‘Greater India’ controversy: Case closed?

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Despite eighty years of debate, there has been little consensus on ‘Greater India’s’ shape and size prior to its collision with Asia. Indeed the last decade has seen models with S–N extensions ranging between 100 and 2800 km. We argue that the southeast Indian Ocean, where the continent lay when it formed part of Gondwana, is fundamental for constraining Greater India proposals. Using the Wallaby–Zenith Fracture Zone as a guide, we show that extensions north of cratonic India ranged from ~950 km in the centre to ~500 and ~600 km respectively, at the Eastern and Western Syntaxes. The proposal is in agreement with recent seismic modelling of Indian continental lithosphere beneath Tibet.

Keywords: Australia, Gondwana break-up, Himalaya, India, Tibet.

It is common knowledge that the Himalayan Mountains and Tibetan Plateau formed following the Indian sub-continent’s collision and subsequent indentation into Eurasia during the middle and late Cenozoic. The orogenic system comprises five elements of which from S–N are the Indian shield or craton, the Indian continental plate rocks in the Himalaya, the Yarlung Tsangpo suture zone containing remnants of Neotethys (the ocean that once separated India and Asia), the Tibetan Plateau forming the deformed edge of Eurasia, and the ‘stable-Eurasia’ backstop plate (Figure 1). Most workers believe that a sixth feature was or is involved, namely an appendage to the Indian craton, the original continental block forming a body called ‘Greater India’. The concept of ‘Greater India’ dates back to at least the 1920s, some forty years before the emergence of the plate tectonic theory. Argand[1] believed that the high ground of the Himalaya and Tibet, much of which is >5 km above sea level, marked the site where a northern extension to the sub-continent had underthrust Asia. Since the advent of the plate tectonic theory, considerable effort has been spent trying to understand the India–Asia collision system, and the processes involved in mountain-building. For many modelling the region, ‘Greater India’ is thus an integral element.

Since the 1970s, following widespread acceptance of the plate tectonic theory, Greater India reconstructions have been primarily based upon three main lines of argument: (a) extensions to bridge an often large physical gap between the Indian shield and southern Eurasia at the time of their supposed collision[2]; (b) extensions deduced from the shortening experienced by Indian-continent rocks now forming the Himalaya[3]; (c) extensions based upon reconstructions of Gondwana, the southern super-continent of which India once formed part until it rifted and drifted away in the Early Cretaceous[4,5]. A small number of Greater India models have been based on combinations of

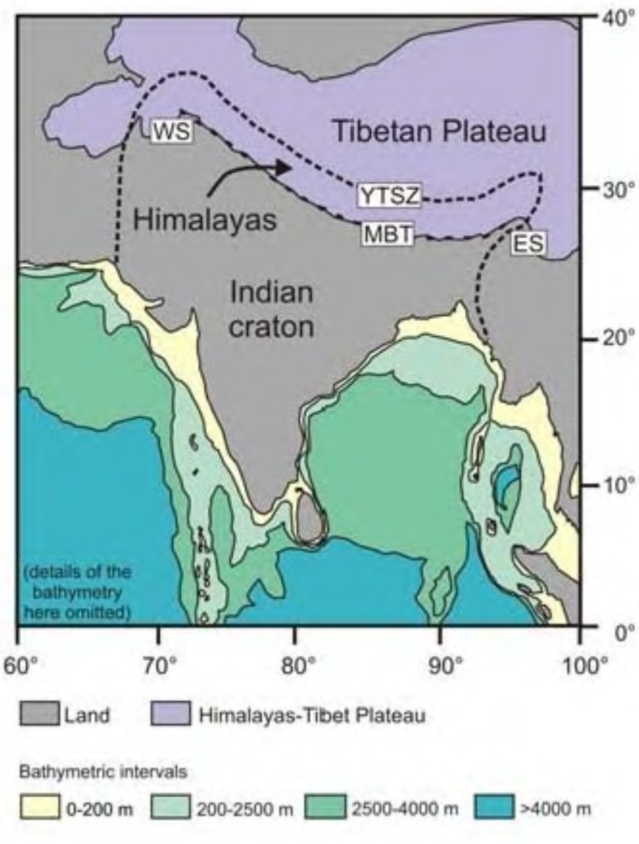

Figure 1. Simplified tectonic map of southern Asia and bathymetric chart of the northern Indian Ocean based on the *GEBCO Digital Atlas*[18]. The Indian craton effectively terminates at the Main Boundary Thrust (MBT). Deformed Indian plate rocks are exposed between the thrust and the Indus River–Yarlung Tsangpo suture (YSTZ), where they form the Himalayas. North of the Himalayas is the Tibetan Plateau. ES and WS are the Eastern and Western Syntaxes.

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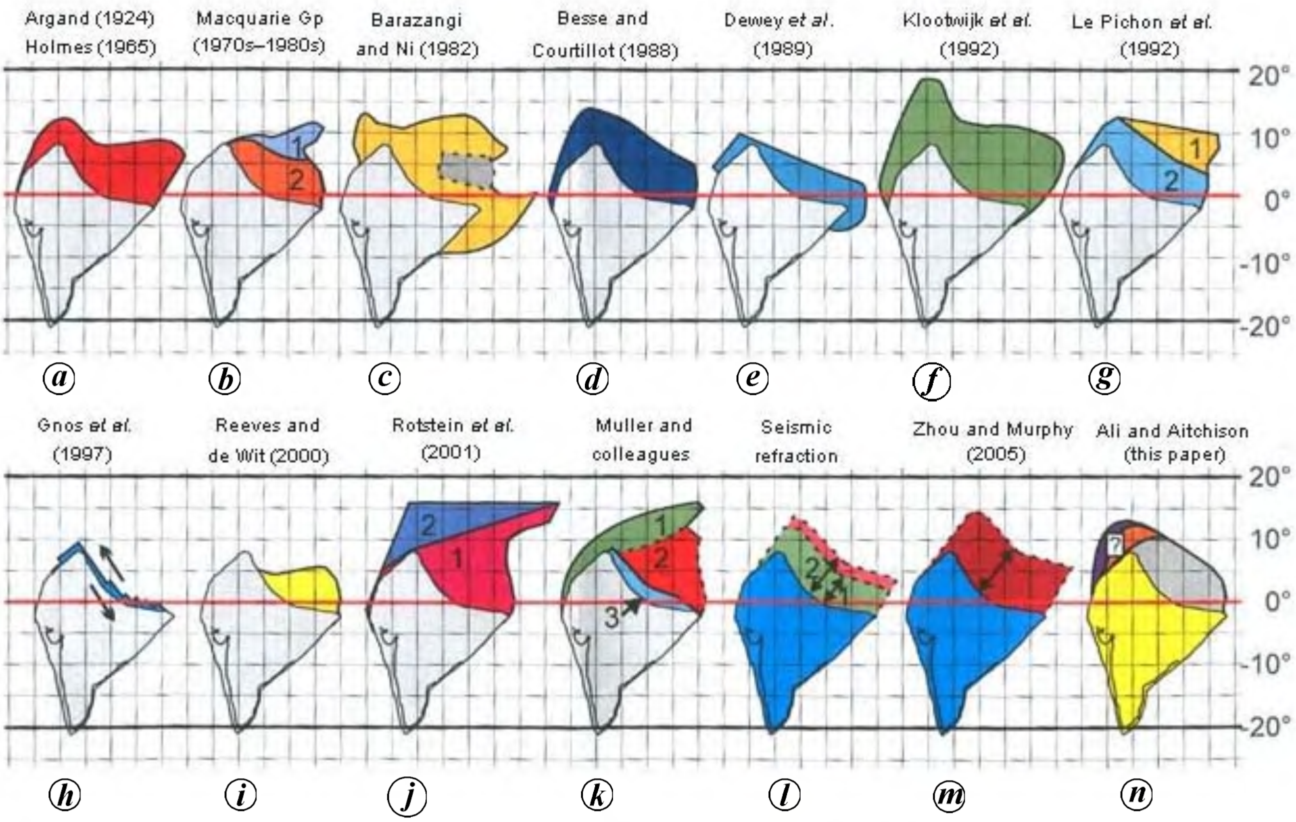

Figure 2. Examples of Greater India reconstructions. The stencil for the Indian craton is positioned on a Galls projection using the 55 Ma pole of Acton[28] and the GMAP plate modelling programme[29]. Complete references for each of the reconstructions can be found in Ali and Aitchison[10]. With (*l*) and (*m*), which are based upon geophysical imaging of the mantle beneath Tibet, the key feature is the arrow length denoting the extent of India beneath the region (corrected for the dip of the subducted part of the sub-continent; see text). The Ali and Aitchison[10] model (*n*) is considered the definitive form (see Figure 3).

(a) and (b)[6]. Other proposed types have followed Argand in using Tibet's northern edge to define the extension[7,8], or through seismic studies aimed at tracing the hidden part of India beneath the main part of Asia[9].

Greater India extension proposals: A wide variety

A selection of the thirty-five Greater India proposals reviewed by Ali and Aitchison[10] are presented in Figure 2. The smallest have appendages with S–N lengths ranging from a few kilometres only (Figure 2 *h*)[11] to ~500 km (Figure 2 *e*)[6]. Some of the larger ones are ~1600 km long (Figure 2 *c*, *k–l*)[5,9], and the largest of all is >2800 km (Figure 2 *j*)[12]. For a continental block involved in one of the earth's most important orogenic systems, this widely disparate set of views presents a problem.

Of the three main methods used to determine Greater India's size and shape, a re-examination of its site within Gondwana offered the best option. Himalayan-shortening estimates (e.g. ~670 km)[13] take no account of the materials that may have been removed from a 'balanced' section, possibly subducted, and structural sheets whose movements have been at moderate or high angles to the arc-normal direction. Critically they provide only minimum values. 'Fill-the-gap' arguments are limited because, the timing of the India–Asia collision is contested. For example, Yin and Harrison[14] suggest collision may have started as early as 70 Ma. By contrast, Rowley[15] favours a 50 Ma event. Also, there are problems with fixing the Eurasia 'backstop', and there are limitations with the quality and coverage (geographical and temporal) of palaeomagnetic data used to position Eurasia's southern edge in Late Cretaceous–middle Cenozoic[16].

India in Gondwana: Key to understanding the problem

Apart from minor modifications suggested by Powell *et al.*[4], the standard pre-break-up Gondwana 'template' follows Smith and Hallam[17]. India's southeast-facing margin is placed against Antarctica, and any extension of Greater India must be positioned west of Australia. Based on Gondwana reconstructions, many Greater India's have been proposed, but almost all are different (e.g. Figure 2 *b*, *g–l*, *h–k*).

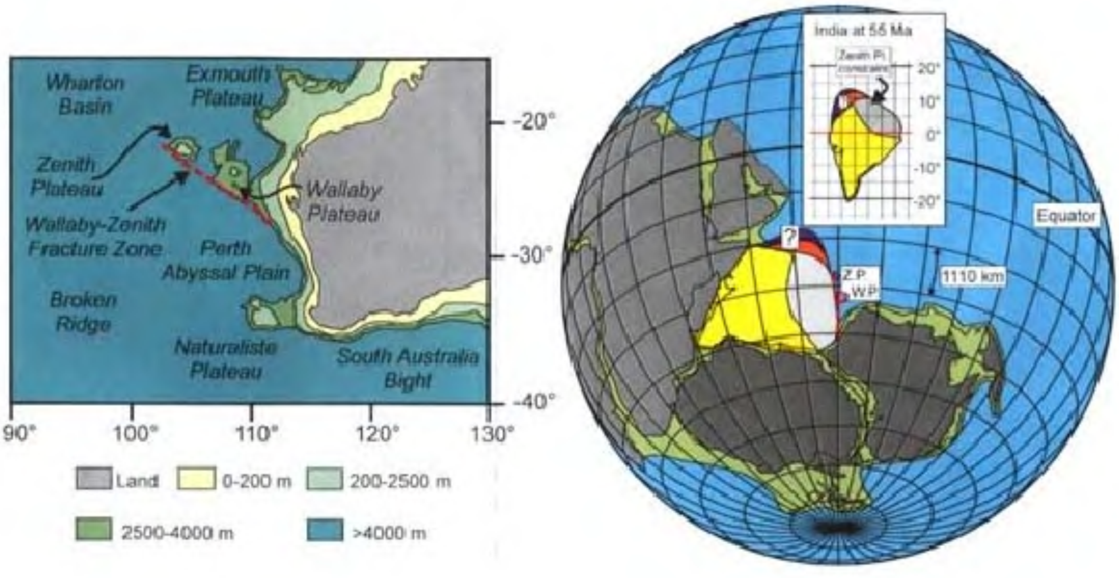

Figure 3. Left, Simplified bathymetric chart of the southeast Indian Ocean (Mercator projection) based on the *GEBCO Digital Atlas*[18]. Note the Wallaby–Zenith Plateau Ridge extending WNW from western Australia. The Wallaby and Zenith plateaus are blocks of thinned continental crust[20,21], and the Wallaby–Zenith Fracture Zone is shown by the red dashed line. South of the fracture zone, the oldest ocean floor in the Perth Abyssal Plain is ~131 Ma (M11 age). Right, Gondwana in the Middle Jurassic (~160 Ma) drawn using the GMAP program[29]. Note the Wallaby and Zenith plateaus and the Wallaby–Zenith Fracture Zone (red dashed line). Also shown is the proposed Greater India extension at this time and at 55 Ma based on Acton's pole[28].

The three undersea features in southeast Indian Ocean are critical for defining Greater India: the Wallaby and Zenith plateaus, their respective tops being 2460 and 1960 m below sea level[18], and the adjacent Wallaby–Zenith Fracture Zone (Figure 3). The two plateaus are continental rafts which although thinned and probably having a narrow ocean-crust separating them, extend the Australian continent for a considerable distance out into the Indian Ocean[19–21]. The importance of the plateau ridge and fracture zone becomes immediately apparent when they are added to a Gondwana reconstruction, as they effectively cap the S–N length (~950 km) of the crust that can be added to northern India (Figures 3 and 2 *n*). Although we are unable to use the features to delimit the continent in the Western Syntaxis area, the relatively uniform along-arc width and character of the Himalaya suggests that the extension to northwestern India was ~600 km. In the east, the extension could not have been more than ~500 km and, using present-day coordinates, it could not have extended east of ~95.5°E, since it would have lapped onto Antarctica and western Australia.

The proposed N–S length limit in the central part of the orogen corresponds with values obtained from recent seismic soundings of the India continental lithosphere in the mantle beneath Tibet (Tilmann and Ni, Figure 2 *l*-2; Zhou and Murphy, Figure 2 *m*)[22,23]. These investigations suggest that the Indian 'slab' extends beneath Tibet at least 800 km from the Main Boundary Thrust.

India's northern boundary

Our modelling also provides important insights into the nature of Greater India's northern boundary. The sharp linear Wallaby–Zenith Fracture Zone and the manner in which Australia–Antarctica from India[4,24] indicate that Cretaceous India's northern edge must have been a transform fault. It follows that this boundary must have been a narrow, well-defined ocean–continent transition zone – it was not a thinned-extended passive margin. Probably the best analogue is the Romanche Fracture Zone, south of Ghana, west Africa, the width of which is just 5–10 km[25,26]. This may bear upon models for the India–Asia collision. Critically, the sub-continent could not have had an extended leading edge, perhaps like western Iberia[27], to 'soft collide' with the continent to the north.

Conclusion

A large number of Greater India forms have been published over the last 80 years since Argand[1] surmised that India had a hidden extension which had 'under-rafted' the Himalaya–Tibet region. Proposed extensions have ranged from just a few kilometres to ~1600 km, with one extreme version around 2800 km. Considering the role of the subcontinent in the most important collision orogen on the planet, this is a somewhat unsatisfactory situation. Fortunately, however, it appears that a definitive form can be established based on detailed bathymetric charts of the SE Indian Ocean and plate reconstructions of Late Jurassic–Early Cretaceous Gondwana. Using this information, it is suggested that the maximum extension in the centre was ~950 km. North of the Eastern and Western Syntaxes, the figure was respectively ~500 and ~600 km. The new information should prove useful to researchers working on the India–Asia collision as well as plate tectonic modellers of the broader region. A consequence of our analysis is that as Australia–Antarctica rotated away from India (starting ~132 Ma), the sub-continent's northern edge formed a transform boundary. We thus argue that ocean–continent boundary (of India) involved in the Asia collision was sharp, and was likely not excessively extended. It may thus impact those workers whose models are based around a 'soft collision–hard collision' scenario.

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