The genesis of Carlin-type gold deposits – current models and future research

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Carlin-type gold deposits, first discovered in northern Nevada in the early 1960s, have enormous gold endowments and have made the Carlin trend one of three gold districts in the world to produce more than 50 million ounces of gold. Forty years of mining and numerous studies have provided a detailed geologic picture of deposits, yet a comprehensive and widely accepted genetic model remains elusive. Currently considered models relate deposits to 1) epizonal plutons that contributed heat and possibly fluids and metals, 2) meteoric fluid circulation resulting from crustal extension and/or widespread magmatism, and 3) metamorphic fluids, possibly with a magmatic contribution, from deep crustal levels. Difficulties in unravelling deposit genesis are directly related to complications in studying the deposits. Minerals that are part of the Carlin event are fine-grained, volumetrically minor, and common (pyrite, quartz, kaolinite, illite). The regions where the deposits are located have experienced several hydrothermal events, and these common minerals precipitated repeatedly in response to many different processes. As a result, bulk analyses of samples simply produce a signal that is a mixture of several events. Microanalyses can produce a signal from a single geologic event, but require careful petrography to distinguish "Carlin" crystals from pre- or post-Carlin crystals.

A number of geochronological studies during the past 5 to 10 years have led to a consensus that the deposits formed during the late Eocene, permitting us to confidently relate the deposits to their tectonic setting. We now recognize that continental rifting followed by compressional orogenies provided a pre-mineral architecture of steeply dipping faults that acted as fluid conduits, high-level shallowly dipping "traps" or aquitards that inhibited fluid ascent to the surface, and reactive calcareous host rocks. Miogeoclinal sequences that formed following active rifting of the continental margin contain reactive silty calcareous rocks, which are the primary host rocks in almost every Carlin-type deposit including all of the >5 million ounce deposits. The main host unit for Carlin-type deposits is the lower plate to the Roberts Mountain thrust. Most giant deposits lie within 100 meters of the thrust or its projection. The thrust is important as it formed a regional aquitard by placing non-reactive, fine-grained siliciclastic rocks with less inherent rock permeability above favorable carbonate stratigraphy and it forced fluids laterally away from conduits and into reactive rock types. NNW and WNW-striking basement and Paleozoic normal faults were inverted during post-rifting compressional events, resulting in structural culminations (anticlines and domes) that in the Eocene served as depositional sites for auriferous fluids. These culminations are now exposed as erosional windows through the siliciclastic rocks of the Antler allochthon.

Extension during the Eocene in the Great Basin was broadly oriented northwesterly to westerly (280° to 330°). The underlying rifted plate margin and northwesterly oriented Paleozoic faults were subparallel to the extension direction and were reactivated as strike-slip or oblique-slip faults. Northeasterly oriented pre-Jurassic fault fabrics were favourably oriented for extension. Mineralization is associated with the heterogeneous shear and tensional reactivation of these older, variably oriented, structures. Fluid flow and mineral deposition appear to have been fairly passive as there is little evidence for overpressured hydrothermal fluids, complicated multistage vein dilatancy, or significant syn-mineralization slip. Geologic reconstructions and fluid inclusions indicate that deposits formed within a few kilometers of the surface.

Ore fluids were moderate temperature (~180–240°C), low salinity (~ 2–3 wt % NaCl equivalent), CO_2-rich (< 4 mole %), and CH_4-poor (<0.4 mole %) with sufficient H_2S (10^{-1} to 10^{-2} m) to transport gold. The singular occurrence of "invisible" gold in pyrite in unoxidized ore indicates that ore fluids were undersaturated in gold until fluids reacted with wallrocks. Fluid-rock reaction liberated reactive Fe in the wallrock, which reacted with sulphur in the fluid to form pyrite. This reaction reduced the aH_2S in the fluid, destabilized the gold-bisulphide complex, and gold and other bisulphide complexed metals were captured as submicrometer structurally bound or native particles in the pyrite. Ore fluids additionally decarbonatized, argillized, and locally silicified wall rocks.

Isotopic studies constrain sources of ore fluid components, but do not provide unequivocal sources or clearly indicate a preferred genetic model. O and H isotopes of minerals and fluid inclusions at the Getchell deposit consistently indicate that ore fluids had a deep magmatic or metamorphic source. However, most similar studies of deposits in the northern Carlin trend and at Jerritt Canyon have identified a meteoric fluid. Sulphur isotopes in ore pyrite from all districts can be derived from a sedimentary sulphur source. However, sulphur in ore-stage pyrite at Getchell exhibit values near 0 per mil, consistent with a magmatic source. Two recent studies at the 30 million ounce Betze-Post deposit in the northern Carlin trend are also consistent with a magmatic sulphur source; however, other studies at this deposit identified higher sulphur isotopic ratios that are not consistent with a traditional magmatic sulphur source. He isotopic studies have been conducted only at the Getchell deposit where inclusion fluids in late-ore stage galkhaite, orpiment, and fluorite contain He with an unequivocal but highly diluted mantle signature.

A compilation of data from all trends and districts provides compelling similarities and requires that all Carlin-type deposits formed in response to similar geologic processes. We propose a deep fluid model in which primitive ore-related fluids were generated in response to removal of the Farallon slab, which promoted deep crustal melting, prograde metamorphism, and devolatilization. Primitive fluids travelled upward through the crust, scavenging ore fluid components along the fluid pathway, and were diluted by deeply circulating meteoric water in the upper crust prior to reacting with wallrocks and depositing gold.