Cooling History of the Pacific Lithosphere: Evidence for Thermal Boundary Layer Instabilities and Dislocation Creep

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Numerous studies based mostly on surface observables (e.g., topography, heat flux) have established that the oceanic lithosphere, particularly across the Pacific, does not cool continuously as it ages. Observations of surface wave dispersion used to construct a model of shear wave speeds and temperatures in the upper mantle establish that the Pacific lithosphere has experienced a punctuated cooling history (Figure 1), cooling diffusively at ages younger than ~70 Ma and then reheating in the central Pacific between ages of about 70 and 100 Ma. At ages from 100 Ma to about 135 Ma, the processes of reheating are substantially weaker than in the Central Pacific. Uppermost mantle temperatures can also be summarized in terms of the “apparent thermal age” of the lithosphere (Figure 2). Using numerical simulations of mantle convection with realistic plate motions and various rheologies, thermal boundary layer instabilities (TBI) are shown to develop naturally as the plate cools. The average thermal structure of the Pacific upper mantle can be matched if the mantle deformation mechanism is dislocation creep ($n = 3$) with an activation energy of about 360 kJ/mol, consistent with that for dislocation creep for olivine determined from laboratory studies.
