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GEOLOGICAL, GEOCHEMICAL, STABLE ISOTOPE, AND FLUID INCLUSION CHARACTERISTICS OF EPITHERMAL GOLD MINERALIZATION, VELVET DISTRICT, NEVADA

W. DALLAM MASTERSON[1] and J. RICHARD KYLE

Department of Geological Sciences, The University of Texas at Austin, Austin, TX 78712 (U.S.A.)

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ABSTRACT

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Gold mineralization in the Velvet District occurs in an eastward dipping sequence of late Tertiary rhyolitic ash-flow tuffs, flows, and tuffaceous sediments in northwestern Nevada. Minor gold and silver concentrations are associated with irregular zones of brecciation, argillic alteration, and quartz veining along north-northeast trending normal faults. Reaction of mineralizing fluids with wallrock produced an argillic alteration assemblage of illite, mixed-layer clays, smectite, and kaolinite. Illite alteration and highest gold concentrations appear to be associated with zones of high water/rock ratios. Kaolinite, smectite, alunite, and opal are postulated to have formed during a steam-dominated episode of alteration.

Fluid inclusion studies indicate that the quartz veins were deposited in the temperature range 230 to 280°C from fluids which had salinities equivalent to 0.2—0.8 weight percent NaCl. $\delta^{18}O$ of quartz veins varies from -2.5 to $+6.7$ $^0/_{00}$ and indicates that the ore fluid must have been Tertiary meteroric water. Stable isotope data appear to define a zone of concentrated fluid flow and potential subsurface mineralization in the southeastern part of the district. Fluid inclusion and isotope studies can be used in combination with more standard geochemical, geophysical, and geological information to provide site-specific targets for epithermal metal concentrations.

INTRODUCTION

The Velvet district is about 25 km west of Lovelock in Pershing County, Nevada, on the west flank of the Trinity Range (Fig. 1). Prospecting in the Velvet area began in 1915 with minor gold and silver production in 1915—1919, 1935, and 1939 (Vanderburg, 1936; Johnson, 1977). Very little work

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[1] Present address: ARCO Alaska, Inc., P.O. Box 100360, Anchorage, AK 99510 (U.S.A.). (U.S.A.)

has been done in the district since the 1930's. About 370 m of underground working are present in five adits and seven shafts; none of the shafts exceeds a depth of 25 m. Two shallow rotary holes were drilled in 1980 to evaluate a major vein and determine the feasibility of small-scale mining operations. The results of these drillholes are confidential but apparently confirm the weak mineralization observed in surface outcrop and subsurface workings (Dave Bloied, pers. commun., 1980).

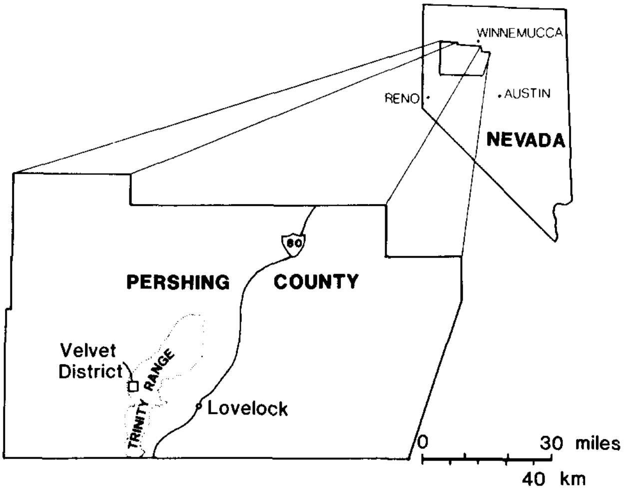

Fig. 1. Location map of the Velvet District.

Surface exposures in the Velvet District are typical of weakly mineralized alteration zones associated with Tertiary volcanic terrains in western North America. Rock chip geochemical sampling in the Velvet District by a mining company revealed anomalous, non-economic amounts of precious metals but failed to show any trends to guide further exploration. The study reported here was undertaken to define the nature of the hydrothermal alteration and metal concentrations and to develop a site-specific exploration model by comparing the district to modern geothermal systems and to productive epithermal metal deposits. Summaries of the characteristics and genesis of other epithermal deposits can be found in papers by Sillitoe (1977), Buchanan (1981), White (1981), and Berger and Eimon (1982).

Five methods of investigation were used to characterize the geothermal system which deposited precious metals in the Velvet District:

(1) Geologic mapping of host rock, veins, and hydrothermal alteration.

(2) X-ray diffraction and petrographic study of hydrothermal alteration.

(3) Analysis of the trace-metal content of altered rock.

(4) Analysis of quartz veins for oxygen isotopic composition.

(5) Determination of the homogenization temperatures and salinities of fluid inclusions in the quartz veins.

SAMPLING AND ANALYTICAL METHODS

Ninety-one rock chip samples were collected and analyzed for gold, silver, lead, and mercury, and 33 samples containing anomalous amounts of gold, silver, or mercury were also analyzed for arsenic, antimony, uranium, and fluorine. Sampling was biased toward silicified and argillized rock, and 56 of the original 91 samples showed obvious quartz veining and/or argillic altera tion. Gold, silver, lead, mercury, arsenic, and antimony were analyzed by atomic absorption spectrophotometry by Hunter Mining Laboratory of Sparks, Nevada. Fluorine content was determined by specific ion electrode and uranium by fluorescence techniques by Skyline Labs of Wheat Ridge, Colorado.

Clays were identified by optical study and by X-ray diffraction. Oriented clay slides were prepared for diffraction analysis by grinding the sample, separating the clay fraction by gravity settling in water, and smearing the water-clay mixture on a glass slide so that the clay flakes would become oriented parallel to the slide as the water evaporated (Carroll, 1970). A General Electric XRD-5 diffractometer was used to identify the clays with nickel-filtered Cu K_α radiation at 35 kV and 23 ma. All samples were X-rayed once at room temperature and then again after exposure to ethylene glycol vapor at 60° C for one hour. Clays which had basal reflections at about 10 Å and did not expand when glycolated were classified as illite. Clays which had basal reflections in the region of 14—15 Å, expanded to 17 Å upon glycolation, and collapsed to 10 Å after heating to 350° C for 1 hour, were classified as smectite. Mixed-layer clays had broad peaks in the region 10.28—15 Å. Clays which had basal reflections at about 7.2 Å that disappeared after heating at 550° C for 1 hour were classified as kaolinite. Dickite was identified in one sample on the basis of peaks of greater intensity than kaolinite and small peaks in the 20—22° 2θ range (Bayliss et al., 1965).

Quartz samples selected for fluid inclusion study were cut to a thickness of 1 mm or less, polished on both sides, and studied petrographically to identify areas of inclusions; suitable material was then cut into small fragments to fit on the heating and freezing chamber of a Chaixmeca microthermometry apparatus. The stage was calibrated with standards of known melting point, as outlined by Roedder (1976). Size of bubbles were measured before and after heating or freezing, and the samples were rerun to ensure that no leakage occurred during the initial run.

The eight quartz samples which were selected for fluid inclusion study were also analyzed for ^{18}O. Clear euhedral crystals were separated from quartz veinlets whenever possible to minimize contamination from clays or chalcedonic silica. After crushing in a steel mortar and pestle, the quartz powder was then leached in concentrated HCl for several hours. After rinsing in distilled water, an X-ray diffractogram was taken to verify that only quartz remained. The quartz was then dissolved by BrF_5 extraction (Clayton and Mayeda, 1963) and analyzed for ^{18}O.

Quartz-water fraction factors in this study were calculated from the relationship $1000 \ln \alpha = (3.38 \times 10^6 T^{-2}) - 2.9$ (Friedman and O'Neill, 1977), and $\delta^{18}O$ is reported relative to the SMOW standard. Chalcedonic silica was avoided because it fractionates ^{18}O differently from quartz for reasons that are not well understood (Knauth and Epstein, 1976).

GEOLOGY OF THE VELVET DISTRICT

Stratigraphy

The Tertiary tuffs, flows, and tuffaceous sediments that host gold mineralization in the Velvet District were previously known only from reconnaissance mapping, and volcanic stratigraphy has not been defined in detail (Johnson, 1977). Most of the alteration and mineralization occurs in an eastward-dipping sequence of ash-flow tuff, water-laid tuff, and tuffaceous sediments (*Tts*; Figs. 2, 3). The ash-flow tuffs contain more pumice and exotic fragments than the water-laid sediments and are not as well sorted. Some of the lithic tuffs contain fragments of phyllite derived from the Triassic-Jurassic Auld Lang Syne Formation which underlies the Tertiary volcanics but is not exposed locally. Large recumbent folds which are interpreted to be slump structures in compacted tuff are exposed in two outcrops. Lenses of tuffaceous sediments are interbedded with the tuffs. The sediments are cemented by opal, chalcedony, and alunite.

An unaltered flow-banded rhyolite (*Tr*) containing about 3% quartz and sanidine phenocrysts crops out in the southern part of the mapped area. Other glassy rocks which are probably rhyolite flows are exposed about 1 km west of the mapped area, where they are associated with diatomaceous sediments. In addition, some of the area mapped as Tertiary tuff and tuffaceous sediment (*Tts*) includes hydrothermally altered sanidine-rich spherulitic rocks of debatable origin which may be felsic flows.

An unaltered andesite flow (*Ta*) containing about 30% zoned plagioclase phenocrysts crops out in the south of the study area. A greenish propylitically altered andesite crops out in a small area near the center of the district. It originally contained about 30% plagioclase phenocrysts, now altered to calcite. Its groundmass has been altered to an assemblage of illite-quartz-K-feldspar and mixed-layer smectite-chlorite. Andesites north of the study area underlie thick sequences of diatomaceous earth and also are interlayered with basalts which cover the diatomite (Johnson, 1977).

Diatomaceous earth is the principal lithology in the Tertiary sedimentary rock map unit (*Ts*). It is interlayered with rhyolitic flows in the western part of the map area, where it contains conglomeratic and opalized layers. The diatomite is thicker and purer to the north of the district, where deposits several tens of meters thick are mined by Eagle-Picher Company. The deposits are believed to be of Miocene age (Johnson, 1977).

The youngest volcanic rocks in the study area are olivine basalt flows (*Tb*)

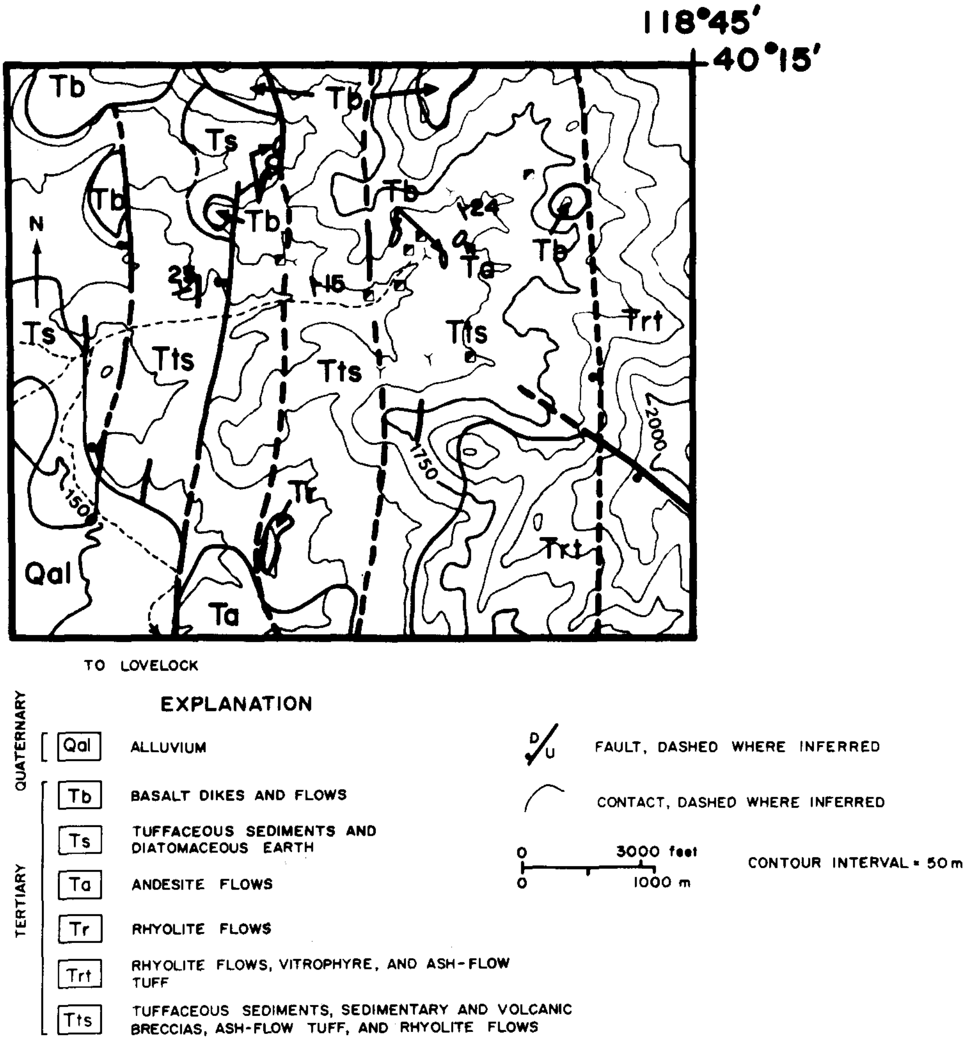

Fig. 2. Geologic map of the Velvet District. Topographic base map of the Velvet District from Seven Troughs 3 NE 7 1/2' Quadrangle (preliminary) after Masterson, 1981).

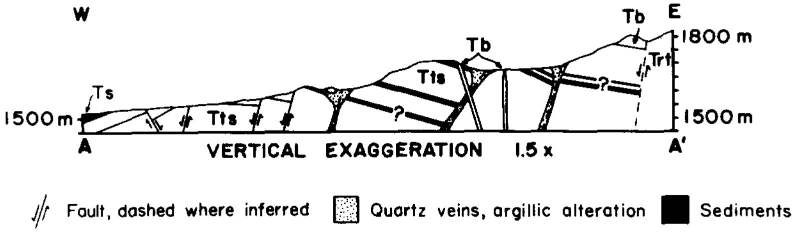

Fig. 3. Geologic cross-section A-A' (after Masterson, 1981).

which have been displaced and tilted by north-northeast-trending normal faults. Two feeder dikes for these flows also trend north-northeast, suggesting that extrusion of the flows accompanied faulting. The coincidence of volcanism and normal faulting is also shown in the northern part of the area where a down-faulted basalt flow dipping about 30° is overlain by an almost horizontal basalt flow. Unaltered basalt dikes cut veins in some areas, indicating that eruption of basalt occurred after mineralization ceased. The basalt flows show evidence of eruption over a topography with some relief, as shown at the base of one flow where cooling joints change from vertical to horizontal where the flow cascaded over a north—south-trending fault scarp. The basalts are reported to be of Tertiary and Quaternary age (Johnson, 1977).

Structure

The tuffs and tuffaceous sediments which host gold mineralization dip eastward at about 20 degrees and are cut by north-northeast-trending normal faults. The strikes of some large quartz veins are parallel to the normal faults, but areas of intense hydrothermal alteration contain at least two sets of veins with differing strikes, indicating that alteration and mineralization were concentrated in areas of intersecting fractures. The dip of north-trending veins and basalt dikes varies from 58 degrees to vertical, with westward dips most common.

Geologic history

The source and age of the volcanic rocks exposed in the Velvet District are not known. It is likely that the tuffs were erupted during initial development of Basin and Range topography, which began in the interval 17—14 m.y. B.P. (Christiansen and McKee, 1978). Radiometric dating of samples from several nearby areas support this age assignment: a rhyolite flow and a quartz latite flow approximately 25 km east of Velvet have K-Ar ages of 13.7—14.8 m.y. B.P. (McKee and Marvin, 1974); adularia from the Seven Troughs District 25 km north of Velvet has been dated at 13.7 m.y. B.P. (Silberman et al., 1973); and a dike in the Ragged Top caldera 20 km south of Velvet has a K-Ar age of 12.7 m.y. (McKee and Marvin, 1974; Willden and Speed, 1974).

Mineralization occurred along normal faults and fractures in the tuffs and tuffaceous sediments. Geologic evidence indicates that alteration and mineralization began after the appearance of andesite but before basalt eruption. Thick deposits of diatomaceous earth accumulated 5—10 km north of Velvet during the interval between andesite and basalt-andesite volcanic activity (Johnson, 1977), suggesting that the hydrothermal fluids responsible for mineralization in the Velvet District may have been discharging into and supplying silica to fresh-water lakes in which diatomaceous earth accumulated. Mineralization ceased before emplacement of basalt dikes in the district, but faulting continued during eruption of basalt flows.

HYDROTHERMAL ALTERATION AND MINERALIZATION

Vein character

Burritt (1919) described the workings at the two inclined shafts and one adit at the end of the access road to the Velvet claims (Fig. 2). The veins in these workings consisted of iron-strained quartz and altered host rock in 6—14 ft (2—4.5 m) wide zones with well-defined walls. Quartz was most abundant near the walls but was also present throughout the width of the veins. The gold concentrations were associated with the quartz and in the altered wallrock surrounding the veins (Burritt, 1919).

Material in the dumps and prospect pits in the district is usually argillized and may contain small quartz veinlets up to a few millimeters wide. In most cases veinlets are surrounded by an envelope of argillation which appears to have formed synchronously with the quartz. ^{18}O analyses also indicate that the hydrothermal solutions which deposited quartz had undergone reaction with the wallrock (see discussion of isotopic data).

The veinlets commonly form an anastomosing network and usually do not have any consistent orientation. Banded quartz veins are uncommon but where present contain several generations of euhedral comb quartz separated by brecciated, sugary microcrystalline quartz. The veins typically contain no minerals other than quartz, clays, pyrite, and iron oxides and hydroxides; adularia was observed in 1 sample.

Quartz in the thin veins usually has a sugary appearance caused by continuous brecciation and movement during crystallization from hydrothermal solutions. Breccia fragments are often replaced by microcrystalline or flamboyant quartz, and some veins contain feathered quartz which is similar in morphology to epithermal quartz veins described by Adams (1920). The space between fragments is typically lined with quartz prisms growing perpendicular to fragments in a comb structure. Larger quartz crystals in brecciated rock commonly show evidence of strain, such as undulose extinction, grid-like twinning pattern, or inclusion-filled fracture planes. Even clear euhedral crystals growing into open space are usually cut by fracture planes which have necked down to form planes of secondary fluid inclusions.

Fluid inclusion investigations of quartz veins

Homogenization temperatures of fluid inclusions were measured to determine the temperature range of quartz vein formation in the Velvet District. All of the quartz veins contain an abundance of inclusions, but most are in linear arrays along healed fractures in the crystals. Isolated large inclusions, far removed from secondary fracture planes, were considered to be primary. Primary inclusions often have negative crystal shapes and are elongate parallel to crystal growth faces. Homogenization temperatures of secondary inclusions in the Velvet District have a temperature spread greater than that observed in primary inclusions (Table I). Despite efforts to identify and eliminate secondary inclusions, some of the spread in homogenization temperatures of primary inclusions in a given sample may be caused by inadvertent measurement of secondary inclusions.

Primary inclusions in quartz from the Velvet District have homogenization temperatures ranging from 214 to 310° C, with an average value of 252° C (Masterson, 1981; Ulrich, 1982; Fig. 4; Table I). The freezing-point depressions of primary inclusions range from −0.4 to −0.1° C, which corresponds to a salinity range of 0.8 to 0.2 equivalent weight % NaCl with a mean of 0.4 weight % (Table I). These temperatures and salinities are similar to most epithermal precious metal deposits (Nash, 1972; Buchanan, 1981; Spooner, 1981). Some inclusions are empty or only slightly wet by fluids, which suggests that the fluids were boiling during quartz deposition (Roedder, 1970).

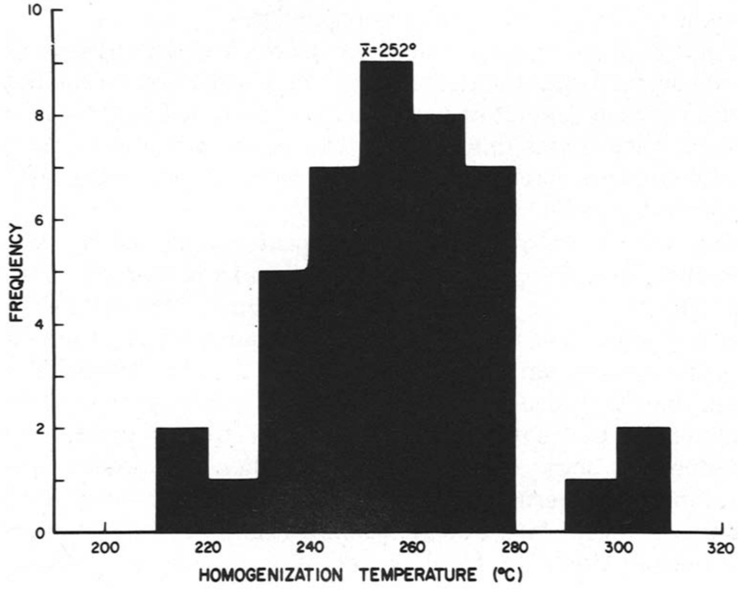

Fig. 4. Frequency distribution of homogenization temperatures of primary fluid inclusions in quartz.

Isotopic investigations of quartz veins

Isotopic analyses of D and ^{18}O in quartz veins, adularia, and altered volcanic rocks in many epithermal precious metal deposits have shown that

TABLE I

$\delta^{18}O$ and fluid inclusion data for quartz from the Velvet District

Sample	Description	$\delta^{18}O_{SMOW}$ $(^0/_{00})$		Homogenization temperatures[1] (°C)				Salinity (wt. % NaCl)
				Primary inclusions			Secondary inclusions	
				No.	Range	Mean	Range	
19	faintly amethystine, euhedral xl (1 cm) projecting into vug	+3.89 +4.19	+4.0	2	218—244	231	—	0.8
26	4 cm vein with 3 generations of quartz; sample from youngest quartz (1 cm)		−2.5		—		136—271	0.4
33	euhedral xls (4 mm) from thin (1 cm) quartz veins		+4.6	2	239—310	274	—	0.4
69	euhedral xls (3 mm) from center of 1 cm thick vein		+5.8		—		195—272	0.2—0.4
72	euhedral xl (6 mm) projecting out from silicified substrate	+6.63 +6.79	+6.7	2	242—245	244	200—233	0.4
78	euhedral xls (1 cm) in thin (3 mm veinlet)		+3.6	7	237—273	258	150—252	0.2—0.8
90	thin (3 mm) veinlet; no euhedral xls	+4.77 +4.84	+4.8		—		—	—
94	euhedral xls (7 mm) from 2 cm wide pods of silification		+2.2	30	214—310	257	301—317	0.4

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[1] Homogenization temperatures are not corrected for pressure.

the ore fluids must have been predominantly meteoric water, although the Comstock Lode does show evidence of magmatic water in its deeper levels (O'Neil and Silberman, 1974). Magmatic water escaping from a body of cooling igneous rock should have δ^{18}O values in the range +6 to +10 $^{0}/_{00}$ (Taylor, 1968). Most epithermal quartz veins, however, were deposited from waters with substantially different isotopic signatures (Taylor, 1973). Some of these deposits (e.g. Tonopah and Bodie) were formed from fluids which are isotopically indistinguishable from meteoric water, so large amounts of water must have been flushed through the host rock and lowered its δ^{18}O to values approaching equilibrium with meteoric water (O'Neill et al., 1973; Taylor, 1973).

Within a given deposit, the δ^{18}O of quartz veins commonly will exhibit a range of values which may be attributed either to quartz precipitation at varying temperatures or to variable oxygen shifts in the fluids depending on the degree to which they have interacted with wallrock. Trends in δ^{18}O values can therefore be used to map the temperature distribution and/or zones of greatest fluid flow in the system. At the Tonopah deposit, a plot of δ^{18}O in altered volcanic host rock makes a circular pattern with lowest δ^{18}O values over the apex of the productive ore zone (Taylor, 1974).

In the Velvet District, δ^{18}O content of the quartz veins is lowest in the southeast and increases to the north and west in a regular fashion (Fig. 5). The range in values, from −2.5 to +6.7 $^{0}/_{00}$, cannot be explained by temperature variations because the dominant 50°C range in primary fluid

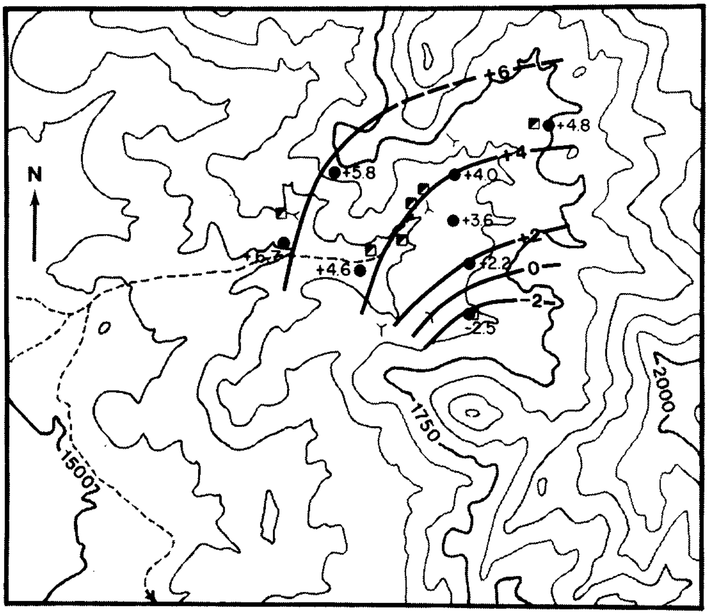

Fig. 5. Map showing distribution of δ^{18}O ($^{0}/_{00}$) of quartz veins in the Velvet District. Low contours define an area of high water/rock ratios in the southeast.

inclusion filling temperatures would cause at most a $3^0/_{00}$ shift in the quartz $\delta^{18}O$. Most of the spread in $\delta^{18}O$ exhibited in the Velvet district therefore must have resulted from varying degrees of water/rock interaction. The area of low $\delta^{18}O$ values probably marks the zone of greatest flushing by hydrothermal fluids and would be a favorable location to explore for subsurface ore.

Taylor (1968) concluded that $\delta^{18}O$ of Tertiary meteoric waters was in the range -13 to $-14^0/_{00}$ over much of western Nevada. At 252°C, the average homogenization temperature of primary fluid inclusions in the Velvet District, quartz in equilibrium with $-13^0/_{00}$ water (assumed value) should have $\delta^{18}O$ equal to $-3.7^0/_{00}$, compared to the value of $-2.5^0/_{00}$ for the late-stage quartz in sample 26. The other 7 analyzed quartz veins are heavier than sample 26, so the hydrothermal fluids which formed them must have been enriched in ^{18}O by exchange with wallrock. Most of the sampled veins are not wide enough to have protected the ascending fluids from reaction with wallrock. The samples taken from the two thickest quartz veins (samples 26 and 94) have the lowest $\delta^{18}O$ values of all the samples, probably because more fluids were pumped through the thicker veins and because fluids in the center of the veins were protected from reaction with wallrock. However, even if samples 26 and 94 are excluded from the data, the trend in $\delta^{18}O$ data is still toward lower values in the southeast (Fig. 5).

X-ray diffraction investigation of argillic alteration mineralogy

Illite and mixed-layer clays are the most abundant products of argillic alteration in the district (Table II; Fig. 6). Kaolinite and smectite are also present in many samples. The clays replace both groundmass and phenocrysts of the host rocks and are usually accompanied by supergene iron hydroxides and oxides. Several samples contain pyrite which is locally altered to limonite and hematite.

Kaolinite is more frequently associated with smectite (3 of 3 samples) and mixed-layer clays (6 of 11 samples) than with illite (2 of 9 samples). In modern geothermal systems at Steamboat Springs, NV, and Wairakei, New Zealand, kaolinite is abundant at shallow depths (< 90 m) and is associated with surficial waters which have become acidic due to oxidation and condensation of H_2S and CO_2 vapors released by boiling at depth (Steiner, 1968; Schoen et al., 1974). Fluid inclusions indicate that Velvet District quartz veins formed at 230—280°C, which would preclude a near-surface origin of the kaolinite if quartz vein formation and kaolinite crystallization were synchronous. It is possible, however, that kaolinite crystallized during a steam-dominated episode of mineralization which was superimposed upon the assemblage of quartz, illite, and mixed-layer clays of an earlier fluid-dominated hydrothermal system. Direct evidence for formation of kaolinite above a zone of boiling is observed at one Velvet District outcrop where a zone of thin quartz veins and mixed-layer clay alteration (sample 20) passes upward

TABLE II

Hydrothermal alteration products of selected samples

Sample number	Au concentration (ppm)	X-ray diffraction identification of clays	Petrographic identification of replacement products (excluding I, S, and Mx)	
			Groundmass	Feldspars
15	0.4	Mx	Q, py, lm	K, Q
17	0.1	I, K, Mx	—	—
20	0.1	I/S	Q, lm	K
25	<0.1	Mx	Q, lm	Q
26	0.1, 0.3	I	Q, lm	lm
27	<0.1	S, K, I	—	—
31	0.3	I	Q, py, lm	(none)
33	0.1	K, I/S, 13A clay	Q, K, lm	K, Q
36	<0.1	K, Mx	—	—
72	0.1	Mx	Q, lm	lm
78	0.2	S	lm	K, Q
90	0.3	Mx	—	—
92	<0.1	I, Mx	—	—
94	0.6	I	Q, lm, py	Q
6T	—	K, Mx	—	—
6T-1	—	A, α-C	A	(none)
6T-2	0.1	K, A, β-C	—	—
8T-8	—	D, S	—	—
T11	—	I	Q	—
V25	—	I, Mx	Q, lm	lm, calcite
VM1	—	I	lm	lm

Clays are listed in approximate order of abundance. All altered feldspars are sanidine with the exception of 25 and V25, which also contain plagioclase. Illite, smectite, and mixed-layer clays are excluded from the petrographic identification columns because of the difficulty in distinguishing them in thin section.

Key to symbols: Q = quartz; K = kaolinite; I = illite; S = smectite; / = mixed layer clay with known interlayer composition; Mx = mixed layer clay with interlayer composition uncertain; D = dickite; A = alunite; lm = liminite or jarosite; C = cristobalite; py = pyrite; — = not analyzed.

into a bleached white tuff (sample 8T-8) which is altered to dickite (a kaolinite-group mineral) and smectite. Kaolinite with alunite and opal (β-cristobalite) was identified in an other altered lithic tuff from the western part of the Velvet District (Fig. 6). A tuffaceous sediment in the same area contains pore-filling alunite cement and opal. The association of kaolinite, alunite, opal, and smectite is suggestive of alteration in an acidic steam-dominated environment such as the Mud Volcano area of Yellowstone Park, where a steam-dominated kaolinite-opal-halloysite-alunite alteration assemblage has been superimposed on an earlier, fluid-dominated quartz-chalcedony-septechlorite-calcite assemblage (Bargar and Muffler, 1982).

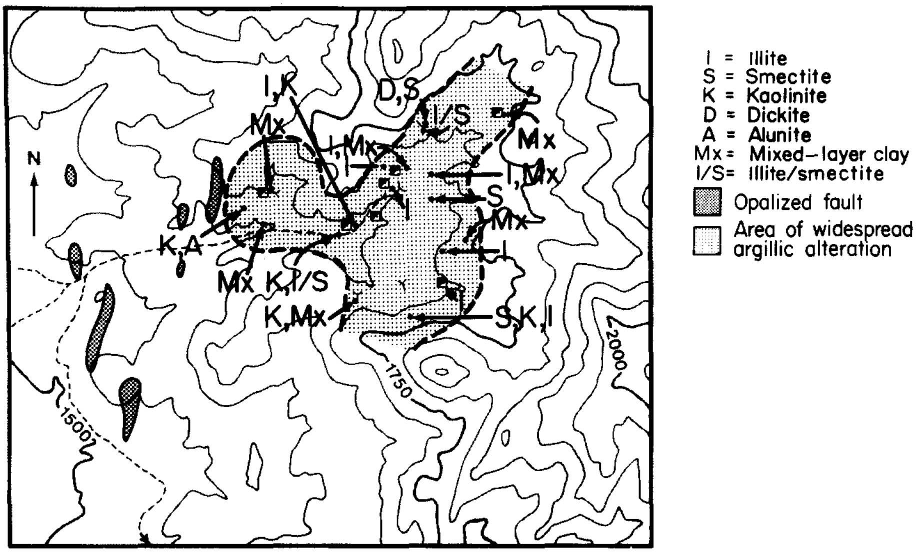

Fig. 6. Map of argillic alteration assemblages in the Velvet District.

It is proposed that most of the kaolinite in the Velvet District was formed by descending acidic condensate as the water table dropped. Lowering of the water table could have been caused by tectonic uplift or by a decrease in the supply of meteoric water to the system. Alternative explanations of kaolinite formation include hypogene alteration by ascending hydrothermal solutions or supergene alteration accompanying oxidation of pyrite during weathering. Hypogene kaolinite has been documented at Goldfield, NV, where it coexists with illite (Harvey and Vitaliano, 1964), in contrast to its more frequent association with mixed-layer clays and smectite in the Velvet District. Weathering and oxidation of pyrite should produce iron oxides and hydroxides which are seldom observed in kaolinite-bearing samples.

Argillic alteration assemblages in the Velvet District cannot be demonstrated to be controlled by hydrothermal fluid temperatures. Illite in sample 94 coexists with quartz veins that formed at an average temperature of 275°C, but mixed-layers clays in samples 33, 72, and 78 formed at both cooler and warmer temperatures (Table I). Application of the fluid inclusion data to conditions of clay mineral formation must be done with caution since it is possible that the present-day clay alteration assemblage has been superimposed upon an earlier episode of quartz vein formation.

Two of the six quartz veins analyzed for ^{18}O are associated with illite alteration (samples 26 and 94; Tables I and II). The $\delta^{18}O$ values of samples 26 and 94 are the lowest of the six veins analyzed, suggesting that illite is associated with zones of high water/rock ratios (Table I). Average gold content of illite-bearing samples is also higher than in samples which have been altered to smectite, kaolinite, and mixed-layer clays (Table II). Kaolinite- and smectite-bearing samples have the lowest average gold concentrations, possibly because gold precipitation was concentrated beneath the vapor-dominated environment where kaolinite and smectite crystallized.

GEOCHEMICAL SIGNATURES OF THE MINERALIZING FLUIDS

Gold, silver, lead, and mercury concentrations were determined in 91 samples in the Velvet District (Fig. 7); 33 of the original 91 samples contained anomalous amounts of gold, silver, or mercury and were also analyzed for arsenic, antimony, uranium, and fluorine. Silver, antimony, and lead concentrations have a positive linear correlation with gold concentration (Table III).

Twenty-eight of 91 samples contained at least 0.1 ppm gold, the lower limit of detection in this study (Fig. 8). Average gold content in these 28 samples is 0.21 ppm (Table III). Maximum gold content is 1.2 ppm. The average Ag/Au ratio (calculated only for 18 samples containing at least 0.1 ppm Au and 1 ppm Ag) is 13. Gold-silver ratios do not correlate with the present elevation of the collection sites.

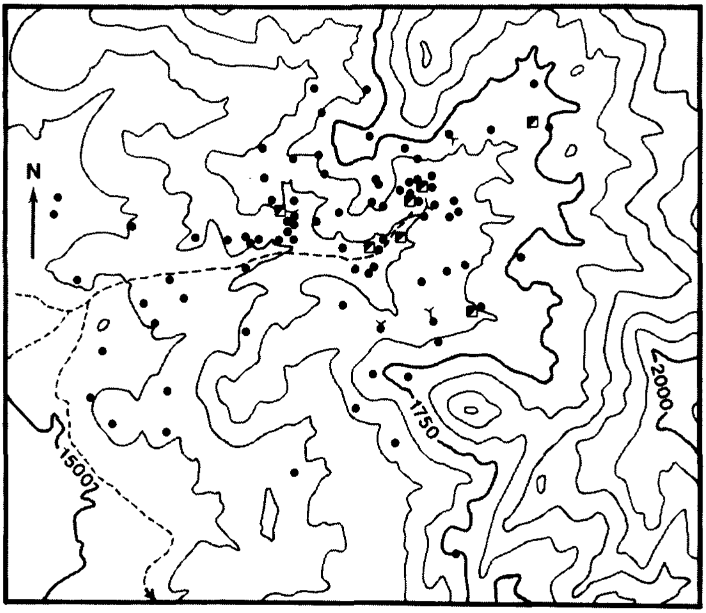

Fig. 7. Map distribution of geochemical samples.

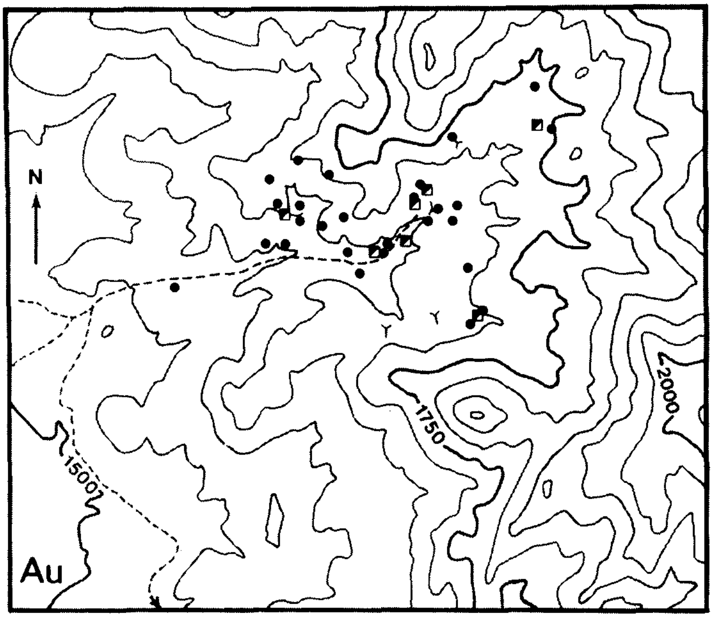

Fig. 8. Map distribution of samples containing at least 0.1 ppm gold.

TABLE III

Elemental concentrations in the Velvet District

	Threshold of detection (ppm)	Number of samples	Mean (ppm)	Standard deviation
Au	0.1	28	0.24	0.26
Ag	1.0	25	3.6	3.15
Hg	N/A	91	3.9	19.5
Pb	N/A	91	32	71.5
As	5	29	322	800
Sb	1	28	13.5	18.9
F	N/A	33	338	141
U_3O_8	2	23	4.9	1.9

Samples were included in the statistical summary only if their concentration exceeded the threshold of detection.

Many investigations have documented the association of mercury with precious-metal mineralization (e.g. Friedrich and Hawkes, 1966; Crosby, 1969; Chan, 1969). The high volatility of mercury allows it to be boiled off and concentrated in the upper part of geothermal systems (White et al., 1971). High Hg values in the Velvet District are widespread and in the western part of the district are associated with opalized fault zones (Figs. 6 and 9).

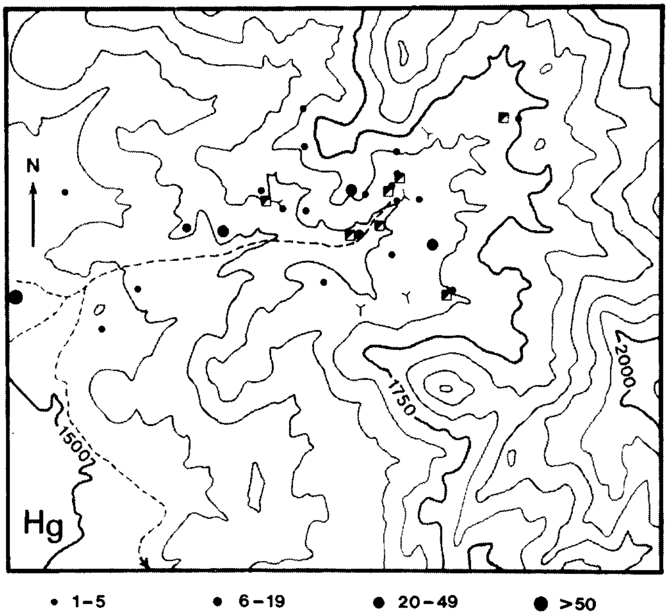

Fig. 9. Map distribution of mercury (ppm).

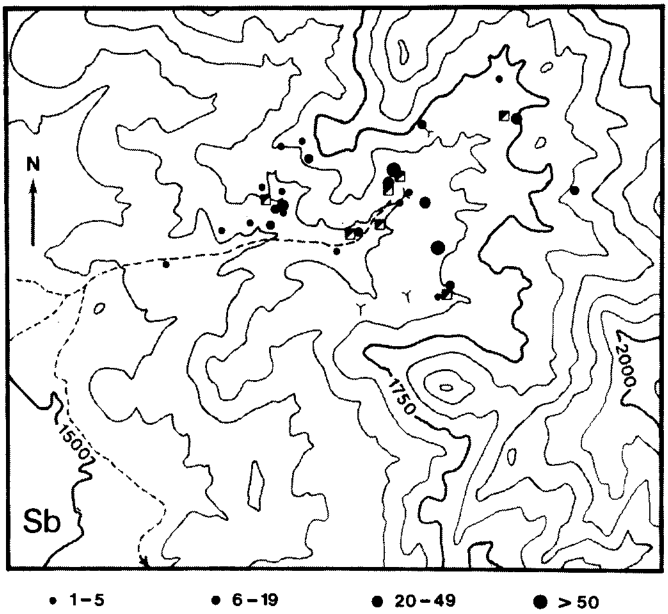

Fig. 10. Map distribution of antimony (ppm).

The antimony-gold correlation is the highest among the seven elements selected for analysis in the Velvet District. The maximum antimony concentration in rock containing at least 0.1 ppm gold is 73 ppm with an average concentration of 11 ppm (Fig. 10, Table III).

Arsenic concentrations average 312 ppm and show a greater range than those of antimony with a maximum value of 3600 ppm (Fig. 11). With one exception, all samples containing greater than 100 ppm As also contain more than 0.1 ppm Au.

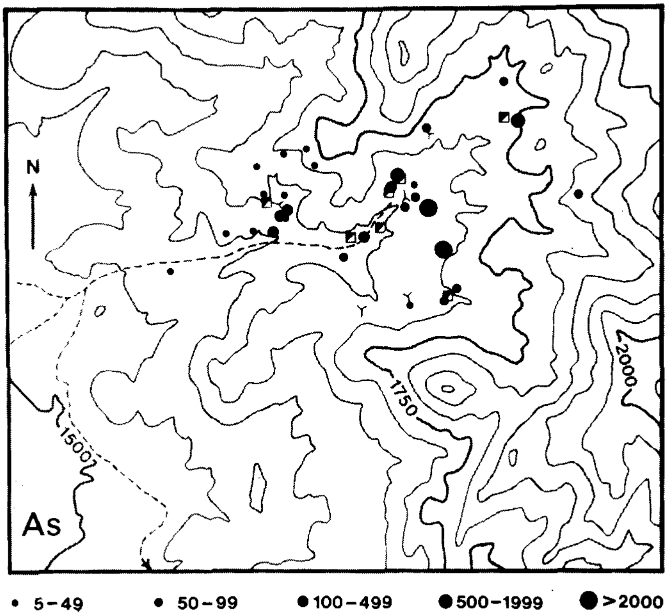

Fig. 11. Map distribution of arsenic (ppm).

Lead concentrations are all below 100 ppm with the exception of 2 samples. If these 2 samples are excluded, the average lead concentration is 23 ± 14.5 ppm (1 σ). Lead has a strong positive correlation with silver and a slight positive correlation with gold.

Uranium and fluorine concentrations vary the least of all the elements analyzed (Table III). Neither element has a statistically significant correlation with gold.

CONCLUSIONS

The fluids which deposited quartz and associated precious metals in the Velvet District had temperatures and salinities similar to many epithermal precious metal deposits. The mineralizing fluids reacted with wallrock along fractures and fault planes, altering the tuffaceous host rocks to illite, mixed-layer clays, smectite, and kaolinite. Clay alteration assemblages and isotopic composition of quartz were controlled by fluid composition, fluid phase, and water/rock ratios, rather than by fluid temperature. Of the techniques utilized in this study, the isotopic composition of quartz veins provides the most clearly defined trends to guide future exploration. Investigation of fluid inclusion characteristics and stable isotope signatures can provide complementary data which in combination with more standard geochemical, geophysical, and geological information can provide site-specific targets for epithermal mineral concentrations.

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