intensity may contain undiscovered mercury deposits. The closed low near Potato Peak also may represent a favorable exploration target, as it is centered near several springs at the head of Rough Creek in a faulted vent area and is very likely associated with highly altered rocks.

About 3½ miles northeast of Potato Peak, a little mercury ore was produced from silicified rhyolite and rhyolite (?) and dacite (?) tuffs in the vicinity of the Paramount mine. The rhyolite bodies are too small to be shown on the map. A belt of steep magnetic gradients over this locality marks the relatively steep south side of an inferred source of the magnetic maximum on the north and partly coincides with the zone of altered rocks and rhyolite (?) intrusive bodies. This coincidence and the fact that the magnetic gradients form part of the flank of a relatively continuous belt of magnetic lows, described previously, indicate that parts of the belt of lows might be favorable for finding additional ore deposits.

In the northern Bodie Hills, the Homestead (Hefler) mine and prospect pits lie between two magnetic maximums that are part of a broad magnetic high east of East Canyon. Here, minor amounts of scheelite occur in tactite along a steep nearly north striking fault in meta-andesite (Ross, 1961, table 6.8) near the source of the high. The weak magnetic response of rocks in this locality may be caused by alteration in the fault zone, which probably extends north and south of the mine workings.

In the northeast part of the area mapped, the Big Indian and Lucky Boy mines (Ross, 1961, table 6.3) are in a zone of low magnetic intensity that extends for several miles across the Wassuk Range. The Big Indian mine, which consists of several adits and shallow shafts, lies in the northern part of the minimum north of Corey Peak. Gold ore was mined from gold-, chalcopyrite-, and pyrite-bearing quartz veins in granodiorite. Very likely the minimum is partly related to deep alteration in the plutonic rocks. The Lucky Boy mine, which has extensive workings including an adit and several shafts, yielded silver, gold, and lead ore from veins in a fracture zone in metavolcanic rocks and marble of the Excelsior Formation near a granitic intrusive contact. The mine workings are in a magnetic minimum that coincides with the general area of the Excelsior outcrops. Gradients along the south side of the low probably mark the main granitic rock contact. The mineralized fracture zone may be a part of a major structure inferred from the continuity of the low intensity zone through the range. Local minimums west of Big Indian Mountain, north of Corey Peak, and near Powell Creek to the east may represent localities of extensive rock alteration that warrant further investigation.

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