Dating gold deposition in a Carlin-type gold deposit using Rb/Sr methods on the mineral galkhaite

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ABSTRACT

Significant effort has been expended in an attempt to date hydrothermal activity that generated Carlin-type gold deposits (CTDs) in the Great Basin of Nevada. Thus far, these efforts have been only partially successful, because the relationship(s) between the dated mineral and hydrothermal activity are equivocal in many cases. Galkhaite, a trace component of at least four CTDs in Nevada, contains significant amounts of Rb and virtually no Sr, making it an ideal candidate for radiometric dating. At the Getchell deposit, galkhaite is paragenetically late, but clearly associated with gold mineralization. Our data place gold mineralization at Getchell at 39.0 ± 2.1 Ma. This is the first unequivocally gold-related date produced for any of the Carlin-type systems. Galkhaite also has been reported at the Carlin, Rodeo, and Betze deposits and is likely present in other CTDs in Nevada. This mineral may provide a solution to the conundrum of dating of CTDs.

Keywords: galkhaite, Getchell mine, Carlin-type deposits, Rb-Sr dating, gold.

INTRODUCTION

Sedimentary-rock–hosted disseminated gold deposits, also known as Carlin-type gold deposits (CTDs), are among the most economically important types of ore deposits currently being sought and mined in the United States. In excess of 3200 t (tonnes) (>100 million ounces) of gold reserves have been identified in northern Nevada, the area hosting the largest proportion of these ore deposits (Christenson, 1993; Teal and Jackson, 1997). Although high-grade parts of some of these deposits, such as at Mercur (Utah) and Getchell (Nevada), have been mined since the last century (Joralemon, 1951; Jewell and Parry, 1987), they were not recognized as a class until the discovery and development of Carlin as a bulk-tonnage mine between 1962 and 1965 (Hausen and Kerr, 1968).

Carlin-type deposits are commonly hosted in silty carbonates to calcareous siltstones and shales, although several other rock types may host ore locally (Radtke, 1985; Ashley et al., 1991; Arehart, 1996). Gold in CTDs is closely associated with hydrothermally generated arsenian pyrite, pyrite, and locally arsenopyrite (Wells and Mullen, 1973; Arehart et al., 1993). Lesser but significant amounts of gold occur in jasperoidal quartz (e.g., Hofstra et al., 1988), and minor amounts are associated with phyllosilicates and carbonaceous matter (Hausen and Kerr, 1968). Arsenic sulfides (realgar, orpiment) are temporally late in the gold stage, and slightly postdate the dominant alteration minerals such as kaolinite, sericite, and quartz. Slightly later in the paragenetic sequence are stibnite, barite, and late calcite, commonly as open-fracture fillings. At Getchell and Carlin, this late-stage assemblage includes a variety of Tl-bearing sulfosalts (Dickson et al., 1979; Bowell et al., 1999) including galkhaite, the subject here. Because of their similarity in appearance to other sulfides, and their generally sparse occurrence, Tl-bearing sulfosalts are likely present in other CTDs but may not yet have been recognized.

GETCHELL DEPOSIT

The Getchell deposit is a CTD located in north-central Nevada, 72 km northeast of Winnemucca. Horton (1999) has provided a detailed history of the discovery, development, and mining operations of Getchell. The deposit is located along the eastern flanks of the 92 Ma Osgood Mountains stock, a granodiorite pluton that intruded Cambrian and Ordovician sedimentary rocks (Fig. 1). The primary lithologies include silty carbonate and calcareous shale metamorphosed to calc-silicate, marble, hornfels, and phyllite proximal to the stock and intruded by felsic dikes and sills. Gold mineralization is hosted primarily in silty calc-arenite marble and calcareous shale that have undergone decarbonatization, argillization, and silicification. Gold occurs in very fine grained, arsenic-rich pyrite grains or as coatings on preexisting pyrite or other sulfides, in a manner typical of CTDs (Arehart, 1996). Getchell is similar to other CTDs in that the ore zones are enriched in Ag, As, Sb, Hg, Tl, and Ba and depleted in base metals. The dominant structure in the region is the north- to northwest-trending Getchell fault zone, considered the primary conduit for ascending mineralizing fluids (Cline and Hofstra, 2000).

PREVIOUS ATTEMPTS AT DATING CTDs

Directly dating gold mineralization in CTDs has been problematic, complicated by the fine-grained nature of alteration and mineralization

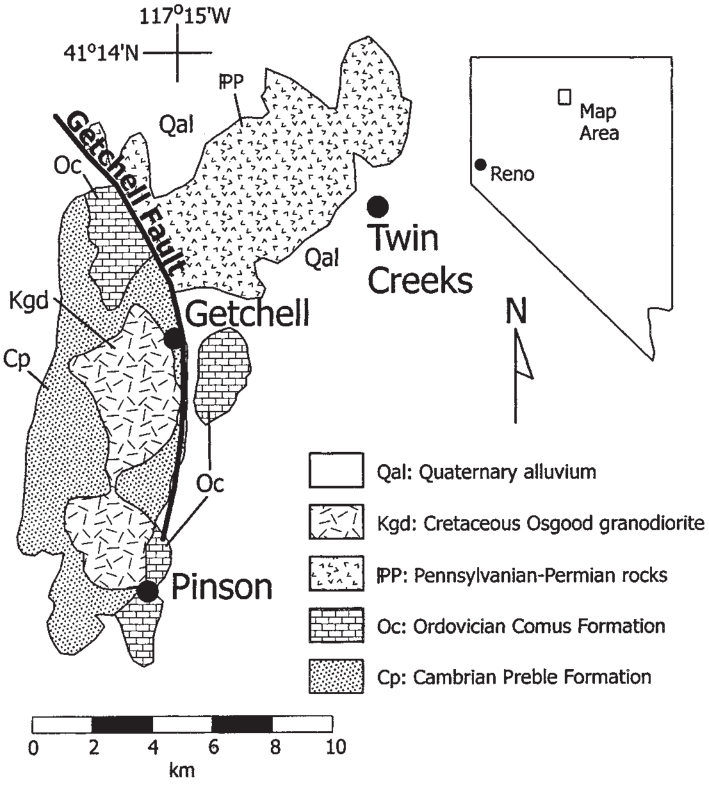

Figure 1. Location and generalized geologic map of northern Osgood Mountains, Humboldt County, Nevada, showing location of Carlin-type deposits, including Getchell. Modified from Willden (1964).

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phases, the lack of datable minerals clearly associated with gold deposition, and uncertainty regarding complex associations between ore-mineral parageneses and alteration assemblages. Results and interpretations can also be hindered by resetting and overprinting caused by multiple hydrothermal events.

Existing age data include geologic constraints based on clearly pre- and postgold phases, plus numerous data from samples with variable, but generally poorly demonstrated, relationships to gold mineralization (Groff et al., 1997). The preponderance of radiometric and paragenetic data indicate that mineralization in most systems was polyphasic (Groff et al., 1997; Hofstra et al., 1999). In many districts, there appears to be an early mineralization event comprising weak skarn mineralization. This early event is clearly related to emplacement of Mesozoic plutonic rocks, such as the Osgood stock near Getchell (Groff et al., 1997; Cline and Hofstra, 2000) or the Goldstrike stock in the Carlin trend (Arehart et al., 1993). Most workers would argue that these intrusive rocks, and their attendant weak skarn systems, are unrelated to CTD mineralization. These intrusive rocks are easily dated and, where mineralized, provide upper constraints on the age of gold. In other cases, there are igneous rocks and supergene phases (primarily alunite) that clearly postdate gold mineralization (e.g., Arehart et al., 1992; Hofstra et al., 1999) and provide lower age constraints on timing of gold. In addition, fission-track data (Arehart et al., 1993; Hofstra et al., 1999; T. Chakurian, 2000, personal commun.) can be used to indirectly limit mineralization.

To date, the closest directly determined ages for mineralization have come from adularia at Twin Creeks (ca. 42 Ma: Groff et al., 1997; Hall et al., 1997), fission-track of apatite at Pinson (42.7 Ma: Hofstra et al., 1999), and mineralized and unmineralized dikes at Beast (ca. 36 Ma: M. Ressel, 2000, personal commun.). Adularia at Twin Creeks encapsulates auriferous pyrite and may have formed close to the time of mineralization (discussed subsequently) but only provides a younger limit. Adularia is not reported from any other CTD and may represent an overprint of a separate hydrothermal system at Twin Creeks (S.E. Kesler, 1999, personal commun.). The relationship of apatite to gold mineralization was not described in Hofstra et al. (1999), but hydrothermal apatite is reported to be present in other CTDs (Ferdock et al., 1997; T. Chakurian, 2000, personal commun.). The dikes at Beast provide fairly tight age constraints on mineralization, but do not provide a direct date.

Early work at Getchell by Joralemon (1951, 1975) considered gold deposition to be Tertiary, on the basis of observations that shallow ore-grade gold mineralization paralleled the surface topography. This idea was discredited by Berger et al. (1975), who noted that ore boundaries were based on economics, not relative elevation. The nearby Osgood granodiorite stock is dated at 92 Ma (Silberman and McKee, 1971; Silberman et al., 1974; Groff et al., 1997). Felsic dikes and sills in the Getchell mine area are considered contemporaneous with the stock; an andesite porphyry dike cropping out in the north pit was dated at 90 Ma (Silberman and McKee, 1971). These dikes and sills are commonly altered and mineralized by Carlin-type processes, providing an upper age constraint on gold deposition.

Recent work by Groff et al. (1997) and Cline and Hofstra (2000) have focused on dating, alteration, mineralization, and paragenesis for the Getchell system. By using fission-track and ^{40}Ar/^{39}Ar methods, Groff et al. (1997) dated igneous rocks and alteration minerals at Getchell and the adjoining Twin Creeks deposit. Groff et al. (1997) and Hall et al. (1997) also dated hydrothermal adularia occurring with gold at Twin Creeks and produced similar dates of ca. 42 Ma. Groff et al. (1997) suggested that the main Carlin-style gold mineralization occurred at ca. 83 Ma and that a lesser episode occurred at ca. 42 Ma; Hall et al. (1997) inferred that the gold was deposited in a single event, concordant with the ca. 42 Ma date.

GALKHAITE

Galkhaite [$(Cs,Tl)(Hg,Cu,Zn)_6(As,Sb)_4S_{12}$] is a mercury sulfosalt common to the Getchell mine, but rare worldwide. It was first described from mercury deposits in Russia (Gruzdev et al., 1972) and has since been found at Getchell and in other CTDs in Nevada (Botinelly et al., 1973; Dickson et al., 1979; Ferdock et al., 1997), at the Hemlo gold deposit in Canada (Robinson, 1986), and at Zarshuran in Iran (Mehrabi et al., 1999). Galkhaite is cubic, space group *I*43*m*, and occurs at Getchell as aggregate masses, crystal groupings, and lone cubes to 1 cm on an edge, though most crystals are <1 mm. It is red to purple to steel gray, with a luster ranging from vitreous to metallic, and has deep red internal reflections. It generally forms cubes and combinations of cubes and dodecahedrons; true dodecahedrons are rare. The distinguishing characteristics of galkhaite are the diagonal striations on the crystal faces, and the drusy quartz matrix on which it occurs.

In the Getchell mine, galkhaite is found in higher-grade refractory ore (generally >8 g/t Au), where it is associated with quartz, pyrite, and stibnite and late calcite, barite, and stilbite. Galkhaite from the Getchell open pits was uncommon and occurred with fluorite, realgar, orpiment, and calcite (Stolburg and Dunning, 1985). Dickson et al. (1979) reported that galkhaite at Carlin occurred with cinnabar, in association with other Tl-bearing minerals such as ellisite (Tl_3AsS_3), weissbergite ($TlSbS_2$), christite ($TlHgAsS_2$), and lorandite ($TlAsS_2$). These minerals have not been reported in situ at Getchell, but lorandite has been identified in mill concentrate (Bowell et al., 1999). Galkhaite is disseminated throughout the Getchell orebody but is concentrated along and within ore-waste contacts and structural intersections. The mineral is commonly encapsulated by Au-bearing silica. Although Groff et al. (1997) and Cline and Hofstra (2000) did not mention the presence of galkhaite, mineral associations and detailed observations of its occurrence and distribution indicate that galkhaite is paragenically late but still gold stage. Many samples of galkhaite have been observed intergrown with stibnite, which both groups of researchers assigned to late gold-stage mineral paragenesis. Silver is a common component of galkhaite, ranging up to 1.6 wt% (Chen and Szymanski, 1981). Bowell et al. (1999) have reported significant Au values in galkhaite from Getchell, ranging between 13 and 117 ppm, as submicrometer inclusions or lattice constituents. We take these elevated gold values as further evidence that the galkhaite is temporally related to the bulk of the gold-rich arsenian pyrite mineralization.

Early research on galkhaite from Getchell focused on mineral description, identification of the primary constituents, and X-ray powder diffraction analyses (Botinelly et al., 1973). Analyses of 21 crystals of galkhaite from the Getchell open pits yielded an average chemistry of the major elements as shown in Table 1 (Chen and Szymanski, 1981, 1982); galkhaite from Getchell underground has similar chemical characteristics. We used laser-ablation inductively coupled plasma mass spectrometry (ICP-MS) techniques to further characterize the trace element geochemistry of galkhaite. The goal was to identify and quantify elements suitable for radiometric dating, such as Re, Os, K, Sm, and Rb. Because galkhaite contains

TABLE 1. ANALYTICAL DATA FOR GALKHAITE FROM THE GETCHELL MINE

Element	Range (wt%)	Average (wt%)
Cs	3.7–7.1	5.1
Tl	nd–4.2	2.4
Hg	48.3–53.0	50.7
Cu	1.6–3.6	3.2
Zn	0.3–2.5	1.8
As	14.5–15.9	15.2
Sb	nd–3.1	0.3
S	20.9–22.7	22.0

Note: Results are from electron-microprobe analyses of 21 crystals collected from the north pit (from Chen and Szymanski, 1981). The average composition of Getchell galkhaite is $Cs_{0.67}Tl_{0.21}(Hg_{4.42}Cu_{0.88}Zn_{0.48})_{\Sigma 5.78}(As_{3.55}Sb_{0.04})_{\Sigma 3.59}S_{12}$, with sulfur normalized to 12; nd—not detected.

large, singly charged elements such as Cs, Tl, and Hg, we expected that it might also contain significant quantities of Rb or K. Spot and line analyses of the mineral revealed trace to ultratrace quantities of Fe, Se, Au, Ag, Ti, Pb, La, V, Mo, K, W, Mn, and, of significance to this study, Rb. From these initial ICP-MS analyses, we estimated Rb concentration to be of the order of 100 to 300 ppm, on the basis of a comparison of the peak intensity for Rb with peak intensities for other elements of known concentration. In several laser-ablation ICP-MS analyses, there appears to be only minor zoning of Rb in galkhaite if at all. Galkhaite also contains virtually no Sr, making it ideal for Rb/Sr dating.

Analytical Methods

For Rb-Sr isotopic analysis, two samples of galkhaite, one 57.1 mg and the other 52.5 mg, were handpicked and cleaned in deionized water. Dissolution was carried out in 15 mL Teflon vials on a hotplate by using a mixture of equal amounts of 6N HCl and concentrated HNO_3. The resulting solution was light blue and free of any solid. For sample 1, each of the three aliquot portions (A, B, and C) was spiked with a high ^{87}Rb/^{84}Sr mixed spike. An aliquot from the sample 2 solution was also spiked with the same mixed spike. The spiked samples were dried, taken up in 3M HNO_3, and loaded on small-volume Teflon columns containing Eichrom Ind. Inc. Sr-specific resin. After elution with 3M HNO_3, the spiked sample Sr was stripped and collected by using deionized water. Isotopic analyses were conducted on a multiple-collector VG Sector solid-source mass spectrometer, equipped with an axial Daly detector ion-counting system. Separated Sr samples were loaded with a $TaCl_5$ solution and phosphoric acid onto single Re filaments. Because of the small sample sizes and large ^{87}Sr/^{86}Sr ratios, most of the samples were measured with the ion-counting system. A small part of the unseparated Rb collected from the sample elutions was directly loaded on the side filament of a triple Re filament assembly and run with a two-Faraday-collector static-analysis routine. Total chemistry blanks were <50 pg for Sr and <10 pg for Rb. The uncertainty in measured ^{87}Rb/^{86}Sr is conservatively estimated to be 2%.

RESULTS

In the Rb-Sr isotopic analysis results in Figure 2 and Table 2, galkhaite sample 1 contains 220 ppm Rb, and sample 2 has 257 ppm Rb. Concentrations of Sr in both samples are very low (<0.1 ppm). A model two-point age can be calculated for each aliquot, assuming an "initial" ^{87}Sr/^{86}Sr (ignoring any blank contribution) of 0.7095. With this assumption, calculated apparent ages for each aliquot are 41.5 ± 0.9 Ma (sample 1, aliquot A), 41.2 ± 0.8 Ma (sample 1, aliquot B), 39.4 ± 0.8 Ma (sample 1, aliquot C), and 39.1 ± 0.8 Ma (sample 2). Because of the extreme Rb/Sr ratio of these samples, the choice of initial values does not significantly affect the final result. The stated uncertainties are based on the error in the measured ^{87}Sr/^{86}Sr, and the assumed 2% uncertainty in ^{87}Rb/^{86}Sr. Because of the low concentrations and relatively small aliquot sizes, the blank contribution to the samples can be significant. Therefore, the Sr analyses represent a mixture of blank Sr, ^{87}Sr produced by decay of ^{87}Rb since the formation of the galkhaite samples, and the initial content of Sr. Because of the high ^{87}Rb/^{86}Sr ratios of galkhaite (>40 000), and the very high (2.4 to 23) measured ^{87}Sr/^{86}Sr ratio of the aliquots, the isotopic compositions of the blank and the initial Sr are virtually the same at the scale of the Rb-Sr isotopic data from the sample aliquots. Hence, the data from the four aliquots fall along essentially a single mixing line on a Rb-Sr diagram (Fig. 2).

ISOPLOT (Ludwig and Titterington, 1994) was used to fit a model 3 line to the data, by weighting each point by the analytical uncertainties and assuming a normal distribution to the value of the ^{87}Sr/^{86}Sr intercept. This procedure is appropriate in this case because each aliquot will have somewhat different proportions of initial and blank Sr. This calculation gives an apparent age of 39.0 ± 2.1 Ma with MSWD = 5.2. The intercept of the best-fit line with the ^{87}Sr/^{86}Sr axis is 0.88 ± 0.53, which is within uncertainty of reasonable values for initial Sr and blank Sr isotopic compositions (0.706–0.720). The scatter of the data around the best-fit line, as indicated by a 5.2 MSWD, is greater than can be accounted for by the analytical errors. Because the data set consists of three aliquots of the same sample and only one other sample, it is unlikely that this scatter is geologic in origin. Instead, it is more likely that the uncertainty in the measured ^{87}Rb/^{86}Sr ratio is greater than 2%, owing to a variable blank contribution. If that uncertainty is assumed to be 4.5%, then the MSWD drops to 1, and the calculated age (and uncertainty) is 39.5 ± 1.2 Ma (^{87}Sr/^{86}Sr intercept = 0.801 ± 0.097). However, the most conservative estimate from the data of the age of the galkhaite would still be 39.0 ± 2.1 Ma.

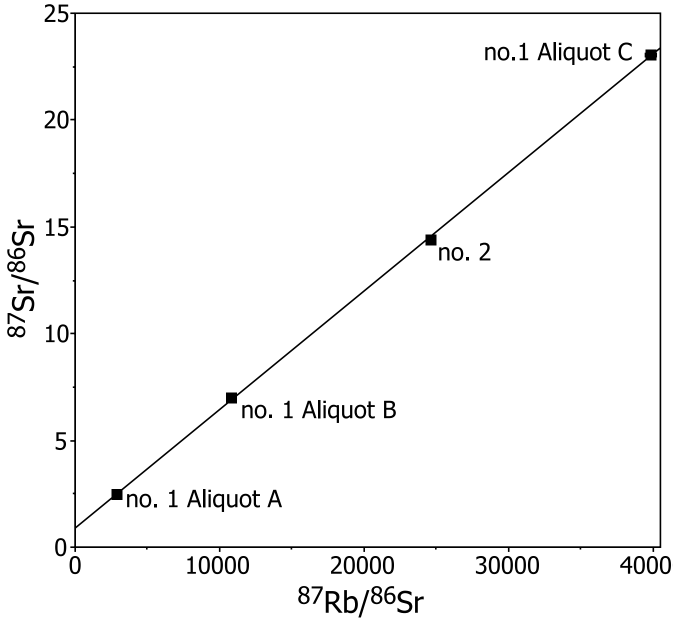

Figure 2. Rb-Sr isotopic diagram for analyses of galkhaite from Getchell Mine, Humboldt County, Nevada. Best-fit line through data indicates age of 39.0 ± 2.1 Ma for galkhaite crystallization. Isotopic data are in Table 2.

TABLE 2. Rb-Sr ISOTOPIC DATA FOR TWO GALKHAITE SAMPLES

Sample	^{87}Rb/^{86}Sr	(^{87}Sr/^{86}Sr) ± 2 σ
No. 1, aliquot A	2,927	2.4364 ± 0.0026
No. 1, aliquot B	10,787	7.0166 ± 0.0039
No. 1, aliquot C	39,866	23.0415 ± 0.0044
No. 2	24,604	14.3814 ± 0.0024

Note: Samples no. 1 and no. 2 are from the 4850 level, 18200 crosscut, Getchell mine, Nevada. Ratios are uncorrected for blank Sr contribution.

DISCUSSION

It is clear that galkhaite at Getchell crystallized during a gold-deposition event, because the galkhaite contains detectable gold, occurs in gold-mineralized ore zones, and is commonly encapsulated by gold-bearing silica. The data presented above fix the timing of gold mineralization at 39.0 ± 2.1 Ma. This date is compatible with the ca. 42 Ma dates of Groff et al. (1997) and Hall et al. (1997) for adularia at the nearby Twin Creeks deposit. However, there is some uncertainty regarding whether the event that produced the adularia is the same one that produced the majority of the Au (Groff et al., 1997; S.E. Kesler, 1999, personal commun.). Cline and Hofstra (2000) have documented in detail the paragenetic relationships at Getchell, and have demonstrated that the As-Sb event is late gold stage. The dating of galkhaite, which is part of this late As-Sb event at the

Getchell mine, provides the first direct date on a phase clearly related to gold mineralization. This is the first time that a direct date has been accomplished for a Carlin-type deposit. Other dating methods such as ^{40}Ar/^{39}Ar or fission track can only bracket mineralization, or date K-bearing minerals believed to form during mineralizing processes. Because of the difficulty of demonstrating contemporaneity of these minerals with gold, such dates may not be valid. Dating nontraditional and exotic minerals such as galkhaite with established techniques might provide the opportunity to date other Carlin-type deposits, as well as other deposit types where paragenetic relationships are clear.

ACKNOWLEDGMENTS

This research was supported by National Science Foundation grant EAR-9805384 to Arehart, and by funding to Tretbar from by the Getchell Gold Corporation and the Center for Research in Economic Geology, University of Nevada, Reno. We thank Marcus Johnston, Casey McManus, and Sarah Tretbar for their critical reviews.

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Manuscript received March 29, 2000
Revised manuscript received July 13, 2000
Manuscript accepted July 19, 2000