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Structural and Isotopic Constraints on Fluid Flow Regimes and Development of Fluid Pathways During Upper Crustal Deformation: An Example from the Taemas Area, Lachlan Orogen, SE Australia

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Structural and stable isotope studies of calcite veins and host-rocks in a one kilometre thick, Lower Devonian limestone sequence in the Taemas area of the Lachlan Orogen in south-eastern Australia indicate that externally-derived fluids migrated through the sequence over a protracted interval during upright folding and associated reverse faulting at temperatures of approximately 200°C. The evolution of fluid pathways was governed by growth of fold-related and fault-related fracture networks at transiently supralithostatic fluid pressures. The internal structures of veins indicate growth during repeated cycles of permeability enhancement and sealing. Systematic increase in d18O of vein calcite upwards through the limestone sequence, and the presence of a marked O-isotope alteration front in the vein system, is related to progressive buffering of fluid compositions by fluid-rock reaction during upwards migration of overpressured, low d18O fluids. Low vein d18O adjacent to some parts of the Warroo Fault, which bounds the eastern side of the limestone sequence, indicates similar fluids also migrated laterally from the Warroo Fault into the limestone sequence. Repeated switching of fractures between high permeability and low permeability states promoted episodic flow and changes in flow paths during progressive deformation. A lack of significant migration of the isotopic front during a protracted flow history is consistent with fluid-rock interaction being associated with numerous, separate pulses of fluid ascending through the percolation network. Modest variations in fluid d18O with time during vein growth are interpreted to be driven by repeated changes in reactive path lengths and reaction rates, as well as flow rates and fluid fluxes, in a discontinuous flow regime. Modelling of coupled advective transport and kinetically-controlled O-isotope exchange between fluid and rock indicates individual fluid batches involved fluxes up to approximately 102m3m-2. Time-integrated fluid fluxes were likely several orders of magnitude higher. Systematic upward changes in vein d18O over an area of 20 km2 requires that, on a time-averaged basis, most of the vein system was hydraulically well-connected to the external fluid reservoir, and that growth of the fracture network occurred by fluid-driven, invasion percolation processes. Repeated failure and sealing events in the fracture system are interpreted to have been driven by episodic migration of fluid pressure waves up through the fracture network, possibly in response to deeper level fault rupture events repeatedly breaching an overpressured, low d18O fluid reservoir.