UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Gold in Big Sagebrush (*Artemisia tridentata* Nutt.) as an Exploration Tool, Gold Run District, Humboldt County, Nevada

By

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ABSTRACT

The Gold Run mining district, also known as the Adelaide mining district, lies in the foothills on the eastern flank of the Sonoma Range. The dominant country rocks in this district are thermally metamorphosed limestone, phyllitic shale, and schist of the Middle and Upper Cambrian Preble Formation that host skarn-, disseminated gold and silver-, and hot springs gold-type mineral occurrences. Big sagebrush--a cold desert species that dominates the terrain over large parts of western United States--was sampled along several traverses that crossed some of these occurrences. Patterns of detectable levels of gold (8 to 28 ppb) in ash of new growth were consistent with areas affected by known or suspected gold mineralization, but the levels were lower than those found in similar samples collected near active, sediment-hosted, disseminated gold mines in northeastern Nevada. Soils collected along one of the traverses where a selenium-indicator plant was common contained no gold above background levels of 2 ppb, but were consistently high in As, Sb, and Zn, and several samples were unusually high in Se. We also found a puzzling geochemical anomaly at a site basinward from active hot springs along a range-front fault scarp. Sagebrush at this site contained a trace of gold and an unusually high concentration of Cd, and the soil had anomalous concentrations of Cd and Bi. The source of this anomaly could be either metal-rich waters from an irrigation ditch that was fed by the hot springs, or leakage along a buried fault. Despite the limited nature of the study, we conclude that gold in sagebrush could be a cost-effective guide to drilling locations in areas where the geology seems favorable for disseminated and vein precious metals.

INTRODUCTION

What role does sagebrush have in gold mining in Nevada? The simple answer is that many mining companies are increasingly involved in using biogeochemical techniques in their exploration efforts, and in Nevada sagebrush covers a large share of the state.

This feasibility study is an initial attempt to see if the gold content in sagebrush from western North America mirrors known or suspected underlying mineralized rocks in a gold district. If so, can it be used successfully as an exploration medium? Results from sampling the current year's growth of big sagebrush (*Artemisia tridentata* Nutt.) along several traverses in the Gold Run district, Humboldt County, Nevada, suggest that the gold content alone may delineate areas of suspected mineral occurrences.

Species of the genus *Artemisia* have been used to locate gold occurrences in the Soviet Union for at least two decades (Aripova and Talipov, 1966; Talipov and Khotamov, 1973; Dvornikov et al., 1973; Talipov, 1982). Aripova and Talipov (1966) reported that all gold occurrences in the Kyzylkum Desert of Uzbekistan had distinct dispersion haloes of elevated levels of gold in all plants sampled, *Artemisia* being the best concentrator. They concluded that biogeochemistry was the most effective method for gold exploration under the conditions of the Kyzylkum area.

Only a few papers have been published on the use of *Artemisia* in mineral exploration of western North America. They cover uranium (Erdman and Harrach, 1981; Diebold and McGrath, 1985), base metals (Lovering and Hedal, 1983), and gold (Huang, 1986). Increasing evidence of the good biogeochemical response of sagebrush over concealed mineralized rocks led Erdman and Olson (1985) to recommend that it be used in areas of the American West where disseminated gold occurrences are common.

ARTEMISIA IN THE SEMI-DESERTS OF EURASIA AND NORTH AMERICA

To gain some appreciation for the importance of Artemisia as a biogeochemical sampling medium in the search for hidden mineral occurrences, we need to look at its extent on both the Eurasian and North American continents. "The large genus Artemisia, especially the two species A. tridentata in North America and A. herba-alba in Asia and North Africa, are dominant over thousands of square kilometers in the cold Northern Hemisphere deserts. It is the only real desert composite genus which shares more than one 'main desert region'" (Shmida, 1985, p. 52).

Eurasia

Many species of Artemisia occupy a large part of the temperate deserts and semi-deserts of Eurasia, which cover an area of ~5 million sq km (West, 1983a). The 30-volume flora of the Soviet Union alone lists 174 species of Artemisia (Bobrov and Tsvelev, 1964). The areas in which Artemisia is a dominant genus extend from the Aral-Caspian region in the west, eastward to the Great Wall of China. In Kazakstan, a region of Central Asian USSR northeast of the Caspian Sea, this vegetation type covers an area of over 3 million sq km compared to only 1.8 million sq km for the sagebrush semi-desert that occupies much of the Great Basin and Colorado Plateau of western North America.

The asiatic species of Artemisia are either herbaceous (non-woody) or are dwarf shrubs. They therefore differ from many of the clearly more brushy forms of Artemisia so widespread in the cold deserts of interior western North America.

North America

In North America the sagebrush-covered cold deserts occur in a region that lies between the Cascade Mountains-Sierra Nevada chain on the west and the Rocky Mountains to the east. These sagebrush deserts are divided into two types (West, 1983b): the Great Basin-Colorado Plateau Sagebrush Semi-desert, in which our study occurs, and the Intermountain Sagebrush Steppe immediately to the north, a vegetation type that typically has perennial bunchgrasses as codominants with woody Artemisia.

The Great Basin-Colorado Plateau Sagebrush Semi-desert type is less rich in herbaceous species than the Intermountain Sagebrush Steppe type and is about one-third as extensive. It is largely restricted to the Great Basin and Colorado Plateau Physiographic Provinces. Nevada has the greatest area, followed by Utah, Arizona, Colorado, California, and New Mexico (Fig. 1).

Sagebrush in the Great Basin dominates the upper parts of broad alluvial valleys (1200- to 1800-m elevations) between fault block mountain ranges that trend mostly north-south. Most species of sagebrush, especially those in the Artemisia tridentata (big sagebrush) complex (Blaisdell et al., 1982), do not tolerate the highly saline soils that occur in the lower parts of the valleys, and tend to occur more on the flanks of the valleys and in the foothills of the adjacent ranges. The sagebrush vegetation type is a distinctive gray-green color with individual plants usually attaining heights no greater than one meter although they can attain heights to 4.5 m in suitable habitats (Blaisdell et al., 1982).

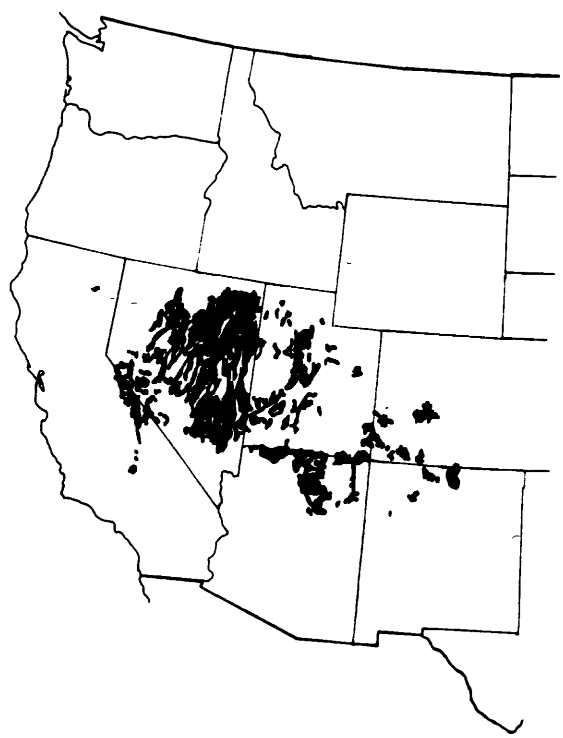

Figure 1. Location of the Great Basin-Colorado Plateau sagebrush semi-desert type in the western United States. (From West, 1983c, p. 332.)

DESCRIPTION OF THE STUDY AREA

The Gold Run (or Adelaide) mining district (Vanderburg, 1938; Willden, 1964) lies at the foot of the east slope of the Sonoma Range, about 25 km southeast of the town of Winnemucca, Nevada. Sonoma Peak, the highest in the range, is 9,421 ft, (2,870 m) and much of the range lies above 7,000 ft (2,130 m). The elevations of the valleys on either side of the range are about 4,500 ft (1,370 m). A sagebrush cover dominates most of the slopes and valleys (Fig. 2).

Geology

Organized in 1866 when placer gold was discovered along Goldrun Creek, the district is composed of several inactive mines, including small placer mines and numerous prospects. Production from the district was chiefly gold, silver, copper, lead and zinc (Stager, unpubl. data, 1983).

Two mining areas are prominent in the western part of the district: the Adelaide mine and the Adelaide Crown mines (Fig. 3). These were active in the late 1930s and early 1940s. Both areas are in shale, limestone, and quartzite of the Middle and Upper Cambrian Preble Formation that has been regionally metamorphosed during an episode of pre-Mesozoic deformation (Marsh and Erickson, 1974). Locally, near the Gold Run district, the Preble Formation has been thermally metamorphosed by a Cretaceous pluton (Erickson et al., 1978).

The Adelaide mine yielded mostly copper and gold but also some by-product silver and lead from a skarn-type deposit. A sampling of ore contained chalcopyrite, chalcocite, pyrrhotite, and pentlandite (?), pyrite, galena, scheelite, and molybdenite, with calcite, orthoclase, diopside, brown and green garnet, and quartz in veins and vugs. The ore is hosted in the strongly folded and faulted Preble Formation. The Adelaide mine consists of several shafts and underground workings, and the associated spoil piles show extensive iron and copper oxide staining. An intrusive is not exposed at the mine, but occurs at a relatively shallow depth in a drill hole just to the north and possibly correlates with a Cretaceous granodiorite exposed in the eastern part of the district (Marsh and Erickson, 1978).

The other mining area is a cluster of mines called the Adelaide Crown mines that lie near an old mill site west of the Adelaide mine. These were first explored in 1920 and became active in the 1930s and early 1940s. They appear to be in epithermal precious metal veins. Willden (1964) reports that the Adelaide Crown mines produced gold, silver, lead, copper, and zinc. These mines consist of several open pits and several clusters of underground workings lined up along a north-striking set of faults . One set of extensive underground workings is caved. Some small skarns occur nearby. Unlike the Adelaide mine to the east, mineralization at the Adelaide Crown mines was controlled by a steeply dipping (≥70 degrees), north-striking system of faults. Several meters east of this mineralized system of steep faults is a thrust fault that possibly correlates with the Roberts Mountain thrust (see Roberts, et al., 1958). This thrust fault brings the allochthonous Valmy Formation of Ordovician age in contact with para-authochthonous transitional assemblage limestones and phyllites of the Middle Upper Cambrian Preble Formation. The thrust does not have any obvious connection with the mineralization. The type of mineralization in the Adelaide Crown mines area appears to conform to the carbonate-hosted Au-Ag (or Carlin-type) model as characterized by Berger (1986), and thus may resemble that of the Pinson and

Figure 2. Sagebrush semi-desert type in the Gold Run district, Nevada. View to the west from site A08 along traverse A; traverse extends from Quaternary gravels in the foreground onto low hills of the Cambrian Preble Formation in the middle distance.

Getchell deposits to the north, and the Carlin deposit to the east. The Carlin-type model is described by Ronkos (1986) as follows:

> 'Carlin-type' gold deposits are those in which the gold occurs as microscopic particles that must be identified by chemical analysis and cannot be recovered by panning. . . . The gold is evenly disseminated over wide areas in the sedimentary rocks and is associated with anomalous arsenic and silver. It has no apparent association with igneous rocks and occurs principally as replacement or stockwork zones with jasperoid development along thrust and normal faults.

The deposit at the Adelaide Crown mines seems to match most, if not all, features of the model. The deposit was hosted by a limestone facies of the Preble Formation and occurs along a steep north-striking fault that rebrecciated the rock in several stages. Rocks of the Preble are strongly silicified and argillized along the faults; thin (average <8 cm in thickness), discontinuous stockwork quartz veins are prominent. Some quartz coatings and veins are gray to bluish-gray--"productive quartz" (that is, quartz carrying precious metals)--according to Berger and Silberman (1986). Red jasper and mostly gray, red, and black jasperoid are common. Hot-spring sinter and tufa occur locally along the fault. Such altered rock associated with the sinter and tufa has a porcelain-like appearance with occurrences of iron and manganese oxides. Cinnabar, orpiment, and realgar are in crusts associated with manganese oxides. Veins of barite and calcite are also present and commonly are silicified. Altered dikes of intermediate composition cut the host rock. Although there is no obvious spatial relationship between the dikes and what was ore, many prospect pits contain altered, punky dike rock, which suggests that the prospectors were particularly interested in the dikes. Analyses of recent rock-chip samples (Cookro, unpublished data) reflect a trace-element assemblage of Au, Ag, As, Sb, Hg, and Tl that is common in sediment-hosted epithermal precious metal deposits (Berger and Silberman, 1986).

Fairly recent geological and geochemical studies of the Edna Mountain 15-minute quadrangle (Erickson and Marsh, 1973; Marsh and Erickson, 1974, 1978), which includes the eastern part of the Gold Run district, provided some direction in our choice of sites for the geochemical traverses described below. The geochemical maps that were published were based on ~5,000 chip samples of selected rock outcrops.

Vegetation

Although sagebrush is the dominant species along all three sampled traverses, we found subtle variations in the associated plants depending on whether soils are residual or alluvial. Along traverses A and B (Fig. 3), big sagebrush is tall and robust where it occurs on the Quaternary alluvium and gravels; cheatgrass (*Bromus tectorum* L.), introduced from the Eurasian deserts in the nineteenth century, is a common undergrowth species. Scattered shrubs of hopsage (*Grayia spinosa* [Hook.] Moq.), saltbush (*Atriplex* sp.), and greasewood (*Sarcobatus vermiculatus* [Hook.] Torr.) occur with big sagebrush on presumably saline soils. On the shallow, residual soils derived from altered or unaltered phyllitic shale or limestone of the Preble Formation, big sagebrush is smaller and other species of shrubs are common associates. These are low sagebrush (*A. arbuscula* Nutt.), horsebrush (*Tetradymia* sp.), Mormon

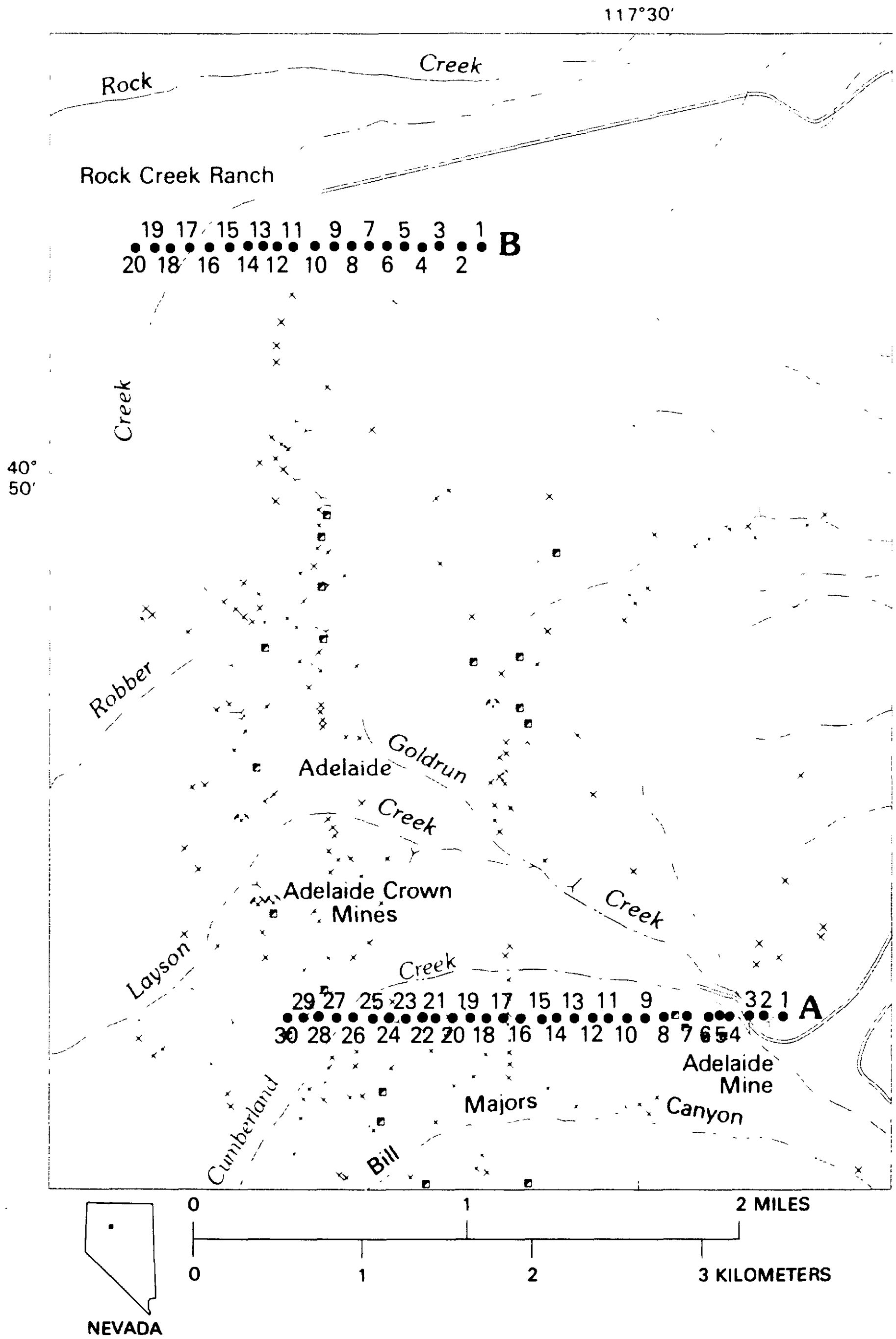

Figure 3. Base map showing site locations along traverses A and B and prospects, adits, and shafts of the mining district.

tea (Ephedra sp.), and dwarf rabbitbrush (Chrysothamnus, [probably] depressus Nutt.). The residual soils are relatively calcic as judged from field testing with dilute hydrochloric acid during sampling.

Observations of the vegetation along traverse C (Fig. 4) suggest a different type of mineralization, possibly hot springs related, associated with altered phyllite of the Preble Formation at that locality. The first indication of an unusual geochemical environment is the fact that a cyanogenic member of the Rose family, desert almond (Amygdalus [Prunus] andersonii [Gray] Greene), was growing on altered rocks of the Preble Formation. Billings (1950, p. 67) reported isolated occurrences of this shrub in areas of hydrothermally altered andesite near Reno, Nevada.

Even more intriguing is the distribution of the selenium indicator (Cannon, 1957; 1960, Table 1), Stanleya pinnata (Pursh) Britton--commonly known as desert plume--on the residual soils. Cannon later reported (1971) that all species of Stanleya require selenium. The presence of Se in this particular setting is encouraging because "Se in plants has potential in exploration for gold and other ores in which Se is present" (Levinson, 1980, p. 881).

A final observation is the occurrence of extremely yellowed (chlorotic) greasewood shrubs near an abandoned shaft on the fault scarp that separates the Quaternary valley alluvium and the Preble Formation (Fig. 4). This yellowing may have resulted from toxic levels of zinc carried in brines to the surface by a nearby spring. Unusually high concentrations of Zn can depress Fe uptake, causing Fe-deficiency chlorosis, not necessarily Zn toxicosis. Extreme levels of Mn in the substrate can also induce chlorosis, and Mn can be a common constituent in thermal waters. In addition to greasewood, other halophytes (salt-tolerant plants) that dominate the fault scarp around the shaft are shadscale saltbush (Atriplex confertifolia [Torr. & Frem.] Wats.) and spiney hopsage. Saltbush and hopsage were not chlorotic; but, unlike greasewood, they are not phreatophytes so their root systems probably were less stressed by the metal-rich ground water from the fault.

Soils were sampled along traverse C in an attempt to help explain these apparent indicator-plant anomalies.

METHODS

Sample Collection

Fieldwork was conducted over a 3-day period, from August 11-13, 1986, and involved collecting mainly sagebrush samples along three traverses at, for the most part, 100-m sampling intervals. Traverse lines were laid out with compass and forester's hip chain. Two of the traverses were oriented normal to a north-trending, steeply dipping fault and associated mineral occurrences. Traverse A (Fig. 3), 3000-m long, begins in an area of known alteration and mineralized rocks in the Preble Formation above the Adelaide (skarn) mine, continues across a 1500-m expanse of mostly unprospected Quaternary alluvium and gravels, and ends again in the Preble Formation crossing the southern extension of the fault zone in which the Adelaide Crown mines are located. Results from traverse A were expected to (1) help understand the response of sagebrush to polymetallic skarn and Au-Ag epithermal occurrences, and (2) determine if the Adelaide Crown trend extends southward along the steep fault. Traverse B was located in a valley to the north of traverse A (Fig. 3) in an area of little outcrop and no visible signs of prospecting. The traverse crosses the Preble Formation and

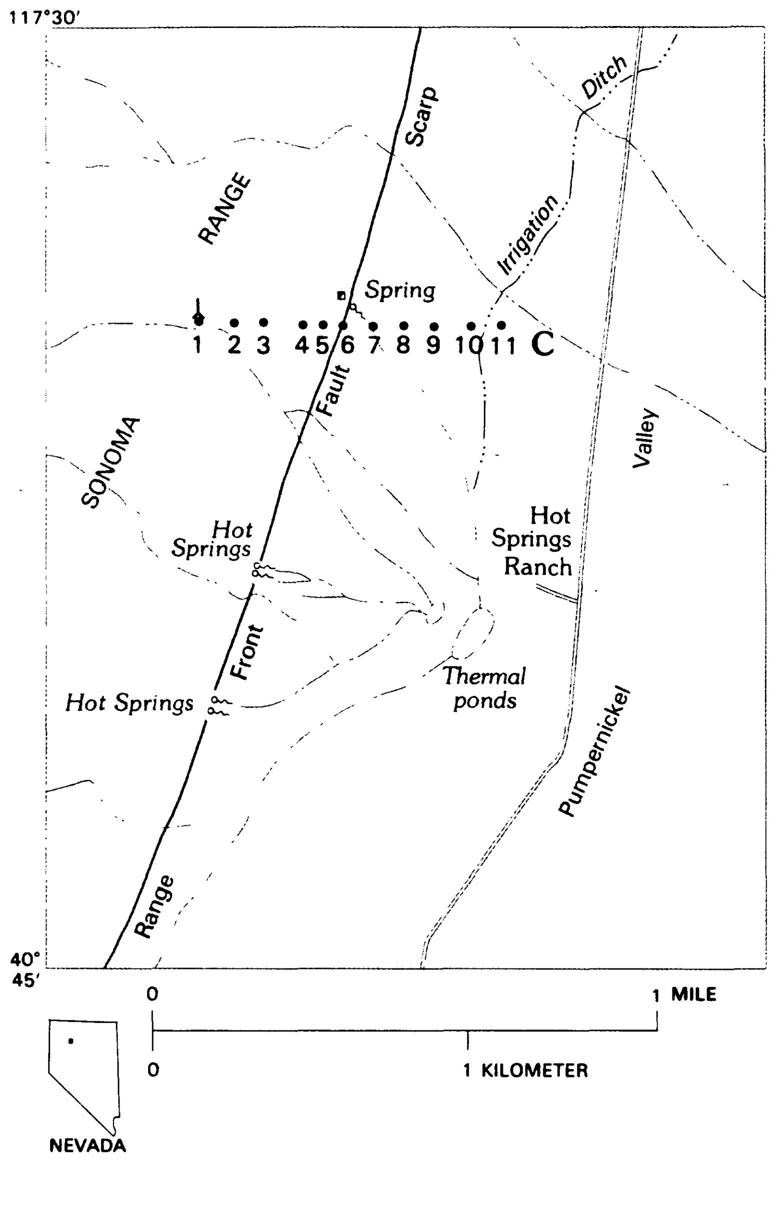

Figure 4.--Base map showing site locations along traverse C. Site C01 is on an undisturbed slope just above a pair of prospect adits in an altered dike.

alluvium. This traverse was selected because sagebrush here might reflect possible underlying mineralized rocks associated with continuation of the north-striking fault zone. Traverse C (Fig. 4) lies just south of the Gold Run district and was chosen to determine if sagebrush might mirror the strong lithogeochemical anomalies for gold, silver, arsenic, antimony, mercury, lead, tungsten, copper, zinc, and molybdenum that were reported for that area by Erickson and Marsh (1973). We were also interested in the possibility that the slightly covered, downthrown block of a Permian-aged calcareous quartzite, resting on the Preble Formation just east of the range-front fault (Marsh and Erickson, 1978) might also be mineralized. The traverse begins in altered Preble phyllitic shale and limestone, crosses a bounding range-front normal fault, and extends into the valley fill.

Sampling for all three traverses was accomplished by selecting three robust shrubs of sagebrush within about a 5-m radius at each site. At many sites a single shrub would not have yielded an adequate amount of material for a sample. More importantly, element concentrations in adjacent individual plants of the same species can differ greatly (Erdman, unpublished data), a problem called heterogeneity of the sampling medium that can result in a large sampling error. Cohen et al. (1987) found moderately large variations in the Au contents (dry-weight basis) of the same parts of neighboring plants. He suggested that composite sampling (collecting the samples from 2 to 3 individuals) might minimize this problem.

A handful of the current year's growth, clipped with pruning shears and placed in 4.5 x 6-in (~10 x 15-cm) cloth sand-sample bags, provided ~50 g of dry material. Stems, leaves, and flowering parts were combined into a composite sample for several reasons: (1) norms have been published for similar samples from the eight physiographic provinces of the western U.S. in which big sagebrush occurs (Gough and Erdman, 1983), (2) comparisons by Lovering and Hedal (1983) of element levels of stems versus leaves and blossoms showed no appreciable differences, and (3) such composite samples are simply more efficient to collect and process. The total number of sagebrush samples from the traverse sites was 60. Three additional samples were collected from adit or prospect waste to assess the effect of these mineralized sources on the concentrations of ore-related elements in sagebrush.

Soils from a depth of 2 cm were collected from a single pit at each site on traverse C, sieved to pass a 2-mm (<10-mesh) screen, and placed in bags. An additional soil sample was taken on traverse C from the waste pile of an exploratory adit just below site C01.

Sample Preparation and Analysis

The unwashed plant samples were first dried to brittleness at ~40 degrees C, then pulverized in a mill to pass a 2-mm screen. About 20 g of the homogenized ground material were then ashed by dry ignition in an electric muffle furnace at about 450 C for 24 h. This amount of dry material yielded the 500 mg of ash needed for the analyses of Au by graphite furnace atomic absorption spectrometry (O'Leary and Meier, 1984), and 250 mg of ash for nine ore-related elements--Ag, As, Bi, Cu, Cd, Mo, Pb, Sb, and Mo--by flame atomic absorption (O'Leary and Viets, 1986). Selenium analyses of pulverized samples from only traverse C were done by fluorometry, after acid digestion of 1 g of dry material (Harms and Ward, 1975).

Ashing serves to preconcentrate Au to more readily detected levels. Because sagebrush is non-cyanogenic (Shacklette, 1974, p. 42), it can probably be ashed without loss of Au as the volatile gold cyanide (Dunn, 1986, p. 21). In fact, loss of Au in ashing has not been demonstrated in thousands of sagebrush samples currently being analyzed in the U.S. (S. Clark Smith, Minerals Exploration Geochemistry, Sparks, Nevada, personal communication).

The precision of the gold data for sagebrush (limit of determination, 8 ppb) is unknown. However, plots of the data, most of which lie at or below the determination limit, tend to reveal patterns that are consistent with known or suspected underlying mineralized rocks.

The 12 soil samples collected along traverse C, including fines from an adit waste, were further sieved to a <600- to >105-micron (<30- to >150-mesh) fraction, then pulverized in a ceramic mill. Splits of this fraction were analyzed for 31 elements by semiquantitative direct-current arc emission spectrography (Myers et al., 1961; Grimes and Marranzino, 1968). Five elements (As, Bi, Cd, Sb, and Zn) were analyzed for by flame AAS. Gold and Se were analyzed for by GFAA (Sanzalone and Chao, 1981); and S by a titrametric method. Gold in the district probably is micron sized. For this reason, analyses for Au were determined on a <105-micron fraction.

Because we will stress the Au results in the body of this report, the chemical analyses are listed in Tables 1 and 2. Concentrations that we consider anomalous are indicated in boldface type.

DATA INTERPRETATION AND ANOMALY DEFINITION

Some geologists tend to judge the element concentrations reported in plant ash in terms of what they expect in soils or rocks, a practise that should be avoided. As an example, Mo concentrations of 10-20 ppm are perfectly normal in the ash of sagebrush from unmineralized areas, but such concentrations would be quite unusual in soils from similar settings. What is clearly anomalous in one sampling medium may be quite normal in another.

Elements in the substrate differ in their availability to the above-ground parts of plants, differences that are well documented. Kabata-Pendias and Pendias (1984) show that although element uptake can vary greatly among different species, Cd is readily taken up in proportion to its concentration in the soil solution. Zinc and Cu are less easily absorbed. Barium and Bi occur at the other end of the availability curve which suggests that they are not easily assimilated. Experience with desert species from Sonora, Mexico (Erdman, unpublished data) suggests that Ba can be very mobile, however.

Temporal (seasonal) change in the concentration of some elements further confounds the interpretation of plant data. This tends to be serious for Au, where its concentrations in the same plant part are usually much higher early in the growth season than later, as Cohen et al. (1987) have reported from their work in Canada and as is documented from other parts of the world. Such changes with time mandate that biogeochemical sampling be conducted within a span of several weeks. Because of this problem, determining element anomalies in plants is much more difficult than for rocks and soils.

Anomalous element concentrations in the sagebrush samples (Table 1) were judged from a combination of sources: baselines reported for this species by Gough and Erdman (1983); scan of the raw data; visual inspection of the histograms for the Cd, Cu, Mo, and Zn data; and from geologic inferences based on where the samples were collected. Gough and Erdman (1983) defined baseline as the expected (central) 95% range of the concentration data. The means (norms) derived from Gough and Erdman (1983) are given in Table 1. Norms for Au and Ag concentrations in sagebrush are not available in the literature and therefore are only estimates based on our experience with Au and Ag concentrations in plant samples.

Soil anomalies were based on strong departures from median concentrations of elements in soils given in a table provided by Geochemical Services, Inc., 2741 Toledo St., Torrance, CA 90503. These medians (norms) are given in Table 2.

RESULTS

The early prospectors' advice, "use gold to find gold," seems to hold true for the analysis of sagebrush in this study. The Au results revealed concentrations in the samples that are consistent with known or suspected mineralized areas along traverses A and C. Only 9 of the 63 samples of sagebrush analyzed for Au had concentrations at or above the 8 ppb limit of determination and 5 of those samples were from sites associated with mineralized veins or faults (Table 1). Almost half of the samples (27) contained only a trace of Au below the stated limit of determination; these are indicated by <s in Table 1. We consider these samples to be of some interest because of their distribution pattern.

Traverse A (Fig. 5)

For the most part, samples with detectable or trace Au apparently contain no other metal anomalies. Sites A01 and A04 are extreme examples of this. The sagebrush containing 8 ppb Au from site A01 grew in an outcrop of silicified limestone of the Preble that formed a ridge just east of the Adelaide mine; no other elements were anomalous. The highest Au concentration in sagebrush--28 ppb--was found at site A04 on Quaternary alluvium beside Cumberland Creek and about 100 meters from Goldrun Creek. This anomaly may be a reflection of Au in ground water from an abandoned mill and tailings pond at the Adelaide settlement about 3 km towards the head of the creek, or placer Au. A 24 ppb anomaly was found in sagebrush that grew in waste from one of the Adelaide mine adits (site A03-X). Secondary Cu minerals evident in the waste pile are probably the source of the Cu anomaly in the plant sample, which also contained anomalous levels of Cd and Zn (Table 1). The sagebrush from site A06 grew in older Quaternary gravels, not alluvium. Gold (16 ppb), Ag, Bi, Cu, and Zn were unusually concentrated in the sample. This site is approximately on strike with limestone of the Preble Formation that crops out north of Goldrun Creek. One of the two 8 ppb Au anomalies from this traverse occurred in sagebrush that grew in waste from a prospected mineralized vein near site A29. The suite of metal anomalies in this plant sample resembles that for the sample from site A03-X at the mine adit, but includes Ag and Mo, an element suite that suggests a similar polymetallic occurrence. Traces of Au or detectible Au occurred in all sagebrush samples from sites 18 through 30, except for the sample from site A27 that grew in floodplain alluvium of Cumberland Creek. Soils from all sites but A18, A19, and A27 were residual derived from the Preble Formation.

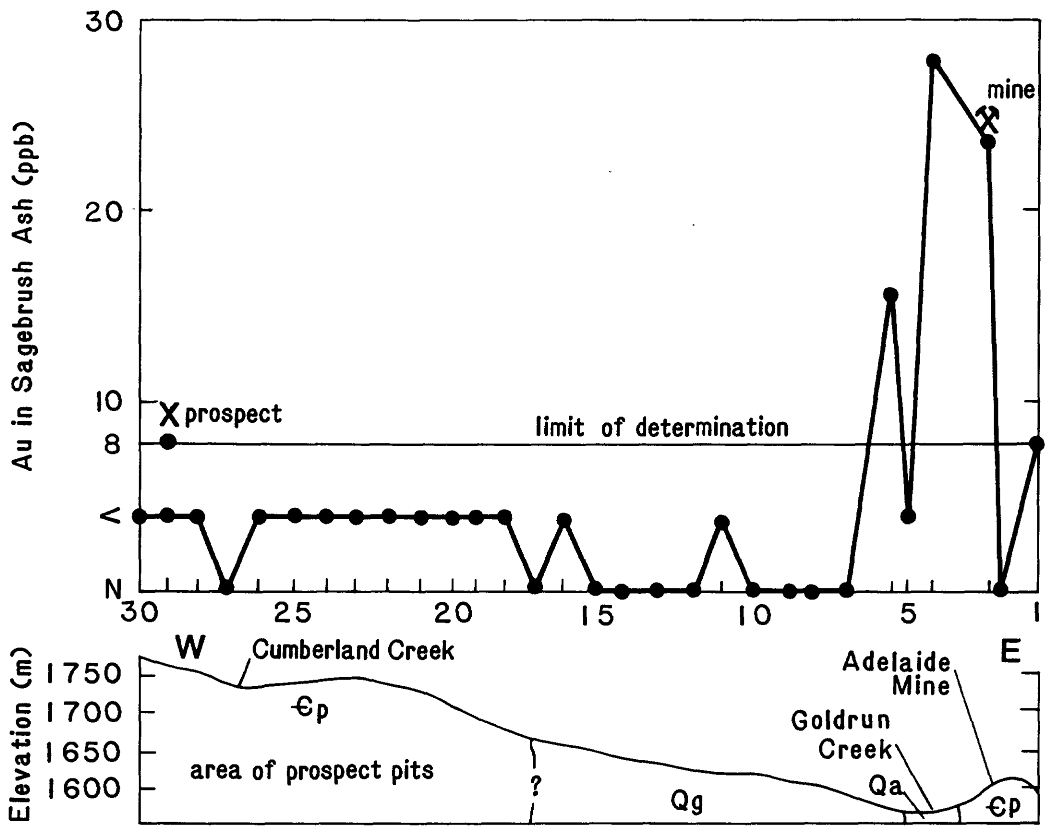

Figure 5. Gold levels in ashed stem-and-leaf samples of sagebrush along traverse A. Samples with traces of Au (reported as as less than the limit of determination) are given a value of 4 ppb and shown as <; those in which no Au was detected are indicated by N.

Traverse B (Fig. 6)

Only very low levels of Au were reported in sagebrush collected along this traverse, and no other elements were of interest except for two Cd anomalies (Table 1). The strongest Au anomaly associated with this traverse occurred at site B14 just west of a ridge that is on strike with mineralized rocks to the south (Fig. 5). Although there was no outcrop at the site, silicified float was abundant. In addition, greasewood was common on the slopes of the ridge from sites B12 through B14. The setting was unusual for this shrub and suggests the proximity of saline waters. An alkali-chloride solution is one of the two main types of aqueous systems associated with epithermal gold deposits; gold is transported as a chloride complex. Such unusual distributions of halophytes outside their normal habitats have been associated with epithermal mineralization in the American Southwest.

Traverse C (Fig. 7)

Results from this traverse proved more surprising and difficult to interpret than those from traverse A and B, and point to three clearly anomalous sites: site C01, above a pair of prospect adits; site C06, on the range-front fault; and site C11, at the eastern end of the traverse in valley fill. Concentrations of As, Sb, and Zn in all soil samples along the traverse were anomalous.

Gold was generally detected in sagebrush that grew on residual soils overlying altered rocks of the Preble Formation. But, except for site C11, Au was not detected in sagebrush growing in Quaternary sediments along the eastern part of the traverse (Fig. 7). None of the Au concentrations in the soils from the traverse proper apparently are anomalous, although detectible Au did occur at sites C01 and C02 at a mineralized dike and at site C06 on the bounding fault that seems to be mineralized, if judged by the anomalous concentrations of Ag, As, S, Zn, and especially Sb and W (Table 2).

An 8 ppb Au anomaly in sagebrush from site C01 is consistent with the slightly higher 12 ppb Au anomaly in the sample of sagebrush that grew in waste from an adit just below. The sagebrush sample from the waste site also showed other metal anomalies besides Au; these included Ag, Cd, Cu, Mo, Pb, and Zn (Table 1). Only two of the 63 plant samples contained detectible Pb and these were from site C01 and the adit waste below. Other metal anomalies in the sample from site C01 include Ag, Cd, and Zn.

The sample of fines from this waste pile was panned and further processed to separate the heavy-mineral non-magnetic (NM HMC) and weakly-magnetic (M HMC) fractions; these samples were analyzed by semi-quantitative emission spectroscopy (ES).

The following table compares some of the analytical results for the sagebrush, soil, and concentrates from the waste site:

Sample	Au	Ag	As	Cd	Cu	Mo	Pb	Zn
Sagebrush	0.012	0.8	<20	22	320	46	70	1,100
Soil	.3	50	1,200	16	300	50	7,000	1,000
M HMC	N	300	2,000	N	1,500	500	50,000	5,000
NM HMC	20	500	5,000	N	300	3,000	>50,000	1,000

Concentrations are in ppm; N, not detected (detection limits by ES for Au are 20 ppm and for Cd, 50 ppm).

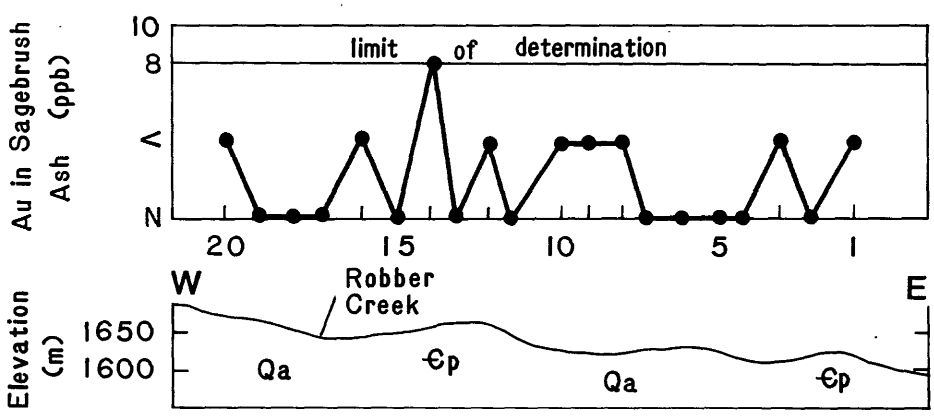

Figure 6. Gold levels in sagebrush along traverse B showing an erratic pattern of detectable and trace Au. Contacts between Qa and -€p not known.

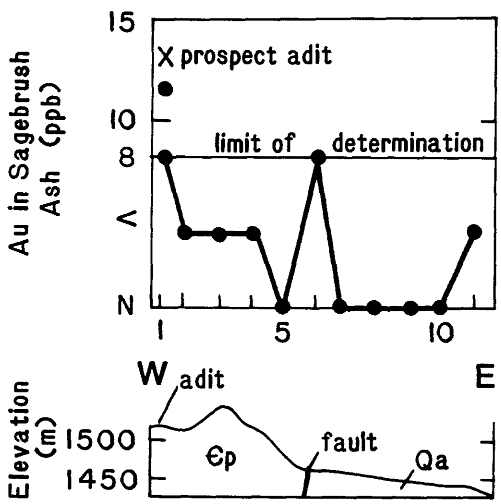

Figure 7. Gold levels in sagebrush along traverse C that reflect a mineralized vein at a prospect (adit), the altered Preble Formation, the mineralized range-front fault, and an anomaly at the eastern end of the traverse.

The anomaly-to-background contrasts tend to decrease markedly from the concentrates to the soil and finally to the sagebrush. These results are in keeping with the thesis that plants tend to mute geochemical differences in the environment, in large measure because of homeostatic (physiological) mechanisms that attempt to maintain relatively uniform element concentrations within the plant.

Site C06 on the range-front fault is unusual in that the coarse, residual soils are strongly iron stained and halophytes, mainly greasewood, dominate the locality. The presence of halophytes indicates that the soils are unusually saline, or at least sodic. Greasewood can indicate the presence in the soil of alkali carbonates (Kearney and Peebles, 1960). The sagebrush sample from site C06 was anomalous in its Au content (Table 1), and the soil had anomalous concentrations of Ag, As, S, Sb, W, and Zn (Table 2). The anomalous W concentrations in soil samples from sites C06 through C09 show an apparent decrease in tungsten eastward from the range-front fault (Fig. 8). The association of W with the hot springs along this fault scarp has been reported for the general region by Erickson and Marsh (1973). Tungsten-bearing hot-spring tufa deposits were mined during World War II at the town of Golconda, 16 km north of the area.

The last anomaly on traverse C occurs at site C11 in Quaternary sediments. The sagebrush sample contained anomalous Cd and a trace of Au, and the soil sample contained anomalous concentrations of Bi and Cd in addition to As, Sb, and Zn. The 6 ppm Bi value in the soil from this site is well above the 0.8 ppm median typical of soils.

The sagebrush samples from traverse C were also analyzed for Mn, Fe, and Li by AAS. Concentrations of Mn and Fe are within ranges judged normal and are therefore not given in Table 1. However, the Li concentrations generally exceed the 50 ppm upper limit of the normal range given by Gough and Erdman (1983) and correspond to the high As, Sb, and Zn levels in soils throughout the traverse (Table 1). Uncommonly high Li levels are often found in geothermal waters and Li is easily taken up by plants affected by such areas (Erdman, unpublished data).

DISCUSSION

Our evidence suggests that Au in sagebrush reflects underlying low-level mineral occurrences, as shown by its response to mineralized sources along traverses A and C. Possible contamination of the samples by wind-blown dust seems to be discounted by the fact that we sampled only new growth, which would have had only a few months of exposure. The Au concentrations in sagebrush sampled, however, are not nearly so high as those found in six "grab samples" collected at several active disseminated Au mines in northeastern Nevada. Concentrations of Au in the ash of the current year's growth of those samples ranged from 65 to 520 ppb.

Sagebrush contained anomalous levels of Ag and of the base metals only where it grows on or close to outcropping quartz veins or skarn. The mineralized source of the Ag is possibly argentiferous galena.

The detectable Bi in sagebrush from site A06 on traverse A and the particulary strong and unique Bi anomaly in the soil from site C11 on traverse C may indicate very local mineralized sources, because the mobility of Bi is reported to be low (Levinson, 1980, p. 867; Kabata-Pendias and Pendias, 1984). According to Orris et al. (1987) Bi is associated with many Au skarn systems.

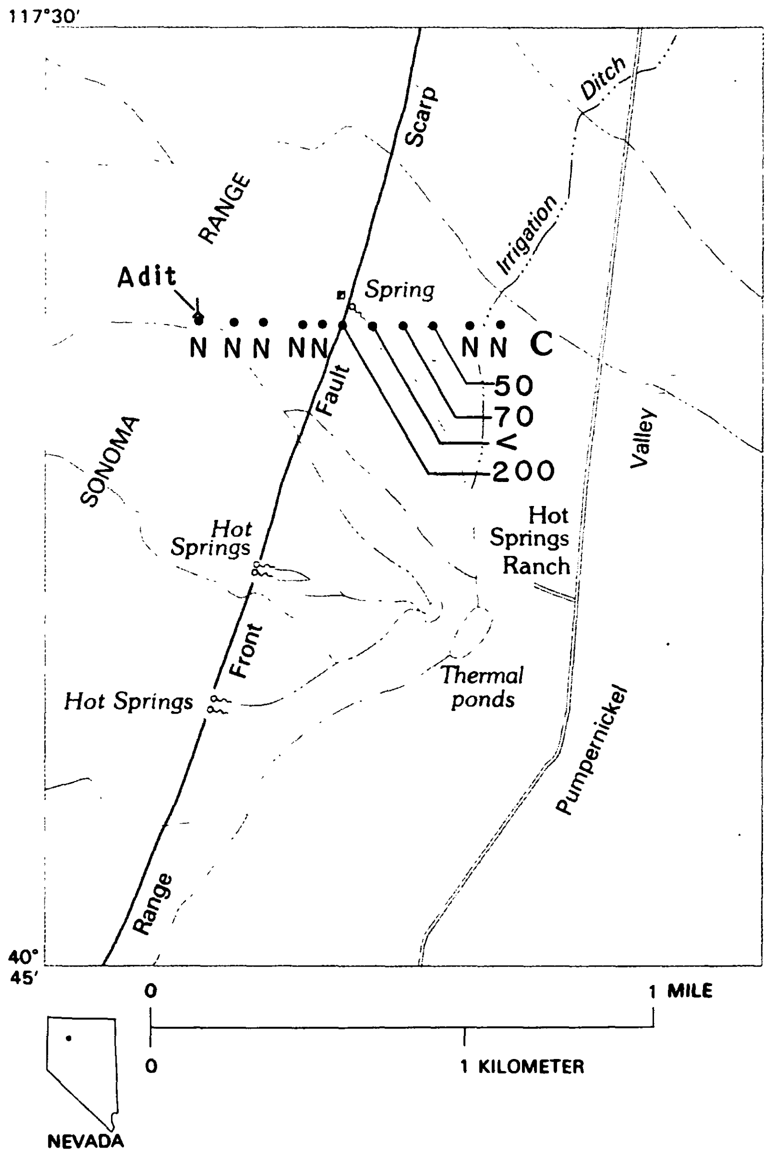

Figure 8. Tungsten in soil samples along traverse C showing anomalies whose source is outcrop along the range-front fault. The < symbol indicates detected, but below the 50 ppm limit of determination.

At the Fortitude Au-Ag skarn deposit, about 40 km southeast of the Gold Run district, Bi is associated with Au and pyrrhotite (Wotruba et al., 1987). This deposit and other gold skarn systems lie within the northwest-trending Battle Mountain-Eureka mineral belt, and the Gold Run district occurs on the extension of that belt (Roberts, 1966, Fig. 7, p. 56). Thirty km southeast of the Fortitude deposit, in the same belt, lies the Hilltop gold deposit in the northern Shoshone Range (Lisle and Desrochers, 1987). Intersecting this belt in the vicinity of the Gold Run district is one of the oldest recognizable structural features in Nevada, "the north-east trending Cordilleran geosyncline that cuts diagonally through northwestern Nevada and extends into central Idaho" (Roberts, 1966, p. 88). A steeply westward dipping normal fault was an important conduit for the hydrothermal fluids that carried the metals in the Fortitude area. The structural setting at the Gold Run district seems to be similar.

The Se anomalies in soils from traverse C do not completely explain the observed distribution of the selenium indicator plant, desert plume--only soils from sites C01, C02 and the waste from the prospect dump (C01-X) were anomalous in Se. Yet this species is widely distributed from sites C01-C06 in soils derived from the Preble Formation. According to Harr (1978, p. 395), species in the genus Stanleya are primary Se accumulator plants that require 1-50 ppm Se in either the soil or water. Since only the soil samples from the adit (site C01-X) and site C01 contained Se within that concentration range, and only the sagebrush samples from those two sites contained Se close to the anomaly threshold for Se of 1 ppm (Gough and Erdman, 1983)--0.45 and 0.60 ppm, respectively--the plants of Stanleya that occur on the slopes of the Preble Formation must be reflecting a source of Se deeper than the surface soils and, for some reason, unavailable to sagebrush.

The selenium anomaly is significant in that this locality may be similar structurally and geochemically to Nevada's now famous Sleeper deposit north of Winnemucca, an open pit mine in valley fill about 1,000 m basinward from a bounding fault scarp. Unusually high concentrations of As, Sb, and Se characterized this fossil hot-spring type Au-Ag deposit. The Se occurs as the Ag mineral, naumannite.

The chlorosis of greasewood along the bounding fault on traverse C has no ready explanation. The soil from that immediate locality is quite high in Sb (Table 2), but the effect of this metal on plants cannot be assessed. According to Lepp (1981, p. 325), little is known about the details of mobilization and adsorption of antimony in soils, or about its toxicity to plants. A Zn-induced Fe deficiency could be the cause of chlorosis; but, although the soils are unusually high in Zn, the Zn concentration in sagebrush from the site is normal.

The geochemical anomalies that we found at the bounding fault and the prospect adits to the west on traverse C are supported by unpublished data on rocks from that area sampled by Marsh and Erickson in 1969. Three samples taken from the hot springs above Hot Springs Ranch and six taken from the shaft area near site C06 (Fig. 4) contained W levels that ranged from 50 to 1,000 ppm. This is undoubtedly the source of the W anomalies in the soil samples collected from the fault and pediment below. Probably the most pronounced anomalies were the >10 ppm Hg concentrations in all but three of the nine rock samples. A sample of altered felsic dike rock from dump waste beside the shaft contained the highest levels of Au and Ag, 0.40 and 13 ppm, respectively. Other metal extremes were As (800 ppm), Sb (100 ppm), Hg (>10 ppm), W (700), and Pb (2,000 ppm). Tellurium was detected (0.2 ppm) in two of the nine samples, and Mo was detected (10-15 ppm) in four of them.

Rock samples were also taken from one of the adit dumps and the portal wall at site C01-X (Fig. 4). The suite of elements with anomalous concentrations was similar to that in rocks from the bounding fault, although the Hg anomalies did not exceed 1.40 ppm and W levels were less than the 50 ppm limit of determination. A sample of quartz vein with iron oxides from the dump contained the highest concentrations (in ppm) for most of the elements analyzed, as follows: Ag (1.0), As (800), Sb (300), Hg (1.10), Te (0.2 ppm) Mo (100 ppm) Cu (2,000 ppm), Pb (1,500 ppm), Zn (500), and Cd (200). Gold was detected, but below the 0.02 ppm limit of determination. However, a similar sample from a small prospect pit about 70 ft uphill from the adit (apparently near site C01 on the traverse) contained the highest Au and Te levels in rocks sampled from this area--0.50 ppm and 0.4 ppm, respectively--as well as anomalous concentrations for most of the elements listed above. The short adit exposed a gossan in shale of the Preble, cut about 5 ft of pale, yellowish-white, argillized dike rock, and ended in normal Preble shale. Mineralized rocks associated with the C01-X and C01 sites seem to relate to a Pb-rich vein system that was overprinted by a younger hot-springs system.

We can propose only two explanations for the anomalies at site C11 on traverse C. One source for the Au, Cd, and Bi may have been metal-rich thermal waters from the hot springs that were used to irrigate the now fallow field where the anomaly occurs, although concentrations of Cd and Bi appeared to be normal in rocks sampled in 1969 from the hot springs. Aerial photos taken in 1979 show a clearly defined ditch that follows the contour between site C10 and C11 (Fig. 4) and connects with the larger of two ponds at Hot Springs Ranch. The heat source driving the hot springs may be a buried pluton that lies beneath the valley (Grauch et al., 1987).

Another explanation is more speculative, but nevertheless plausible, especially considering that the geologic cross section (Marsh and Erickson, 1973) just north of the traverse suggests that the valley fill at the site is quite shallow and is underlain by the Preble Formation. The anomaly at site 11 could be caused by a leakage halo from an underlying mineralized fault (gold-bearing skarn ?) that lies parallel to the fault scarp at site C06, a setting that is documented in other parts of the Basin-and-Range Province in Nevada.

The key pathfinder element for locating disseminated Au deposits in the western United States is arsenic. Unfortunately, the method we used to determine As in sagebrush lacks the sensitivity needed to detect this element; a 20 ppm limit of determination is 10 times the 2 ppm (in ash) that is the norm established for big sagebrush by Gough and Erdman (1983). The abundance of "less thans" (<s) for As in Table 1 suggests that a more sensitive method may provide more useful As data, but there is no assurance that sagebrush reflects an As-rich substrate. Cohen et al. (1987) found a poor response to underlying As-bearing soils and rocks in all species he sampled; arsenic anomalies that did occur were not always coincident with the Au anomalies. The analytical sensitivity was also not adequate to determine Ag, Sb, Bi, and Pb in sagebrush ash.

The anomaly-to-background contrast for Cd in sagebrush is clearly the largest among the elements given in Table 1. Such high concentrations (maximum, 22 ppm) over a background concentration of about 2 ppm (Gough and Erdman, 1983) can be explained by the fact that Cd is one of the few elements that are extremely easily taken up by plants, as discussed above. Conversely, the apparent inability of sagebrush to reflect a strong Bi anomaly in the substrate can be explained by its low availabilty.

CONCLUSIONS

Although the results are not definitive, they show that gold is accumulated in sagebrush at detectable levels in mineralized areas where surface soils contained gold at only background levels. We therefore recommend that this easily recognized species common to the semi-arid deserts of the West be used where conventional exploration methods may be unsuitable or too expensive.

ACKNOWLEDGMENTS

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TABLE 1--Element concentrations in the ash of new growth (stems and leaves combined) of big sagebrush samples, Gold Run district, Nevada; concentrations in ppm, except for gold (ppb)

Sample #	Au (8)	Ag (0.2)	As (20)	Bi (2)	Cd (0.2)	Cu (10)	Li (4)	Mo (2)	Pb (10)	Zn (10)
Norms	~1	<0.1	2	--	1.3	120	8.8	18	22	380
				Traverse A						
A01	**8**	N	N	N	1.2	200	--	20	N	240
A02	N	**0.4**	<	N	3.8	**400**	--	12	N	**500**
A03-X	**24**	N	<	N	**4.6**	**500**	--	34	N	**700**
A04	**28**	N	<	N	3.4	220	--	10	N	200
A05	<	N	N	N	1.8	170	--	16	N	200
A06	**16**	**0.4**	<	**4**	3.8	**540**	--	20	N	**460**
A07	N	N	<	N	3.8	190	--	22	N	200
A08	N	N	N	N	2.0	170	--	22	N	300
A09	N	N	N	N	2.2	260	--	16	N	300
A10	N	N	N	N	1.8	200	--	14	N	320
A11	<	N	N	N	1.0	160	--	20	N	280
A12	N	N	N	N	2.8	200	--	14	N	260
A13	N	N	<	N	1.4	210	--	24	N	260
A14	N	N	<	N	0.8	200	--	16	N	300
A15	N	N	<	N	2.6	180	--	**42**	N	280
A16	<	N	<	N	0.8	210	--	30	N	280
A17	N	N	N	N	3.6	190	--	16	N	340
A18	<	N	<	N	3.0	150	--	16	N	340
A19	<	N	N	N	2.4	140	--	12	N	320
A20	<	N	N	N	2.4	160	--	10	N	380
A21	<	N	N	N	**5.8**	240	--	18	N	400
A22	<	N	N	N	4.4	160	--	20	N	320
A23	<	N	<	N	**5.4**	190	--	20	N	300
A24	<	N	<	N	2.0	140	--	16	N	300
A25	<	N	N	N	2.0	180	--	30	N	360
A26	<	N	N	N	2.6	190	--	22	N	360
A27	N	N	N	N	2.6	**290**	--	16	N	360
A28	<	N	N	2	3.2	210	--	26	N	320
A29	<	N	<	N	3.4	200	--	20	N	320
A29-X	8	0.4	<	N	**6.8**	**290**	--	**56**	N	**480**
A30	<	N	N	N	0.8	200	--	18	N	200

TABLE 1.--Continued

Sample #	Au (8)	Ag (0.2)	As (20)	Bi (2)	Cd (0.2)	Cu (10)	Li (4)	Mo (2)	Pb (10)	Zn (10)
				Traverse B						
B01	<	N	N	N	2.0	140	--	16	N	180
B02	N	N	<	N	3.2	160	--	14	N	280
B03	<	N	<	N	1.2	170	--	32	N	280
B04	N	N	N	N	4.4	240	--	34	N	260
B05	N	N	<	N	3.4	140	--	32	N	220
B06	N	N	<	N	1.2	190	--	24	N	240
B07	N	N	N	N	2.8	180	--	20	N	200
B08	<	N	N	N	1.4	230	--	24	N	280
B09	<	N	N	2	2.0	240	--	30	N	300
B10	<	N	<	N	2.6	210	--	22	N	260
B11	N	N	N	N	0.8	170	--	14	N	240
B12	<	N	<	N	1.4	210	--	20	N	280
B13	N	N	N	N	1.6	260	--	32	N	380
B14	**8**	N	N	N	0.6	250	--	24	N	240
B15	N	N	N	N	1.6	210	--	34	N	280
B16	<	N	N	N	1.6	190	--	14	N	240
B17	N	N	N	N	**5.6**	140	--	32	N	120
B18	N	N	N	2	3.0	240	--	20	N	140
B19	N	N	<	N	2.6	200	--	30	N	220
B20	<	N	N	N	**6.0**	240	--	20	N	240
				Traverse C						
C01	**8**	**0.2**	<	N	**16**	240	**50**	20	**20**	**980**
C01-X	**12**	**0.8**	<	N	**22**	**320**	20	**46**	**70**	**1100**
C02	<	N	N	N	**6.0**	180	**90**	28	N	360
C03	<	N	N	N	2.2	130	**50**	22	N	240
C04	<	N	N	N	0.8	130	**55**	12	N	260
C05	N	N	N	N	1.2	160	**70**	18	N	200
C06	**8**	N	N	N	1.2	150	25	24	N	200
C07	N	N	N	N	2.8	180	**160**	16	N	300
C08	N	N	N	N	**4.6**	220	**70**	36	N	200
C09	N	N	N	N	**6.0**	240	**95**	**46**	N	160
C10	N	N	N	N	**9.2**	250	35	24	N	200
C11	<	N	N	N	**13**	230	40	32	N	180

<, indicates trace but less than the given lower limit of determination, LLD, in parentheses; N, not detected; --, no data; antimony was looked for at an LLD of 4 ppm, but not detected; anomalous concentrations given in boldface; X indicates sample from mine or prospect site.