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# Amount of Asian lithospheric mantle subducted during the India/Asia collision

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A B S T R A C T

Body wave seismic tomography is a successful technique for mapping lithospheric material sinking into the mantle. Focusing on the India/Asia collision zone, we postulate the existence of several Asian continental slabs, based on seismic global tomography. We observe a lower mantle positive anomaly between 1100 and 900 km depths, that we interpret as the signature of a past subduction process of Asian lithosphere, based on the anomaly position relative to positive anomalies related to Indian continental slab. We propose that this anomaly provides evidence for south dipping subduction of North Tibet lithospheric mantle, occurring along 3000 km parallel to the Southern Asian margin, and beginning soon after the 45 Ma break-off that detached the Tethys oceanic slab from the Indian continent. We estimate the maximum length of the slab related to the anomaly to be 400 km. Adding 200 km of presently Asian subducting slab beneath Central Tibet, the amount of Asian lithospheric mantle absorbed by continental subduction during the collision is at most 600 km. Using global seismic tomography to resolve the geometry of Asian continent at the onset of collision, we estimate that the convergence absorbed by Asia during the indentation process is ~1300 km. We conclude that Asian continental subduction could accommodate at most 45% of the Asian convergence. The rest of the convergence could have been accommodated by a combination of extrusion and shallow subduction/underthrusting processes. Continental subduction is therefore a major lithospheric process involved in intraplate tectonics of a supercontinent like Eurasia.



## 1. Introduction

The long-lasting collision between India and Asia causes profound changes over immense areas, building the Earth's largest and highest topography, and provides unequaled opportunities to study the mechanics of continental deformation (Fig. 1). Global seismic tomography suggests that this extreme topography is related to successive continental subduction episodes of the Indian continent (e.g. Replumaz et al., 2010a). Positive wavespeed anomalies are commonly interpreted as remnants of slabs, and evidences for past Indian subduction episodes are preserved as deep anomalies (IN and TH in blue in Fig. 1). In this paper, we show that global seismic tomography provides also evidence of past Asian continental subduction. We estimate the length of the Asian lithospheric slabs subducted since the beginning of collision, and we calculate the amount of convergence that is absorbed by Asian continental subduction since then.

To do so, we have to know the geometry of the Asian continent at the beginning of collision. Plate tectonic reconstructions constrain the northward motion of the Indian Plate since the mid-Lower Cretaceous (e.g. Patriat and Achache, 1984; Besse and Courtillot, 2002; Molnar and Stock, 2009), but cannot alone resolve the position of the plate boundary between India and Asia at the onset of collision. The southern Asian geometry at that moment has been previously estimated using the present-day geometry of the indentation marks left by the impact of India onto the Asian margin, with a presumably linear geometry between Sumatra and the mouth of the Indus river (e.g. Tapponnier et al., 1986; Le Pichon et al., 1992) or using continental paleomagnetic data (e.g. Halim et al., 1998). Seismic tomography independently constrains the position of the plate boundaries. In particular, the NW–SE-trending positive anomaly beneath India, at depths between 1000 and 1600 km, is thought to record the location of late Mesozoic Tethys subduction (marked as TH in Fig. 1; van der Voo et al., 1999; Replumaz et al., 2004; Hafkenscheid et al., 2006; Richards et al., 2007). The TH anomaly marks the past position of the trench between the Indian and Asian continents (Fig. 1). This anomaly vanishes at depths shallower than about 1100 km, indicating a slab break-off after the beginning of the continental Indian plate subduction, likely when the slab reached a critical length (Chemenda et al., 2000). The paleo-geometry of the Indian continent northern boundary at the time of break-off is drawn along the top of the TH anomaly (Negredo et al., 2007). This boundary is similar to the previously estimated linear geometry between Sumatra and the mouth of the Indus (Tapponnier et al., 1986). By combining the paleo-position of India and the length of the Indian slab as it is now subducting beneath the Hindu Kush, Negredo et al. (2007) inferred the

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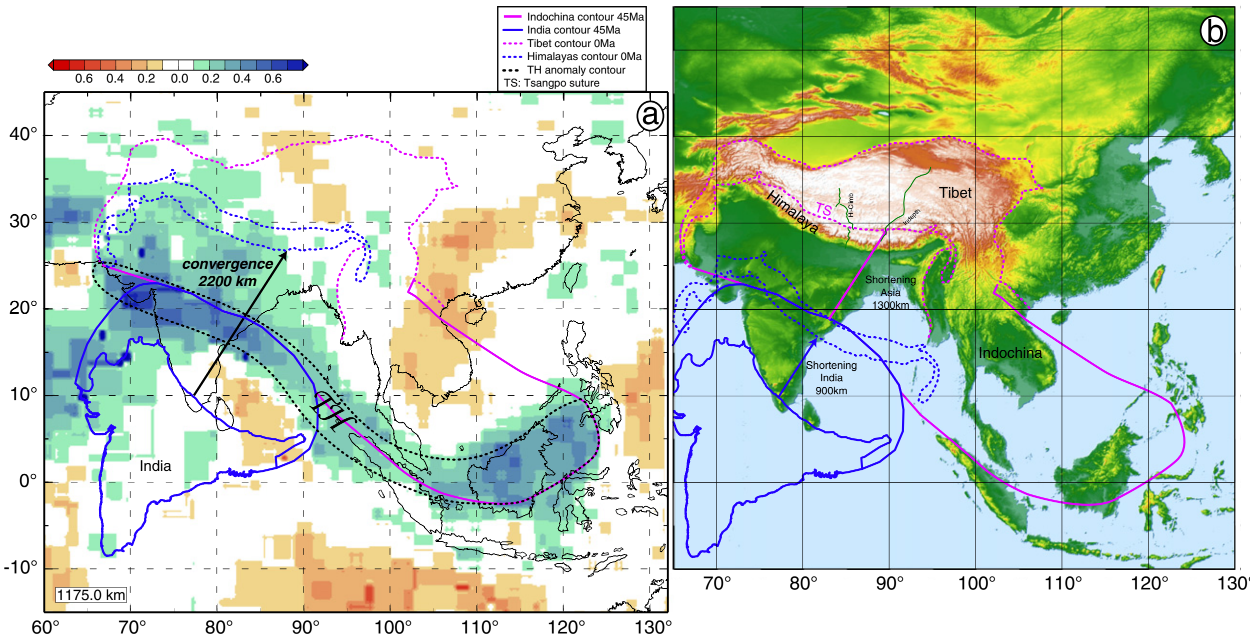


**Fig. 1.** a) P-wave tomographic section at 1175 km depth showing wavespeed anomaly at −/+0.8%, positive anomaly in blue, negative in red. Positive anomaly are related to colder material, commonly interpret as remnant of slab sinking into the mantle. Looking at the anomalies at depth permits to deduced the past position of the subduction zones. Beneath India, the NW–SE-trending anomaly TH is thought to record the location of late Mesozoic Tethys subduction. By using the paleo-position of India and the length of the Indian slab as it is now subducting beneath the Hindu Kush, Negredo et al. (2007) deduced the north–south length of the Indian continent at the indentation initiation and drew the paleo-geometry of the Indian continent northern boundary along the paleo-trench, north of the TH anomaly (blue contour). We measure the distance between the paleo-position of the Himalayan front and its present-day position as an estimation of the convergence, ~2200 km (black arrow). b) Topographic map with approximately the same extend than the tomographic section. We compare the paleo-geometry of Indian continent with the present-day contour of Himalayas (dotted blue line between the Himalayan front and the Tsangpo suture, TS, moved to the position of India at 45 Ma), and Tibet (dotted pink line). We measure the distance between the paleo and the present-day Himalayan front, ~900 km (blue arrow). It is an estimation of the convergence absorbed by India. The distance between the paleo and the present-day Tsangpo suture is ~1300 km (pink arrow). It is an estimation of the convergence absorbed by Asia.

north–south extent of the Indian continent at the time of break-off (blue contour in Fig. 1a) and estimated the age of break-off at ~45 Ma. This age is younger than the 57–55 Ma estimated for the first continent–continent contact, deduced concordantly from exhumation of ultrahigh-pressure rocks (de Sigoyer et al., 2000; Guillot et al., 2003; Leech et al., 2005), the final closure of Neotethys recorded by the end of marine sedimentation at 55 Ma (Garzanti et al., 1987), and the appearance of continental red beds at ~51 Ma (Garzanti et al., 1996). This younger age of break-off suggests that some amount of Indian continental subduction occurred before break-off (e.g. Guillot et al., 2008). This time of slab break-off corresponds to the beginning of the indentation process, when India left behind the detached oceanic slab and began to impinge upon the Asian margin.

Comparing the paleo-geometry of the continents at the time of break-off and the present-day shape of the continents, we estimate the magnitude of convergence absorbed by the post-collisional deformation of the Indian and Asian continents (Fig. 1). The mechanism of deformation of each continent is different. The Indian continent deforms over a narrow area forming the high Himalayan range which grows up by scraping of the upper Indian crust, while the lower crust and underlying lithosphere bend and underthrust the range (Nábělek et al., 2009). Separated from the upper crust, the Indian continental lithosphere is heavy enough to subduct into the mantle (Capitanio et al., 2010). Deep tomographic positive anomalies suggest multiple successive continental subduction episodes of the Indian continent (Replumaz et al., 2010a). The prominent anomaly IN observed between 450 and 900 km depths (Fig. 2) has been interpreted as a slab formed by Indian continental lithosphere which subducted most probably between 40 and 15 Ma beneath central Tibet (Replumaz et al., 2010a). The Asian continental upper plate deforms over a broad area forming the Tibetan Plateau (pink contour Fig. 1b). The Tibetan plateau appears as a homogeneous zone of high elevation that could be generated by a homogeneous deformation process (England and Houseman, 1988). However very narrow shear zones, ~10 km width but running over several thousands of kilometers and absorbing hundreds of kilometers of displacement (Leloup et al., 2001), suggest that the deformation is localized in the upper crust (Tapponnier et al., 1986; Replumaz and Tapponnier, 2003). In contrast, continental subduction is thought to accommodate convergence at lower crust and lithospheric mantle levels (Mattauer, 1986; Willett and Beaumont, 1994; Tapponnier et al., 2001; De Celles et al., 2002). Seismic profiles show evidence of southward Asian subduction down to 300 km in Central Tibet (e.g. Kind et al., 2002). Toward the western syntax, earthquakes down to 200 km and tomographic positive anomaly down to 400 km reflect on-going southward Asian subduction beneath the Pamir (Burtman and Molnar, 1993; Negredo et al., 2007). The purpose of this paper is to use global deeper seismic tomography to find evidence of older Asian continental slabs and to estimate the amount of the lithospheric mantle of Asia that has been subducted since the beginning of collision.

## 2. Mantle tomographic positive anomalies beneath the collision zone

### 2.1. Tomographic model

We investigate the mantle structure beneath the collision zone down to 1500 km depth (Figs. 1 and 2), by means of a P-wave global mantle tomographic model obtain using the method described by Bijwaard et al. (1998), but augmented with additional arrival times from well-located earthquakes at both teleseismic and regional distances (Villaseñor et al., 2003). In total, more than 14 million arrival times from 300,000 earthquakes, nearly 4 times the amount used in Bijwaard et al. (1998), were reprocessed using the EHB methodology (Engdahl et al., 1998). This global model has been already used in several papers focusing on different regions (Replumaz et al., 2010b;