

# Low-sulfidation epithermal deposits of the central Basin and Range Province, USA

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**Abstract:** The Basin and Range Province is host to many important low-sulfidation epithermal deposits. Within this broad zone of extension, epithermal deposits are hosted by specific areas of Miocene and younger bimodal volcanism. In northern Nevada, rifting and related volcanic activity occurred in response to thermal bulging during the development of the Yellowstone hotspot. The Colorado River Extensional Corridor in southern Nevada, adjoining eastern California and northwestern Arizona, is a major zone of Miocene crustal extension formed during the transformation of the western margin of North America from a convergent to a transform plate boundary. The style of mineralization in the low-sulfidation epithermal deposits in these areas is strongly controlled by the nature of the volcanic successions. High-grade, low-tonnage deposits are commonly found in flow-dominated volcanic successions where ore deposition occurred through short-lived periods of fluid flashing. In contrast, low-grade, large-tonnage deposits are more commonly located in clastic-dominated successions where fluid infiltration of the permeable hosts and cooling predominated.

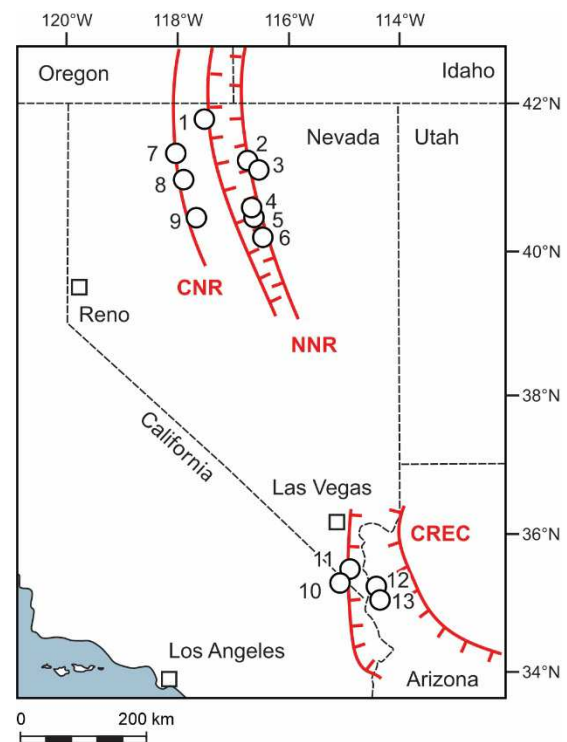
## 1 Introduction

The Basin and Range Province is a highly extended part of the Northern American Cordillera that stretches from Canada through the western United States, and across much of Mexico. It encompasses the area between the Cascade Ranges and the Rocky Mountains in the north, the Sierra Nevada and the Colorado Plateau in the center, and surrounds the Sierra Madre Occidental Range in northern Mexico in the south. Commencing in the Miocene, block faulting caused the development of the characteristic pattern of alternating basins and ranges (Eaton 1982).

For over 150 years, low-sulfidation epithermal deposits within the Basin and Range Province have been a major source of precious metals for the United States. This contribution provides a brief overview of examples of epithermal deposits and districts located within specific areas of crustal extension in northern Nevada and in the border region between Nevada, California, and Arizona.

## 2 Northern Nevada Rift

The Northern Nevada Rift (NNR) is a 5 to 30-km-wide zone of regional extension that can be traced for at



**Figure 1.** Map of the central Basin and Range Province showing the locations of low-sulfidation epithermal deposits discussed in the text. NNR = Northern Nevada Rift; CNR = Central Nevada Rift; CREC = Colorado River Extensional Corridor. 1 = Buckskin National; 2 = Midas; 3 = Ivanhoe district; 4 = Mule Canyon; 5 = Fire Creek; 6 = Buckhorn; 7 = Sleeper and Jumbo; 8 = Sandman and Ten Mile district; 9 = Goldbanks; 10 = Castle Mountain; 11 = Searchlight; 12 = Katherine (Union Pass); 13 = Moss and Oatman district.

least 500 km (Fig. 1) from Oregon to east-central Nevada (Zoback et al. 1994). The NNW-trending rift zone is characterized by bimodal basalt-rhyolite volcanism. Deep-seated mafic dike emplacement is reflected in a pronounced positive regional aeromagnetic anomaly. Rift formation was initiated at ~16.5 Ma and was related to WSW-ENE regional extension perpendicular to the then-active subduction zone along the western margin of the North American continent, as well as thermal bulging associated with the development of the Yellowstone hotspot (Zoback et al. 1994; John et

al. 2000; Ponce and Glen 2002). Rifting and associated igneous activity continued until ~14 Ma as the hot spot progressively migrated to the northeast (Zoback et al. 1994; John et al. 2000).

The NNR is host to several important low-sulfidation epithermal deposits and districts. This includes the Buckskin National deposit in the National district, which was intermittently mined from 1906 to 1941. The deposit is hosted by a ~700-m-thick succession of Miocene massive rhyolite and associated volcanoclastic facies capped by a 30-m-thick carapace of finely laminated silica sinter and silicified epiclastic deposits (Vikre 2007). Most notable is the ~1.8-m-thick Bell vein that can be traced over a strike length of 1.3 km.

The Midas deposit is hosted by a Miocene bimodal basalt-rhyolite succession that is over 1.5 km in stratigraphic thickness (Leavitt et al. 2004). Mining commenced in 1907 and continued until 1942 (Goldstrand and Schmidt 2000). Modern underground mining between 1998 and 2013 yielded an estimated 2.4 Moz Au and 32.8 Moz Ag at a grade of 15 g/t Au and 204 g/t Ag (John et al. 2018). Between 2014 and mine closure in 2017, 112,000 oz Au and 4.9 Moz Ag were produced. Mining focused on steeply dipping epithermal veins, including the Colorado Grande vein, which can be traced over a strike length of ~2 km, with high-grade ores occurring over a vertical extent of 500 m.

At the Fire Creek deposit, Paleozoic basement rocks are overlain by a 150-m-thick succession of interbedded lithic tuffs, basalt flows and sills, and thin laminated lacustrine sedimentary deposits. Overlying volcanic rocks include a 120- to 200-m-thick package of basalt flows, which are the main host to high-grade veins. The package of basalts is overlain by a thick succession of tabular andesite flows. Between 2016 and 2020, Fire Creek produced 339,238 oz Au and 544,361 oz Ag. Other important deposits in the NNR include those of the Ivanhoe district as well as Mule Canyon and Buckhorn (John et al. 2000).

### 3 Central Nevada Rift

The Central Nevada Rift (CNR), located ~80 km to the west of the NNR (Fig. 1), is manifested by a positive magnetic anomaly (Ponce and Glenn 2002). The acute anomaly can be traced for over 250 km from the Nevada-Oregon border to the south. The location of the Sleeper deposit in the Slumbering Hills coincides with this anomaly. Sleeper is hosted by Miocene volcanic rocks which were deposited on Mesozoic basement rocks. The volcanic succession includes a <200-m-thick basal volcanoclastic unit that is overlain by a 150-m-thick unit of basaltic to andesitic flows and associated breccias. A pumiceous lapilli tuff unit separates the basaltic to andesitic flows from an overlying, >300-m-thick porphyritic rhyolite that is the main host to ore. Epithermal veins are up to 5 m in

width, with grades ranging from 50 to 100 g/t Au. The veins occur in a zone that is 300-m-wide and 1200 m in strike length. Four continuous high-grade veins have been identified that can be traced over a strike length of ~200 m each, with a down-dip extent of >300 m (Nash et al. 1995). <sup>40</sup>Ar/<sup>39</sup>Ar dating of adularia from the veins suggests that the mineralization at Sleeper formed between 16.2 ± 0.4 and 14.1 ± 0.6 Ma (Conrad et al. 1993). Mining of the deposit between 1986 and 1996 yielded ~1.7 Moz Au and ~2.3 Moz Ag (Wilson and Brechtel 2017). Jumbo, which was the most important producer in the historic Awakening district, is located ~6 km to the SE of Sleeper.

The deposits of the Sandman area are located further to the south along the CNR (Fig. 1). Mesozoic basement rocks are overlain by a 250-m-thick succession of rhyolitic airfall and epiclastic tuffs, mafic flows, and fluvial siltstone, sandstone, and conglomerate. Low-grade precious metal enrichment is associated with pervasive quartz-adularia flooding of the host rocks and zones of minor quartz-adularia veining (Lauha et al. 2010). The Ten Mile district immediately to the south has yielded ~20,000 oz Au between 1900 and 1942. Ores occur within the Mesozoic basement rocks (Bowell et al. 2000).

The Goldbanks deposit (Fig. 1) comprises a geological resource of 166 Mt of ore grading 0.48 g/t Au and 1.40 g/t Ag (Stone et al. 2000). Mesozoic basement rocks are unconformably overlain by a succession of lithic sandstone, poly-lithic breccia, mudstone, and opaline silica that hosts cinnabar deposits. The succession is capped by basalt flows. The main low-grade, large-tonnage ore zone occurs in permeable clastic rocks. The blanket-shaped deposit is 2 km by 1 km in area and ~90-m-thick (Stone et al. 2000).

### 4 Colorado River Extensional Corridor

The Colorado River Extensional Corridor (CREC) is a 70- to 100-km-wide zone of extension that stretches for ~200 km from southern Nevada into Arizona (Fig. 1; Faulds et al. 2001). In the north, the boundary between the CREC and the Colorado Plateau to the east is marked by a single west-dipping fault zone. In central Arizona, the eastern boundary of the CREC is less abrupt and characterized by a broad transition zone. To the west, the CREC is bordered by the moderately extended Mojave Desert (Faulds et al. 2001).

Extension in the CREC broadly coincided with the transformation of the western margin of North America from a convergent to a transform plate boundary (Dickinson and Snyder 1979). Volcanism in the northern part of the corridor commenced at ~22 Ma in the Oatman area (Faulds et al. 2001; Gans and Gentry 2016) and subsequently swept north arriving in the Lake Mead area at ~12 Ma. Magmatism ceased at ~11 Ma in the south but continued until ~4 Ma in the northern CREC (Faulds et al. 2001).

The CREC is host to several major low-sulfidation deposits. This includes Castle Mountain, which is located west of the main zone of extension. The lower section of the host stratigraphy of this deposit is composed of trachybasalt and trachyandesite flows and related autobreccia. The bulk of the low-grade, large-tonnage resource is hosted in volcanic rocks that formed during an episode of intense felsic volcanism, which resulted in the deposition of thick aprons of massive to poorly sorted tuff breccia around rhyolite lavas and domes. Vertical breccia bodies interpreted to represent phreatic eruption deposits are spatially closely associated with the rhyolite centers (Capps 1996; Tharalson 2021). Low-grade, large-tonnage ore zones are largely confined to pervasively silicified clastic and brecciated volcanic facies. Initial open pit mining at Castle Mountain was conducted between 1991 and 2004, yielding 1.24 Moz Au. The deposit contains proven and probable reserves of 4.17 Moz Au at grades of 0.51 g/t Au. In addition, a measured and indicated resource of 1.47 Moz Au has been identified at an average grade of 0.62 g/t Au (Secrest et al. 2021).

The Searchlight district is a relatively small but historically important gold producer. Between 1902 and 1954, the district produced 246,991 oz Au and 352,522 oz Ag (Bown 1977). The veins contained native gold, chalcopyrite, galena, local pyrite, and sphalerite. Fluid inclusion and textural evidence suggests that the veins can be classified as low-sulfidation epithermal deposits (Cline and Lledo 2009).

Ongoing exploration in the historic Katherine (Union Pass) district has resulted in high-grade intercepts at the historic Tyro mine and further to the south in the former Arabian mine area, highlighting the potential of this district characterized by outcropping high-grade veins (Lausen 1931).

The Oatman district in northwestern Arizona is a historically important low-sulfidation epithermal district in the CREC (Ransome 1923; DeWitt et al. 1991). Discovered in 1863, the ~6.2-km-long Moss vein is one of the most significant epithermal veins in the district. Between 2019 and 2023, open pit mining of the vein produced 161,900 oz Au and 1,136,000 oz Ag (Mako press release December 31, 2024). The Moss vein is hosted by the Peach Springs Tuff, which was deposited during the  $18.78 \pm 0.02$  Ma (Ferguson et al. 2012) eruption of the Silver Creek Caldera, and a monzonite that postdates caldera formation.

## 5 Ore Textures and Metal Deposition

There is a strong volcanological and rheological control on the nature of the low-sulfidation epithermal deposits in the Basin and Range Province. High-grade, low-tonnage deposits are primarily hosted in competent host rocks. In these deposits, ores are typically confined to crustiform veins or breccias that contain

distinct bands enriched in ore minerals. Dark-gray to black bands visible in hand specimen are commonly enriched in Ag-bearing minerals (Tharalson et al. 2019; Zeeck et al. 2023). Distinct colloform bands that contain mostly native gold are present at Sleeper and Fire Creek (Saunders 1990; Milliard 2020; Tharalson et al. 2023).

Ore minerals in the colloform bands have dendritic shapes. This includes centimeter-sized naumannite dendrites at Buckskin National (Tharalson et al. 2023). The ore mineral dendrites are hosted by fine-grained quartz that formed through recrystallization of a non-crystalline silica precursor (Taksavasu 2017; Zeeck et al. 2023). At Sleeper, dome-shaped gold dendrites are hosted in a partially isotropic silica matrix containing microspheres that are 1–5  $\mu\text{m}$  in size (Tharalson et al. 2023). Relic microspheres are also present in colloform bands at Buckskin National (Taksavasu et al. 2018).

At deposits such as Buckskin National, Midas, Fire Creek, and Moss, quartz formed through recrystallization from a silica precursor includes mosaic quartz that is characterized by interpenetrating grain boundaries. Flamboyant quartz shows cores rich in inclusions or radiating arrays of inclusions. In addition, large prismatic quartz grains containing recrystallization fronts typified by the occurrence of pseudoprimary inclusions are common. The prismatic quartz commonly shows feathery domains that have a splintery appearance in crossed-polarized light.

The textural characteristics of high-grade ores suggest that precious metal deposition in low-sulfidation epithermal deposits commonly resulted from flash vaporization of the hydrothermal liquids, causing deposition of noncrystalline silica and ore minerals at far-from-equilibrium conditions (cf. Monecke et al. 2023).

In contrast, low-grade epithermal ores are commonly hosted in permeable host lithologies including poorly sorted volcanoclastic deposits. Mineral precipitation in low-grade, large-tonnage deposits presumably occurred via cooling of the hydrothermal fluids during host rock infiltration. Fluid flashing did not occur or was restricted to local upflow zones where prior silicification of the host rocks created more competent rocks.

Both styles of low-sulfidation epithermal deposits represent viable exploration targets although exploration strategies may need to differ between targets hosted by flow-dominated and clastic-dominated volcanic succession.

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