Carlin-Style Sediment Hosted Gold Deposits

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Introduction

Disseminated gold deposits have been known as an exploration target since the early 1960s when the Carlin deposit was discovered in the Great Basin, northeastern Nevada. Gold deposits of this style are characteristically very fine-grained. They were considered to be too low to be mined economically. A low gold price and lack of processing technology to recover fine-grained gold from low-grade materials made this style of gold deposit unattractive.

Development of processing technology for recovery of micron-sized gold and low to high bulk grade of the ore body has created an important exploration opportunity in the global gold search. Because of the ore body shape and metal distribution, many deposits of this style are amenable to open pit mining. These are the reasons why the average cash costs of most of sediment-hosted deposits are very competitive, which makes them an attractive target.

A brief description in the following sections is mainly referred to some Carlin-style gold deposits in the Great Basin, Nevada, in which many researches have been done. In fact, it is the only Carlin belt, which is well known as one of the largest gold provinces and relatively well studied. Other less developed or under-explored Carlin trends may include South China Carlin trend in the Yunan Province and North Vietnam Carlin trend in the Caobang-Thai Nguyen-Lang Son Provinces, Vietnam.

Economic Geology Aspect

World gold production is mostly from primary epigenetic gold deposits and neglectable amount from secondary placer deposits. Several deposit types have been noticed as principal sources of gold production. They include porphyry-type gold-copper deposits, epithermal deposits both low and high sulfidation styles, mezothermal gold deposit, contact metasomatic-skarn gold-copper deposit, volcanogenic massive sulphide-Kuroko type deposit, Witwatersrands-type gold deposit, and sediment-hosted gold deposit.

Excluding porphyry copper-gold deposits (for which gold is by product), a review of the world's largest gold deposits shows that sediment-hosted gold deposit and Witwatersrand-type are ranked as the top two gold contributors for the world gold production, followed by mesothermal greenstone belt and epithermal types. Of the world's top 41 gold deposits, 53% are sediment-hosted, accounting for a 13,716.95t or 441 million ounces (Moz) gold resource (Pawlitschek, 1998, pers. com.). There are several gold mineralization styles, which can be broadly categorized as sediment-hosted deposits. Apart from Carlin-style there are other styles of sediment-hosted deposits such as Muruntau style (e.g., Muruntau and Bendigo) and banded – iron formation style (e.g., Homestake, Montana Hill 50, Mt Magnet, Western Australia).

A number of Carlin-type deposits in the Great Basin, which are considered as sediment-hosted type, can be categorized into mega and major deposits by the Sillitoe 1989's classification containing >400 and 100-400 metric tons gold respectively. Included in the megadeposits are Betze-Post (923.7 t), Gold Quarry (429.2t) and Twin Creeks (~400t). Some major deposits are Pipeline (283t), Meikle (177.3t), Carlin (176.4t), Lone Tree (164t) and Jerritt Canyon (158.6t). The Great Basin overall has recorded some major gold discoveries with a total of 10,000 t or 321.5 Moz (Thorman, 1995) constituting one of the world's largest gold provinces. It hosts several gold trends/districts e.g. Carlin, Battle Mountain, Eureka, Getchell, and Jerritt Canyon. Twenty-one economic deposits have been discovered in the Carlin trend since the early 1960s.

Average cash costs of most of sediment-hosted deposits are more competitive which fall well below US$200/ounce than other types of gold deposits. Mine operations of the Witwatersrand type commonly require high cash operating costs around US$300/ounce or more. Relatively low cash operating costs for sediment-hosted deposits would insulate the mines from the effects of fluctuating gold prices and make them an attractive exploration target.

Tectonic-Geologic Environments of Carlin-style Mineralization

The Carlin-type deposits of the Great Basin have formed by interactions between the hydrothermal system, structures and host lithologies. Some major geologic points, gathered from the regional

geologic and tectonic setting, that have contributed to the genesis of these deposit include:

- A geologically long-active zone of crustal weakness marked by crustal thinning and faulting;
- A regional tectonic environment of crustal thinning with sustained heat flow;
- Long lived, deep seated structures penetrating anomalously thin crust;
- Regional extensional tectonics;
- Multiple episodes of hydrotermal and intrusive activity;
- Reactive and highly permeable carbonate and/or carbonaceous host rock.

Tectonic-geologic environments favorable for the formation of gold deposit involve large to small scales from regional, district to deposit scales. District scale geologic controls are indicated by linear trends of the deposits and a deposit scale determines the geometry and pattern of orebodies and small intrusives. District scale factors controlling the formation, size and quality of individual orebodies depend largely upon the local lithostructural characteristics, which provide permeability, cap-trap systems, feeder structures and favorable rock compositions (Figure 1).

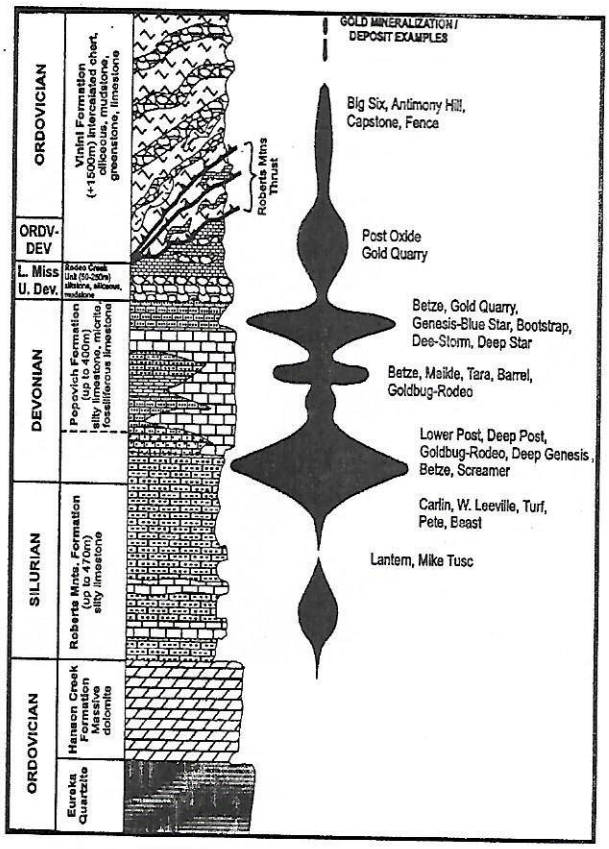


Fig 1: Lithostrcutural controls of Carlin type gold deposits (Teal and Jackson, 1997)

Significant Features and Signatures of Carlin-style Gold Deposit

Major Structural Control

The linearity of the gold and copper trends and concentration of igneous rocks along them suggest that deep-penetrating regional structures controlled the emplacement of magmas generated in the lower part of the crust or upper mantle. Major fault zones play a significant role in providing feeders for accessing magmas and hydrothermal fluids and in creating traps for depositing ores (Figure 2). Repeated movement on these faults has produced zones of weakness, which favored emplacement of magmas and hydrothermal activity.

Host Rock

The most common type of host lithology is thinly bedded, silty dolomite and limestone. The thinly bedded laminated limestone and dolomitic siltstone of the Roberts Mountain and Popovich Formations are host to major deposits as Carlin, Betze-Post and Gold Quarry (Figure 1).

Lithologic and unconformity contacts are also locally important cap forming low-angle structures as in cases of Gold Quarry, Twin Creeks, Getchell and Post Oxide. In the Vista pit at Twin Creek, gold mineralization extends laterally along the base of massive limestone of the Etchart Formation just above the contact with non-reactive basalt of the Leviathan allochton. Contrast between permeable and impermeable cap rocks is critical (Figure 2).

Non reactive and non-porous rock such as densely welded tuffs, flows, intrusions, quartzites, hornfels, siltstones and argillites may also host gold mineralization, provided there was enough structurally or hydrothermally-induced permeability. In those cases the ore bodies are tabular, veinlike, or irregular, and are confined to the open spaces created by fracturing.

High-angle Structures

High-angle faults are critical features in the formation of the Carlin ore bodies because they provide the feeder conduits for the gold-bearing fluids. They may be either normal or reverse. They contribute greatly to mineralized environments by means of one or more of the following:

- Serving as primary and secondary fluid conduits;
- Enhancing structural permeability;
- Allowing access for hydrothermal permeability-producing fluids to receptive host rocks and structures;

- Juxtaposing lithologies of contrasting permeability that may focus later hydrothermal fluids; and
- Providing access to intrusions, which may provide fluids and/or heat to the hydrothermal system or may act as fracture-controlled conduits.

Low-angle Structures

Low-angle structures in hydrothermal gold deposit are represented by thrust faults and imbricated thrust zones, and by detachment faults, which are related to compression and extensional tectonism, respectively. Thrust faults and/or low angle faults serve as important ore controls in some deposits. Tectonic brecciation and brittle fracturing result in zones of increased ground preparation and permeability favorable for gold deposition.

Domes and Anticlines

Antiformal structures at both regional and local scales, are also important ore controls in providing sites of fluids movement and deposition within the hydrothermal environment e.g. Bluestar-Genesis, Twin Creeks and Betze-Post. Fold hinge zones and axial plane cleavage provide increased permeability and allow reaction between the sedimentary rocks and hydrothermal fluids. Hence highly fractured zones at fold axes provide ideal structurally permeable sites for gold deposition. When these zones develop in carbonate rocks and allow for the introduction of hydrothermal permeability-generating fluids, and are in turn capped by the impermeable rocks, they become the most effective localizing mechanism observed in the Great Basin.

Hydrothermal Alteration

Pervasiveness and intensity of hydrothermal alteration varies both within and among deposits, depending on the magnitude of the system, nature of host rock (composition, texture, and permeability-porosity), density of structural conduits, and pre-mineralization effects of thermal metamorphic events.

Hydrothermal alteration features at the Carlin deposits as summarized by Christensen (1993) are mainly characterized as the following processes/alteration steps and simplified in Figure 2.

- Decarbonation/dissolution of carbonate (calcite removal);
- Dolomitization (the outermost alteration halo)
- Argilization of primary silicate minerals (mostly sericitization);
- Silicification;
- Gold-enriched sulfidation of reactive iron in host rock (formation of gold-bearing sulphides)

Silicification is more intense where spatially associated with gold/high grade gold (Figure 2). Realgar (As2S2), orpiment (As2S3), stibnite (Sb2S3) and Cinnabar (HgS) are commonly associated with ores.

Hydrothermal permeability (such as decarbonation, sanding and/or collapse brecciation) developed in carbonate sedimentary sequences, and primary porosity of bedded sedimentary and volcanic rocks, produce permeable horizons that may be mineralized by later hydrotermal fluids. In this case, mineralization extends laterally away from the feeder structures (usually high containing grade) into these permeable units (Figure 2).

Gold Nature and Fluid Chemistry

Carlin-type gold mineralization is characterized by the disseminated mode of occurrence of micron to sub micron-sized gold (50-200A) in calcareous sediments. Gold particles are found in the crystal lattices and zoned rims of pyrite and arsenical pyrite (Hausen and Kerr, 1968; Radtke, 1985; Bakken, 1990; Sha, 1992; Teal and Jackson, 1997).

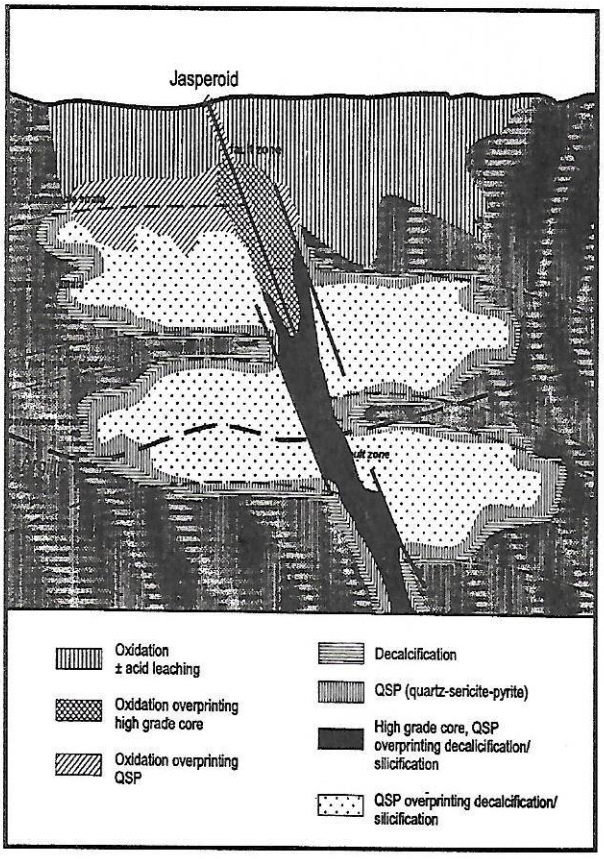


Fig 2: Simplified model of Carlin type gold deposit (Maryono, 1998)

A high Au:Ag ratio is commonly observed in most deposits. The ratio is within the range 10:1 to 20:1; therefore no economic recovery of silver has been recorded. Minor secondary gold enrichment in the oxidized zone approximately 100m below the present surface has been recorded and classified as oxidized ore. The other five types, which are primary unoxidized ores, are normal, siliceous, carbonaceous, pyritic and arsenical ores.

Characteristic trace elements associated with the Carlin-type gold mineralization differ between deposits. The gold in this deposit was probably transported as a bisulphide complex (Kuehn, 1989; Hofstra et al., 1991; Ilchik and Barton, 1997). Gold bearing fluids are interpreted to be highly evolved, low salinity (1-7%NaCl equiv.) and enriched in both H2S and CO2.

Gold transport was favored by low-chlorinity, intermediate oxidation state and slightly acid fluids. Enrichment of H2S concentration in the ore fluid results in sulfidation of reactive iron in the host rock causing precipitation of gold bearing pyrite. Due to high CO2 content, a depth of formation for Carlin deposits has been estimated to be on the order of 4.4 K2 km within a temperature range of 1800 to 2450 C (Kuehn, 1989; Ilchik and Barton, 1997). Depositional mechanism of gold is interpreted to be as results of fluid mixing, wall rock reaction, sulfidation and cooling.

Comparation With Epithermal Gold Deposits

Carlin-style sediment-hosted gold deposits and epithermal gold deposits share few similarities but on the other hand they display some substantial differences that make them separated. From Table 1 below, it's apparent that Carlin-type and epithermal gold are different (Maryono, 1998). The differences are displayed both at the regional scale features, which define their tectonic-geological environments, and the deposit scales, which are derived from district and deposit characteristics.

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Reference

Bakken, B.M., 1990, Gold mineralization, wall rock alteration, and geochemical evolution of the hydrothermal system in the main ore body, Carlin Mine, Nevada, in: Geology and Ore deposits of the Great Basin, Reno/Sparks, Nevada, Program with abstracts, p. 54-55.

Christensen, O., 1993, Carlin Trend Geologic Overview, in: Christensen (editor), Integrated Methods in Exploration and Discovery, Society of Economic Geology Conference Field trip Guidebook, p.12-26.

Hausen, D.M., and Kerr, P.F., 1968, Fine Gold Occurrence at Carlin, Nevada, in Ridge, J.D. (editor), Ore deposits of the United States. 1993-1967 (Graton-Sales vo1): New York, American of Mining Institute, Metallurgical and Petroleum Engineers, p.904-908.

Hofstra, A.H., Leventhal, J.S., Northrop, H.T., Landis, G.P., Rye, R.O., Birak, D.J. and Dahl, A.R., 1991, Genesis of Sediment-Hosted Gold Deposits by Fluid Mixing and Sulfidation: Chemical Reaction Path Modeling of Ore-Depositional Processes Documented in Jerritt Canyon District, Nevada, SE of Geology v. 19, p.36-40.

Parameters	Carlin-type	Low-sulfidation epithermal
Setting	Miogeocline, basin association, extentional tectonics	Volcanic arc
Gold occurrence	Micron-sized	Variable
Base metal content	Insignificant	Variety from low to high
Silica gangue	Jasperoid, pervasive silicification, quartz as open-space filling uncommon	Ubiquitous and abundant as open space filling
Gold precipitation mechanism	Sulfidation of host rock, mixing, cooling and dilution	Boiling and mixing
Surface attributes	Not identified	Sinter, silicified horizons and acid leach zones common
Depth of formation	2-5 km	<2 km
Ore-forming fluid	Low salinity, enriched H2S and CO2, highly evolved, fairly acid, some components derived from host rocks (S, C, As)	Low-moderate salinity, low-mod H2S and CO2, with magmatic origin components, near neutral, major components from magma-host rock origin
Pathfinder association	As, Sb, Hg, Tl, PGE	As, Hg, Sb, Pb, Zn, Cu, Ag
Genetic link to magma	Unclear	Robust

Ilchik, W.L. and Barton, M.D., 1997, An amagmatic origin for Carlin-type Gold deposits, in: Vikre P, Thompson TB, Bettles K., Christensen O., and Parrat R., Carlin-Type Gold Deposits Field Conference, Guidebook Series Volume 28, SEG, p.223-226.

Kuehn, C.A., 1989, Study of Disseminated Gold Deposits Near Carlin, Nevada: Evidence for deep geologic setting of ore formation: Ph.D. dissertation, Pennsylvania State University, 395p.

Maryono, A., 1998, Carlin-Style sediment-Hosted Gold deposits: An exploration Opportunity, with a case study on the Great Basin Gold Province, Nevada USA, in: Prosiding Ikatan Ahli Geologi Indonesia, PIT XXVII, December 1998.

Radtke, A.S., 1985, Geology of the Carlin Gold Deposit, Nevada, US Geological Survey Professional Paper 1267.

Sha, P., 1992, Gold Concentration and Distribution of Iron Sulfides from Unoxidized Ores in the Gold Quarry Deposit and Implications for the Genesis of Carlin-Type Disseminated Gold Deposits, unpub. Ph.D. dissertation, Tuscaloosa, Alabama, Univ. of Alabama.

Sillitoe, R.H., 1989, Gold Deposits in Western Pacific Island Arcs: The Magmatic Connection, Economic Geology Monograph 6, p.274-291

Teal, L. and Jackson, M., 1997, Geologic Overview of the Carlin Trend Gold Deposits and Description of Recent Deep Discoveries, in Vikre P, Thompson TB, Bettles K., Christensen O., and Parrat R., Carlin-Type Gold Deposits Field Conference, Guidebook Series Volume 28, SEG, p.3-37.

Thorman, C.H., Brooks, W.E., Snee, L.E., Hofstra, A.H., Christensen, O., and Wilton, D.T., 1995, Eocene-Oligocene Model for Carlin-Type Deposits in Northern Nevada (abstract), Geology and Ore Deposits of the American Cordillera, Reno/Sparks, Nevada, Programs with Abstract, p. A-75.

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