Fluid origin of the Ixtacamaxtitlán hydrothermal deposits, Puebla State, Mexico

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Abstract

The hydrothermal deposit of Ixtacamaxtitlán (Puebla, Mexico) is made up by a succession, from bottom to top, of quartz veins and stockwork enclosed in a porphyritic subvolcanic body, a kaolinitized rhyolitic tuff and a layered opal deposit. This vertical arrangement coupled with the distribution of the different alteration assemblages lead to the interpretation of the whole as a low-sulfidation epithermal deposit. The fluid inclusion study carried on the veins and the stockwork along with the stable isotopic analyses performed on the kaolinitized bodies helped us to propose two major hydrothermal events that occurred in the area: an early event, characterized by hot, hypersaline fluids (up to 280 °C and 36 wt.% NaCl eq.) closely associated with a potassic alteration episode; and a late event, distinguished by cooler and dilute fluids (up to 150 °C and 4 wt.% NaCl eq.), associated with propylitic and quartz–sericite alterations at depth and acid–sulfate alteration close to the paleosurface due to steam-heated phreatic waters. Post-trapping changes found affecting the primary fluid inclusions (hook-shaped morphologies) suggest that there was an uplifting period between the two stages.
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1. Introduction

The Ixtacamaxtitlán municipality is located north of the Puebla State in Central Mexico (Fig. 1). The local geology comprises (1) Lower to Middle Cretaceous limestone formations of the Sierra Madre Oriental and (2) igneous intrusive and extrusive rocks of Tertiary to recent age, of the Sierra Madre Occidental and the Trans-Mexican Volcanic Belt (TMVB). The hydrothermal deposits of the area are hosted by the Coyoltepec Pyroclastic Deposits (Carrasco-Núñez et al., 1997) and the plutonic to subvolcanic rocks (diorites to granitic porphyries) that intruded the pyroclastics deposits. The area is overlain by basalts and andesites of the TMVB. This paper describes the geochemical origins of the hydrothermal vein deposits, which are thought to have formed during uplift and cooling of a porphyritic subvolcanic body.

2. Hydrothermal deposits

Subvertical veins of quartz, chalcedony and subordinate sulfides (pyrite and chalcopyrite), up to 1–
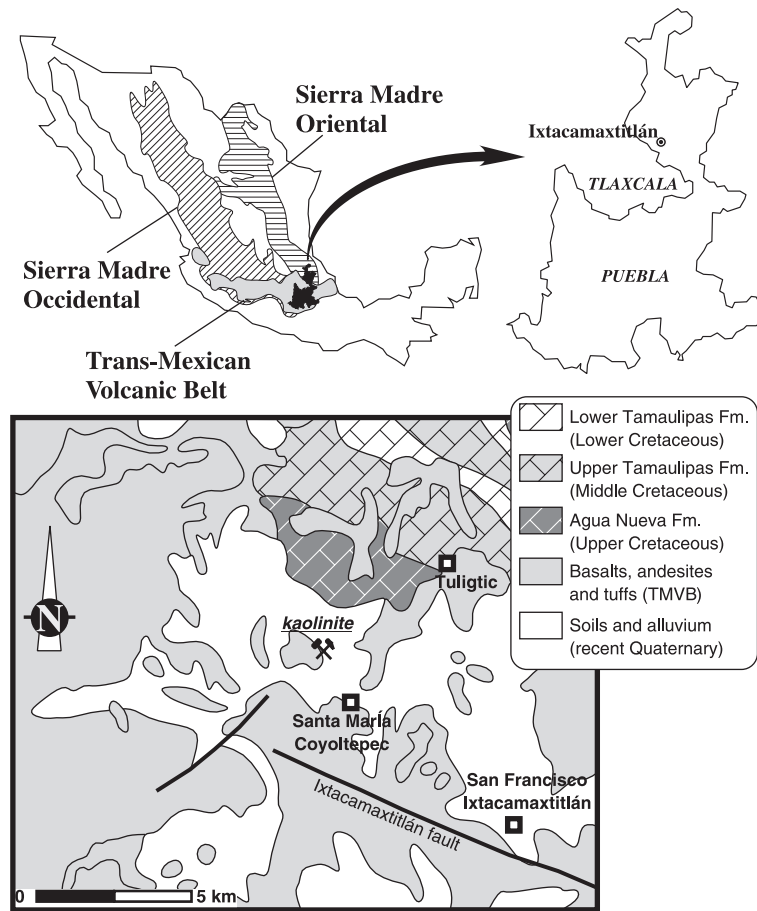
Fig. 1. Geographical and geological setting of the hydrothermal deposits of Ixtacamaxtitlán.

1.5 m thick, are found crosscutting a quartz porphyritic subvolcanic body. These veins are mostly massive to banded, with some cockade structures and quartz-lined vugs, containing highly altered fragments of the enclosing porphyries. Both at the top and laterally to the former veins, a quartz−pyrite−chalcopyrite ± sphalerite stockwork formed. The enclosing subvolcanic rocks show up to 1-cm-thick propylitic haloes surrounding the quartz veinlets. Outwards, a potassic alteration assemblage is found, mainly represented by the pseudomorphism of former magmatic amphibole crystals to a mesh of secondary biotite (biotitization). A late, pervasive kaolinization of the feldspars affected the subvolcanic rocks, preserving the original magmatic texture.

Kaolinization is strongly developed into the rhyolitic tuff unit that overlies the subvolcanic rocks, originating as an up to 50-m-thick subtabular kaolinitic body. The lower part of the kaolinitized sequence is crosscut by quartz and/or opal veinlets that are continuous from the underlying stockwork. Some of the original internal structures of the tuffs are well preserved throughout the entire kaolinitized sequence, being the variable amounts of residual quartz a reflection of the original changes in mineral composition. Bulk-rock analyses show no significant Au and Ag values in this kaolinitized bodies.

Partially eroded silica caps are found on top of the kaolinitized units. They consist of a set of several meters thick opal layers interbedded with kaolin-bearing vuggy horizons. Some of the layers contain

primary structures that suggest the opal deposition in a subaerial environment: bioturbation marks, imprints of vegetal remains and very abundant mud cracks (Camprubí et al., 2001). This unit is commonly crosscut by subvertical thin opal veinlets, coupled with microbrecciation of the opal layers, which could represent the feeder channels of the hydrothermal solutions on their way to the paleosurface. The above units are interpreted as in situ sinters. Some thin, massive silica layers found within the kaolinitized tuffs subconcordant with the tuff lamination are interpreted as formed in a steam-heated paleowater table.

3. Fluid inclusion study

A fluid inclusion study was undertaken to define the history of the vein-forming solutions. Standard and thick sections were used for petrographic examination. About 10 double-polished quartz wafers were selected for microthermometric determinations. The analyses were performed on a Linkam THMS-600 heating–freezing stage calibrated using synthetic fluid inclusions (triple point of distilled water, 0.0 °C; CO_2-bearing fluid inclusions, -56.6 °C) and chemical products (Merck). Accuracy in measurements are about ± 0.2 °C for freezing runs and ± 2 °C for heating runs. Salinities were calculated using the Mac-FlinCor package (v. 0.92; Brown and Hageman, 1994).

Suitable fluid inclusions for microthermometric studies were found in quartz from both the stockwork and the veins. Clusters of fluid inclusions (10−40 μm average size) were found randomly distributed within quartz crystals (primary) and in healed fractures that crosscut the growth bands (secondary). Primary fluid inclusions are three-phased, with sizes between 10 and 30 μm and with a degree of filling (liquid + halite/vapor) of about 0.8. Secondary biphase fluid inclusions (aqueous fluid + vapor bubble) have sizes between 10 and 50 μm, and present a visual degree of filling from 0.8 to 0.9. Post-trapping changes in primary three-phase fluid inclusions are evident in some samples, so these inclusions were carefully avoided for microthermometric analyses, although it is noteworthy that some modified inclusions display a hook-shaped morphology as described by Vityk and Bodnar (1995).

Preliminary analyses on primary fluid inclusions show homogenization temperatures between 240 and 281 °C and solubility temperatures of halite (Tfh) between 180 and 282 °C, with a calculated salinity between 31 and 36 wt.% eq. NaCl. Secondary fluid inclusions show eutectic temperatures of about -26 °C, suggesting the presence of $CaCl_2$ in the solutions. Ice melting temperatures are around -6 °C, corresponding to a calculated salinity around 4 wt.% eq. NaCl, and homogenization temperatures cluster between 140 and 150 °C.

4. Stable isotope data

Hydrogen and oxygen isotopic compositions of kaolinite samples were analyzed at the Actlabs Laboratories. Oxygen was analyzed by attacking the kaolinite BrF_5 at ∼ 650 °C in nickel pumps following the procedure of Clayton and Mayeda (1963). Hydrogen was analyzed by dehydration of kaolinite at 1400 °C for 20 min, purifying the water extracted by using cold traps. Isotope measurements were performed in a Finnigan Mat 251 mass spectrometer and are reported as the delta permil notation with respect to the V-SMOW standard.

The kaolinite δD values range between -59 ‰ and -86 ‰, and $\delta^{18}O$ values range between $+10.6$ ‰ and $+20.4$ ‰ (Fig. 2). Before discussing the hydrogen and oxygen isotope compositions of these kaolinites, it is first necessary to choose the most appropriate kaolinite–water isotopic fractionations from those that are currently available. This aspect is especially critical for the hydrogen isotopic fractionation, as the available fractionation equations diverge considerably. After a careful examination of the different equations and published discussions, we used the empirical kaolinite–water hydrogen fractionation factors of Marumo et al. (1980). To obtain a self-coherent data set, we also chose the empirical kaolinite–water oxygen fractionation equation of Land and Dutton (1978).

The results are compared (Fig. 2) with the available data from present-day meteoric and hydrothermal fluids from Los Humeros geothermal field (González-Partida et al., 2001), located in a similar geographic and geohydrological setting, close to the study area. The calculated δD compositions for hydrothermal
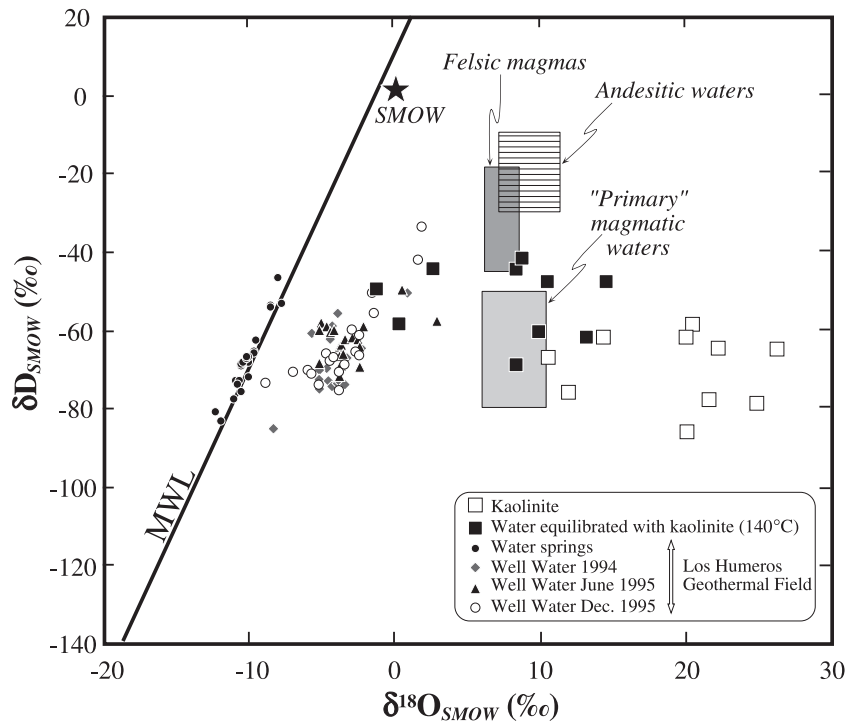
Fig. 2. $\delta^{18}O$ vs. δD plot for the kaolinites and kaolinite-equilibrated water at 140 °C. See text for further explanations.

waters in equilibrium with kaolinite at 140 °C are comparable and partially overlap the δD composition of the hydrothermal water sampled at Los Humeros. The oxygen isotopic compositions of both kaolinite and the calculated hydrothermal water in equilibrium show a marked shift to heavier oxygen compositions, with the lighter calculated $\delta^{18}O$ values overlapping the compositions from Los Humeros Geothermal field.

5. Discussion and conclusions

The high temperatures and salinities (up to 280 °C and 36 wt.% NaCl eq., respectively) recorded in primary three-phase fluid inclusions from the quartz veins and the stockwork match with the hydrothermal alteration developed at a relatively high temperature (biotitization) on the intrusive host hypabyssal rocks. The occurrence of a pervasive biotitization of the former amphiboles in the host rocks, underneath the kaolinitized sequence and sinters, suggests that the host hypabyssal rocks formed originally at deeper le-

vels. Moreover, following Vityk and Bodnar (1995), the hook-shaped morphology displayed by some primary three-phase fluid inclusions can be interpreted as the result of an isothermic decompression path, which caused the partial necking of the inclusions due to inner overpressure. This decompression can only be due to the uplifting of the host hypabyssal rocks.

Secondary fluid inclusions record a late hydrothermal event at lower temperature (140 °C) and salinities ($\sim$ 4 wt.% eq. NaCl). The calculated isotopic composition of water in equilibrium with the kaolinitic sequence, at temperatures similar to those found in the secondary fluid inclusions, plots close and underneath to the meteoric water line, partially overlapping the Los Humeros geothermal fluids. These evidences coupled with the petrographic observations suggest that acid meteoric waters, probably steam-heated, altered the rhyolitic tuffs. This would have occurred when acid vapors exsolved from deeper hydrothermal fluids by boiling reached the local paleowater table and condensed.

The fluid circulation during the kaolinization of the rhyolitic tuffs scavenges silica and reaches the surface giving rise to the amorphous silica (opal) deposits found in the area. The structures found in the opal layers indicate the presence of a hot spring pool controlled by climate stationarity, with alternate periods of wet season (with hydrothermal activity and deposition of silica) and dry seasons (with the subsequent water table retreat and sediment desiccation).

The presence of geochemical anomalies of Au and Ag in the stockworks of the Ixtacamaxtitlán area, plus the structure of the deposit, may indicate the occurrence of an Au–Ag low-sulfidation epithermal deposit at depth with economic potential.

Acknowledgements

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