The Himalayan Pile-Up: Revised Plate Reconstructions Provide Evidence of Multiple Accretion Events During the Himalayan Orogeny

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The concept of “the collision” of India to Eurasia dominates the literature on the Himalaya. However, controversy surrounds the timing as to when this took place. One hypothesis suggests that this event occurred at ~50-55 Ma, whilst other hypotheses suggest that this event may have occurred earlier (~70 Ma) or later (~34 Ma) (Yin and Harrison 2000; Aitchison et al. 2007). This has led to a debate as to which time is the most appropriate age of “the collision”. However, the logic that is adopted in this debate implies that there can only be one “main” collision. Yet, many workers also recognise that the Himalaya could have developed due to a number of accretion events (e.g. Searle and others, 1987). However, the problem remains that the accretion of India to Eurasia is deemed more important than any of the other accretion events that occurred during the closure of Tethys.

Perhaps this fixation with the idea of “the collision” is related to the results of past plate-tectonic reconstructions. All published plate reconstructions of India’s motion relative to Eurasia show a single slow-down event at 45 Ma (Molnar and Tapponier 1975) or 50-55 Ma (Patriat and Achache, 1984; Dewey and others, 1989; Molnar and Stock, 2009). This rapid deceleration in the velocity of the Indian plate is usually taken to indicate the time of “the collision” between India and Eurasia. However, the same reconstructions also suggest that India is thousands of kilometres south of Eurasia at 45 Ma or 50-55 Ma. This in turn led to the concept of Greater India, an extension of the northern margin of the Indian continent that is invoked to “fill the gap” between India and Eurasia (Ali and Aitchison, 2005).

However, any individual tectonic reconstruction is based on a sequence of linked assumptions through space and time, and it is usually the resultant (regional or planetary) configuration that receives the greater emphasis when a reconstruction effort is reported. Whereas such configurations lend themselves to comparative analyses, the underlying assumptions (e.g. starting configurations and subsequent process) that lead to the different results are not easily appreciated or analysed. Too often, an individual tectonic reconstruction is difficult to assess in respect of its underlying, linked assumptions. Additionally, a change in the assumptions used in one reconstruction can lead the same processes to a different result. For example, suppose a well-accepted reconstruction has been incorporated into several subsequent reconstruction efforts. Revision of this reconstruction (e.g. by incorporation of additional or revised data) would flow through to affect all dependent reconstructions. This would necessitate revision of the configurations and their comparisons, possibly resolving conflicting results. Currently, because of the under-exposure of the assumptions and interpretation paths, revising a reconstruction with new information is extremely difficult.

Using the Indian plate as an example, we revised a number of widely accepted reconstructions of India relative to Eurasia. In doing so, we also noted the lineage of data, decisions and assumptions of each of these reconstructions. We then plotted all of this information graphically with a mind-map, which we refer to as The Didactic Tree. The aim of The Didactic Tree is to “teach” the reader about the lineage of data, decisions and assumptions that are made in any reconstruction. The reader can then use or modify any part of the tree to produce a new reconstruction, and a future reader can easily do the same, and so on.

Using this approach we identified that all previous reconstructions of the Indian plate are based on out-of-date geological timescales, or old data/reconstructions of the African or North American plates (to close the plate circuit with Eurasia). We therefore used more up-to-date motion histories for India relative to Africa, Africa relative to North America and North America relative to Eurasia. We also utilized the capabilities of the Pplates deformable reconstruction software (http://rses.anu.edu.au/tectonics/projects/p-plates/) to simulate the opening of the East African Rift.

The results of our reconstruction suggest that the Indian plate experienced several accelerations and decelerations over the past 100 Ma. If we follow the same line of logic as past reconstructions, each observed slow-down event could be interpreted as marking a discrete accretion event. Interestingly, each of the observed changes in velocity correspond with known tectonic episodes along the length of the Alpine-Himalayan orogen (Lister and others, 2001), including the proposed ages for "the collision", with slow-downs at 66 Ma, 57 Ma, 52 Ma and 34 Ma. In addition to this, our results also suggest that the final slow-down of the Indian plate began at 27 Ma. At this time there was also a major vertical-axis rotation from NE to N. This was followed by a period of slow, steady-state motion for 6-7 Ma before the plate again rapidly accelerated and rotated back from N to NE at 20 Ma. The Indian plate finally began to slow in interspersed bursts between 0-18 Ma.

The fluctuations in velocity profile of the Indian plate's motion between 0-100 Ma fit well with the idea that orogenesis consists of several episodes of crustal shortening and extension (Lister and Forster, 2009). However, our results do not fit with the idea that Barrovian metamorphism in the Himalaya is the result 20-30 Ma of prograde heating in a shortening regime and a slow, progressive evolution of a pressure-temperature path.

Our results also suggest that the northern margin of India was several thousands of kilometres south of Eurasia between 45-55 Ma. The slowest velocity of the Indian plate that we observe in the past 100 million years occurs between 18-25 Ma. At 25 Ma, our reconstruction suggests that there is approximately 750-1250 km between India and Eurasia. Interestingly, this distance is similar to the ~950 km maximum possible extent of Greater India that was defined by Ali and Aitchison (2005). In light of these results, we suggest that all tectonic models of the Himalaya require revision.

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