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Constraints on cooling of the lower ocean crust from epidote veins in the Wadi Gideah section, Oman Ophiolite

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Determining the depth, extent, and timing of high-temperature hydrothermal alteration in the ocean crust is key to understanding how the lower oceanic crust is cooled. We report data from 18 epidote veins from the Wadi Gideah section in the Wadi Tayin block, which is a reference section for alteration of the lower crust formed at a fast oceanic spreading center. ^{87}Sr/^{86}Sr ratios feature a narrow range from 0.70429 to 0.70512, while O isotope compositions vary between - 0.7 and +4.9‰ in $\delta^{18}O_{SMOW}$. These compositions indicate uniform water-rock ratios between 1 and 2 and formation temperatures in the range of 300 to 450˚C. There is no systematic trend in Sr and O isotope compositions down section. Fluid inclusion entrapment temperatures for a subset of four samples linearly increase from 338˚C to 465˚C in lowermost 3 km of crust of the Wadi Gideah section. Salinities are uniform throughout and scatter closely around seawater values.

We developed a numerical cooling model to assign possible crustal ages to the thermal gradients observed. For pure conductive cooling, these ages range between 4 and 20 Ma. Our thermal model runs with a high Nusselt number (Nu) of 20 down to the base of the crust indicate that the epidote veins may record this near-axial deep circulation in crust of only 0.1 Ma (5-7 km off axis). When off-axis circulation is shut off in the more distal flanks, however, massive conductive reheating of the lower crust by as much as 200˚C is predicted to take place. But there is no evidence for prograde metamorphic reactions in the samples we studied (or other hydrothermally altered oceanic gabbros). An intermediate model, in which Nu is 20 down to 2 km for the first 0.1 Ma and Nu is then 4 down to 6.5 km depth off axis to 1 Ma, is consistent with the permeability distribution within the ocean crust and predicts a thermal gradient for the lower crust that matches the observed one for ages between 1 and 3 Ma. The most plausible explanation for the origin of the epidote veins is that they formed in off-axial hydrothermal systems that reach the base of the crust within 50-150 km off the axis. This deep circulation provides an efficient mechanism for mining heat that escapes the crust in the young flanks of mid-ocean ridges where a sizeable fraction of the global oceanic hydrothermal heat flux is expected to take place.