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CONSTRAINTS ON THE AGE OF GOLD MINERALIZATION AND METALLOGENESIS IN THE BATTLE MOUNTAIN-EUREKA MINERAL BELT, NEVADA

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Introduction

THE Roberts Mountains of north-central Nevada are comprised of Paleozoic sedimentary rocks that host several gold deposits and subeconomic gold resources (Fig. 1). These gold occurrences are within a regional alignment of precious and base metal deposits in north-central Nevada termed the Battle Mountain-Eureka mineral belt (Roberts, 1966). Field relations and radiometric ages in three areas of the Roberts Mountains (Maher et al., 1990) allow assignment of minimum and probable maximum ages for gold mineralization. New radiometric age data from the Roberts Mountains and other precious and base metal deposits within the Battle Mountain-Eureka mineral belt are combined in this report with previously published geologic data to construct a metallogenic framework for gold and other metallic deposits in north-central Nevada.

Age determinations reported in Table 1 were done in the laboratories of the U. S. Geological Survey, Menlo Park, California, using standard isotope dilution procedures described by Dalrymple and Lanphere (1969). The analyses were performed on mineral concentrates prepared by heavy liquid, magnetic, electrostatic, and handpicking procedures. Potassium analyses were performed by lithium metaborate flux fusion-flame photometry techniques, the lithium serving as an internal standard (Ingamells, 1970). Argon analyses were performed using a 60° sector, 15.2-cm radius, Nier-type mass spectrometer or a five-collector mass spectrometer (Stacey et al., 1981). Precision of the data, shown as the ± value, is the estimated analytic uncertainty at one standard deviation (68%). It represents uncertainty in the measurement of radiogenic ^{40}Ar and K_2O in the sample and is based on experience with replicated analyses in the Menlo Park laboratories. The decay constants used for K and the ^{40}K/K abundance ratio are those adopted by the International Union of Geological Sciences Subcommission on Geochronology (Steiger and Jäger, 1977).

Field Relations

Roberts Creek volcanic center

A middle Tertiary volcanic center at the headwaters of Roberts Creek contains a central maar that is partially filled with a stratified sequence of rhyolite tuffs, herein named the Roberts Creek volcanic center (Figs. 1 and 2). The oldest unit of the Roberts Creek volcanic center is a crystal-lithic rhyolite tuff that unconformably overlies clastic rocks of the Mississippian Webb Formation and the Devonian Devils Gate Limestone (Fig. 2; Browne, 1989). The tuff is hydrothermally altered to quartz-chlorite-epidote-pyrite-carbonate, which is overprinted by quartz-barite-jarosite. Siltstone and argillite of the Webb Formation contain the same hydrothermal minerals and locally host anomalous gold mineralization (up to 0.2 g/t). The presence of identical hydrothermal alteration minerals in both tuff and Paleozoic clastic rocks indicates that hydrothermal alteration may have occurred simultaneously in both rock types. Younger tuffs that fill the Roberts Creek volcanic center are unaltered and, therefore, postdate hydrothermal alteration. The younger, overlying tuffs are locally capped by unaltered basalt flows which yields a K-Ar age of 13.6 ± 0.4 Ma (sample 9, Table 1, and Fig. 2).

K-Ar dating of biotite from an unaltered, pink, crystal rhyolite tuff, which overlies the altered crystal-lithic rhyolite tuff of the Roberts Creek volcanic center (Fig. 2), establishes a minimum age for hydrothermal alteration of 34.2 ± 1.1 Ma (sample 10, Table 1). The fine-grained nature of hydrothermal minerals within altered crystal-lithic rhyolite tuff precludes direct dating of hydrothermal alteration in this unit. Petrographically, the altered crystal-lithic rhyolite tuff is indistinguishable from other early Oligocene tuffs exposed in north-central Nevada (Browne, 1989). Further, the absence of pre-Oligocene volcanic rocks in the Roberts Mountains makes it unlikely that the altered crystal-lithic rhyolite tuff was derived from an undocumented pre-Oligocene volcanic event. Therefore, the hydrothermally altered crystal-lithic tuff most likely was deposited after the onset of Oligocene magmatism in the Roberts Mountains which began at about 38 Ma (McKee, 1986). Thus, hydrothermal alteration and concomitant anomalous gold mineralization in the Roberts Creek volcanic center most likely occurred between 38 and 34 Ma.

Roberts Creek Mountain and Chert Cliff

Hydrothermally altered siltstone of the Webb Formation and Devonian carbonate rocks crop out

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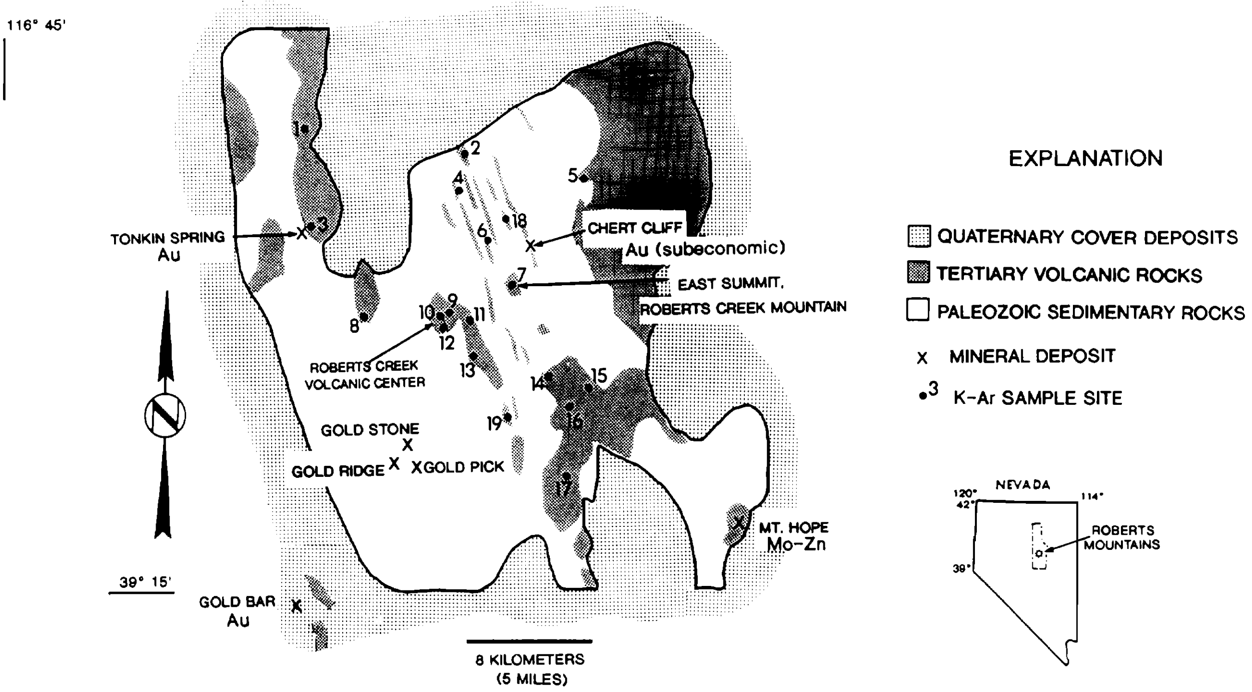

FIG. 1. Location map of the Roberts Mountains with generalized geology, K-Ar sample sites, and areas discussed in the text. Numbered localities correspond to sample numbers listed in Table 1.

nearly continuously from the east summit of Roberts Creek Mountain to Chert Cliff (Figs. 1 and 3). Hydrothermal minerals present in the Webb Formation are similar to those in the Roberts Creek volcanic center, whereas Devonian carbonate rocks are variably silicified and barite veined. At Chert Cliff, the Webb Formation hosts a small gold deposit (Fig. 3) and anomalous (0.1-1.5 g/t) gold mineralization is widespread throughout the area. On the east summit of Roberts Creek Mountain, an exogenous dome of unaltered rhyodacite porphyry, referred to as the east summit dome, overlies and intrudes argillite and

TABLE 1. Radiometric Ages of Volcanic Rocks from the Roberts Mountains

Sample (Location number in Fig. 1)	Material dated	K_2O (wt %)	^{40}Ar° (mole/g)	^{40}Ar°/S^{40}Ar (%)	Age (Ma)
1	Plagioclase	0.97	4.7653×10^{-11}	17	33.4 ± 2.5
2	Whole-rock basalt	1.385	2.8281×10^{-11}	28	14.1 ± 0.4
3	Biotite	7.91	4.3392×10^{-10}	73	37.5 ± 1.2
4	Whole-rock basalt	2.360	5.4569×10^{-11}	6.2	16.2 ± 3.6
5	Biotite	7.80	4.1290×10^{-10}	61	36.4 ± 1.2
6	Whole-rock basalt	1.161	2.6192×10^{-11}	51	15.6 ± 0.3
7	Biotite	8.42	4.1545×10^{-10}	80	33.9 ± 1.0
8	Sanidine	7.04	2.5453×10^{-10}	39	24.8 ± 0.8
9	Whole-rock basalt	1.661	3.2745×10^{-11}	42	13.6 ± 0.4
10	Biotite	8.58	4.2619×10^{-10}	82	34.2 ± 1.1
11	Whole-rock basalt	1.948	4.6043×10^{-11}	50	16.3 ± 0.4
12	Alunite	6.77	5.1537×10^{-11}	48	5.3 ± 0.16
13	Biotite	8.68	3.1979×10^{-10}	64	25.4 ± 0.8
14	Whole-rock basalt	1.760	3.9224×10^{-11}	24	15.4 ± 0.5
15	Whole-rock basalt	1.725	4.6506×10^{-11}	34	18.6 ± 0.7
16	Biotite	8.56	4.3927×10^{-10}	48	35.3 ± 1.1
17	Sanidine	6.44	2.6931×10^{-10}	39	28.8 ± 1.0
18	Whole-rock gabbro	0.358	9.1091×10^{-12}	13	17.6 ± 2.0
19	Alkali feldspar	3.87	1.8978×10^{-10}	88	33.7 ± 1.1

Constants used: $\lambda^{40}K\epsilon = 0.581 \times 10^{-10}\ yr^{-1}$, $\lambda^{40}K\beta = 4.962 \times 10^{-10}\ yr^{-1}$, $^{40}K\epsilon/K_{tot} = 1.167 \times 10^{-4}$ mole/mole

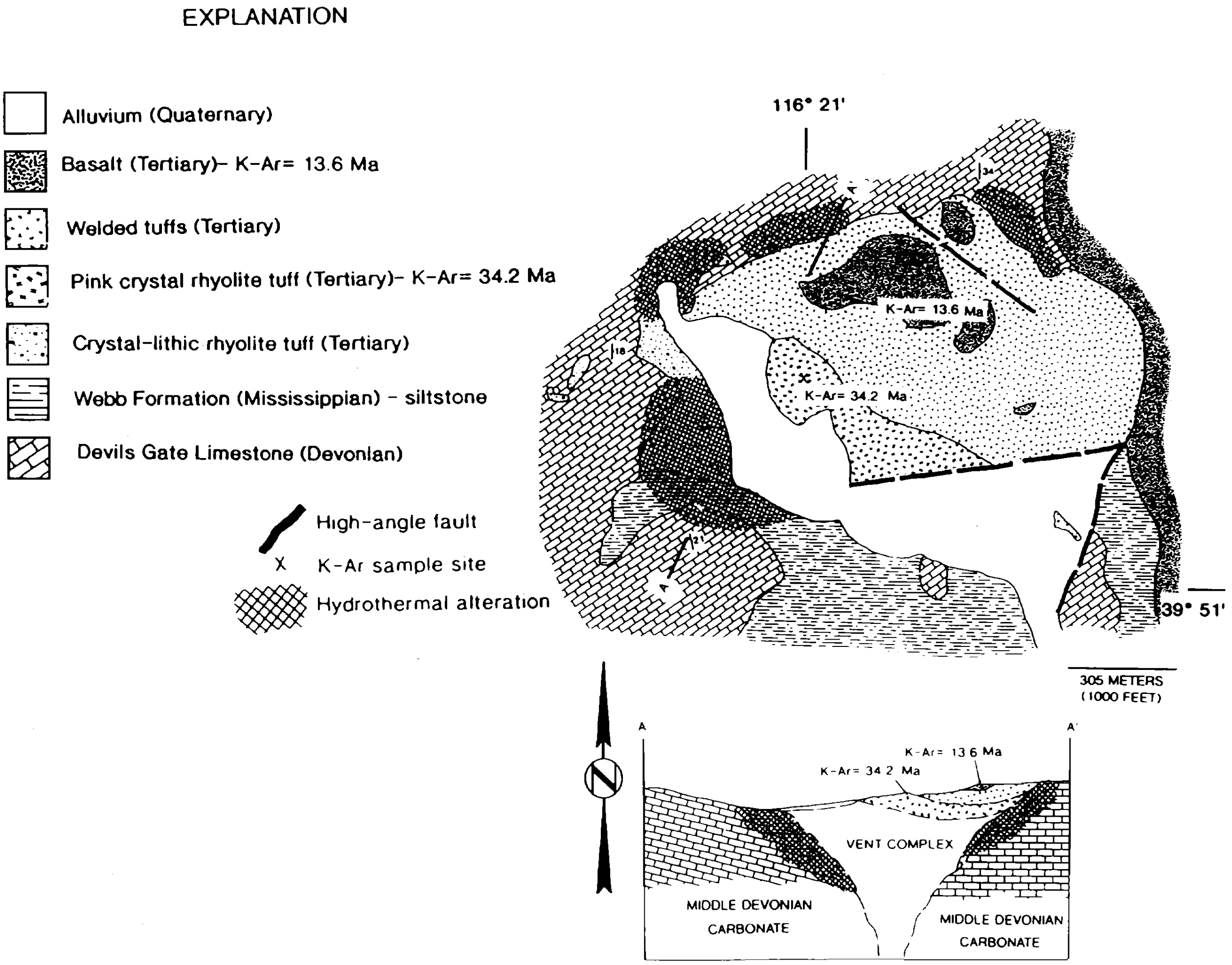

FIG. 2. Geologic map and section of the Roberts Creek volcanic center, central Roberts Mountains.

siltstone of the Webb Formation that contains gold mineralization (Fig. 3). The unaltered dome, which postdates gold mineralization, yields a K-Ar age of 33.9 ± 1.0 Ma (sample 7, Table 1), which places a minimum age of about 34 Ma on gold mineralization at the east summit.

The Chert Cliff gold deposit is intruded by several basalt and basaltic andesite dikes which are part of a much larger dike swarm that is exposed extensively in the northern Roberts Mountains (Fig. 3; Murphy et al., 1978; McKee, 1986). The dikes were emplaced during a middle Miocene magmatic event that is well-documented throughout north-central Nevada (McKee and Noble, 1986). The average age of mafic dikes and flows in the Roberts Mountains is about 16 Ma and one near Chert Cliff yields an age of 17.6 ± 2.0 Ma (sample 18, Table 1, and Fig. 1). These dikes are unaltered, indicating that they are younger than the gold mineralization at Chert Cliff.

Tonkin Spring mine

The Tonkin Spring mine is located 13 km northwest of Roberts Creek Mountain (Figs. 1 and 4). Gold mineralization occurs in a series of thrust blocks containing siltstone, arenite, silty limestone, and greenstone assigned to the Ordovician Vinini Formation (Murphy et al., 1978). Overlying the gold-mineralized rock is a crystal-lithic rhyolite tuff which is locally hydrothermally altered to a clay-bearing assemblage (Hardistry, 1983; Mehrtens, 1986). The clay-altered tuff is overlain by an unaltered andesite flow (Fig. 4). The tuff is dated by K-Ar methods at 37.5 ± 0.4 Ma (sample 3, Table 1) and the andesite at 33.4 ± 2.6 Ma (sample 1, Table 1). Absence of hydrothermal alteration in the andesite adjacent to the gold deposit establishes a minimum age of 33.4 ± 2.6 Ma for the gold deposit. If the hydrothermal alteration in the rhyolitic crystal-lithic tuff is related to gold mineral-

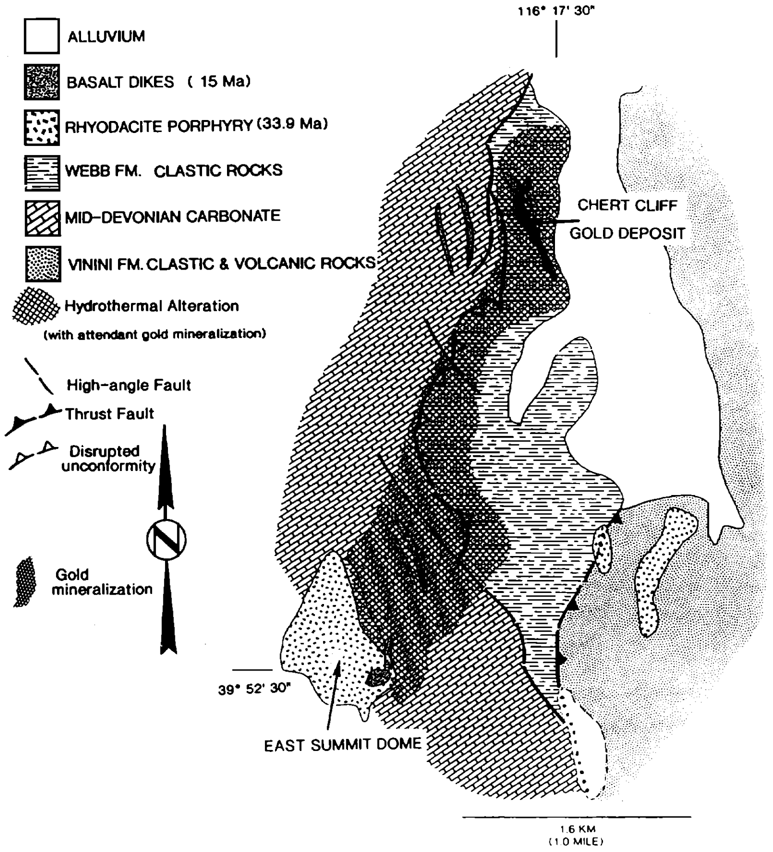

FIG. 3. Geologic map of the East Summit dome-Chert Cliff area, northern Roberts Mountains.

ization, then the age of gold mineralization at the Tonkin Spring mine is further restricted to between approximately 37 and 33 Ma.

Discussion

Age of gold mineralization in the Roberts Mountains

Two periods of Tertiary igneous activity in the Roberts Mountains have been previously recognized (McKee, 1986): an early Oligocene calc-alkaline event and a middle Miocene basaltic event.[1] New radiometric data for the Roberts Mountains delineate three groups and refine the associations. A cluster of radiometric ages occurs at about 38 to 32 Ma and represents the onset of Tertiary magmatic activity (Fig. 5). These ages are for calc-alkaline felsic to intermediate volcanic rocks, such as those of the Roberts Creek volcanic center and east summit rhyodacite porphyry dome. A late Oligocene to early Miocene magmatic event is indicated by a cluster of radiometric ages at approximately 25 Ma (Fig. 5). Though volumetrically small, the late Oligocene volcanic rocks occur at a number of places in the Roberts Mountains and adjacent areas. These rocks represent a waning in calc-alkaline eruptive activity prior to the onset of basaltic volcanism at about 20 Ma (Table 1, Fig. 5). The middle Miocene basaltic dikes and flows have radiometric ages which cluster at approximately 16 Ma (Table 1, Fig. 5). Within the Roberts Mountains, these rocks are unaltered and apparently unrelated to gold or other types of mineralization.

An early Oligocene age for the onset of volcanism in and near the Roberts Mountains is consistent with the earliest Cenozoic volcanism recognized elsewhere in north-central Nevada (McKee and Silberman, 1970; McKee et al., 1976; McKee and Noble, 1986). The hydrothermally altered tuffs at the Tonkin Spring mine and the Roberts Creek volcanic center probably represent the first pulse of magmatic activity associated with this regional early Oligocene igneous event and are overlain by unaltered Oligo-

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[1] The terms "calc-alkaline" and "basaltic" here refer to igneous products of two fundamentally different tectonic regimes. Calc-alkaline rocks have higher Ca, Mg, Sr, and Al contents than do basaltic rocks of a similar SiO_2 content, which reflects the degree of cation depletion during crystallization. The alkali feldspar in calc-alkaline rocks is rich in K; in basaltic rocks, it is relatively rich in Na.

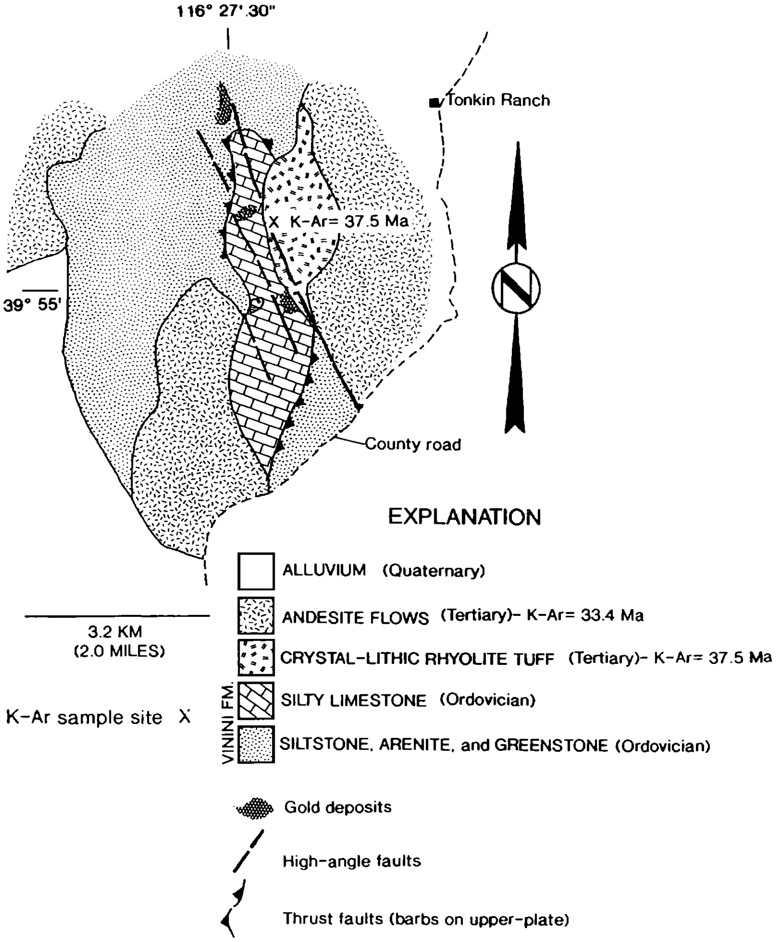


FIG. 4. Geologic map of the Tonkin Spring mine area, northern Roberts Mountains (geology modified from Murphy et al., 1978, and Gesick, 1987).

cene volcanic rocks. At the east summit of Roberts Creek Mountain, gold mineralization is in Paleozoic strata which are intruded by unaltered rhyodacite porphyry. The age of unaltered rocks at each of these three widely spaced localities is 33 to 34 Ma. Although direct radiometric dating of hydrothermal minerals associated with gold mineralization in the Roberts Mountains has not been possible, the minimum ages mandated by the unaltered tuffs combined with the earliest Oligocene(?) age for hydrothermally altered volcanic rocks spatially associated with gold mineralization indicate that the age of gold mineralization in the Roberts Mountains is probably early Oligocene, between 38 and 34 Ma, and is apparently no younger than 34 Ma.

The only previously reported date for gold mineralization in the Roberts Mountains is 24 Ma at the Gold Bar mine, based on K-Ar dating of a rhyolitic welded tuff (Broili et al., 1988). The rock dated was collected from an outcrop several thousand feet south of the Gold Bar deposit. There is no gold mineralization within the unit nor in close proximity to it (Dan Hart, pers. commun., 1989). Recent work by Masinter (1991) indicates that unaltered rhyolite ash-flow tuff, of Oligocene(?) age, overlies the middle Devonian limestone that hosts gold mineralization at Gold Bar, 200 m east of the Gold Bar deposit. This field relation

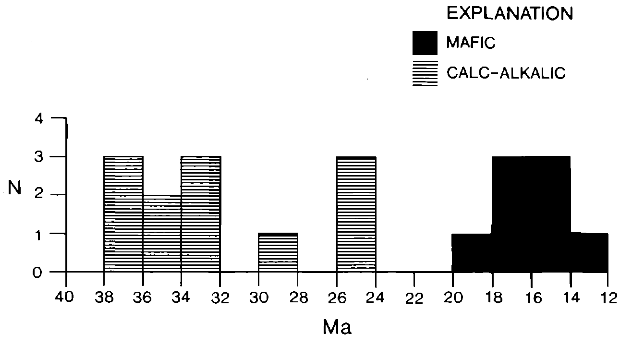


FIG. 5. Histogram of K-Ar ages of volcanic rocks in the Roberts Mountains.

TABLE 2. Reserves of Mineral Deposits and Ages of Mineralized and Spatially Associated Igneous Rocks in the Battle Mountain-Eureka Mineral Belt

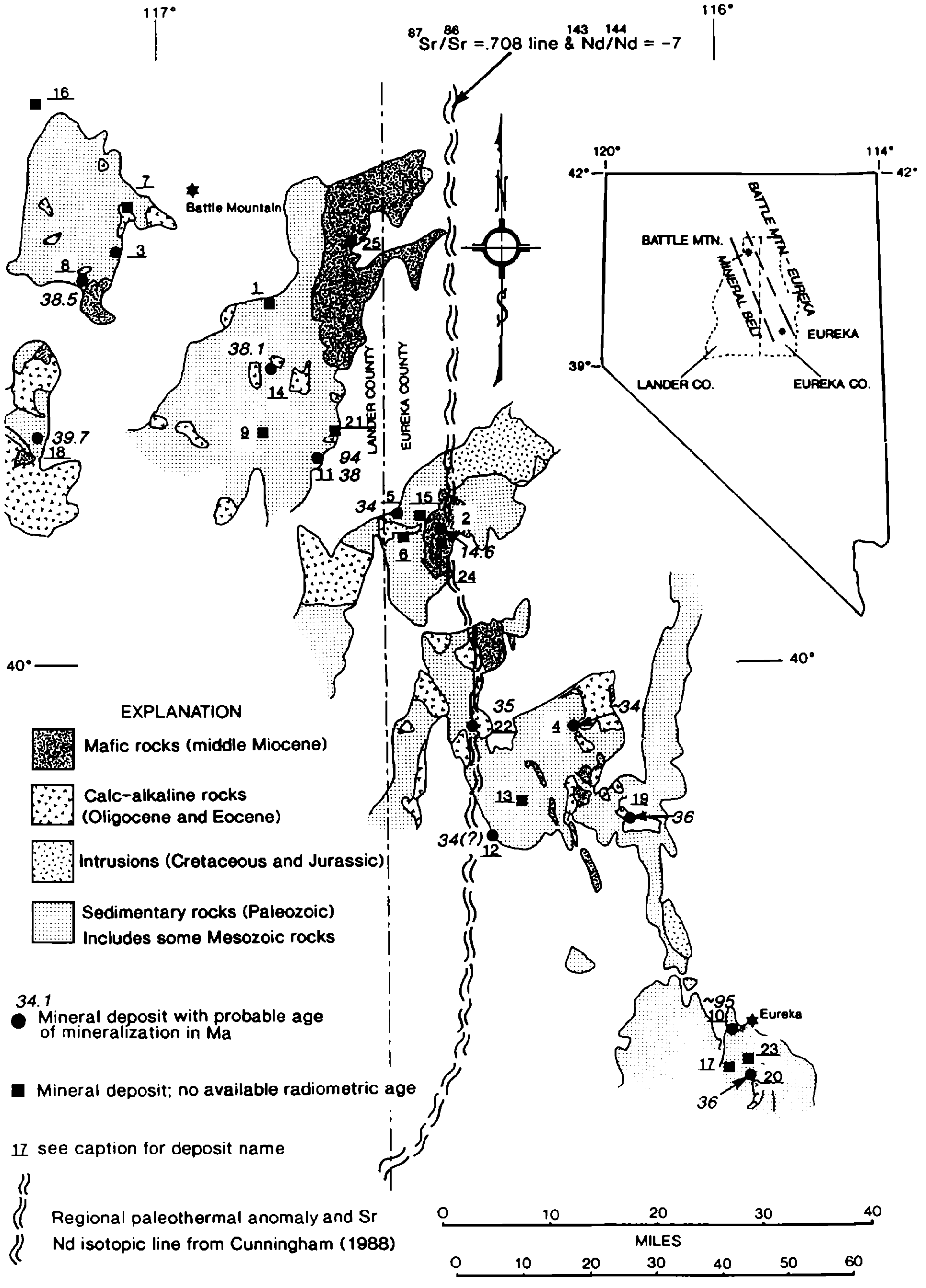
Deposit/mine	Reserves or production (M oz)	Age of associated igneous rocks or mineralization (Ma)	References	Location on Figure 6
Betty O'Neil	4.5 Ag	Oligocene (?)	Couch and Carpenter (1943)	1
Buckhorn	0.25 Au	14.6	Wells and Silberman, (1973), Monroe, et al. (1988), Jennings (1991)	2
Buckingham	? Mo	Cretaceous	Theodore et al. (1992)	3
Chert Cliff	0.04 Au	38 to 34	ASARCO Inc. files, Maher et al. (1990)	4
Cortez Gold	1.0 Au	34	Bonham and Hess, 1989	5
Copper basin	3.0 Mt @ 1.75% Cu	Oligocene (?)	Theodore et al. (1982), Theodore et al. (1973)	7
Copper Canyon (Fortitude, Tomboy, Minnie, Surprise, etc.)	1.87 Au	37.2	Wotruba et al. (1988), Bonham and Hess (1989), Theodore et al. (1973)	8
Elder Creek	0.14 Au	?	Western Minerals activity report (1989)	9
Eureka-Ruby Hill	1.65 Au	~100	Shawe et al. (1989)	10
Gold Acres/Pipeline	3.2 Au	94,38	Rytuba (1985), Bonham and Hess (1989), Northern Miner (1992)	11
Gold Bar	0.35 Au	Oligocene (?)	Massinter (1991)	12
Gold Ridge, etc.	0.47 Au	Oligocene (?)	Mining Business Digest (1991)	13
Hilltop	0.76 Au	38.1	Lisle and Desrochers (1988)	14
Horse Canyon	0.33 Au	34 (?)	Foo and Hebert (1987), Bonham and Hess (1989)	15
Marigold	0.35 Au	Tertiary (?)	Bonham and Hess (1989), McGibbon (1991)	16
McCollughs Butte	9.0 Mt @ 12% CaF_2	Cretaceous	Barton (1981), ASARCO Inc. files	17
McCoy-Cove	3.4 Au, 142 Ag	39.7	Kuyper (1988), Bonham and Hess (1989)	18
Mt. Hope	450 Mt @ 0.13–0.32% MoS_2, 10 M lbs Zn	36	Silberman and McKee (1971), Lowe et al. (1985), Roberts et al. (1967)	19
Ratto Canyon	~0.20 Au	36	Blake et al. (1975), Bonham and Hess (1989)	20
Tenabo	~0.20 Au	?	Coral Gold Corp. annual report (1990)	21
Tonkin Spring	0.31 Au	37–33	Maher et al. (1990), This paper	22
Windfall	0.21 Au	Eocene-Oligocene	Bonham and Hess (1989)	23
Zeke	0.11 Au	Miocene (?)	ASARCO Inc. files	24
Mule Canyon	0.85 Au	Miocene (?)	A. Schumacher, Pers. commun. (1990)	25

indicates that the age of gold mineralization at Gold Bar could be pre-Oligocene(?). Although these relations do not rule out a late Oligocene age for the Gold Bar deposit, field evidence is inconclusive.

Regional gold metallogenic framework

Within the Battle Mountain-Eureka mineral belt, radiometric ages of igneous rocks associated with gold mineralization define three distinct magmatic events: (1) Middle to Late Cretaceous (100–85 Ma), (2) early Oligocene (about 35 Ma), and (3) middle Miocene (about 15 Ma) (Table 2, Fig. 6). Gold deposits and cospatial igneous rocks may be genetically related, although it is often not possible to relate definitively a specific gold deposit with a specific igneous rock type.

The oldest group of mineral deposits in the Battle Mountain-Eureka mineral belt is Middle to Late Cretaceous in age, some of the deposits have gold as a by-product. The Cretaceous group of deposits is typified by the polymetallic ores of the Eureka district, which contained in excess of 1.5 Moz Au (Langlois, 1970; Shawe and Nolan, 1989) and the Buckingham molybdenum porphyry deposit at Battle Mountain (McKee, 1992). These deposits are accompanied by significant amounts of other metals (Pb, Zn, and W) and are spatially and genetically related to Late Cretaceous subequigranular intermediate to felsic com-



Geology modified after Stewart and Carlson (1978)

FIG. 6. Geologic map of the Battle Mountain-Eureka mineral belt showing distribution of base and precious metal deposits. Additional data for the deposits shown are given in Table 2.

position intrusions (Langlois, 1970; Theodore et al., 1992).

The early Oligocene group of igneous rocks and spatially associated gold deposits are widespread in the Battle Mountain-Eureka mineral belt (Fig. 6). Based on known gold reserves and production, the Oligocene group is the most significant economically in the mineral belt (approx 12.4 Moz reserves and production; Table 2, Fig. 6). These deposits all have gold as the principal ore metal although the skarn deposits near Battle Mountain also have appreciable silver and copper (Fig. 6). The large subeconomic molybdenum porphyry deposit at Mount Hope is also early Oligocene in age (Silberman and McKee, 1971; Fig. 6).

Miocene basalt within the Battle Mountain-Eureka mineral belt hosts at least two gold deposits, Buckhorn and Mule Canyon (Fig. 6). These deposits are volumetrically small in terms of gold production and reserves (approx 1.2 Moz reserves and production; Table 2, Fig. 6) when compared to deposits associated with Oligocene igneous rocks. This relationship contrasts with deposits elsewhere in north-central Nevada where large volumes of precious metal mineralization are temporally and/or spatially associated with middle Miocene mafic magmatism (Noble et al., 1988). Gold mineralization is clearly synvolcanic at one location, the Buckhorn mine, where siliceous sinter related to the gold-depositing hydrothermal event is interstratified with middle Miocene eruptive rocks (Monroe et al., 1988). This relationship is in concordance with radiometric ages of about 15 Ma for hydrothermal adularia in the gold deposit and 14.6 Ma for the enclosing basalt (Wells and Silberman, 1973; Jennings, 1991).

That gold mineralization has formed intermittently during distinct magmatic pulses over 100 m.y. of crustal history within a linear geographic area suggests at least two possibilities: the source of the gold for these deposits is not the magmas spatially associated with each deposit, and a pre-Late Cretaceous structure(s) is responsible for localizing these gold deposits.

The mixing of differing deposit types of variable ages throughout the Battle Mountain-Eureka mineral belt would require fortuitous localization of gold-bearing magmas of differing petrogenesis to account for all gold deposits. We propose, instead, that each magmatic pulse provided sufficient heat flow to allow widespread circulation of meteoric water which acquired gold from pre-Late Cretaceous country rock using a mechanism similar to that proposed for several sediment-hosted gold deposits in north-central Nevada (Dickson et al., 1979; Radtke, 1981; Hofstra et al., 1988). In certain deposits, an increment of magmatic fluid is probably crucial to ore formation (e.g., Fortitude, McCoy; Fig. 6), whereas at other deposits it is unlikely that any magmatic fluid was involved (e.g., Buckhorn). Because of a paucity of other pre-Late Cretaceous rocks in the Battle Mountain-Eureka mineral belt (Stewart and Carlson, 1976), it is likely that the gold in these deposits was acquired from the Paleozoic sedimentary section. Studies by Mullens (1980), Poole and Desborough, (1985), and Nelson, (1990) show that several Paleozoic formations are sufficiently enriched in trace metals including gold to supply the metal budget required for the gold deposits of the Battle Mountain-Eureka trend. Thus, no magmatic input of gold is necessary or geologically warranted for these deposits.

A very pronounced magnetic anomaly, the so-called central Nevada rift (Zoback and Thompson, 1978), is coincident with the mineral belt. The anomaly is caused by a narrow zone of relatively magnetic basaltic rocks at the surface and in the upper crust (Mabey, 1966). It extends diagonally north-northwest across the geomorphic grain which, in central Nevada, is produced by northeast-trending horsts and grabens. Within the anomaly, middle Miocene basaltic rocks are exposed at the surface in the Roberts Mountains (Fig. 6) and the Cortez Mountains as extensive north-northwest–trending dikes. Elsewhere along the anomaly, basaltic rocks do not reach the surface or are present as thin lava flows which would not produce the observed magnetic anomaly. On the western edge of the Roberts Mountains, several long and continuous north-northwest–trending faults parallel the basaltic dikes and the magnetic anomaly (Murphy et al., 1978). These faults are unique in central Nevada in their length and trend; they are coincident with the Battle Mountain-Eureka mineral belt.

Cunningham (1988) proposed that the edge of the buried Precambrian craton in central Nevada, as indicated by $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ compositions, may be significant in localizing gold deposits in north-central Nevada. The Battle Mountain-Eureka mineral belt, however, obliquely crosses the inferred buried craton edge (Fig. 6), suggesting that the edge of the Precambrian craton had no influence on localizing mineral deposits in the Battle Mountain-Eureka mineral belt.

Basement gravity analyses by Blakely and Jachens (1991) clearly show an abrupt crustal change along a north-northwest–trending line. The crustal gravity change results from relatively dense upper crust northeast of the belt to less dense upper crust to the southwest that is coincident with the magnetic anomaly and the Battle Mountain-Eureka mineral belt.

The many diverse features coincident in the upper crust, including a regional magnetic anomaly, a regional gravity change, a series of unique, long, north-northwest–trending faults, and the alignment of mineral deposits, suggests that a fundamental structure is present in the crust which controls these alignments. This structure most likely is a manifestation of crustal evolution perhaps as far back as the Paleozoic but more likely in the Cretaceous. None of the north-northwest–trending features appear related to Basin and Range tectonism. The north-northwest orientation of middle Miocene basaltic dikes in the Roberts Mountains and Cortez Mountains indicates that northeasterly trending post-middle Miocene Basin and Range structure did not influence dike emplacement. Because gold mineralization in the Battle Mountain-Eureka mineral belt is middle Miocene or older, it is likely that Basin and Range tectonism played no role in localizing gold mineralization in the belt or in north-northwest–oriented mineral belts in north-central Nevada. The onset of Oligocene magmatism, with an attendant increase in heat flow within the Battle Mountain-Eureka structural zone, is largely responsible for the localization of most of the gold deposits now being exploited in the region.

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Constraints on the age of gold mineralization and metallogenesis in the Battle Mountain-Eureka mineral belt, Nevada (Brian J.Maher, Edwin H.McKee, Quentin J.Browne; 1993). 40Ar/39Ar, K/Ar, and fission track geochronology of sediment-hosted disseminated gold depositsat at Post-Betze, Carlin Trend, Northeastern Nevada - a reply (Arehart G.B., Foland K.A., Kesler S.E., Naeser C.W.; 1995).Â For the next description of a Carlin-type deposit, readers had to wait 30 years, until Joralemonâ€™s 1951 paper on the Getchell gold deposit. Joralemon recognized the importance of â€œinvisibleâ€ gold at Getchell and other deposits in Nevada, and likened them to mercury deposits and active hot spring systems, an idea that remained popular for many decades, and that may still hold validity. MINERALIZATION EVOLUTION A `three-stage model of metallogenesis`habsed on the progressive increase of gold concentration related to the evolution of the shear zone haas been proposed based on Bonnemaison and Marcoux (1990): (i) The First Stage of Mineralization. A first stage of gold mineralization in the second-order shear zones is common in Borborema Province.Â During this stage the fluid/rock interaction placed constraints on the mass transfer, causing a change in the pyrite-pyrrhotite ratio (programmed heating released sulphur to from pyrrhotite and retrograde cooling allowed re-growth of pyrite). (ii) During the second stage, the mineral assemblage is enriched in elements that indicate a plutonic influence, in particularly K, F, and B, but also Pb, Bi Ten deposits in the Carlin, Getchell, and Battle Mountain-Eureka trends contain more than 5 million ounces (Moz) of Au and four deposits contain more than 10 Moz (Fig. 2). The Carlin trend contains the largest endowment of Au identified to date for such deposits in Nevada, and produc-tion has now exceeded 50 Moz (Nevada Bureau of Mines and Geology, 2004).Â The suture zone, which is well defined in the Cheyenne belt of Wyoming, has a westward trend into northern Nevada where it becomes a broad zone of inter-mixed Paleoproterozoic and Archean rocks (Lush et al., 1988; Tosdal et al., 2000; App. Fig. A3).Â Bars indicate the location of Carlin-type gold mineralization in each section.