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1991, pp. 317-321. <https://doi.org/10.56577/FFC-42.317>

*in:*  
*Geology of the Sierra Blanca, Sacramento, and Capitan Ranges, New Mexico*, Barker, J. M.; Kues, B. S.; Austin, G. S.; Lucas, S. G.; [eds.], New Mexico Geological Society 42<sup>nd</sup> Annual Fall Field Conference Guidebook, 361 p.  
<https://doi.org/10.56577/FFC-42>

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## FLUID INCLUSION INVESTIGATION OF THE MID-TERTIARY HELEN RAE GOLD MINE, NOGAL DISTRICT, NEW MEXICO

ANDREW R. CAMPBELL, JAMES A. PORTER\* and SCOTT E. DOUGLASS  
Department of Geoscience, New Mexico Institute of Mining and Technology, Socorro, New Mexico 87801

**Abstract**—The Nogal mining district contains porphyry-type primary deposits, breccia pipes, and precious- and base-metal veins. The Helen Rae deposit is a precious-metal vein containing quartz, calcite, pyrite, sphalerite, galena and native gold. Quartz is paragenetically early and is followed by sulfides, which compose only about 2 wt% of the vein material. Gold deposition followed the sulfides and gold grains exhibit rims that have been depleted in silver, presumably by supergene leaching. The final hypogene mineral to be formed is carbonate. Primary fluid inclusions in quartz were found both with, and without, solid crystals in the inclusions. The inclusions have average values for homogenization temperature (Th) of 200°C and average salinities of 16 eq wt% NaCl. Inclusions in calcite have very low salinities of 0 to 3 wt% NaCl and Th values from 146°C to 165°C.  $\delta^{18}\text{O}$  values of quartz range from 6.0 to 13.5‰ with corresponding  $\delta^{18}\text{O}$  H<sub>2</sub>O values from -4.4 to 3.1‰. Two calcite samples have values of 23.6 and 24.2‰, with corresponding  $\delta^{18}\text{O}$  H<sub>2</sub>O values of 0.7 and 1.3‰. The lightest water values are associated with barren quartz or late calcite veins and the heaviest values are from the mineralized veins. The fluid inclusion and isotope evidence suggest that two fluids were involved in ore mineralization. The high salinities of the mineralizing fluid are unusual for gold mineralization, perhaps providing evidence for the involvement of fluids from the porphyry systems in the district.

### INTRODUCTION

The Nogal mining district has produced Au, Ag, Zn, Pb and Mo since about the 1880s. Total production from the district as of 1973 was estimated by Thompson (1973) to be about \$1,000,000. Although most mining activity ceased in the 1930s, there is some present activity on placers and reworking mine dumps. Recently, the district has seen an increase in exploration activity and development work has been done on both the Helen Rae and Great Western mines. Interest has also been shown in the Vera Cruz mine, and the Parsons-Rialto group.

The Nogal mining district is located in the Sierra Blanca Mountains in central New Mexico (Fig. 1). Elevations of the district range from 1900 m to 2800 m with slopes that are forested in cedar, scrub oak and ponderosa pine. Rainfall is 38 to 63 cm/yr. Important drainages in the district are Bonito and Nogal Creeks.

The major deposits of the Nogal mining district are the Vera Cruz, Helen Rae—American, the Parsons-Rialto group and the Great Western. Fig. 1 shows the location of these mines as well as some of the other mines in the Nogal mining district.

### GEOLOGIC SETTING

The geology of the district is dominated by volcanic rocks which, together with some intrusive phases, make up the Sierra Blanca igneous complex. The volcanics are up to 1000 m thick in the area of Nogal Peak. The basal unit, the Walker Andesite, is 700 m thick and comprises a series of andesite flows and flow breccias. In the area of Nogal Peak, the Walker Andesite is overlain by 300 m of trachyte flows, known as the Nogal Peak trachyte. Six kilometers to the northeast, the Walker Andesite is overlain by 250 m of Church Mountain Latite. The relationship between the trachyte and latite is unclear, as correlation is impossible due to erosion (Thompson, 1973). The intrusive rocks of the district occur as stocks, dikes and sills of various compositions. There are three known stocks in the district. The Rialto stock is located in the center of the district, about 1 km east of Nogal Peak. It is a hornblende-biotite monzonite and may be the oldest of the three stocks (Thompson, 1973). The Bonito Lake stock, south of the Rialto intrusion, is a biotite syenite with a K-Ar age of  $26.6 \pm 1.3$  Ma (Thompson, 1973). The Three Rivers stock, the largest of the three stocks, is located in the southernmost part of the district, and is composed of a leucosyenite porphyry. The Three Rivers stock has a K-Ar age of  $25.8 \pm 1.1$  Ma (Thompson, 1973). Dikes and sills in the district are numerous and are of many different compositions.

The area is cut by a few district-wide faults, although for the most part faults are small and localized. Faulting is normal and shows minor displacements. These faults strike predominantly in three directions, north-south, northeast-southwest and east-west. Based on the occurrence of mines and prospects, mineralization appears to "trend" north-east-southwest. The Rialto-Parsons group, the American-Helen Rae and the Vera Cruz mines are aligned (Fig. 1). The Crown Renewed-OK deposits and the Great Western mine are located southwest of the Rialto. While this N28°E "trend" is not a fault, it does parallel two major faults in the district, and also corresponds to the strike of the Capitan dike swarm. Although the relationship between this north-northeast "trend," faulting with the district, and the dike swarm is unknown, it is clear that mineralization is favored along this "trend."

### DISTRICT MINERALIZATION

There appear to be four styles of mineralization in the Nogal mining district: (1) disseminated-porphyry deposits, (2) breccia-pipe deposits, (3) precious-metal veins, and (4) placer deposits.

#### Disseminated porphyry type occurrences

Disseminated molybdenum and copper mineralization occurs in the intensely argillically altered northern half of the Rialto stock. Molybdenite is concentrated around a small breccia pipe near the center of the stock; molybdenum abundance decreases outward from the central breccia. Copper sulfides are disseminated over a wider volume than is molybdenum (Thompson, 1973). This deposit has been classified as a breccia-type molybdenum deposit (Griswold and Missaghi, 1959; Thompson, 1968; Giles and Thompson, 1972) and is included by Westra and Keith (1981) in their classification of alkalic molybdenum stockwork deposits. However, Thompson (1973) pointed out that the altered stock is also enriched in copper, and because the size of the copper anomaly is larger than that of the molybdenum anomaly, its potential as a low-grade copper deposit should be explored.

#### Breccia pipes

These deposits are characterized by intense silicic alteration and brecciation of the surrounding country rock. Many of the fragments of the adjacent country rock are so altered that identification of the primary rock types is impossible. The breccia pipes are roughly circular in map view, cone-shaped (narrowing upward) in cross section, and are aligned on a N28°E trend. They are, starting from the southernmost, Great Western, Parsons, or Fulmer, a small unnamed occurrence, and the Vera Cruz. Mineralization in the breccia pipes contains pyrite, chal-

\*Present Address: P.O. Box 69, Nogal, New Mexico 88341

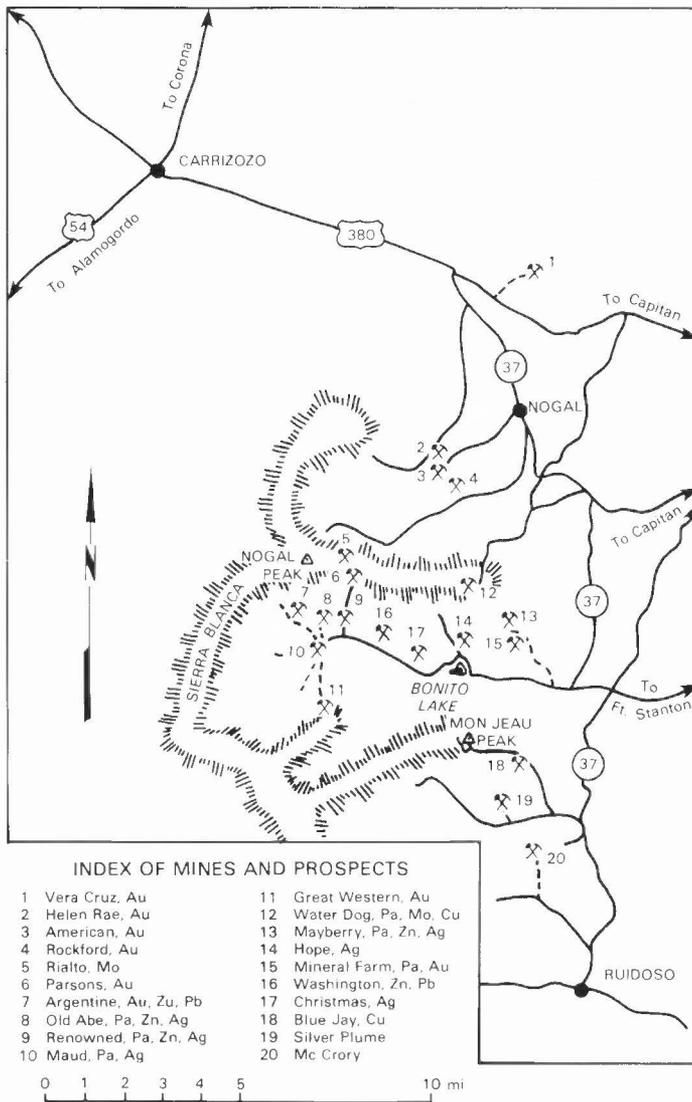


FIGURE 1. Index map of the Nogal mining district. Modified from Griswold (1959) with additions from Thompson (1973).

copyrite, minor bornite and gold. These sulfide minerals have been altered to oxides by surficial processes to form caps or halos of iron oxides over the breccia pipes. More details of the breccia pipes are provided by Thompson (1973), Eng (1991) and Ryberg (1991).

#### Precious-metal veins

The precious-metal veins are narrow fracture-filling systems associated with usually minor visible alteration of the surrounding host rock. In the area of the Helen Rae, they appear to be emplaced on normal faults of relatively minor movement (1 to 30 m), typifying veins throughout the district. Commonly, the alteration is composed of minor sericite and pyrite. This sericite zone ranges from 0 to 12 cm in thickness. However, locally, argillic alteration can extend up to 10 m from the vein. Alteration of the host rock seems to be controlled by permeability of individual andesite units. These veins show strong surficial weathering zones in the form of Fe oxides and Mn oxides (mostly pyrolusite). Supergene alteration seems to have a maximum depth of 30 m on the Helen Rae veins.

#### MINERALOGY OF THE HELEN RAE MINE

Mineralization at the Helen Rae mine is contained in veins of quartz and dolomitic carbonate emplaced in several interlocking fracture networks. Forty-five samples of vein material were taken for a paragenetic and fluid inclusion study of the deposit.

The Helen Rae vein consists of quartz, pyrite, sphalerite, chalcopyrite, galena, native gold and carbonate, all of which are hypogene in origin. Supergene minerals are mainly iron and manganese oxides. The following paragenetic descriptions are based on hand-sample and thin-section analyses.

#### Quartz

Quartz is paragenetically early in the Helen Rae assemblage. The earliest quartz appears to be confined to the lower elevation of the Helen Rae system; it is found only in samples from the adit level below the supergene zone. This euhedral quartz is hexagonal, showing uncorroded, well-developed faces, and contains numerous healed fractures delineated by the presence of numerous planes of secondary inclusions. Interior zones in early quartz crystals also show areas full of solid inclusions, many of which show well-developed crystal habit. Some of the inclusions appear to be cubes; many others are more rhomb-shaped. If these inclusions are halite they provide an interesting constraint (lower bound) on the salinity of the ore fluid. Independent mineralogical or chemical identification of these solid inclusions is needed. Minor chalcedonic quartz occurs with the supergene minerals and is barren of visible fluid inclusions.

#### Sulfides

A well-defined paragenetic assemblage of sulfides includes, in order of emplacement, pyrite, sphalerite, chalcopyrite and galena. Contacts between these sulfides are distinct, but the contact between sulfides and later gold is somewhat irregular. The total sulfide content of vein ores is less than 2 wt%.

#### Native gold

Native gold was deposited after sulfides but before carbonate. The gold is somewhat mat-like in texture and consists of a mass of intergrown fibers and octahedrons. When viewed under reflected light, the gold shows fractures rimmed by areas that are somewhat darker and approximately 20  $\mu$  wide. These areas are depleted in silver, suggesting that Ag was leached from Ag-bearing native gold ("electrum"), probably by supergene processes. SEM quantitative analysis shows that as much as 20% of the original silver has been leached from these areas. SEM observations of freshly broken faces of gold grains reveals the presence of solid inclusions trapped within the gold. Some of these inclusions are sulfides, whereas others are composed mainly of K, Na and Cl. We speculate that some solid inclusions may be sylvite/halite, and that such inclusions may be genetically similar to those found in early quartz. However, another hypothesis must be considered. When a gold grain is broken open in preparation for SEM analysis, the opened fluid inclusions leave behind an evaporite residue that is mainly salt. Whether the sylvite/halite originated as a solid inclusion or as a fluid inclusion evaporate, its presence implies that the gold was deposited from the same fluid as the quartz and validates the assumption that we can use fluid-inclusion evidence from quartz to look at the fluid responsible for gold precipitation.

#### Carbonate

The final primary mineral to be deposited in the Helen Rae vein system is a Mg-Ca-Mn carbonate. This carbonate is white to light pink and forms encrustations and void fillings in the previous vein material. The open space fillings show well-developed rhombs of the carbonate.

#### Supergene minerals

The most prominent supergene mineral is manganese, in the form of pyrolusite. This pyrolusite is intergrown with a chalcedonic quartz and very minor carbonate and forms a centrally lying stringer in the vein.

Covellite is found as supergene alteration of chalcopyrite in the primary sulfide assemblage. Covellite is minor in quantity and shows limited volumetric distribution.

#### FLUID-INCLUSION STUDY

Fluid inclusions were studied in both quartz and calcite (Fig. 2). Although sphalerite was examined for inclusions, it was too opaque to

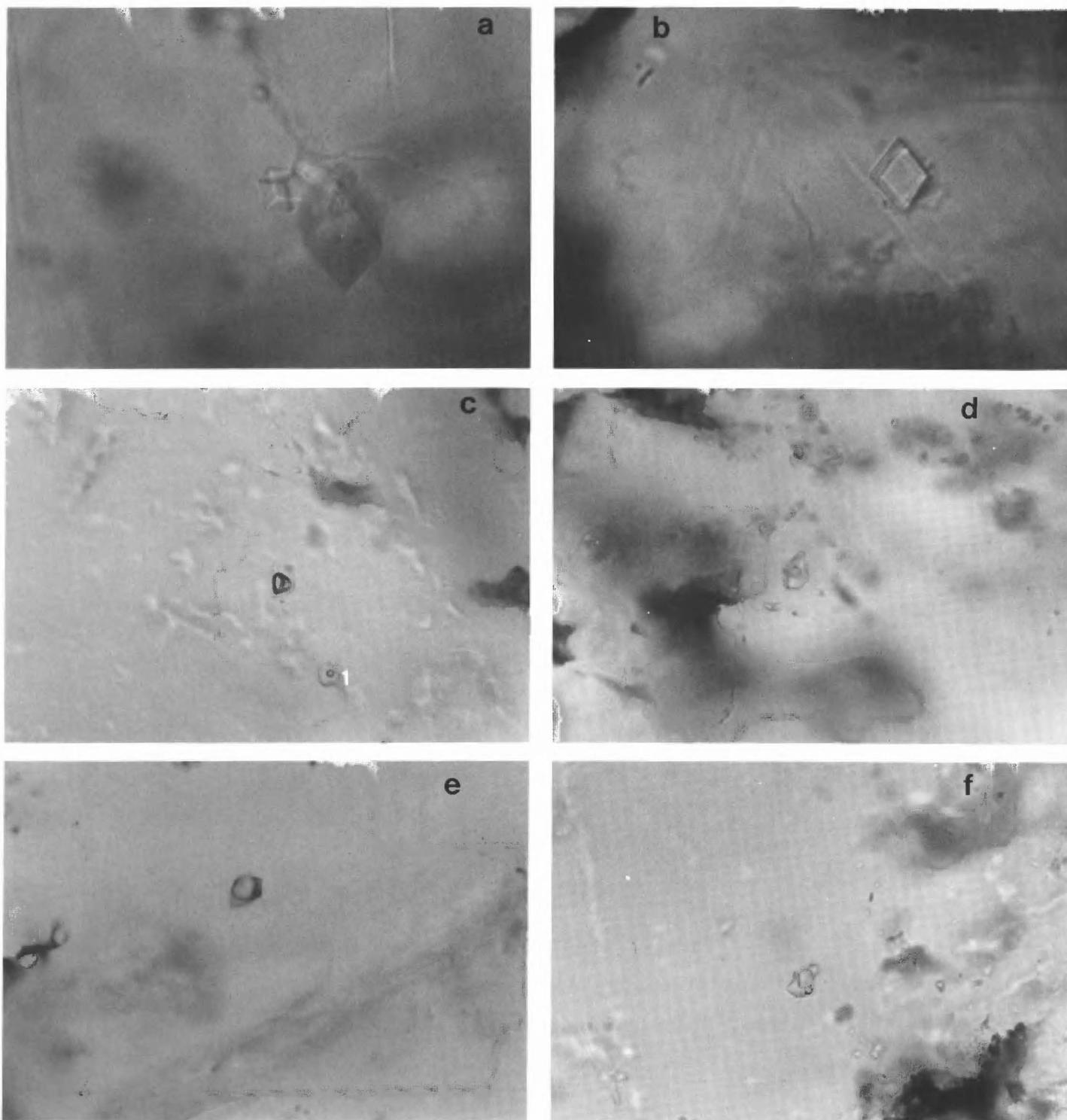


FIGURE 2. Photomicrographs of fluid and solid inclusions. a, Solid inclusion of seemingly cubic shape,  $\times 1000$ . b, Solid inclusion, possibly carbonate, showing rhombic nature,  $\times 1000$ . c, Transmitted-light micrograph of quartz in Helen Rae ore,  $\times 400$ . Large vapor-rich inclusion has probably decrepitated. Liquid-rich inclusions are of type 1a. Inclusion no. 1 homogenized at  $260^{\circ}\text{C}$  and froze at  $-16^{\circ}\text{C}$ . d, Transmitted-light micrograph of quartz in Helen Rae ore,  $\times 400$ . Large primary inclusion type 1a. Inclusion homogenized at  $210^{\circ}\text{C}$  and froze at  $-19^{\circ}\text{C}$ . e, Transmitted-light micrograph of quartz in Helen Rae ore,  $\times 400$ . Large primary inclusion with included mineral, type 1b. Vapor bubble homogenized at  $183^{\circ}\text{C}$ . f, Transmitted-light micrograph of quartz in Helen Rae ore,  $\times 400$ . Large primary inclusion with included mineral, type 1b. Vapor bubble homogenized at  $210^{\circ}$ .

be of use. Inclusions were observed in seven sections but thermometric measurements were obtained in only five. A total of 63 homogenization temperatures (Th) and 51 freezing-point-depression (Tm) measurements were recorded in quartz, while four Th and four Tm measurements were made on inclusions in carbonate. In samples that contained carbonate as well as quartz, inclusions in the carbonate were measured first because of their tendency to decrepitate.

Two types of primary inclusions were observed in quartz. The first group consists of primary inclusions without daughter minerals. These inclusions are referred to as type 1a. The type 1a inclusions are elliptical to irregular in shape and have vapor bubbles. They are found in areas isolated from the other primary inclusions. Temperatures of homogenization for these inclusions range from 151° to 265°C, with their salinities from 9.8 to 22.0 eq wt% NaCl. Eighteen of these inclusions were studied for Th and with 11 corresponding Tm measurements.

The other group of primary inclusions has included minerals. These inclusions are referred to as type 1b. Thirty-one inclusions were observed with included minerals; 20 were closely studied. The daughter minerals in these inclusions are large crystals that do not dissolve with heating above 450°C. It is possible that these included minerals consist of solid halite/sylvite, trapped from the liquid as the fluid inclusion formed. This would explain why the crystals did not redissolve upon heating, as a normal daughter halite crystal would. It is also possible that the included minerals may not be halite/sylvite but rather a carbonate that is more sluggish to redissolve. Solid inclusions of a similar mineral occurring in the quartz are numerous in the area of these fluid inclusions. This supports the hypothesis that the crystals in the fluid inclusions are included (rather than true daughter) minerals. The salinity from freezing measurements on type 1b inclusions ranges from 18.9 to 22.6 wt% NaCl. This salinity range is similar to that of the type 1a inclusions. If indeed the included minerals are halite, the actual salinity of the inclusion fluids at their corresponding homogenization temperature is considerably higher than salinities measured by freezing, and can be calculated based on the assumption that the fluid was NaCl-saturated at the time of trapping. The salinity calculated by considering the fluid to be saturated at the measured Th is from 30 to 35 eq wt% NaCl.

Secondary inclusions, referred to as type 2, were found in all samples of quartz. These inclusions were confined along fracture planes having no preferred orientation. Inclusion morphology ranges from elongate to irregular, with evidence for necking observed for only two inclusions. No daughter minerals were observed in these inclusions. Vapor bubbles, when observed, occupied less than about 10% of the inclusion cavity. Only 25 vapor bubbles were observed in 70 secondary inclusions. Twenty-five inclusions were measured for homogenization temperature and of these, six were measured for freezing-point depression. Three additional inclusions, without vapor bubbles, were measured for freezing-point depression. All secondary inclusions had homogenization temperatures ranging from 133° to 212°C and salinities from 0 to 3.2 eq wt% NaCl.

#### Inclusions in carbonate

The four inclusions found in calcite were primary in origin. They were two-phase, liquid-dominated inclusions and contained no daughter minerals. These inclusions had homogenization temperatures ranging from 146° to 165°C and salinities from 0 to 3 eq wt% NaCl.

#### Oxygen isotopes

In order to better understand the origin of the mineralizing fluids, preliminary oxygen isotope data were collected. Eight samples of quartz and two samples of calcite were analyzed. The results are given in Table 1, as both the  $\delta^{18}\text{O}$  value of the minerals and the calculated  $\delta^{18}\text{O}$  value for the fluid from which the minerals deposited. The water values are calculated using an average fluid-inclusion temperature of 220°C for quartz and 155°C for calcite. The spread in the  $\delta^{18}\text{O}$  H<sub>2</sub>O values is suggestive of fluid mixing. Two different samples from the Helen Rae give the highest  $\delta^{18}\text{O}$  values of 3.8 and 3.1‰. These samples are taken from the quartz that contains the solid inclusions and is paragenetically associated with gold mineralization.

TABLE 1. Stable isotopic composition of minerals and calculated fluid values. Water in equilibrium with quartz is calculated at 220°C using the fractionation equation from Matsuhisa et al. (1979) and for calcite at 155°C using the equation from O'Neil et al. (1969).

| Sample Number | Mineral | $\delta^{18}\text{O}$ | $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ |
|---------------|---------|-----------------------|--|
| 7240-HR1      | quartz  | 13.5                  | 3.1  |
| HR Dump       | quartz  | 13.3                  | 2.9  |
| 7240-HR1      | quartz  | 14.2                  | 3.8  |
| 8170-HR1      | quartz  | 11.2                  | 0.8  |
| 7260-A1       | quartz  | 10.5                  | 0.1  |
| 7260-A1       | quartz  | 9.5                   | -0.9                                       |
| 8160-V1       | quartz  | 7.4                   | -3.0                                       |
| 7180-R1       | quartz  | 6.0                   | -4.4                                       |
| 7250-HR4      | calcite | 24.2                  | 1.3  |
| 7280-A1       | calcite | 23.6                  | 0.7  |

#### INTERPRETATION

The results of the fluid-inclusion study are shown in Fig. 3. This figure and the resulting interpretation assumes that the included minerals seen in the type 1b inclusions are not halite.

The main mineralizing fluid has an average Th of about 200°C and an average salinity of about 16 eq wt% NaCl. The secondary inclusions in the quartz seem to result from the same fluid that deposited (and formed primary inclusions in) the late stage calcite. Because of its lower temperature and low salinity the carbonate-depositing fluid is most likely meteoric in origin.

The solid inclusions of carbonate(?) in the quartz may have deposited in response to mixing of the ore fluid with CO<sub>2</sub>-bearing(?) meteoric water. This mixing first deposited gold, quartz and small amounts of carbonate, and as the meteoric-water input increased, the fluid continued to deposit mainly carbonate. This implies that the original temperature and salinity of the ore fluid was higher than that now recorded by the fluid inclusions that trap a diluted ore fluid.

The fluid apparently responsible for mineralization at the Helen Rae is not typical for gold deposits. The normal fluid for epithermal style mineralization has a much lower salinity, usually in the range of 0–5 eq wt% NaCl. One type of gold deposit that does seem to have similar fluid characteristics is the detachment-fault-related gold deposit. These

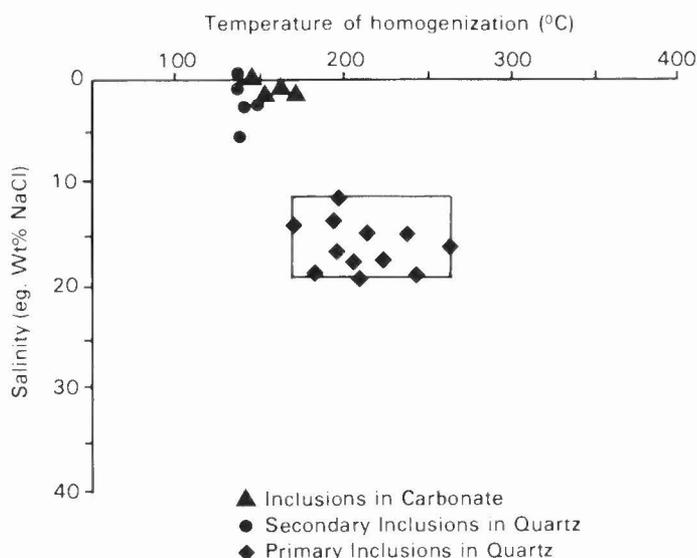


FIGURE 3. Results of fluid inclusion analysis of Helen Rae samples. The fluids responsible for deposition of quartz average about 220°C and have an average salinity of 16 eq wt% NaCl. Secondary inclusions in quartz seem to have trapped the fluid responsible for carbonate deposition.

deposits have salinity in the 15 to 20 eq wt% NaCl range and temperatures from 200° to 300°C (Wilkins et al., 1986).

Given the high salinities of the Helen Rae mineralizing fluid and the abundance of intrusive igneous rocks in the area, it seems highly likely that magmatic fluids have played some role in the ore-forming process. The Rialto stock is a very likely source for the initial fluids for the Helen Rae vein structure. Not only is this stock a prominent member of the Nogal structural trend, it also has been extensively hydrothermally altered. The high-salinity fluids of the Helen Rae vein system could easily have been generated by this type of porphyry system. If the Rialto stock did provide fluid for the Helen Rae vein system, the mineralization of this system could be more deeply rooted than presently thought.

The results of the fluid inclusion study suggest that two fluids were involved in the mineralization at the Helen Rae mine. One of the fluids was quite saline and presumably carried the ore metals. The other fluid had a very low salinity and lower temperature and may have caused mineral deposition by mixing. The heavier  $\delta^{18}\text{O}$  values could result from magmatic water mixed with meteoric water, or from a meteoric water which has undergone extensive isotopic exchange with the host volcanic rocks. One of the lowest values is from sample 8160, which has a  $\delta^{18}\text{O}$   $\text{H}_2\text{O}$  of  $-3.0\text{‰}$ . This sample is from a late barren quartz vein encountered in the Vindicator access shaft and is not closely associated with the mineralized Helen Rae vein. This value presumably represents a fairly pure meteoric water. Other Helen Rae and American samples lie between these two extremes and could represent mixing of the two fluids. However, the extremely light value ( $-4.4\text{‰}$ ) found in a sample from the Rockford mine is not explained by this hypothesis.

Upon first inspection, the Helen Rae appears to be epithermal in origin. Closer inspection has proven that this is not the case. The Helen Rae veins were deposited by fluids of high salinity and medium temperature and with  $\delta^{18}\text{O}$  values heavier than for most epithermal deposits (Fig. 4). The geologic literature is almost devoid of information on high salinity, medium-to-high-temperature gold deposits that are epithermal in appearance.

More extensive sampling for oxygen and hydrogen isotopic analysis is being undertaken to define better the chemical and physical characteristics of the two postulated end-member fluids involved in mineralization. The model developed for the Helen Rae will eventually be applied district-wide to quantify the sources of the mineralizing fluid.

#### ACKNOWLEDGMENTS

We thank Marlow Sharpe for his assistance and access to the Helen Rae property. We appreciate reviews of the manuscript by W. Chavez and R. Chamberlin. This work was partially supported by a grant from the New Mexico State Mining and Mineral Resources Research Institute during 1990–1991.

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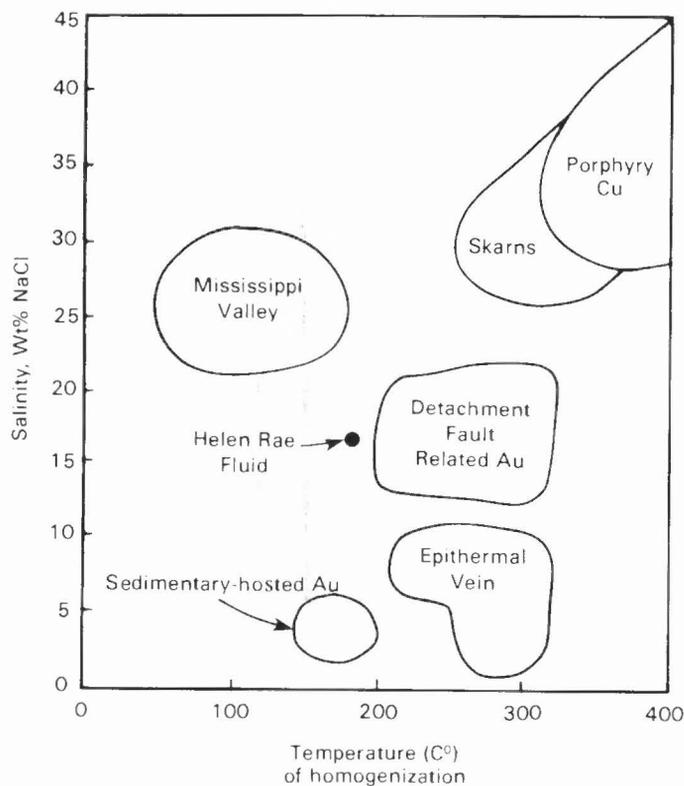


FIGURE 4. Comparison of Helen Rae fluids to other types of deposits. The Helen Rae fluids are not similar to the fluids involved in typical epithermal vein mineralization.

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The historic Glass stamp mill was the first to operate in the White Oaks district. Named for Professor Glass, this 10-stamp mill first saw service reducing gold ore at the Rita mine beginning in 1883. Later it was leased briefly by the Old Abe Company. Thereafter it moved to the southeast side of town and stored on the Sam Wells ranch where it was photographed in January 1918. New Mexico Bureau of Mines collection No. 1665, courtesy of Richard H. Jahns and John Kelt.