Using Pyrite to Track Evolving Fluid Pathways and Chemistry in Carlin-type Deposits

Anthony A. Longo, Jean S. Cline
Geoscience Department, University of Nevada Las Vegas, 4505 Maryland Parkway, Las Vegas, NV USA 89154-4010

John L. Muntean
Nevada Bureau of Mines and Geology, University of Nevada Reno, Mailstop 178, Reno, NV, USA 89557-0088

Abstract. Submicron Au in Carlin-type deposits in northern Nevada, USA, occurs in trace-element-rich pyrite, and zoning of the trace element signatures varies across pyrite rims and vertically and laterally across these deposits. These patterns reveal the chemical evolution and flux of ore fluids along individual fluid pathways and further indicate the relative timing of permeable fluid pathways with respect to one another.

Ore pyrite chemistry along one east-west transect at Turquoise Ridge in the Getchell district demonstrates fluid ingress from the east dipping Getchell fault at depth into the hanging wall, but also reveals that ore deposition migrated in an east to west direction toward the Getchell fault over time. This east to west evolution of permeability indicates transient opening and sealing of ore fluid pathways during mineralization and may have been a response to changing strain domains related to movement along the master Getchell fault during incipient extension and ore deposition.

Keywords: Gold, Carlin-type deposits, pyrite, fluid pathways, trace element chemistry, Getchell, permeability

1 Introduction

Carlin-type gold deposits in northern Nevada, USA, one of the world's major gold producing regions, occur in trends or districts of multiple deposits hosted in favourable silty carbonate rocks. Deposit morphologies vary within districts and exhibit forms ranging from stratiform to tabular (Cline et al. 2005), reflecting a combination of host rock and structure geometries. Deciphering ore fluid pathways is difficult because of variable deposit morphologies and the absence of significant traceable alteration and mineralization at depth or laterally. This lack of visible pathways makes it challenging to explore for additional ore zones in and near deposits. It also complicates efforts to formulate genetic models leading to a range of models from lateral secretion of meteoric ore fluids to vertical ascent of deep metamorphic/magmatic fluids via crustal faults.

Au-bearing pyrites carry primary mineralization in these deposits and have distinctive and variable trace metal signatures interpreted to reflect evolved ore fluid chemistry in time and space. Some pyrite rims are chemically zoned, revealing relative timing of ore *pyrite* chemistries, and therefore ore *fluid* chemistries. This study tests the hypothesis that ore pyrite chemistries can be used to decipher the evolution of ore fluids and fluid pathways. We report on ore pyrite chemistries, which we use as fingerprints to identify the evolution of fluids and pathways in time and space. Improving our understanding of fluid pathways facilitates deposit- and district-scale exploration and contributes to deposit fluid-flux models.

2 Turquoise Ridge Deposit Geology

The Turquoise Ridge deposit, Getchell district northern Nevada, is located in the hanging wall of the Getchell fault (NNW strike, ~40-55°E dip), the primary ore-controlling structure in the district (Hotz and Wilden 1964). Information from hundreds of closely spaced underground diamond drill holes and surface holes was used to prepare detailed 1:600 scale underground, east-west cross sections that illustrate lithologies, alteration, structure, and contoured Au grades. The cross sections reveal generally N-dipping stratigraphic units cut by the Getchell fault and subsidiary high-angle faults in the hanging wall. Sections reveal that the ~40 Ma mineralization (Tretbar et al. 2000) is strongly controlled by high-angle hanging wall faults, margins of Cretaceous dacite porphyry dikes sub-parallel to the Getchell fault, a sedimentary breccia, and favourable reactive calcareous host rocks. Au grades >3.4 ppm correlate strongly with moderate to strong decalcification and argillization. Cross-section 60300N (Fig. 1) was selected for this study as it intersects three important ore zones and is the location of dense underground drilling. Geologic relationships, particularly patterns of alteration and gold grade, suggest that 1) ore fluids moved upwards along the Getchell fault and permeable zones adjacent to the Getchell parallel dacite dike (Fig. 1), 2) fluids also likely accessed high-angle structures and locally adjacent favourable units where they reacted with host rocks and deposited trace-element-rich pyrite, and 3) fluids exited ore zones by continuing up high-angle structures that acted as fluid exhaust zones.

We interpreted fluid pathways based on these patterns and collected drill core samples below, within, and above ore zones. Deep samples were collected to test the Getchell fault as the master ore fluid pathway. On the east side of section 60300N, 148 Zone ore fluids (Fig. 1) were interpreted to have flowed along and perhaps punched through a dacite dike and either continued flowing up high angle fracture zones to feed the 148 Zone, or continued flowing upward and westward along the margins of the dike, feeding the High Grade Bullion (HGB) ore zone. On the west side of the section ore fluids were interpreted to have risen along the Getchell fault and migrated into high-angle hanging wall fracture zones forming the Better Be There (BBT) zone and possibly also contributing to HGB ore. Above the deposits ore fluids appear to have moved upward through fracture/fault zones and along contacts.

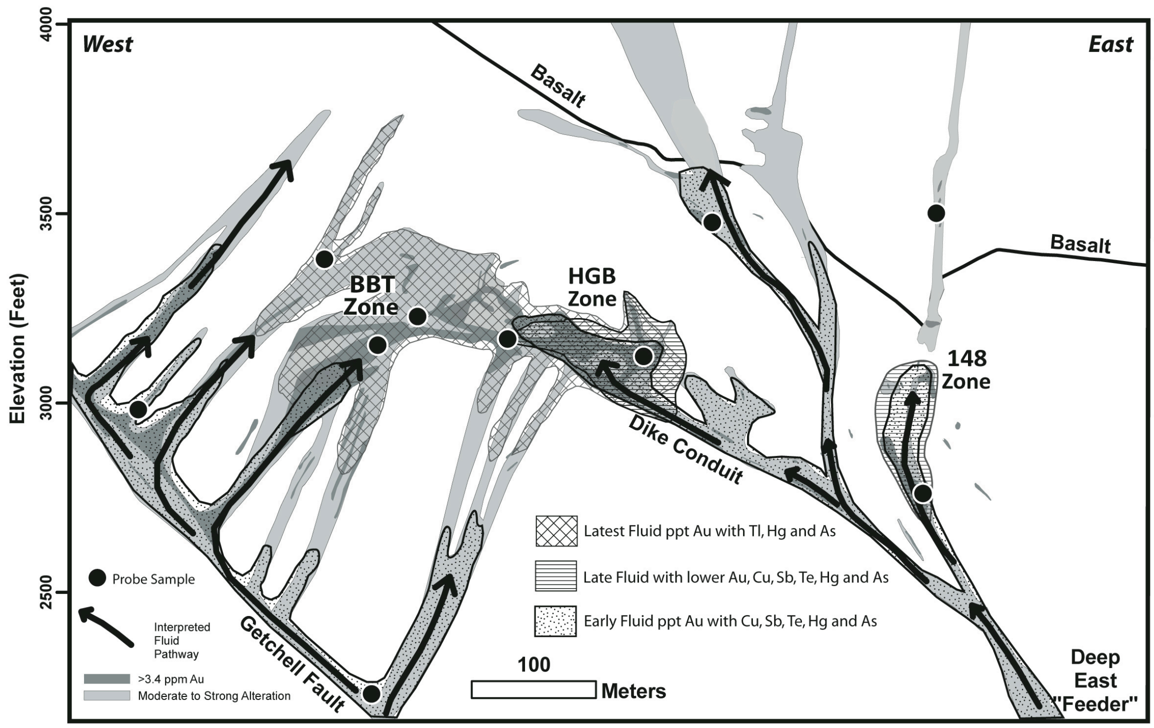

Figure 1. East-west cross-section 60300N looking north, illustrating relationships between, alteration, mineralization and structure. Note the close correlation between alteration and Au grades >3.4 ppm. Arrows indicate interpreted ore fluid pathways based on pyrite chemistry analyses (black circles mark analysed sample locations).

3 Ore Pyrite Morphology and Chemistry

Au-bearing pyrite in a Carlin-type deposit was first examined and recognized by Joralemon (1951) at the Getchell deposit. Subsequent studies identified two types of ore-stage pyrite: tiny (<5 µm) spheroidal pyrite with ragged “fuzzy” rims, and core-rim (CR) pyrite with 1-35 µm trace-element-rich rims on earlier formed pyrite cores (Weaver and Cline 1999; Cline and Hofstra 2000; Cline 2001; Cline et al. 2003; Longo et al. 2008). These studies demonstrated that pyrite chemistry varied and Cline et al. (2003) and Longo et al. (2008) concluded that, given relatively constant ore fluid temperatures of ~180-220°C (Cline and Hofstra 2000), these variations reflected ore fluid chemical evolution in time and space.

We analysed pyrites for 22 elements including Au using a JEOL electron probe microanalyzer JXA-8900 with a 1µm beam diameter at UNLV, Las Vegas, NV, USA. Operating conditions included an accelerating voltage of 20kV and a beam current of 5nA. Standards include pure metal CM1 standards for Ag, Bi, Sb, Se, Sn, W; CM2 metal complexes for Hg (HgS), Tl (TlBr), Te (PbTe); pure metal Geller standards for Au, Co, Mo, Ni; MAC standards for As (As), Cu (chalcopyrite), S and Fe (pyrite), Pb (galena), Zn (sphalerite) Ca and Si (wollastonite); and an SMH standard for Ti (ilmenite).

The most important ore elements (approximate detection limits in parentheses) include Au (~90 ppm), As (~310 ppm), Hg (~95 ppm), Tl (~400 ppm), Sb (~110 ppm), Te (~130 ppm) and Cu (~210 ppm). Analyses reveal distinctive pyrite chemistry and zoning within each of the three ore zones and in low grade ore along the Getchell fault.

CR pyrites from the 148 Zone (Fig. 1; whole rock samples, 34.0-82.2 g/t Au) display rims with two zones: an inner rim of Au >1000 ppm, As, Cu and Te and an outer rim with lower concentrations of the same elements. Hg and Sb are present, but low; Tl is absent.

CR pyrites from the HGB zone (whole rock samples, 2.8-161.0 g/t Au) (Fig. 1) display up to three zones: an inner high Au (>1500 ppm) zone and a middle lower Au zone that correlate, respectively, with the inner and outer zones in 148 pyrites. A third outer zone contains high Au (>1500 ppm) with elevated Tl, Hg, and As and decreased Cu and Te (Fig. 1). Lower grade sample pyrites from HGB display a single rim with elevated As and Hg, and lower Au, Sb and Tl similar to the outermost zone in HGB CR pyrites. Fuzzy pyrites in HGB contain high Au (>1000-3500 ppm) associated with highest As, Hg, and Tl, also correlative with outer rims in HGB CR pyrites.

CR pyrites from the lower grade BBT zone (whole rock samples, 1.7-11.3 g/t Au) (Fig. 1) display a single unzoned rim that contains elevated Au, As, Hg, Tl, similar to outer rims at HGB. BBT fuzzy pyrites have highest Hg and Tl with highest Au, and highest Sb with elevated Au, also correlating to outer rims at HGB.

Single stage unzoned rims from CR pyrites in low grade zones along the Getchell fault display elevated Au (>500 ppm), with high concentrations of As, Cu, Te, Sb and Hg; Tl is absent. This chemistry is similar to the inner rims at HGB and the 148 zone.

4 Ore Zone Grades and Fluid Pathways

Collectively these patterns are interpreted to indicate that early ore fluids precipitated elevated Au, Cu, Sb, Te, Hg, and As in inner pyrite rims at 148 Zone and HGB, and also in lower concentrations in pyrites along the Getchell fault; later, ore fluids precipitated lower concentrations of the same elements forming outer rims at 148 Zone and middle rims at HGB. Subsequently, an ore fluid with a modified chemistry precipitated elevated Au, As, Hg, and Tl in outer rims at HGB, in single, unzoned rims at BBT, and in fuzzy pyrites at HGB and BBT.

These patterns suggest that early ore fluids travelled up the Getchell fault and accessed high angle fault/ fracture zones in the hanging wall on the west side of section 60300N. On the east side of the section early fluids also ascended into the hanging wall and travelled upward along high-angle structures into the 148 Zone, and upward and westward and contributed to ore in HGB (Fig. 1). Pyrite chemistry suggests that these early ore fluids did not access the BBT zone. Over time, the chemistry of the fluid accessing 148 and HGB evolved or conditions changed such that pyrite rims became more “dilute” in the same elements. Eventually, access of this ore fluid to the 148 Zone was restricted or terminated, perhaps as the fault zone sealed or fluid flux ceased. Subsequently, chemically distinct ore fluids accessed the BBT and HGB zones, depositing high-grade ore at HGB and lower grade ore at BBT. The pathway by which this fluid reached these ore zones is either outside of section 60300N or remains unidentified within this section. The apparent westward migration of permeability from the Deep East Feeder and 148 Zone to the HGB and BBT may reflect movement on the Getchell fault and migrating strain domains during incipient extension and mineralization ~40 Ma. Over time, permeability to the HGB and BBT either decreased and ore fluid flux was reduced or eliminated, or ore fluids were no longer fed upward along the Getchell fault into this region.

The abundance of late ore-stage realgar in the vicinity of the BBT indicates that after deposition of the last visible ore-stage rim there was an influx of cool meteoric waters, collapse of the hydrothermal system, and precipitation of late ore-stage realgar in response to system cooling (Hofstra et al. 1991). This event signals termination of Au and pyrite deposition in this part of the deposit. It is currently unclear if ore deposition terminated in response to high level fracturing and incursion of meteoric fluids, or hydrothermal collapse owing to decreased ore fluid flux.

The presence of high-grade ore appears to be related to pyrite rim zoning which correlates to ore grade in the three ore zones. Pyrites in the 148 Zone with high-gold inner rims and low-Au outer rims contribute to high-grade ore locally reaching 30-60 g/t. Three-stage rimmed pyrites in HGB contribute to grades exceeding 150 g/t and form some of the highest grade ore in the deposit. Pyrites along the Getchell fault and in the BBT have single zone rims with high Au and also Au-rich fuzzy pyrite, but contribute to lower Au grades overall, generally <15 g/t. These patterns suggest that high grades result, at least in part, from the presence of multiple rims of ore pyrite, that may reflect lengthier periods of ore fluid flux and ore deposition, perhaps related to longer periods of transient permeability.

Acknowledgements

We thank Karl Marlowe and Barrick Gold for support through access to the deposit, drill core, and geologic information. We also greatly appreciate past generous support from Getchell Gold, Placer Dome Exploration, and the many geologists who have contributed to our understanding of these deposits over many years. Funding for this project was provided by the USGS MERIT program (06HQGR0179) to Jean Cline and the National Science Foundation to Jean Cline (0635658) and John Muntean (0635657). Reviews by Jeff Mauk (University of Auckland) and Nick Mortimer (GNS Science) contributed to this submission.

References

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

Cline JS, Hofstra AH (2000) Ore fluid evolution at the Getchell Carlin-type gold deposit, Nevada, USA. European Journal of Mineralogy 12:195-212

Cline JS, Stuart FM, Hofstra AH, Premo W, Riciputi L, Tosdal RM, Tretbar DR (2003) Multiple sources of ore-fluid components at the Getchell Carlin-type gold deposit, Nevada, USA. In Eliopoulos D et al. (eds) Society of Geology Applied to Mineral Deposits 2:965-968

Cline JS, Hofstra AH, Muntean JL, Tosdal RM, Hickey KA (2005) Carlin-type gold deposits in Nevada: Critical geologic characteristics and viable Models. In Hedenquist JW, Thompson JFH, Goldfarb RJ, Richards JP (eds) 100th Anniversary Volume: Society of Economic Geologists: Littleton, CO, p. 451-484

Hofstra AH, Leventhal JS, Northrop HR, Landis GP, Rye RO, Birak DJ, Dahl AR (1991) Genesis of sediment-hosted disseminated gold deposits by fluid mixing and sulphidisation: Chemical-reaction-path modeling of ore-depositional processes documented in the Jerritt Canyon district, Nevada. Geology 19:36-40

Hotz PE, Willden R (1964) Geology and mineral deposits of the Osgood Mountains quadrangle, Humboldt County, Nevada. US Geological Survey Professional Paper 431, 128 p

Joralemon P (1951) The occurrence of gold at the Getchell mine, Nevada. Economic Geology 46:276-310

Longo AA, Cline JS, Muntean J (2008) Compositional variations in Au-bearing pyrite from a Carlin-type Au deposit, Getchell, Nevada: Geological Society of America Abstracts with Programs 40:51

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

Weaver KD, Cline JS (1999) Geochemistry of ore-stage and non-ore pyrite and marcasite from the Getchell Carlin-type gold deposit, Nevada: Geological Society of America, Program with Abstracts 31:A-106