Geophysical Research Abstracts
Vol. 17, EGU2015-5602, 2015
EGU General Assembly 2015

Fluid storage and transport in thrust belts: the Gavarnie Thrust system revisited

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There has been renewed interest in the pressure and movement of fluids in thrust systems in recent years with the discovery and increasing importance of slow slip earthquakes. Unfortunately the overpressured regime thought to be the source region for both normal and slow-slip earthquakes is inaccessible to direct observation, so information about the actual water content, flow regimes and permeability structure at the time of thrusting can only be obtained in exhumed rocks.

The Gavarnie Thrust System in the Pyrenees (including the immediate footwall of the thrust and overlying thrust sheets) is exceptionally well studied in terms of structural and microstructural work, fluid inclusions, and isotopic tracing of fluid flow. Southward thrusting by 12-15 km occurred during the Eocene, and the current geometry of the thrust is a broad dome, allowing sampling at many locations. There is abundant evidence for near-lithostatic fluid pressures at depths of 8-15 km in the crust and temperatures of 300-400 °C, and fluids at these levels are dominated by hypersaline brines with Cl/Br ratios indicating evaporation of seawater. They are inferred to be derived from widespread Triassic evaporates, and stored in underlying redbeds and fractured basement rocks. There is also evidence from fluid inclusions for periodic pressure cycling down to near-hydrostatic values. This is thought to be related to co-seismic fault valve behaviour with release of fluid both into the shallow thrust and into steeply dipping shear zones in the hangingwall. Isotopic studies of carbonate mylonites along the Gavarnie thrust indicate unidirectional southward (structurally upward) flow of fluid , again probably mainly during transient veining events. These relatively slow moving fluids appear to have fed into a hydrostatic regime with topographically driven flow at higher levels.

If time averaged permeability was high, most of the fluid would have rapidly escaped, since there is little opportunity to replenish fluid by metamorphic dehydration in the Pyrenees. This does not appear to have occurred, suggesting that any enhanced permeability events were shortlived and perhaps form patches of limited size. Fluid can be stored at various scales: in fluid inclusions in vein minerals and on grain boundaries (eg. pressure shadows in cleaved rocks); in veins and pull-aparts in competent layers such as dolomite within calcite mylonites; and in structural culminations such as the Pic de Port Vieux, where development of fold-thrust structures allowed slow dilation with evidence from fluid inclusions for influx of fluid from both footwall and hangingwall. This latter can be considered a dynamic form of storage generated by deviatoric stress and strain at high fluid pressure (not "hydraulic fracture"), whereas fluid inclusions can be considered passive storage. Stored fluid in such sites can be expelled during seismic events (both slow and fast slip) where the pressure regime in large volumes of crust will change dramatically.