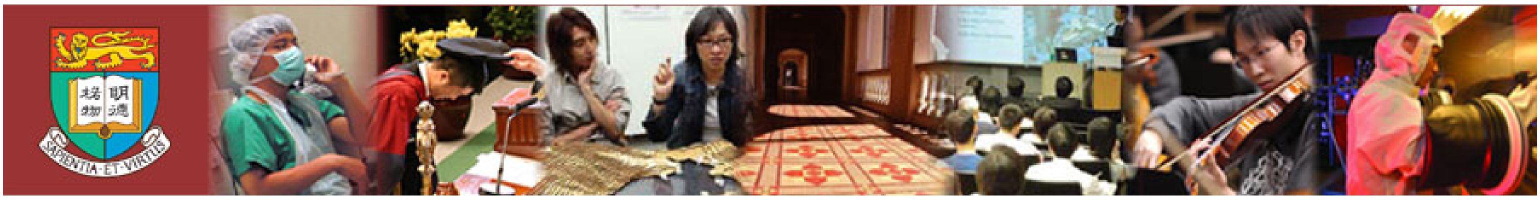

Comment on "Restoration of Cenozoic deformation in Asia and the size of Greater India" by D. J. J. van Hinsbergen et al.

Jason R. Ali[1] and Jonathan C. Aitchison[2]

Received 25 December 2011; revised 29 May 2012; accepted 1 June 2012; published 14 July 2012.

Citation: Ali, J. R., and J. C. Aitchison (2012), Comment on "Restoration of Cenozoic deformation in Asia and the size of Greater India" by D. J. J. van Hinsbergen et al., *Tectonics*, *31*, TC4006, doi:10.1029/2011TC003091.

1. Introduction

[1] Despite decades of investigation and literally thousands of research papers, there remain strongly divergent opinions on a number of key features/phenomena associated with the India-Asia collision system and the Himalayan Mountain-Tibetan Plateau orogen that resulted. One particularly contentious issue concerns the timing of contact between the two continents; although many favor an early Eocene/early–middle Eocene age, recent proposals have ranged from ~65 Ma [e.g., *Cai et al.*, 2011] to ~35 Ma [*Aitchison et al.*, 2007].

[2] In order to deduce the collision timing, we argue that detailed understanding is required first of the elements associated with the suture zone, and second, the broader geodynamic configuration before and during the contact. Regarding the former, the following are critical: (i) age of the youngest marine sediments; (ii) age of the youngest subduction-generated calc-alkaline volcanic rocks; (iii) identification and full interpretation of any trapped terranes; (iv) age and clast-assemblage lithologies of any molasse formations; (v) ages of the youngest entrained blocks in any mélange deposits plus that of the matrix. From a plate-modeling perspective, we need to know (i) past position of stable Eurasia; (ii) extent of deformation (shortening, extrusion etc) Eurasia's leading edge experienced after the contact; (iii) motion path of the Indian block; (iv) size of the Indian sub-continent prior to the collision, which is commonly referred to as "Greater India."

[3] Recently, *Van Hinsbergen et al.* [2011a, 2011b] have proposed a new collision scenario. In their model, contact is interpreted to have taken place at 50 Ma, and following a structural restoration of Asia's southern margin, a sub-continent extension is proposed that bridges the gap between the Indian craton (to the south of the Himalayan frontal thrust) and the Lhasa Block; ~1350 km in the west, ~2600 km in the east. By corollary, a huge amount of lithosphere must therefore have been subducted/underthrust beneath the Asian margin in Tibet. The model has provoked our interest, not only because the hypothesized Greater India is the largest so far presented [see *Ali and Aitchison*, 2005], but we consider it to suffer from two "unintended-consequence" flaws.

2. Problem of Refitting India Back Into Gondwana

[4] Although the extension proposal of *van Hinsbergen et al.* [2011a], based around a 50 Ma contact can in theory explain the collision (to avoid potential misunderstanding, though, we reiterate our long-held view that the India-Asia collision occurred ~15 my later), a problem arises when it comes to positioning their Greater India at its former site in Gondwana (before the Early Cretaceous, ~130 Ma). Since the classic "tight-fit" reconstruction of *Smith and Hallam* [1970], there has been widespread consensus over the manner in which India (eastern), Australia (western) and Antarctica (eastern) are considered to have once abutted [e.g., *Schettino and Scotese*, 2005; *Cocks and Torsvik*, 2006] (see *Ricou* [1994] for a radical alternative). The issue with the *van Hinsbergen et al.* [2011a] model is that not only does the eastern side of the extension overlap western Australia (Figure 1a), but it fails to accommodate various rafts of continental crust that are present offshore, specifically the Exmouth, Wallaby and Zenith plateaus plus the Carnarvon Terrace. It was the second and third features [see also *Colwell et al.*, 1994; *Symonds et al.*, 1998] that prompted us [*Ali and Aitchison*, 2005] to propose a Greater India whose northern edge was delimited, at least in the eastern and central parts, as including the area today occupied by the Perth Basin, southwest of the Wallaby-Zenith Fracture zone (Figure 1a). The recent paleontologically focused publications of *Quilty* [2011] and *Stilwell et al.* [2012] add considerable weight to this proposal. They indicate that in the Late Jurassic (Oxfordian-Kimmeridgian), around 12 my prior to the India's rifting from the Australian margin, the Wallaby Plateau occupied a shallow marine site. Thus, the widely held view is that the edifice is "continental" and is capped by sea-ward dipping reflectors; critically it is not an Early Cretaceous submarine large igneous province resulting from excessive magmatism as the oceanic crust off western Australia formed. We therefore argue that the various plateaus west of Australia act to eliminate large tracts of lithosphere from the *van Hinsbergen et al.* [2011a] Greater India.

[1]Department of Earth Sciences, University of Hong Kong, Hong Kong, China.
[2]School of Geosciences, University of Sydney, Sydney, NSW, Australia.

Corresponding author: J. R. Ali, Department of Earth Sciences, University of Hong Kong, Pokfulam Rd., Hong Kong, China. (jrali@hku.hk)

0278-7407/12/2011TC003091

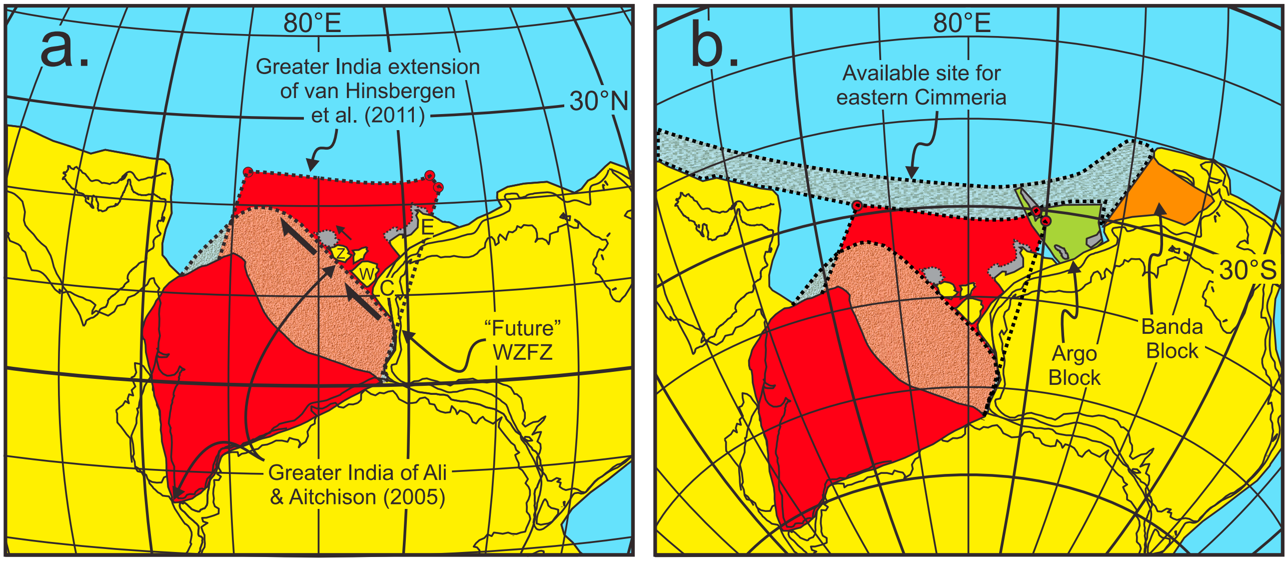

Figure 1. (a) Reconstructions of Gondwana and Greater India in the Eocene (50 Ma) and (b) Early Permian (275 Ma) using the GMAP software of *Torsvik and Smethurst* [1999]. In the former, the supercontinent has been rotated such that the India part matches that in the 50 Ma scenario depicted in *van Hinsbergen et al.* [2011a, Figure 5]. Note that the Wallaby (W), Zenith (Z) and Exmouth (E) plateaus have been "nudged" in a southeasterly direction back to their approximate locations prior to India's Early Cretaceous (130–132 Ma) break-out [see *Symonds et al.*, 1998]; for reference, the grey-shaded areas represent the present day edges/outlines of Zenith and Exmouth. Another important submarine continental fragment is the Carnarvon Terrace (C). The abbreviation WZFZ = Wallaby-Zenith fracture zone. The aim of the Early Permian reconstruction (b), is to show that eastern Gondwana's Tethyan margin was too far north to accommodate paleomagnetic data from the Cimmerian terrane Baoshan sub-block that rifted from the supercontinent at about this time (see text). On this map the Argo and Banda blocks of *Hall* [2011] are also shown; respectively they today form the East Java- West Sulawesi and SW Borneo-West Java terranes in central southern Indonesia [*Hall*, 2011, Figures 4, 5, and 9]. Note though that the former is in its Middle Miocene configuration [*Hall*, 2011, Figures 12, and 13]—since that time, the Sumba Island region has rifted from the main block due to the eastward propagation of the Sunda Trench-Arc system. For reference, South Sulawesi, Sumba and East Java respectively sit towards the SE, SW and NW corners of the stencil.

[5] Concerning Greater India's northwestern extremities, although we were unable to use similar elements to define the block's boundaries, based on the uniform width and broadly similar nature of the deformed Indian upper-crustal sequences along the entire strike-length of the Himalayas (∼2500 km), we suggested that it followed a similar line before wrapping back to connect with western edge of the craton.

3. Consequences for Earlier Periods in Gondwana's History

[6] A major episode in Gondwana's history involved the Early Permian (Artinskian stage, ∼275 Ma) detachment of the Cimmerian super terrane. Dwarfing in length any of the modern sliver blocks (e.g., Lord Howe Rise, Tasman Sea; Palawan block, offshore SE Asia), remnants of Cimmeria form an ostensibly continuous belt stretching ∼13,800 km, from central Italy to east of Sumatra (Indonesia), via Greece, Turkey, Iran, Afghanistan, Tibet, southwest China, Myanmar and Thailand [*Stampfli et al.*, 2001; *Metcalfe*, 2011]. From a plate modeling perspective, one of the intriguing aspects concerns how specific portions of the terrane fitted back to their original sites; it is in this context, we argue that the Greater India of *Van Hinsbergen et al.* is problematic. A specific issue is the Baoshan sub-block of western Yunnan province, SW China; the paleomagnetic investigation of *Huang and Opdyke* [1991] indicates that a series of rift-related basalts (Woniusi Formation) were erupted at ∼42°S. Although the paleolatitude determination was based upon directions from just three localities (19 sites), our recent work, as yet unpublished (five localities, 31 discrete cooling units), confirms the earlier findings. Applying the statistics of *McFadden and Reid* [1982] to the old and new data sets results in a tilt-corrected mean inclination of 61.0°, where $\alpha95$ = 7.6° and k = 40.8 (N = 8), implying that the eruptions took place at 42.1°S – with errors, the permissible range is 34.0°S–51.9°S. However, if the Greater India of *Van Hinsbergen et al.* is incorporated into Gondwana (using the appropriate rotation poles listed in *Torsvik et al.* [2008], and ignoring the problems alluded to in the preceding section), it is difficult to position the Baoshan sub-block against the supercontinent at a latitude that can accommodate the paleomagnetic data (Figure 1b). The edge of the likely matching margin of Gondwana (northern Greater India-northern Australia) sat ∼30°S; the ground directly adjacent to the Greater India's northeastern corner is unavailable; the ocean floor here dates from the latest Jurassic (Hole 261)

[*Veevers et al.*, 1974] /earliest Cretaceous (Hole 765) [*Ludden et al.*, 1990], and is thought to be the original site of the Argo and Banda blocks that today form terranes in central southern Indonesia [*Hall*, 2011].

4. Conclusion

[7] For the two reasons outlined above, we contend that the "Greater India" of *van Hinsbergen et al.* [2011a] is untenable when (i) key geotectonic features of the eastern Indian Ocean-western Australia region and (ii) accommodation of Cimmerian-terrane blocks are considered. Any model attempting to delimit the Indian sub-continent's pre-Asia-collision size needs to be compatible with tectonic configurations that are applicable for earlier times in the block's history.

[8] **Acknowledgments.** Douwe van Hinsbergen kindly supplied rotation data that enabled us to replicate the *van Hinsbergen et al.* [2011a] tectonic model. Formal critiques by an anonymous reviewer and Robert Hall were very useful. Our research on the India-Asia collision has almost exclusively been supported by grant awards from the Hong Kong Research Grants Council; recent paleomagnetic studies of the Baoshan block were funded by an award to JRA (HKU7001/10).

References

Aitchison, J. C., J. R. Ali, and A. M. Davis (2007), When and where did India and Asia collide?, *J. Geophys. Res.*, *112*, B05423, doi:10.1029/2006JB004706.
Ali, J. R., and J. C. Aitchison (2005), Greater India, *Earth Sci. Rev.*, *72*, 169–188, doi:10.1016/j.earscirev.2005.07.005.
Cai, F., L. Ding, and Y. Yue (2011), Provenance analysis of upper Cretaceous strata in the Tethys Himalaya, southern Tibet: Implications for timing of India–Asia collision, *Earth Planet. Sci. Lett.*, *305*, 195–206, doi:10.1016/j.epsl.2011.02.055.
Cocks, L. R. M., and T. H. Torsvik (2006), European geography in a global context from the Vendian to the end of the Palaeozoic, *Geol. Soc. Lond. Mem*, *32*, 83–95, doi:10.1144/GSL.MEM.2006.032.01.05.
Colwell, J. B., P. A. Symonds, and A. J. Crawford (1994), The nature of the Wallaby (Cuvier) Plateau and other igneous provinces of the west Australian margin, *AGSO J. Aust. Geol. Geophys.*, *15*, 137–156.
Hall, R. (2011), Australia–SE Asia collision: Plate tectonics and crustal flow, *Geol. Soc. Spec. Publ.*, *355*, 75–109, doi:10.1144/SP355.5.
Huang, K. N., and N. D. Opdyke (1991), Paleomagnetic results from the Upper Carboniferous of the Shan-Thai-Malay block of western Yunnan, China, *Tectonophysics*, *192*, 333–344, doi:10.1016/0040-1951(91)90107-4.
Ludden, J. N., et al. (1990), *Initial Reports of the Deep Sea Drilling Project*, vol. 123, U.S. Gov. Print. Off., Washington, D. C.
McFadden, P. L., and A. B. Reid (1982), Analysis of palaeomagnetic inclination data, *Geophys. J. R. Astron. Soc.*, *69*, 307–319, doi:10.1111/j.1365-246X.1982.tb04950.x.
Metcalfe, I. (2011), Tectonic framework and Phanerozoic evolution of Sundaland, *Gondwana Res.*, *19*, 3–21, doi:10.1016/j.gr.2010.02.016.
Quilty, P. G. (2011), Late Jurassic foraminifera, Wallaby plateau, offshore Western Australia, *J. Foraminiferal Res.*, *41*, 182–195, doi:10.2113/gsjfr.41.2.182.
Ricou, L.-E. (1994), Tethys reconstructed plates, blocks and their boundaries since 260 Ma from Central America to south-eastern Asia, *Geodin. Acta*, *7*, 169–218.
Schettino, A., and C. R. Scotese (2005), Apparent polar wander paths for the major continents (200 Ma to the present day): A palaeomagnetic reference frame for global plate tectonic reconstructions, *Geophys. J. Int.*, *163*, 727–759, doi:10.1111/j.1365-246X.2005.02638.x.
Smith, A. G., and A. Hallam (1970), The fit of the southern continents, *Nature*, *225*, 139–144, doi:10.1038/225139a0.
Stampfli, G. M., G. D. Borel, W. Cavazza, J. Mosar, and P. A. Ziegler (2001), Palaeotectonic and palaeogeographic evolution of the western Tethys and PeriTethyan domain (IGCP Project 369), *Episodes*, *24*, 22–28.
Stilwell, J. D., P. G. Quilty, and D. J. Mantle (2012), Paleontology of early Cretaceous deep-water samples dredged from the Wallaby Plateau: New perspectives of Gondwana break-up along the Western Australian margin, *Aust. J. Earth Sci.*, *59*, 29–49, doi:10.1080/08120099.2011.615864.
Symonds, P. A., S. Planke, O. Frey, and J. Skogseid (1998), Volcanic evolution of the Western Australian continental margin and its implications for basin development, in *The Sedimentary Basins of Western Australia 2: Proceedings of the PESA Symposium*, edited by P. G. Purcell and R. R. Purcell, *Pet. Explor. Soc.*, pp. 33–54, Perth, Aust.
Torsvik, T. H., and M. A. Smethurst (1999), Plate tectonic modelling: Virtual reality with GMAP, *Comput. Geosci.*, *25*, 395–402, doi:10.1016/S0098-3004(98)00143-5.
Torsvik, T. H., R. D. Müller, R. Van der Voo, B. Steinberger, and C. Gaina (2008), Global plate motion frames: Toward a unified model, *Rev. Geophys.*, *46*, RG3004, doi:10.1029/2007RG000227.
van Hinsbergen, D. J. J., P. Kapp, G. Dupont-Nivet, P. C. Lippert, P. G. DeCelles, and T. H. Torsvik (2011a), Restoration of Cenozoic deformation in Asia and the size of greater India, *Tectonics*, *30*, TC5003, doi:10.1029/2011TC002908.
van Hinsbergen, D. J. J., B. Steinberger, P. V. Doubrovine, and R. Gassmöller (2011b), Acceleration and deceleration of India-Asia convergence since the Cretaceous: Roles of mantle plumes and continental collision, *J. Geophys. Res.*, *116*, B06101, doi:10.1029/2010JB008051.
Veevers, J. J., et al. (1974), *Initial Reports of the Deep Sea Drilling Project*, vol. 27, 1060 pp., U.S. Gov. Print. Off., Washington, D. C.