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Thrust initiation and its control on tectonic wedge geometry: An insight from physical and numerical models

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ABSTRACT

We performed a series of sandbox experiments to investigate the initiation of thrust ramping in tectonic wedges on a mechanically continuous basal decollement. The experiments show that the decollement slope (β) is the key factor in controlling the location of thrust initiation with respect to the backstop (i.e. tectonic suture line). For $\beta = 0$, the ramping begins right at the backstop, followed by sequential thrusting in the frontal direction, leading to a typical mono-vergent wedge. In contrast, the ramp initiates away from the backstop as $\beta > 0$. Under this boundary condition an event of sequential back thrusting takes place prior to the onset of frontal thrust progression. These two-coupled processes eventually give rise to a bi-vergent geometry of the thrust wedge. Using the Drucker-Prager failure criterion in finite element (FE) models, we show the location of stress intensification to render a mechanical basis for the thrust initiation away from the backstop if $\beta > 0$. Our physical and FE model results explain why the Main Central Thrust (MCT) is located far away from the Indo-Tibetan plate contact (ITSZ) in the Himalayan fold-and-thrust belts.

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1. Introduction

In collisional tectonic regimes the crustal uplift generally varies across the orogenic trend, forming wedge-shaped profiles of the mountain belts. Such tectonic wedges are broadly of two geometrical types: *mono-vergent* and *bi-vergent* (Fig. 1a). Mono-vergent wedges develop their highest surface elevations at the hinterland boundary, and their entire surface topography slopes towards the foreland (Davis et al., 1983; Dahlen et al., 1984; Chappel, 1978; Panian and Wiltschko, 2007). In contrast, bi-vergent wedges form their topographic slopes both in the hinterland and foreland directions, which constitute two parts: retro- and pro-wedges, respectively (Konstantinovskaia and Malavieille, 2005; Persson and Sokoutis, 2002; Willet, 1999; Storti et al., 2000). A large number of authors have investigated the evolution of mono-vergent wedges either through physical (Davis et al., 1983; Dahlen et al., 1984; Mulugeta, 1988; Koyi, 1995; Liu et al., 1992; Mandal et al., 1997; Storti et al., 2007; Bose et al., 2009) or numerical model (Willett et al., 1993; Willett, 1999; Panian and Wiltschko, 2007) experiments. According to their models, mono-vergent wedges grow by sequential frontal thrusting in the foreland direction, and they maintain a maximum topographic elevation always at the backstop. Recent experimental studies suggest that the mode of wedge evolution can significantly change with the geometric and kinematic boundary conditions, such as the backstop geometry and the location of basal velocity discontinuity (Persson and Sokoutis, 2002; Willet, 1999; Storti et al., 2000). Sandbox experiments with a wedge-shaped backstop produced thrust wedges with bi-vergent geometry (Persson and Sokoutis, 2002). They grow by sequential back thrusting over a frontal thrust. Bi-vergent wedges can also form in convergent settings containing singularities in the velocity condition of the basal plate. The wedges grow asymmetrically as they propagate faster towards the direction of the incoming basal plate, producing a larger number of frontal thrusts in the pro-wedge (Storti et al., 2000; Hoth et al., 2008). Numerical simulations, on the other hand, show higher symmetry between the pro- and retro-wedges, which grow more or less equally away from the point of singularity, i.e. velocity discontinuity (Willett, 1999).

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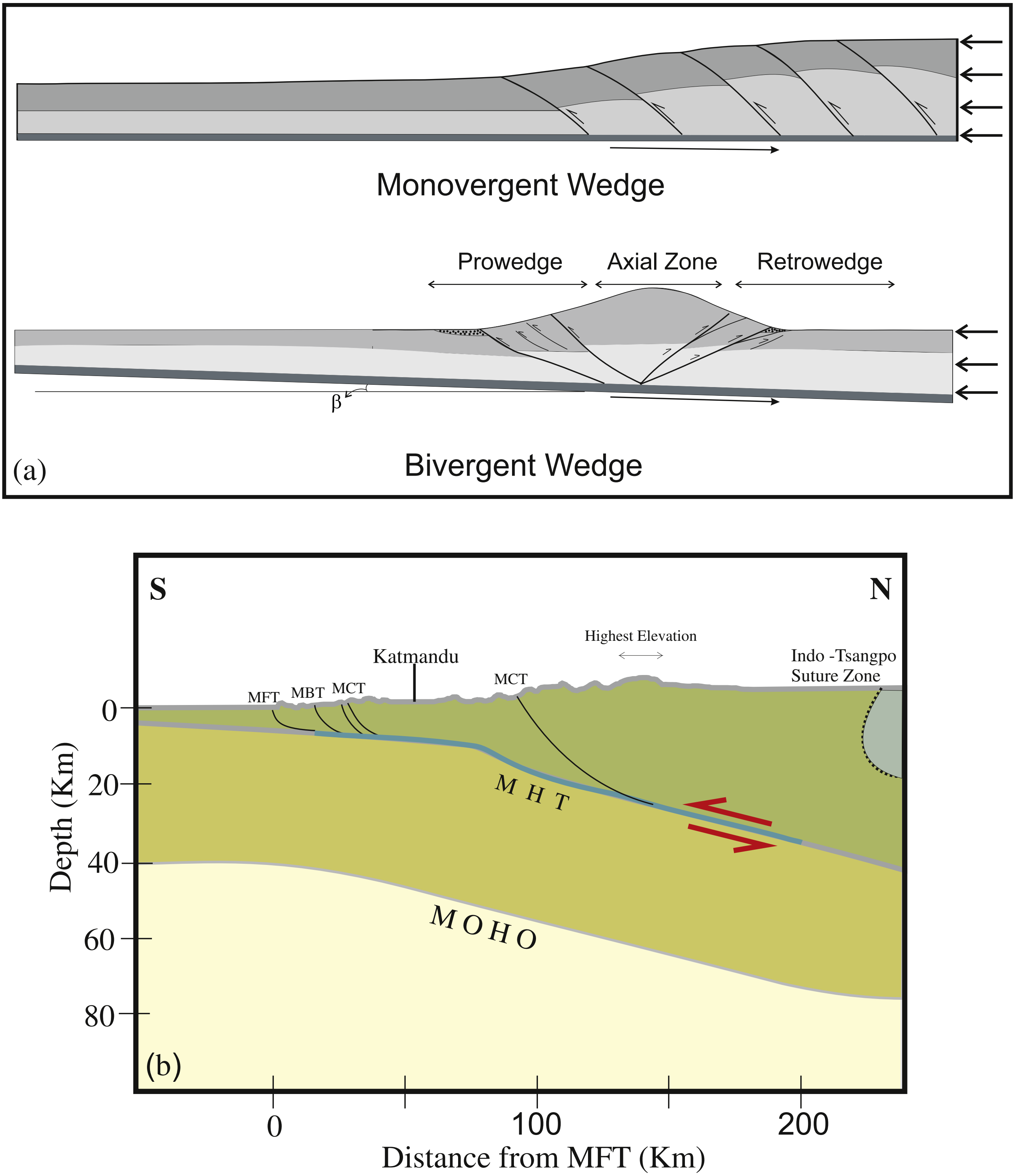

Fig. 1. (a) Schematic models of mono- and bi-vergent wedges, and associated thrust architectures. Arrows at the base show the movement direction of basal plate. Arrows on the right end indicate constraint of the hinterland backstop. Note that in case of bi-vergent wedge the zone of maximum elevation (Axial Zone) occurs away from the backstop. β: basal slope. (b) Simplified cross section across central Nepal Himalaya showing the topography of the Himalayan wedge (after Avouac, 2007). Main Himalayan Thrust (MHT) acts as the basal decollement.

A line of experimental investigations focuses upon the tectonic framework required for the development of bi-vergent wedges. Experiments with inclined backstops have shown that a pair of frontal and back thrusts originates from a point on the basal decollement. The back thrust remains active to transport the older frontal thrusts in the hinterland direction, allowing a new frontal ramp to form at the backstop. This process forces the material to spill over the buttress surface, giving rise to bi-vergent geometry of the wedge in the advanced stage (Persson and Sokoutis, 2002). But the effect of buttress geometry may not always correlate with natural tectonic

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