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Early Ore Deposit Observations and Advances by Waldemar Lindgren, A Rock-solid Foundation for Our Society

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During the 1990s and early 2000s, when Carlin researchers were trying to understand how Carlin deposits formed, difficulties, particularly the fine-grained nature of the mineralization, made ore characterization challenging. Carlin-type ores are distinct from other ores because they form replacement bodies, contain primary ionic gold in generally microscopic arsenian pyrite crystals, and exhibit alteration that is subtle but dominated by decarbonatization of silty calcareous rocks.

Ore mineralogy, textures, fluid inclusion studies, and numerical models indicate that gold did not precipitate in response to boiling or fluid cooling, but instead gold ions were captured by precipitating arsenian pyrite that formed rims on older pyrite crystals. Although a few studies determined pressure and temperature conditions during ore formation and sources of ore-fluid components, these studies did not converge on a genetic model and, instead, led to a proliferation of models that could be sorted into three classifications: (1) epizonal plutons contributed heat and possibly fluids and metals (Sillitoe and Bonham, 1990; Henry and Boden, 1998; Henry and Ressel, 2000); (2) meteoric fluid circulation resulting from crustal extension scavenged and precipitated metals with or without heat from widespread magmatism (Ilchik and Barton, 1997; Emsbo et al., 2003); and (3) metamorphic fluids from deep or mid-crustal levels, possibly with magmatism, transported and precipitated metals (Seedorff, 1991; Hofstra and Cline, 2000).

The difficulties in sorting out the genesis of Carlin-type deposits were related to the complex geologic history of northern Nevada and deposit features. Main ore-stage minerals (quartz, pyrite, illite, and dickite) are fine grained, typically microscopic, and volumetrically minor. Additionally, northern Nevada has undergone multiple diagenetic and hydrothermal events that also produced many of these same minerals, and these events were overprinted by or superimposed on the main-ore stage. Further complications include supergene alteration that oxidized some orebodies, contributing to misinterpretations about deposit genesis during the early years of mining. Bulk analyses of mineralized samples simply produced a mixture of several events. Analysis of mineral separates and microanalysis of pyrite, quartz, and fluid inclusions produced results related to the main-stage minerals; however, such analyses required time-intensive petrography to unravel mineral parageneses and to distinguish gold-related pyrite, quartz, and clay minerals from similar pre- or post-ore minerals. Perseverance and the continued study of newly discovered deposits eventually led to the recognition that these deposits formed at temperatures around 220°-240°C and that the deposits are genetically related to magmatism.

In hindsight, a read of early writings by Waldemar Lindgren dating to 1907, provide a clear origin for these deposits. In Lindgren's textbook *Mineral Deposits* he provides drawings of photomicrographs of jasperoid alteration identical to that typical of Carlin deposits. He further includes in this text his Classification of Mineral Deposits, first presented in 1911. We now know that Carlin-type deposits clearly fit the category of deposits with an "origin dependent on the eruption of igneous rocks……by hot ascending waters of uncertain origin, but charged with igneous emanations" at intermediate depths and temperatures of 200°-300°C. Lindgren called these deposits "mesothermal" deposits.