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Clumped isotope constraints on fluid processes and heat advection during late Variscan brittle failure of carbonate rocks

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Clumped isotope temperatures (T($\Delta_{47)}$) for macroscopic hydrothermal calcite veins from the Lower Carboniferous limestone of the Peak District, U.K. and the Clare Basin, Ireland indicate that late Variscan brittle failure is accompanied by high rates of fluid flow and heat advection along fault surfaces. Moreover, the veins are often zoned with regard to both temperature and oxygen isotope composition indicating that fluid movement is episodic and occurs in pulses.

A striking feature of the data sets for both the Peak District and Clare Basin is that veins, including multiple samples from single veins, plot on well defined two end-member mixing lines in T-$\delta^{18}O_{fluid}$ space. The data for veins in the Clare Basin indicate that they precipitated at a temperature between 100° and 160°C, and for the Peak District between 30° and 100°C. The veins precipitate from a mixed fluid comprised of: (i) a hot, isotopically evolved end member (T>160°C, $\delta^{18}O_{fluid} > +12\%_{,VSMOW}$) and; (ii) a cooler, isotopically depleted fluid more characteristic of meteoric groundwaters (T <40°C, $\delta^{18}O_{fluid} < -5\%_{,VSMOW}$).

The vein precipitation temperatures are in accord with a simple two end-member mixing process with temperature acting as a conservative property. We envisage a simple physical model in which hydraulic fractures propagate rapidly as a result of sharp increases in pore fluid pressures. The origin of the elevated fluid pressures is not clear. The timing of vein formation and association with hydrocarbon bearing shales suggests that overpressure could have been the result of gas generation within adjacent sedimentary basins. Episodic failure would result from the increases in pore fluid pressure. So-called gas pulsars have been described before but to our knowledge have not been implicated in brittle failure processes in the upper crust.