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COMMENT
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This article is a comment on Rowley (2019) https://doi.org/10.1029/2017TC004802.

Key Points:

- The paper by Rowley incorrectly argues that paleomagnetic data do not support a Greater India Basin Hypothesis
- The APWP predicted by a fully continental Greater India hypothesis is systematically offset from and thus inconsistent with the data
- Paleomagnetic data render the chance that continental Greater India was ever thousands of kilometers wide negligible

Supporting Information:

- Supporting Information S1

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Comment on "Comparing Paleomagnetic Study Means With Apparent Wander Paths: A Case Study and Paleomagnetic Test of the Greater India Versus Greater Indian Basin Hypotheses" by David B. Rowley

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The northernmost rocks in the India-Asia collision zone that were off-scraped from continental crust of the Indian plate are the nappes of the so-called Tibetan Himalaya, and the paleogeographic area between the Tibetan Himalaya and modern undeformed India is known as "Greater India." Paleomagnetic data have long been used to infer that the paleolatitudinal distance between the Tibetan Himalaya and India, defining the width of Greater India, was in Early Cretaceous, Triassic, and Ordovician time not more than some hundreds of kilometers wider than today (e.g., Bian et al., 2019; Huang et al., 2015; Klootwijk & Bingham, 1980; Qin et al., 2019; Torsvik et al., 2009; van Hinsbergen et al., 2012, 2019; Figure 1). This is consistent with (i) shortening records of the Himalaya that show that some 500–600 km (perhaps up to 900 km) of upper continental crust was stacked (in two episodes: in the latest Paleocene-earliest Eocene (~55 Ma), and since the latest Oligocene (~30–25 Ma) with no demonstrated record of nappe accretion in the intervening period (Long et al., 2011); (ii) with tectonic reconstructions of the west Australian margin that argue that during the Early Cretaceous breakup of east Gondwana, continental India did not extend beyond a prominent fracture zone (the Wallaby fracture zone) limiting its width to ~800 km (Ali & Aitchison, 2005; Gibbons et al., 2012); and (iii) with seismic tomographic constraints that the modern Indian continent that is imaged below Tibet today is of similar shape and area as predicted by a Gondwana fit of Greater India against the Wallaby fracture zone (van Hinsbergen et al., 2019).

An alternative way to estimate the width of Greater India is through kinematic reconstruction of Tibet, in combination with the age of initial collision between the Tibetan Himalaya and the south Asian margin. Asia-derived sediments in the Tibetan Himalayan stratigraphy of 58 ± 2 Ma (Hu et al., 2015; Orme et al., 2015), combined with ~55 Ma ages for the oldest high-pressure metamorphism in Tibetan Himalayan rocks demonstrating deep continental underthrusting (de Sigoyer et al., 2000) constrain a ~58–56 Ma onset of collision. Recent reconstructions estimated shortening and extrusion in Asia since 58–56 Ma at ~1,000 (van Hinsbergen, Kapp, et al., 2011; van Hinsbergen et al., 2019) to ~2,000 km (Ingalls et al., 2016). These Asian reconstructions, the 58–56 Ma collision age, and the restoration of India relative to Eurasia using the Indo-Atlantic plate circuit (van Hinsbergen, Steinberger, et al., 2011) together constrain the size of Greater India at the moment of collision. Ingalls et al.'s (2016) reconstruction estimated 2,600 km (assuming a 56 Ma collision), and van Hinsbergen et al. (2019) estimated ~4,000 km (assuming a 58 Ma collision). Both estimates are considerably larger than the width reconstructed for continental Greater India based on west Australian margin, Himalayan shortening, seismic tomographic, or paleomagnetic constraints.

There are currently two conceptual explanations for these disparate estimates for the size of Greater India. van Hinsbergen et al. (2012) proposed that between the Early Cretaceous and the Paleocene collision, the Tibetan Himalaya rifted away from and drifted northward considerably faster than India, opening a conceptual Greater India Basin (GIB) in its wake. Subduction of this basin would then have occurred in the early Eocene-latest Oligocene time window without demonstrated nappe accretion in the Himalaya. The latest version of this reconstruction (van Hinsbergen et al., 2019) is conservative in that it reconstructs the maximum shortening estimates from the Himalaya and predicts an APWP for the Tibetan Himalaya that for the Early Cretaceous and Triassic predicts paleolatitudes close to those observed (Figure 1a), whereby an even tighter Tibetan Himalaya-India fit, that is, assuming more GIB extension, would further optimize the correlation.

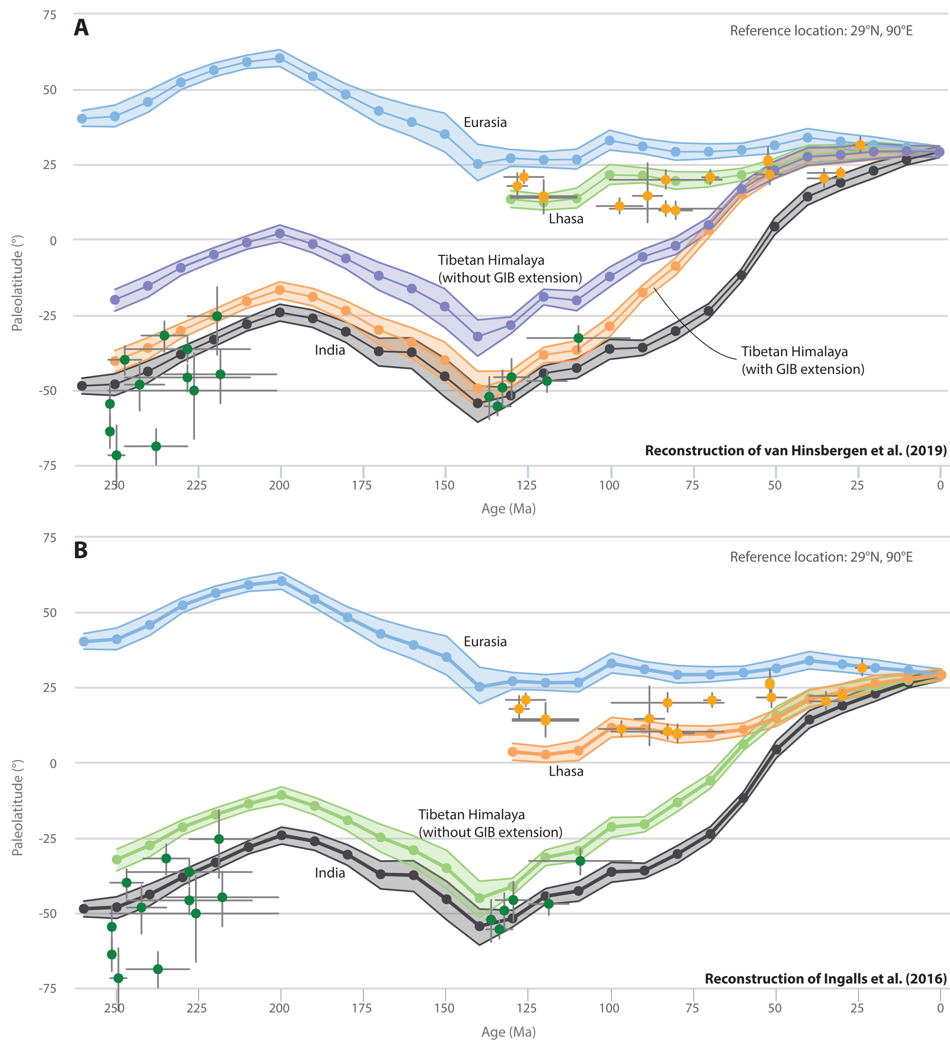

Figure 1. Global Apparent Polar Wander Path of Torsvik et al. (2012) in the coordinates of (a) Eurasia (blue curve), India (black curve), the Lhasa terrane according to the reconstruction of van Hinsbergen et al. (2019; green curve), and the Tibetan Himalaya according to the reconstruction of van Hinsbergen et al. (2019) following the GIB hypothesis (orange curve), or assuming no Greater Indian extension (purple curve); (b) Eurasia (blue curve), India (black curve), the Lhasa terrane according to the reconstruction of Ingalls et al. (2016; orange curve), and the Tibetan Himalaya according to the reconstruction of *Ingalls* et al. (2016; green curve). Paleomagnetic data compilation as in van Hinsbergen et al. (2019), with additional recent poles from Qin et al. (2019) and Bian et al. (2019) for the Tibetan Himalaya and Meng et al. (2017), Ma et al. (2017), and Tong et al. (2017) for the Lhasa Block.

Ingalls et al. (2016), instead, followed the widespread assumption that there was no oceanic crust between India and Asia since the 58 ± 2 Ma collision and assumed that there was a 2,600 km wide continental Greater Indian promontory. They inferred that this enormous continental promontory has largely subducted, leaving the Himalaya as a highly incomplete geological record of continental subduction and questioning the validity of previous west Australia reconstructions. Their reconstruction predicts a paleolatitude curve for the Tibetan Himalaya that lies well north of published paleolatitudes for the Early Cretaceous and Triassic (Figure 1). Reported paleolatitudes for the upper Cretaceous and Paleocene of the Tibetan Himalaya (Patzelt et al., 1996; Yi et al., 2011) are consistent with both scenarios as both predict a wide Greater India for that time, but were recently argued to be remagnetized (Huang, Lippert, Jackson, et al., 2017; Huang, Lippert, Zhang, et al., 2017).

Rowley (2019) argued that his “more rigorous” statistical approach favors the “Greater India” scenario of Ingalls et al. (2016) over the “Greater India Basin” scenario of van Hinsbergen et al. (2012). He correctly points out that a widely used approach to compare individual paleomagnetic poles with an APWP reference pole is flawed. In that approach, a paleomagnetic study pole from a tectonic block is interpreted to signal tectonic motion of that block relative to a main continent from which an APWP is available, if the distance from the individual pole to the APWP is larger than the square root of the sum of the 95% cones of confidence (A_{95} of Fisher, 1953) of the pole and the APWP. Rowley (2019) showed that the distribution of individual poles used to calculate the Global APWP of Torsvik et al. (2012) is obviously much wider than the A_{95} of the mean of those poles. Rowley (2019) therefore argues that when comparing an individual pole to an APWP, the dispersion of the poles behind the reference path should be taken into account. To that end he proposes to use an alternative error estimate—the K_{95}—as reference to compare individual paleomagnetic poles against. This K_{95} parameter represents the deviation of the sample, embracing 95% of samples if they are normally distributed, and is for the Global APWP of Torsvik et al. (2012) on the order of 15–20°. In other words, one or two poles that fall far from an APWP do not necessarily indicate major tectonic motion.

When they originally proposed the Greater India Basin hypothesis, van Hinsbergen et al. (2012) used the two Upper Cretaceous and Paleocene paleomagnetic poles to calculate, in the "classical" way, a much wider distance from the Tibetan Himalaya to India in the Uppermost Cretaceous and Paleocene, than for the much larger number of Cretaceous, Triassic and Ordovician poles that would rather suggest a paleogeographic distance similar to today of no more than a few hundred kilometers. This way, van Hinsbergen et al. (2012) quantified thousands of kilometers of Greater India Basin extension. Following the arguments of Rowley (2019) one could indeed argue that the two poles, for the Upper Cretaceous and Paleocene, of Patzelt et al. (1996) and Yi et al. (2011) are outliers, which could fall within the K_{95} envelope of an APWP for the Tibetan Himalaya that essentially coincides with that of India. In other words, as recently also pointed out by Qin et al. (2019), from a paleomagnetic point of view, a scenario in which Greater India was never wider than a few hundred kilometers, is defendable. However, one should realize, as pointed out by van Hinsbergen et al. (2019), that in such a scenario, the Tibetan Himalaya could not possibly have collided with Asia until well into the Miocene, which is inconsistent with all geological evidence. A 58 ± 2 Ma Tibetan Himalaya-Asia collision age demonstrated by geological observations is only possible if after the Early Cretaceous an amount of Greater India Basin extension has occurred that is even higher than that calculated by van Hinsbergen et al. (2012).

Surprisingly, however, Rowley (2019) does not argue that the two poles on which van Hinsbergen et al. (2012) based the GIB hypothesis, but instead all other paleomagnetic poles from the Tibetan Himalaya, are outliers. Because the paleomagnetic poles of the Lower Cretaceous and Triassic of the Tibetan Himalaya fall (just) within the K_{95} envelope of the Global APWP of Torsvik et al. (2012) rotated in Tibetan Himalayan coordinates predicted by the reconstruction of Ingalls et al. (2016), Rowley (2019) concludes that these data demonstrate the validity of that path, and he even goes so far as to claiming that the GIB hypothesis is not supported by those data.

Both of these conclusions are not defendable. First, the GIB hypothesis is clearly consistent with and supported by the data: that hypothesis predicts an APWP for the Tibetan Himalaya that lies within the Early Cretaceous and Triassic paleomagnetic data scatter obtained from the Tibetan Himalaya (Figure 1). Adding a K_{95} envelope by no means invalidates this solution, it only explains why the data points that fall outside of the A_{95} of the predicted path do not invalidate that path.

Second, Rowley's (2019) conclusion that his predicted APWP based on Ingalls et al. (2016) is consistent with the paleomagnetic data from the Tibetan Himalaya for the Early Cretaceous and Triassic because each pole falls within the K_{95} envelope is hard to defend: all poles from the Lower Cretaceous and Triassic predict paleolatitudes that plot south of the predicted paleolatitude of Ingalls et al. (2016) and Rowley (2019) (Figure 1a). Rowley (2019) argues that because each individual pole falls within the K_{95} envelope and in isolation does not falsify his predicted path, all poles together also do not falsify that path. This argument is obviously flawed: While there is a 50% chance that a single pole falls on one side of the average, the chance that 18 data points drawn from an evenly distributed scatter around a mean all plot far on one side of that mean is negligible. The chance that a coin when flipped lands same side up 18 times in a row, is less than 0.0004%.

So using Rowley's (2019) statistical arguments, one could argue that Greater India was never wider than a few hundred kilometers. As pointed out by van Hinsbergen et al. (2019), based on paleomagnetic data alone (particularly given the probable remagnetization for the Upper Cretaceous and Paleocene poles; Huang, Lippert, Jackson, et al., 2017; Huang, Lippert, Zhang, et al., 2017) one cannot argue for a GIB hypothesis, but this hypothesis is the only one that reconciles the narrow Early Cretaceous Greater India with a 58 ± 2 Ma collision age. A thousands of kilometer wide continental Greater India as advocated by Ingalls et al. (2016) and Rowley (2019) gives an APWP that is systematically offset from, and is thus not supported by the paleomagnetic data, even if every individual data point falls within a K_{95} envelope. And because these paleomagnetic data form the sole quantitative basis for Rowley's (2019) assumption of a thousands of kilometer wide continental Greater India—all other quantitative lines of evidence from marine magnetic anomalies, structural geology, or seismology do not require or support a continental Greater India larger than ~800 km (van Hinsbergen et al., 2019)—the chance that the 58 ± 2 Ma collision recorded in the Tibetan Himalaya represented the collision of the major Indian and Asian continents, is negligible. There must have been thousands of kilometers of oceanic crust between these continents when the Tibetan Himalaya became involved in collision, and in contrast to Rowley's (2019) claim, this GIB hypothesis is paleomagnetically supported, while Rowley's (2019) alternative is not.

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