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Deciphering the complex evolution of a polyphase fault/fracture network and its control on fluid circulation and ore deposition through macro- to micro-scale observations

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In the Kiggavik area (Nunavut, Canada), uranium mineralization is hosted in outcropping metamorphosed Archean to Paleoproterozoic basement rocks that were likely covered by the nearby Paleoproterozoic sandstones of the Thelon basin infill (1667-1540 Ma). The uranium mineralization is controlled by faults and fractures which developed during a long-lasting polyphase brittle tectonic history spanning from ca. 1850 Ma (after the Thelon and Trans-Hudsonian orogenies) to ca. 1270 Ma (before emplacement of MacKenzie dikes) for the main fracturing events.

The Kiggavik area is explored by AREVA and the understanding of the fracture network is critical in order to unravel the regional tectonic history and to constrain the stress fields that triggered the circulation of uranium-bearing basinal fluids in the basement. This understanding was made possible through the accurate characterization of the multiple fault kinematics and the related fracture sets using microstructural measurements on outcrops and drillcores for the meso-scale, combined with analyses of fluid inclusions planes (FIP) and petrographic investigation of fracture cements for the micro-scale.

Our results show that the main, long-lived ENE-WSW and NE-SW fault zones in the Kiggavik area, formed during the Thelon and Trans-Hudsonian orogenies, were subsequently mineralized in four stages (U0, U1, U2, U3), each stage being associated with distinctive fracture sets, alteration and mineralization patterns related to fault reactivation and fluid circulation. U0, inferred to be of magmatic origin, likely occurred at ca. 1830 Ma and is related to micro-brecciation and weak chloritization under a WSW-ENE compressional stress. Following this event, an intense quartz brecciation, iron oxidation and veining occurs at ca. 1750 Ma. This silicifying event observed along the NE-SW and ENE-WSW trending main faults is likely of magmatic epithermal origin and gave birth to the so-called "Quartz Breccia". The Quartz Breccia compartmentalized subsequent faulting events and behaved as an impermeable barrier for hydrothermal and meteoric fluids. Both the U0 mineralization and the subsequent silicifying events reflect the importance of pre-Thelon magmatic-related fracturing/fluid circulation events on controlling the later development of fault zones. U1, U2 and U3 postdate deposition of the Thelon formation; U1 and U2 mineralization events are associated with two fracturing stages that occurred in response to a far-field compressional stress that evolved from WNW-ESE to NE-SW/ENE-WSW. Both formed at ∼1500-1300 Ma and are related to circulation of Thelon-derived U-bearing basinal brines, preferentially in hard-linked overlapping fault-relay zones. While U2 is associated with narrow fault zones and mineralized damage and core zones, U3 is associated with wider fault zones and mostly mineralized damage zones. A post U1/U2 tectonic event predating emplacement of the Mackenzie dikes and associated with a NE-SW oriented extensional stress caused normal-dextral offset of the orebodies by reactivating preferentially NW-SE and E-W oriented, steeply dipping faults. This fracturing event triggered circulation of reducing fluids, remobilizing and reprecipitating the previous uranium stock.

This study emphasizes the importance of accurately characterizing the structural drains ("plumbing system") at different scales to decipher the history of ore deposition, and more generally of fluid-rock interactions in basement rocks in a complex, polyphase tectonic setting.