

SPACE-TIME EVOLUTION OF THE HYDROTHERMAL ACTIVITY IN A VOLCANIC DOME : THE CERRO BONETE EPITHERMAL TYPE MINERALIZATIONS (BOLIVIA)

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In a volcanic system, part of the activity corresponds to the circulation of hot fluids, which are responsible for the alteration of the percolated rocks and the transfert of chemical elements (metals or not). Thanks to accurate studies of the minerals developed during these fluid-rocks interactions (mineral composition, geothermometers, related fluid inclusions), it is possible to define the characteristics and the space-time evolution of this hydrothermal activity in a cooling volcanic dome.

The Cerro Bonete massif in Bolivia (near the Argentinian border) (fig.1) belongs to the Early Cenozoic magmatic belt, which extends all along the Bolivian orocline. In the area, the oldest volcanic formation is the Rondal formation, which corresponds to high-K, meta-aluminous andesites and andesi-basalts. After erosion, they are followed by the intermediate to acid volcanics of the Quehua formation. It consists of voluminous (up to 700 m) pyroclastics flows cut and overlain by coalescent lava domes, flow breccias and lava flows. They are high-K, peraluminous rhyodacites (Fornari et al, 1993 ; Bailly, 1994). These domes host several mines and prospects known as the "Bolivian polymetallic veins", mined out for some of them during the spanish times (Sugaki et al, 1986 ; Richter et al, 1992). Two of them were studied (Bailly, 1994). Bolivar mine (Ag, Bi, Pb, Zn, Cu) consists of a subvertical E-W vein emplaced in an extrusive dacitic volcanic dome, whereas Lipeña mine (Sb) was mined in the Rondal lavas.

In Lipeña mine, the mineralization (pyrite, marcasite, stibnite, realgar, orpiment) precipitation in the vein is related to the replacement, in the wall-rocks, of the primary igneous assemblage (olivines, pyroxenes, plagioclases) by montmorillonites (\pm marcasite, pyrite) and farther from the vein by mixed-layered minerals (\pm jarosite). These mineralogical transformations are geochemically characterized by a strong leaching of Ca, Mg, Mn, Na, trace and rare earth elements.

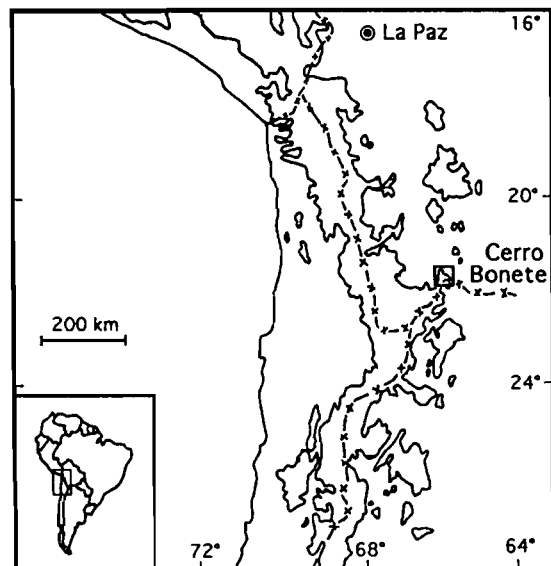


fig.1 - Location of the Cerro Bonete area on eastern border of the cenozoic volcanic belt

In Bolivar mine, in getting farther away from the vein, the dominant illite - subordinate chlorite (chamosite) association is replaced by a dominant chlorite (brunsvigite)-subordinate illite one. In the same way, a decrease of the X_{Fe} ratio for both illite and chlorite (fig.2) and an increase of the phengitic substitution rate of the illites occur.

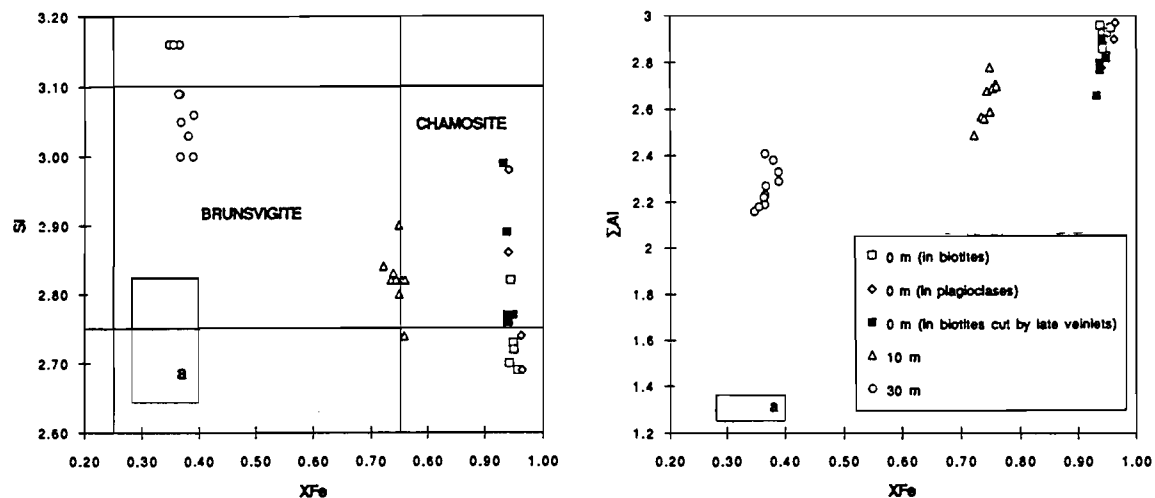


fig.2 - ΣAl and Si vs X_{Fe} diagrams for the chlorites developed in the wall-rocks according to their distance to the vein. The box (a) corresponds to the composition of the unaltered biotites in the reference sample.

During the alteration, Na and Ca are strongly leached, whereas large amounts of Fe and K are added. In the vein, the chlorites are the only alteration minerals observed in close association with each stage of mineralization deposition. Even if they are all chamosites, significant chemical variations occur between the different generations. Both chlorites and illites are used in order to estimate the water/rock ratios during fluid circulation and the fluid temperatures in the vein and the wall-rocks. Combined with fluid inclusion studies, they lead to a multi-staged, space-time evolution of the hydrothermal activity during the volcanic dome cooling (fig.3).

Stage 1 is initiated by the raising, towards shallow levels, of deep, hot (around 350°C), moderately salted (4.9 to 16.8 wt % eq. NaCl) and reduced hydrothermal fluids. The arsenopyrite-pyrite assemblage precipitates in fractures created in the dome by the fluid pressure. Simultaneously a pervasive chloritization of the biotites is observed up to at least 30 m from the vein. At 30 m, the water/rock ratio is low, the chlorite composition is controlled by the composition of the former minerals and there is a thermic equilibrium between the fluids and the cooling dome around 260 °C. After this first pulsation, the illites crystallization occurs in the previously fractured dome, in response to mixing of colder and less salted fluids, probably of meteoritic origin, with the previous ones.

Stage 2 corresponds to a second pulsation of hot (250-190°C) fluids. They are associated to the polymetallic mineralization (Bi-Ag-Pb-Zn-Cu). The percolated volume is smaller due to an increasing fluid channelization in a colder dome (around 190°C ?)

The last stage (stage 3, sulfides-carbonates) corresponds to a third pulsation of more hot (230-290°C) and Ca-enriched fluids. This stage is only observed within the vein. A possible continuity of the hydrothermal activity between stages 2 and 3 seems to be argued by the progressive increase of the fluid salinities and temperatures.

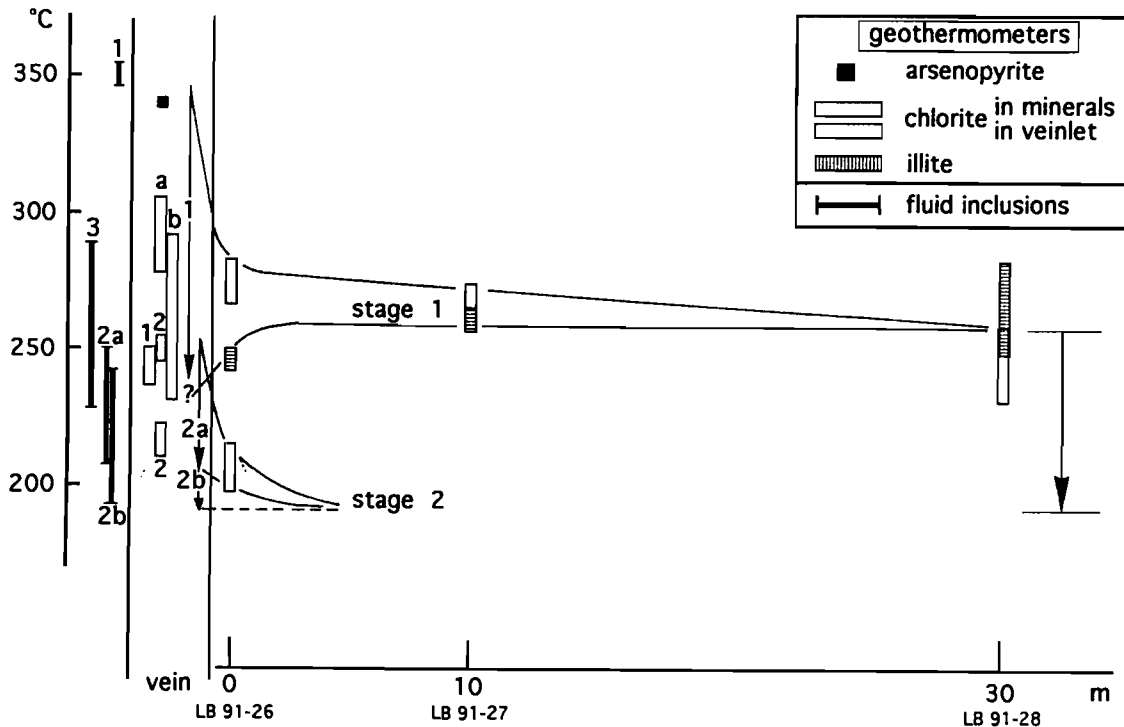


fig.3 - Space-time evolution of the fluid temperature and of the percolated volume in the Bolivar dome during its cooling.

Such a space-time fluid evolution with several pulsations of hot volcanic fluids and mixing with dilute meteoritic fluids, is often described for the epithermal-type ore deposits related with volcanic activity (Hedenquist et al, 1992 ; Hedenquist and Lowenstern, 1994 ; Marcoux, 1995).

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