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Tectonic conditions of hydrothermal polymetallic vein-type mineralization, Sainte Marie-aux-Mines, France

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The Sainte-Marie-aux-Mines (SMM) mines host one of the most famous and oldest silver deposits in Europe. The SMM district is located in the central part of the Vosges mountains, France, within gneiss and granites of the Moldanubian zone. The SMM district includes the Neuenberg E-W vein-type Cu–Ag-As/Pb-Zn deposit and the Altenberg N-S vein-type Pb–Zn–Ag deposit. Deposition of the SMM hydrothermal mineralization occurred under a brittle tectonic regime that might be connected to neo-Variscan and/or post-Variscan tectonics, in a similar way as the polymetallic vein deposits of the Black Forest, Germany.

A structural study was done in the Neuenberg area, in the vicinity of the Saint-Jacques vein, and within the Gabe Gottes mine, considering the orientation, extent, chronology and density of faults as well as the nature of the infilling minerals. In the Gabe-Gottes mine, the Saint-Jacques vein comprises multiple successive, sub-parallel subvertical veinlets with gangue minerals, mostly carbonates and quartz, and metal-bearing phases, sulfides and sulfosalts. The veinlets are 2 to 50 cm thick and strike N80° to N110°, the earlier veins slightly dipping towards the north, and the latest one, to the south. Seven systems of faults were identified, which may be classified into three major groups formed respectively before, during and after the main stage of ore deposition:
a) Pre-mineralization faults - These consist of sinistral NE-SW strike-slip faults, and NW-SE and NE-SW steeply dipping normal faults. These could be related to Carboniferous events considering their relationships with the granitoid intrusives present in the mine area (Brézouard leucogranite ∼329 Ma), and the extensional tectonics developed during exhumation processes.
b) Faults associated with the main ore-deposition - These faults could be related to late-Hercynian processes from compressional to extensional tectonic regimes. Mineralization controlling faults consist of dextral and sinistral E-W strike-slip faults. Early strike-slip movements are assessed by the presence of striated iron oxides, the crystallization of which is considered to be early during the ore deposition process. Mineralizing fluids were probably fluorine-rich as F-bearing minerals, sericite, chlorite and apatite are present in the chlorite zone associated with early sulphide-rich ores. The E-W mineralized faults are only easily compatible with the tectonics known in Permian times.
c) Late-stage faults - These could be related to the numerous changes in plate configuration which occur during the Mesozoic and Cenozoic times, in accordance with the creation of the Paris basin, the opening of Atlantic ocean and Rhine Graben, as well as with the Tethys closure. For example, the vertical lineation superposed on an horizontal lineation observed on mineralized rocks indicate reactivation of the former E-W mineralized veins under a normal movement. The latter may correspond to an extensive regime known during Oligocene times. On the other hand, one of the major late-stage faults strikes N-S and is related to a dextral strike-slip system, which could be considered as Miocene. It is expected that fluid remobilization occurred during fault reactivation, a process which could have led to successive ore deposition following the emplacement of the major E-W mineralized veins. A fluid inclusion study in the gangue minerals of the Gabe Gottes is now under investigation. This together with isotopic studies will help to determine the source of the mineralizing fluids, as well as the conditions of ore deposition.

Keywords: Faults, polymetallic mineralization, variscan orogeny, Gabe-Gottes, Sainte-Marie-aux-Mines, Vosges, F-rich fluids.