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The role of meteoric fluid flow in the thermomechanics of extensional detachments

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Extensional detachments are likely the simplest structures in which the interaction and feedbacks among fluid flow, deformation, and heat transfer can be studied. Cordilleran-type detachments are typically short-lived, self-exhuming structures that cooled rapidly and therefore preserve an excellent record of their deformational and thermal history. Detachments are a first-order thermal boundary; they separate a dynamic lower crust that flows viscously and accommodates thinning and upward advection of partially molten material and magma bodies in domes, from an upper crust that remains relatively cool, as evidenced by thermochronometry techniques. Metamorphic and fluid inclusion studies show that rocks in the footwall of detachments experience rapid decompression followed by rapid cooling, a result that is supported by numerical models of temperature-dependent viscous flow during crustal extension. Detachment zones themselves are the location of extreme metamorphic temperature gradients, with several hundreds of degrees collapsed into a few hundred meters of section. It is commonly assumed that this metamorphic gradient is the result of a geotherm that was highly attenuated by deformation (thinning) within the detachment. While this may be partly the case, an increasing body of thermometry data suggests that the dynamic geotherm may have already been very steep within the detachment while it was active. This is possible if the detachment is kept cool from above while heated from below, resulting in efficient thermal exchange.

We propose that flow of surface-derived fluids is critical to maintaining high thermal gradients across detachments on the scale of hundred to thousand meters. Surface fluids penetrate the crust and indeed are present in detachments; the hydrogen isotopic composition of hydrous minerals in numerous detachment mylonites demonstrates that synkinematic hydrous minerals grow in the presence of a meteoric fluid. Localized shifts in oxygen isotope values of quartz and other silicates toward lower values reflect the transient time-integrated effects of fluid/rock interaction. Rheological analyses of detachments based on quartz microstructures show that high differential stress persists in detachments, even when quartzite deforms at high temperature. This high stress may even allow the rock to alternate between fracture and dislocation creep (e.g. fluid inclusion planes overprinted by migrating grain boundaries). Therefore, fluids likely play a major role in the thermal structure of extending crust, allow the detachment zone to act as a layer of efficient heat exchange, and participate in and possibly even control the mechanical behavior of detachment mylonites.