India–Eurasia collision chronology

PATRIAT and Achache's analysis[1] of the convergence between India and Eurasia led them to conclude that India collided with Eurasia around anomaly 22 time (~50 Myr), confirming an earlier interpretation based on geological relationships in northwestern India that collision was pre-Middle Eocene[2], probably around anomaly 23 time[3] (~52 Myr). Geological evidence from the Lhasa region[4,5] also suggests that obduction of the suture-zone rocks onto the leading edge of India occurred there in the pre-Eocene inteval, and that any significant shortening in the Lhasa Block was complete before the end of the Palaeocene[5].

These observations pose a problem for Patriat and Achache's model[1] because in their Figs 1*b* and 4, 50 Myr ago southern Tibet was located some 7° north of the presently exposed northern boundary of India. Patriat and Achache[1] suggest that the 700 km of continental crust necessary to fill this gap was consumed first by subduction of ~400 km of Indian continent beneath southern Tibet from 50 to 44 Myr, and then by continued continental underthrusting and internal deformation to account for another 300 km of north-south shortening before 37 Myr. There are at least three problems with this model.

(1) Deformation in the supposed continental subduction and underthrust zone (Indus-Tsangpo suture) should be of Eocene age, rather than late Cretaceous or early Palaeocene as shown by field relationships[4,5].

(2) The now-vanished continental crust would have lain between the Tethyan Himalaya and southern Tibet, in which case the Tethyan Himalaya would have lain in the interior of the Indian continental block before collision, and not at its leading edge as is widely accepted[2,6,7].

(3) Southern Tibet would have had a much thicker than normal continental crust from mid-Eocene to present, in which case isostatic rebound would have led to a Palaeogene rise of the Tibetan plateau, for which there is no geological evidence.

These problems disappear if the pre-collisional shape of India is extended northwards to take account of its original size in Gondwanaland[8,9]. A pre-collisional Greater India with its northern edge extending as far north of the exposed Indian Shield as the Kun Lun is today would not only have collided with southern Tibet by the postulated 50-Myr collision time, but could later have underthrust its broken-off leading edge, the Tethyan Himalaya, to produce the 70-km continental crust beneath Tibet. The underthrusting could have been as a series of intracontinental slices[10] rather than a single continental underthrust[2,3].

Recognition of the Tethyan Himalaya as the leading edge of Greater India obviates the necessity to postulate 700 km of Eocene continental subduction and underthrusting beneath southern Tibet, and raises the possibility that the threefold sequence of events suggested by Patriat and Achache occurred in almost exactly reverse order. Initial shortening within Eurasia is taken up by block rotation and lateral extrusion along sinistral strike-slip faults[11], then followed by crustal thickening through internal deformation and the beginning of continental underthrusting, and finally, when the continental underthrust zone is sufficiently well established, large-scale continental subduction occurs[2,9].

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ACHACHE AND PATRIAT REPLY—Powell *et al.* estimate the pre-collisional shape of India after 'its original size in Gondwanaland'. This coincides with the present position of the Kun Lun belt. We think this method is highly questionable and thus, such an estimate must be considered as speculative.

The problems allegedly raised by our model call for the following comments:

(1) The Cretaceous to Palaeocene F_1 deformation observed in the Yarlung Zangbo suture zone is related to northward subduction of oceanic crust[1,2]. It is followed by a larger-scale although less intense younger F_2 deformation which can be associated with crustal subduction and shortening[1,2].

(2) The observation of Tethyan sediments in no way contradicts the model of subduction of 400 km of continental crust and only requires a 500-km-wide continental shelf north of India, before the collision. Whether this can still be considered as the so-called leading edge of India is merely a matter of vocabulary.

(3) The age of rise of the Tibetan plateau is still an open question. In particular, there is no valid evidence against a Palaeogene rebound.

We therefore do not see any real objection to our model in the comment by Powell *et al.* Furthermore, several field observations seem to contradict the reversed sequence of events suggested by these authors. First, a recent palaeomagnetic study[3] of Tethyan sediments in Tibet has shown the amount of shortening in the MCT to be 400 ± 400 km, thus much less than required by the proposed model. Second, structural and geochronological data indicate that significant underthrusting occurred in the Indian continent (Kangmar Thrust, Main Central Thrust, Main Boundary Thrust) between 45 and 35 Myr ago (see ref. 3). And third, the magnetic anomaly pattern in the South China Sea indicates that the motion along the Red River fault (and thus the extrusion of Indochina[4]) did not start until anomaly 13 time (36 Myr), that is, 15 Myr after the beginning of the collision (see ref. 5).

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