Colorado State University SEG Student Chapter Field Trip Guidebook

Carlin-Style Deposits of Nevada

March 16-22, 2019

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Special Thanks To:

NEWMONT

NuLegacy Gold CORPORATION

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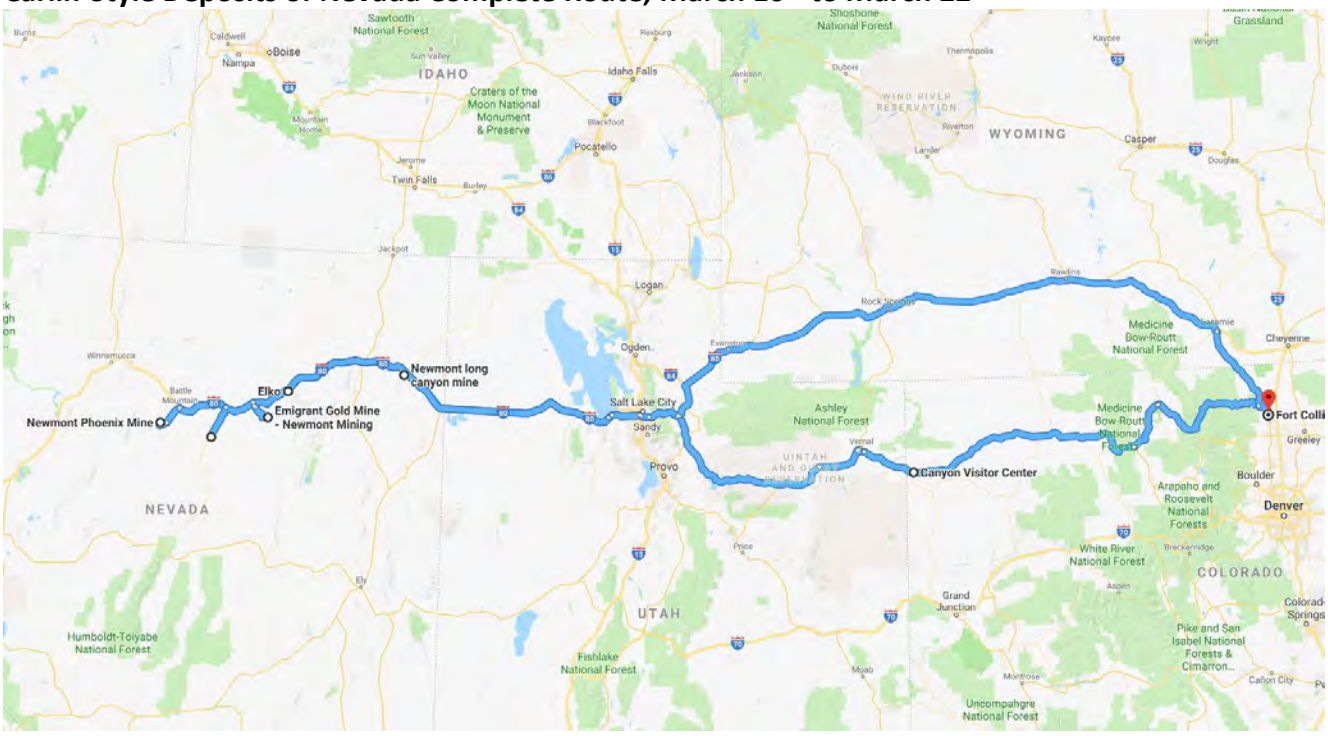
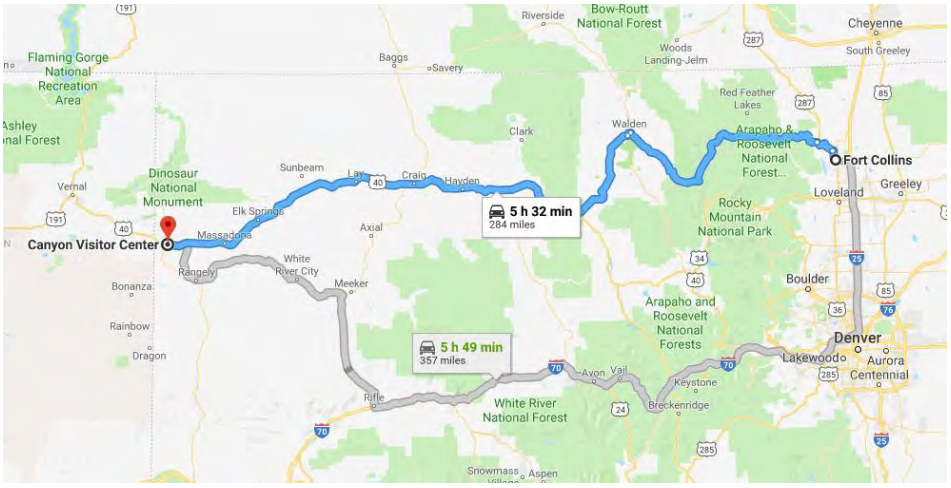
Field Trip Itinerary

Carlin-Style Deposits of Nevada Complete Route, March 16th to March 22nd



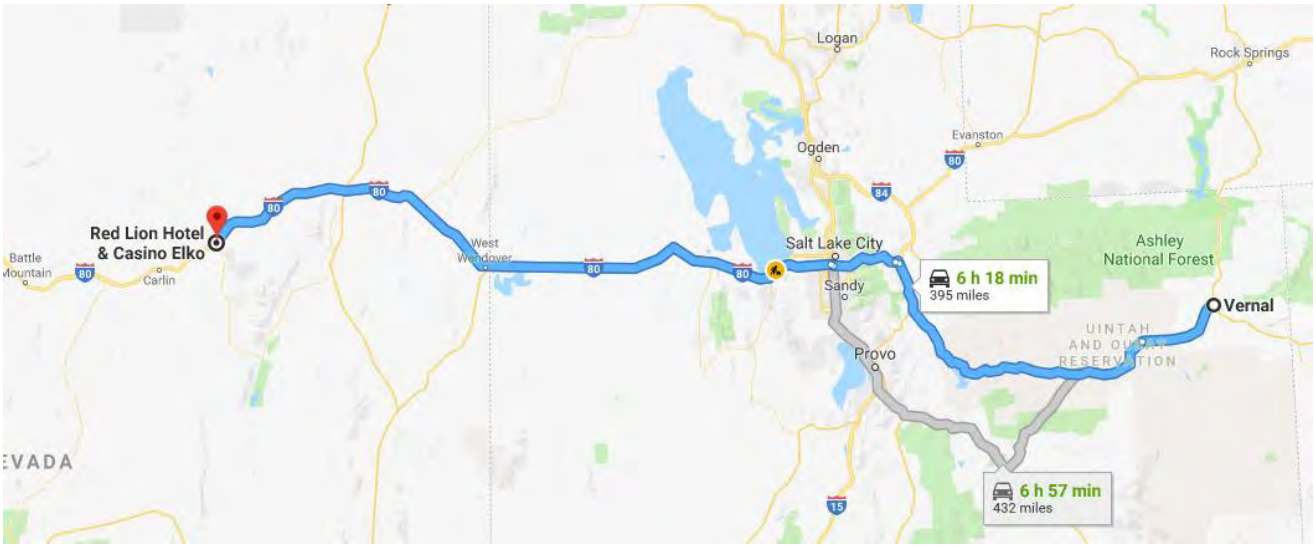
Day 1: Saturday, March 16th

- 8:00 AM Depart Fort Collins, Colorado
- Meet at 7:30 AM at the front of Warner.
- Drive to Dinosaur National Monument. (~ 5 hrs 30 min, 284 miles)
- ~2:00 PM Arrive at DNM Visitor Center
- 6:00 PM Depart for Vernal, UT
- Hotel in Vernal, UT



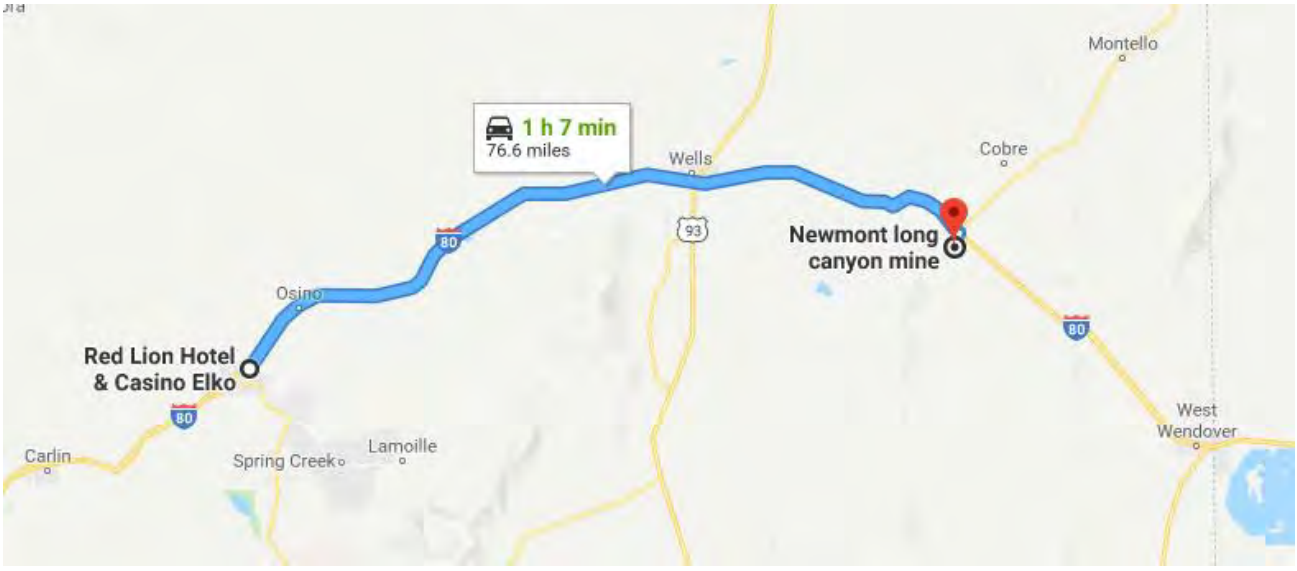
Day 2: Sunday, March 17th

- 8:00 AM Depart from DNM for Elko, NV (~6 hrs 20 min, 395 miles)
- 2:30 PM Arrive at Red Lion Hotel & Casino
- Grocery Shopping, prep for week



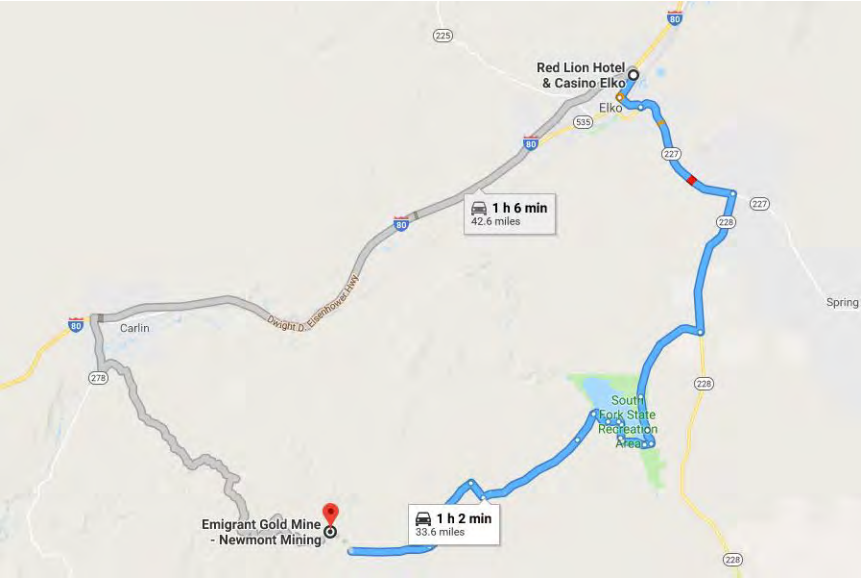
Day 3: Monday, March 18th

- 7:00 AM Depart from Red Lion Hotel (~1 hr 7 min, 77 miles)
- 8:00 AM Meet with Dr. Thompson, travel to Long Canyon Mine
- ~4:00 PM Depart Long Canyon Mine for Red Lion Hotel
- ~5:00 PM Arrive at Red Lion Hotel



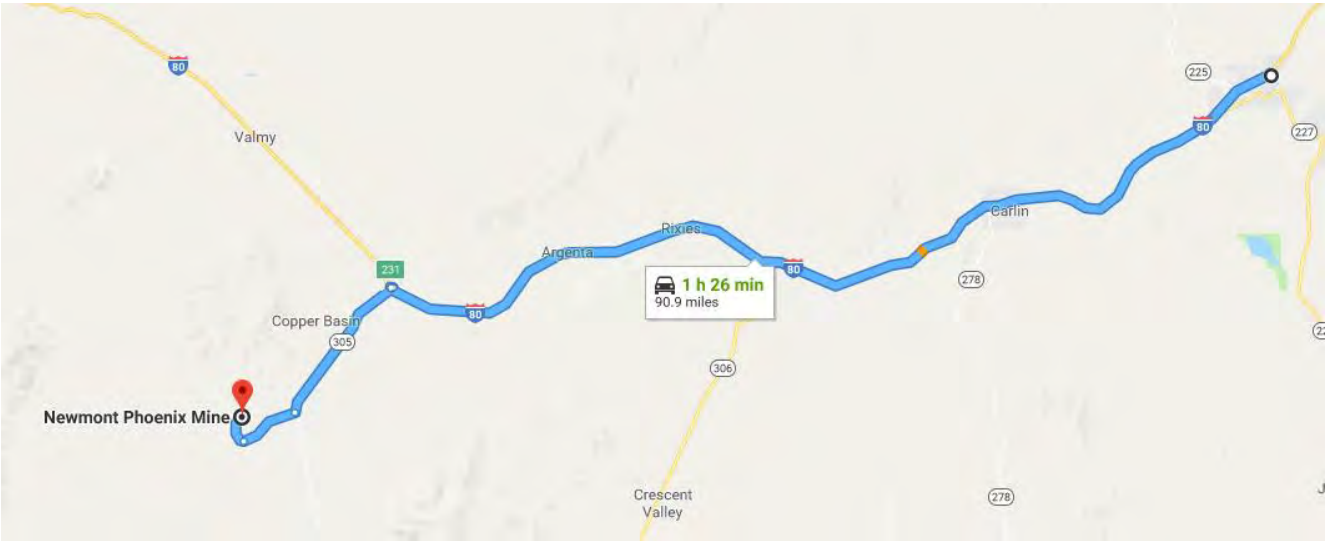
Day 4: Tuesday, March 19th

- 7:00 AM Depart from Red Lion Hotel (~1 hr 6 min, 42.6 miles)
- 8:00 AM Meet with Dr. Thompson, travel to Emigrant Mine
- ~4:00 PM Depart Emigrant Mine for Red Lion Hotel
- ~5:00 PM Arrive at Red Lion Hotel



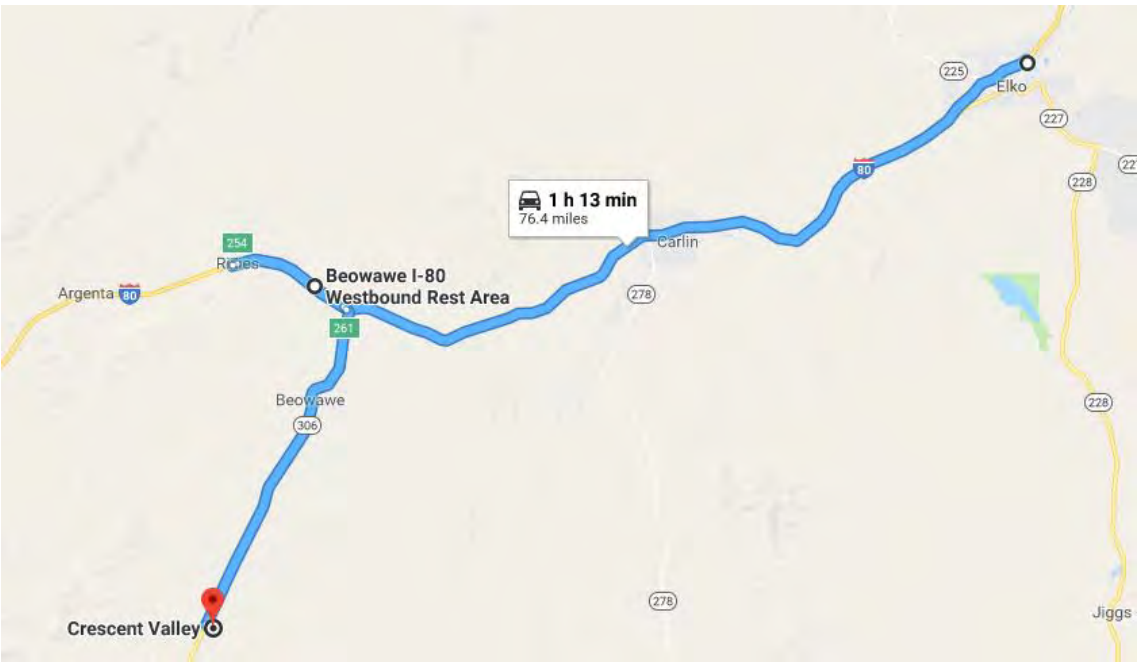
Day 5: Wednesday, March 20th

- 6:30 AM Depart from Red Lion Hotel (~1 hr 26 min, 90.9 miles)
- 8:00 AM Meet with Dr. Thompson, travel to Phoenix Mine
- ~4:00 PM Depart Phoenix Mine for Red Lion Hotel
- ~5:30 PM Arrive at Red Lion Hotel



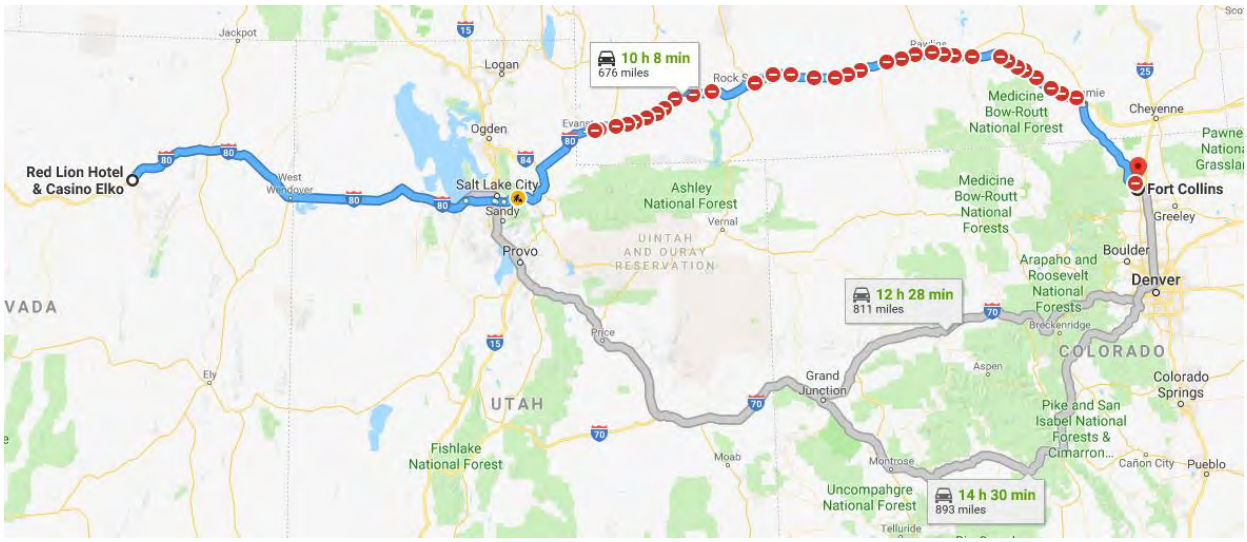
Day 6: Thursday, March 21st

- 9:15 AM Depart from Red Lion Hotel (~73 min, 76 miles)
- 10:00 AM Meet with Dr. Steininger, travel to Cresent Valley Prospect sites
- ~5:30 PM Arrive at Red Lion Hotel



Day 7: Friday, March 22nd

- 8:00 AM Return to Fort Collins (~10 hrs 10 min, 676 miles)
- ~5:30 PM Arrive in Fort Collins



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Alex Hegley – (706) 421-0348
Fallaye Diallo – (720) 369-5091

Lodging

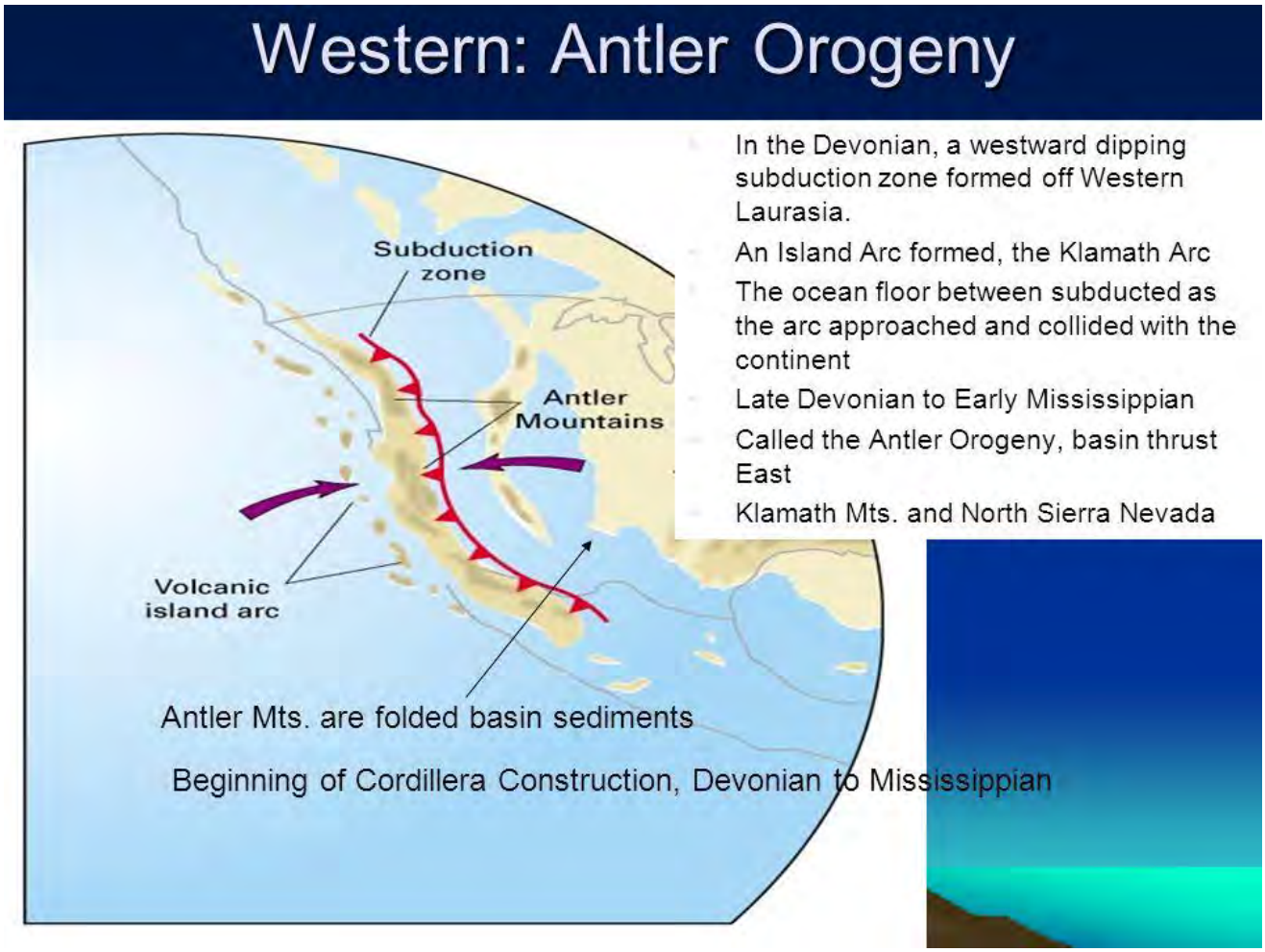
Date	City	Site	Address	Phone No.
Night 1: 3/16	Vernal, UT	Days Inn	1092 W US-40 Vernal, UT 84073	(435) 363-4939
Night 2: 3/17-3/22	Elko, NV	Red Lion Hotel & Casino	2065 Idaho St Elko, NV 89801	(775) 738-2111

Geologic History of Nevada

Alex Hegley – B.S. Student, Colorado State University, alexhegley1@gmail.com

Before the concept of plate tectonics geologists struggled to explain the mountains and the presence of oceanic rocks of Nevada. The Antler Orogeny is the first significant orogeny that influenced the ancestral North American continent named Laurentia. Unlike most orogenies the Antler Orogeny does not involve continents or cratons colliding, rather it involves oceanic plate subduction under a craton. However, in this instance island arc volcanoes similar to the modern East Indies were dragged into and eastward subduction starting in the late Devonian and having continued effects into the Mesozoic. This system of volcanic island arcs called the Klamath Arc collided with the North American craton named Laurentia. This collision and the stresses developed as subductive plate drag continued to try to drag the craton under had far reaching effects on the western portion of Laurentia. This event developed into the Antler Orogeny which is the mountain building event that created the ancestral Rocky Mountains and much of the topography and confusing stratigraphy of Nevada. The region of northwest Nevada that we are visiting in the vicinity of Elko is at the border of the Antler Allochthon and Antler Foredeep regions.

The presence of Antler Orogeny deposits of oceanic basalts and other rocks in Nevada continues to confuse and infuriate geologists.



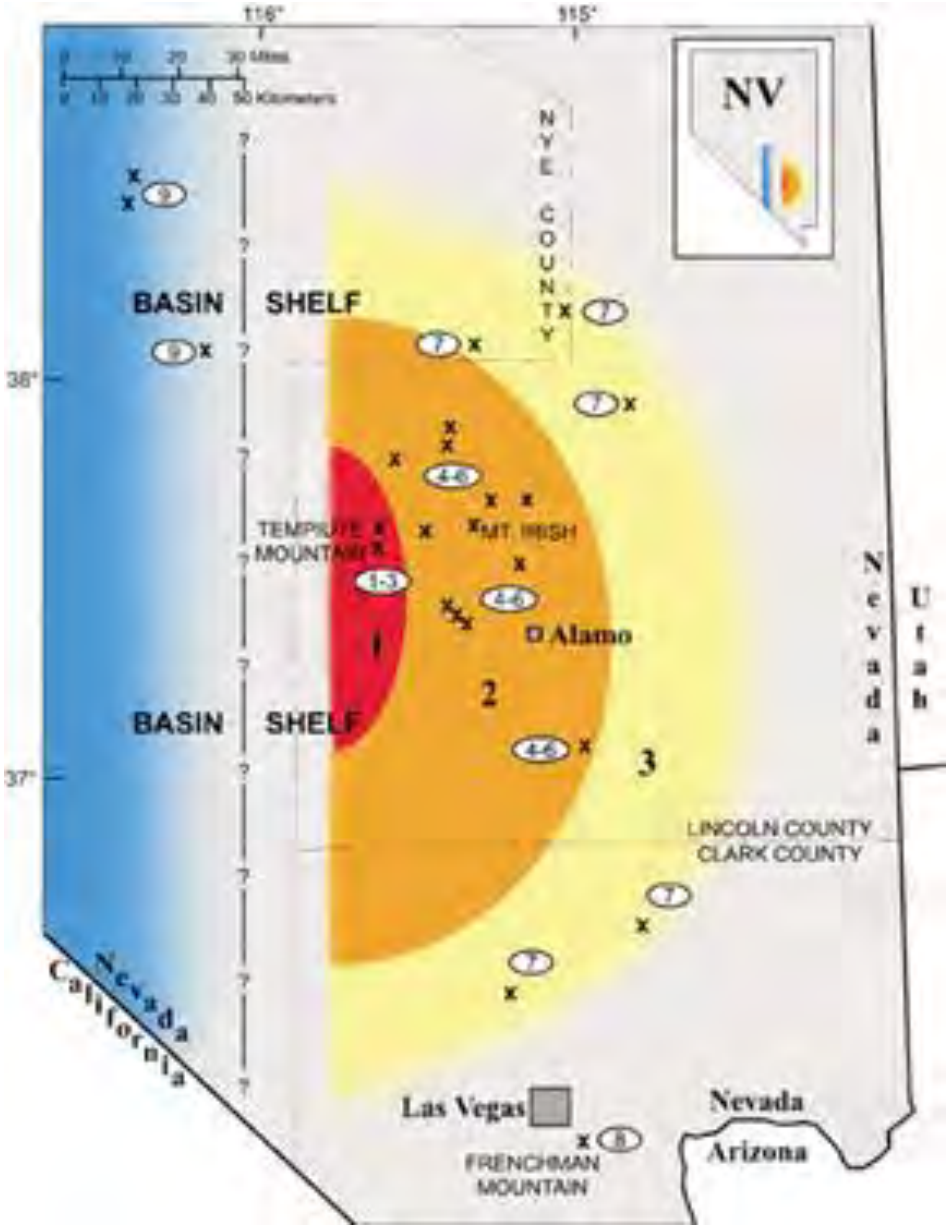
The stratigraphic column is out of sequence, and presence of extensive conglomerate beds add to the problem, and subsequently the arguing. That is before we even begin to talk about the meteor strike that may or may not exist. The evidence of the Orogeny has third and fourth order layers of complexity. Those being the extensive faulting both major and minor, and volcanism and intrusion that is evident by the carlin type deposits around Elko. There are several opposing theories that are supported by observation and scientific evidence, but there is no real consensus.

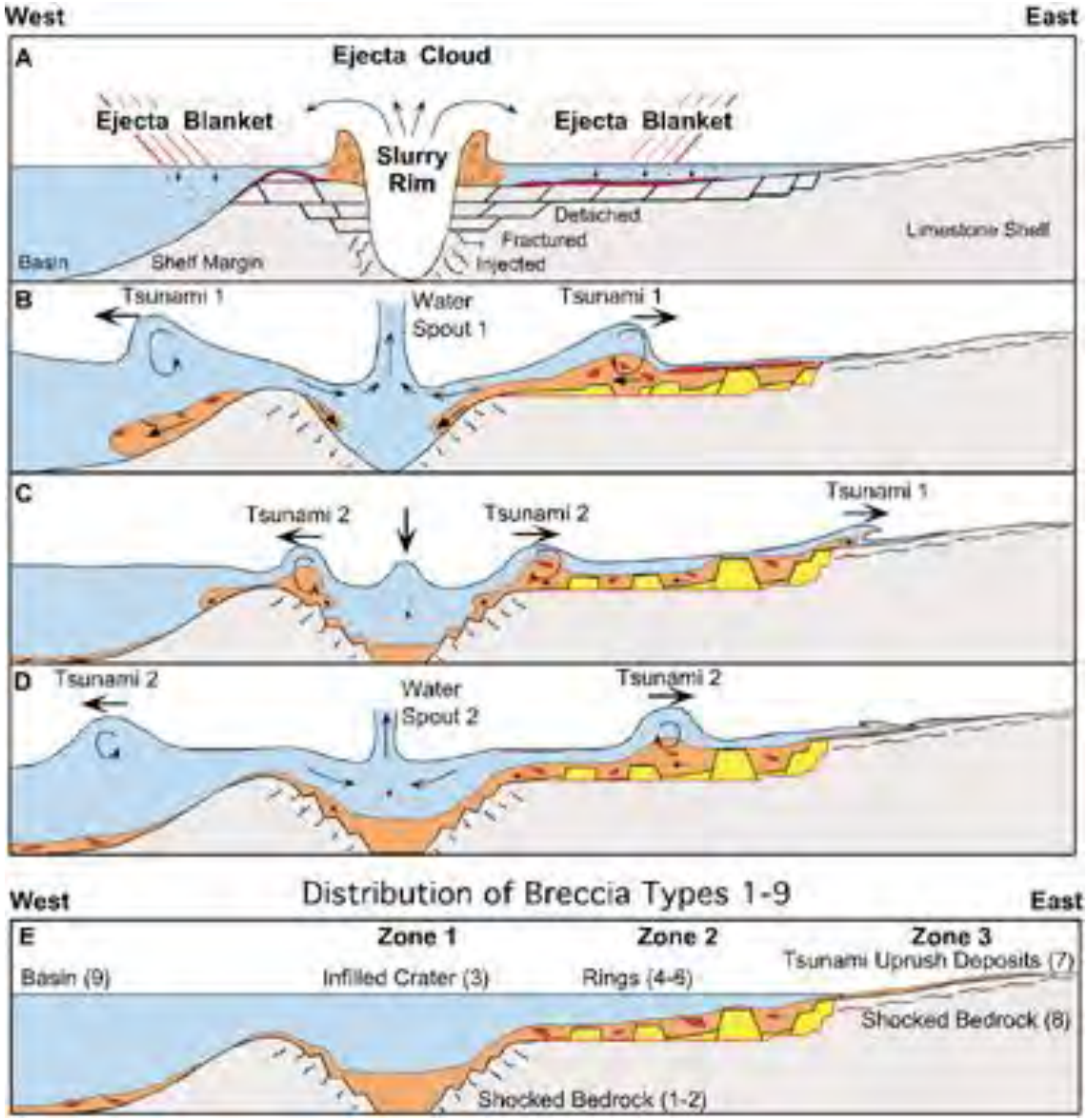
What can be agreed upon is that in the Devonian there was a volcanic arc island chain similar to the modern-day East Indies that collided with the Laurentia, the craton that became the North American continent. The Island Arc called Kalmath was on a plate that was subducting underneath Laurentia from west to east until the island arc made contact. Kalmath is still in place and is what forms most of California and is now a part of the North American continent and is being subducted by the pacific plate in the west to east orientation. It is everything after this that is problematic.

Antler Orogeny

The presence of Antler Orogeny deposits of oceanic basalts and deep marine sediments and other rocks in Nevada continues to confuse and infuriate geologists. There are several opposing theories that are supported by observation and scientific evidence, but there is no real consensus. What can be agreed upon is that in the Devonian there was a volcanic arc island chain similar to modern day East Indies that collided with the Laurentia, the craton that became the North American continent. The Island Arc formed on an oceanic plate subduction zone with the continental shelf of Laurentia subducting underneath it from the east. This island arc is still in place and is what forms most of California and is now a part of the North American continent and is being subducted by the pacific plate in the west to east orientation.

As Laurentia continued to subduct its continental shelf westward towards the island arc chain oceanic sediments and limestones starts undergoing compressional deformation.





This deformation resulted in folding and thickening of sedimentary beds. As this compression continued ocean floor basalts and deep-water sediments began to overlay the shallow marine limestones developing the distinctly infuriating stratigraphic sequence of Nevada.

Alamo Impact Breccia

During the Devonian, 370 million years ago, there was a wet impact meteor strike off the coast of Laurentia. The strike landed in what would later become central Nevada. The resulting breccia is now outcropped in 25 different ranges and covers with an area of roughly 100,000 km^2. This breccia includes shocked quartz and averages 10 m in thickness and the estimated volume of rock displaced is 1,000 km^3. The largest explosively displaced clasts that have been discovered are tens of meters in in size. The crater is no longer intact and as the meteor landed offshore in the accretion zone between Laurentia and Kalmath in a marine environment before the two land masses contacted each other. This adds a layer of complexity to the Antler Orogeny stratigraphic column in central and northern Nevada.

The strongest evidence that these breccia are impact derived and not volcanic is that these breccia and disrupted stratigraphic sequences are the shocked quartz grains. Several thousand

quarte grains were analyzed in thin section. Most show 3 directions of shock lamellae, with some showing as many as 6 directions. There are also spherical clasts within the breccia that contain fossil remnants and shocked quarts. These lapilli clasts were dehydrated and liquified during their launch from the Alamo Event. While in flight these clasts became spherical and were then precipitated as a blanket which then rehydrated and lithified. These lapilli beds are rare because of the extensive deformation in the region from the continuing Antler Orogeny deformation and later intrusions. The Alamo Impact event is dated as roughly 3 million years before the late Devonian extinction event and is estimated to be sub-critical in its energy level partly due to being a wet impact. The impact also created vertical fractures within the shallow marine limestone beds and the subsequent tsunami also left a thin layer us uprush deposits on land.

Volcanism, Earthquakes, and Intrusion Episodes

The state of Nevada has been subject to an exceptional amount of other geologic activity in the past 400 million years. Each of which episode further scrambles and adds complexity and difficulty in determining the exact nature of the Nevada's original formation. During the Mississippian (320 Ga) the Antler Orogeny was still underway and began to form the folds and thrusts from west to east along with the Roberts mountain thrust. In the Pennsylvanian (290 Ga) the antler highlands formed and quickly eroded to deposit more carbonate east and south. The Permian (251 Ga) episodes of volcanism began in the western portion of the state near the California border. The Triassic and Jurassic (251-114 Ga) had explosive episodes of volcanism throughout the state due to subduction off the coast of California which deposited thick ash layers. This is also an era of igneous intrusion into the carbonate beds that formed the famous carlin and skarn deposits. The Cretaceous (65 Ga) hosts many more granitic igneous intrusions and the formation of the Sierra Nevada mountains, these intrusions caused the enrichment of the majority of the mineral and ore deposits. In this era the southeastern portion of the state was once again folded and thrust from west to east by the Sevier Orogeny. In the Cenozoic (65 Ga to present) Nevada passed over the Yellowstone hotspot. This caused further enriching or ore and copper. The Valleys between mountain ranges experience elevation drop due to extension in the crust. The Cenozoic also had the ice ages and glaciers in the high elevations. Mountain building, earthquakes, volcanism, and geothermal activity continue to this day.

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Stratigraphy of Northeast Nevada

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The state of Nevada includes mountains and valleys; it comprises a majority of the Great Basin, and is the highest producer of gold in the United States. The geology of the state, particularly the stratigraphic record, will reveal the varied past of the land. Multiple tectonic events are evident in the rock record, and the fossils found in Nevada tell how the natural environment has changed over geologic time. Today, Nevada has a unique geologic makeup that has formed over billions of years. Nevada makes up most of the Great Basin of the United States, a region of uplifted ranges between basin valleys. There is infrequent rainfall and low-energy rainfall, but the Great Basin produces abundant mineral resources such as lithium, silver, and gold (Britannica, 2019). The rock record of Nevada reveals the many geologic events and environments the state has undergone over geologic time.

The oldest rock record in Nevada dates to the Precambrian Eon, but those rocks are not well preserved and do not reveal much information about this time. The Paleozoic Era is much more well-preserved: Nevada was a shallow marine region, and the deposition from this time reflects that environment in fine-grained, low-energy sedimentary rocks (Price, 2004). The Antler Orogeny occurred in the late Devonian, and from that event the Roberts Mountain thrust and allochthon originated. During the Mesozoic Era, the state was divided, with igneous intrusions occurring in the west and sedimentary deposition in the east (Price, 2004). The Sevier Orogeny also occurred across western North America. The Cenozoic Era was a time of basin extension and lots of volcanic and tectonic activity; the ore deposits that now make the region so prosperous in mineral resources formed at this time (Price, 2004). Today, the geologic surface of Nevada is mostly recent sedimentary rock and exposed igneous and volcanic rock from the Cenozoic (Stewart and Carlson, 1978).

Across the state of Nevada, the stratigraphic record varies with the landscape; the northeast corner where many gold deposits exist is a unique stratigraphic area, with many allochthons, or large units of rock that have been displaced from their original places of formation by tectonic activity. The Cordilleran Orogenic Belt runs through Nevada, which contains a record of three orogenic events: the Antler, Sonoma, and the Sevier. Of these three, only the Antler and Sonoma are located in the northeast region of the state (DePietro, 2013). At the base of this stratigraphic record is the Cordilleran Miogeocline, which is a deposit of shallow marine sediment from the continent's Late Precambrian passive margin. Both the Antler and Sonoma have sedimentary lithologies that have undergone thrust faulting and folding (DePietro, 2013). The Antler Orogeny is the oldest of these, having begun in the late Devonian Period and continued into the Mississippian Period. The Antler Orogeny can be seen in the foreland where the Chainman Shale and the Diamond Peak formation transgress to the east across the miogeocline (DePietro, 2013). At this time, the Roberts Mountain allochthon was thrusted to where it is located now. This allochthon is exposed in many locations including the Tuscaroro Mountains, Roberts Mountains, Candelaria Hills, and Battle Mountain. The Roberts Mountain allochthon consists of shales, sandstones, limestones, and basalts from the late Cambrian to late Devonian, indicating a varying marine environment of deposition. This allochthon is the same age as the Cordilleran miogeocline, but overlies it because it was moved eastward from its original location (DePietro, 2013). The Sonoma Orogeny, a collision of an offshore volcanic arc with the mainland, lasted from the mid- to late Permian Period. The result of this event is the Golconda allochthon, located above and west of the Roberts Mountain allochthon. This allochthon consists of chert, conglomerates, sandstones, and volcanic debris; these are evident of the back-arc basin that was originally between a continental margin and a volcanic arc. The Golconda allochthon is exposed in the Toquima and Sonoma ranges and at Antler Peak (DePietro, 2013).

These events and features create a unique stratigraphic record of the changes Nevada's land has undergone.

The paleontology of Nevada is also an extensive source of information for the geologic past of the area. As with the general rock record, Precambrian fossils are not well preserved in Nevada, but based on bacteria fossils, the area was flooded by shallow seawater. The Paleozoic Era began as a shallow sea as well with reef communities and graptolites, and until the Devonian the land was a deep ocean basin (Paleontology Portal). By the Permian, the sea level had dropped and left the eastern region as dry land, as evidenced by plants fossils. During the Mesozoic Era, sea level changes and tectonic activity were abundant, and the sea continued to recede. In the western marine areas, ammonites are abundant. By the Cenozoic Era, tectonic activity and mountain building continued, and the Great Basin we see today formed. Mammals such as ancient rhinos and giant sloths lived at this time (Paleontology Portal).

One of the most abundant resources in Nevada is gold, and there is a cluster of gold mines in Elko County. The majority of these gold deposits are placers: deposits of sand or gravel in fluvial or lacustrine environments containing particles of valuable minerals. Two of the major mine district of this northeastern corner of the state are the Mountain City District and the Charleston District. Mountain City, located north of Patsville, NV, is sourced in gold veins in a granodiorite pluton which mineralized during the Cretaceous Period (Johnson, 1973). The Charleston District, located south of the town Charleston, is sourced in gold veins in Paleozoic sedimentary rock (Johnson, 1973). These are only two major mining districts in Elko County; Nevada is the greatest gold producing state in the country, and there are mines across the state.

The stratigraphic record of Nevada tells the story of multiple orogenies and changes in sea level, all of which have formed the state we know today. The northeast region of the state is a unique area with abundant gold deposits and stratigraphic structures that show the changes in landscape since the Precambrian Eon.

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CARLIN TYPE GOLD DEPOSITS

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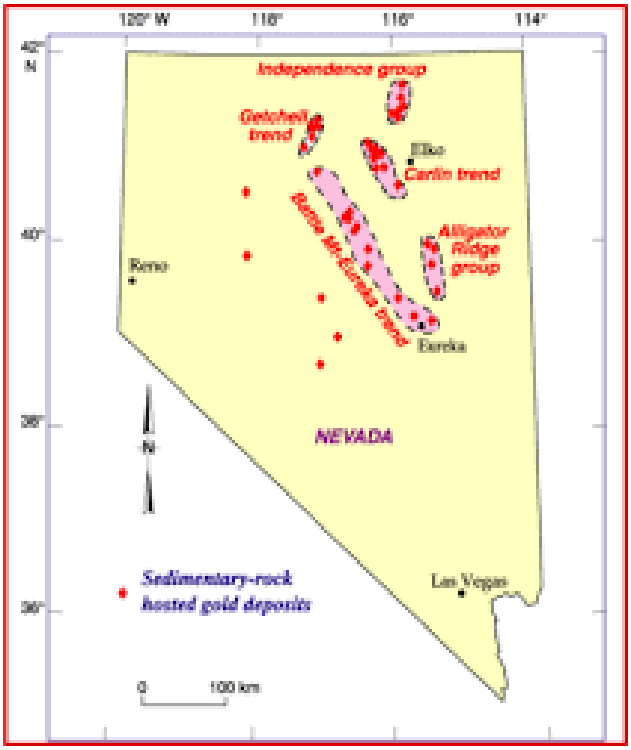
Introduction

The Carlin type deposit is a hydrothermal epigenetic deposit that form at low temperature. This type of deposit has been first discovered and described in Nevada. The one discovered in this area is 100 000 km squared big and was deposited in the Cenozoic. The deposition of the ore mineral is disseminated. As associated minerals we can find As, Hg, Sb, and sulfide minerals, these minerals are found in altered carbonate rocks. The name of the deposit comes from Carlin mine in Nevada. The Gold mineral found in this type of deposit is not visible, but it is found by chemical analysis. The host rocks associated to the ore mineral are mostly sedimentary, with the presence of igneous dykes.

Figure 1: Location of the Carlin type deposits in the State of Nevada

Geologic Setting

The geologic setting of the Carlin type deposit is composed of different sequences that resulted in the formation of the ore deposit on a long span of time. The temperature required to form Carlin type deposit is from 150-250 degrees C, at 1-6 km depth (Ridely 2015). The



geologic setting of this deposit can be split in several sequences in which tectonic activities were involved. The host rocks for the ore mineral are carbonate rocks, mainly Limestone, Dolomite, and shale; there are also presence of igneous intrusion. The sedimentary sequences have been folded and faulted, but there is no sign of metamorphism. In Areas were the Carlin type deposit exist the crust has undergone extensional deformation. The ore minerals are controlled by both strata bound and structure. The sequences that form the deposit goes as follow, the wall rocks are the carbonate rocks that are the host rocks as well.

There have been contradictions when it comes to the genesis of the formation of the Carlin type deposits. For the Carlin type deposits located in Nevada we can say that there is a general consensus when it comes to agreeing on a typical formation process. First, we have the deposition of the carbonate rocks described as a Transitional sediment deposited from deep water, this sediment deposition was overlying an already fault-sliced Proterozoic-Cambrian sediment, these faults had been created during the ripping apart of the continents. at this time the continental shelf margin of America cut through the state of Nevada. Then a volcanic arc has started moving in the east direction from the sea, this is when the oceanic crust was moving eastward from the result of a subduction zone. The subduction activity folded the sediment deposits present, resulting in the reactivation of the faults that were present in the Proterozoic- Cambrian sediment; this tectonic activity forced the faults to deep steeper. During all this subduction activities, a new slab of crust has intruded the mantle below the sediment deposits. Around 150ma due to all the Orogeny occurring in the continent the state of Nevada was a high relief area. The thrusting was still ongoing during all that time, as a hot mantle moved right below the lower continental crust around the state of Nevada, the Oceanic slab has been melted, now that we have a heavier continental crust, this will result in the up rise of the magma transporting the ore mineral. with the presence of the reactivated faults

and the presence of folds, the hot hydrothermal fluid could easily make its way up.

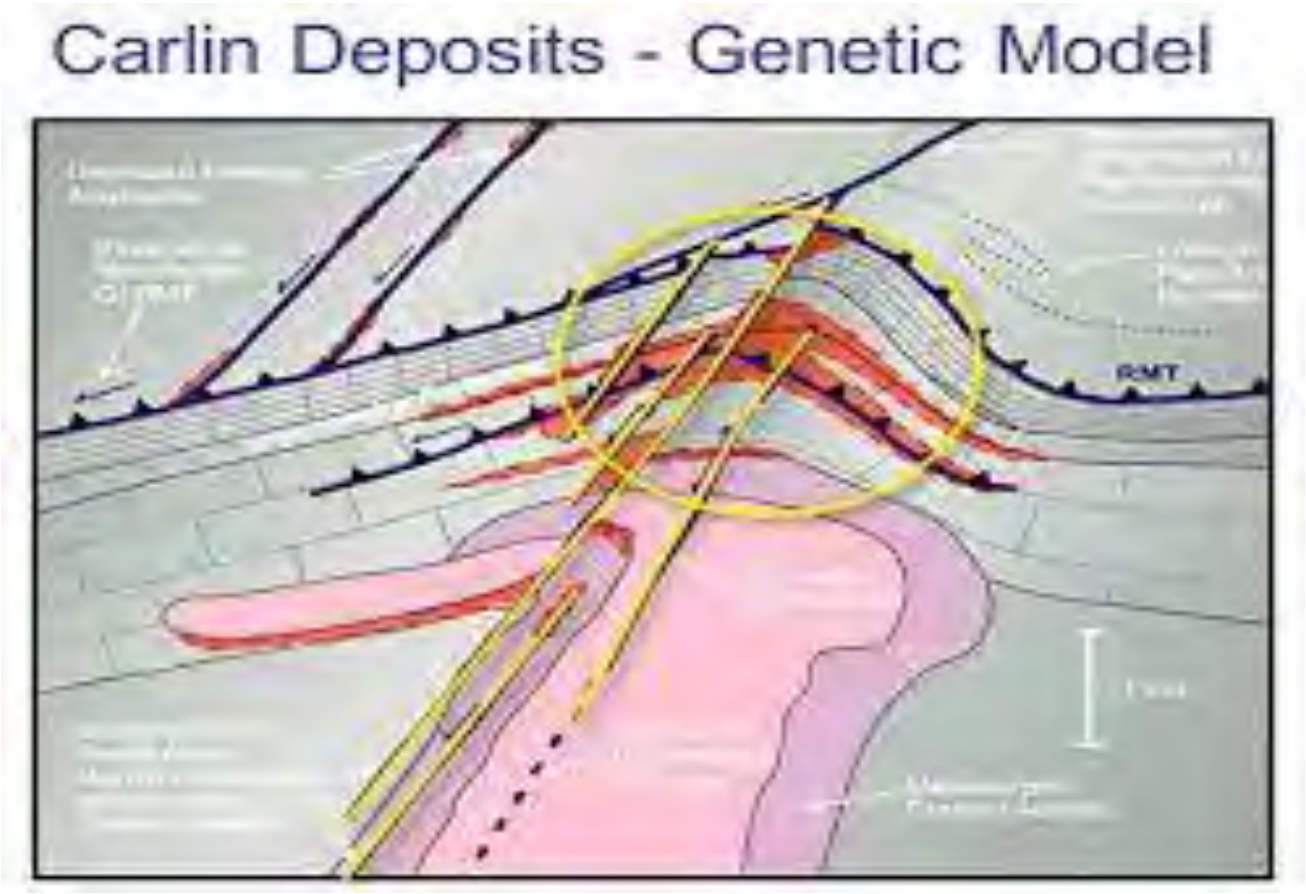
Mineralization and Alteration

The process of ore mineralization in the Carlin type deposit may have been reached at higher temperature than the surrounding (Ridely 2015). The formation of the ore in the host rocks could not have taken place at the temperature present at the location, therefore the intruded fluids had to be at a higher temperature than the surrounding materials. This process caused hydrothermal alteration, since the surrounding materials were cooler than the hydrothermal fluid, alteration had to occur. The stratabound future in this type of deposit, point us to the idea that the ore fluid only decided to associate with certain type of rock present, with carbonate rocks present, with their characteristic of fast dissolution, they happen to be the best fit for host rocks. The dissolution in carbonate rocks creates porosity when they come in contact with the hydrothermal fluid, which makes a good path way for the ore fluid. With all that, Au precipitation could be another process occurring during the same mineralization process, since the hydrothermal fluid contains Sulfuric acid, sedimentary reacts when they come in contact with the fluid, making them more pores and altered, this then result in the precipitation of Arsenopyrite and pyrite, this will cause a reduction in the solubility of the gold as bisulfide gold. The ore is disseminated in the rocks, the most important alteration present is Argillic.

Figure 2: Genetic model of the formation of the Carlin type deposit.

Conclusion

Carlin type deposits are very important for the production of Gold, because the mineral that is mainly produced from this deposit is Au. This type of deposit is being mine in Nevada by Newmont and Barrick, where both companies are making major profits from these deposits. The formation is the result of the formation of



continents. The ore in the deposit can only be located by chemical analyses. The deposit is associated with altered carbonate rocks. The geologic setting for Carlin type deposits is based on a succession of tectonic movements, and hydrothermal fluid intrusion, which created chemical reactions that resulted in the precipitation of Au. The two main productions occurring in this area of Nevada are done by Barrick and Newmont.

References:

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Gold Processing Techniques

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Introduction

Gold has played a key role in the mining and exploration industry for well over a

millennium. Records show that Ancient Egyptian dynasties have conducted gold exploration operations since at least 1156 BC (Adams and Willis, 2005). Gold was first sourced through alluvial deposits and only required panning techniques be used. Prospectors would use gold pans and water to sift through alluvial sediment. The high density of gold (19.3g/cm^3) allowed for the sediment to wash away, and leave the prospectors with small chunks of gold that could be melted down and forged into a more substantial unit (Adams and Willis, 2005). As the exploration for other sources of gold continued, deposits such as the Carlin deposits of Elko, Nevada were discovered.

Many of these deposits house what is known as "invisible gold." The gold in these deposits is typically a few micrometers in size and requires much more in depth methods to process the gold into quantities that are profitable (Kongolo and Mwema, 1998,). Gold is often found in sulfide minerals such as pyrite and arsenopyrite, and is often associated with silver in an alloy compound known as electrum. Other prominent minerals relating to gold ore deposits include the telluride minerals, other sulfides, copper, and iron (Kongolo and Mwema, 1998,). The three most notable gold ore processing/recovery techniques include mercury amalgamation, gravity concentration, and cyanidation and heap leaching (Eugene and Mujumdar).

Mercury Amalgamation

The process of creating amalgam from mercury and metals such as gold and silver has been around since approximately the sixteenth century. Mercury amalgamation is generally only used for gold measuring roughly "30 microns in diameter or greater" **(**Eugene and Mujumdar, p. 6). The first step in the amalgamation process is to extract rock or sediment that contains an approximate gold to rock/sediment ratio of "4.0 to 20.0 g/ton" (de Lacerda and Salomons, 1998, p. 7). The sediment is then crushed by the use of a grinding mill, or sifted by mesh nets and carpeted riffles (Figure 1). The metallic-rich sediment is then placed into "amalgamation drums, where it is mixed with liquid mercury" (de Lacerda and Salomons, 1998, p. 8). After the alloying of the mercury and gold has occurred, the amalgam is roasted either using a retort or a pan and open flame. This roasting process allows the mercury to dissipate leaving behind a gold with relatively high levels of impurities **(**de Lacerda and Salomons, 1998**)**.

Another amalgamation process is also used to process gold. After the metallic-rich sediment is crushed and sifted, it is placed on top of copper plates that have "a thin layer of mercury onto which the noble metals adhere" (Adams and Willis, 2005, p. xxxvi). The thin layer of

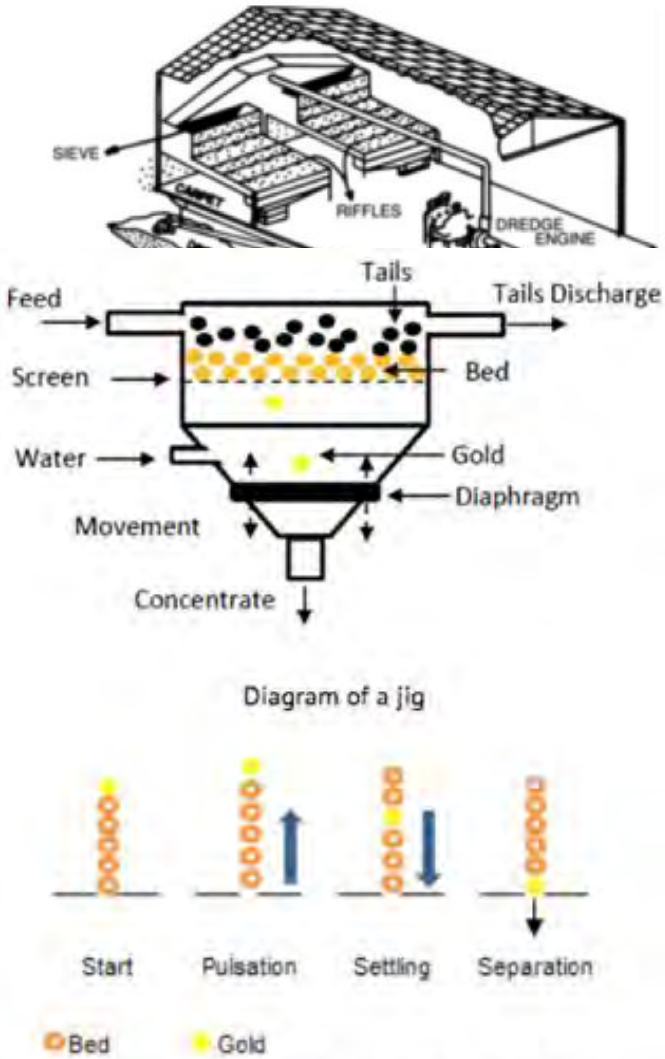

Figure 2. A diagram of a gravity concentration jig, and the stratification of gold ore and bed material (Michaud, 2017)

amalgamated gold is then scraped off the copper plates and heated in a retort to distil the mercury from the gold (Adams and Willis, 2005). This processing method is not used by the large mining corporations of today because of the unavoidable exposure to mercury, however, it is still used by many small mining operations in countries such as Brazil and the Philippines (de Lacerda and Salomons, 1998).

Gravity Concentration

The main concept of processing gold by gravity concentration is very similar to that of the older panning method. Both processes rely on the density and specific gravity of gold compared to the gangue minerals. The process begins by liberating the gold via "communition and grinding" (Kongolo and Mwema, 1998, p. 283). This process breaks down the sediment and rock containing the gold into particles ranging in size "from a few mm…to approximately 40 microns" (Kongolo and Mwema, 1998, p. 283). The particles are then separated by size in order to allow the specific gravity of gold (19.3) and the gangue minerals (2.7-3.5) to correctly separate the gold when suspended in a solution (Kongolo et al., 1998). There are many different ways to separate gold from gangue minerals using gravity concentration, however, the most prominent tools used include a sluice, jig, shaking table, and different centrifuge systems (Kongolo and Mwema, 1998).

The sluice is one of the oldest tools used to separate gold by gravity concentration. Sluices are channels that consist of multiple riffles built into the base of them with a thin bed of sand lining the bottom. These riffles are designed to slow down the particles moving through the slurry of water and crushed rock and cause turbulence throughout the flow. This turbulence causes the material with greater density to fall to the bottom and get trapped by the sand as the less dense material continues to move with the water (Michaud, 2017).

A jig consists of a cylindrical container lined with mesh of a given size at the bottom. It relies on the settling rate of gold to separate it from other particles. Crushed material is placed into the jig on top of a bed of high density steel balls. Water is then forced upwards from the bottom of the jig agitating all of the material above the mesh. The fall velocity due to the specific weight of each material allows for the gold to make its way down to the bottom of the jig below the bed of steel balls. This process is repeated multiple times until the material has been stratified by density (Figure 2) (Michaud, 2017). The jig is typically used before the metallic-rich rock is completely ground up "in order to avoid overgrinding" of gold bearing rock (Michaud, 2017)

Shaking tables consists of surface covered with riffles, and a motor that activates the shaking of the table. The concept of this method of gravity concentration is to shake the table as a mixture consisting of water and gold bearing crushed rock flows over it. As the table oscillates, the less dense particles will move farther to one direction than the denser sediment. This causes the gangue to separate from the concentrated gold bearing rock (Michaud, 2017).

Many different centrifugal systems have been created to help separate gold from gangue. Some of these systems include the Knelson concentrator and the falcon concentrator. These systems typically utilize a ribbed, cone shaped centrifuge to separate gangue from concentrated sediment. Slurry is placed in the cone and rotated so that the higher density material is gathered at the top of the cone, and the gangue is gathered at the bottom (Figure 3) (Michaud, 2017).

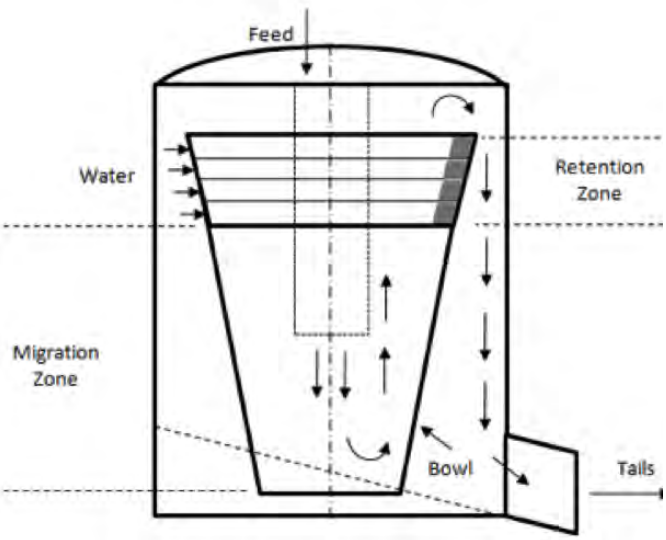

Figure 3. Schematics of a Falcon concentrator (Michaud, 2017).

Cyanidation and Heap Leaching

After gravity concentration methods of separation have occurred, the slurry of sediment, approximately 75 microns, and water is then moved to tanks in order to begin the cyanidation process (Michaud, 2017). This is the most common method of processing gold ore, and the method most utilized by corporations such as Newmont Goldcorp in Elko, Nevada (Newmont Mining Corporation). After the slurry is added to the Pachuca tanks, a weak solution of sodium cyanide is added as well as "Lime or sodium hydroxide (in order to) adjust the pH value (to) 10-11" (Kongolo and Mwema, 1998, p. 284). If the solution becomes any more acidic the dangerous gas hydrogen cyanide may form. The cyanide solution then begins to dissolve the gold as well as any silver present in the slurry. This leaching process can take "8-24 hours," and in some cases even longer (Kongolo and Mwema, 1998, p. 284). Sulfide minerals such as stibnite, chalcocite, and pyrrhotite are known to rob the gold of cyanide, therefore, slowing the process down. In contrast, minerals such as galena have been found to increase the leaching properties of gold and cyanide (Deschenes, 2005). Oxygen is forced through the Pachuca tanks in order to keep the slurry suspended, as well as to help force the reaction between gold and cyanide, as seen in Elsner's Equation. This process of cyanidation is said to recover approximately 85%-95% of the gold available in the rock (Eugene and Mujumdar, p. 7).

(Elsner's Equation) $4Au + 8NaCN + O_2 + 2H_2O \rightarrow 4Na[Au(CN)_2] + 4NaOH$

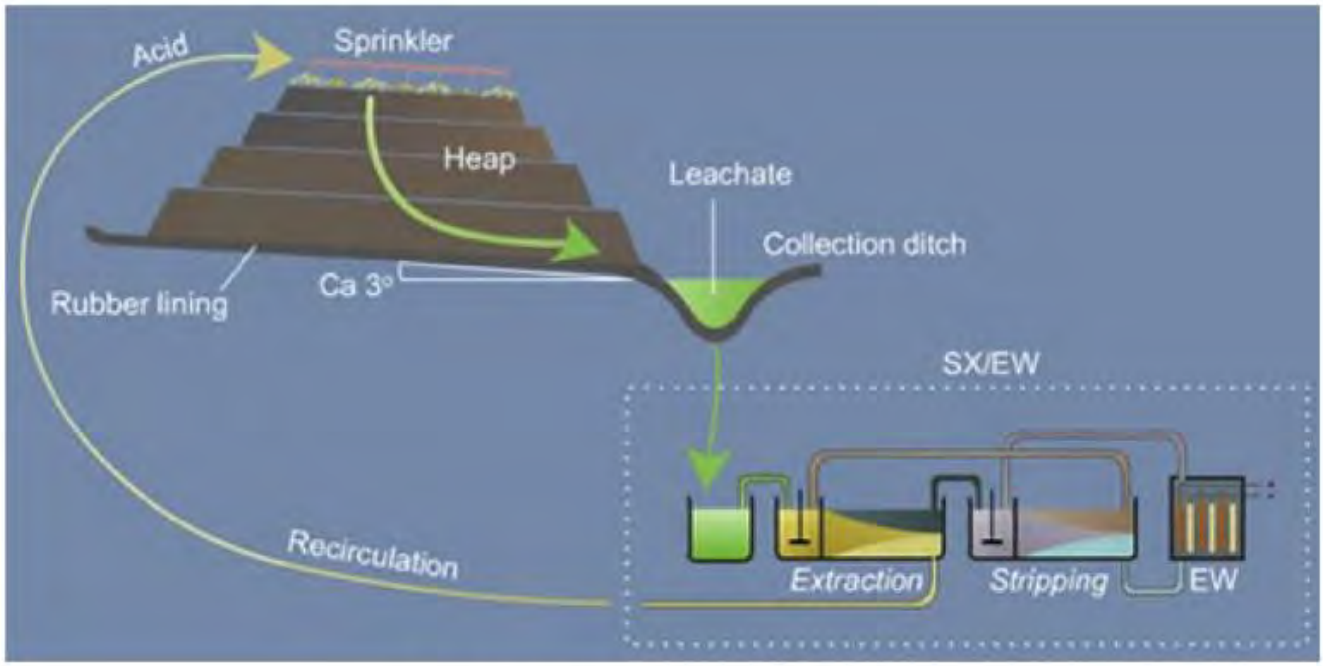

Figure 4. Heap leaching process of gold ore (Michaud, 2018).

This cyanidation process has allowed for the processing of gold ore that was once said to be of too low grade. This low-grade ore is now processed through a procedure called heap leaching. Crushed gold ore is mounded on top of an impermeable liner, and a weak cyanide solution is then dropped along the top of the pile. This sodium cyanide solution dissolves the gold as it works its way down through the pile (Eugene and Mujumdar). The gold filled cyanide solution, or leachate, is then collected in a collection ditch (Figure 4). The pile that is being heap leached must be "porous enough to allow the solution to trickle through it," therefore, the gold ore does not have to be broken down to the same small size that cyanidation using Pachuca tanks needs (Eugene and Mujumdar, p. 7). The entire leaching process will depend on the size of the pile, however, the typical leaching time is 60 to 90 days, and recovers approximately 60%-80% of the gold (Eugene and Mujumdar).

After all of the gold has been dissolved into the sodium cyanide solution, it must then be separated from the solution by means of granular, activated carbon. Carbon made of coconut shells is often used to remove the gold, and is then separated from the solution by different sieving processes (Kongolo and Mwema, 1998). The next step in this process is the extraction of the gold from the carbon, or elution. To begin the elution process, the gold filled carbon is placed in a "fixed bed column where the elution solution is pumped through" (Kongolo and Mwema, 1998, p. 286). The solution carrying the gold is then pumped through "electro-winning cells, which extract metals from the solution using an electrical current" (Newmont Mining Corporation). After the electroplating of the gold it is then smelted in a furnace at roughly 1,202 degrees F, and then poured into dore bar molds (Newmont Mining Corporation).

Conclusion

Processing methods of gold ore have come a long way since the basic gold panning method. Since then, we have developed techniques that have allowed us to process and recover "invisible gold," and low grade gold ore that we would other wise never have been able to profit off of. From finding visible gold nuggets, to extracting elemental gold trapped within

other minerals, these new techniques will carry the gold industry into the new age.

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Goldstrike Deposit

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Introduction

The Goldstrike Mine is on the western flank of the Tuscarora Mountains and is within the northern Carlin Trend. Gold mineralization at Goldstrike is controlled by favorable stratigraphy and structural complexity. Like most Carlin type deposits, the gold was epithermally deposited in carbonate or silicate sedimentary rocks. These carbonate and silicate sedimentary rocks have been metamorphosed to varying degrees. Gold mineralization was emplaced approximately 39 Ma ago along favorable stratigraphy and structural features such as faults, folds and along contacts between sedimentary rocks and the Goldstrike stock (Evans et al). The faulting provided a channel for mineralizing fluids. Intense fracturing along the Goldstrike stock caused solution collapse and brecciation of the surrounding sedimentary units (Evans et al). Lithology and alteration contacts act as permeability barriers causing mineralization along them. Interpreting lithology, alteration, and structure act as great guides to gold mineralization. The mine property consists of 6870 acres in north central Nevada and is about 25 miles north of the town of Carlin. The mine is owned by Barrick Gold Corporation which has a large portfolio of operating mines and projects. The Goldstrike mine contains both an open pit and underground operations. According to the Goldstrike technical report of 2017, the mine is on a general production schedule 24 hours a day, seven days a week. The Goldstrike complex has an extremely large Betze-Post open pit mine and underground mines. The Betze and Post pits merge into a single large pit with underground workings extending from it (Evans et al). The Betze-Post open pit mine uses a traditional truck and shovel fleet to recover gold bearing rock. The mine has an immense equipment fleet which is projected to be used throughout the mine life. The current open pit production plan shows that 13.51 million tons of ore grade 0.112 oz/st Au will be mined and rehandled from stockpiles from 2017 to 2031 (Evans et al). This is the eighth deepest open pit mine in the world. The gold producing open pit is about 2 miles long and 1.5 miles wide. The depth of the pit is approximately 1,300 feet. The underground mine production has 11 separate zones stretching a length of 12,000 feet. The underground mine is located a vertical distance of approximately 600 to 2,000 feet below the surface. There is both shaft and ramp entries to the underground mine. The underground gold production has decreased over time with the reduction of ore grade and despite increases in production rate. The underground mineral reserves projected total is 6.26 million tons at 0.228 oz/st Au (Evans et al). In general, there are two mining methods used underground at the Goldstrike mine.

Figure 4-1

TABLE 16-2 OPEN PIT MINE EQUIPMENT FLEET
Barrick Gold Corporation - Goldstrike Mine

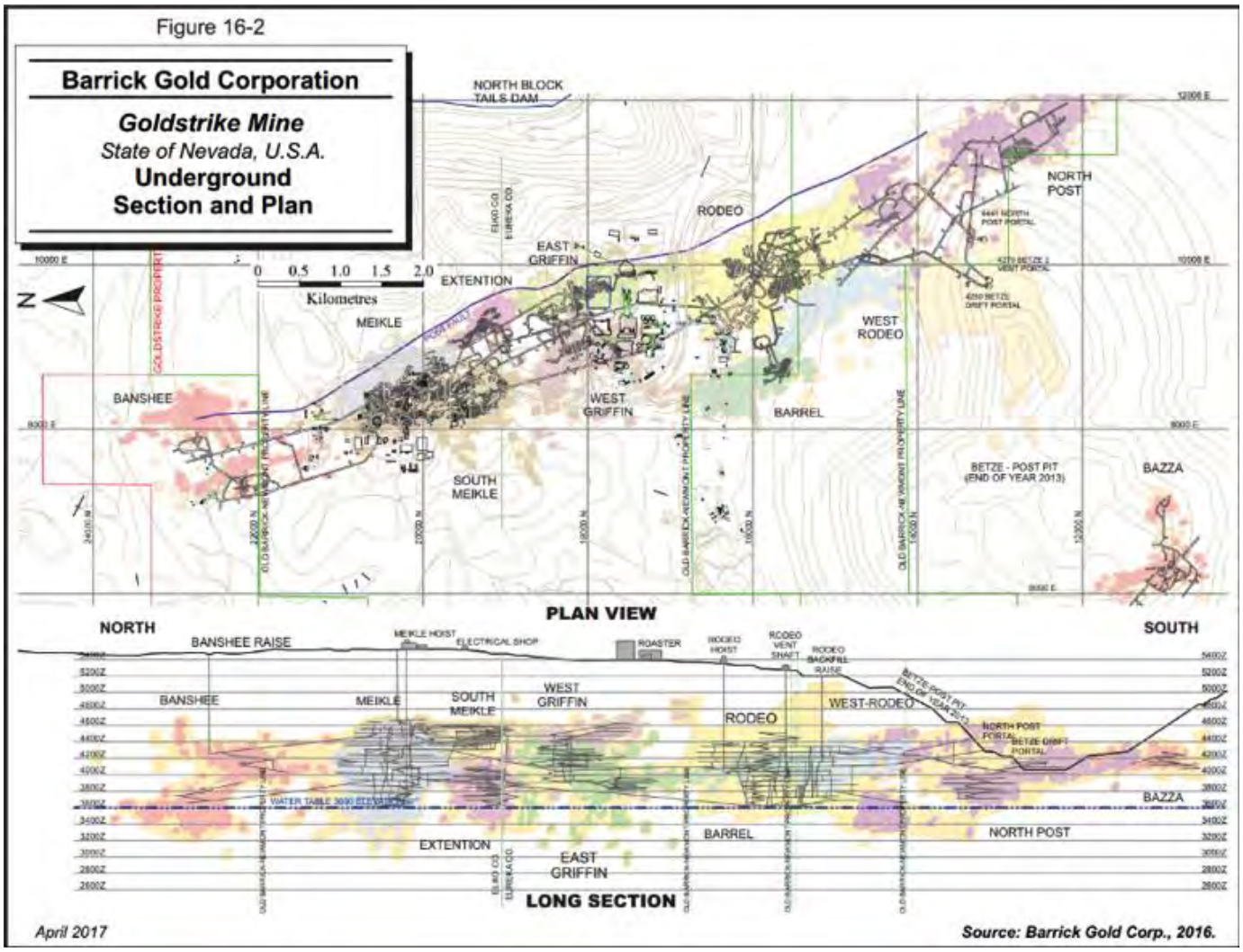
Equipment	Manufacturer	Quantity	Fleet Availability (%)
930E Truck (290t)	Komatsu	24	88
685 Truck (Meikle)	Komatsu	-	89
CAT 785	Caterpillar	2	89
Komatsu HM400 Articulated Water Truck	Komatsu	1	75
685 Truck (water)	Komatsu	1	89
930E Water Truck	Komatsu	3	87
Drills2	Atlas Copco	3	83
Electric Shovel (2800) 143	P&H	-	88
Electric Shovel (2800) 144	P&H	1	88
Electric Shovel (4100) 191	P&H	1	91
Electric Shovel (4100) 192	P&H	1	91
5500 Hydraulic Shovel 182	Hitachi	1	88
LeTourneau Loader	LeTourneau	1	73
CAT 6040 Trackhoe	Caterpillar	1	85
Cat 992 Loader	Caterpillar	2	86
Cat D10 & D11 Dozer	Caterpillar	5	86
Rubber Tire Dozer	Caterpillar	6	86
Graders (CAT 16 Class)	Caterpillar	6	86
Backhoes	Various	2	86
Cat 992 K Loader (Rehandle)	Caterpillar	3	89
Cat 777 G Haul Truck (Rehandle)	Caterpillar	4	89
Cat 777 G Water Truck (Rehandle)	Caterpillar	1	89
Cat D10 T Dozer (Rehandle)	Caterpillar	2	95
Cat D10 T Dozer (Landfill)	Caterpillar	1	86

Both mining methods rely on cemented backfill for support. In relatively good ground conditions, a longhole stoping method is used. This method leaves behind an open space and artificial support is provided. The second mining method is called underhand drift and fill and is used in poor ground conditions. This method provides a backfill roof for subsequent lifts in the mining cycle. The total measured and indicated gold resources at Goldstrike mine is 1.6 million ounces (Evans et al). Interestingly, the mine has only been dewatered to the 3,500 ft elevation level and the ore deposits extend below the 3,500 ft elevation. Mineral Reserves are not included from any material that is below the 3,500 ft elevation. There is potential to increase the Mineral Reserves at depth if dewatering is extended further (Evans et al). In fact, Goldstrike mine is the third largest gold producing mine in the world (Holmes).

Mining History

The earliest gold mining in the northern part of the Carlin Trend occurred at the Bootstrap and Blue Star mines prior to the discovery of gold at the Goldstrike. Gold was originally discovered at Goldstrike in 1962 by Atlas Minerals. Gold was first mined from the upper portion of the oxidized Post fault zone (Evans et al). Trenching and drilling by Newmont Mining in 1966 discovered low-grade gold in fault zones cutting a diorite intrusion (the Goldstrike stock). Although this early exploration identified significant gold grades, no development occurred due to the low gold price at the time (Evans et al).

From 1973-1974, exploration funded by Lac Minerals Ltd. identified soil geochemical anomalies and low-grade gold mineralization. From 1975 to 1977, Polar and Pancana operated a small open pit and heap leach. The Goldstrike mine was purchased by Barrick Gold Corporation in 1986 for $62 million dollars. Barrick discovered the underground Meikle deposit in 1989 by deep drilling. Barrick continued mining the large Betze-Post open pit. In 1989, the underground Meikle reserve was estimated to be 9.3 million tons containing 0.283 oz/ton (Evans et al). Newmont Gold corporation had operations to the south of the Goldstrike mine. In 1989, Newmont reported a drill intersection of 350 feet at 0.768 oz/ton of gold. Negotiations were undertaken between Barrick and Newmont for the joint development of the Deep Post orebody. In 1994, Barrick discovered mineralized zones within the Goldstrick property at Screamer, North Post, West Betze, Rodeo, and Griffin. Heap leach ore production from the Betze-Post pit continued from the time of purchase to the end of 1998 (Evans et al). Oxide mill ore processing started in 1988 and the autoclave portion of the mill started operations in early 1990. The 1999 Asset Exchange with Newmont resulted in the acquisition of the Goldbug, West Rodeo, Barrel, and North Post deposits. These deposits were in the Newmont land corridor separating the Betze-Post and Meikle mines. In 2000, the processing of ores by the roaster began. Past production from the Goldstrike Mine from 1987 to the end of 2016 totals 42.8 million ounces of gold (Evans et al).



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The Boulder Batholith

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The Boulder Batholith is ~4,000 km^2 intrusion located in southwestern Montana. It was emplaced in the Late Cretaceous and it dominantly composed of the Butte Granite with other minor granitic intrusions surrounding it (Du Bray, 2012). The batholith intruded into Mesoproterozoic to Mesozoic sedimentary rocks and the Late Cretaceous Elkhorn Mountains Volcanics (Du Bray, 2012). The emplacement of the batholith was associated with a period of regional eastward thrust faulting.

The Boulder Batholith was dated using zircon U-Pb geochronology. Three different samples were dated and it was found that the intrusion was likely composite. The dates showed that the pluton was formed during two episodes of magmatism, 76.7 ± 0.5 Ma and 74.7 ± 0.5 million years (Du Bray, 2012). This conclusion does not, however, fit with the petrographic and chemical data of the Boulder Batholith which indicates the magmatism was one event that spanned 2 million years (Du Bray, 2012).

The peripheral intrusions are classified as dominantly grandiorite and monzogranite with plagioclase, alkali feldspar, quartz, biotite, and hornblende making up the bulk mineralogy. The Boulder Batholith hosts the world-class Butte Cu-Ag deposit as well as other mineral deposits (Du Bray, 2012). The Butte Cu-Ag deposit provides about ~35 million tons of global copper resource (Dilles, 2014). This deposit also produces Mo, Zn, Mn, Pb, and Ag (Dilles, 2014).

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