North American ice sheet dynamics controlled by obliquity (41 ka) during the early Pleistocene

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During the Pleistocene, large continental ice sheets episodically apperead in the Northern Hemisphere, covering large parts of Europe and North America. Besides the results based on benthic oxygen isotope records, which predominantly represent variations in global ice volume, little is know about the timing of and astronomical control on the advances and retreats of the continental ice sheets in the Northern Hemisphere during the late Pliocene and early Pleistocene (3-2 million years (Ma) ago).

Here we therefore present the first orbitally-resolved records of terrestrial higher plant leaf wax input to the North Atlantic covering the last 3.5 Ma, based on the accumulation of long-chain *n*-alkanes and *n*-alkanl-1-ols at IODP Site U1313 [1]. These lipids are a major component of dust, even in remote ocean areas, and have a predominantly aeolian origin in distal marine sediments. Our results demonstrate that around 2.7 Ma, coinciding with the intensification of the Northern Hemisphere glaciation (NHG), the aeolian input of terrestrial material to the North Atlantic increased drastically. Since then, during every glacial the aeolian input of higher plant material was up to 30 times higher than during interglacials. We argue that the increased aeolian input at Site U1313 during glacials is predominantly related to the episodic appearance of continental ice sheets in North America and the associated strengthening of glaciogenic dust sources. The records thus reflect the timing of the advances and retreats of the North American ice sheets. Evolutional spectral analyses of the *n*-alkane records were therefore used to determine the dominant astronomical forcing in North American ice sheet advances over the last 3.5 Ma. These results demonstrate that during the early Pleistocene North American ice sheet dynamics responded predominantly to variations in obliquity (41 ka), which argues against previous suggestions of precession-related variations in Northern Hemisphere ice sheets during the early Pleistocene [2].

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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 narrow low-velocity zone along the Main Himalaya Thrust [1]. The zone extends approximately from the 28.5°N latitude, dipping to ~40 km depth at the latitude of the Yarlung Tsangpo Suture (YTS), and then continues horizontally beneath the Lhasa Block to approximately 32°N latitude. Nabelek et al. [1] 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 model

Development of the partially molten zone was modeled numericaly following [2]. The model domain is 600x140, 1 km grid. The initial conditions are steady-state with subduction of the Indian lithosphere beneath the Himalayas and Tibet at 3 cm/y. Temperature is 25°C at the surface and 1300°C at the bottom of the lithosphere. Radiogenic heat production (Ah) in the Indian crust was constrained by the average 70 mW/m^2 surface heat flux of the stable northern Indian crust. Ah in the upper plate was assumed to be 2 $\mu W/m^3$ throughout and in the mantle 0.01 $\mu W/m^3$. Subduction of the Indian lithosphere at 3 cm/y keeps the crust above the MHT refrigerated. The model accounts for temperature-dependent thermal diffusivity [2, 3] and power-law temperature dependence of the shear strength (τ) of quartz [4]. Strain heating in the ductile regime is given by $\tau \cdot \varepsilon$, where ε is the strain rate. Strain rate in a 3 km wide shear zone is $3 \cdot 10^{-13}$ s^{-1}. Heat production at this strain rate is ~100 $\mu W/m^3$ at 550°C and ~10 $\mu W/m^3$ at 750°C [2].

Model results

Strain heating was assumed to occur along the length of the MHT, but only within the ductile regime. With subduction only, shearing produces a narrow, partially molten zone that extends from below the Himalayas to the northern end of the model domain. The partially molten zone is underlain by an inverted temperature gradient. The ductile regime extends further to the south along the MHT, in accord with observations [1]. Thus, the calculations demonstrate the feasibility of producing the observed low-velocity, partially-molten zone along the MHT in the deep crust.

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