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Timing and tectonic significance of regional fracture systems in Paleozoic platform rocks, east central North America: new insights from U-Pb dating of vein calcite

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Sub-vertical systematic joints in Paleozoic carbonate and clastic cover rocks display regionally continuous trajectories across large tracts of southern Ontario, Pennsylvania, Michigan, Ohio, and northern New York state, and smaller domains of anomalous orientations. NW- to NNW- trending joints extend from penetratively deformed Carboniferous to Devonian sedimentary rocks in the Appalachian foreland in the southeast into undeformed Ordovician to Pennsylvanian rocks in the north (south central Ontario) and northwest (Michigan basin). These fractures likely record tectonic loading associated with the Paleozoic Alleghenian orogeny. A second set of regionally pervasive joints trends EW to ESE. Based on their association with ca. 180 Ma lamprophyre dykes in Ontario, we ascribe these fractures to far field regional extension related to initial Jurassic breakup of the North Atlantic, development of the St. Lawrence rift system and reactivation of the Ottawa-Bonnechere graben. ENE-trending joints are ubiquitous throughout the region and are parallel to the current horizontal maximum in situ stress, suggesting a neotectonic origin.

Ordovician rocks exposed south of the Paleozoic-Precambrian unconformity in southeast Ontario contain a dominant set of NNE to NE-trending joints that closely track the structural grain of gneissic basement rocks of the underlying Grenville orogeny. Basement fractures do not cross the unconformity, suggesting a passive tectonic inheritance mechanism, which we attribute to compaction and hydraulic fracturing of the stratigraphically lowest units over a structurally-controlled corrugated basement.

Uranium-lead isotopic analyses were carried out on calcite vein material collected from outcrops and drill core at the Bruce nuclear site, Tiverton, Ontario, on the east flank of the Michigan basin. LA-ICPMS and ID-TIMS analyses yielded ages for calcite veins and vugs within >650 m deep Ordovician units of 434 $\pm$ 5 Ma. This finding is consistent with hydraulic fracturing within the deep Ordovician sequence during compaction and diagenesis up to 20 Ma after deposition. In contrast, NNW- and ENE-trending fractures in near surface Devonian rocks at the Bruce site yield U-Pb calcite infill ages over the period 80-100 Ma. Vein calcite within ENE-trending fractures within surface outcrops of Ordovician carbonate rocks exposed 350 km to the east yields a U-Pb age of 106 $\pm$ 5 Ma. These observations indicate a widespread Mesozoic fluid flow event that is either synchronous with or postdates the formation age of the youngest ENE-trending fractures. High pore fluid pressures during this event must also have been sufficient to open older fracture sets in the upper, Devonian, levels of the sequence but too low to infiltrate deeper levels. The ca. 100 Ma fluid flow event coincides with the onset of sea floor spreading and ridge push in the North Atlantic as well as the passage of the Great Meteor Hot Spot close to the study region. We speculate that the former initiated horizontal loading that led to the formation of regional ENE neotectonic fractures, and that the latter triggered a thermal +/- uplift event that flushed the Paleozoic platform sequences with carbonate brines, which infiltrated both older and younger fracture sets at shallower crustal levels.