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CARLIN GOLD MINE, LYNN DISTRICT, NEVADA

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ABSTRACT

Gold of Tertiary age is being produced from Newmont Mining Company's Carlin mine in the Lynn district, northern Eureka County, Nev. The ore occurs along a northeast-trending fault zone in fractured siltstone and limestone of Silurian and Devonian age below the Roberts Mountains thrust fault. The ore is largely oxidized, and the gold occurs in particles mostly smaller than 5 microns in altered and iron oxide stained rock. Galena, cinnabar, stibnite are found locally in the ore zone.

The discovery of the Carlin mine in 1962 was the result of intensive prospecting carried on by Newmont geologists following suggestions by the U. S. Geological Survey that metallization might be found along certain mineral belts in north-central Nevada. By 1964 ore reserves totalled 11 million tons containing about 3.5 million ounces of gold. A cyanide mill of 2,000 tons daily capacity was put into operation in May, 1965.

INTRODUCTION

Carlin Gold Mining Co., a subsidiary of Newmont Mining Corp., began gold production in May, 1965, 2 years and 8 months after the first hole was drilled in ore-grade material. The 11 million-ton orebody contains about 3.5 million ounces of gold and extends for 1.5 miles across the crest of the Tuscarora Mountains. The open pit mine is located in the Lynn district in northern Eureka County 20 miles northwest of Carlin, Nev. A 2,000-ton-per-day cyanide mill is located adjacent to the pit at an elevation of 6,500 feet above sea level (figs. 1 and 2).

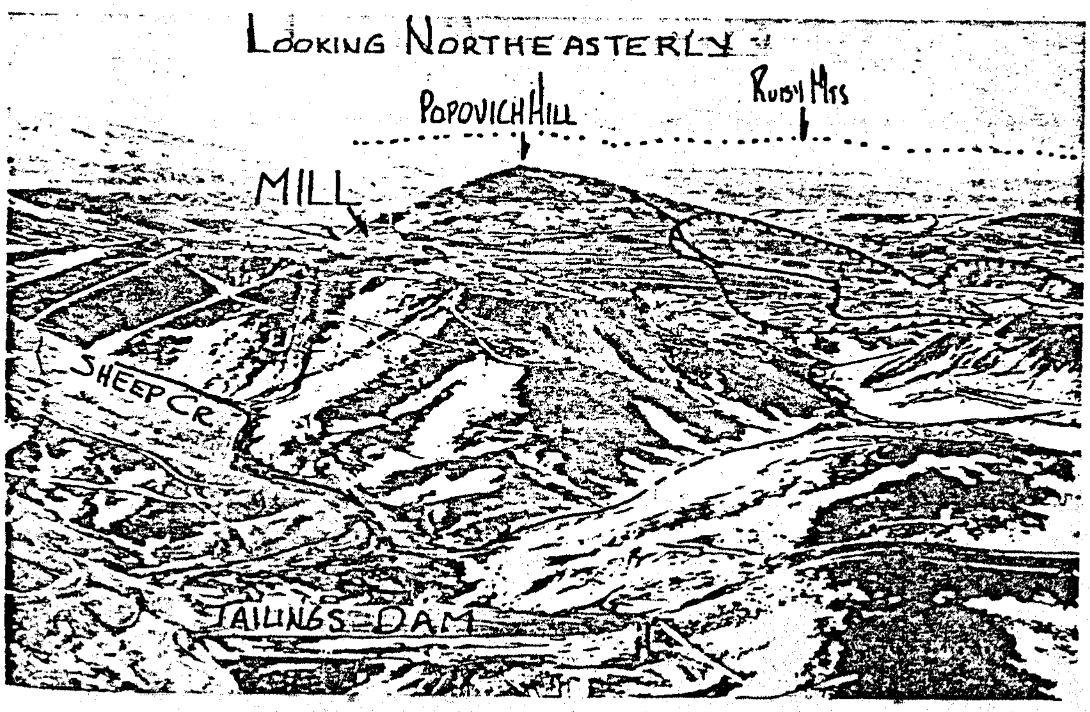

FIGURE 1. Aerial view of the Carlin Gold mine.

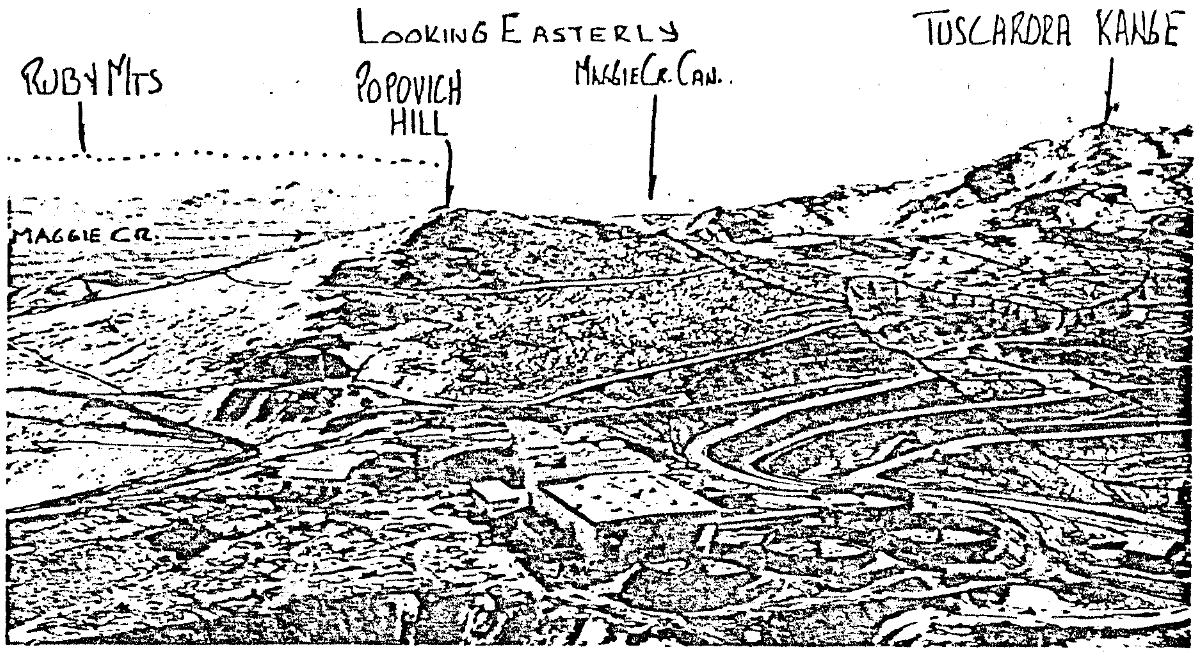

FIGURE 2. Aerial view of the mill, taken prior to completion. Stripping of overburden in progress in right background.

Sub-micron sized gold occurs in irregular fingers and lenses replacing Silurian-Devonian dolomitic siltstone and silty dolomitic limestone in lower-plate eastern assemblage rocks exposed in the Lynn window in close proximity to the Roberts Mountains thrust fault. This fault has been determined to be of early Mississippian age (Roberts, 1960). The siliceous volcanic western assemblage rocks of the upper plate have been moved easterly to southeasterly for distances on the order of 100 miles from their original sites of deposition, and have overridden the eastern or carbonate assemblage rocks. Normal faulting and erosion have since then caused the exposure of the eastern assemblage rocks in windows such as the one in the Lynn district. Figure 3 shows the location of the Carlin Gold mine, and a generalized geologic section illustrating the rock and structural relationships.

Discovery

The discovery was a result of planned testing of gold districts associated with known outcrops of the Roberts Mountains thrust fault. Intensive surface sampling and dry rotary drilling were carried out at and adjacent to the bedrock workings and placer diggings of the 60-year-old Lynn mining district. Most of the previous production of the Lynn district, nearly $150,000 (Vanderburg, 1936), came from gold placer deposits worked by both dry and wet methods. A small portion of this early production was from the siliceous shales of the Ordovician-age Vinini formation in the upper plate of the Roberts Mountains thrust fault. Earlier classification of the siliceous shales as "bedded rhyolite flows" (Emmons, 1910) is a measure of the deceiving appearance of these rocks. A small prospect pit on a massive barite outcrop in limestone within the lower-plate rocks showed some galena but no gold, and has now been removed by mining within the main part of the orebody. No visible or "panning" gold has been found in the lower-plate carbonate rocks.

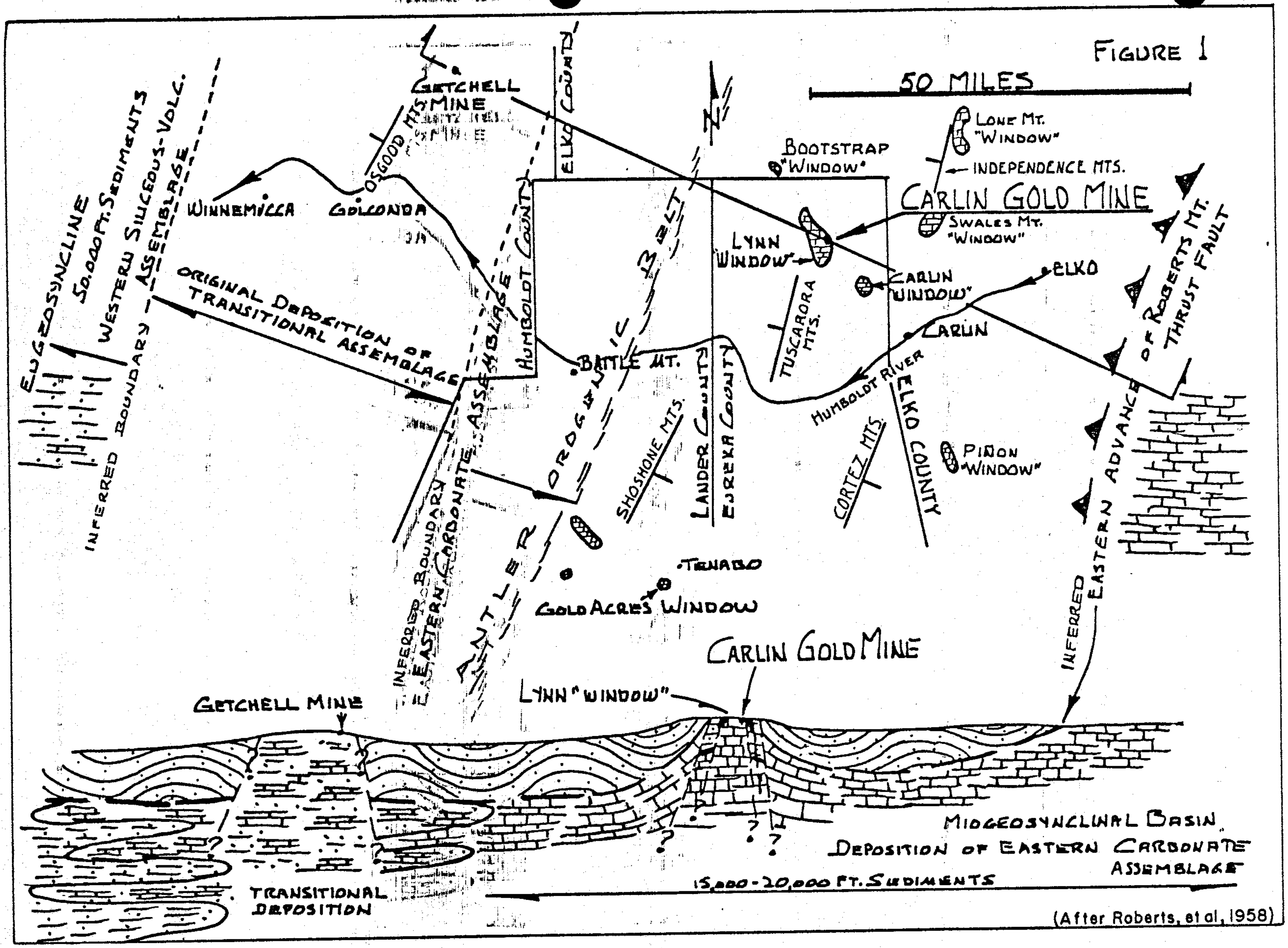

FIGURE 3. Generalized location map of part of northern Nevada showing site of Carlin Gold mine (upper), and generalized geologic cross section through the mine.

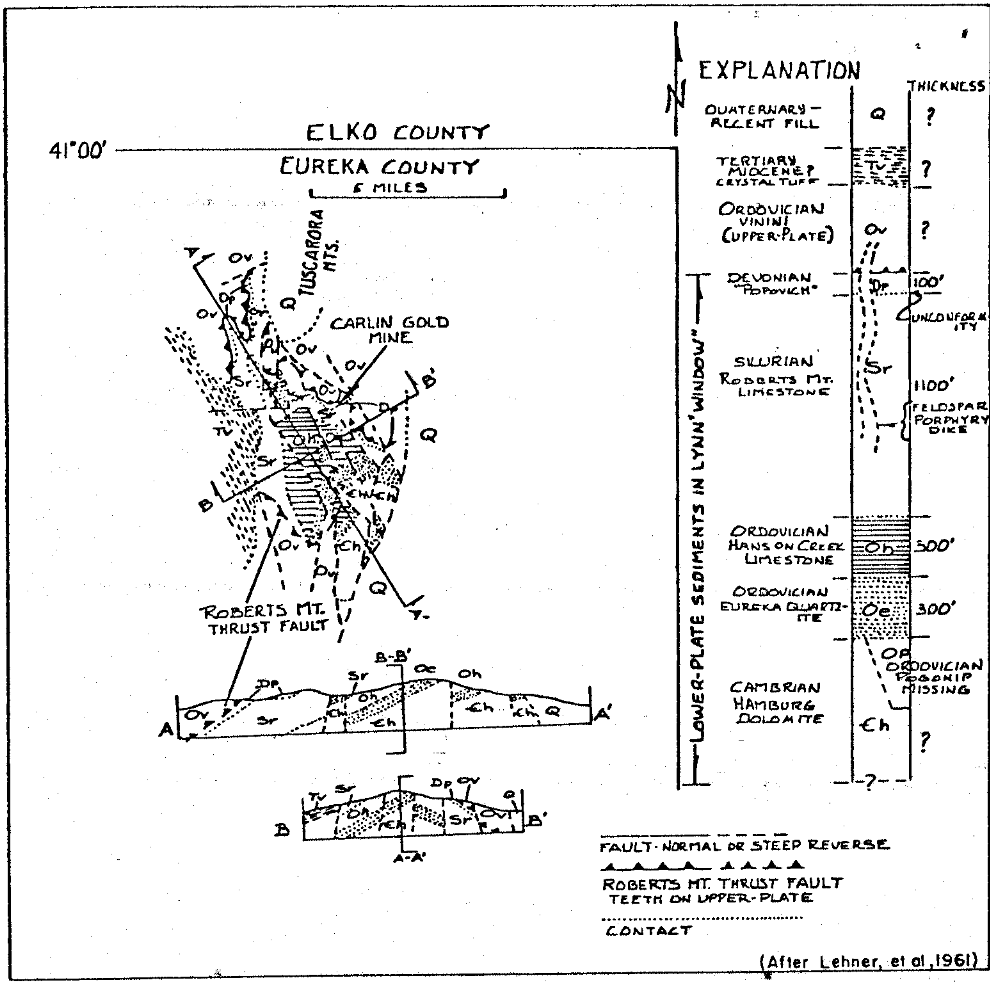

FIGURE 4. Geologic sketch map and sections in the vicinity of the Carlin Gold mine.

Regional Structural Setting

Newmont Exploration Ltd., Newmont Mining Corp.'s exploration division, initially concentrated its exploration on the Roberts Mountains thrust fault following publication of Roberts' (1960) interpretation of the alignment of mineralized districts in northeastern Nevada in or adjacent to windows of carbonate rocks in the footwall of the Roberts Mountians thrust fault. Roberts, Hotz, Gilluly and Ferguson (1958) had previously reviewed the regional structure and stratigraphy of north-central Nevada. The authors also related that in 1928 T. B. Nolan and in 1933 Edwin Kirk called attention to the different facies of Ordovician sediments in the Roberts Mountains in central Eureka County. Kirk suggested that thrusting must be involved, and in 1942 C. W. Merriam and C. A. Anderson found and named the thrust fault after the Roberts Mountains. James Gilluly in 1954 recognized the Roberts Mountains thrust fault in the Cortez quadrangle, and in 1955 Roberts and R. E. Lehner traced the thrust fault northeastward through Eureka and Elko counties into Idaho northeast of Rowland. These publications (and discussions with Dr. Roberts and his associates) led Newmont to the Lynn district and introduced its geologists to the complex structural and stratigraphic history of the region before guidelines for mineral exploration were established.

SEDIMENTARY ROCKS

Lower-plate Rocks

Two lower-plate sedimentary formations crop out in the mine area (see fig. 4). The name Popovich after an early prospector in the district has been informally applied to the younger formation in the mine area. Fossil evidence has been used to place the "Popovich" tentatively at the base of the Upper Devonian. In the mine area gray, fossiliferous medium- to thin-bedded limestone and sandy limestone with some bioclastic units forms the upper portion of the Popovich unit. Stratigraphically below these sediments are alternating limy siltstones and dolomitic siltstone with intercalated limestone lenses. There appears to be an unconformity with some movement between the "Popovich" and the subjacent Roberts Mountains formation of Silurian age.

The Roberts Mountain formation in the mine area is predominantly thin- bedded limy and dolomitic siltstone with discontinuous limestone lenses. Sandy horizons are numerous and discontinuous. Both formations contain syngenetic and epigenetic chert lenses that can make up to 40 percent of the ore zone in places, but the average is closer to 5 percent in the total orebody. Sediments within the ore zone vary from 70 to 90 percent silica, considerably higher than in the more limy rocks surrounding the ore zone. Silt and chert content of the Roberts Mountains formation appears higher than described elsewhere. In the Cortez quadrangle (Gilluly and Mazursky, 1965) increase of lime in the siliceous assemblage and potash-bearing silt in the carbonate assemblage is related to possible transitional sedimentation.

The Hanson Creek formation of Ordovician age is in apparent normal contact with the overlying Roberts limestone in the footwall of the orebody and south of the mine. The black chert marker at the base of the Roberts Mountains formation is exposed at this contact. The Hanson Creek formation consists of about 300 feet of fossiliferous, alternating light- and dark-gray limestone and dolomitic limestone beds with some chert.

Farther south and forming the crest of the Tuscarora Mountains is the contact with the subjacent Ordovician Eureka quartzite. This formation is estimated to be 300 feet thick, and is considerably displaced by steep faulting and not well-mapped. It consists predominantly of orthoquartzite with some sandy layers. The color is pure white to slightly grayish and tan-white. The subjacent Cambrian Hamburg dolomite forms a good portion of the east side of the Tuscarora Mountains within the Lynn "window" and is of unknown thickness, since its lower members are covered by recent sediments of the Maggie Creek drainage. The Hamburg is characterized by the "zebra" banding of black and white alternating, coarse-crystalline dolomite and limestone. The Pogonip formation has not been identified between the Eureka quartzite and the Hamburg, but it is possibly present; detailed mapping is not yet complete.

Upper-plate Rocks

The upper-plate Vinini formation (Ordovician) adjacent to the ore zone contains limy horizons that are apparently discontinuous within the more abundant siliceous shale and quartzite. These limy horizons are indistinguishable from the

Devonian "Popovich" unit of the lower-plate; the thrust plane is easily masked when these two units are brought into fault contact. The predominant lithologic units of the Vinini near the mine are carbonaceous, fractured cherty shale and dark-gray quartzitic shale. Less abundant are coarse-grained, iron-stained brown quartzite sandstone horizons. Black, fine-grained to aphanitic quartzite and gray orthoquartzite are occasionally seen. Farther from the mine to the north, well-bedded siliceous, light-brown to black cherty shale predominates. Beds vary from 1/2" to 3" in thickness. At unmeasured horizons within these shales, fossiliferous, cherty, light-to-dark gray limestone lenses occur. These limy lenses in places resemble the lower plate rocks and have been erroneously mistaken for them. Adjacent to the mine, pyrite mineralization in the upper and lower-plate rocks has resulted in bleaching to light-brown and buff colors as a result of oxidation.

IGNEOUS ROCKS

The only igneous rocks in the mine area are narrow dikes of feldspar porphyry. Dikes occur outside the mine area where they are seen to vary in texture and mineral content, and may include dikes that range from quartz monzonite to granodiorite within the same intrusive mass. The youngest sediments cut by these dikes belong to the upper Devonian Popovich unit. Within the orebody, the dikes contain gold, are highly altered and in some instances almost completely replaced by microcrystalline quartz; the dikes in general follow the northwesterly trend of structure in and adjacent to the Lynn window. The dikes vary from a few inches to a few feet in thickness and show no topographic expression even where quartz replacement is strong. Similar-appearing dikes are present in the Big Six mine area 2 miles to the north. Mineralized dikes are also known at the Bootstrap mine 8 miles to the northwest in Elko County and at the Goldacres mine 45 miles to the southwest in Lander County. Dikes that appear to be similar in composition in northeastern Nevada may be as young as late Tertiary (Schilling, 1965) but are more likely to be early Tertiary in age.

STRUCTURE

Block faulting and tilting within the Lynn window has resulted in an overall northwesterly plunging anticlinal configuration of the sediments. Minor folding is observed closely adjacent to the Roberts Mountains thrust fault (fig. 4). The anticlinal axis parallels the northwesterly elongated axis of the Lynn window which crosscuts the northerly strike of the Tuscarora Mountain block. Many mineralized fractures and porphyry dikes parallel the northwesterly direction. The Bootstrap, Lynn, Carlin and Pinyon windows share a northwesterly alignment over a distance of 40 miles in Elko and Eureka counties (fig. 3). The Carlin Gold orebody has an overall northeasterly strike paralleling the outcrop of the Roberts Mountain thrust fault. A few low-angle faults are recognized in rocks above and below the Roberts Mountain thrust fault, but they apparently have very small displacement. The attitude of the thrust fault is dependent on the configuration of the local uplift, and does not necessarily conform with the inferred northeasterly strike shown in figure 3. The thrust fault within the Lynn district is sub-parallel to bedding in the lower-plate carbonate sediments, and appears to remain in the same stratigraphic position for great distances. Within the Lynn district, the thrust fault has not been seen to cut lower-plate carbonate rocks younger than the base of the Upper Devonian. Faulting within the Lynn district older than the Roberts Mountain thrust fault has not been identified, but it is inferred where the Devonian rocks are missing from the lower-plate sequence. An irregular erosion surface at the unconformity between the Silurian and Devonian formations is probable. Faulting and uplift indicated in Late Devonian time is probably closely connected within the Antler orogeny described by Roberts and others (1958).

The Lynn window is truncated and elevated on its eastern border by late Tertiary basin-and-range faulting. Uplift of the eastern edge of the Tuscarora Mountain block elevates Cambrian-age Hamburg dolomite to a greater height than the Miocene tuffs on the western flank of the range. Upper-plate rocks bordering the Lynn window appear to have been tilted similarly to the northwest. Similar westerly tilting of the sedimentary rocks in the Independence Mountains can be observed in and adjacent to the windows exposed at Swales Mountain and Lone Mountain to the east and northeast of the Lynn district (figs. 3 and 4).

Crosscutting of the complex internal structure of the Ruby Mountains southeast of Elko by the late Tertiary basin-and-range faulting has been described by Sharp (1939). The same type of cross-cutting is shown strikingly in the Tuscarora Mountains (fig. 4).

Block faulting within the Lynn window has been put to practical use in water development. Ample water to furnish 500 gpm to the mill comes from a 300-foot well drilled in an east-west fault that elevates Ordovician-age Eureka quartzite alongside Silurian-age Roberts Mountain limestone. The water level in this structure is several hundred feet higher and 2 miles closer to the mill than the abundant water in Boulder Valley to the west.

Geomorphology of the Tuscarora Mountains in the vicinity of the Carlin Gold mine is closely linked with structure and lithology. North of the mine, upper-plate siliceous Vinini shale rises 700 feet above the mine elevation. South of the mine resistant Eureka quartzite of the lower-plate rises an equal distance above the mine.

MINERALIZATION

Gold mineralization in the Lynn window is found in both upper- and lower-plate sedimentary rocks ranging in age from Ordovician to Upper Devonian. Dikes of Tertiary age are also mineralized. Ferguson's (1929) classification of Nevada's gold-rich deposits as early to middle Tertiary (pre-Esmeralda) would include Carlin's high-gold content deposit. Gold mineralization within the Lynn window has not been proven to be closely related in time or space to associated metals, some of which are often used as ore "indicators" in other areas.

The most abundant metals found in from 40 to 63 samples taken from rotary drill hole cuttings within and adjacent to the ore zone are shown:

Barium	Arsenic	Strontium	Manganese	Antimony	Gold
2,000ppm	1,000ppm	700ppm	200ppm	170ppm	0-10ppm

It will be noted that 10 ppm gold is near the published average grade of ore reserves, or 0.32 ounces per ton. Barite is common in the Lynn district, as it is elsewhere in northeastern Nevada. In the mine area, barite occurs with greatest frequency near the outcrop of the Roberts Mountain thrust fault without regard to the presence of gold.

Ketner, (1963) described bedded barite deposits in the Shoshone range as being unrelated to the sulphide deposits, but epigenetic and closely associated with Devonian chert. In the Carlin deposit, galena and native arsenic have been observed in the barite; native arsenic was seen under high magnification.

Barite, pyrite, and iron oxides are the most commonly observed minerals in the mine area. Calcite is present in moderate amount, but no black calcite has been observed. Galena, cinnabar, and stibnite have been recognized without the aid of a hand lens. Cinnabar is easily panned in several areas within the gold-bearing portions of the orebody as well as in non-gold-bearing areas.

No guide minerals observable in mining benches indicate gold mineralization, and complete dependence on assaying is required to control ore grade during mining. Gold particles are extremely fine, and it is probable that as much as 90 percent of the gold is present in particles measuring less than 1 micron in maximum dimension. The largest particle seen is in the 5-micron range (fig. 5). Gold has also been observed in particles as small as 0.01 micron in size, or just 75 times the size of the gold atom. This gold can occur within siltstone or as inclusions in microcrystalline quartz veins that cut pyrite grains having dimensions in the 1-micron range. Pyrite is identified without the hand lens in fresh rocks.

The major portion of the orebody is largely oxidized, and is free from carbonaceous material and pyrite. The refractory effect of some types of carbon on gold extraction by cyanide is well known. Some gold within the microcrystalline quartz veins is also refractory. The absence of carbon and pyrite from the major portion of the orebody is probably the result of oxidation. The "bleached" or carbon and pyrite free area is closely related to the present surface, and is most pronounced in the vicinity of strong fracturing. Unoxidized portions of the orebody are gray to black, and indicate the presence of either or both pyrite and carbon; gold may or may not be present. At depth and laterally away from the orebody, residual carbon and

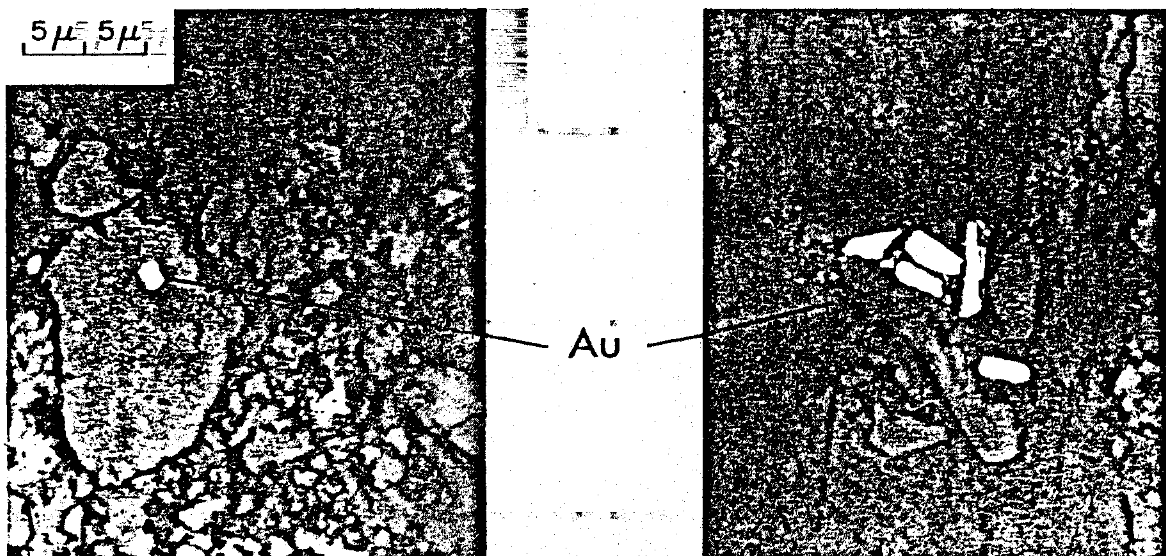

FIGURE 5. Photomicrograph showing gold particles typical of the coarser fraction present in this deposit. Magnification approximately 1600 x.

pyrite content increase. Prominent fractures within the orebody have apparently been responsible for the introduction of pyrite, gold, and other minerals as well as providing access to later supergene solutions. In unoxidized portions of the orebody, carbon of possible petroliferous origin can be present in amounts of several percent, and is associated with pyrite in 1- to 20- micron sizes. Carbon phases in 0.5- to 50-micron range show micro-pore spaces, and this material was probably important in precipitation of gold. Ore-grade gold mineralization has been drilled as deep as 700 feet below the surface, but no pannable gold has been found in oxidized or unoxidized condition in concentrations as high as 4 ounces per ton.

Gold-silver ratios vary from one extreme to the other, but the overall content of the orebody may be in the range reported earlier by Vanderburg (1936) for the placer gold in the Lynn district. Vanderburg stated that the placer gold varied from 920 to 960 in fineness or a gold-silver ratio between 11 to 1 to 24 to 1. Not enough information from bullion is available at this date to make a general statement on gold-silver ratios in the Carlin deposit. Assays of the small amounts of silver found in drill hole cuttings are probably not dependable for calculating an overall gold-silver ratio. It appears probable however that a 10 to 1 gold-silver ratio may be present. This ratio has been reported by Joralemon (1951) from bullion returns for the Getchell mine in Humboldt County. Ferguson (1924) reported a gold-silver ratio of 17 to 1 from bullion returns for one of the mines at Manhattan, Nev. The Goldacres and Bootstrap mines (H.Treweek, personal communication) show gold-silver ratios from bullion returns of over 20 to 1. These two deposits are both associated with the Roberts Mountain thrust fault. Bullion reports do not always reflect the possible losses of silver and gold in slag, or fumes or possibly in the tailings of treatment plants. The Carlin, Goldacres and Bootstrap deposits have no reported realgar or orpiment as do the high gold-silver ratio deposits at Getchell and Manhattan.

Age of Mineralization

The age of mineralization presents an interesting study and is important in the exploration for mineral deposits. Gold mineralization associated with hotsprings (White, 1955), and with basin-and-range faulting (Page, 1965), suggests recent age of mineralization. At Carlin, there is no evidence of gold mineralization near the basin-and-range faults nor is there evidence of hot spring action in the area.

Silicification

Addition of silica to the orebody in several forms is recognized, three of which can be mapped in the field. The most obvious form of silicification converts thin-bedded Roberts Mountains sediments to a dark-brown prominently outcropping rock that has a very similar appearance to the siliceous shales of the Vinini formation of the upper plate. This condition has resulted in the erroneous classification of such rocks as klippe of upper-plate sediments. This silicification has protected the affected sediments from oxidation and bleaching, and they appear as dark-brown patches with similar colored soil. In some outcrops this silicification appears to be closely associated with shear zones along which hydrothermal solutions were introduced. In other outcrops, silicification appears to be associated with supergene solutions resulting in formation of silicified "scabs."

Another form of silica is light colored and apparently is later than barite and also later than at least some of the "bleaching" of sediments. Gold can occur with this stage of silicification, but most of it is seen in the footwall of the orebody. A sample of barite from this type of silicified outcrop showed a bright metallic inclusion that proved to be metallic arsenic when tested with the electron probe. Stibnite has also been found with such silicification.

A third form of silica is in the form of white stringers that carry no gold and are usually found at some distance from the orebody. Quartz stringers such as these are seen near a prospect 1 mile to the west near lead-silver-copper mineralization in the Hanson Creek formation.

Laboratory study of rocks within the ore zone and along the Roberts Mountains thrust fault adjacent to the ore zone, show the addition of silica and clay minerals by hydrothermal solutions and the removal of carbonate minerals. A series of samples taken from a 6-foot ditch dug across the fault on the west side of the orebody showed a major amount of montmorillonite and lesser illitic clays and quartz in the fault zone; carbonate minerals were absent from the fault zone and from the adjacent units of the Vinini and Roberts Mountains formations. Of the various metals present in small amounts, titanium,arsenic and zinc were slightly higher in most gouge samples from the Roberts Mountain thrust fault. More samples must be taken before generalizations can be attempted.

Within the gold-bearing Roberts Mountains formation, siltstone particles are commonly enlarged by authigenic overgrowths. Overgrowth rims often contain relict inclusions of clays and carbonates along the relict grain boundaries and are attributed to addition of silica during mineralization. Such enlarged particles contain visible gold within micropore spaces that range in size from 1 to 50 microns. A feldspar porphyry within the mineralized zone is almost completely replaced by microcrystalline quartz. Highly siliceous cherty rocks that are mineralized with gold account for over 70 percent of the refractory ores. Refractory gold mineralization in pyrite-bearing rocks is locked within microcrystalline quartz within the pyrite, and cannot be made available to cyanide solutions even when the quartz is separated from the pyrite by extremely fine grinding. Associated with the hydrothermal addition of silica are potash-bearing sericite and illite; no evidence of anomalous potash clays or silts introduced during sedimentation has been found.

Examination of rock chips from within the ore zones and immediately adjacent to these zones is aided by the preparation of rock chip boards from rotary drill hole cuttings. A 40-power binocular microscope is used effectively to demonstrate many instances of sandy texture in the better-mineralized ore. Considerable areas that do not show such coarsely porous texture are strongly mineralized, however, and the micro-porous texture apparently suffices for the solutions that were present. Numerous quartz veinlets less than 3 mm wide are easily seen adjacent to the mineralized bands.

ACKNOWLEDGEMENTS

This article contains much information that was accumulated by the geologists who discovered the Carlin Gold deposit, and by the company officials who directed exploration efforts that resulted in discovery. Research and laboratory study on

mineralogy and metallurgy at the Company's Danbury, Conn., office also has been used. A comprehensive article by Frank McQuiston, Jr., Vice President, and Robert Hernlund, metallurgist, giving metallurgical and other details of the Carlin Gold operation, was published in the November 1965 issue of Mining Congress Journal. Mr. Peter N. Loncar, Carlin Gold mine superintendent, presented a paper on open pit mining at the October 7, 1965 Phoenix, Arizona meeting of the A.I.M.E.

A list of references acknowledges many who have contributed to the present state of knowledge of the structure and ore deposits of the region.

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