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GEOLOGY OF THE CARLIN DISSEMINATED REPLACEMENT GOLD DEPOSIT, NEVADA

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INTRODUCTION

The Carlin gold deposit is in the Lynn mining district, northern Eureka County, Nevada, U.S.A., about 29 km northeast of the town of Carlin. The deposit is at an approximate altitude of 2,000 m near the crest of the Tuscarora Mountains.

Placer gold was first discovered in the district in 1907 and was traced to erratic occurrences of coarse gold in quartz veins in the Vinini Formation about 1.5 km north of the Carlin deposit. The disseminated gold ores of the Carlin deposit were discovered in 1962 by geologists of Newmont Exploration Ltd., a subsidiary of Newmont Mining Corp. After an extensive geochemical sampling program within an area known to contain mineralized rock, approximately 76,000 m of rotary development drilling on a 30 m grid delineated 10 million metric tons of gold ore averaging about 10 grams Au/metric ton. The Carlin mine was in production within 3 years of the initial discovery.

The highly automated cyanide mill at the Carlin mine, rated at 1,820 metric tons per day, is currently treating that amount of oxidized gold ore plus an additional 455 tons of primary unoxidized ores requiring special induced oxidation treatment prior to cyanidation (Scheiner, Lindstrom, and Henrie, 1968). Total production from the Carlin gold mine as of late 1977 was approximately 93,300 kg of gold from about 8.5 million metric tons of milled ore. About 64.5 million metric tons of waste have been removed during mining. The estimated life of the mine has been extended several times, and is at present 7 years.

REGIONAL GEOLOGIC HISTORY

The Cordilleran geosyncline in northern Nevada in pre-Carboniferous time contained 15,000 m of clastic and siliceous sediments in the west and carbonates in the east. Beginning in Late Devonian time, major uplift accompanying the Antler orogeny took place, and the clastic-siliceous rocks moved eastward, overriding the carbonate rocks to form the Roberts Mountains thrust system. Although multiple thrust slices have been recognized locally, the contact between the upper and lower plates in the vicinity of the Carlin deposit is well defined.

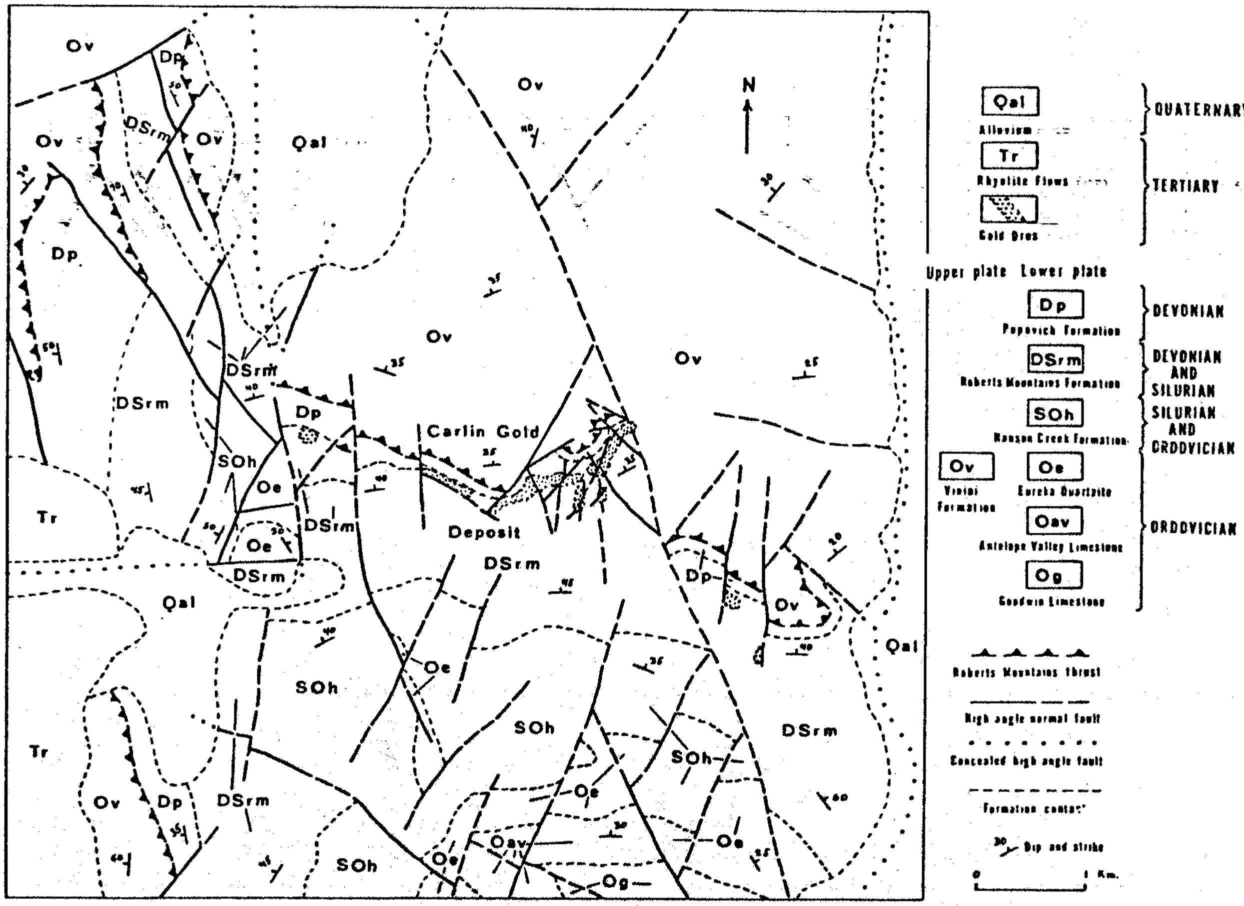

FIGURE 1. Generalized geologic map of the northern Lynn window.

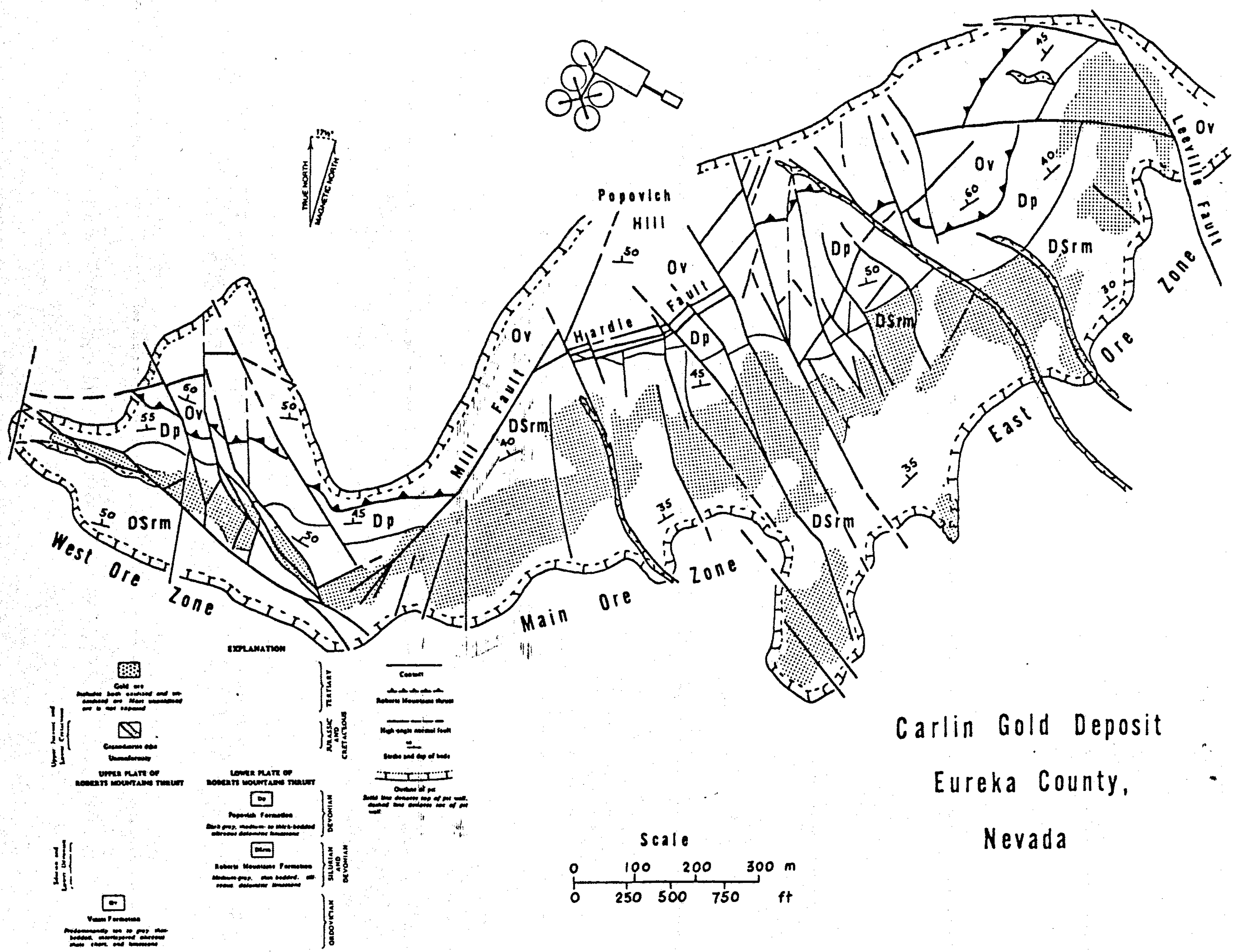

FIGURE 2. Geologic map of the Carlin gold deposit.

Additional deformation, mainly as local uplift and doming, began in north-central Nevada in Late Pennsylvanian time. Igneous activity, represented by intrusive stocks and dikes, occurred in Late Jurassic and (or) Early Cretaceous time.

Most of the block-faulted mountain ranges were formed by tectonic activity during Tertiary time. Associated processes include uplift, high-angle gravity faulting, crustal tension and extension, volcanism, high heat-flows, and geothermal activity. The Carlin deposit formed at shallow depth in the roots of hot-springs systems during the evolution of the Basin and Range province in late Tertiary time (Radtke and Dickson, 1976).

REGIONAL GEOLOGY

The structural and stratigraphic relations in the northern part of the Lynn district are shown in figure 1. The sedimentary rocks in the Tuscarora Mountains have been uplifted to form an anticlinal structure that plunges approximately 45° northwest and has been modified by high-angle normal faults of Tertiary age. The range is flanked by large basin-range faults and is broken into numerous blocks by high-angle normal faults, some of which served as channels for the hydrothermal gold-bearing solutions. Some of these faults had pre-Tertiary initial movement and are filled by igneous dikes of Late Jurassic and (or) Early Cretaceous age.

Sedimentary rocks of three formations are well exposed in and near the Carlin deposit. Rocks of the Ordovician Vinini Formation, in the upper plate of the Roberts Mountains thrust, consist of interbedded chert, shale, and quartzite with minor sandstone lenses, and thin limestone beds. The youngest unit in the lower plate, immediately below the Roberts Mountains thrust and exposed in the Lynn window, consists of massive to thin-bedded limestone of the Devonian Popovich Formation (Hardie, 1966; Akright, Radtke and Grimes, 1969) ranging in thickness from 60 to more than 200 m. This unit is underlain by the Roberts Mountains Formation of Early Silurian to Early Devonian age. It is about 600 m thick and consists principally of thin-bedded laminated silty dolomite and dolomitic limestone. Most of the gold ore bodies at Carlin occur within the upper 100 m of the Roberts Mountains Formation.

The Roberts Mountains Formation is underlain by 150–200 m of thick-bedded dolomite of the Middle Ordovician to Early Silurian Hanson Creek Formation. The Hanson Creek Formation is underlain successively by older Ordovician units of the Eureka Quartzite, and the Antelope Valley Limestone and Goodwin Limestone of the Pogonip Group (fig. 1).

Geologists at the Carlin mine have classified the high-angle faults in the Lynn window into four sets based on attitudes and approximate ages. The earliest of these sets, striking between N. 45° E. and east-west, includes the prominent Hardie fault system in the Carlin deposit (fig. 2). Vertical movement of more than 600 m on this structure positioned the Roberts Mountains thrust below the surface north of the fault. The Hardie Fault forms the northern boundary of the Lynn window in this area. Many of the faults with similar strikes are not shown on figure 2 because of the scale of the map. In many places the margins of the Lynn window are formed by high-angle faults rather than the Roberts Mountains thrust.

The next younger faults strike to the north, and this set of faults and the earlier set are displaced by a later set of normal faults trending between N. 45° E. and north-south. A prominent fault of this later set is the Mill fault, which strikes N. 45° E. to north-south and forms the western boundary between upper and lower plate rocks in the main pit (fig. 2). Faults of the youngest set are strong prominent structures with northwest trends, such as the Leeville fault, which forms the eastern boundary of the Lynn window in the mine area (figs. 1 and 2). However, some northwest-trending faults are filled with Late Jurassic and (or) Early Cretaceous dikes, indicating that some of the faults with this trend are very old (Radtke, 1973). Many of the northwest-trending faults, including those containing igneous dikes, served as channels for the Tertiary hydrothermal gold-bearing solutions. Later rejuvenation of movement on many of the high-angle structures further complicates the structural picture at Carlin.

ORE BODIES

The gold ore bodies occur in three principal areas referred to as the west, main, and east ore zones. Many general similarities exist among the various ore zones, yet ore bodies within each zone show differences in geometry and structural controls (fig. 2; and Radtke, 1973) and in mineralogy and chemistry (Harris and Radtke, 1976; Radtke, Rye, and Dickson, in press).

West Ore Zone

The west ore zone consists of a tabular veinlike body about 250 m in length striking about N. 60° W. and dipping 60°–70° N. This ore body is in altered dolomitic carbonate rock in the hanging-wall side of a high-angle normal fault. In the southwest part of the zone the ore body thickens into an oval or pipe-shaped body plunging about 70° N. Most of the ore in the zone is oxidized; characteristic features of the unoxidized ores include a lack of arsenic, antimony, and mercury sulfides, and the lowest content of organic carbon and the highest content of barium of any of the ore zones.

Main Ore Zone

This ore zone includes an area of gold-mineralized rock about 900 m long extending from the southwest end of the main pit to the southeast side of Popovich Hill (fig. 2; and Radtke, 1973). Most of the ore bodies in the zone south and southeast of Popovich Hill are stratiform masses up to 30 m thick with attitudes corresponding closely to those of the host rocks. The ore bodies southwest of Popovich Hill form a continuous irregular-shaped mass of mineralized dolomitic carbonate rock about 400 m long and 15–20 m thick. The ore zone narrows to a few meters thick at the southwest end and terminates against gouge-filled faults. Important ore controls were provided by high-angle normal faults trending from north-south to N. 45° W. (fig. 2) and less prominent northeast-trending structures shown on the map by Radtke (1973).

The main ore zone contains large amounts of both oxidized and unoxidized ores; most of the unoxidized ores are in the areas south and southeast of Popovich Hill. Both general types of ore are characterized by wide ranges in the content of silica, and unoxidized ores also vary greatly in content of pyrite and organic carbon. Sulfides and sulfosalts of arsenic occur in unoxidized ores, and together with base-metal sulfides, are sporadically distributed in deep levels in barite veins.

East Ore Zone

The east ore zone contains a series of discontinuous ore bodies of irregular shape in the upper 100 m of the Roberts Mountains Formation southeast and east of Popovich Hill. Small amounts of ore also occur in basal carbonate beds of the Popovich Formation and in shaly beds of the Vinini Formation east of the Leeville fault (fig. 2; and Radtke, 1973). Important structural controls were provided by: (1) northwest-trending high-angle normal faults several of which contain pre-ore igneous dikes (fig. 2; and Radtke, 1973); and (2) intersections between these faults and others trending north-south to N. 45° E. not included on figure 2 but shown on the detailed map by Radtke (1973).

Unoxidized or weakly oxidized ores make up the bulk of the ores in the east ore zone. These ores show wide ranges in chemical and mineralogical compositions and commonly contain large amounts of introduced hydrocarbons and very small amounts of dispersed and vein barite. Numerous rare minerals have been found and described in carbonaceous and siliceous rocks in the east ore zone, including frankdicksonite, BaF_2 (Radtke and Brown, 1974); carlinite, Tl_2S (Radtke and Dickson, 1975); christite, $TlHgAsS_3$ (Radtke, Dickson, Slack, and Brown, 1977); and ellisite, Tl_3AsS_3, and weissbergite, $TlSbS_2$ (F. W. Dickson and A. S. Radtke, unpublished data).

GENESIS OF THE DEPOSIT

The ore bodies in the Carlin deposit formed during Late Tertiary time by mineral deposition from hydrothermal fluids that penetrated shattered dolomitic beds in the upper part of the Roberts Mountains Formation. Sets of high-angle normal faults served as channels for the hydrothermal solutions. Important chemical and mineralogical features of the paragenesis are shown in figure 3. Details of the geochemistry, stable isotopes, and the chemical model for the Carlin deposit are given in a paper by Radtke, Rye, and Dickson (in press).

The thin-bedded laminated silty dolomite host rocks contained about 25–50 percent dolomite, 20–30 percent quartz, 15–20 percent argillaceous material, 5–20 percent calcite, 1–3 percent chert, and 1–3 percent total pyrite,

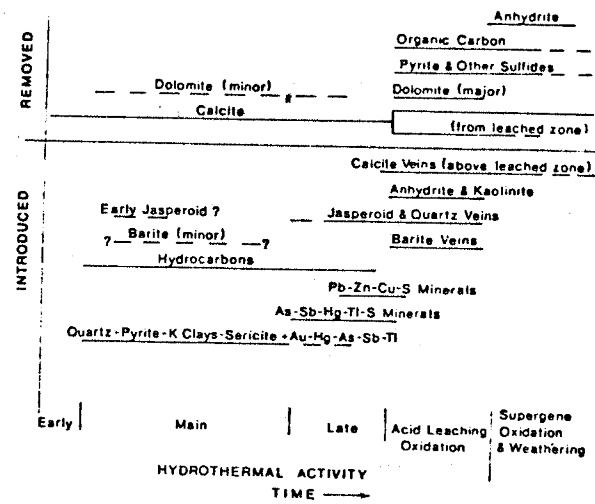

FIGURE 3. Paragenetic diagram for the Carlin gold deposit (after Radtke, Rye, and Dickson, in press).

organic carbon, and accessory heavy minerals. The hydrothermal fluids which were at temperatures between 175°–225°C and contained silica, aluminum, iron, sulfur, potassium, barium, gold, mercury, arsenic, antimony, thallium, lead, zinc, copper, and organic materials reacted with the host rocks resulting in the following processes and paragenesis (fig. 3). Calcite was dissolved out of the rock matrix, dolomite rhombs were corroded, fine-grained quartz was precipitated, and kaolinite, sericite, and pyrite formed. Gold and mercury were precipitated on organic materials and together with arsenic, antimony, and thallium, formed thin coatings on surfaces of pyrite (Radtke and Dickson, 1974). Gold also formed in small seams, patches, and microscopic veinlets of quartz (Hausen and Kerr, 1968).

Later in the paragenesis sulfide and sulfosalt minerals of arsenic, antimony, and thallium formed at deep levels mostly spatially separated from base-metal sulfides. Hydrocarbons were introduced, and quartz veins and jasperoid bodies, some containing gold, formed at various depths. Near the surface the fluids boiled, H_2SO_4 was produced by oxidation of H_2S, and rocks and ores at shallow depths underwent acid leaching. Important features of this acid leaching and oxidation included the removal of calcite and dolomite and bleaching of the rocks, oxidation of sulfides and carbonaceous materials, and formation of barite veins. Most of the gold in acid-leached oxidized ores occurs as fine-grained particles of metallic gold associated with iron oxides, clays, or microscopic quartz. Rocks and ores to a depth of about 50 m below the bottom of the zone of acid leaching were weakly oxidized by supergene meteoric waters after hydrothermal activity ceased.

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