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Microstructural analysis of calcite-filled fractures inherited from basement structures, southern Ontario, Canada: long term instability of the craton?

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Intra-cratonic regions are generally characterized by tectonic stability and low seismicity. In southern Ontario, Canada, moderate levels of seismicity have been recorded over the last few decades reaching magnitudes of 5 MN, indicating that the geosphere is not as stable as predicted. The stratigraphy of the region consists of Ordovician limestone with a thickness of ~200 m that unconformably overlays the Mesoproterozoic crystalline Grenville Province. Subsequent tectonism including repeated Paleozoic orogenies and rifting along the east coast of North America has reactivated Proterozoic structures that have propagated into the overlying carbonate platform forming mesoscopic-scale brittle structures. Exposed along the shores of Lake Ontario are decameter-scale fracture zones, with a fracture spacing of 0.5 to 10 meters. The dominant fracture set trends E-W, and often forms conjugate sets with less prominent NNE-oriented fractures. More locally, an older NW-oriented fracture set is cross cut by the E-W and NNE oriented fractures. Regionally, there have been six directions of maximum horizontal stress in southern Ontario since the Precambrian, with the current orientation of maximum stress oriented ENE as a consequence of far field Atlantic ridge-push forces generated at distant plate boundaries. Calcite mineralization along fractured surfaces locally form sub-horizontal slickenside fabrics which are covered by a layer of euhedral calcite crystals, suggesting that fracture dilation (and fluid flow) occurred after fracture slip to allow the growth of calcite crystals. Due to the proximity of the carbonate units to the crystalline basement, we expect the calcitic veins to be enriched in rare earth elements and are presently conducting geochemical analyses. The calcite veins and surfaces vary from 2.5 cm to 1 mm thicknesses, often with larger calcite crystals in the center of the vein and smaller crystals at the vein boundaries, likely representing nucleation on small grains of the wall rock. Some veins show minor displacement, including the mm-scale with fractured and displaced fossil fragments, and cm-scale offsets at the outcrop. The calcite veins show evidence of low temperature deformation (~200°C) through undulous extinction, bulging grain boundaries, tension gashes structures, and extensive lamellar twinning. The width and density of twinning (twin planes/mm) provides information regarding the temperature of deformation. The calcite crystals show two populations of twinning: type I (>10 μm), and type II (tabular twinning) with an average thickness of 35 μm, and a maximum thickness of 81 μm. Twinning can only accommodate a limited amount of strain such that the calcite lamellar twinning is often kinked, broken and offset, suggesting reactivation of the calcite-filled fractures. U-Pb calcite ages from calcitic veins in the Ordovician units within the Ottawa graben are c. 400 Ma and within Devonian units at the edge of the Michigan Basin in Canada are c. 110 Ma. Additional geochronology on the calcite from southern Ontario will help resolve the timing of fracture reactivation and is an important factor in consideration of the location of a deep geological repository for Canada's nuclear waste.