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GENESIS OF THE LOMA GALENA DEPOSIT, NAVIDAD DISTRICT, PATAGONIA ARGENTINA

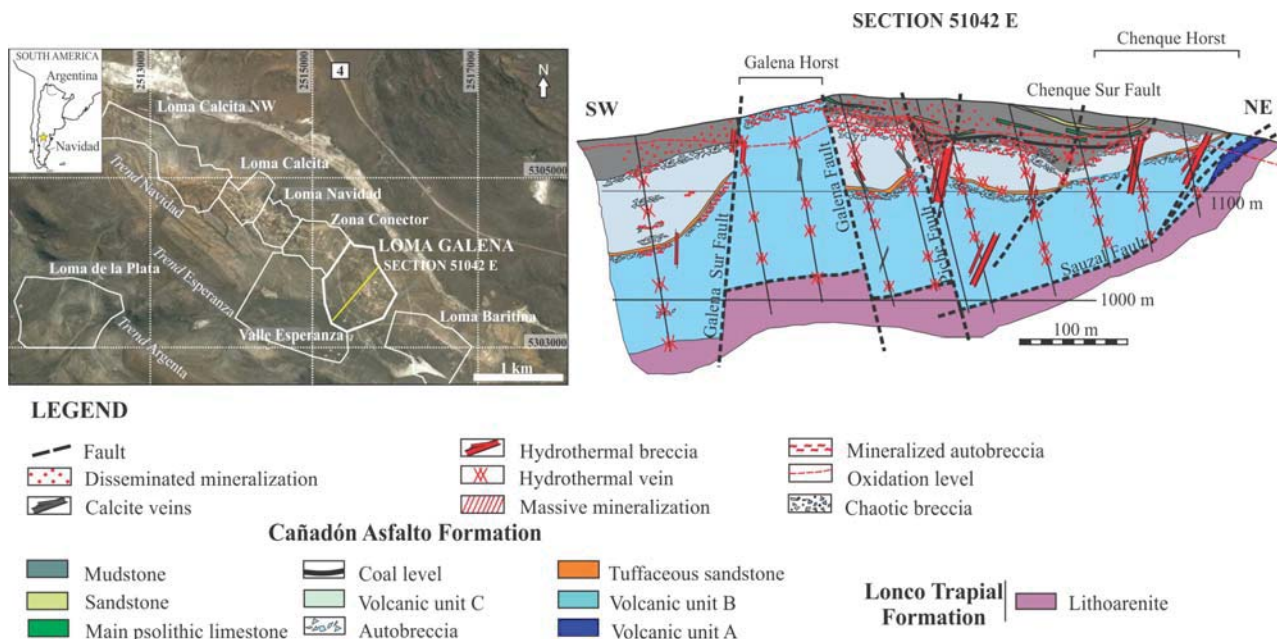
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Loma Galena (6410.8 t Ag, 997,130 t Pb) is one of the eight deposits of the world class Ag + Pb ± (Cu, Zn) Navidad district (19.670 t Ag and 1.32 Mt Pb) located in the west of the North Patagonian Massif of Argentina. The deposit was formed in an active continental rift basin during the Middle Jurassic, when subaerial volcanic activity was contemporaneous with lacustrine sedimentation. The normal faults that delimited the horsts and grabens in the deposit and the Sauzal fault, a detachment fault, acted as the main conduits for the upflow of hydrothermal fluids (Fig. 1). The deposit has a lithologic control and the highest metal anomalies are found in highly permeable and reactive autobrecciated mafic volcanoclastic rocks interbedded in the volcano-sedimentary Cañadón Asfalto Formation (Fig. 1).

The volcanic rocks are high-K basaltic andesite to dacite in composition and they have yielded LA-ICPMS U-Pb zircon ages of 173.9 ± 1.9 Ma and 170.8 ± 3.0 Ma. Lava flows surrounded by autobrecciated carapace were dominantly extruded in subaerial conditions whereas hyaloclastite and peperite facies suggest contemporaneous subaqueous volcanism synchronous with sedimentation. Lacustrine sedimentation represented by calcareous mudstone with pisolithic and laminated limestone, sandstone, chert and coal overlies the volcanic rocks. A Sr-rich evaporite layer interbedded in the sedimentary succession indicates intermittent drying out of the lake and hypersaline conditions.

The mineralization occurs in veins and hydrothermal breccias that lie on the structural hanging wall and footwall of the main faults, in mineralized autobreccia and chaotic breccia at the contact between volcanic and sedimentary rocks, and disseminated in the organic-rich sedimentary rocks. The earliest mineral infill of veins and breccias consists of calcite I and siderite with crustiform, cockade and platy textures, followed by two main episodes of mineralization. During the first mineralization stage precipitated framboidal pyrite and colloform pyrite, marcasite, galena and sphalerite. During the second stage chalcopryrite, bornite and tennantite-tetrahedrite with minor amounts of covellite and digenite replaced the early sulfides. Colloform bands of pyrite and marcasite show the highest Ag contents, although all sulfides and sulfosalts carry Ag. Sulfides are rarely observed in situ, on the walls of veins; they are usually found as transported fragments cemented by several pulses of chalcedony deposition with minor barite. Late infill consists of calcite II, barite II, quartz and strontianite. Hydrothermal breccias present voids with a geopetal infilling with detrital material of sand-silt size and variable composition (chalcedony, quartz, calcite, ankerite, barite, sulfides, rock fragments) with parallel lamination.





Volcanic rocks next to veins and breccias are altered and replaced by albite, adularia, calcite, celadonite, quartz, chlorite, sulfides, chalcedony, several types of clay minerals (kaolinite and smectite with illite-smectite mixed layers and traces of tosudite), Fe-Mg-Mn carbonates and calcite II. In the sedimentary rocks, the clasts are replaced by chalcedony, kaolinite and carbonates. Calcite and chalcedony also fill micro-veinlets.

The sulfur isotopic signatures of sulfides hosted in veins and hydrothermal breccias ($\delta^{34}\text{S}$ -0.9 to +8.3‰) are more restricted than the $\delta^{34}\text{S}$ of sulfides hosted in the autobreccia, chaotic breccia and sedimentary rocks ($\delta^{34}\text{S}$ -15.4 to +12.9). The sulfur isotopic signature of hydrothermal barite varies between +15.7 and +22.0‰. The isotopic composition of celestite from the evaporite layer in the sedimentary rocks is 35.3‰.

Calcite I from veins has $\delta^{13}\text{C}$ values between -4.4 and -0.3‰ and a $\delta^{18}\text{O}$ of +19.7 to +22.1‰. Calcite 2 also from veins and breccias displays $\delta^{13}\text{C}$ values between -3.5 and -1.7‰ and $\delta^{18}\text{O}$ values of +11.2 to +15‰. Chalcedony II infill of veins and breccias has $\delta^{18}\text{O}$ between +16.2‰ and +18.4‰. Late quartz infill of veins and breccias has a $\delta^{18}\text{O}$ of +12.4‰.

Calcite I hosts aqueous fluid inclusions with a salinity close to 16.4 wt.% NaCl equiv. that homogenize between 165.8 and 208.3°C. Barite hosts aqueous fluid inclusions that homogenize to liquid in the range of 111-169°C. Fluid inclusions in calcite II have lower salinity (0 to 4.2 wt.% NaCl equiv.) and homogenization temperatures (58 to 95°C) than calcite I.

Early calcite I (siderite?) precipitated in veins and breccias from fluids with high salinity (~16.4% wt. NaCl eq.), temperatures (T_h) <208 °C, and isotopic compositions of $\delta^{18}\text{O}$ fluid= 7.4‰ to 11.6 ‰ and $\delta^{13}\text{C}$ CO_2 -6.4 to -2.3 ‰. Calcite I, albite, adularia, celadonite, and chlorite formed during the interaction of deeply derived chloride-rich fluid with the host volcanic rocks. The system intermittently boiled, as evidenced by platy texture in the calcite infill of veins and breccias. The steam generated during boiling at depth could condense in the overlying sedimentary rocks, forming H_2S and CO_2 -rich steam-heated waters. The abundance of black shale and the sulfur isotope values suggest that the bottom waters of the lake were anoxic and the loci of abundant biogenic sulfate reduction.

Mixing of the upflow chloride-rich fluid with H_2S -rich steam-heated water efficiently precipitated Ag bearing pyrite, marcasite, sphalerite and galena and dissolved some early formed hydrothermal phases in the altered volcanic rocks followed by the precipitation of tosudite and abundant kaolinite. The subsequent stage introduced Cu with Ag through fluids of limited circulation from the north and channeled by the Sauzal fault, and replaced some previous sulfides. Evidences that support the sulfide formation by fluid mixing are the following: a) the sulfur isotopic signatures of sulfides indicate a mixed source, with sedimentary sulfur derived from the biogenic reduction of the sulfate from the evaporite interbedded in the lacustrine sedimentary rocks and deep hydrothermal sulfur; b) the textures of sulfides such as framboids of pyrite and colloform pyrite-marcasite that are indicative of quick supersaturation, and, c) the high metal contents in sulfides and sulfosalts.

Once the H_2S was consumed, the diluent was CO_2 -rich steam-heated water. Gradual cooling and dilution of chloride fluids by mixing with descending CO_2 -rich steam-heated water may also account for the successive formation of illite-smectite, smectite, chalcedony, barite, carbonates rich in Fe and Mn, and calcite II in veins and breccias, in the volcanic and overlain sedimentary rocks at Loma Galena.