Exploration for Ore Deposits of the North American Cordillera

FIELD TRIP GUIDEBOOK

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1984 Regional Symposium

CONTENTS

FIELD TRIP 1.

SEDIMENT-HOSTED GOLD DEPOSITS
Field Trip Leader: Dana Durgin

Road Log / Trip Guide: Reno to Elko
Dana Durgin .... FT 1- 1

Pinson Mining Company
Staff .... FT 1-11

General Geology of the Carlin Gold Mine
Anthony R. Adkins and Joseph C. Rota .... FT 1-17

Bell Mine—Jerritt Canyon
Ruth Carraher .... FT 1-25

FIELD TRIP 2.

SEDIMENT-HOSTED PRECIOUS METAL DEPOSITS
Field Trip Leader: Charles Hauntz

Road Log / Trip Guide: Reno to Ely
Charles Hauntz .... FT 2- 1

Northumberland Gold Deposit, Nye County, NV
John W. Motter and Peter E. Chapman .... FT 2- 9

History and Geology of the Alligator Ridge Gold Mine, White Pine County, NV .... FT 2-27

Geology and Ore Deposits of the Taylor Silver District
Stuart R. Havenstrite .... FT 2-37

FIELD TRIP 3.

PRECIOUS METAL DISTRICTS IN SOUTHERN AND WESTERN NEVADA
Field Trip Leaders: Larry J. Garside
Harold F. Bonham, Jr.

Road Log / Trip Guide: Sterling Mine, Goldfield District, Hasbouck Mountain (Divide District), Tonopah District, and Borealis Mine
Larry J. Garside and Harold F. Bonham, Jr. .... FT 3- 1

FIELD TRIP 4.

PRECIOUS METAL DISTRICTS IN WEST-CENTRAL NEVADA
Field Trip Leaders: Larry J. Garside
Harold F. Bonham, Jr.

Road Log / Trip Guide: Candelaria Mine, Goldfield District, Tonopah District, and Bell Mountain Mine.
Larry J. Garside and Harold F. Bonham, Jr. .... FT 4- 1

FIELD TRIP 5.

CANCELLED
Trip 5 is replaced by Trip 7.

FIELD TRIP 6.

MASSIVE SULFIDE DEPOSIT
Trip Leader: Steven P. Kilbreath

The Western World Massive Sulfide Deposit, Yuba County, California
Steven P. Kilbreath .... FT 6- 1

FIELD TRIP 1.
SEDIMENT-HOSTED GOLD DEPOSITS

GENERAL GEOLOGY OF THE CARLIN GOLD MINE

Anthony R. Adkins and Joseph C. Rota
Carlin Gold Mining Company

INTRODUCTION

The Carlin mine is located in north central Nevada, in the Lynn Mining district, in northeastern Eureka County, 40 miles northwest of Elko, Nevada. The mine is operated by the Carlin Gold Mining company, a wholly owned subsidiary of Newmont Mining Corporation.

Pre-Carlin Gold mining activity started with the discovery of placer gold in Lynn Creek in 1907. The following years saw sporadic activity from both shallow surface and underground mines, with placer deposits being the most productive. All production was from the Ordovician Vinini Formation, producing gold, silver and copper values estimated at $214,100. (Roberts, and others 1967).

In the early 1960's, Newmont Exploration began investigating the area based on a report by the U.S.G.S. Mapping and claim staking were followed by drilling in 1962, with significant gold values found in the third drill hole. The mine is located in an area adjacent to known mineralization, and the orebody cropped out at the surface. Construction of a cyanidation mill was started in June, 1964, and gold was first poured in April, 1965. (Hausen and Kerr, 1967).

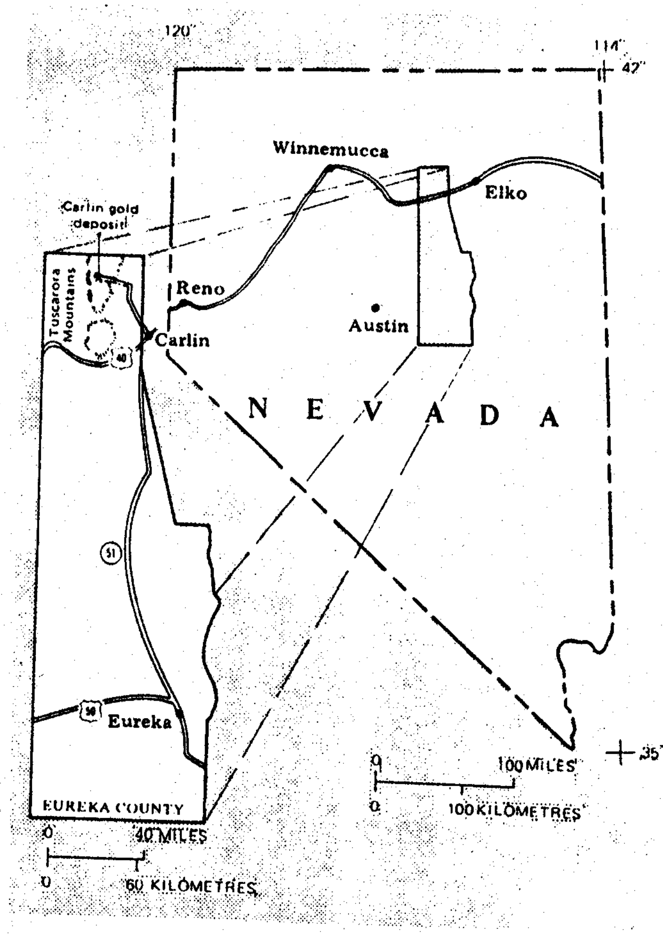


Figure 1. The location of the Carlin gold deposit in north-central Nevada.

GEOLOGY

General

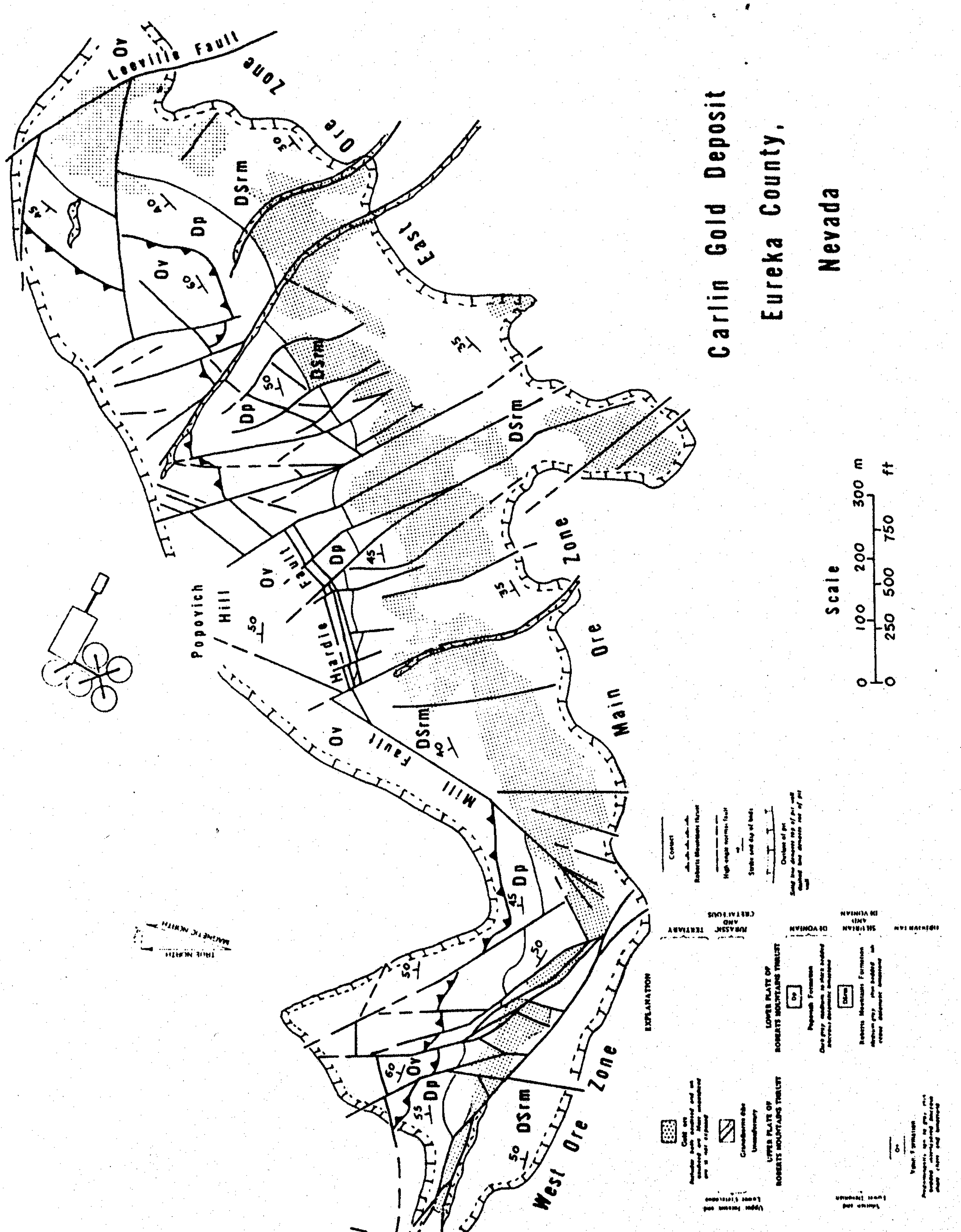
Regionally, the mid-Paleozoic to possible earliest Mesozoic Roberts Mountains thrust fault placed upper plate cherts and shales of the Ordovician Vinini Formation, over a lower plate Cambrian to Devonian age, carbonate sequence. The thrust itself was most likely not a single thrust sheet, but consisted of numerous inbrecate slices that have, in some areas, apparently shuffled isolated slabs of lower plate rocks between upper plate thrust slices. Subsequent doming, high angle faulting and erosion have combined to expose several windows that align with a general northwest trend.

The Carlin mine is located near the northeastern edge of one of these windows, the Lynn window. At the minesite, Silurian and Devonian carbonates of the lower plate are exposed through overlying upper plate Ordovician cherts and siliceous shales. The general orientation of all units is along a northeast strike, dipping northwest.

Sediments

The Silurian Roberts Mountains Formation, originally a platy, silty dolomitic limestone, has been strongly altered in mineralized areas. Carbonate removal, along with local bleaching and iron staining, left a porous low-density rock that ranges in composition from an argillaceous to dolomitic siltstone. Replaced ore-bearing rocks have densities that vary from 1.95 to 2.40, while fresh limestones from near Maggie Creek have density values of approximately 2.65 (Hausen and Kerr, 1967). The Roberts Mountains Formation is the major host for gold mineralization at the Carlin Mine.

The Devonian Popovich Formation unconformably overlies the Roberts Mountains Formation. In the mine a



(Radtke and Noble, 1978)

Figure 2. Geologic map of the Carlin gold deposit.

10 to 20 foot thick reddish-maroon-tan unit considered the top of the Roberts Mountains Formation, consists of thin bedded siltstones with abundant lenticular chert nodules and serves as an effective marker bed between the two formations. The Popovich Formation consists of a fine to medium grained, medium to thick bedded (nearly massive towards the base) dolomitic limestone. Some movement appears to have occurred along the contact with the underlying formation. The Popovich Formation has been hydrothermally altered along its base and along joints and fractures. Carbonate removal and subsequent clay and iron oxide replacement occurred yielding altered rock densities of approximately 1.60, as compared with fresh rock densities of 2.75 (Hausen and Kerr, 1967).

The uppermost formation, the Ordovician Vinini Formation, is separated from the underlying carbonates by the Roberts Mountains thrust fault. At Carlin, the Vinini consists of an interbedded sequence of thin black chert and black siliceous shales. The shales contain minor primary carbon, although some areas have had secondary carbon introduced by hydrothermal means. In general the Vinini has not been strongly affected by any of the alteration processes. Exceptions occur where faults and dikes cutting the formation acted as conduits, allowing some wall rocks to become slightly clay altered.

Igneous rocks in the pit occur solely as fault filling dikes, and are either dacitic or quartz latitic in composition. However, the general term quartz porphyry is used as a field description. The dikes range in thickness from several inches to ten feet, and pinch or swell rapidly over short distances. Barite veins and spare base metal mineralization appear to be closely related to the dike intrusion. Both the barite and base metals, along with the dikes, predate gold mineralization. Subsequent low temperature alteration of the dikes to essentially quartz and secondary clays occurred during later gold mineralization. Age determination of the dikes, based on biotites from a nearby quartz diorite intrusion, is approximately 121 ± 5 m.y. (Hausen and Kerr, 1967). A dike in the southwest corner of the main pit, dated by Morton and others (1977), is considered to be at least 131 ± 4 m.y.

Structure

The deposit has undergone two types of faulting of at least five ages. Earliest is the Roberts Mountains thrust, then high angle faulting. In order of decreasing age, they trend easterly, northerly, northeasterly and northwesterly. All faults are considered to be pre-mineralization, with some possible rejuvination on the younger faults that coincide with Basin and Range development. Some of the larger faults, such as the Hardie, Mill and Leeville, act as a barrier to the orebody, presumably by displacing the favorable host rocks away from the sites of gold deposition.

Porous "white" silicification is most common along northwest faults that cut the orebody and some ore grade material of importance is located adjacent to such faults. (Hausen and Kerr, 1967). However, high angle fault zones are sparsely mineralized and the Roberts Mountains thrust appears to have had no influence over ore deposition.

ALTERATION

Hypogene

According to West (1976), the major hydrothermal alteration types that have affected all rocks in the Carlin ore zones are: argillization, silicification, pyritization, and decarbonatization. Bleaching, often accompanied by an impoverishment in gold values is locally prominent. A comparison of unaltered and altered Roberts Mountains Formation carbonate rock revealed that the altered phase showed a drop in carbonate content and an increase in illitic clays, kaolinite and silica, all presumably due to hydrothermal activity.

A hydrothermal origin is presumed for the abundant illitic clays, as they are often found in alteration zones around hot springs or metalliferous veins. Laboratory experiments suggest that for both hydrothermal and sedimentary occurrences, the formation of illite is generally favored by alkaline conditions and by high concentrations of aluminum and potassium. (Deer, and others 1975). This argillic alteration apparently accompanied the pre-gold decarbonatization stage. Most ore samples contain 20% to 40% illite. (Hausen and Kerr, 1967).

At Carlin, as at many gold deposits, a close association exists between silica and gold. Zones of quartz microveinlets, vuggy and drusy quartz, and cherty silicification are prominent in close association with gold-bearing zones. Some of this silica occurs as porous chimney-like ellipsoidal masses of finely recrystalized quartz. Other forms of silica present do not appear to be related to mineralization. These are: 1) early, barren, white bull-quartz veining in area rocks of all ages. 2) Silicification bordering barite-filled faults. The barite was associated with a weak, pre-gold base metal sulfide mineralization phase. 3) Surface silicification from replacement of beds by circulation of silica-charged meteoric waters that die out with depth, and 4) Original sedimentary chert beds and detrital quartz grains in the Roberts Mountains Formation. (West, 1976; Hausen, 1967).

Epigenetic pyrite is locally auriferous, containing visible gold in cavities and external fractures. Growth rings suggest that at least two generations of pyritization have occurred in the ore bodies. The earlier generation of pyrite occurred before gold deposition began, the second generation of pyrite accompanied mainstage gold deposition. (Hausen and Kerr, 1967).

Pre-gold mineralization activity is represented by early de-carbonatization of the Roberts Mountains and lower Popovich Formations. This event took place after extensive structural fracturing had occurred. Initial penetration was made by low-temperature fluids, probably less than 200°C, which were undersaturated with regard to calcite. These fluids dissolved calcite from the rock matrix, resulting in both an increase in porosity and permeability, and a net decrease in bulk density, (e.g. ground preparation). (Radtke and Nobel, 1978).

According to Radtke and Noble (1978), post gold mineralization hydrothermal activity is generally known as the acid leaching/oxidation stage, although some ore deposition may have continued during its initial phases. This stage is characterized by strong acid leaching of shallow rock and ores by H_2SO_4 produced from the oxidation of H_2S. The vapor phase H_2S was driven off by the boiling (at 275°-300°C) of ore-forming fluids at the end of the main stage of gold mineralizing hydrothermal activity. Most of the remaining calcite and large amounts of dolomite were removed from the Roberts Mountains Formation and from the base and fractures/faults in the overlying Devonian Popovich Formation. Organic carbon compounds and pyrite were oxidized, remobilized silica was introduced and kaolinite and anhydrite formed. Calcite veins formed above and below the zone of acid leaching, sometimes cross-cutting mineralization.

Supergene

Following the close of hydrothermal activity the rocks and ores underwent oxidation by cool meteroic supergene waters. Locally, these waters penetrated 50+ meters below the bottom of the acid-leached zone. Anhydrite was dissolved, remnant sulfides and organic materials in the rocks above and below the acid leached zone were oxidized, and small amounts of calcite were removed (Radtke and Noble, 1978).

The oxidation of the deposit resulted in the removal of carbon, as well as oxidation of iron sulfides and iron staining of the ore zones. The absence or presence of carbon in the altered Roberts Mountains Formation within the mine area appears to be a matter of permeability differences in the sediment due to two basic factors: 1) The habit of original sedimentation was such that it produced sandy beds or horizons with less carbon and a higher overall permeability and porosity, 2) the wide variances in the intensity of structural fracturing produced select areas of high permeability. Both conditions permitted a deeper and more complete process of carbon removal and oxidation. The supergene oxidation profile for the most part parallels the erosion surface and the carbon ore generally decreases in amount with an increase in depth of burial (West. 1976).

MAIN STAGE MINERALIZATION

According to Radtke and Noble (1978), the ore bodies in the Carlin deposit were formed during late Tertiary time by hydrothermal fluids which penetrated shattered dolomitic beds in the upper 100 m of the Roberts Mountains Formation. Although high-angle normal faults served as conduits for the mineralizing hydrothermal solutions, they have not become significantly mineralized. The main hydrothermal event stages (early — late) may have occurred over a period of 100.000 years.

Hausen (1967), and Radtke and Noble (1978), state that the major lithologic types of gold-bearing host rocks in the Roberts Mountains Formation are: a) siltstones, b) dolomitic limestones, c) argillaceous siltstones and d) silicified rocks. The ore forming fluids moved through these host beds at between 175° and 200°C. Undersaturated in $CaCo_3$ and supersaturated in SiO_2 they dissolved calcite and deposited quartz. Introduced elements were: Si, Fe, S, Al, K, Ba, organic compounds and the distinctive Carlin elemental association of Au, Hg, As, Sb, Tl. Gold thio (HS^-), complexes were precipitated (Seward, 1973) along with As, Sb and Tl, and concentrated on rims of pyrite. Gold was also absorbed selectively by, or nucleated onto, surfaces of illitic clays and quartz. Over 90% of the gold is sub-microscopic (<.2 microns in diameter), with the balance ranging from .5 to 5 microns. The average gold fineness is .900. In the vicinity of ore bodies gold mineralization continues into the quartz porphyry dikes, but in other areas may be essentially absent from the igneous intrusions. The dikes are highly argillized and contain little or no original feldspars, only quartz, koalinitic and illitic clays.

According to Radtke and Noble (1978), late stage hydrothermal events included deposition of sulfide and sulfosalt minerals of As, Sb, Hg, Tl, and the introduction of large amounts of hydrocarbons. These hydrocarbons were probably leached from lower plate carbon bearing carbonate source rocks by meteoric waters circulating in the thermal system. This remobilized carbon material, along with pyrite, can be found deposited in the barren Vinini Formation, as well as in the lower ore zones. Microprobe analysis has shown that little or no gold was detected in carbonaceous material which was suggested by some workers as the site of gold deposition at the Carlin deposit. (Wells and Mullens, 1975). Another late stage feature was the formation of jasperoidal bodies and quartz veins. Typical jasperoids are masses of erosionally resistant silicate rock formed by intense leaching of carbonate beds and the addition of massive amounts of silica. This process usually occurs in a near-surface environment through the circulation of silica-laden meteoric waters. Not to be confused with chert, these bodies are often associated with large faults, as they are often strongly brecciated and cemented by silica. Outcrops exposed on the periphery of the present pit were recently sampled and showed anomalous arsenic values. Gold values fell within background ranges.

ORE BODIES

The gold ore at Carlin occurred in three principle areas referred to as the west, main (deep main), and east ore zones. These ore zones had many similarities, yet displayed differences in geometry, structural controls, mineralogy and chemistry. (Radtke and Noble, 1978).

West Ore Zone

This ore zone contained a 340 meter-long veinlike ore body, striking approximately N60°W and dipping 60°-70°N. The southeast end of this zone widened into an oval "pipe" plunging about 70°N. High-angle normal faults had strong control over this orebody. The vein-like section of the orebody rested in the hanging wall of a high-angle fault. On one bench, the footwall of this fault contained a highly altered (Cretaceous?) igneous dike cut by barite veinlets. This ore zone contained the most barium and least organic carbon of the three ore bodies, probably due to a higher degree of structural fracturing and increased oxidation of the area. No visible As, Sb or Hg sulfides occurred in this zone. (Radtke and Noble, 1978).

Main Ore Zone

The main ore zone contained large, connected ore bodies of variable gold content, for approximately 915 meters along a roughly east-west strike. Strong stratigraphic and structural controls were reflected by the northeast portion of this zone. The ore formed a sheetlike mass up to 30 meters thick, striking east-west and dipping 38°-40°N, very similar to the attitude of the host rocks. Possible ore fluid conduits are represented by high-angle faults trending N45°E to N45°W and include a larger dike-filled northwest trending fault in the central part of the present pit (Radtke and Noble, 1978).

The southwest part of the main ore zone contained a tabular ore body of 395 meters in length, 20-30 meters in thickness, striking N45°E and dipping 50°-70° NW. At the southwest end of the main pit this ore body thins and pinches out against impermeable breccias of the Mill Fault. Intersections of numerous north-trending high-angle faults controlled ore deposition in this area (Radtke and Noble, 1978).

The main (and presently mined deep main) ore zones

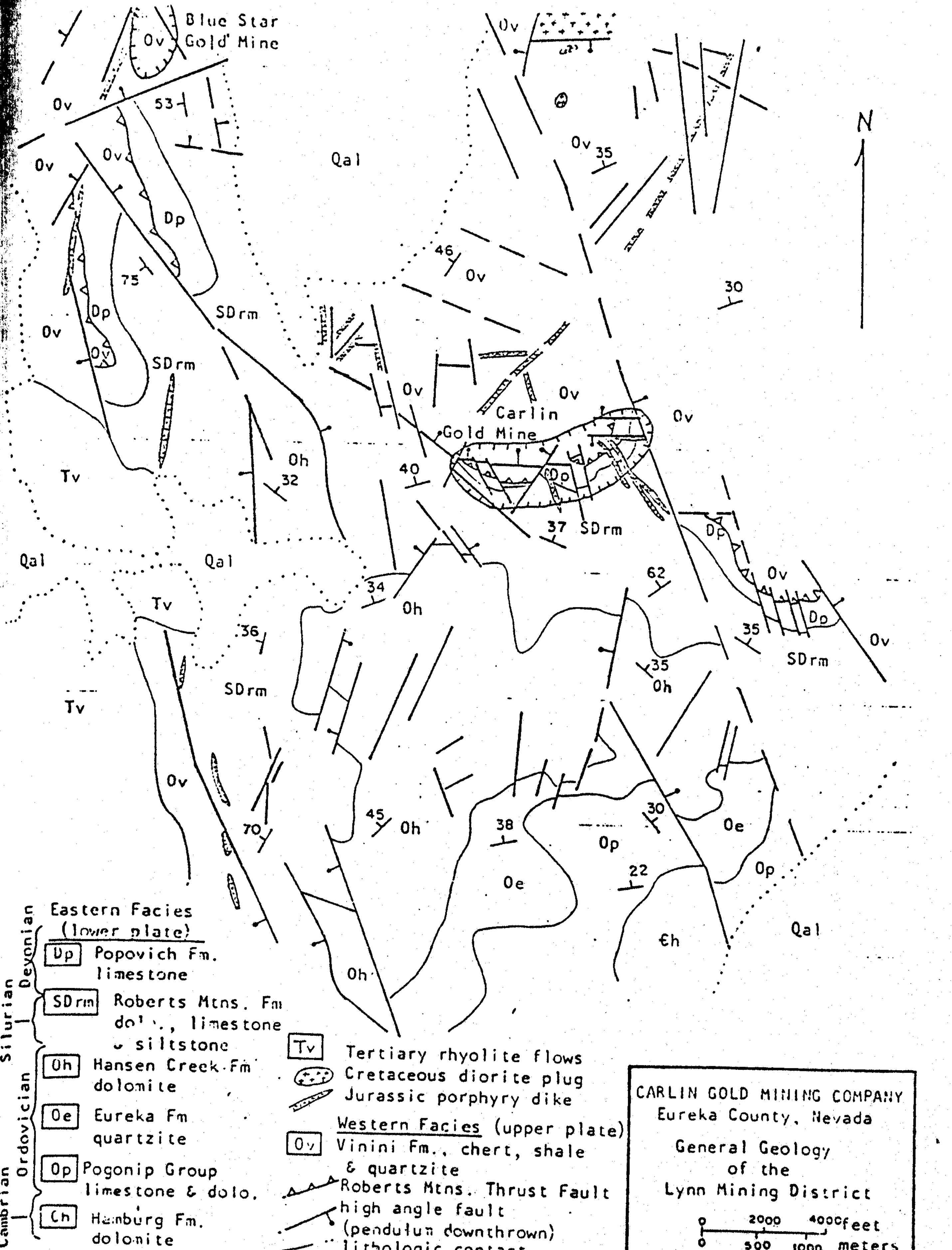

Blue Star
Gold Mine
Carlin
Gold Mine
N
Qal
Ov
Dp
SDrm
Oh
Oe
Op
Tv
Eastern Facies
(lower plate)
Devonian
Silurian
Ordovician
Cambrian
Dp Popovich Fm. limestone
SDrm Roberts Mtns. Fm dol., limestone & siltstone
Oh Hansen Creek Fm dolomite
Oe Eureka Fm quartzite
Op Pogonip Group limestone & dolo.
Ch Hamburg Fm. dolomite
Tv Tertiary rhyolite flows
Cretaceous diorite plug
Jurassic porphyry dike
Western Facies (upper plate)
Ov Vinini Fm., chert, shale & quartzite
Roberts Mtns. Thrust Fault
high angle fault (pendulum downthrown)
lithologic contact
CARLIN GOLD MINING COMPANY
Eureka County, Nevada
General Geology
of the
Lynn Mining District
0 2000 4000 feet
0 500 1000 meters
scale

Figure 3.

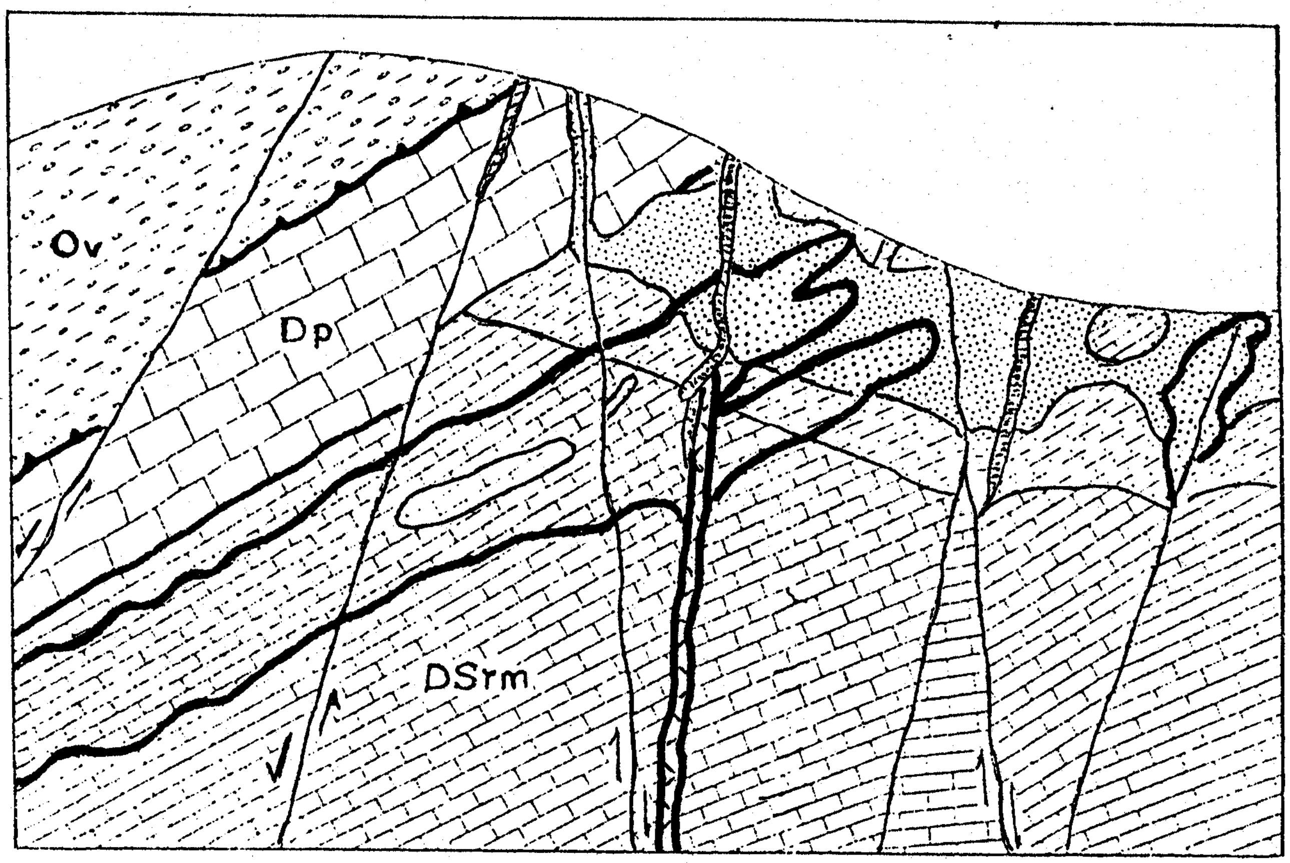


Figure 4. Schematic north-south cross section through the main ore zone and Popovich Hill.

Lithologic units include Vinini Formation (Ov) above Roberts Mountains thrust underlain by Popovich Formation (Dp) and Roberts Mountains Formation (DSrm). Zone of late supergene alteration (dots and dashes) extending below and above zone of leaching alteration (small open circles). Main ore zone includes lower unoxidized ores and upper oxidized ores. Calcite veins are shown in cross-hatched pattern, barite veins in horizontal bar pattern, jasperoid bodies in solid black dot and line pattern. Note igneous dike intruded along fault near center of figure in broken dash pattern and quartz vein along dike in solid dot pattern.

contain about 70% of the known gold in the deposit. Additional deep exploration drilling on the main ore zone in 1975-76 delineated ore extensions down dip in the Roberts Mountains Formation. This drilling project was named the "Deep Main." The ore zone it defined bears the same name. Both the main and deep main ore zones contain oxidized and unoxidized ore. The introduction of organic carbon by hydrothermal fluids reaches 5% locally, as in the east ore zone. Arsenic sulfides and sulfosalts are common in fractures in mineralized carbonate rocks. These minerals and base metal sulfides also occur in deep parts of barite veins in the main ore zone, usually aligned with northwest trending fracture systems. Some of the barite in these veins has been replaced by microcrystalline quartz veinlets (Hausen, 1967).

The south extension orebody was developed on the southern edge of the main ore zone, stratigraphically below the normal ore body within the host formation. It was locallized along a cluster of northerly trending faults, and consisted of oxide ore only (West, 1976). This orebody was in an area of high silicification, due to the large faults acting as solution conduits.

East Ore Zone

This ore zone was aligned on a northeast strike for approximately 750 meters that pinched out in the Vinini Formation east of the Leeville fault. Most of the ore occurred in an irregular elongate tabular body trending N20°E and dipping 35°-45°W. This attitude is conformable to the host rocks and, to the northeast, swings to an east-west direction in a reflection of pre-mineralization folding of the host rocks. At the southwest edge of the ore zone a thick (60 meters) continuous pipe-shaped mass of ore plunges 30°NE and narrows to 15 meters (Radtke and Noble, 1978).

Overall stratigraphic control and the influences of feeder faults on gold deposition were reflected in the shapes and attitudes of the east ore bodies. Two sets of high-angle faults, N40°-45°W and N-S to N45°E, provided structural controls. Igneous dikes were intruded along the northwest-trending faults (Radtke and Noble, 1978).

The unoxidized ore bodies show the larges variations in mineralogy and chemical composition and contain a variety of rare minerals such as: frankdicksonite (BaF_2), carlinite (Tl_2S), christite ($TlHgAsS_3$), weissbergite ($TlSbS_2$), and ellisite (Tl_3AsS_3), as well as other thallium-arsenic-antimony-mercury sulfides and sulfosalt minerals. Other features include a heavy (>5%) enrichment in hydrocarbons and only small amounts of barite. (Radtke and Noble, 1978).

MINING AND MILLING

According to McQuiston and Hernlund, (1965), original re reserves at Carlin came from 800 4¾-inch rotary drill oles totalling 250,000 linear feet. Assay samples were iken at five-foot intervals. Original ore reserves were stimated at 11 million tons averaging 0.32 oz/t gold, with n approximate stripping ratio of 3:1.

Mining efficiency and equipment size have increased ver the years since the 1964 opening of the mine. In 1982, ver 10 million tons of ore and waste were removed from e pit. Of this amount 750,000 tons were run through rlin's 2500 t.p.d. cyanide mill. Preg-robbing carbon ore treated by a chlorine-oxidation unit before entering the in milling circuit. Refined gold fineness at Carlin is 99. Average yearly gold production is 120,000 oz.

In 1982, ore reserves were estimated at 4.7 million tons raging 0.164 oz/t gold.

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