MINERALOGICAL AND GEOCHEMICAL CARACTERISATION OF PALEOFLUID CIRCULATIONS THROUGH FRACTURED SHALES IN POLYPHASED TECTONIC CONTEXT

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At the Tournemire experimental site (Aveyron, France), the French Institute for Radioprotection and Nuclear Safety (IRSN) studies a 250 m thick, fractured, Domerian and Toarcian shale formation as natural analogue to HLNW disposal site. The site is located on the Western Border of the Causse basin, to the South of Massif Central (Aveyron, France), and consists of a former train tunnel passing through the upper part of the shale formation. The shale constitutes a low permeability layer between two limestone and dolomite aquifers. The study area corresponds to an E-W trending block, limited to the North and the South by two major E-W faults inherited from the Paleozoic tectonic phase and crossed by a less important fault, oriented NE-SW. All these faults have reverse offset. Deformation occurred in two main tectonic phases: a Jurassic extensional phase followed by an uplift during Cretaceous and an Eocene compressional phase. The Jurassic extension is characterised by three events defined by $\sigma 3$ oriented successively ENE-WSW, NW-SE and N-S. The Eocene compression is related to the Pyrenean orogeny and is characterised by two successive stress states with $\sigma 1$ directions N20 and N160. Thermal history reconstruction indicates that basin inversion occurred during Aptian, and could be related to the Durancian isthmus uplift. Extension is coeval with sedimentation in the Causse basin whereas compression is related to an erosion period. This study focuses on fluid paleocirculation in fractures initiated and developed (or reactivated) during each deformation phase, in shale, limestone and dolomites. Calcite veins were sampled in fractures well characterised for their kinematics and were studied by petrological methods. Redox conditions and nature of fluids in fractures during veins crystallisation were inferred from *in situ* chemical analysis, fluid inclusions and stable isotopes composition in calcite.

Calcite constitutes the main fracture fillings, sometimes with dolomite, pyrite or barite. In limestone and dolomite formations, Fe and Mn concentrations are higher in calcite formed during extension than in calcite formed during compression. In the Toarcian shale, Fe and Mn concentrations in calcite are similar during both extension and compression, except in a N130 sinistral fault active during compression at the Tournemire site. In veins formed during the Mesozoic extension, $\delta^{18}O$ values range from 18.1 to 21.4‰ *SMOW* for crystallisation temperatures between 70 and 120°C. In calcite veins formed during the Eocene compression, $\delta^{18}O$ vary between 21.7 and 24.2‰ *SMOW* for crystallisation temperature between 30 and 40°C. In all calcite veins, $\delta^{13}C$ range from –2 to 1.2‰ *PDB*, excepted in veins in Aalenian limestone (-4.5‰ *PDB*) and in geodes from the N130 fault (-0.7 to –4‰ *PDB*).

Veins associated with the extension phase in the limestone and dolomite formations crystallised from fluids with $\delta^{18}O$ between –1.0 and +3.0‰ considering the temperature range

given by fluid inclusions. Such compositions could indicate that calcite crystallised from fluids derived from sea water or that fluids were equilibrated with limestone formations, since they were deposited in a marine environment. Veins observed in the Toarcian shale crystallised from a fluid with high $\delta^{18}O$ (+4.7‰ SMOW) indicating strong water-shale interactions. Fractures in the shale were probably not connected outside the formation during extension and fluids in these fractures were shale pore water.
During compression, calcite veins crystallised from fluids with an important meteoric water component. In the shale, these fluids result from a mixing between formation water and meteoric water diffused from local aquifers prior to the compression and are expelled from host rock in the fractures. Reduced conditions prevailed during both deformation phase, as indicated by high Fe content in calcite veins. The N130 fault at the Tournemire site could connect with Aalenian limestone during compression, marked by a $\delta^{13}C$ decrease in calcite and variations in Fe concentration.