Exploration for precious metal mineralization in the Guanajuato mining district, Mexico using petrography and fluid inclusions

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Abstract. The Guanajuato mining district in Mexico was discovered in 1548. Ore shoots are localized along three major NW vein systems, the La Luz, Veta Madre and Vetas de la Sierra. More than 1200 samples were collected from surface outcrops, underground mine and historical and recent drill core. Most of the samples were assayed for precious and base metals. In this study, we describe a technique based on petrography of gangue minerals and fluid inclusion characteristics that may be applied in exploration for Au-Ag deposits to identify targets from samples collected on the surface, in drill holes and underground workings. Features associated with boiling that have been identified (e.g. colloform silica-texture, and jigsaw silica-texture) and other minerals, including illite, adularia and bladed calcite are also indicative of rapid growth and are characteristic of boiling systems. Because boiling is an effective mechanism for precipitating Au-Ag from hydrothermal fluids, the presence of mineral textures indicative of boiling is a desirable feature in exploration. In many samples, textural evidence for boiling is supported by coexisting liquid-rich and vapor-rich fluid inclusions, or FIs consisting of only-vapor-rich inclusions, suggesting “flashing” of the hydrothermal fluids. Several traverses along surface outcrops and perpendicular to the veins show that samples collected from within 25 m of the main veins show increasing Au-Ag abundances that correlate with an increase in features that indicate boiling. This approach helps to establish new targets for detailed exploration. Importantly, textural and fluid inclusion evidence for boiling has been observed in the deepest levels where samples were collected, suggesting that additional precious metal resources may occur beneath these levels.

Keywords: Fluid inclusions, boiling, flashing, mineral exploration

1 Introduction

Successful exploration for mineral deposits requires tools that the explorationist can use to distinguish between targets with high potential for mineralization and those with lower economic potential. In this study, we describe a technique based on gangue mineral textures and fluid inclusion characteristics that has been applied to identify an area of high potential for gold-silver mineralization in the epithermal Ag-Au deposits at Guanajuato, Mexico. It is now well known that mineralization in these deposits is often genetically related to boiling (Figure 1).

Figure 1. Schematic representation of the relationship between depth and pressure (top) and the types of fluid inclusions, mineral textures and precious metal grades (bottom) for systems undergoing gentle boiling (or effervescence) and those that flash. The L-V curve represents the depth-pressure conditions for a fluid whose density is equal to the density of the liquid phase that would be in equilibrium with vapor at that pressure (and temperature). In a gently boiling system, liquid at a pressure slightly greater than the pressure on the liquid-vapor curve (path B0 B1) and boiling or effervescence begins. The fluid continues to follow the liquid-vapor curve as it flows towards the surface (path B1 B2). Below the depth at which boiling begins, euhedral or massive quartz (or calcite) precipitates in response to gradually decreasing temperature along the flow path and traps FIs consisting of liquid-rich FI with consistent liquid to vapor ratios. Above the bottom of the boiling horizon
euhedral quartz precipitates, trapping coexisting liquid-rich and vapor-rich fluid inclusions. Depending on the intensity of boiling, chalcedony or plumeose quartz may also precipitate in this region. Depending on the concentration of precious metals in the liquid before boiling occurs, precious metals may deposit at or above the bottom of the boiling zone. If the fractures are mostly closed at depth, the fluid (liquid) will be at pressures above hydrostatic and perhaps approaching lithostatic. Quartz precipitating from this fluid will be either massive or euhedral and contain FIAs consisting of liquid-rich FI with consistent liquid to vapor ratios. If the fracture opens in response to seismic activity or increased fluid pressure, the pressure may decrease rapidly to less than hydrostatic (path F0→F1), causing the liquid phase to instantly vaporize, or flash. In this case, amorphous silica with colloform texture will precipitate and FIAs consisting of all-vapor inclusions may be trapped as secondary inclusions in previously formed quartz. Most or all of the precious metals in the original liquid will precipitate at the bottom of the boiling zone to produce a high-grade (bonanza) ore zone, with little or no precious metals below or above this horizon.

Theoretical and experimental data indicate that boiling can be an effective mechanism to deposit gold in the epithermal environment because boiling can cause the fluid pH to increase or decrease, and can also cause the Eh (oxygen fugacity) to increase or decrease (Henley and Brown, 1985; Shenberger and Barnes, 1989).

2 Petrography

Samples were examined using a petrographic microscope to identify the minerals and to classify the textures of quartz, adularia, and calcite (Figure 3).

Next, the sample was examined systematically to identify fluid inclusion assemblages (FIAs) and the types of fluid inclusions in each FIA. An FIA represents a group of fluid inclusions that were all trapped at the same time (Goldstein and Reynolds, 1994; Bodnar, 2003). FIAs may be composed of primary inclusions trapped during precipitation of the host phase, or may contain secondary inclusions that are trapped along fractures in the host phase at some time after the mineral has formed. FIAs in samples from the Guanajuato Mining District (GMD) were further classified as containing liquid-rich inclusions with consistent liquid-to-vapor ratios and a trapped illite crystal (Figure 4A), coexisting liquid-rich and vapor-rich inclusions with a broad range in liquid-to-vapor ratios and a trapped illite crystal (Figure 4B), and assemblages consisting of only vapor-rich inclusions (Figure 4C).

3 Geological setting

The GMD is one of the largest silver-producing districts in the world. Ore shoots are localized along three major northwest trending vein systems, the La Luz, Veta Madre and Vetas de la Sierra (Figure 5). The GMD is located at the southern end of the Sierra Madre Occidental Oligocene volcanic province and between the Sierra Madre Oriental and the Trans-Mexican volcanic belt (Clark et al., 1982). Aranda-Gómez et al. (2003) divide the rocks in this area into a “basal complex” and “cover rocks”.

Figure 3. Photomicrographs of silica textures indicative of boiling observed in samples from the GMD. Jigsaw texture quartz observed in plane polarized light (A) and under crossed polars (B). Feathery texture quartz observed in plane polarized light (C) and under crossed polars (D). Flamboyant texture quartz observed in plane polarized light (E) and under crossed polars (F). Plumose texture quartz observed in plane polarized light (G) and under crossed polars (H). Colloform texture silica observed in plane polarized light (I) and under crossed polars (J). Lattice bladed calcite observed in plane polarized light (K) and under crossed polars (L). Lattice bladed calcite replaced by quartz observed in plane polarized light (M) and under crossed polars (N). Colloform-banded jigsaw texture silica observed in plane polarized light (O) and under crossed polars (P). Colloform-banded plumose texture silica observed in plane polarized light (Q) and under crossed polars (R). Ghost-sphere texture silica observed in plane polarized light (S) and under crossed polars (T). Rhombic adularia observed in plane polarized light (U) and under crossed polars (V). Pseudo-acciular texture (W). Crustiform texture (X). The following textures are not indicative of boiling: Rhombic calcite observed in plane polarized light (Y). Comb texture quartz observed in plane polarized light (Z). Zonal quartz texture observed in plane polarized light (AA). Massive texture quartz (BB).

Figure 4. Photomicrograph (A) Showing liquid-rich inclusions with trapped illite in quartz. (B) Showing coexisting liquid-rich and vapor-rich inclusions indicative of boiling. (C) Showing a trail of vapor-rich-only inclusions indicative of intense boiling or “flashing”.

Figure 5. Location map of the Guanajuato Mining District showing locations of three major veins (La Luz, Veta Madre &
Sierra) and various mines in the district. (modified from Church, 1907 and Taylor, 1971).

The basal complex consists of metamorphosed marine sediments of Mesozoic to early Tertiary age, while the Cenozoic cover rocks are composed of continental sediments and subaerial volcanic rocks. The Cenozoic volcanism has been divided into seven pulses (Randall et al., 1994; Aranda-Gómez et al., 2003), ranging in age from about 51 Ma to 8 Ma. Felsic to intermediate volcanism that occurred from 37 to 27 Ma produced the rock units and structures that host the mineral deposits (Buchanan, 1979; Godchaux et al., 2003). More than 1200 samples were collected from surface outcrops, underground mine and historical and recent drill core. Ore textures vary and include breccia, colloform silica texture and clay minerals. Mineralization styles in the district show much variability between and within deposits, from precious metal-rich to more base-metal-rich zones, and from gold-rich to silver-rich zones. Fluid inclusion and mineralogical features indicative of boiling have been characterized within all of the different mineralization styles from all three vein systems in the GMD. Most of the samples (approximately 90%) were also assayed for Au, Ag, Cu, Pb, Zn, As, Sb.

Figure 6. Relative abundance of the different mineral textures and fluid inclusion characteristics in samples from the GMD, Mexico.

4. Application in exploration for epithermal precious metal deposits

4.1 Veta Madre system

Exploration in Veta Madre focuses on surface, drill core and underground workings. Previous work suggests precious metal mineralization is likely to be encountered as deeper levels of the Veta Madre system are explored and developed (Moncada et al., 2012a). Based on the strong evidence for boiling in the deep levels at Rayas/Cata, the Santa Margarita vein was discovered (Moncada and Bodnar, 2012b) (Figure 7).

Figure 7. (A) Plan view of the Veta Madre showing surface sample locations and general geology (modified from Stewart, 2006). Tvbx: Veta Madre vein exposed at surface; TEmbx: Tertiary (Eocene) volcanic breccia derived from the massive lava flows; TEmnl: Tertiary (Eocene) massive andesite lava flows over lain by volcanic breccia; TESS: Tertiary (Eocene) monomictic to polymictic conglomerates, breccias, sandstones and ash tuffs; Kaflp: Cretaceous rhyolite, quartz porphyry dikes and small plugs; Ksh: Cretaceous mudstone, slate, muscovite schist, ptyllite, sandstone, quartz arenite, limestone interbeds; Kanfl: Cretaceous andesite lave flow. (B) Longitudinal section of Veta Madre including drill core samples, projected onto the Veta Madre. No vertical exaggeration. (C) Several features have been recognized in the Veta Madre that indicates the presence of boiling fluids. The total number of these features shown by each sample was recorded as the “boiling intensity factor”.

Traverses perpendicular to veins were conducted in the vicinity of San Vicente (Figure 8) and Cebada mines.

Figure 8. Boiling intensity factor (A) and Au (B) and Ag (C) grades of samples collected along a traverse perpendicular to the Veta Madre, and boiling intensity factor for samples from an angled drill core from the surface to the Veta Madre. JT = jigsaw texture silica; CT = colloform texture silica; PT = plumeose texture silica; FI = fluid inclusions.

4.2 La Luz system

The La Luz system samples were collected from the Plateros, Melladito, Intermediate, Nombre de Dios,
Bolañitos, San José, Lucero, Karina, Daniela and Belén veins. Traverses perpendicular to veins were conducted in some of the veins (eg. Melladito and Intermediate veins, Figure 9).

Samples from the GMD show a wide range in silica textures and orebody form controlled by structural and hydrothermal processes. Some of these textures, including colloform texture, plumose texture and jigsaw texture, are indicative of rapid precipitation, such as occurs when fluids boil. Other mineral phases, including illite, rhombic adularia and bladed calcite are also indicative of rapid growth in a hydrothermal system and are characteristic of boiling systems. Because boiling is an effective mechanism for precipitating gold and silver from hydrothermal fluids, the presence of mineral textures indicative of boiling is a desirable feature in exploration for geothermal systems and ore controls of a fossil geothermal system. Golden. Colorado, Colorado School of Mines. Doctoral Thesis p. 138.

Figure 9. Drill hole number 1 from the San Ignacio property showing gold and silver values (top axis) and the percent of samples that show evidence of boiling as a function of elevation or depth in the drill hole. The depth (elevation) where the drill core intersected the Melladito and Intermediate veins is highlighted in red.

Figure 10. Schematic east-west cross section of the GMD showing the different veins and distribution of fluid inclusions and silica and calcite mineral textures present as a function of depth. (CT) Colloform silica texture, (PT) Plumose silica texture, (JT) Jigsaw silica texture, (BC) Bladed calcite replaced by quartz, (Adu) Adularia, (S/I) Sericite/illite smectite.

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References


