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Gold-Bearing Deposits in North-Central Nevada and Southwestern Idaho[1]

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With a section on

Periods of Plutonism in North-Central Nevada

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Abstract

Gold-bearing deposits in north-central Nevada occur in a wide variety of geologic environments related to major stratigraphic and structural features. These environments include pre-Tertiary sedimentary and metamorphic rocks, granitic rocks, and volcanic rocks of pre-Tertiary and Tertiary age which have been complexly deformed. The deposits were formed during five principal intrusive metallogenic episodes; the oldest is Jurassic, two are Cretaceous, one early Tertiary, and the last, late Tertiary. Three major epigenetic groups of gold-bearing deposits are recognized: replacement deposits, disseminated deposits, and veins. The replacement deposits may be subdivided in order of decreasing temperature of formation into contact pyrometasomatic deposits, base-metal deposits, and peripheral gold-silver deposits. The disseminated gold deposits seem to be intermediate in mineralogy between the peripheral replacement deposits and low-temperature veins, but differ in that they contain only minor amounts of silver. They are here considered to be a distinct group. The veins are subdivided into two classes: veins in pre-Tertiary and granitic rocks and veins in or associated with Tertiary volcanic rocks.

Contact pyrometasomatic deposits have yielded significant production in only one district, Battle Mountain (Copper Canyon and Copper Basin), where calc-hornfels containing pyrite, chalcopyrite, pyrrhotite, arsenopyrite, sphalerite, and galena was mined as copper-gold ore. Base-metal replacement deposits occur at Eureka (silver-gold-lead-zinc) and Copper Canyon (copper-gold and zinc-lead-silver). Peripheral gold-silver deposits occur at Eureka and Copper Canyon.

Disseminated gold deposits such as Carlin, Cortez, Getchell, and Gold Acres, which are relatively new discoveries, have yielded significant production to date and have excellent potential for continued large-scale future production. They are characterized by generally low-temperature mineral assemblages which include pyrite, quartz, gold, realgar, stibnite, cinnabar, sphalerite, and galena.

Gold-quartz veins in pre-Tertiary and granitic rocks generally contain sulfide assemblages similar to those of the high-temperature replacement deposits; medium-temperature veins are characterized by tetrahedrite, galena, sphalerite, and pyrite; low-temperature veins by pyrite and galena and by stibnite-quartz. Veins in volcanic rocks or in basement rocks just beneath are divisible into three types: argentite-quartz-adularia veins containing pyrite, gold, and sparse galena and sphalerite; argentite-quartz-adularia veins characterized by pyrite, gold or electrum, argentite, naumannite, and lesser amounts of base-metal sulfides; and stibnite-quartz veins containing argentite and silver sulfosalts, locally with adularia.

Introduction

Metal deposits in Nevada were subdivided by Ferguson (1929) into two principal groups, those associated with intrusive rocks and those with volcanic rocks (Table 1). This classification is still valid except that the disseminated gold deposits discovered during the last 40 years at Getchell, Gold Acres, Carlin, and Cortez do not fit readily into the scheme and some modification is required (Joralemon, 1951; Ketner, in Gilluly and Gates, 1965; Roberts, 1960, 1964, 1966; Hardie, 1966; Erickson et al., 1966; Hausen and Kerr, 1968; Hewitt, 1968; Wells, Stoiser, and Elliott, 1969). In addition, many new data on the structural environment, geochronol-

[1] Publication authorized by the Director, U. S. Geological Survey.

ogy, and geochemistry of the ore deposits are available. Some of these new data will be summarized here with particular emphasis on the gold-bearing deposits in north-central Nevada and southwestern Idaho (Figs. 1, 4). In this report Roberts is responsible for the geologic framework and sections on replacement deposits; Roberts and Radtke for the section on disseminated deposits; Coats for the sec-

TABLE 1. Metallogenic Epochs in Nevada (Ferguson, 1929)

I Deposits associated with intrusive rocks	
A. Jurassic or Cretaceous Argentiferous quartz veins	B. Early Tertiary Base metals, silver and gold
II Deposits associated with volcanic rocks	
C. Pre-late Miocene Silver-gold deposits	D. Post-late Miocene Gold-silver deposits

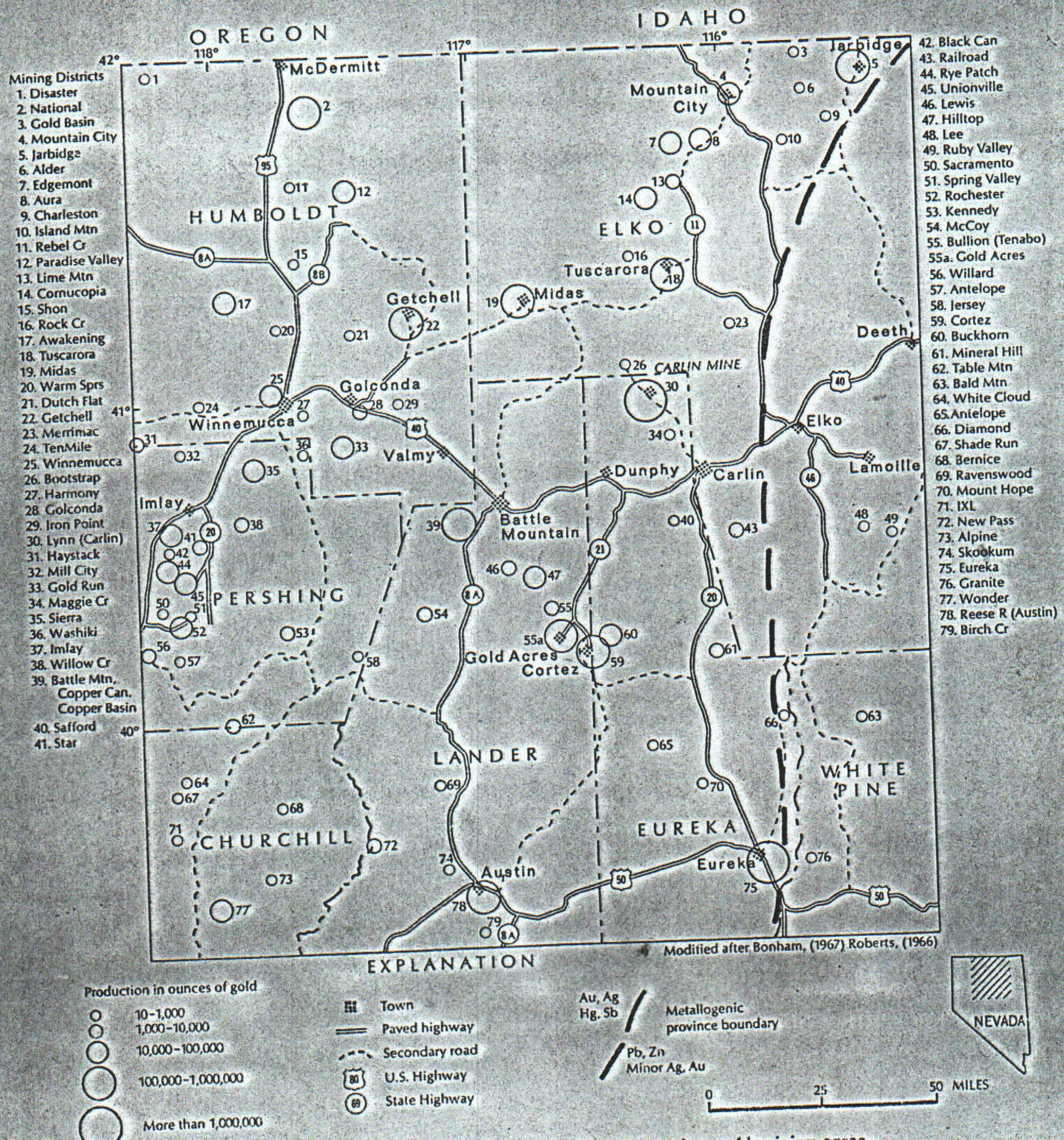

FIG. 1. Index map of north-central Nevada showing gold mining areas.

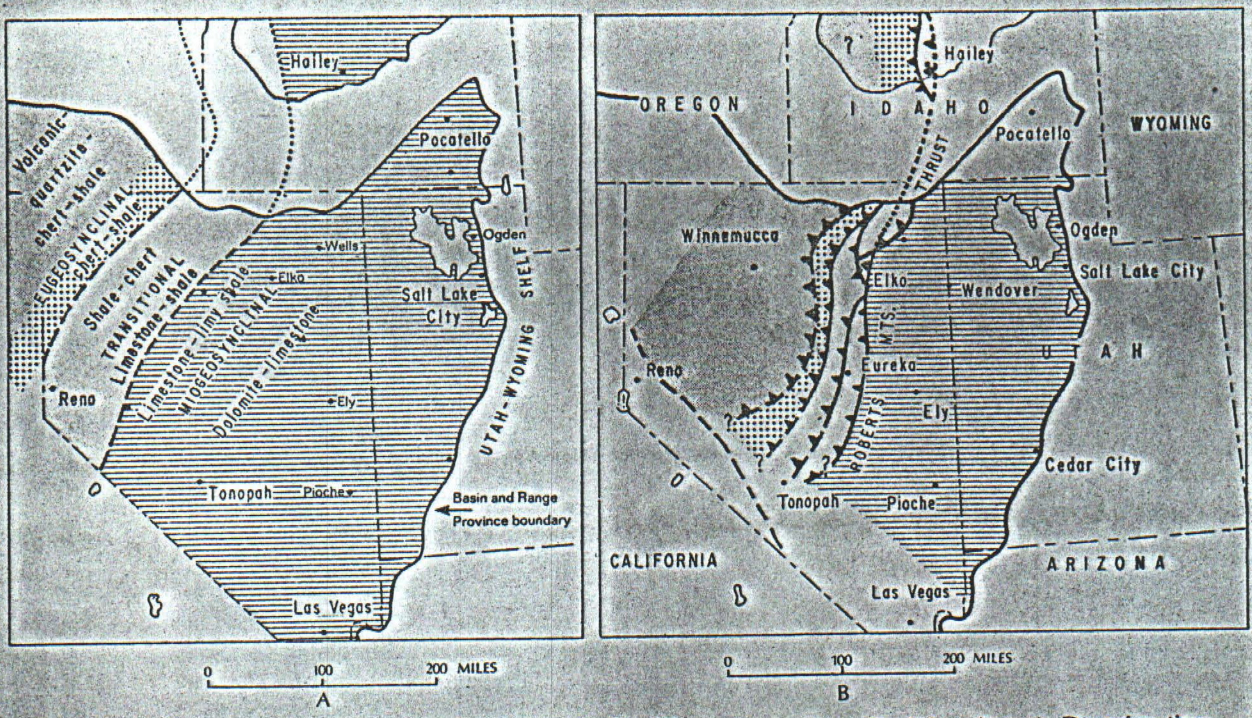

FIG. 2. *A*, Map showing distribution of facies in the Cordilleran geosyncline, Cambrian through Devonian time. *B*, Distribution of facies after late Devonian to early Mississippian thrusting.

tion on veins; and Silberman and McKee for the section on age of plutonism.

Structural and Stratigraphic Framework

Precambrian Time

The ore deposits of the Western United States are localized in a structural framework that formed in Precambrian time and which has continued to develop till the present day. The Precambrian structural tectonic events developed northeasterly, east-west, and northwesterly stratigraphic and structural trends (Roberts, 1957, 1960, 1966, 1968; U. S. Geol. Survey, 1968). The principal northeasterly trend was paralleled by the Cordilleran geosyncline, which formed in late Precambrian time and was a zone of major subsidence until Late Devonian time. East-west orogenic trends along zones of Precambrian deformation have been recognized in central Utah; these trends have been projected into western Utah and Nevada (Roberts et al., 1965; Zietz et al., 1969), where they are recognized in east-west alinements and uplifts and in block faulting. Northwesterly trending features that probably follow structures of Precambrian origin include mineral belts characterized by lines of fractures, domes, and faults.

Paleozoic Time

The Cordilleran geosyncline, which came into existence in late Precambrian time, was the site of deposition of three principal facies in northeasterly trending belts (Fig. 2*A*): an eastern carbonate facies (miogeosynclinal) and a western siliceous and volcanic facies (eugeosynclinal), separated by a transitional facies. Deposition in these belts continued until Late Devonian time, when it was interrupted by the Antler orogeny that lasted until Middle Pennsylvanian time (Roberts et al., 1958; Kerr, 1962; Smith and Ketner, 1968).

During the Antler orogeny, in latest Devonian or earliest Mississippian time, a great glide plate moved eastward from the orogenic belt into central Nevada. The plate was composed mostly of eugeosynclinal and transitional rocks and it overrode rocks of the carbonate facies, reaching points along a sinuous line from Eureka nearly to Wells (Fig. 2*B*). Uplift along northwest-trending belts at places formed domes in Late Pennsylvanian time; these domes were further accentuated during Mesozoic and early Tertiary intrusion and deformation, forming a favorable structural and stratigraphic environment in which gold-bearing deposits were localized.

Mesozoic and Tertiary Time

During early Mesozoic time north-central Nevada was intermittently covered by shallow seas; local volcanism and plutonism in Permian and Early Triassic time heralded orogeny at the end of Jurassic (Muffler, 1964; Wallace and Tatlock, 1962; Wallace, Tatlock, and Silberling, 1960; Wallace, Tatlock, Silberling, and Irwin, 1969). Since then, the region has been undergoing uplift and erosion. In late Mesozoic time, block-faulting, accompanied by igneous intrusions and volcanic activity, ushered in a new regime which culminated in the development of basin-and-range structure. The cycle began with the emplacement of intrusive bodies during late Eocene and early Oligocene time, followed soon after by widespread volcanism throughout Oligocene, Miocene and Pliocene time. Block-faulting, which gave rise to the present topography, was most intense in Pliocene and early Pleistocene time.

Metallogenic Provinces

Nevada may be divided into two major metallogenic provinces: a western one, characterized by gold, silver, tungsten, mercury, and antimony deposits; and an eastern province, characterized by lead and zinc deposits with minor silver and gold[2] (Figs. 1, 5) (Ferguson, 1920; Bateman, 1950; Roberts, 1966). The boundary between the provinces is gradational and roughly bisects north-central Nevada. Copper, tungsten, and molybdenum deposits occur in both provinces.

The ore deposits of the western or precious metal province occur mostly in eugeosynclinal Paleozoic and Mesozoic rocks (shale, chert, graywacke, volcanic rocks, and minor limestone) and in overlying Tertiary rocks. The eugeosynclinal rocks were deposited on simatic oceanic crust 5–10 km thick. The ore deposits of the eastern or base-metals province occur mainly in miogeosynclinal carbonate rocks (limestone, dolomite, and minor shale) that were deposited on sialic crust.

The boundary between the two provinces coincides broadly with the boundary between major geosynclinal trends and with the frontal zone of the Roberts Mountains thrust fault. The nature of these relationships is not clear, but processes related to geosynclinal sedimentation and subsequent orogeny resulted in conversion of the upper mantle under the geosyncline to continental crust with consequent magmatism and volcanism during several epochs (Bateman, 1950; Coats et al., 1965; Roberts, 1968).

Periods of Plutonism in North-Central Nevada

In north-central Nevada (Fig. 3) there are approximately 50 plutons of coarse-grained equigranular to porphyritic quartz-monzonite to granodiorite. These bodies range from about 130 to less than 1 square kilometer in outcrop area. Although many bodies appear to be distributed randomly in the region, others may be structurally controlled. Thirty-one of these plutons have been dated by the K-Ar method, and their ages are considered representative of the times of major plutonism.

The grouping of ages indicates that plutonism occurred during five periods in the Mesozoic and Cenozoic (Fig. 4). The oldest group of dates in Jurassic (168 to 143 m.y. old), then follow two Cretaceous groups (105 to 87 and 71 to 68 m.y. old, respectively), the next group is early Tertiary (40 to 30 m.y. old) and the youngest group is late Tertiary (16 to 10 m.y. old).

Widespread tectonic activity including the emplacement of large granitic bodies west of central Nevada in the Sierra Nevada is reflected by the plutons of the two older age groups in north-central Nevada. The oldest group of north-central Nevada plutons are the same age as parts of the Inyo and Yosemite intrusive epochs of the Sierra Nevada batholith as defined by Evernden and Kistler (1970; Fig. 4). The older of the Cretaceous periods of plutonism in north-central Nevada is about midway in age between the Huntington Lake and Cathedral Range Sierran intrusive epochs of Evernden and Kistler (1970; Fig. 4), and a number of plutonic rocks in the Sierra Nevada batholith have been dated at about 100 m.y. as well. The younger Cretaceous intrusive rocks in north-central Nevada (70 m.y. old) correspond in age to early Laramide, as defined by Damon and Mauger (1966). The early Tertiary (40 to 30 m.y. old) plutons in north-central Nevada are the same age as the start of Tertiary igneous activity in the Great Basin (McKee and Silberman, 1970a, b). Plutonic rocks of Laramide and middle Tertiary age are not found in the Sierra Nevada, suggesting that the two younger periods of plutonism (70 m.y. and 40 to 30 m.y.) in north-central Nevada are not related to Sierran intrusion but are related to geologic events in the eastern Great Basin.

Large bodies of plutonic rocks younger than about 30 m.y. old are not known in north-central Nevada, but widespread volcanic rocks younger than about 16 m.y. old probably have deep-seated plutonic equivalents not exposed at the present level of erosion. This younger group (16 to 10 m.y. old) shown in Table 2 was defined by McKee and Silberman (1970a) from occurrences in the Sheep Creek Mountain and northern Shoshone Ranges, and is represented by basaltic andesite to rhyolite flows and dikes. A swarm of these dikes and flows also occurs in the Cortez Mountains and Roberts Mountains (Fig. 3).

Roberts and Coats consider that the five intrusive epochs in north-central Nevada also represent distinct metallogenic epochs, and have so designated them in Table 2. The replacement deposits were

[2] An exception to this pattern is the Ely district, which contains porphyry copper deposits; the gold content of the ore is low, but the total production is significant because of the enormous tonnage of ore treated.

Figure 3


118°
117°
116°
41°
40°
39°
HUMBOLDT
ELKO
PERSHING
LANDER
EUREKA
CHURCHILL
NYE
Winnemucca
Battle Mountain
Carlin
Elko
Austin
Eureka
Osgood Mts
Tuscarora Mts
Sonoma Range
Buffalo Mt
Battle Mountain
East Range
Tobin Range
Fish Creek Mts
Shoshone Range
Cortez Mts
Stillwater Range
Alpine
Mountains
Clan
Toiyabe Range
Simpson Park Range
Roberts Mts
Diamond Range
Shoshone Mts
Toquima Range
Monitor Range
Antelope Range
80
50
NEVADA
120°
114°
42°
36°
0 10 20 30 40 50 MILES

Figure 3 (cont'd.)

	Age in m.y.	
1. Osgood Mountains pluton	90	
2. Gregg Canyon pluton	104	
3. Buffalo Mountain plutonic complex	146	159
4. Stony Basin pluton	105[1]	
5. Lee Peak pluton	150	
6. Granite Mountain (Humboldt Range) plutonic complex	30[2]	
7. New York Canyon pluton	69	
8. Trenton Canyon pluton	87	
9. Copper Canyon pluton	38	
10. Elder Creek pluton	37	
11. Tobin pluton	153	
12. McCoy pluton	153	
13. Hilltop pluton	38	
14. Granite Mountain (Shoshone Range) pluton	37	
15. Gold Acres quartz monzonite	99	
16. Goat Ridge pluton	35	
17. Tenabo pluton	38	
18. Cain Creek pluton	155	
19. Ravenswood pluton	71	
20. Swales Mountain pluton	39	
21. Frenchie Creek plutonic complex	143[3]	153
22. Mill Canyon pluton	150[3]	
23. Cortez dike	34[1a]	Wells and others, 1969
24. Cortez dike swarm	-	
25. Iowa Creek pluton	68	
26. Grass Valley pluton	68	
27. Austin pluton	157	
28. Walti pluton	33	
29. Clipper Gap pluton	151	
30. Northumberland pluton	154	
31. Mount Hope pluton	36	
32. Whistler Mountain pluton	152[3]	
33. Ruby Hill	100	

Intrusive epochs in north-central Nevada

- V — 16-10 (Late Tertiary)
- IV — 40-30 (Early Tertiary)
- III — 71-68 (Late Cretaceous)
- II — 105-87 (Cretaceous)
- I — 168-143 (Jurassic)
- undated intrusive body

Note: The age of Grass Valley Pluton (No. 26) should read 168 m.y., not 68 m.y.

FIG. 3. Plutons in north-central Nevada. Modified from Map 30, Nevada Bureau of Mines by Roland V. Wilson and Richard R. Paul. K-Ar age and name of pluton listed.

formed during the first four of these epochs; certain of the disseminated gold deposits are also apparently associated with igneous rocks of the first three

Table 2. Intrusive and metallogenic epochs in north-central Nevada

Intrusive and Metallogenic epoch	Age span, m.y. before present	Characteristic metals and source of data
V Late Tertiary	16- 10 (McKee and Silberman, 1970a)	Gold, silver, mercury (Gilluly and Masursky, 1965; Wells, Stoiser, and Elloitt, 1969; Schilling, 1965)
IV Early Tertiary	40- 30 (Silberman *et al.*, 1969; McKee and Silberman, 1970a)	Major base metals, gold, silver, antimony (Roberts, 1966; Wells, Stoiser, and Elliott, 1969)
III Late Cretaceous	71- 68 (This Report)	Tungsten, silver, gold.
II Cretaceous	105- 87 (This Report)	Tungsten, base metals, gold (Hotz and Willden, 1964)
I Jurassic	168-143 (This Report)	Tungsten, minor base metals, minor silver and gold (Muffler, 1964; Coats *et al.*, 1965; Coats, 1967; Gilluly and Masursky, 1965)

epochs, but the principal gold metallization may have taken place during the fourth (40–30 m.y.). The veins contained in granitic and pre-Tertiary rocks were mostly formed during the first three epochs; the veins in volcanic rocks were formed during the last two epochs.

Mineral Belts

The principal gold deposits in north-central Nevada occur in mineral belts that trend northwestward and northeastward (Roberts and Lehner, 1955; Roberts, 1957, 1966). The principal northwesterly belts that have been recognized are the Lynn-Railroad, Battle Mountain-Eureka, Getchell-National, and Lovelock-Austin; the northeasterly Shoshone-Jarbidge belt cuts across the northwesterly trends (Table 3; Fig. 5).

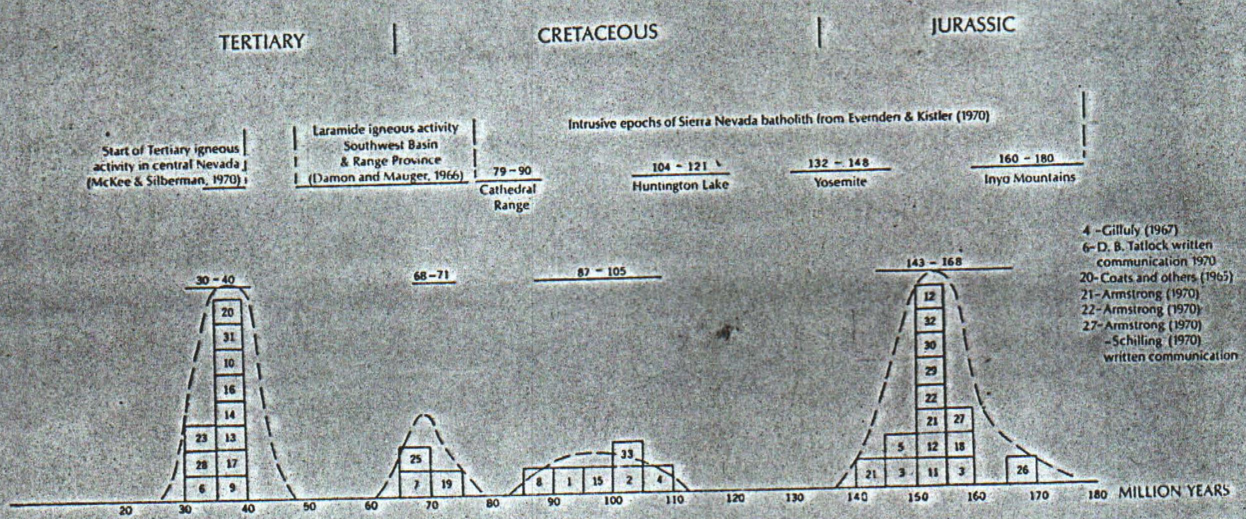

FIG. 4.

Table 3. Mineral belts in north-central Nevada

Mineral belt and trend	Geology	Commodities	Basis for recognition	Source
Lynn-Railroad N. 40°-47° W.	Paleozoic limestone, calcareous siltstone	Au, Ag, Pb	Alinement of windows intrusive bodies and districts; aeromagnetic data	Roberts and Lehner (1955); Roberts (1957, 1960); Hardie (1966); Hausen and Kerr (1968); Roberts *et al.* (1967).
Battle Mountain-Eureka N. 40°-47° W.	Paleozoic chert, shale, limestone; calcareous conglomerate	Au, Ag, Cu Pb, Zn	Alinement of districts and intrusive bodies; aeromagnetic data; geochemical data	Roberts and Lehner (1955); Nolan, Merriam, and Williams (1956); Nolan (1962); Roberts and Arnold (1965); Roberts *et al.* (1965); Shawe (1965); U.S. Geol. Survey (1968).
Getchell-National N. 25°-30° W.	Paleozoic chert, shale, limestone; calcareous conglomerate	Au, Ag, W	Alinement of districts; aeromagnetic data	This paper.
Lovelock-Austin N. 40° W.	Paleozoic chert, shale, volcanic rocks; limestone	Ag, Au, Pb, W	Alinement of districts; aeromagnetic data	Roberts and Lehner (1955); Roberts, (1966); Ross (1953).
Shoshone-Jarbidge N. 40° E.	Paleozoic chert, shale, volcanic rocks; Tertiary volcanic rocks	Barite, Au Ag, Hg, W	Alinement of district, fracture zones, and geosynclinal trends	Ketner *in* Gilluly and Gates (1965); Roberts (1966); D. R. Shawe (oral commun., 1966); Landwehr (1967).

The mineral belts have been defined from structural, geophysical, and geochemical evidence (Roberts, 1966, p. 57). Structural evidence is best shown by the striking northwestward alinement of windows in the upper plate of the Roberts Mountains thrust fault, as along the Lynn-Railroad and Battle Mountain-Eureka belts. The northwest trends are considered to be of probable Precambrian age, and may have developed as a set of fractures normal to the earlier northeast-striking geosynclinal trends. Shawe (1965; U. S. Geol. Survey, 1968, p. A30) considers them to be strike-slip faults. Geophysical evidence includes a series of broad aeromagnetic anomalies that follow a N40°W zone related to stocklike intrusive bodies such as those of Lewis, Gold Acres, and Hilltop districts (Roberts, 1966). Pertinent geochemical evidence is the isotopic composition of lead in galena from deposits along the Battle Mountain-Eureka and Lynn-Railroad belts. The ratios of lead isotopes of the two belts are distinctly different, suggesting that the lead may have been derived from different mantle sources (Arthur Pierce, oral communication, 1963).

Fig. 5. Mineral belts in north-central Nevada modified Roberts (1966).

The intrusive rocks in north-central Nevada follow at least two tectonic trends (Fig. 3): (1) northeasterly, parallel to Cordilleran geosyncline trends, and (2) northwesterly, parallel to deep-seated fracture systems which control the mineral belts. A possible northeasterly alinement of plutons of group I extends from Austin (27 on Fig. 3) along the Toiyabe Range to the Frenchie Creek plutonic complex (21 on Fig. 3); another local alinement includes plutons southwest of Gregg pluton (2 on Fig. 3). A notable northwesterly alinement of plutons of group IV lies in the Battle Mountain-Eureka mineral belt.

Table 4. Gold-bearing deposits in north-central Nevada and southwestern Idaho

Est. T.°C	I. Replacement deposits	Est. T.°C	II. Disseminated deposits	Est. T.°C	III. Veins: Veins in pre-Tertiary stratified rocks and plutons	Est. T.°C	III. Veins: Veins associated with Tertiary volcanic rocks
150		*					
		*	Disseminated gold deposits (pyrite, quartz, gold, realgar; minor stibnite, cinnabar, sphalerite, galena) (Carlin; Cortez; Gold Acres) Est. depth 2,000-5,000 ft	*	Stibnite-quartz (SQ) veins (±pyrite, minor galena) (Battle Mountain) Est. depth 1,000-5,000 ft		Stibnite-gold (SG) veins (±argentite, polybasite, electrum, minor cinnabar). National) Est. depth 1,000-3,000 ft
225		*					Argentite-adularia-quartz (AAQ) veins (±naumannite, (Jarbidge; Midas) Est. depth 1,000-4,000 ft
	Peripheral gold deposits (pyrite, gold, argentiferous galena, sphalerite, minor tellurides)[1] (Battle Mountain) Est. depth 3,000-10,000 ft				Tetrahedrite-quartz (TQ) veins (tetrahedrite, gold, sphalerite, galena, rhodochrosite) (Gold Creek; Reese River) Est. depth 2,000-5,000 ft		Argentite-adularia-quartz (AA) veins in pre-Tertiary rocks (±naumannite, gold, pyrite, galena) (Silver City; Tuscarora) Est. depth 2,000-5,000 ft
300	Base metal replacement deposits (pyrite, argentiferous galena, arsenopyrite, chalcopyrite, siderite, sphalerite, gold) (Battle Mountain; Eureka) Est. depth 3,000-10,000 ft			*	Arsenopyrite-quartz (AQ) veins (arsenopyrite, gold, pyrite, galena, sphalerite) (Battle Mountain) Est. depth 3,000-10,000 ft		
375	Pyrometasomatic deposits (scheelite, molybdenite, pyrrhotite, bismuthinite, arsenopyrite, pyrite, galena, chalcopyrite, sphalerite; gold in sulfides) (Battle Mountain; Eureka) Est. depth 3,000-10,000 ft						
450							
Ranges	Pyrometasomatic (est.)[2]; * Replacement * (est.)[3]; *Peripheral (est.)[4]*		Disseminated		SQ veins (est.)[4]; TQ veins (est.)[3]; AQ veins (est.)[3]		SQ veins (est.)[4,5]; AAQ veins in vol. (est.)[5]; AA veins (est.)[5]

[1]Mineral assemblages characteristic of each group shown in parentheses; not all species listed are found in each deposit.
[2]Temperature range of pyrometasomatic deposits from Ridge (1969, p. 1816-17) 300°-600°C., Park and MacDiarmid, 1964, p. 210.
[3]Range of mesothermal replacement deposits and veins from Ridge (1969, p. 1817); Sawkins (1964, p. 883-919); Roedder and Creel (1965); Roedder (1967); Meyer *et al.* (1969, p. 1412); Helgeson and Garrels (1968); Lovering (1950).
[4]Ranges of peripheral deposits and low-temperature stibnite-quartz and stibnite-gold veins using upper mesothermal and leptothermal ranges from Ridge (1969, p. 1817); Dickson and Tunell (1969, p. 1690); White (1967); Browne (1969).
[5]Ranges of veins in volcanic rocks from Ridge (1969, p. 1817); near-surface veins from White (1955, p. 103-108, 140-141); White (1967); Browne (1969).
*Temperature determinations by U.S. Geol. Survey (1970, p. A7) and from Nash and Theodore (1971), and Radtke (unpub. data on Carlin and Cortez deposits).

Gold Deposits

Classification

On the basis of form and host rock, gold deposits in north-central Nevada and southwestern Idaho may be divided into three major classes: replacement deposits, disseminated deposits, and veins. The replacement deposits may be subdivided into pyrometasomatic deposits, base-metal replacement deposits, and peripheral gold deposits. Carlin-type disseminated gold deposits appear to be a distinct class and are treated here separately. The veins have been subdivided into veins in pre-Tertiary and granitic rocks and veins in or associated with Tertiary volcanic rocks. Characteristics of these deposits have been summarized in Table 4 to show the inferred relationship in mineralogy and temperature and depth of formation of one group to another. It is recognized that the isogeothermal surfaces are curved over intrusive bodies and along structural features so that some estimates of depth of formation may need modification.

Replacement Bodies

Replacement bodies have been the most productive ore deposits in north-central Nevada. They were mostly discovered in the 1860's and dominated the American mining scene during the 1870–90 period. The Eureka district leads in production with more than $120 million, mostly in gold, silver, and lead. Battle Mountain is next with more than $20 million (Roberts and Arnold, 1965; Meisinger, 1969), followed by Cortez with more than $13 million.

The replacement deposits are generally arranged zonally around small stocks of quartz monzonite or granodiorite. The central zone is characterized by

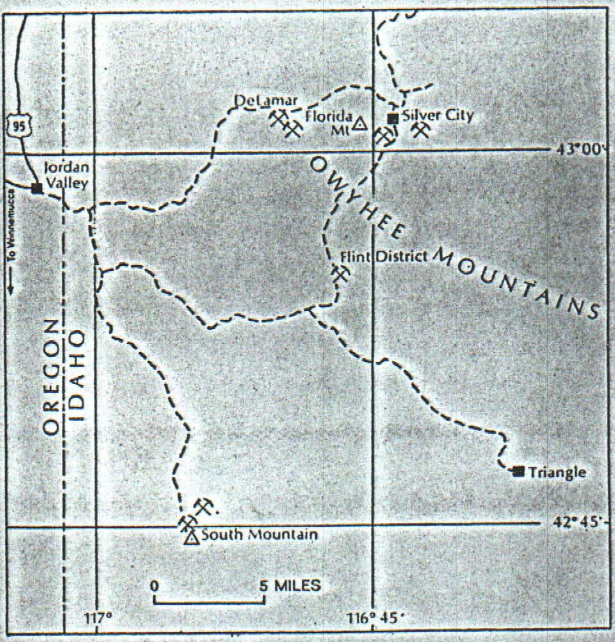

FIG. 6. Index map of southeastern Idaho.

a pyrometasomatic assemblage of high-temperature silicate and sulfide minerals. This zone is bordered by an inner envelope of base-metal replacement bodies containing gold and silver, and grades outward into peripheral gold-silver deposits. This zonal arrangement has been noted at Eureka, Battle Mountain, South Mountain, and Cortez.

The pyrometasomatic deposits represent the highest temperature gold-bearing deposits in the region. Gangue minerals include garnet, hedenbergite, ilvaite, diopside, wollastonite, zoisite, and related minerals; the ore minerals, which commonly appear to have been introduced later than the silicates, include pyrrhotite, pyrite, arsenopyrite, chalcopyrite, and some sphalerite and galena. The gold content is generally low. Ore was mined from the pyrometasomatic zone at Copper Canyon and South Mountain chiefly for its base-metal content.

Replacement base-metal deposits in the Eureka and Cortez districts are in dolomite of early Paleozoic age; the deposits in the Battle Mountain district are in conglomerate and limestone of late Paleozoic age. All these deposits are characterized by pyrite, arsenopyrite, pyrrhotite, and varying amounts of chalcopyrite, sphalerite, and galena. Quartz and calcite are the principal gangue minerals. Many of the ore bodies contain significant amounts of silver and gold, and some ore bodies were mined principally for their precious-metal content.

Peripheral gold deposits associated with base-metal deposits occur in the Eureka, Battle Mountain, and Cortez districts. These deposits are generally in outer zones beyond the main base-metal deposits, and thus far have yielded only small production. They are of interest principally because they are thought to form a link between some base-metal deposits containing precious metals and the disseminated gold deposits. The nature of this link will be discussed in the section on disseminated deposits.

Southwestern Idaho.—Gold-bearing replacement deposits on South Mountain in southwestern Idaho include pyrometasomatic and base-metal replacement bodies which are in Paleozoic(?) limestone and shale cut by granodiorite (Lindgren, 1900; Piper and Laney, 1926; Sorenson, 1927) (Fig. 6). The flanks of South Mountain are overlapped on all sides by Tertiary volcanic rocks which conceal the relationship of the Paleozoic(?) limestone and related rocks to Paleozoic rocks in other parts of Idaho and Nevada. The pyrometasomatic deposits associated with granodiorite on South Mountain contain high-temperature silicates such as hedenbergite, ilvaite, diopside, and garnet; the sulfides are pyrite, chalcopyrite, arsenopyrite, sphalerite, and a little galena. The replacement deposits which fringe the pyrometasomatic zones contain similar sulfide assemblages. All of these deposits contain small amounts of gold and silver, but the principal gold-bearing ore bodies were found in the associated veins (Sorenson, 1927, p. 40).

Battle Mountain district.—The Battle Mountain district contains a full range of replacement deposits, including pyrometasomatic, base metal, and peripheral. The principal production has come from the Copper Canyon and Copper Basin areas (Roberts and Arnold, 1965).

The district is underlain by silicic and volcanic rocks of the upper plate of the Roberts Mountains thrust (Scott Canyon, Valmy, and Harmony Formations) which was overlapped by late Paleozoic rocks (Battle Formation, Antler Peak Limestone, and the Edna Mountain Formation) and overridden by the Golconda thrust plate. The ore bodies at Copper Canyon are mostly in the Battle Formation just below the Golconda plate. The ore bodies at Copper Basin are in the Battle Formation and the underlying Harmony Formation.

The Copper Canyon mine was worked in several stages: in the 1860's and 1870's high-grade copper deposits along faults were mined; in the 1930's through 1957 copper-gold ore in underground workings was milled by the International Company and Copper Canyon Company; since 1967 copper-gold ore from an opencut north of the underground workings together with sulfide ore from Copper Basin has been milled by the Duval Corporation in a 5,000-ton-per-day plant at Copper Canyon.

The ore mined in underground workings at Copper Canyon was mainly in calcareous conglomerate and hornfels of the Battle Formation; adjacent to the Copper Canyon stock these rocks were metamorphosed to calc-hornfels. During later stages of metallization the silicates were altered to chlorite and clay minerals, and sulfides including pyrite, pyrrhotite, arsenopyrite, chalcopyrite, and minor sphalerite and galena were introduced. This ore ranged in grade from 0.5 to 1 percent copper, and contained 0.10 to 0.25 ounces gold, and about 1.5 ounces silver to the ton.

At Copper Basin, gold ore was found in the Carissa and Copper King mines in metamorphosed limestone beds of the Harmony Formation and in overlying Battle Formation adjacent to intrusive bodies. This ore contains remnants of garnet, diopside, epidote, pyrite, pyrrhotite, and chalcopyrite in a groundmass of chlorite and clay minerals. The copper in the ore occurred mainly as supergene cuprite and chalcocite. About 9,100 tons of this ore was mined which averaged 2.96 percent copper and 0.49 ounces gold and 2.15 ounces silver to the ton.

Between Copper Canyon and Copper Basin, gold- and silver-bearing veins are found in outer zones beyond the base-metal replacement bodies. These veins include the following mineral assemblages: pyrite-quartz containing gold and silver (Buena Vista), stibnite-quartz (Antimony King) and a quartz-telluride (Telluride) (Roberts and Arnold, 1965).

At the White and Shiloh mine, silver-gold ore was mined from peripheral replacement bodies and veins. The primary ore contained small amounts of pyrite, sphalerite, and galena, but was mined principally for its silver content. The silver was mostly in galena, but Whitehill (1873, p. 48) reported wire silver and pyrargyrite in the oxidized ore.

Eureka district.—The ore bodies at Eureka have been described by Curtis (1884), Nolan (1962, p. 41–46), and Nolan and Hunt (1968, p. 966–991). Most occur in the Eldorado Dolomite and Hamburg Dolomite of Cambrian age, which are cut by intrusive quartz diorite dated at 100 m.y. by K-Ar. The pyrometasomatic central zone at Eureka has not yielded significant tonnages of ore, but surrounding replacement bodies have yielded ore valued at more than $120 million, largely in gold, silver, and lead. The average grade of 1,317,388 tones mined from 1869 to 1901 was as follows: gold, 1.1 ounces; silver, 27 ounces; and lead, 17 percent. One deposits in the southern part of the district on Prospect Ridge contain more gold than those in the central part.

The pyrometasomatic (tactite) bodies consist mainly of garnet, diopside, tremolite, epidote, zoisite which are altered to chlorite and serpentine; magnetite, pyrite, and pyrrhotite occur sporadically in the tactite (Nolan, 1962, p. 46). The gold and silver content of this material has not been reported.

The replacement ore bodies range in form from irregular, chimneylike bodies to podlike and tabular bodies. The ores that were mined during the 1860's and 1870's were mixtures of cerussite, anglesite, mimetite, plumbojarosite, calamine, smithsonite, malachite, and iron oxides along with relict galena, sphalerite, pyrite, and minor quartz. During oxidation, iron, zinc, and sulfur were largely removed, leaving lead, gold, and silver relatively concentrated. Ore on the deeper levels is largely unoxidized.

The peripheral ore bodies in the Eureka district on Prospect Ridge are typified by those of the Windfall mine (Nolan, 1962, p. 44, 70; Nolan and Hunt, 1968, p. 989). These ores consist mostly of sanded dolomite and quartz veins containing a little limonite and the ferric arsenate, scorodite, derived from the oxidation of pyrite and arsenopyrite. Gold was presumed to occur as the native metal. Production from 1908 to 1916 totaled 65,132 tons valued at $349,428. In addition to gold, the ore contained small amounts of zinc, copper, and antimony; locally it contained silver and lead. The metal content of these ores clearly differs from that of the central and inner zones, suggesting that they formed in a cooler environment.

Disseminated gold deposits

The disseminated gold deposits are relative newcomers to the Nevada mining scene. They may have been tested by the bonanza-seeking prospectors of the late 1800's, but their comparatively low grade made them less attractive than the richer veins and replacement deposits. In addition, the gold was mostly too fine grained to be recovered in a pan and could be detected only by fire assay. Although early day placer operations in the vicinity of Carlin and Cortez (Vanderburg, 1936, 1938, 1939) indicated the presence of lode gold, no veins of significant size were found in the disseminated gold deposits. Gold-bearing veins at Tenabo, 3 miles north of Gold Acres open pit, and in the Lynn district, which were the probable source of nearby placers, were workable only in the oxidized zone. As workings proceeded downward, costs rose, and the sulfide ores were generally too lean in gold for shipment to smelters.

The disseminated gold deposits became economic following the increase in price of gold from $20.67 to $35 an ounce in 1934. Gold Acres in 1936 was the first deposit to be put into production (Vanderburg, 1939, p. 39). Getchell followed in 1938 (Joralemon, 1951); during World War II production was stopped for several years, then resumed in 1962 through 1967. Rising costs, a fixed gold price, and metallurgical problems ultimately made operations unprofitable at Gold Acres and Getchell. In 1961 the Carlin deposit, which was much higher in grade, was discovered; operations began in 1965 (Hardie, 1966). More recently, in 1968, the Cortez mine was put into operation.

Current production of gold from the disseminated deposits has raised Nevada to second rank in gold production in the United States, after South Dakota. Other shows of disseminated gold mineralization in north-central Nevada are still being explored, and it seems likely that some of these will become productive in future years. Only a small part of the potentially productive ground has been thoroughly tested to date because most of the region is covered by thrust plates, volcanic rocks, and alluvium (Nolan, 1950; Roberts, 1966; Stewart and McKee, 1968; Gott and Zablocki, 1968).

The disseminated gold deposits thus far discovered in north-central Nevada are spatially related to the Roberts Mountains thrust fault. Ore bodies discovered thus far formed in the thrust zone or within a few hundred feet below it in carbonate rocks, especially where the thrust has been domed. The thrust zone therefore appears to exert an overall regional control. Roberts (1966), however, has emphasized that three other significant requirements must be met in order for an ore body to form: (1) a source for gold-bearing solutions; (2) fractured and permeable ground to permit access of solutions; and (3) precipitants, such as carbonate and(or) organic carbon (Radtke and Scheiner, 1970), must be available in a potential ore zone. The role each ore control played apparently varied from deposit to deposit.

The genetic relationship of the disseminated gold deposits to the gold-bearing replacement deposits, on the one hand, and to the vein deposits, on the other, is still uncertain. The disseminated deposits are a special kind of replacement deposit in that large amounts of carbonate are replaced by silica, but they contain mineral assemblages which more closely resemble those of the low-temperature veins than those of the replacement deposits. Unoxidized ores in the Getchell and Carlin deposits are characterized by pyrite and realgar; in the Carlin deposit by cinnabar, stibnite, and a little galena and sphalerite; and in the Cortez deposit, by only pyrite and gold.

In addition to gold, significant amounts of other elements were introduced during ore deposition into all the disseminated deposits. The most important of these elements are silica, iron, barium, arsenic, mercury, antimony, lead, zinc, copper, and tungsten. Data comparing the minor element contents in fresh host rocks with that of oxidized gold ores at Carlin are given by Akright, Radtke, and Grimes (1969); at Gold Acres by Wrucke, Armbrustmacher, and Hessin (1968); at Getchell by Erickson et al. (1964); and at Cortez by Wells, Stoiser, and Elliott (1969).

The disseminated gold deposits contain rather characteristic gold:silver ratios in the range of 9:1 to 30:1, which serves to set them apart from other gold-silver and silver-gold deposits in Nevada. Among the replacement deposits at Eureka, the silver-gold ratio was about 27:1 (Nolan, 1962) and at Copper Canyon it was about 18:1; the veins show more variation, ranging from 1:1 at National to 230:1 at Mountain City.

Coexistence of the assemblage stibnite-realgar-cinnabar as at Getchell and Carlin are uncommon in the Western States, but have been recognized locally at Bingham, Utah, where stibnite and cinnabar were deposited during late-stage metallization on upper levels in the U. S. and Lark mines (Rubright and Hart, 1968); in the Mercur area, Utah (Gilluly, 1932; Hewitt, 1968); and at the White Caps mine, Manhattan district, Nevada (Ferguson, 1924; Hewitt, 1968). Mercury and antimony sulfides also occur in hot spring environments (White, 1955; Schoen and White, 1965; Dickson and Tunell, 1968), and a close relationship between disseminated gold deposits and hot springs has been suggested by Joralemon (1951) and by Hausen and Kerr (1968); this implies that the deposits formed at shallow depths. Roberts and Coats do not support this implication, but instead suggest that the disseminated deposits formed at depths greater than 2,000 feet. This figure is based on restoration of the rock units that are thought to have covered the deposits at the time of formation in early Tertiary. Restoration is complicated by post-ore volcanism and basin-and-range faulting, but 2,000 feet seems to be a minimum. For example, Nash and Theodore (1970) estimate that as much as 4,000 feet of cover may have been eroded from the Copper Canyon area following emplacement of the intrusive body (38 m.y.) and prior to extrusion of the welded tuff (33.6 m.y.; McKee and Silberman, 1970a) that covered the region. Assuming a constant erosion rate of 6 cm/1,000 yr., which Judson (1968) suggests is the average present rate for the United States, then as much as 2,400 meters (7,874 feet) could have been eroded since early Oligocene time. Erosion was almost surely not constant, however, and a more realistic figure would be from 2,000 to 4,000 feet.

The Getchell deposit is spatially associated with an intrusive body emplaced in the second intrusive epoch (105–87 m.y.), and the Gold Acres deposits with an unexposed intrusive body of the same epoch

(99 m.y.),[3] but veins in the Tenabo and Cortez areas are associated with Oligocene intrusive bodies of the fourth epoch (40–30 m.y.; Wells, Stoiser, and Elliott, 1969; Wrucke, Armbrustmacher, and Hessin, 1968; Wrucke and Armbrustmacher, 1969; Silberman, Wrucke, and Armbrustmacher, 1969). At Gold Acres pyrite, arsenopyrite, sphalerite, and galena are associated with altered dikes and tactite in greenstone; sericite in the dikes has been dated at 94 m.y. (M. L. Silberman, written communication, 1970). The associated gold metallization in chert and shale nearby could be younger than this, however, and may represent an Oligocene overprint on a higher temperature pyrometasomatic metallization of Cretaceous age. The reason for this speculation is that the mineral assemblage commonly found in the disseminated gold deposits here and elsewhere is distinctly lower temperature than implied by the tactite assemblage at Gold Acres.

Detailed discussion of the geochemistry of these types of gold deposits and that of individual deposits in each group is beyond the scope of this paper. Basic data on transport of gold in hydrothermal solutions were given by Helgeson and Garrels (1968) and by Helgeson (1969). The chemical model proposed by Helgeson and Garrels for vein deposits in which gold is carried in acid solutions as the aurous chloride complex at temperatures above 175° C also fits well for the disseminated deposits at both Carlin and Cortez (Radtke and Scheiner, 1970). In the case of disseminated deposits at Carlin, Gold Acres, and Getchell, the types and amounts of carbonaceous materials in the host rocks were a dominant influence on gold deposition.

Silica is a ubiquitous constituent in all types of gold deposits. In disseminated deposits, fine-grained quartz was precipitated along with gold. Small jasperoid bodies containing widely varying amounts of gold are present in and near these deposits. Quartz makes up the bulk of the gangue minerals in virtually all vein deposits. Although replacement deposits commonly contain only small amounts of silica with the ore, numerous barren and gold-bearing quartz veins usually are located on the periphery of these districts. The close association between gold and quartz in many deposits, plus the dependence of silica solubility on temperature, forms the basis for studies of fluid inclusions in quartz to gain information on temperatures and composition of gold-bearing solutions.

Studies of the disseminated gold deposits are still being carried on by the U. S. Geological Survey and by the mining companies. Many new data are being assembled which will lead to a better understanding of these significant ore bodies. Basic information on the Getchell, Carlin, Cortez, and Gold Acres gold deposits will be summarized briefly below.

[3] The igneous rock yielding this date came from a drill hole at about 500 feet below the open pit at Gold Acres.

Getchell deposit.—Joralemon (1951), Hotz and Willden (1964), and Erickson et al. (1964) have described the Getchell gold mine in the Osgood Mountains, north-central Nevada, which has yielded more than 436,000 ounces of gold valued at more than $15 million (Bergendahl, 1964). The principal ore body extends along the Getchell fault zone. The gold deposit at Getchell is associated with the Osgood Mountains stock, which has been dated by M. L. Silberman by the K-Ar method as 90 m.y. Tungsten deposits along the margin of the stock are believed to be genetically related to the stock (Hobbs and Clabaugh, 1946; Hotz and Willden, 1964). The mineral assemblage of the gold deposits appears to be distinctly lower temperature than the assemblage of the tungsten deposits, and the gold deposits are considered by Roberts and Coats to be considerably younger, possibly early Tertiary. It should be emphasized that the gold deposit itself has not been dated as yet, so this conclusion is tentative.

Joralemon (1951, p. 270–73) has described the gold deposits in detail as follows: "The gold ore bodies are sheet-like masses that lie along the various strands of the Getchell fault zone. They extend at least 7000 feet horizontally and 800 feet down the dip, and vary in width from a few feet to more than 200, averaging about 40 feet wide. . . . The veins consist of sheared and mineralized argillite and limestone cut by quartz and calcite veins and containing a soft, plastic gumbo that has replaced the sediments. The gumbo is the principal gold-bearer. . . . [It] is unusual in that while it appears to be a fault gouge, it actually consists of minute subhedral quartz crystals embedded in a nearly submicroscopic intergrowth of quartz and amorphous carbon. . . ."

Joralemon (1951, p. 273) suggested that the "gumbo" formed hydrothermally. Roberts considers that the "gumbo" is an alteration product of carbonaceous shale or argillite and chert of the upper plate of the Roberts Mountains thrust which was caught up in the Getchell fault, and that the Getchell gold deposit is one of the disseminated type which was localized in the upper plate rocks as well as in carbonate rocks of the lower plate. The association between quartz, organic carbon, and gold is similar to that noted at Carlin, Gold Acres, and other deposits in north-central Nevada.

Many of the geologic and geochemical features of the Getchell deposit closely resemble those of the Carlin deposit described by Radtke and Scheiner (1970). Most of the gold in the unoxidized carbonaceous rocks at Getchell could not be concentrated by ordinary milling processes, and the ore had to be roasted before cyanidation; evidently a significant amount of the gold was associated with organic material. The ores generally contain a low-temperature mineral assemblage of quartz, gold, realgar, stibnite, pyrite, and minor amounts of other sulfides. Small amounts of arsenopyrite have been recognized locally. Gold ores at Getchell are characterized by significantly larger percentages of arsenic (mainly as realgar) than any of the other disseminated deposits.

The distribution of gold within the Osgood Mountains stock was studied by Neuerberg (1966). He found that the gold content in the stock was one or two orders of magnitude greater than for crustal and granitic rocks, but did not establish a clear-cut spatial relationship between high-gold zones in the stock and gold deposits along the Getchell fault.

Cortez gold deposit.—The Cortez silver district was discovered in 1862, shortly after the discovery of the Austin district, and was productive during several stages until the 1930's (Vanderburg, 1938; Gilluly and Masursky, 1965). The Cortez gold mine, 3 miles north of the old silver camp, was discovered in 1965 following the discovery at Carlin. Erickson and Marranzino (1961) and Erickson et al. (1961, 1964) had been carrying on a program of geochemical studies in the Cortez district, but no gold determinations were made on the samples. After the discovery at Carlin, some samples from the earlier program at Cortez were rerun for gold. Anomalous amounts of gold were detected in some of them; this led to resampling of the areas by the Geological Survey and the Cortez joint venture group, which revealed that ore of commercial grade might be present. Subsequent exploration during 1965–68 resulted in the discovery of 3.4 million tons of ore containing about 0.30 ounces of gold per ton.

The host rocks of the Cortez gold body are described by Gilluly and Masursky (1965), Elliott and Wells (1968), and Wells, Stoiser, and Elliott (1969) as altered calcareous siltstone and limestone of the Roberts Mountains Formation and limestone of the Wenban Limestone. These rocks are cut by intrusive igneous rocks of Jurassic and early Tertiary age and overlain by Tertiary volcanic rocks. The ore may be genetically related to biotite-quartz porphyry dikes and sills of Oligocene age (34 m.y.) that cut the Roberts Mountains and Wenban Formations in the ore zone, or to younger igneous rocks in the area (Wells, Stoiser, and Elliott, 1969).

The zone of gold metallization is not controlled by any obvious structural feature, but it trends northwestward, parallel to the strike of the Roberts Mountains thrust at the mouth of Mill Canyon nearby. Wells, Stoiser, and Elliott (1969, Fig. 6) show the ore body in a tight, overturned fold in the Roberts Mountains Formation; the overlying Wenban Limestone was apparently not involved in this fold, indicating that the two units may be separated by a reverse fault. Roberts believes that the Roberts Mountains thrust plate probably covered the area at the time of metallization and may have exerted an important structural control on ore deposition. In addition, the Cortez district lies within the Battle Mountain-Eureka mineral belt that trends N35°–45°W in this area; this belt apparently lies along a deep-seated fracture zone which localized plutonic bodies in Mesozoic and Tertiary time and localized ore deposits during several metallogenic epochs (Roberts, 1966; Roberts et al., 1967).

Gold ores of the Cortez deposit are characterized by quartz, metallic gold, various iron oxides after pyrite, and small amounts of remnant carbonates and clays. Fine-grained gold is dispersed through the oxidized and hydrothermally altered carbonate rocks. Coarser grained metallic gold occurs in small quartz veins and is intergrown with partly oxidized hydrothermal pyrite scattered through the host rocks.[4]

Carlin deposit.—The Carlin gold deposit is in the northeast corner of the Lynn window in the Tuscarora Range of northern Eureka County. Excellent descriptions of the geologic environment of the Carlin deposit are given by Hardie (1966) and Hausen and Kerr (1968). Radtke and Scheiner (1970) recently discussed the geochemistry of gold deposition at Carlin. The Carlin mine was put into operation in 1965. By January 1, 1970, 3,694,405 tons had been milled and 1,218,497 ounces of gold recovered; ore reserves are 6,251,000 tons averaging 0.253 ounces of gold per ton.

Gold ore bodies of the Carlin deposit are in the upper part of the Roberts Mountains Formation, several hundred feet below the Roberts Mountains thrust. Although gold is dispersed through certain intervals of carbonate host rocks, suggesting local stratigraphic control, crosscutting relations between mineralized zones and bedding, plus the geometric relationship between mineralized areas and certain sets of high-angle faults and intersections of fault sets, indicate that structural controls are critical. Unoxidized gold ore bodies of the Carlin deposit are characterized by gold-organic compounds plus minor amounts of metallic gold, quartz, barite, realgar, pyrite, lesser amounts of various other sulfide minerals including stibnite, cinnabar, sphalerite and galena, plus remnant illite and carbonates. Near-

[4] Radtke considers that most of the carbonaceous materials in the host rocks were destroyed either by a process of "weathering oxidation" or by thermal metamorphism induced by igneous intrusion prior to gold mineralization. Thus, the influence of organic carbon on the deposition of gold at Cortez was less than that at Carlin. Details of the genesis of the Cortez ores will be discussed in a paper by Radtke, Scheiner, and Christ (unpublished manuscript).

surface ore bodies reflecting strong oxidation and secondary alteration contain mainly quartz and illite, minor carbonates and iron oxides, plus barite and extremely fine-grained metallic gold (Radtke and Scheiner, 1970).

Gold Acres deposit.—The Gold Acres deposit is at the edge of the Gold Acres window on the east flank of the Northern Shoshone Range. From 1935 to 1957 the mine yielded about 2 million tons of ore from which about $10 million in gold was recovered. Since 1961 the mine has been inactive.

The ore deposits at Gold Acres are in the brecciated zone of the Roberts Mountains thrust and in rocks above the thrust which have been complexly broken by younger high-angle faults. The ore occurrence therefore differs significantly from that of the Carlin and Cortez deposits, which are largely within the lower plate. The thrust zone at Gold Acres contains sheared and brecciated chert and shale of the upper plate, as well as fragments of lower plate limestone; in addition, it also contains dikes of altered felsitic intrusive rock and tactite zones with pods and veinlets of pyrite, arsenopyrite, and a little sphalerite and galena; according to Wrucke and Armbrustmacher (1969) the gold content of this material is low. The quartz monzonite, as mentioned above, has been dated at 99 m.y. and sericite in the sheared zone at 94 m.y. (M. L. Silberman, written communication, 1970). Gold quartz veins in the northern part of the Tenabo district nearby are associated with Oligocene intrusive bodies (Silberman et al., 1969). Roberts believes that the gold metallization at Gold Acres may be related to these younger igneous bodies, and was superimposed upon an older pyrometasomatic deposit.

Gold-bearing disseminated ore is erratically distributed within the thrust zone and along fracture zones and in felsite (Wrucke and Armbrustmacher, 1969). No simple pattern of the distribution of gold has been worked out; fragments of limestone of the Roberts Mountains Formation in the thrust zone are of ore grade only where cut by veins of iron oxide. It therefore seems that control by fractures dominates over lithologic control. An overall lithologic control is nevertheless possible, because comminuted carbonate rock and carbonaceous material in the thrust zone are in a position where they could have influenced the precipitation of gold from hydrothermal solutions.

Veins

Gold-bearing veins in north-central Nevada and southwestern Idaho belong to two major groups, those that cut only pre-Tertiary rocks and are related to the replacement deposits, and those that are related to volcanic rocks and that may cut pre-Tertiary rocks, volcanic rocks, or both (Ferguson, 1929; Nolan, 1933).

Gold-bearing sulfide veins cut replacement bodies at Eureka and Battle Mountain, Nevada (Hill, 1915), and South Mountain, Idaho (Sorenson, 1927). These veins contain relatively high-temperature sulfide assemblages similar to those of the base-metal replacement deposits.

A minor class of quartz veins found in the older rocks includes those of massive texture, and with simple mineralogy, principally pyrite, sphalerite, galena, and tetrahedrite. These veins have been found associated with many plutons (e.g., Gold Creek, Mountain City) but have not been economically mineable.

In two areas, veins in granitic plutons have textures and mineral compositions suggesting that they are, in part, of later and shallower origin than the pluton. These areas are Mountain City and Austin (Reese River), Nevada. At Mountain City, hydrothermal alteration of Tertiary volcanic rocks near the gold-silver veins gives indirect evidence for the relative youth of the gold-silver veins. At Austin, Nevada, veins in the mineralized area, which is areally restricted compared to the exposures of the pluton of quartz monzonite, are made up largely of vein quartz that Ross (1953, p. 58) recognized as being formed in at least three stages. Ross regarded chalcedony and flamboyant quartz, which are areally restricted, as being possible associates of Tertiary volcanic rocks which rest on the granitic rocks. Pyrite is in large part contemporaneous with early milky quartz and rhodochrosite, but most other sulfides, particularly the silver-rich ones, are related to a later generation of fine-grained quartz. The sulfide minerals identified (Ross, 1953, p. 56) include galena, sphalerite, chalcopyrite, arsenopyrite, pyrargyrite, stephanite, polybasite, enargite, and xanthoconite.

The Austin and Mountain City vein systems resemble in sulfide mineralogy the veins of Silver City, Idaho. At Silver City, however, the veins may be traced from the underlying granite pluton up into the volcanic rocks.

Stibnite-quartz veins are found in an outer zone surrounding replacement deposits and high-temperature veins at Battle Mountain (Roberts and Arnold, 1965). They are also found in the Mount Lewis and Hilltop districts (Lawrence, 1962, 1963), where they are associated with silver-gold veins that contain argentite and silver sulfosalts and are related to intrusive rocks of Oligocene age.

Other classes of veins related to Tertiary volcanic rocks are the low-temperature veins containing pyrite, gold (electrum), argentite, naumannite, pyrargyrite, proustite, and other sulfosalts in a quartz-adularia gangue, and the quartz-stibnite-gold veins (National, Nevada) (Lindgren, 1900; Hewett, 1964; Hewett and Radtke, 1967).

In the following discussion, veins typical of the principal groups will be described; the higher temperature veins will be described first.

Copper Canyon.—The Superior vein in the Copper Canyon underground mine yielded high-grade secondary copper ore on the upper levels and sulfide ore below the 300 level (Roberts, 1951; Roberts and Arnold, 1965). The ore minerals include pyrite, pyrrhotite, arsenopyrite, and sphalerite in quartz gangue; this assemblage is similar to that in the replacement bodies. Individual particles of metallic gold in these sulfide ores are not abundant even under high magnifications, and most of it is probably finely disseminated in the sulfides, especially pyrrhotite and pyrite. In a drill core at Copper Canyon free gold was found in a pyrite-amethystine quartz veinlet. This veinlet may well have formed late in the metallogenic cycle at a distinctly lower temperature than the main ore phase.

Peripheral gold-silver deposits in and near Copper Canyon are characterized by pyrite, quartz, and argentiferous galena (Roberts and Arnold, 1965, p. B32), with minor amounts of sphalerite, arsenopyrite, and tellurides. These deposits are mostly veins containing lenticular shoots of gold-silver ore, but locally the ore replaced favorable beds adjacent to the veins. The gold content ranged from 0.08 to 2.80 ounces per ton and silver from 4 to 55 ounces per ton.

Stibnite-quartz veins containing a little pyrite occur in the outer zone of metallization between Copper Canyon and Copper Basin at the Apex and Antimony King mines. These veins do not contain much gold, but are listed here to show their place in the zonal scheme. A pocket of rich silver ore was mined during the early days at the Antimony King, but these veins are normally low in precious metals.

Flint district, Idaho.—Gold-bearing veins in the Flint district (Fig. 6) are mostly composed of massive white quartz, tetrahedrite, and other sulfosalts with arsenopyrite, pyrite, and chalcopyrite; the ore averaged 20–30 ounces gold per ton. Other veins in the district are mostly quartz and stibnite with traces of silver; still others are pyritic quartz veins and native gold (Piper and Laney, 1926).

The Trade Dollar vein system, a half-mile southwest of Silver City on Florida Mountain, cuts granodiorite on the lower levels, Tertiary basalt on intermediate levels, and overlying rhyolite on the upper levels (Lindgren, 1900; Piper and Laney, 1926, p. 118). The veins are massive and consist of comb quartz, adularia, and a little calcite. The ore minerals include pyrite, native gold, argentite, naumannite, and silver sulfantimonides. The average Au:Ag ratio was about 1:190 in the Trade Dollar-Black Jack vein; the ore averaged 0.246 ounces gold and 47.2 ounces silver per ton.

The veins at De Lamar, 4 miles west of Silver City, are composed mostly of lamellar quartz which cuts late Tertiary rhyolite (Lindgren, 1900; Piper and Laney, 1926, p. 106). The silver ore minerals are principally argentite, naumannite, polybasite, and related sulfides. Gold occurs mainly as electrum. The ore averaged 0.15–0.50 ounces gold and 20–50 ounces silver per ton.

National district.—Gold-silver quartz-adularia veins in the National district yielded spectacular ores in the period from 1908 to 1920 (Lindgren, 1915; Willden, 1964). Ore as rich as $135,000 a ton was recorded; much ore was valued at $20 a pound. The veins, which cut volcanic rocks of probable Miocene age, are mostly banded and show excellent radial or comb structure. The principal sulfide was stibnite, along with pyrite, and a little chalcopyrite, arsenopyrite, sphalerite, and galena; most of the gold and silver was in electrum, but, in addition, silver was found as cerargyrite and pyrargyrite.

Jarbidge.—The Jarbidge mining district was discovered in 1909, and between 1910 and 1949 produced about $10 million in gold and silver. Substantial production ended about 1937, and minor production continued through 1948 (Granger et al., 1957, p. 84). The silver-gold ratio averaged about 3 to 1.

All the production of precious metals from the Jarbidge mining district has come from quartz-adularia-bearing veins and lodes in the Tertiary Jarbidge Rhyolite, a thick sequence of phenocryst-rich rhyolite flows, with minor tuff and welded tuff. In the mineralized area, narrow horsts of Prospect Mountain(?) Quartzite of Cambrian age appear within the rhyolite terrane. The rocks underlying the quartzite have not been disclosed by mining, but 3 or 4 miles to the southwest, quartzite rests in thrust contact on Paleozoic limestone (Coats, 1964, p. M21).

The age of the mineralization has not been determined directly. Two K-Ar dates on the Jarbidge Rhyolite from nearby areas are 16.8 (Coats, 1964, p. M11) and 15.4 m.y. (Evernden et al., 1964, p. 194). A sample from near the uppermost part of the unconformably overlying ignimbrite (the Cougar Point Welded Tuff) in the Owyhee quadrangle about 30 miles to the west, was dated by John Obradovich as 12.2 m.y. (Coats and Stephens, 1968). The Cougar Point postdates the mineralization. As the mineralization is believed to be closely related to the eruption of the late Miocene(?) Jarbidge Rhyolite, the mineralization is also probably late Miocene.

The ore deposits in the rhyolite follow steeply dipping faults, trending generally north to northwest; a few have northeast trends. The gangue minerals, in addition to quartz and adularia, include early calcite (largely replaced), barite, fluorite, kaolinite, and halloysite; ore minerals include pyrite, gold, argentite, and naumannite (Schrader, 1923, p. 50–52; Davidson, 1960).

Mountain City (*Cope*).—The original discoveries of silver-gold ore in the Mountain City district have been shaded into obscurity by the later production of copper ore from the Mountain City Copper Company's Rio Tinto mine. The copper deposits are genetically unrelated to the silver-gold deposits (Coats and Shephens, 1968). The proportion of silver to gold in the bullion produced from the veins during the period 1869–1932 was about 230 to 1.

The gold and silver deposits of the Mountain City mining district are quartz veins, mostly in a pluton that ranges from granodiorite to quartz monzonite in composition. Near the southern margin of the pluton, veins cut Paleozoic sedimentary rocks. In the central part of the pluton, near the town of Mountain City, veins occur near, but not in, a narrow east-trending graben of rhyolitic rocks, which are hydrothermally altered near the veins.

After a long period in which these mines were dormant, one, the Protection, was reopened in 1946 and continued to produce until 1948. Total ore produced during this 3-year period is estimated at 2 thousand tons, averaging about 40 ounces of silver and three-quarters of an ounce of gold per ton. It seems likely that two different epigenetic types of precious-metal deposits are present here at Mountain City, one consisting of Cretaceous pyritic gold-quartz veins, which have not been mined but have contributed gold to the placers, and the other of Tertiary silver-gold veins, which have furnished most of the production. Sanidine from pumice, in an unaltered part of the rhyolite tuffs mentioned above, was dated by J. C. Von Essen (written communication, 1969) at 30 m.y. The mineralization that is spatially associated with the alteration of these rocks may be any age younger than 30 m.y.

Cornucopia.—Mining operations at Cornucopia extended from 1873 to 1882. Old tailings were retreated in 1937–40. Total production (Granger et al., 1957, p. 41) was $1,273,000. Silver-gold ratio in the later production was 68 to 1. Information on the weight ratios of silver-gold for the earlier production is unknown.

The mineral deposits are in propylitized andesite, argillized near the veins (Lovering, 1949). Primary structures in the wallrocks are unclear. Emmons (1910, p. 64) reported quartz-porphyry exposed in the mine workings, but outcrops were not seen in 1966. Altered and mineralized rocks are overlain unconformably by rhyolite ignimbrite and andesite, both of which postdate mineralization. Coats (1967, p. 1) found evidence for the existence of unexploited parts of veins beneath the later volcanic rocks. The age of the mineralization is not precisely known, but the ignimbrite yielded sanidine that was dated by J. C. Von Essen (written communication, 1969) at 15 m.y.

The ore bodies are sheeted zones in andesite; they trend eastward and dip steeply northward. Primary minerals are quartz, barite, pyrite, argentite, tetrahedrite, and possibly pyrargyrite. Comb structure is present in the quartz veins. In places, silicified country rock was worked. The maximum grade of mill-run ore reported to Emmons (1910, p. 64) was 400 ounces silver per ton. Reworking of the tailings yielded 0.13 ounces of gold and 9 ounces of silver per ton.

Tuscarora.—The Tuscorora district was discovered in 1867. Placer gold was mined for a number of years, mostly by Chinese; the total production was about $700,000 (Nolan, 1936, p. 14). The lode deposits were discovered in 1871, and the recorded production through 1941 (Granger et al., 1957, p. 153) was 128,165 ounces of gold and 7,138,684 ounces of silver, for a silver-gold ratio of about 44 to 1. Production since 1941 has been negligible.

The bedrock in the mineralized area consists chiefly of two types: (1) a bedded series of rhyolitic tuff and interbedded andesitic flows, and (2) intrusive andesite bodies of irregular shape (Nolan, 1936, p. 14). The bedded series dips east or southeast quite regularly but is cut by many faults, mostly of north to northeast trend with indeterminate dip and displacement. Recent mapping has shown that the Tuscarora district is bounded on the north by a narrow horst of Valmy quartzite and chert; no ore bodies seem to have been mined in it.

The age of the mineralization at Tuscarora was determined by a K-Ar date on adularia from the Modoc Vein (E. H. McKee, written communication, 1970) as 38 m.y.

Emmons (1910, p. 60) and Nolan (1936, p. 28) recognized two kinds of ore deposits at Tuscarora, silver lodes and gold-bearing fracture zones. The deposits in the andesite are relatively narrow veins or lodes, those in the bedded pyroclastics are wide and poorly defined brecciated zones. In the gold deposits, the weight ratio of silver to gold is 4 or 5 to 1; in the silver lodes it is nearly 150 to 1. Nolan considered and rejected as explanations for the difference both zoning and different epochs of mineralization; he believed that the lodes and veins in andesite were richer in silver because of more effective supergene enrichment, while the silver-bearing supergene solutions were removed or dissipated in the wide fracture zones in the bedded pyroclastics. However, the material mined in the most successful gold producer, the Dexter, was notably pyritic, where fresh (Emmons, 1910, p. 61), and it is difficult to understand why available silver should not have been precipitated by this pyrite. Differences in the chemistry of the wallrock may be responsible for differences in the silver-gold ratio in the ores.*

The principal gangue minerals are quartz, adularia, and calcite; the principal ore minerals were, according to accounts summarized by Nolan, argentite, stephanite, proustite, pyrargyrite, pyrite, enargite, arsenopyrite, bornite, chalcopyrite, sphalerite, and galena. Secondary horn silver and native silver were common. The textures are simple, at least in the very low grade material that remains. Crude crustification and vuggy textures may be recognized.

The grade of ore as mined ranged from $50 to $200 per ton in the early days of production, but fell to as little as $6 per ton in 1890 for one mine (Nolan, 1936, p. 31).

Gold Circle.—The Gold Circle (Midas) district was discovered in 1907 (Emmons, 1910, p. 48). Mining essentially terminated in 1942. Production statistics are summarized by Granger et al. (1957, p. 65). From 1908 to 1949 the Gold Circle district produced 401,752 tons of ore containing 126,726 ounces of gold and 1,630,268 ounces of silver; the average grade of the ore produced was thus 0.314 ounces gold and 4.60 ounces of silver per ton; the silver-gold weight ratio was 12 to 88. During the last years of production, the grade fell to about $5 per ton.

The rocks in the known mineralized area are entirely Tertiary volcanic rocks. Emmons (1910, p. 47) mentioned an outcrop of shaly limestone about 5 miles from Midas; this has not been verified, but it suggests that the Midas district may be underlain in part by rocks of the eastern carbonate assemblage. The Tertiary volcanic rocks include premineralization rhyolite and andesite and postmineralization rhyolite ignimbrites of the Cougar Point Welded Tuff, known to be as young as 12.2 m.y. in this region (Coats and Stephens, 1968, p. 1083).

The ore deposits are veins, sheeted zones, and breccia zones that follow faults in the volcanic rocks. These structures strike generally N30° to 60°W; the dip ranges from 65°NE to vertical, locally steeply west.

The age of mineralization has recently been determined at 15.0 by K-Ar dating of adularia collected by Dan Shawe (R. H. Marvin, written communication, 1968).

The vein material is principally quartz and altered wallrock, with minor amounts of calcite and adularia (Rott, 1931, p. 16). Some calcite is early, and has been partly replaced and removed by later vein-forming solutions. The veins and lodes are relatively high grade, but narrow, extensive brecciated zones are low in grade. The metallic minerals are pyrite, stromeyerite, and native gold, with tetrahedrite, proustite, chalcopyrite, and sphalerite much less common.

Buckhorn.—The Buckhorn mine northeast of Cortez is in siliceous shale of Tertiary age which is overlain by andesitic flows (Roberts et al., 1964). The workings explore an area 650 feet long, 245 feet wide, and 120 feet deep which has yielded 39,024 ounces gold, 311,278 ounces silver, and 319 pounds copper valued at $1,109,838. The ore body consisted of pyritic siliceous breccia zones, oxidized to a depth of 100 feet, that strike N5°W and dip 75°E; the andesite and shale adjacent to the ore were extensively argillized. Correlative andesite near Tenabo has been determined by K-Ar methods to be 16 m.y. old (McKee and Silberman, 1970a).

Summary and Conclusions

Gold-bearing deposits in north-central Nevada belong to three principal groups: replacement and disseminated deposits and veins which were formed during five principal metallogenic epochs, in the early Mesozoic, late Mesozoic, early Tertiary, and late Tertiary. The replacement deposits were mostly formed during the first four epochs; the disseminated deposits are thought to have formed mostly during the fourth epoch, although age data are available for only one deposit, Cortez; and the veins formed during all five epochs.

The replacement deposits are zonally arranged around intrusive centers: from the center outward are central pyrometasomatic deposits, outer base metal and associated gold and silver deposits, and peripheral gold deposits. The disseminated gold deposits occur in a unique environment associated with the Roberts Mountains thrust. They are characterized by low-temperature mineral assemblages and may be genetically related to the replacement deposits, but if so, they formed in cooler zones, possibly nearer the surface or on the flanks.

Exploratory programs in north-central Nevada should be directed towards testing zones below the disseminated deposits for potential base-metal replacement deposits in favorable stratigraphic units and structural zones near intrusive centers. The major mineral belts are the most favorable zones in which to conduct exploratory programs for base-metal deposits as well as disseminated deposits.

The gold- and silver-bearing veins likewise may be related to replacement or disseminated deposits, so favorable stratigraphic and structural zones be-

* or the veins were open channels for a longer time, and the composition of the mineralizing solutions progressively changed.

neath productive vein systems should also be carefully evaluated by geochemical and geophysical methods.

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