Fluid Migration and Brittle Tectonothermal Evolution in the Central Fennoscandian Shield

- Recorded by Fracture Minerals and Wall Rock Alteration

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ABSTRACT

The Forsmark area in central Sweden has been investigated as a potential geological host for a final repository of spent nuclear fuel by the Swedish Nuclear Fuel and Waste Management Company (SKB). High quality drill core material from the upper 1 km of the central Fennoscandian Shield has been obtained during the site investigations and has provided a unique opportunity for detailed fracture mineralogical investigations. In this thesis, a multi-analytical approach for recognising events of fluid migration and brittle tectonothermal evolution by analysis of fracture minerals and wall rock alteration is presented. The basis for this study has been the establishment of a relative sequence of fracture mineralisations obtained by investigations of cross-cutting relations and mineral overgrowths. Based on this sequence, representative fracture mineral samples have been selected for further analysis, e.g. $^{40}Ar/^{39}Ar$ dating, stable isotopes, trace element geochemistry and fluid inclusions. Statistical analysis of the orientation of fractures lined with different minerals has also been carried out.

Four major events of fracture mineralisation have been distinguished in the Forsmark area. The two first events are associated with hydrothermal alteration of the wall rock, causing a red-staining due to hematite dissemination. The alteration is characterised by chloritisation of biotite, saussuritization of plagioclase and partial replacement of magnetite by hematite. The oldest event occurred sometime between 1.8 and 1.1 Ga, possibly during a late stage of the Svecokarelian orogeny. Precipitation of epidote, quartz and chlorite occurred at temperatures between c. 200° and 350°C in preferably sub-horizontal to gently dipping fractures or steep, WNW-ESE to NW-SE fractures.

These fractures are cut by fractures sealed with hematite-stained adularia and albite, prehnite, hematite-stained laumontite, calcite and chlorite which are prominent along steep, ENE-WSW to NNE-SSW and NNW-SSE fractures. These minerals precipitated under hydrothermal conditions at temperatures between 150° and 250°C. $^{40}Ar/^{39}Ar$ dating of fracture filling adularia and K-feldspar fragments in breccias shows that a major event of hydrothermal circulation associated with both reactivation and formation of fractures occurred in the area at 1.1 to 1.0 Ga, probably due to far-field effects from the Sveconorwegian orogeny. This event was followed by a period with some dissolution of fracture minerals.

During the Palaeozoic, sometime between 460 and 277 Ma, fluids emanating from a sedimentary cover rich in organic material migrated downward into the basement, mainly during reactivation of older fractures, but formation of new fractures is also inferred during this period. It is suggested that far-field effects from the Caledonian orogeny and/or the overburden of the Caledonian foreland basin is responsible for this tectonothermal event. The youngest generation of fracture minerals is dominated by clay minerals and thin precipitates of calcite in hydraulically conductive fractures and in the upper part of the bedrock. Minor occurrences of pyrite and goethite have also been found. This event is poorly constrained in time, and precipitation may have occurred episodically from the Late Palaeozoic to the present. These minerals are mainly found in sub-horizontal to gently dipping fractures, inferred as Proterozoic structures. However, some fractures in the upper part of the bedrock may have formed relatively recently due to stress release during e.g. Quaternary deglaciations.

Keywords: Fennoscandian Shield, fracture minerals, hydrothermal alteration, palaeohydrogeology, stable isotopes, $^{40}Ar/^{39}Ar$ dating, Forsmark, nuclear waste repository, Sveconorwegian, Caledonian.

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