Tectonophysics 492 (2010) 99–107

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Crustal mass budget and recycling during the India/Asia collision

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ARTICLE INFO

Article history:
Received 8 January 2010
Received in revised form 27 May 2010
Accepted 29 May 2010
Available online 8 June 2010

Keywords:
Crustal budget
Continental subduction
India/Asia collision
Ancient plate boundary inferred from tomography

ABSTRACT

The long-lasting collision between India and Asia has resulted in crustal and lithospheric deformation of both continents, providing unequalled opportunities to evaluate their long-term mechanisms of deformation. We have quantified a crustal mass budget for the collision by comparing the present-day and initial crustal volumes of the Indian and Asian continents involved in the collision. Initial crustal thickness was estimated from the non-deformed parts of the continents, whereas their initial extent was mapped from their contours at the onset of collision, using seismic tomography. We quantify the portion of the initial crustal thickness of both continents stored within the currently thickened crust or redistributed due to extrusion. For the Indian continent, this portion amounts to about 19 km, far lower than the mean observed present-day crustal thickness of the Indian craton of about 38 km. We conclude that between 40 and 50% of Indian crust has been recycled into the mantle by continental subduction, corresponding to a decoupling level at about 15–19 km depth. For the Asian continent, the estimated crustal thickness stored during collision is about 33 km, close to the initial Asian crustal thickness. We estimate that only 3% of the Asian crust was recycled into the mantle. This corresponds to one episode of continental subduction, occurring most probably soon after the initiation of collision along the Bangong suture. We identify the related slab using seismic tomography. The strong contrast between India and Asia implies an age-dependent capacity of the continental crust to be recycled into the mantle. This result has to be taken into account for further analysis of global crustal recycling during Earth's history.

1. Introduction

The indentation of Asia by India has resulted in crustal deformation of both continents, causing profound changes over immense areas and building the Earth's largest and highest topography (Fig. 1). This long-lasting collision between two continents provides unequalled opportunities to study the mechanics of continental deformation. Several models have addressed the question of the long-term strength of the continental lithosphere during the collision (for a review see Willett and Beaumont, 1994). One end-member model assumes that the entire lithosphere thickened as a thin viscous sheet, with broadly distributed shortening of both crust and mantle absorbing plate convergence (England and Houseman, 1989; Molnar et al., 1993). The other end-member model assumes that only the upper crust thickened, decoupled from a more plate-like behaviour of the underlying lower crust and mantle lithosphere, which did not thicken but was subducted (Meyer et al., 1998; Tapponnier et al., 2001; Replumaz et al., 2010a). Intermediate models allow the transfer of Indian crust below Asia (DeCelles et al., 2002; Hetenyi et al., 2007; Nábělek et al., 2009). The first model implies conservation of crustal mass during the collision, while the second allows a portion of the lower crust to be subducted into the mantle. Intermediate models allow transfer of crustal material between the two continents. In this paper, we aim to quantify the partitioning of crustal deformation between shortening through thickening, erosion and extrusion, and loss of lower crust into the mantle by subduction. This crustal mass budget on a continental-scale will assist in interpreting the long-term mechanics of continental deformation for young orogenic belts, such as the Asian continent, and ancient continental shields, such as the Indian subcontinent.

The position of the plate boundary between India and Asia at the onset of collision has been estimated previously using the present-day geometry of the indentation mark left by the impact of India onto the Asian margin, with a presumably linear geometry between Sumatra and the mouth of Indus (Fig. 1; Tapponnier et al., 1986; Le Pichon et al., 1992). The amount of thickening has been estimated in 2D, along north–south lines, using topography as an indicator of crustal thickness. Using the surface of the indentation mark as an indication of the total surface loss during the collision, the relative amounts of shortening and eastward extrusion of continental material have been discussed. Nowadays, the Moho has been imaged precisely beneath the collision zone and the crustal thickness is well-constrained

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doi:10.1016/j.tecto.2010.05.023

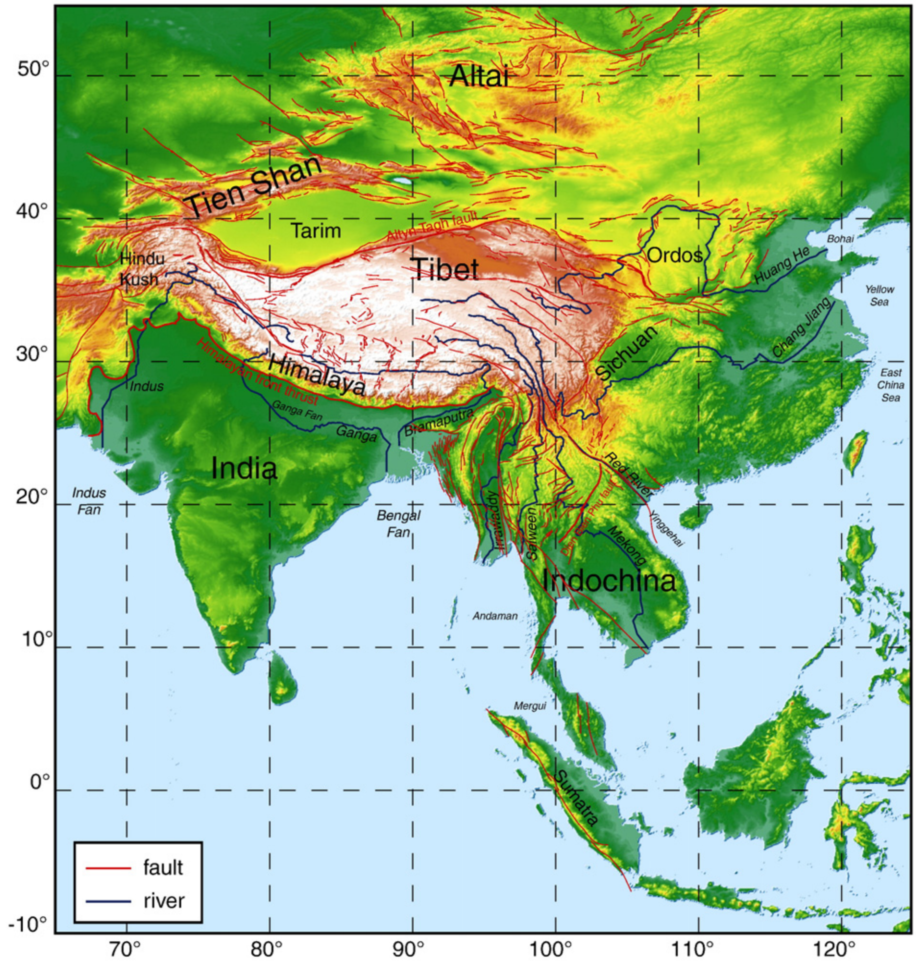

Fig. 1. Topographic map showing zones thickened during collision (brown and white) and zones not affected by the collision (green and yellow). Sutures (position from Valli et al., 2008), faults and rivers are portrayed.

(Mooney et al., 1998; Villaseñor et al., 2001; Li et al., 2006). Seismic tomography has been successful in mapping remnants of ancient slabs (e.g. van der Hilst et al., 1997; Bijwaard et al., 1998). The position of these can be compared to previous plate boundary positions, provided that the slabs sink vertically (e.g. van der Voo et al., 1999). We use those constraints to improve the previous 2D shortening estimations and to develop a crustal mass budget in 3D.

2. Present-day contour of continental blocks

Relics of the Tethys Ocean that used to separate the northern margin of India from the southern margin of Eurasia can be traced along the Indus–Tsangpo suture zone (in purple on Fig. 2). Considering the origin of the crust and the timing of deformation, we divided the collision zone in three blocks (Fig. 2). We call these Himalaya, Indochina and Tibet, although they are not identical to the current geographical extent of the Himalayan range, Indochina peninsula or Tibetan Plateau, respectively. The Himalayan block is the part of the Indian continent involved in the collision process, while the rest of the continent remained undeformed. The active deformation front migrated southwards during the collision, from the Indus–Tsangpo suture to the present-day Himalayan front (Robinson et al., 2001; DeCelles et al., 2002). North of the Indus–Tsangpo suture, the Indochina and Tibet blocks were parts of Asia when India collided. The Indochina block comprises the Indochinese peninsula and the southern part of the Tibetan Plateau. At the onset of collision, the Indochina peninsula was located partially in front of the collision zone, as deduced from the rotation pole of the peninsula (Briais et al., 1993) and tectonic reconstructions (Leloup et al., 2001; Replumaz and Tapponnier, 2003). It formed a compact block with the southern part of the Tibetan Plateau. To the west, this block has been thickened to form the southern Tibetan Plateau (Tapponnier et al., 2001), while to the east the Indochinese peninsula has been extruded southeastward between 30 and 15 Ma (Briais et al., 1993). It slid more than 700 km along a fault that extended from the South China Sea to the western part of the collision zone (Leloup et al., 2001). A portion of this fault has been preserved along the Red River from further deformation during the post-extrusion collision process, and is known as the Ailao Shan shear zone (Leloup et al., 2001). The Tibet block comprises the part of the Tibetan Plateau north of this extrusion fault. It was thickened since the Oligo-Miocene by thrusts propagating northward along the Altyn Tagh fault (Métivier et al., 1998; Meyer et al., 1998). Several hypotheses have been envisaged for the continuation of the extrusion fault within the Tibetan Plateau (Fig. 2): along the Jinsha suture (Tapponnier et al., 2001); the Bangong suture (Replumaz and Tapponnier, 2003; Leloup et al., 2001); or the Shiquanhe suture (Tapponnier et al., 1986). Each of the hypotheses for the limit between the Indochina and Tibet blocks leads to a different estimate of the partitioning of the Asian crustal mass between these blocks, which allowed us to discriminate between them.

3. Present-day thickness of continental blocks

We compiled a Moho depth map combining the contours obtained for China from seismic refraction/wide angle reflection profiles (Li et al., 2006), with the regional contours obtained from inversion of surface wave velocities (Villaseñor et al., 2001) (Fig. 3). The zones with a Moho depth greater than 50 km, i.e., the Tibetan Plateau, the Himalaya, the