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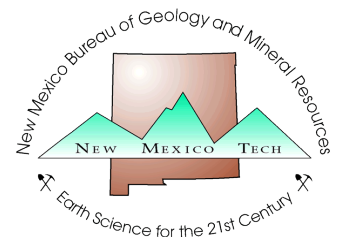
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# Temperature of mineralization in Mogollon mining district and vicinity, southwest New Mexico

by *Theodore J. Bornhorst, Gretchen R. Kent, Kevin L. Mann,* and *Scott R. Richey,* Department of Geology and Geological Engineering, Michigan Technological University, Houghton, MI 49931

## Introduction

Cenozoic mineral deposits are scattered throughout southwest New Mexico. These deposits are typically base and precious metals and often are associated spatially with mid-Tertiary volcanic centers (Elston and others, 1976; Elston and Erb, 1979). The mineralization in the Mogollon mining district consists of Ag–Au- (Cu–Pb-) bearing veins that were open-space fillings along pre-existing faults. Hypogene ore and gangue minerals of the district are listed in Table 1; quartz and calcite are the principal vein-filling minerals. Ferguson (1927) recognized a general paragenetic sequence for the entire district with quartz followed by calcite and then fluorite; there is a gradual transition from one mineral to the next. Where fluorite is abundant, precious-metal mineralizaton generally does not occur. Hypogene mineralization was followed by supergene enrichment. A detailed description of the district can be found in Ferguson (1927).

The Mogollon mining district is situated spatially on the margin of the Bursum caldera (Fig. 1). Recent radiometric age dating of mineralization at Mogollon has shown that these deposits are approximately 15 to 18 m.y. old (Kent, 1983; Ratté and others, 1983; Ratté, 1981). Silicic volcanic activity related to the Bursum caldera occurred from about 25 to 28

m.y. ago (Ratté, 1981). Located south and east of the Mogollon mining district are various small mines and prospects with associated hydrothermally altered rocks (Fig. 1; *see* Ratté and others, 1979). One of these mines, the Lone Pine mine, is noted for the occurrence of native tellurium (Ballmer, 1932).

TABLE 1—Hypogene vein-filling minerals in the Mogollon mining district, southwest New Mexico (compiled from Ferguson, 1927).

| Nonmetallic minerals | Metallic minerals | |
|---|---|---|
| Quartz | Pyrite | Stromeyrite |
| Calcite | Chalcopyrite | Chalcocite |
| Fluorite | Galena | Tetrahedrite |
| Adularia | Sphalerite | Pyrargyrite |
| Rhodochrosite | Bornite | Specularite |
| Chlorite | Argentite | |

## Fluid-inclusion studies

Fluid inclusions represent mineralizing fluids trapped in minerals. Studies of fluid inclusions can provide data about the temperature and composition of the fluids (Roedder, 1979). We have looked at more than

50 doubly polished thin chips from the Mogollon mining district and vicinity. Suitable fluid inclusions were found in 21 samples (Table 2).

Typical inclusions consist of liquid with a small vapor bubble. Most visible inclusions are irregular in shape and less than 0.04 mm in diameter. Fluorite contains comparatively large, isolated inclusions with negative crystal shapes that we interpret as primary. In a sample of fluorite from Sacaton, a negative crystal-shaped inclusion had dimensions of up to 0.2 mm on a side. Most primary inclusions in the fluorites were about 0.04 mm in cross section. Obvious secondary inclusions in fluorite were generally small (less than 0.08 mm in diameter) and followed fractures. Inclusions in calcite and quartz were less easy to classify because the minerals are highly fractured. Most inclusions followed fracture and/or cleavage planes. Inclusions for analysis were selected because of their isolation and shape; none of these inclusions showed evidence of necking. The fluid inclusions analyzed in calcite and quartz may be primary, pseudosecondary, or, less likely, secondary. Definite secondary inclusions in samples F–6 and C–2 were homogenized at temperatures between 145 and 170°C, and they were homogenized in sample PC–1 at temperatures between 100 and 160°C. These temperatures are lower than temperatures reported in Table 2. We believe the fluid-inclusion data reported are representative of the main stage of mineralization.

The salinities of the fluid inclusions were determined from the freezing-point depression, and they are expressed as equivalent weight percent NaCl (Table 2). The composition of the inclusion fluid was determined in four samples of fluorite by leaching crushed samples with deionized water followed by atomic-absorption analysis (Table 3). The leach solutions represent a sample of both primary and secondary fluids. Within the optical size range of our microscope (>0.001 mm diameter inclusion), fluorite from the Goldspar prospect has roughly equal amounts by volume of primary and secondary inclusions, whereas the other samples analyzed have greater than 75% secondary inclusions. The secondary inclusions in our samples generally are smaller than the primary ones so we optimized crushing size for the best extraction of primary fluids.

## Discussion and summary

The homogenization temperatures of the fluid inclusions show a progressive decrease in temperature with time based on the generalized paragenetic sequence of quartz to
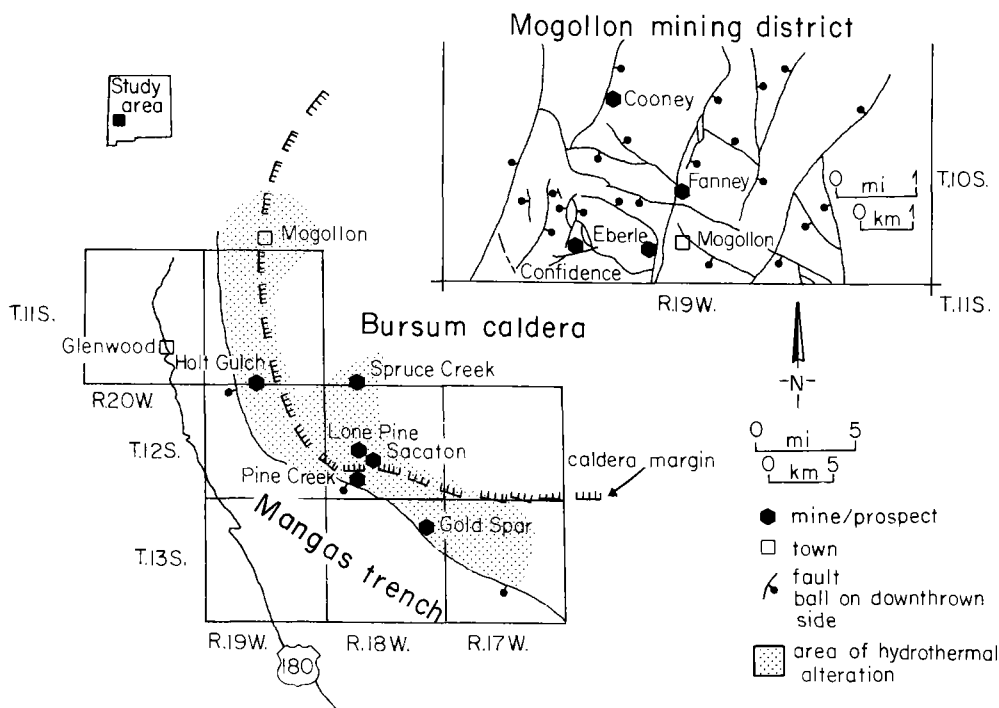


FIGURE 1—Location map of study area, Mogollon mining district and vicinity, southwest New Mexico. Location of mines and prospects along the southwest margin of the Bursum caldera are shown; the Mangas trench, a basin and range graben, is south of the caldera.

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TABLE 2—Homogenization temperatures and salinity determined on fluid inclusions from the Mogollon mining district and vicinity, southwest New Mexico. *Variable gas/liquid ratios and temperatures reported represent minimum ratios.

| Sample | Description | Homogenization temperature | | | Salinity | |
|---|---|---|---|---|---|---|
| | | Number of inclusions | Range (°C) | Mean (°C) | Number of inclusions | Mean salinity (equiv. wt.% NaCl) |
| **Fanney mine** | | | | | | |
| F–1 (surface) | Quartz | 5 | 202–258 | 221 | 3 | 3.4 |
| F–3 (900 ft level) | Quartz | 8 | 195–248 | 211 | 1 | 3.4 |
| F–6 (900 ft level) | Calcite | 9 | 204–228 | 224 | 3 | 3.4 |
| F–21 (surface) | Calcite | 1 | | 241 | | |
| **Confidence mine** | | | | | | |
| C–2 | Quartz | 6 | 249–269 | 260 | 3 | 3.4 |
| C–3 | Quartz | 8 | 254–271 | 262 | 2 | 3.4 |
| **Eberle mine** | | | | | | |
| EU–3 (200 ft level) | Fluorite* | 3 | 183–185 | 184 | 2 | 3.2 |
| EU–3a (200 ft level) | Fluorite* | 4 | 158–166 | 162 | | |
| EU–4 (200 ft level) | Quartz | 2 | 231–243 | 237 | 1 | 3.3 |
| EU–4 (200 ft level) | Calcite | 1 | | 241 | | |
| E–34 (200 ft level) | Calcite | 3 | 210–235 | 235 | 1 | 3.5 |
| E–35 (200 ft level) | Calcite | 3 | 205–227 | 214 | 2 | 3.2 |
| **Gold Spar** | | | | | | |
| RC–1 | Fluorite, white | 10 | 164–189 | 176 | 4 | 3.3 |
| RC–2 | Fluorite, green | 6 | 180–216 | 202 | 2 | 3.4 |
| **Pine Creek** | | | | | | |
| PC–1 | Fluorite, green | 7 | 164–177 | 172 | 1 | 3.4 |
| **Holt Gulch** | | | | | | |
| HG–1 | Fluorite, green | 6 | 162–178 | 171 | 3 | 3.3 |
| **Sacaton** | | | | | | |
| S–1 | Fluorite, green | 3 | 164–167 | 166 | | |
| S–2 | Fluorite, white | 6 | 160–170 | 163 | 3 | 3.3 |
| **Lone Pine** | | | | | | |
| LP–1 | Fluorite, white | 5 | 157–165 | 161 | 1 | 3.4 |
| LP–2 | Fluorite, green | 3 | 178–181 | 179 | | |
| **Spruce Creek** | | | | | | |
| 85–1 | Fluorite, green | 8 | 183–209 | 191 | 3 | 3.4 |

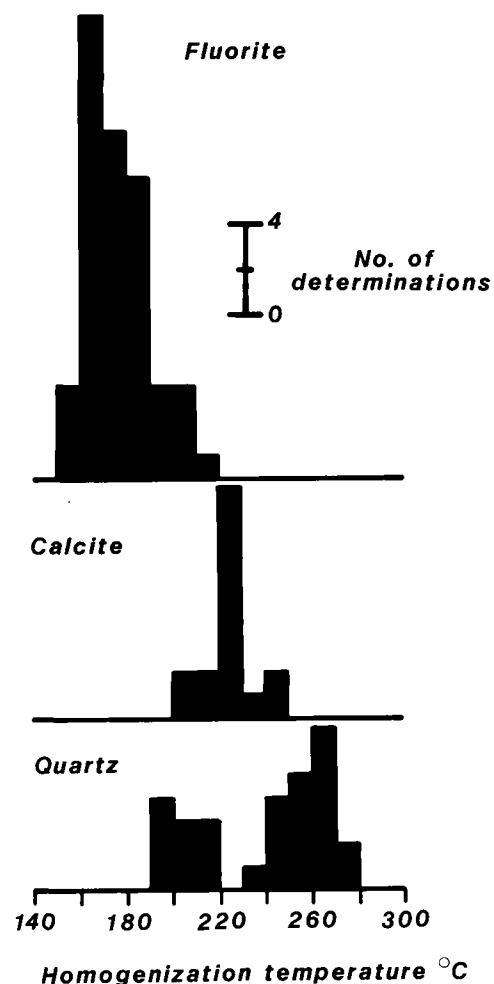| Summary | Number of inclusions | Mean (°C) | One standard deviation |
|---|---|---|---|
| Quartz (high T variety >238°C) | 19 | 257 | 11 |
| Calcite | 17 | 224 | 11 |
| Fluorite | 61 | 176 | 14 |



FIGURE 2—Histograms of fluid-inclusion homogenization temperatures in quartz, calcite, and fluorite, roughly in paragenetic order from oldest to youngest. No pressure corrections were applied.

TABLE 3—Composition of fluid-inclusion leach solutions for fluorites from the Mogollon Mountains in ppm. About 15 grams of optically clean fluorite were crushed and leached with 50 ml of deionized water. The leach solutions were analyzed by atomic-absorption spectrometry calibrated to standard solutions. Precision of the data is approximately ±5% of the amount determined for Na and K; it is approximately ±30–50% for Mg and Mn at < 0.05 ppm and ±10% at > 0.05 ppm. The data presented are normalized to 10 grams of sample.

| | Sacaton | Holt Gulch | Pine Creek | Gold Spar |
|---|---|---|---|---|
| Na | 0.6 | 0.7 | 0.5 | 0.5 |
| K | 0.3 | 0.5 | 0.2 | 0.8 |
| Mg | 0.03 | 0.07 | 0.09 | 0.3 |
| Mn | 0.03 | 0.02 | 0.08 | |

calcite to fluorite (Fig. 2). The data for quartz suggest a bimodal distribution in homogenization temperatures. The lower peak may represent secondary fluid inclusions formed during late calcite or early fluorite mineralization. No inclusions were found in samples that are believed to be the earliest formed quartz, thus the initial mineralizing fluids may have been hotter than indicated by the samples analyzed. Salinity values show no consistent trend with time, and they cluster around 3.3 weight percent equivalent NaCl (Fig. 3). The Na/K ratios of extracted primary/secondary inclusion fluid are between 0.6 and 2.5. These values fall within the low range of those reported for mineral deposits by Roedder (1979). The relatively high-K content of these fluids is consistent with the strong K-metasomatism of vein host rocks in the district (Kent, 1983).

The gas/liquid ratio for inclusions within individual samples is reasonably constant, except for fluorite samples from the Eberle mine. Isolated, negative crystal-shaped inclusions with variable gas/liquid ratios and up to 90 volume percent gas have been found in two samples of fluorite from Eberle mine. However, in these samples there are also numerous negative crystal-shaped inclusions that are clearly connected to fractures and have leaked. Thus, it is possible that the variable gas/liquid ratios in isolated inclusions are due to leaking along fractures that are now healed and/or too small to be visible. Variable gas/liquid ratios, if primary, would suggest that the fluid was boiling during fluorite deposition. At the Eberle mine quartz was deposited at a temperature of 240°C or more from fluids that apparently were not boiling. A lower temperature fluid that had boiled during fluorite deposition (150–180°C) would have required a combination of the following conditions during quartz to fluorite mineralization: 1) a change from lithostatic to hydrostatic pressure ($P_{fluid} \geq P_{lithostatic}$); 2) a dramatic drop in hydrostatic pressure if the vein was open to the surface; and/or 3) a significant amount of erosion. Because the origin of the variable gas/liquid ratios is disputable, we believe that the fluids probably were not boiling at the depth of Eberle mineralization. A pressure of more than 33 bars is required to prevent boiling during quartz deposition (Haas, 1971). In a vein open to the surface this corresponds to a hydrostatic depth of more than 375 m.

A temperature of about 230°C (uncorrected for pressure) for quartz and calcite deposition at the current top of the Fanney vein requires a pressure of more than 27 bars to prevent boiling (Haas, 1971). In a vein open to the surface this corresponds to a hydrostatic depth of more than 325 m. The top of the Fanney vein today is higher topographically (170 m) than the part of the Eberle vein that was sampled. If one assumes there was no structural adjustment after mineralization, then the thickness of cover during Eberle mineralization could have been 500 m or more.

The hydrothermal fluids responsible for the Cenozoic mineralization in the Mogollon mining district had temperatures that varied with time from greater than 270°C to 180°C. They had a constant salinity of about 3.3 equivalent weight percent NaCl with Na/K ratios of 0.6 to 2.5. The temperatures and minimum depth estimates of mineralization and the abundance of base-metal sulfide minerals in the Mogollon mining district are typical of those found in the deeper levels of precious-metal deposits associated with volcanic terranes (Buchanan, 1981).
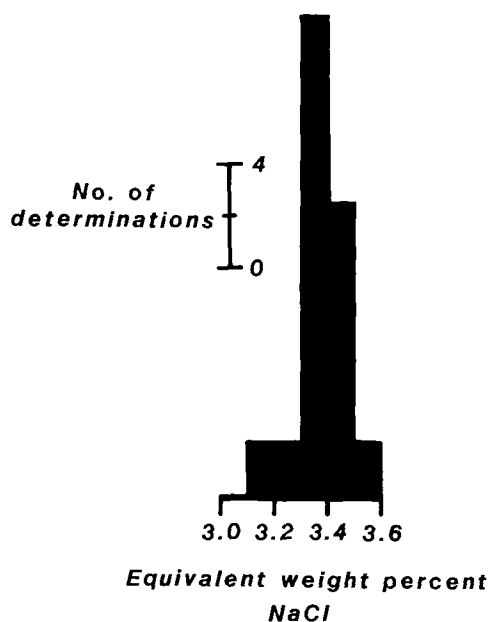
FIGURE 3—Histogram of equivalent weight percent NaCl determined from the freezing-point depression of fluid inclusions.

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| Date / commodity | Operator info | Location |
|---|---|---|
| 1–18–84 mill | Operator—Mica Mill, Mica Mine, Mica Inc., Box 2403, Santa Fe, NM 87504; Supt.—Wayne Brown, phone: 852–2727; Other official—George Rosen, Box 2422, Santa Fe, NM 87504 | Rio Arriba Co.; private land; ores milled or refined—mica; capacity of mill:—50,000 tons per day; directions to mill: 12 mi north of Espanola on NM–68 |
| 2–3–84 limestone | Operator—Herzog Contracting Corp., 1900 Garfield Ave., St. Joseph, MO 64503; Gen. Mgr.—Stan Herzog, 1900 Garfield Ave., St. Joseph, MO 64503, phone (816) 233–9001; Person in charge—Frank Storbakken, P.O. Box 1936, Deming, NM, phone: (505) 546–2770; Gen. Supt.—Arnold Shipp, 1900 Garfield Ave., St. Joseph, MO 64503; Other official—Randy Herzog, 1900 Garfield Ave., St. Joseph, MO 64503, phone (816) 233–9001; Property owner—U.S. Government, Bureau of Land Management, 1705 Valley Drive, Las Cruces, NM 88005 | Grant Co.; sec. 17, T. 24 S., R. 14 W.; Deming mining district; federal land; directions to mine: 1.7 mi north of the intersection of US–10 and NM–81 |
| 2–3–84 uranium | Operator—Crownpoint, Westinghouse Electric Corp., Uranium Resources Div., Penn Center 3–400, P.O. Box 355, Pittsburgh, PA 15230; Gen. Mgr.—E. J. Miles, Westinghouse Electric Corp., P.O. Box 355, Pittsburgh, PA 15230; Gen. Supt.—Salvador Chavez, Westinghouse Electric Corp., Crownpoint Project, P.O. Box 777, Crownpoint, NM 87313; Other official—T. H. Ritner, Westinghouse Electric Corp., P.O. Box 355, Pittsburgh, PA 15230; Property owner—Westinghouse Electric Corporation | McKinley Co.; sec. 24, T. 17 N., R. 13 W.; private land; directions to mine: 0.5 mi northwest of Crownpoint, NM, on Church Road |
| 2–10–84 Silver, lead, zinc | Operator—Prospect N, PICOM Corp., Ltd., P.O. Box 361, El Prado, NM 87529 (company change of name); Gen. Mgr.—James R. Grainger, same address; Person in charge—James R. Grainger, same address; Property Owner—James R. Grainger | Sierra Co.; sec. 12, T. 13 S., R. 9 W.; Hermosa mining district; federal land; underground; directions to mine: 0.5 mi east on forest road 157 at Wagonbed Spring, 20 mi south of Winston, NM, and 1 mi north of Hermosa, NM |
| 2–16–84 sodium | Operator—New Mexico Salt & Minerals Corp., P.O. Box 2262, Carlsbad, NM 88220; Gen. Mgr.—Dale W. Janway, Minesite, NM–31, phone: 745–3658; Gen. Supt.—Herman Justice, same address; Other officials—Marvin Watts and Bill Buzbee, Carlsbad, NM; Property owner—New Mexico Salt & Minerals Corp. | Eddy Co.; sec. 18, T. 23 S., R. 29 E.; Eddy mining district; private land; directions to mine: on NM–31 5 mi east of Loving, NM |
| 2–16–84 silica | Operator—LeRoy Jones Mining Co., 1812 Mesquite, Lordsburg, NM; Gen. Mgr.—Leroy Jones, same address, phone: 542–9525 | Hidalgo Co.; sec. 36, T. 21 S., R. 17 W.; Gold Hill mining district; federal land; directions to mine: 1 mi southeast of WD Ranch |
| 3–5–84 clay | Operator—Kight Clay Pit, Kight Construction, P.O. Box 413, Hatch, NM 87937; Gen. Mgr.—Claude Kight, same address, phone: 267–4653; Gen. Supt.—Earl Kight, E. Herrera Rd., Hatch, NM, phone: 267–4962; Property Owner—U.S. Dept. of the Interior, Bureau of Land Management, Las Cruces, NM 88001 | Doña Ana Co.; sec. 23, T. 19 S., R. 4 W., state land; directions to pit: 3 mi west on NM–28 on south side of road |
| 4–3–84 gold | Operator—Clinnken Dagger, Bickerstaff pit, 8513 Marquette NE, Albuquerque, NM 87108; Gen. Mgr.—Hanzle Janoltona, same address, phone: 268–2269; Property owner—Hanzle Janoltona | Bernalillo Co.; T. 10 N., R. 6 E.; private property; directions to mine: go south 8 mi on NM–214, east 5 mi to Juan Thomas, north 2.25 mi |
| 4–16–84 copper | Operator—Burro Chief Copper Co., Drawer B, Tyrone, NM 88065; Gen. Mgr.—Richard E. Rhoades; same address; Gen. Supt.—T. R. Snider; same address; Property owner—Burro Chief Copper Co., 2600 N. Central Ave., Phoenix, AZ 85004–3015 | Grant Co.; sec. 15, T. 19 S., R. 15 W.; private land; directions to mine: approximately 1 mi southwest of Phelps Dodge Corp. |