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High and Low Temperature Oceanic Detachment Faults

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One of the most important discoveries in Plate Tectonics in the last ten years is a “detachment mode” of seafloor spreading. Up to 50% of the Atlantic seafloor has formed by a combination of magmatism and slip on long-lived, convex-up detachment faults, forming oceanic core complexes (OCC). Two end-member types of OCC can be defined: The Atlantis Bank on the Southwest Indian Ridge is a high temperature OCC sampled by ODP Hole 735b. Deformation was dominated by crystal-plastic flow both above and below the solidus at 800-950 °C, over a period of around 200 ka. In contrast, the Atlantis Massif at 30 °N in the Atlantic, sampled by IODP Hole 1309D, is a low temperature OCC in which crystal plastic deformation of gabbro is very rare and greenschist facies deformation was localised onto talc-tremolite-chlorite schists in serpentinite, and breccia zones in gabbro and diabase. The upper 100m of Hole 1309D contains about 43% diabase intruded into hydrated fault breccias. This detachment fault zone can be interpreted as a dyke-gabbro transition, which was originally (before flexural unroofing) a lateral boundary between active hydrothermal circulation in the fault zone and hangingwall, and intrusion of gabbroic magma in the footwall. Thus a major difference between high and low temperature detachment faults may be cooling of the latter by active hydrothermal circulation.

2-D thermal modelling suggests that if a detachment fault is formed in a magmatically robust segment of a slow spreading ridge, high temperature mylonites can be formed for 1-2 ka provided there is no significant hydrothermal cooling of the fault zone. In contrast, if the fault zone is held at temperatures of 400 °C by fluid circulation, cooling of the upper 1 km of the fault footwall occurs far too rapidly for extensive mylonites to form. Our models are consistent with published cooling rate data from geospeedometry and isotopic closure temperatures. The control on this process is likely a combination of geometry and timing of deformation; if the fault zone forms within a large semi-molten gabbro body it will be isolated from hydrothermal fluid, whereas if a series of small melt bodies collect in the footwall of a permeable detachment fault, they will cool rapidly.

A corollary of our model is that at slow spreading ridges the depth of melt lenses and hence the dyke gabbro transition is determined not by spreading rate (as has been suggested at fast spreading ridges) but by the effective depth of high permeability and hence hydrothermal circulation. In actively faulting environments permeability can exist to greater depths, and magma can only easily rise above these depths as dykes or volcanics. The type of detachment fault formed may depend on whether detachment faults nucleate in a robust magmatic system where they can root into a melt zone, or if magma collects in the footwall of an active fault.