A strain-heating model for the seismic low-velocity zone along the Main Himalaya Thrust

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Seismic low-velocity zone along the MHT

Recent Hi-CLIMB seismic experiment, using an 800 km long, densely spaced seismic array across Nepal and southern Tibet has revealed a low-velocity zone along the Main Himalaya Thrust (MHT; Nabelek et al, 2009). The narrow low-velocity zone extends approximately from the 28.5°N latitude, dipping to ~40 km depth at the latitude of the Yarlung Tsangpo Suture, and then continues horizontally beneath the Lhasa Block to approximately 32°N latitude. Nabelek et al. (2009) interpreted this deep low-velocity zone to be the result of increased ductility and partial melting. The narrowness of the low-velocity zone along most of the length of the MHT requires a mechanism by which the partial melting is localized. Strain heating along the ductile portion of the MHT provides such a mechanism.

Parameters of numerical models

A finite-difference model that incorporates strain-heating produces a narrow, localized partial melting zone along the MHT thrust (Fig. 1). The 600 km x 140 km model domain had 1 km grid spacing. The initial conditions were steady-state with subduction of the Indian lithosphere beneath the Himalayas and Tibet; however, topography was ignored. Temperature at the surface was held at 25°C and at the bottom of the lithosphere at 1300°C. Radiogenic heat production in the Indian crust was constant at 2 $\mu W/m^3$ in the upper 20 km and 0.7 $\mu W/m^3$ in the lower 15 km. This heat production results in surface heat flow of 70 mW/m^2 that is the average for the stable northern Indian crust. Given the preponderance of lithologies of oceanic sedimentary provenance and granites above the MHT, heat production in the upper plate was assumed to be 2 $\mu W/m^3$ throughout. Heat production in the lithospheric and convecting mantle was assumed to be 0.01 $\mu W/m^3$. In the initial steady state, the subduction of the Indian lithosphere at 3 cm/y keeps the crust above the MHT refrigerated.

The numerical calculations followed those in Nabelek et al. (2010). They accounted for temperature-dependent thermal diffusivities and rheologies of crustal materials. Thermal diffusivities (*D*) of crustal lithologies vary exponentially from >1.5 mm^2/s at 25 °C to as low as 0.4 mm^2/s at >600 °C (Whittington et al., 2009). The inverse correlation of *D* with *T* results in model steady-state lithospheric geotherms that are straighter in comparison with geotherms calculated with the frequently-used constant *D* of 1 mm^2/s. This makes heating of the crust to melting temperatures in heat flow models more challenging than most previous models would suggest. Moreover, the inverse correlation shows that hotter rocks retain their heat longer.

Volumetric strain heating due to deformation in the ductile regime is given by $A_{sh} = \tau \times \dot{e}$, where τ is the shear strength of a rock and $\dot{e}$ is the strain rate. Strain rate for a 3 km wide shear zone undergoing simple shear resulting from 3 cm/y subduction is $3 \cdot 10^{-13}$. Assuming power-law temperature dependence of τ for quartz (Rutter and Brodie, 2004), the volumetric heat production at this strain rate is ~100 $\mu W/m^3$ at 550°C and ~10 $\mu W/m^3$ at 750°C (Nabelek et al., 2010). Thus, heat production by simple shear at this tectonically driven strain rate far exceeds the heat production from reasonable concentrations of radioactive elements, and it is even higher for dry pyroxene, olivine, and feldspar.

Model results

In calculations, strain heating was assumed to occur along the length of the MHT, but only within the ductile regime of the crust, the extent of which increases as temperatures become more elevated. The depth dependence of the schist solidus is from Patiño-Douce and Harris (1998). With subduction only, shearing along the MHT produces by 20 m.y., when steady-state begins to be approached, a molten zone between 450 km and the 600 km right boundary of the model domain. A more rapid subduction, hence a larger strain rate, does not produce a significantly longer molten zone because increased strain heating is offset by increased refrigeration by the subducting plate. However, when southward thrusting of the upper plate at 1 cm/y is introduced into the model, then a narrow, partially molten zone becomes more extended, from 310 km to the end of the model domain (Fig. 1). The partially molten zone is underlain by an inverted temperature gradient. The southward thrusting compresses isotherms near the surface from the Himalayas to southern Tibet. The compression of isotherms results in model heat flow of >100 mW/m^2 that is consistent with published values. Thus, although no provision was made in this preliminary model for topography of the India-Tibet transect and the depth of MHT is not precisely located in the model, the calculations nevertheless demonstrate the feasibility of producing the observed low-velocity, partially-molten zone along the MHT in the deep crust.

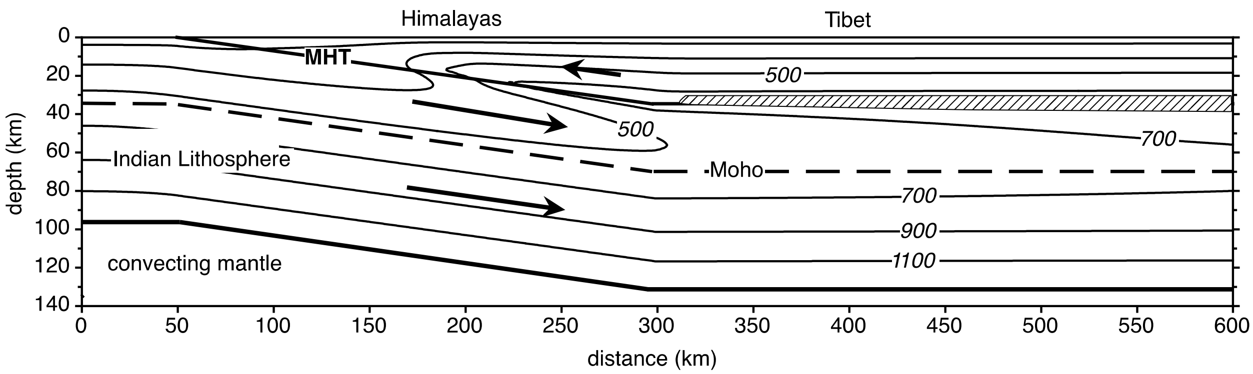

Figure 1. Model domain showing subducting Indian lithosphere beneath the Himalayas and Tibet. Below the lithosphere is convecting mantle that constraints temperature in the bottom of the lithosphere to 1300°C. Dashed line is the Moho. Isotherms in 200° intervals (italics) are shown for a model with strain heating occurring along the ductile portion of the Main Himalaya Thrust (MHT) for 20 m.y.. Striped band shows region where temperatures of the schist solidus were reached in the model.

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