2155 White, 1985

Geologic Characteristics of Sediment-and Volcanic-Hosted Disseminated Gold Deposits— Search for an Occurrence Model

Edwin W. Tooker, Editor

A study of current information on disseminated gold occurrences as a basis for developing an empirical occurrence model

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Vein and Disseminated Gold-Silver Deposits of the Great Basin Through Space and Time

By Donald E. White

CONTENTS

INTRODUCTION

In a recent paper, White and Heropoulos (1983) tabulated all the data currently available on precious-metal deposits of the Great Basin, especially in Nevada and the immediately adjacent parts of surrounding States. Of these deposits (table 1), 48 are in Nevada, 2 each are in nearby parts of California, Idaho, and Utah, and 1 is in Arizona. White and Heropoulos focused on deposits that have been radiometrically dated (45 districts or deposits) or that had at least preliminary data on salinities of ore fluids and (or) temperatures of deposition (from temper-atures of homogenization and freezing-point depressions of fluid inclusions). Many mineralization ages were determined by standard potassium-argon methods on mineral separates of nearly pure adularia (hydrothermal K-feldspar, mainly by Silberman and McKee, 1974, and Silberman and others, 1976, 1979). Although such ages should be relatively reliable, they may not represent the total timespan of ore deposition of a single deposit or a district. Other K-bearing minerals and altered rocks were utilized for dating some deposits without suitable adularia or alunite; these ages are probably less reliable.

Salinity data were available for only nine deposits or districts—far too few to permit reliable conclusions. The fluids of epithermal vein systems are generally dilute, mostly ranging from 0.2 to 2 weight percent NaCl equivalent, but some inclusion fluids from Rochester (Vikre, 1981) and Tenmile (Nash, 1972) range as high as 6 and 7 weight percent NaCl equivalent. For comparison, active geothermal systems do not exceed 0.8 weight percent NaCl equivalent in salinity (Brook and others, 1979; White and Heropoulos, 1984).

Nash (1972) made the most intensive search for suitable fluid inclusions from disseminated deposits. He concluded that Gold Acres is characterized by inclusion fluids of 5.4 to 7.3 weight-percent-NaCl-equivalent salinity, with filling temperatures of about 160°-185°C. These temperatures are considerably lower than those of typical epithermal veins, most of which range from 200° to 300°C and average about 250°C (table 1; Buchanan, 1981).

Of the 55 deposits or districts listed in table 1, 17 have been called disseminated, Carlin type, bulk mining, or invisible gold, as distinguished from those that contain typical precious-metal veins, which generally occur in volcanic rocks. Of these 17 deposits, 7 have mineralization ages of less than 40 m.y. that probably differ little from those of typical volcanic-hosted vein deposits, except for a broader dispersion of the ore metals in sedimentary rather than in volcanic rocks.

At least 10 "disseminated" ore districts and, possibly, many unlisted recent discoveries are in sedimentary rocks older than the widespread mid-Tertiary volcanism of the Great Basin. Do these deposits differ in significant ways other than age and host rocks? Were their ore fluids more saline than the 2 weight percent NaCl equivalent of most volcanic-hosted veins? Were their temperatures, heat sources, hydrodynamics, and tectonic environments also

Table 1. Locations, mineralization ages, ore-fluid salinities, and temperatures of gold-silver deposits of Nevada and adjacent States

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District	Lat N.	Long W.	Age (m.y.)	Salinity (wt pct NaCl equiv)	Temperature (°C)	References
			Nevada			
Adelaide	40°51'	117°30'	14	---	---	S
Aurora	38°17'	118°54'	11	.2-1.7	227-255	Bu, N, S
Blue Star*	40°54'	116°19'	37.5	---	---	B
Borealis*	38°40'	118°45'	5	---	---	B
Buckhorn	40°10'	116°25'	14.6	---	---	Bu, S
Buckskin	38°59'	119°20'	---	---	---	B
Bullfrog	36°55'	116°48'	9	---	---	Bu, S
Bullion*	40°23'	116°43'	35	---	---	S
Camp Douglas	38°21'	118°12'	15	---	---	G, S
Carlin*	40°45'	116°18'	---	---	150-200	N
Cedar Mountain (Bell)*	38°35'	117°47'	---	.2-1.7	250	Bu
Comstock Lode	39°03'	119°37'	13	---	250-300	Bu, S
Cornucopia	41°32'	116°16'	15	---	---	Bu
Cortez*	40°08'	116°37'	35	---	150-200	B, N, S
Cuprite	37°31'	117°13'	---	---	---	A
Divide	37°59'	117°15'	16	---	---	Bu, S
Getchell*	41°12'	117°16'	90	---	---	B, S
Gilbert	38°09'	117°40'	8	---	275	Bu, S
Gold Acres*	40°15'	116°45'	94	5.4-7.3	160-185	B, N
Gold Circle	41°15'	116°47'	15	---	175-200	Bu, S
Gold Strike*	40°59'	116°22'	76.4	---	---	B
Goldfield	37°43'	117°13'	20-23	---	200-300	A, Bu, S
Hasbrouck*	37°59'	117°16'	16	---	---	B
Humboldt	40°36'	118°11'	73	---	---	Bu
Jarbidge	41°52'	115°26'	14	---	---	Bu, S
Manhattan	38°33'	117°02'	16	.4-1.9	220	N, S
National	41°50'	117°35'	15.5	---	---	Bu
Northumberland*	38°57'	116°47'	84.6	---	---	B
Peavine	39°36'	119°55'	---	---	---	A
Pinson*	41°10'	117°17'	90?	---	---	B, S
Pyramid	39°52'	119°37'	21	---	---	A
Ramsey (Lyon)	39°27'	119°19'	10	---	221	Bu, S
Rawhide	39°01'	118°20'	16	---	---	Bu, S
Rochester*	40°17'	118°09'	58-79	6	270-310	N, V
Round Mountain*	38°42'	117°04'	25	.2-1.4	250-260	B, N, S
Searchlight	35°27'	114°55'	---	---	---	Bu
Seven Troughs	40°29'	118°46'	14	---	240-318	S
Silver Dike	38°19'	118°12'	17.3	---	300	G, S
Silver Peak	37°47'	117°43'	5	---	---	Bu, S
Standard*	40°31'	118°12'	73	---	---	B
Steamboat Springs	39°23'	119°45'	3	.2	≥90-230	S
Sulphur	40°53'	118°40'	1.8-2.1	---	---	A, W
Talapoosa*	39°27'	119°19'	10	---	---	S
Tenmile	41°02'	117°53'	16	.4-7.3	≥135-330	N, S
Tonopah	38°04'	117°14'	19	<1	240-265	Bu, S
Tuscarora	41°17'	116°14'	38	---	---	Bu, S
Widekind	39°35'	119°45'	---	---	---	A
Wonder	39°24'	118°06'	22	---	---	Bu, S

Table 1. Locations, mineralization ages, ore-fluid salinities, and temperatures of gold-silver deposits of Nevada and adjacent States—Continued

District	Lat N.	Long W.	Age (m.y.)	Salinity (wt pct NaCl equiv)	Temperature (°C)	References
			California			
Bodie	38°12'	119°00'	7.2-8.0	---	215-245	S
Monitor	38°42'	119°40'	5	---	---	S
			Arizona			
Oatman	35°02'	114°23'	---	---	220	Bu
			Idaho			
DeLamar	43°02'	116°50'	---	---	---	Bu
Silver City	43°02'	116°44'	15	---	---	Bu, P
			Utah			
Gold Strike*	37°23'	113°53'	78.4	---	---	Bu
Mercur*	40°19'	112°12'	---	---	---	Bu

similar? These and some other unresolved questions are considered below.

Acknowledgments

The concepts proposed in this chapter are the outgrowth of my efforts to resolve some of the questions raised during the 1982 U.S. Geological Survey workshop and a subsequent (1983) conference in Reno, Nev. (White and Heropoulos, 1983), on active and fossil hydrothermal-convection systems of the Great Basin.

Many individuals have provided essential data utilized or reinterpreted by me. Thanks are especially due to M. L. Silberman, H. F. Bonham, Jr., J. H. Stewart, L. J. Buchanan, R. P. Ashley, R. O. Fournier, J. T. Nash, Chris Heropoulos, A. B. Wallace, W. C. Bagby, T. G. Theodore, and Larry Garside. By no means is there general agreement among researchers on those "fossil" systems that are "epithermal gold-silver deposits" hosted by mid-Tertiary and younger volcanic rocks. Many veins in volcanic rocks are underlain by nonvolcanic rocks, generally of Mesozoic or Paleozoic age. The initial selection of deposits for table 1 was primarily based on a comparison of production values from H. F. Bonham's maps of gold production (Bonham, 1976) and silver production (Bonham, 1980). To be included in table 1, a district must have had important production of Au or Ag (4th rank or larger, as categorized on Bonham's maps) but relatively small production of base and other metals; my intent was to eliminate districts mined primarily for Cu or Pb-Zn, but with total production so large that minor Au and Ag indicated first-rank precious-metal production from byproduct Au and Ag. This tentative list was then examined by R. P. Ashley and H. F. Bonham, Jr., or was included in earlier published discussions of epithermal precious-metal deposits by Lindgren (1933), Nolan (1933), or Buchanan (1981). For the deposits of table 1 designated with an asterisk as "disseminated" or "bulk mining," I depended primarily on the map and brief discussions noted by Bonham (1982).

AGES OF ORE DEPOSITS AND THEIR RELATIONS TO VOLCANISM

Cretaceous systems

Nine of the ore systems listed in table 1 have indicated mineralization ages older than 44 m.y. (fig. 1). The Rochester district (Vikre, 1981) may, in part, be as young as 58 m.y., but all the other districts, including part of the Rochester, have ages between 73 and 94 m.y. Only a few of these districts have been dated reliably by adularia closely associated with ore, and so the true mineralization ages are not yet firmly established.

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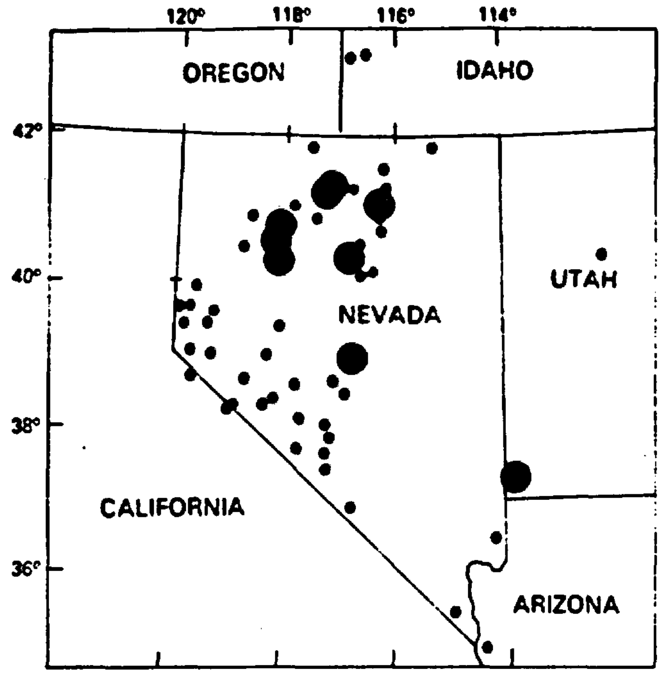

Figure 1. Nevada and parts of adjacent States; large dots denote locations of gold-silver deposits of Cretaceous and early Tertiary age (older than 44 m.y.). Small dots denote all other deposits listed in table 1.

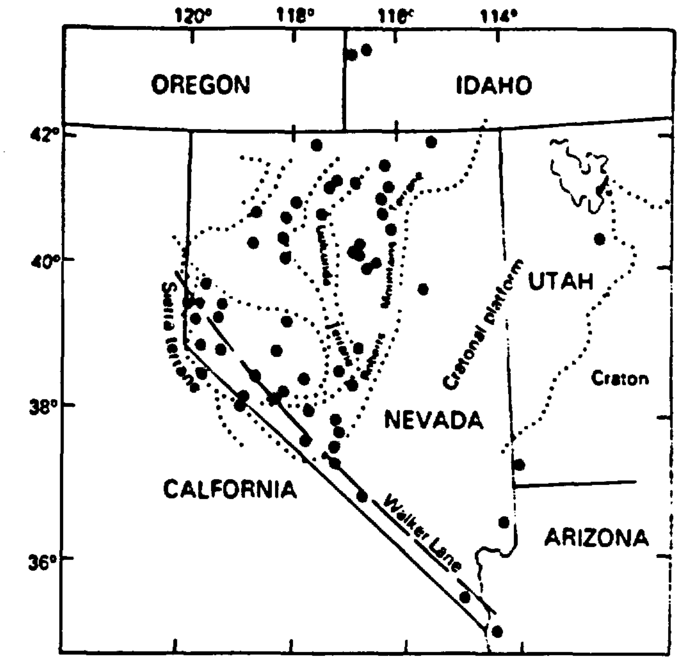

Figure 2. Nevada and parts of adjacent States, showing distribution of miogeosynclinal and accreted terranes (see fig. 64).

although the Rochester district is of interest mainly for its silver. Most districts show little obvious relation to belts of volcanic rocks, although the Rochester, again, is an exception because it occurs in volcanic rocks of the Koipato Group of Mesozoic age.

The distribution of the older deposits shown in figure 1 shows no coherent pattern. A cluster occurs in north-central Nevada which seems to be associated with the accreted Golconda and Roberts Mountains terranes (fig. 2) and are sharply limited by the east boundary of the Roberts Mountains terrane. Exceptions are the Gold Strike district of southwestern Utah, and Alligator Ridge, which have not yet been dated.

A long time lapse may have occurred between Cretaceous and middle Tertiary precious-metal-ore generation, possibly from about 73 to 38 m.y. B.P. Firm conclusions cannot yet be drawn from the limited data; however, many new deposits of the disseminated type have been discovered in the past 5 to 10 years, most of which are not yet reliably dated (or data not yet released). Major thrust faulting and accretion of terranes from elsewhere had already occurred. Crustal extension and thinning, with consequent increased conductive heat flow and early stages of formation of the Great Basin, had not yet started.

Evolving trends of mid-Tertiary and younger volcanic and precious-metal systems

The pattern of mid-Tertiary and younger volcanism and its relations to precious-metal-ore deposits have been interpreted as belts that develop sequentially. Stewart and Carlson (1976) and Stewart and others (1977) emphasized arcuate, generally east-west-trending belts, each successively younger to the south over time. Silberman and others (1976) also emphasized an east-westward trend that migrates southward but rotates into near-coincidence with the northwest-trending Walker Lane (near the common northwest boundary of Nevada and California). North-southward and northeastward trends are not specifically recognized.

Although I depend strongly on the primary data from these authors for most of my interpretations, I prefer to interpret the pattern of evolving volcanism during and after mid-Tertiary time as a sharply flexed arc consisting of an east-northeast-trending southern arm and a north-northeast-trending northern arm, joining in east-central Nevada (fig. 3); over time, this arc broadens and migrates southward and westward. The gold-silver deposits as a whole (bottom, fig. 1; table 1) show a stronger north-northeastward than an east-westward or northwestward trend. In the following sections, I suggest these main trends, with dominance shifting over time. Mineralization trends tend to be short and sharp in space and time, not always coinciding with the crudely contemporaneous volcanic trends.

Trends from 43 to 34 m.y. B.P.

Stewart and others (1977) showed the distribution of volcanic rocks that range in age from 34 to 43 m.y. (fig. 3). Although several interpretations of their generalized distributions have been published, I visualize figure 3 as a sharply flexed arc with west-southwestern and north-northeastern limbs that join at an

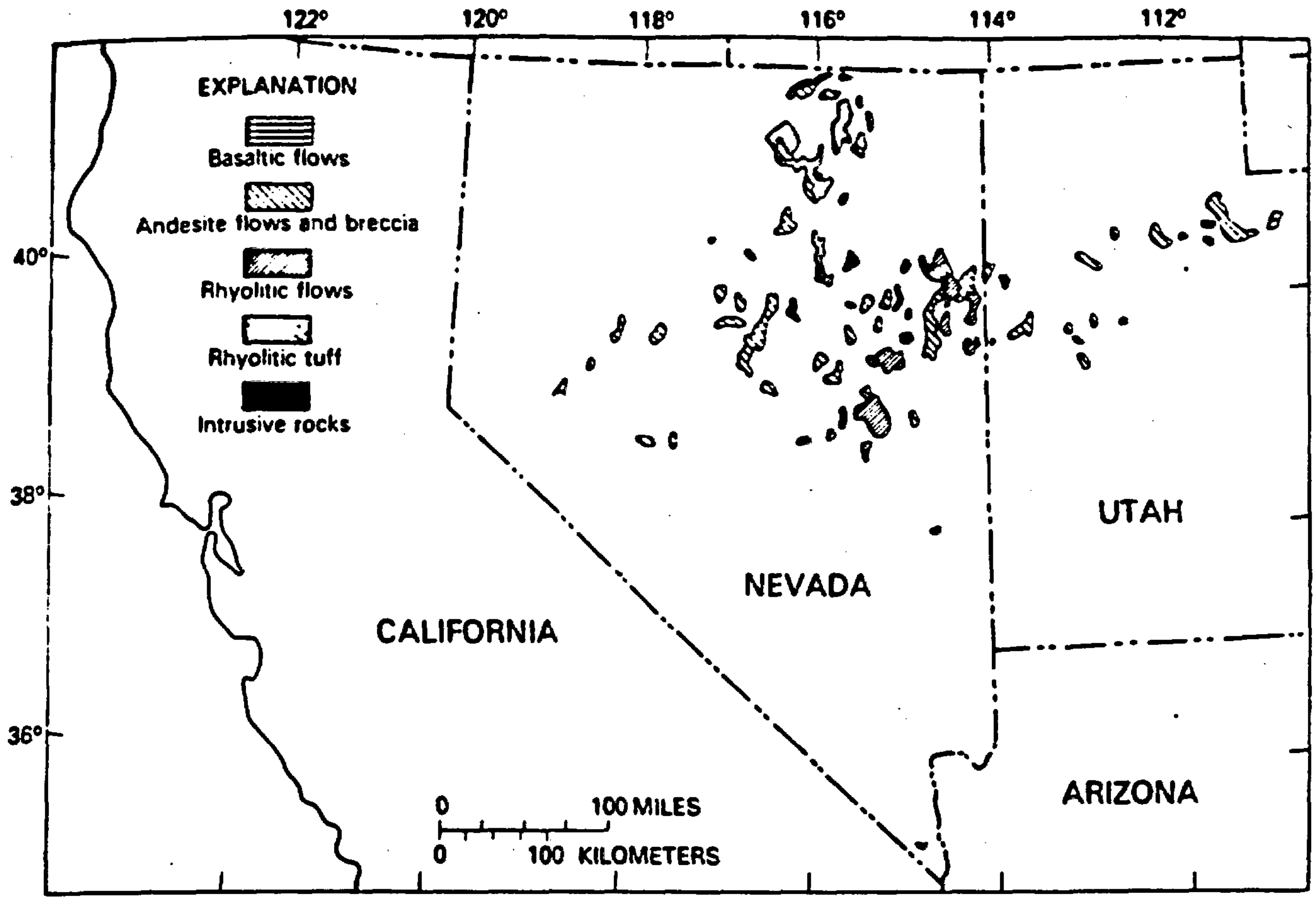

Figure 3. Nevada and parts of adjacent States, showing distribution of volcanic rocks that range in age from 34 to 43 m.y. (from Stewart and others, 1977, fig. 1A).

apex in east-central Nevada. Andesitic flows and breccia are dominant in the southern limb, rhyolitic flows are abundant near the sharp flexure, and rhyolitic tuff is most abundant along the north-northeastern limb. Intrusive rocks are sporadic throughout the arc. Only a single caldera, Mount Lewis, was recognized by Stewart and others (1977) in north-central Nevada south of Battle Mountain, but all mapped rhyolitic ash-flow tuff occurs considerably northeastward of this caldera. The terrane boundaries shown in figure 2 have no apparent influence on the volcanic arc, the types of volcanism, or the positions of calderas.

Four precious-metal districts with indicated ages within the same 34-43-m.y.-age range as the volcanic rocks have been recognized (fig. 4). All four districts are tightly restricted within a timespan of 4 m.y. from 38 to 35 m.y. B.P., are alined along the northeast-trending arm of the volcanic arc of figure 3, and are superposed over the general area of highest concentration of Cretaceous(?) deposits (fig. 1).

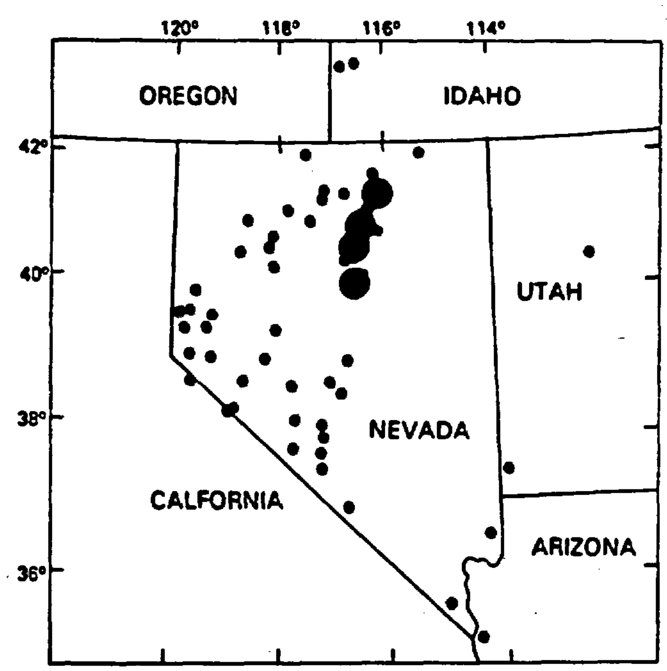

Figure 4. Nevada and parts of adjacent States, showing locations of gold-silver deposits with mineralization ages of 34 to 43 m.y. (large dots).

Trends from 34 to 17 m.y. B.P.

The volcanic evolution of southward-migrating east-west-trending belts that previous authors have emphasized, was most firmly established during

34-17 m.y. B.P. The southern limb of the arc of figure 3 advanced slightly westward, while its east end strengthened and rotated more rapidly southward than its west end. Contemporaneously, the moderately strong northern limb of the arc of figure 3 weakened as it advanced westward (fig. 5). Thus, a strong northwestward trend crudely parallel to the Walker Lane, emphasized by the previously cited authors, became most firmly evident. Rhyolitic ash-flow tuffs were the dominant volcanic rocks in southwestern Nevada and eastern California. Stewart and Carlson (1976, sheet 2) identified 11 definite calderas, 8 probable calderas, and 2 northwest-trending volcanotectonic depressions, the largest approximately 100 km long by 50 km wide. More calderas probably exist, especially in western and northeastern Nevada, where concealed calderas seem likely to account for the distribution of many ash-flow tuffs.

Six epithermal gold-silver districts were generated within this volcanic period, all of which formed within the timespan 25-17 m.y. B.P. (fig. 6), approximately parallel to the Walker Lane. These districts include the important Round Mountain, Tonopah, and Goldfield, Nev., districts, which as a group trend north-south. These ore districts are not restricted to any one volcanic type but occur mainly in areas of andesitic rocks, commonly with later rhyolite tuff. No recognized epithermal mineralization occurred in the volcanic time interval 34-25 m.y. B.P.

Trends from 17 to 6 m.y. B.P.

Most students of Great Basin volcanology consider that all the volcanic rocks erupted from 17 to 6 m.y. B.P. belong to a single broad volcanic period. The volcanic arc of figure 3 had expanded westward and southward during the time interval shown in figure 5, as described above, and then expanded farther to the west (fig. 7). Its southern limb weakened somewhat but remained dominantly rhyolitic. Andesite flows and breccia became dominant in the western part of the expanding arc. In the northern and northeastern limbs of the arc, basalt flows became a major volcanic component, in part in bimodal association with rhyolite flows, especially in northern Nevada and southern Idaho. Only 2 rhyolitic calderas were identified on the northeast limb of the arc, in contrast to 10 mapped and 2 probable calderas shown

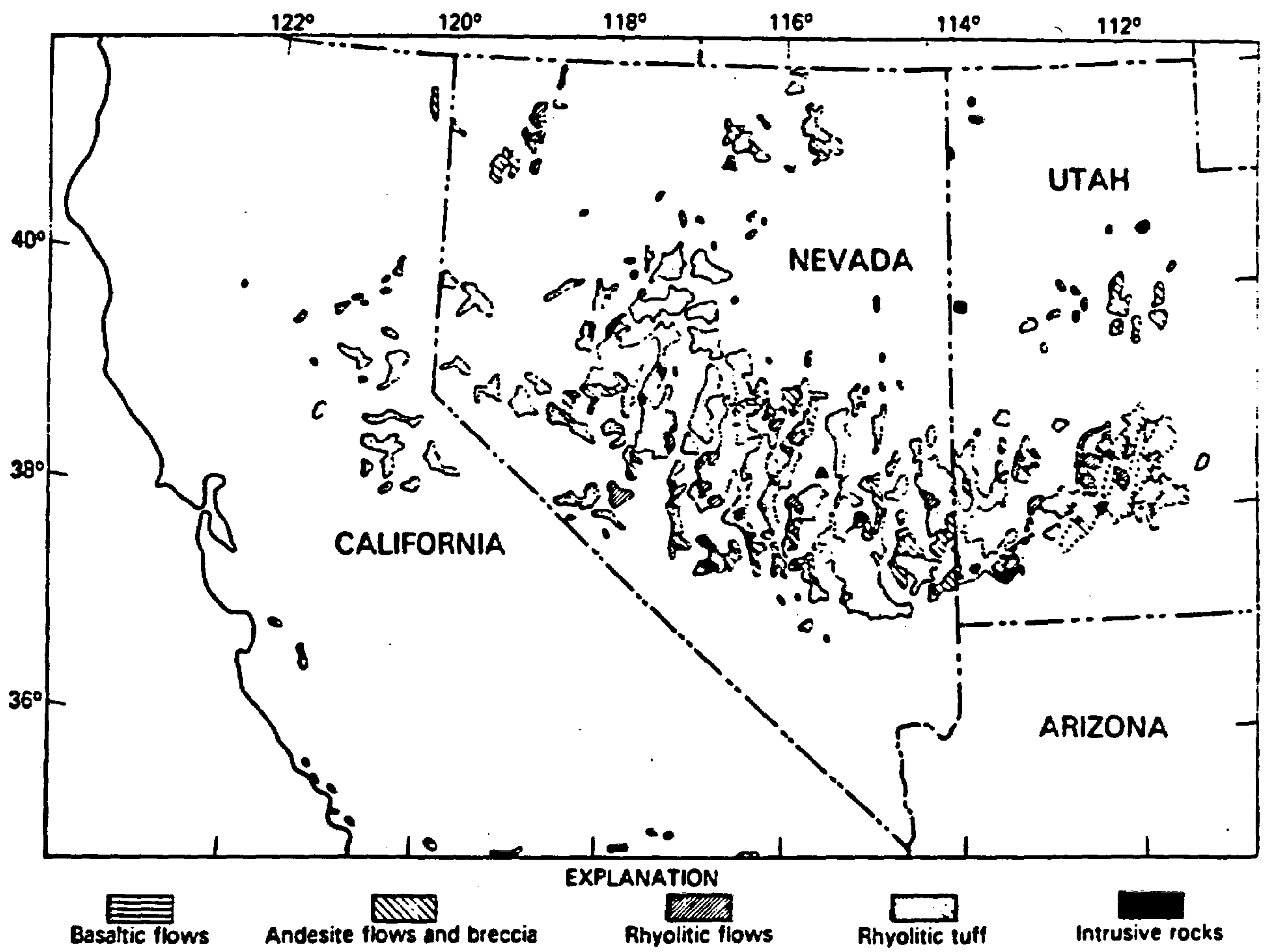

Figure 5. Nevada and parts of adjacent States, showing distribution of volcanic rocks that range in age from 17 to 34 m.y. (from Stewart and others, 1977, fig. 1B; see fig. 3 for key).

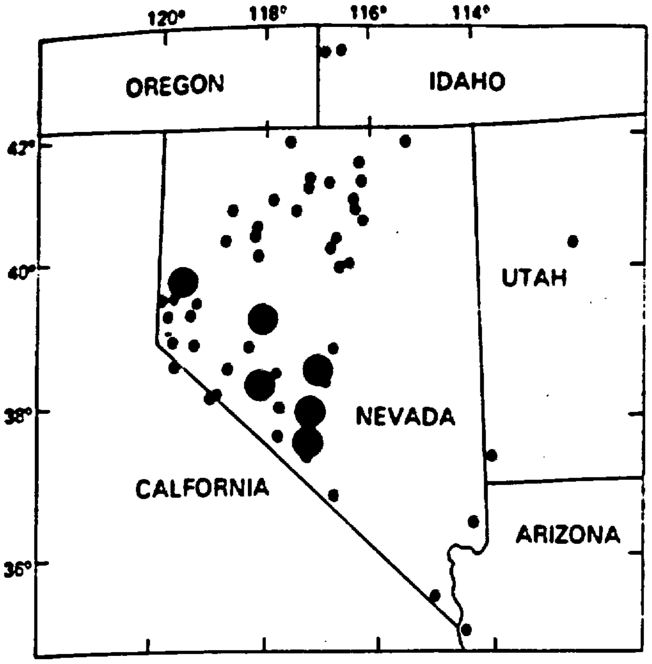

Figure 6. Nevada and parts of adjacent States, showing locations of gold-silver deposits with mineralization ages of 17 to 25 m.y. (large dots).

by Stewart and Carlson (1976, sheet 3) on the southern limb of the volcanic arc.

Although epithermal gold-silver deposits of the volcanic period 17-6 m.y. B.P. are also generally considered as a single group, the pattern of evolution suggests a significant change near 14 m.y. B.P. that justifies subdivision into an older and a younger group. The climax in ore deposition, as viewed by the number of dated ore districts, occurred within the short period 17-14 m.y. B.P. (fig. 8). A total of 15 districts from table 1 are included in this group, none of which are of first rank except, possibly, the Silver City-DeLamar district in southwestern Idaho. The Jarbidge, Manhattan, and National districts are the largest of the age group in Nevada. Seven districts of figure 8 occur within the general Walker Lane of southwestern Nevada, but a relatively distinct cluster of eight districts are in and near north-central Nevada, within the general region of mineralization shown in figures 1 and 3.

The later part of this volcanic period (approx 14-6 m.y. B.P.) was accompanied by a further evolution of the mineralization trends (fig. 9). The Walker Lane trend of ore deposits shifted a little farther southwestward to includes the major Comstock lode, as well as the Aurora and Bullfrog districts of Nevada and Bodie, Calif. Seven Troughs (13.7-14 m.y. old) can be viewed either as a westward extension of the cluster in figure 8 or as a continued but weakening northeastward extension from the apex of ore deposits in figure 9.

Trends from 6 m.y. B.P. to present

During the past 6 m.y., Nevada has been almost devoid of volcanism except for local basalt flows (fig. 10), andesite, and a few rhyolite domes near Steamboat Springs south of Reno. Long Valley caldera in California erupted rhyolite ash-flow tuff and, together with Mono Craters just to the north, extruded small rhyolitic domes (G, fig. 10). Figure 10 shows, however, that westward migration and expansion of volcanism are still continuing, though declining in intensity.

Epithermal ore deposits formed about 5 m.y. B.P. along the Walker Lane trend (Monitor, Calif., and Borealis and Silver Peak, Nev., fig. 11). Steamboat Springs (S, fig. 11), which has been active during the past 3 m.y. (Silberman and others, 1979), and Sulphur, Nev., (1.8-2.1 m.y. old, table 1), are the youngest representatives of the epithermal gold-silver group (White, 1981; White and Heropoulos, 1984). Continuing thermal activity in the resurgent dome of Long Valley caldera, Calif. (G, fig. 10), may also be generating an epithermal ore deposit, as suggested by the presence of Ag and Au in some hot-spring sinters, along with the commonly associated "volatile" elements As, Hg, Sb, and Tl (White and Heropoulos, 1983).

However, the existence of ore-grade Au and Ag in minable amounts (neglecting the problems of mining water-saturated rocks at high temperatures) has not been demonstrated for any active hot-spring system. Sulphur, Nev. (1.8-2.1 m.y. old), continues to exhale sulfur gases and may contain the size and grade of an economic ore deposit (A. B. Wallace, oral commun., 1981).

Although Steamboat Springs, Sulphur, and, possibly, Long Valley are examples of active generation of epithermal gold-silver deposits, this type of mineralization now seems to be declining in frequency and intensity in the Western United States, though possibly not in New Zealand, Kamchatka, and elsewhere.

ENIGMAS OF DISSEMINATED GOLD-SILVER DEPOSITS

In recent years, major attention has been focused on disseminated precious-metal ore deposits, generally minable for their dispersed fine-grained or "invisible" gold. Table 1 and the previous discussion suggest that the existence of at least two types of ore deposits may be causing at least part of the confusion. The younger deposits (less than 40 m.y. old) may be similar in origin, composition of ore fluids, hydrodynamics, tectonic environment, and near-surface generation to the classic "fossil" volcanic-hosted vein deposits, except for differences in physical characteristics of the host rocks. All of these younger deposits may be "volcanic centered" and owe their thermal energy and, probably, part of their mineral content and water to underlying volcanic sources. The distribution of volcanism and ore generation (figs. 3-11) shows convincingly that both of these phenomena are broadly related in space and time, but that ore generation is restricted to short time intervals requiring some special tectonic and other geologic conditions. Much more abundant data on the ages of these ore deposits may provide much new understanding of paleotectonics, for one example. A vein represents a fossil open channel that was permeable to upward flow of mineralizing fluids. Although this channel was eventually filled with quartz and other "self-sealing" hydrothermal minerals (Keith and others, 1978), the strike of a widening vein was at that time either in the direction, or close to the direction, of minimum horizontal stress. Probably no method other than radiometric dating of K-bearing gangue minerals can provide changes in principal stress directions through a large area over millions of years.

A second type of disseminated deposit seems to differ greatly from the first in its reported ages (generally older than 70 m.y.) and in other characteristics. We have only fragmentary data on the tectonic settings, ages, temperatures of deposition, salinities, and other characteristics of the ore fluids of this group. For many years I assumed that the relative abundances of As, Sb, Hg, and Tl in high-temperature active hot-spring systems and some disseminated deposits (especially Carlin and Getchell) provided strong evidence for closely related origins. However, figure 1 and table 1 demonstrate that many disseminated deposits may be pre-Tertiary, their fluid-inclusion salinities distinctly higher (if Gold Acres and Rochester, Nev., are typical), and their temperatures generally lower than those of many vein deposits and some active hot-spring systems. If their reported age differences are real, the tectonic and volcanic environments of these deposits probably differed also.

Until more reliable data on these older(?) disseminated deposits are available, we should be careful in reaching any firm conclusions on a common origin. My present tendency is to suggest that the older sediment-hosted deposits were saturated by "evolved connate" waters (White, 1981), possibly convectively circulating below a low-permeability barrier that became less permeable over time because of self-sealing. These systems could have been geopressured, with fluids dispersing into surrounding pore water, losing heat by conduction but with little or no venting of fluids directly to the surface, or mixing with meteoric waters.

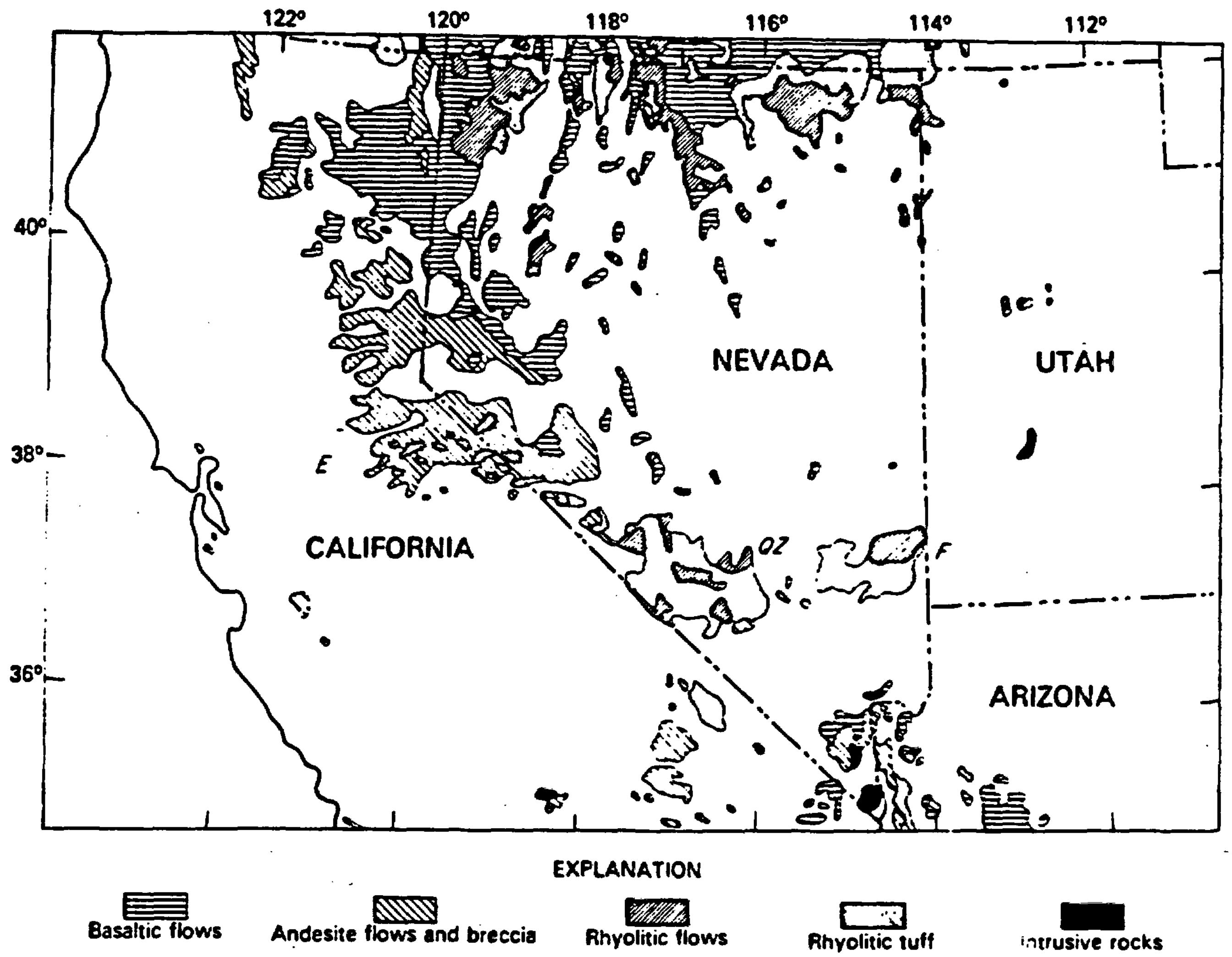

Figure 7. Nevada and parts of adjacent States, showing distribution from volcanic rocks that range in age from 6 to 17 m.y. (from Stewart and others, 1977, fig. 1C).

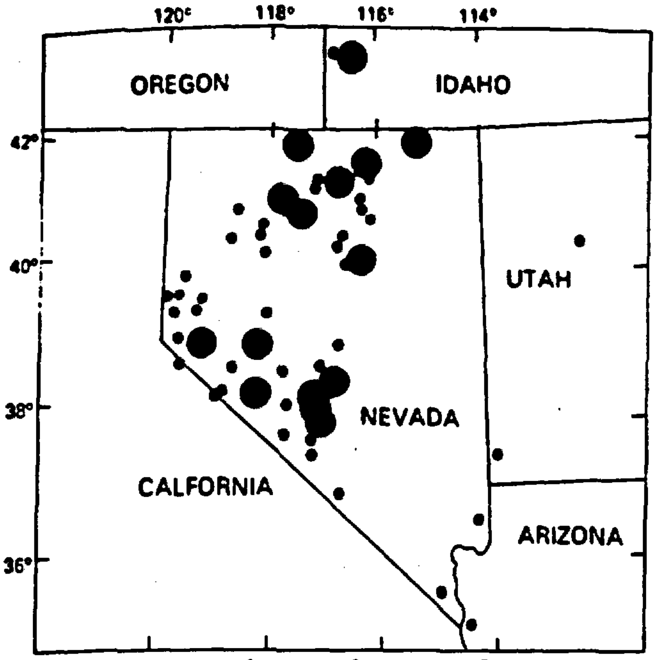

Figure 8. Nevada and parts of adjacent States, showing locations of gold-silver deposits with mineralization ages of 14 to 17 m.y. (large dots).

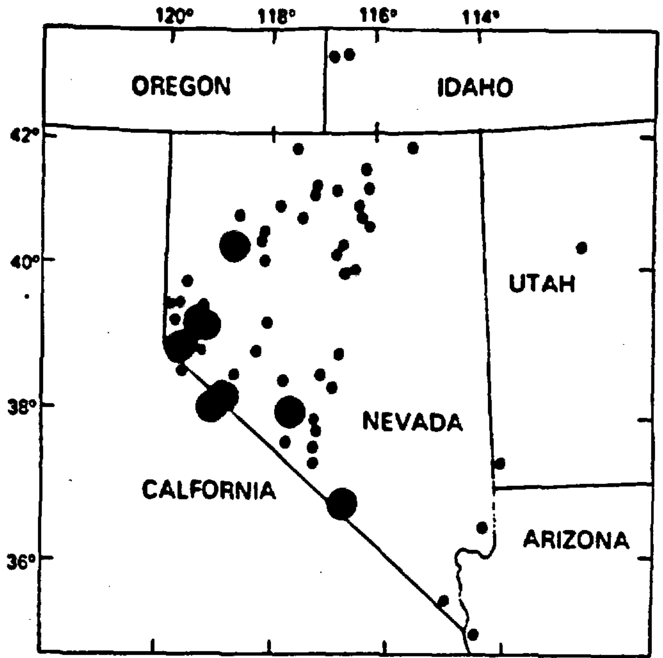

Figure 9. Nevada and parts of adjacent States, showing locations of gold-silver deposits that range in age from 6 to about 14 m.y. (large dots).

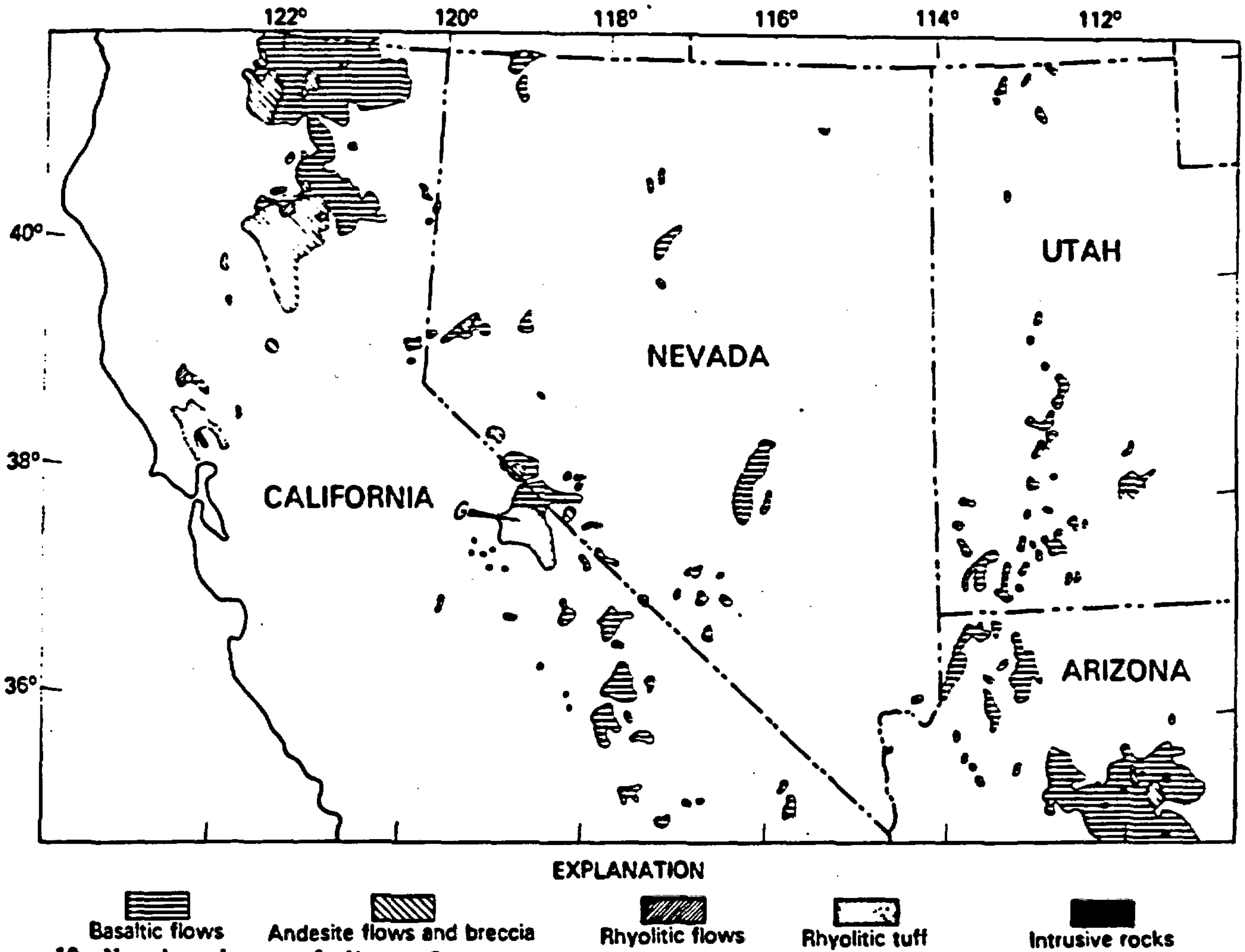

Figure 10. Nevada and parts of adjacent States, showing distribution of volcanic rocks that range in age from 0 to 6 m.y. (from Stewart and others, 1977, fig. 1D).

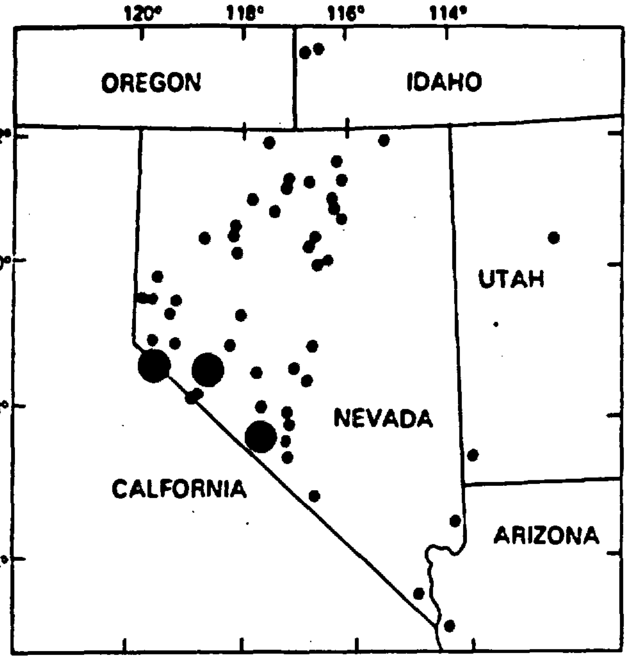

Figure 11. Nevada and parts of adjacent States, showing locations of gold-silver deposits with mineralization ages of 0 to 6 m.y. (large dots). Steamboat Springs (S) is the only active system, but Sulphur (Su) has feeble discharges of warm gases.

REFERENCES CITED

Bonham, H. F., Jr., 1976, Gold producing districts of Nevada (2d ed.): Nevada Bureau of Mines Geologic Map 32, scale 1:1,000,000.

—— 1980, Silver producing districts of Nevada (2d ed.): Nevada Bureau of Mines Geologic Map 33, scale 1:1,000,000.

—— 1982, Reserves, host rocks, and ages of bulk-minable precious metal deposits in Nevada: Nevada Bureau of Mines and Geology Open-File Report 81-1 and Preliminary Report 82-9, 4 p.

Brook, C. A., Mariner, R. H., Mabey, D. R., Swanson, Jr., Guffanti, Marianne, and Muffler, L. J. P., 1979, Hydrothermal convection systems with reservoir temperatures ≥ 90°C, in Muffler, L. J. P., ed., Assessment of geothermal resources of the United States—1978: U.S. Geological Survey Circular 790, p. 18-85.

Buchanan, L. J., 1981, Precious metal deposits associated with volcanic environments in the Southwest, in Dickinson, W. R., and Payne, W. D., eds., Relations of tectonics to ore deposits in the Southern Cordillera: Arizona Geological Society Digest, v. 14, p. 237-262.

Garside, L. J., and Schilling, J. H., 1979, Thermal waters of Nevada: Nevada Bureau of Mines Geology Bulletin 91, 163 p.

Keith, T. E. C., White, D. E., and Beeson, M. H., 1978, Hydrothermal alteration and self-sealing in Y-7 and Y-8 drill holes in northern part of Upper Geyser Basin, Yellowstone Park, Wyoming: U.S Geological Survey Professional Paper 1054-A, p A1-A26.

Lindgren, Waldemar, 1933, Mineral deposits (4th ed.: New York, McGraw-Hill, 930 p.

Nash, J. T., 1972, Fluid inclusion studies of some gol deposits in Nevada; in Geological Surve research, 1972: U.S. Geological Surve Professional Paper 800-C, p. C15-C19.

Nolan, T. B., 1933, Epithermal precious-meta deposits, in Ore deposits of the western state (Lindgren volume): New York, America Institute Mining Metallurgical Engineers, p. 623-640.

Pansze, A. J., Jr., 1975, Geology and ore deposits o the Silver City-De Lamar-Flint region, Owyhee County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 161, 79 p.

Silberman, M. L., 1984, Geochronology of hydrothermal alteration and mineralization, in Geothermal Resources Council Conference on Energy and Mineral Resources of the Northern Great Basin, Reno, Nev., 1983. Proceedings (in press).

Silberman, M. L., and McKee, E. H., 1974, Ages of Tertiary volcanic rocks and hydrothermal precious-metal deposits in central and western Nevada, in Guidebook to the geology of four Tertiary volcanic centers in central Nevada: Nevada Bureau of Mines Report 19, p. 67-72.

Silberman, M. L., Stewart, J. H., and McKee, E. H., 1976, Igneous activity, tectonics, and hydrothermal precious-metal mineralization in the Great Basin during Cenozoic time: Society of Mining Engineers Transactions, v. 260, no. 3, p. 253-263.

Silberman, M. L., White, D. E., Keith, T. E. C., and Dockter, R. D., 1979, Duration of hydrothermal activity at Steamboat Springs, Nevada, from ages of spatially associated volcanic rocks: U.S. Geological Survey Professional Paper 458-D, p. D1-D14.

Stewart, J. H., and Carlson, J. E., 1976, Cenozoic rocks of Nevada: Nevada Bureau of Mines and Geology Map 52, scale 1:1,000,000.

Stewart, J. H., Moore, W. J., and Zietz, Isidore, 1977, East-west patterns of Cenozoic rocks, aeromagnetic anomalies, and mineral deposits, Nevada and Utah: Geological Society of America Bulletin, v. 88, no. 1, p. 67-77.

Vikre, P. G., 1981, Silver mineralization of the Rochester district, Pershing County, Nevada: Economic Geology, v. 76, no. 3, p. 580-609.

White, D. E., 1981, Active geothermal systems and hydrothermal ore deposits, in Economic Geology, 75th anniversary volume, p. 392-423.

White, D. E., and Heropoulos, Chris, 1983, Active and fossil hydrothermal convection systems of the Great Basin, in Geothermal Resources Council Conference on Energy and Mineral Resources of the Northern Great Basin, Reno, Nev., 1983, Proceedings.