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Unraveling the history of a rock

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Alteration products generated by the interaction of rock-forming minerals with mineralized hot waters have long been used to describe and classify different groups of hydrothermal mineral deposits. Potassium-rich white mica, commonly referred to as sericite, is an alteration mineral associated with many types of precious-metal ores, from near-surface volcanic-rock related deposits to deeper crustal low-sulfide quartz-gold veins. Thus, it is logical to presume that sericite in Carlin-type, sedimentary-rock-hosted, gold deposits is related to the gold mineralization. But are things as they seem?

While studying the Carlin-type ores and surrounding rocks at the Jerritt Canyon, Nevada, gold deposits, U.S. Geological Survey scientists documented that the element potassium is not geochemically enriched in the gold ores, and ore textures and alteration minerals indicate that well-crystallized white mica is not part of the alteration mineral assemblage that accompanied gold mineralization. It appears that potassium was either not mobile in the gold-bearing fluids and (or) was somewhat deficient in those fluids.

Designing a simple, but elegant experiment, USGS scientists separated several grain-size fractions of white micas for radiometric age determinations, using material from both unmineralized and gold-bearing sedimentary formations. Using a high-precision age-dating technique known as the $^{40}\text{Ar}/^{39}\text{Ar}$ method, it was discovered that nearly all of the dated micas, regardless of grain size or degree of alteration yielded ages that were near the original age of the host rocks, approximately 440 Ma–360 Ma. This evidence corroborates the interpretations of the geochemical data and mineralized-rock textures. There is no apparent genetic relation between most of the white micas in the Jerritt Canyon deposit and the gold mineralization.

Why is the relation of white mica to gold in Carlin-type deposits important? In addition to serving as a characterizing, ore-related alteration mineral for ore-deposit modeling, the potassium in white micas makes it a useful mineral for deter-

mining the time of mineralization and unraveling the thermal history of a rock. The radiometric dating of unaltered portions of mineralized intrusive dikes that transect ore-bearing rock at Jerritt Canyon restrict the timing of gold mineralization to younger than 40.8 Ma, the middle part of the Eocene geologic epoch. Therefore, the persistence of older $^{40}\text{Ar}/^{39}\text{Ar}$ dates obtained from different size fractions of white mica imply to researchers that the temperature of the gold-mineralizing system and (or) the duration of the hydrothermal event were insufficiently high or long to reset the age of preexisting mica.

Jerritt Canyon is particularly well-suited to the study of the alteration accompanying Carlin-type deposits. Large igneous intrusions that may have generated additional stages of hydrothermal alteration, besides that accompanying the gold, are not present in the area. Large intrusions appear near many other Carlin-type deposits, and their thermal history may have affected the resolution of the timing of gold mineralization in these districts. Nevertheless, clues suggestive of a similar history may be gleaned from these other districts. For example, in the Preble gold deposit in the Osgood Mountains west of Jerritt Canyon, a 100-million-year age was obtained from a coarse white mica in a mineralized granitic dike. However, coarse white mica from adjacent, sedimentary-rock-hosted gold ore, is considerably older. If both micas date gold mineralization, then their discordance presents a problem. They should be the same age. However, the Jerritt lesson teaches us to question if either is the correct age. Such clues are cryptic, but the mica data imply that the white-mica saga is more complicated at such dated deposits than has previously been recognized. Future clarification of the age of mineralization will be an important step in understanding the genesis and predicting locations of this economically important type of gold deposit.



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Renewed interest in copper mining



Between 1845 and 1968 native copper mines in Michigan's Keweenaw Peninsula produced over 13 billion pounds of copper and 16 million ounces of silver; but when the last mine closed in 1968, the area slid into economic depression. Renewed interest in copper mining in the region has recently been sparked by the discovery of seven small, high-grade, basalt-hosted chalcocite (Cu_2S) deposits located in the northern end of the Keweenaw Peninsula, peripheral to the native copper district. USGS geologists have been studying these deposits since 1991 as part of a larger investigation of the metallogeny of the Midcontinent Rift, a 1.1-billion-year-old failed rift that extends for more than 2,000 km through the North American midcontinent.

The chalcocite deposits contain a total of about 7 million tons of ore with an average grade of 2.3 percent copper. The largest of the deposits is estimated to have mineable reserves at 1.1 million tons, grading 4 percent copper, and is scheduled for development in 1995 by a joint venture between Great Lakes Minerals and Brookline Minerals.

Copper in the deposits occurs primarily in two associations:

- stratabound chalcocite in brecciated and amygdular basalt-flow tops, and

- chalcocite, and rarely native copper, in veins and tension fractures in basalt and andesite dikes.

The predominance of native copper in the Michigan copper district makes this type of sulfide mineralization unusual. However, the spatial distribution of copper sulfide mineralization and native-copper mineralization, coupled with the commonality of associated gangue minerals, suggests a genetic link between the two types of copper mineralization.

Using information gained from a detailed study of the chalcocite deposits, USGS geologists are developing a general model for copper mobilization, transport, and precipitation in rocks of the Midcontinent Rift. This model will help to explain the widespread occurrences of copper throughout the rift and to assess the copper resource potential of rift-related rocks. □

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Seismic tomography characterizes fractured bedrock



The contamination of ground water caused by the leachate from mines and their tailings is a significant environmental issue for the minerals industry. Of particular importance is the behavior of leachate in fractured bedrock because the velocity at which leachate in fractures migrates is several orders of magnitude higher than that in soils. Thus the first step in isolation and remediation of contaminated ground water in bedrock is finding those fractures that have a high hydraulic conductivity. Although invaluable information about fractures can be obtained from data collected in monitoring wells (i.e., core, geophysical logs, packer tests, and tracer tests), the orientation and spatial connection of the fractures between the wells also is needed. One geophysical method that can provide some of this crucial information is seismic tomography.

To acquire data for seismic tomography, a source in a well (or on the surface) is used to generate a seismic wave, which propagates through the ground. An array of receivers in a second well is used to record the passing wave. Then the source is moved to another location, and more data are acquired. This process

is repeated many times so that the ground between the wells is thoroughly sampled along many different paths. To process these data, the time required for the wave to travel from each source to each receiver is measured, and then, with a parameter estimation algorithm, all these times are used to determine the speed of propagation in the region between the wells. The result is a map or image showing the spatial variations in speed. To interpret the image, the speeds adjacent to the well must be correlated with information from the well (i.e., core, geophysical logs, etc.). After this correlation is established, the image can be used to interpolate the properties of the region between the wells.

USGS scientists have applied this technique to hydrologic investigations and have been able to trace fracture zones having a high hydraulic conductivity between wells. □

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