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The role of rheology in the evolution of oceanic thermal boundary layer instability structures after a change in plate motion direction

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Thermal boundary layer instabilities (TBI) have been proposed to explain the deviation in oceanic topography and heatflow from the cooling half-space model for oceanic plates spreading away from the mid-ocean ridge. The dynamics of this process have been previously studied in several numerical and laboratory experiments. TBI are largely controlled by the available gravitational energy of cold lithosphere above a hotter mantle, and the rheology of lithosphere and mantle. Recent comparison of 3-D dynamical flow models with seismic models show that the predominant deformation mechanism in the upper mantle below the Pacific is dislocation creep with an activation energy of about 360 kJ/mol. This is consistent with laboratory results, and provides new evidence for the existence of TBI in oceanic lithosphere.

We use these flow models to derive the effect on the evolution of TBI structures of a sudden change in the plate motion direction, such as may have occurred at around 43 Ma, and suggested by the bend in the Hawaii-Emperor volcanic chain. We studied and quantified the change in TBI structures as a function of time for several rheological parameters such as deformation mechanism (diffusion vs. dislocation creep), activation energy, and rheological layering. Our results suggest that in the dislocation creep regime, TBI structures aligning with the new plate motion direction can develop well within 43 Ma. In the diffusion creep regime, such alignment is likely to take much longer, depending on the rheological conditions. These results will provide estimates on what to expect in future (e.g. seismic) observations of small-scale thermal structures in oceanic lithosphere.