Fluid Pathways at the Turquoise Ridge Carlin-type Gold Deposit, Getchell District, Nevada

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Abstract. Fluid pathways at the Turquoise Ridge Carlin-type gold deposit are deduced from patterns of lithology, structure, hydrothermal alteration, gold grade, carbonate oxygen isotopes and trace elements. Auriferous fluids migrated up the NNW-striking Getchell fault and entered antithetic and NE-striking small-displacement faults in the hanging wall, which, along with a pre-ore dike, served as conduits to high-grade ore bodies located up-dip. Flow was mainly fracture-controlled; evidence for extensive pervasive fluid flow is lacking. The base of the largest ore zone coincides with the footwall of a reactive sedimentary carbonate breccia unit, the base of ferroan calcite-bearing rocks, and a gradient in the organic carbon content of the host rocks. Abundant late ore-stage realgar occurs along the west side of Turquoise Ridge and marks the collapse of the hydrothermal system by incursion of meteoric waters down and into the Getchell fault zone. The patterns of fluid flow agree with percolation theory, whereby at low strain, flow along the Getchell fault linked the source of fluids and metals with sites of discharge into reactive host rocks. Small strain changes likely occurred during the change from compressional to extensional tectonics in the Eocene in northern Nevada.

Keywords. Gold, Carlin, Nevada, fluid pathways, Getchell, permeability, isotopes, trace elements

1 Introduction

Carlin-type gold deposits of late Eocene age in Nevada account for about 6.5% of annual worldwide gold production. Despite their importance, several aspects of their origin remain enigmatic. Lack of agreement centers around the source, pathways, and depositional mechanisms of the auriferous hydrothermal fluids that formed the deposits. Results are presented from an ongoing research program on the Getchell district aimed at developing a geological and geochemical time-space framework. We are identifying pathways at the underground Turquoise Ridge deposit that allow us to study the chemical evolution of ore fluids as they travelled to sites of deposition, precipitated gold, and exited ore zones.

2 District Geology

As summarized by Chevillon et al. (2000), Carlin-type gold ore bodies in the Getchell district are hosted primarily by Cambrian-Ordovician carbonates and clastic rocks with interlayered basaltic rocks. The Cambrian-Ordovician rocks were complexly deformed prior to the deposition of Pennsylvanian-Permian carbonates, likely during the Antler orogeny. The Palaeozoic rocks were intruded by the Cretaceous Osgood stock and dikes of dacite porphyry. No intrusive rocks in the Getchell area have been dated as Tertiary. The primary ore-controlling structure in the district is the Getchell fault zone, which runs along the northeastern flank of the stock. It strikes NNW, dips 40-55°E, and has a long, complex history with evidence for normal, reverse, and strike-slip motion.

The Getchell district has produced approximately 4.5 Moz of gold from ore with an average grade of about 10 g/t Au. Ore was originally mined from open pits along the Getchell fault and underground in the footwall of the fault. Ore is now being mined from the underground Turquoise Ridge deposit in the hanging wall of the Getchell fault. At the end of 2008, proven and probable reserves were 9.6 million tonnes grading 17.2 g/t Au.

Mineralization is Eocene in age, based on a 39.0±2.1 Ma Rb-Sr age on galkhaite (Tretbar et al. 2000). Ore-stage mineralization consists of ore-stage Au- and trace-element-rich pyrite, and is accompanied by varying abundances of kaolinite, illite, and jasperoid quartz (Cail and Cline 2001). Textural relationships suggest this assemblage formed in response to fluid-rock reaction and replacement. Late-ore-stage minerals consist of drusy quartz, orpiment, fluorite, stibnite, realgar, and calcite (Cline 2001).

3 Geology of Turquoise Ridge

The geologic framework presented here is based on construction of detailed 1:600 scale underground cross-sections based mainly on closely spaced fans of underground core holes. The sections were then incorporated into a 3D GOCAD model. An EW underground cross-section through the core of the Turquoise Ridge deposit is shown in Figure 1.

The geology of the Turquoise Ridge deposit is complex. It is characterized by stratigraphy that lacks marker units and exhibits rapid facies changes and soft sediment deformation features. The lowermost unit is mostly carbonaceous mudstones and limestones with interlayers of calcarenite turbidites, which are overlain by a series of limestone debris flow breccias that pinch out to the south. Above this unit are slumped limestones and tuffaceous mudstones. An overlying pillowed basalt has a blunt southern edge that strikes west-northwest across the north end of Turquoise Ridge. Further up-section the rocks are predominantly tuffaceous mudstone with thin basalt flows and sills. The host rocks are complexly deformed, mainly into roughly N-trending, W-verging folds.

Dacite dikes cross-cut the Cambrian-Ordovician section. The most prominent dike cuts across the entire north end of Turquoise Ridge. The dike is 1 to 6 m thick and is sub-parallel to the Getchell fault, but has a shallower dip. Zircons from the dike have been dated by U-Pb at 115 Ma (K. Hickey, written commun. 2008). Continuity of the dike demonstrates Tertiary extension was characterized by low-displacement faults (<5 m).

4 Controls on Gold Mineralization and Alteration at Turquoise Ridge

Inspection of gold grades at a variety of scales utilizing gold grade thickness maps, block models of gold grade, the GOCAD district model, and detailed cross-sections indicate that controls on mineralization are complex intersections of: 1) NNW-striking high-angle fracture zones that are sub-parallel to the Getchell fault, 2) WNW-trending margin of the sedimentary breccia unit and basalt, 3) margins of NNE-trending folds, 4) NE-trending fracture zones, and 5) calcareous lithologies.

Figure 1 shows decalcification, argillization and silicification are confined to narrow zones that include: 1) the Getchell fault, 2) high-angle, antithetic fracture zones in the hanging wall of the Getchell fault, 3) the main dacite dike described above (dike conduit, Fig. 1), and 4) high-angle NNW- and NNE-trending fracture zones in the hanging wall of the dike (148 zone, Fig. 1). The largest zone of alteration is on the west side of the cross-section where the high-angle antithetic fracture zones intersect the dike (HGB and BBT zones, Fig. 1). Moderately to strongly altered rocks in Figure 1 typically contain grades of >0.34 g/t gold. The HGB zone, which constitutes the bulk of the ore, occurs above the antithetic fracture zones and straddles the dike in the sedimentary breccia unit, which occurs between underlying carbonaceous rocks (>0.5% org. C) and overlying, less carbonaceous rocks (<0.2% org. C). The HGB also occurs just above a transition from underlying calcite to ferroan calcite (rock and veins) that is interpreted to be a pre-ore feature.

Abundant realgar is more extensive on the west side of Figure 1. Contour maps of realgar thickness in drill holes show that realgar is abundant on the west side of the entire Turquoise Ridge deposit, along a zone parallel to the Getchell fault. Realgar was very abundant in the open pit ore along the Getchell fault and in the underground footwall ore.

5 Carbonate Isotopes and Trace Elements

Unaltered rocks are commonly within meters of ore zones, making exploration and development difficult. Oxygen and carbon isotopes in limestones and trace elements were determined to evaluate whether there was fluid flow and cryptic alteration outside the zones of visible alteration. Samples for analysis were collected along transects across visually altered zones (Fig. 1).

Cumulative distribution curves of the 126 analysed samples show a distinct break in $\delta^{18}O$ at 17.6‰, below which, most samples are visually altered. Values >17.6‰ are considered to be local background caused by Cretaceous thermal metamorphism, evidenced by recrystallizaton of limestone and formation of biotite in tuffaceous mudstones. Taylor and O'Neil's (1977) isotopic study of the skarn deposits in the Getchell district demonstrated marbles had $\delta^{18}O$ values between 16.6 and 20.7‰.

Though Figure 1 shows samples are locally depleted in $\delta^{18}O$ in and adjacent to altered zones, patterns are inconsistent. High $\delta^{18}O$ values are common in kernels of unaltered rock within and adjacent to HGB zone. The data indicate a low fluid flux around ore bodies and zones of visually altered rock.

However, trace elements in samples, from which calcite was analysed for isotopes, are commonly anomalous in visually unaltered rocks. Zones of ≥10 ppb Au form halos that are typically <10 m wide. All samples from the Getchell fault zone assayed >10 ppb, reflecting greater fluid flux. Mercury (>10 ppb) forms a very similar pattern to gold, but forms a wider halo (~10-20 m). Elevated arsenic (>100 ppm) commonly extends 20-30 m into the visually unaltered rock.

The results suggest fluid flow in the visually unaltered rocks surrounding ore and alteration zones was limited to narrow bleached fractures that are commonly present. We are further testing this hypothesis by doing isotope analyses along individual limestone beds adjacent to and progressively away from fractures. We will also utilize a portable XRF to test fracture surfaces for trace elements.

6 Interpretation of Fluid Pathways

Hydrothermal fluids are interpreted to have come up the Getchell fault and migrated up NNW-trending, steeply W-dipping fracture zones in the hanging wall. These appear to have fed the overlying HGB ore zone. On the eastern end of Turquoise Ridge, there appears to be a steeply dipping, NE-trending fracture zone that tapped fluids from the Getchell fault at depth (Deep East Feeder, Fig. 1). The upwelling fluids either punched through the dacite dike and continued flowing upward along steeply dipping fracture zones (148 zone, Fig. 1) or they travelled westward up-dip along the

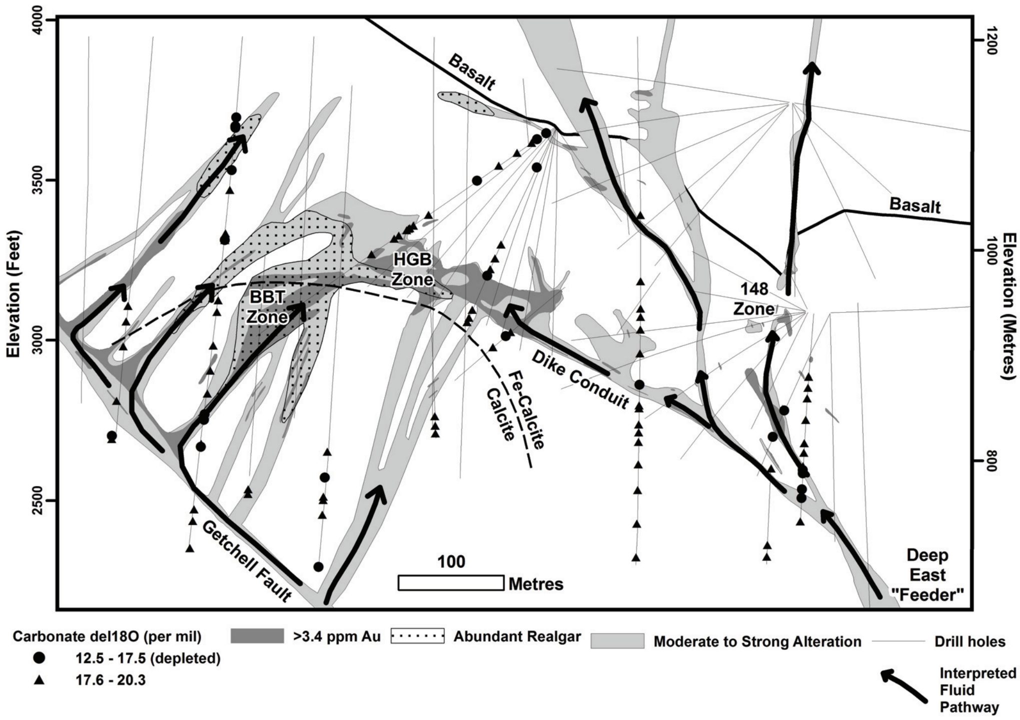

Figure 1. EW cross-section, looking north, through the core of the Turquoise Ridge deposit. The top of the section is ~0.5 km below the surface and the bottom is ~1 km below the surface.

margins of the dike and escaped upward along high-angle fracture zones. Fluid flow in the exhaust zones was passive and opportunistic and took advantage of local fractures and lithologic contacts. In most cases, fluid flow was discordant to stratigraphy.

The base of the large HGB ore zone coincides with the footwall of the sedimentary breccia unit, reflecting possibly greater reactivity and secondary permeability of that unit. Decalcification of ferroan calcite at the base of the HGB would have resulted in a source of iron for sulfidation and deposition of gold-bearing pyrite during water:rock interaction. Also, the gradient in the carbon content of the host rocks at the base of the HGB permits a redox control to gold deposition. We interpret the realgar to be the result of incursion of meteoric water down and into the Getchell fault zone during collapse of the hydrothermal system.

The flow paths proposed for Getchell are consistent with the model put forward by Cox et al. (2001) that explains why ore is typically hosted along second-order, low-displacement faults, rather than first-order structures like the Getchell fault. At low strain, a percolation threshold is reached when enough flow elements connect to form a backbone element (e.g., Getchell fault) that allows fluid flow across the entire width of the flow network and links the source of fluids and metals with the site of deposition and discharge. This situation maximizes fluid/rock interaction in downstream, dangling elements where fluid is discharged into surrounding fractured, reactive host rocks (e.g., the sedimentary breccia unit). Such small strain changes that result in percolation networks and tapping of fluid reservoirs likely occurred during the change from compressional to extensional tectonics in the Eocene in northern Nevada.

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References

Cail TL, Cline JS (2001) Alteration associated with gold deposition at the Getchell Carlin-type gold deposit, north-central Nevada. Economic Geology 96:1343-1359

Chevillon V, Berentsen E, Gingrich M, Howald W, Zbinden E (2000) Geologic overview of the Getchell gold mine geology. SEG Guidebook Series, 32: 195-205

Cline JS (2001) Timing of gold and arsenic sulfide mineral deposition at the Getchell Carlin-type gold deposit, north-central Nevada. Economic Geology 96:75-90

Cox SF, Knackstedt MA, Braun J (2001) Principles of structural control on permeability and fluid flow in hydrothermal systems. In: Richards JP, Tosdal RM (eds) Structural Controls on Ore Genesis, Reviews in Economic Geology, 14:1-24

Taylor BE, O'Neil JR (1977) Stable isotope studies of metasomatic Ca-Fe-Al-Si skarns and associated metamorphic and igneous rocks, Osgood Mountains, Nevada. Contributions to Mineralogy and Petrology 63:1-49

Tretbar D, Arehart GB, Christensen JN (2000) Dating gold deposition in a Carlin-type gold deposit using Rb/Sr methods on the mineral galkhaite. Geology, 28:947-950