

Indo-Atlantic plate accelerations around the Cretaceous-Paleogene boundary: A time-scale error, not a plume-push signal

L. Pérez-Díaz¹, G. Eagles² and K. Sigloch¹¹Department of Earth Sciences, University of Oxford, South Parks Road, OX1 3AN Oxford, UK²Alfred Wegener Institut, Am Handelshafen 12, 27570 Bremerhaven, Germany

ABSTRACT

It has been suggested that plume arrival at the base of the lithosphere introduces a push force that overwhelms the balance of torques driving plate circuits, leading to plate-tectonic reorganizations. Among the most compelling evidence in support of a “plume-push” mechanism is the apparent coincidence between eruption of the Deccan flood basalts around 67–64 Ma and a short-lived increase in Indian (and decrease in African) plate speed. Using existing and newly calculated high-resolution plate-motion models, we show that plate divergence rates briefly increased throughout the Indo-Atlantic circuit, contrary to the expected effects of plume-push. We propose that this circuit-wide spike in divergence rates is best explained as the artifact of a magnetic reversal time-scale error around the much studied Cretaceous-Tertiary boundary, and that the period spanning chrons C29–C28 lasted 70% longer than currently assumed. Corrected for this error, the residual long-term patterns of Indo-Atlantic plate motions and accompanying plate-tectonic reorganization are explicable in terms of maturation of the circuit’s spreading ridges, without invoking a significant plume-push force.

INTRODUCTION

A tectonic plate’s motion is maintained by a balance of torques generated by its internal gravitational potential, that of the subducting material attached to it, and the pattern of flow in the mantle beneath the plate. Because plate boundaries and slabs are long-lived features, and mantle convection time scales are on the order of tens of millions of years, plate motion should evolve only gradually. Large and sudden changes in a plate’s motion may thus be interpreted in terms of other mechanisms acting in the Earth system. One such mechanism may be a radial gravitational “plume-push” force related to lithospheric doming during the episodic rise of massive mantle plume heads. The arrival of the Deccan-Réunion plume beneath the southwestern part of the northward-moving Indian plate starting at 67 Ma (Fig. 1A) is the most-studied example.

The schematic velocity triangles in Figures 1B and 1C illustrate the effects of the introduction of a Deccan-Réunion plume-push force from the mantle (M), as suggested by Cande and Stegman (2011). Depicted by thick red arrows,

the plume-push force opposes the preexisting motion of the African (AFR) plate, decelerating it, but it aligns with the preexisting motions of the Indian (IND) and, possibly, Antarctic (ANT) plates, accelerating them. These changes are represented by the lengthening of the IND-M and ANT-M vectors and shortening of the AFR-M vector between Figures 1B and 1C.

The changed vectors skew the triangles (Figs. 1B and 1C) to predict acceleration of the divergent motion of India relative to Africa (IND-AFR) and Antarctica (IND-ANT) and simultaneous deceleration of Africa’s divergence from South America (SAM-AFR) and Antarctica (AFR-ANT). Therefore, if the arrival of the Réunion plume introduced a plume-push force at the southwestern edge of the Indian plate, its effects should be observable in the spacings of conjugate magnetic anomaly isochrons throughout the circuit, and not just those in the Indian Ocean.

Limited to the 10 m.y. resolution of O’Neill et al.’s (2005) models of absolute plate motion, van Hinsbergen et al. (2011) suggested that the Indian plate indeed accelerated northward over the mantle in the Late Cretaceous. Cande and Stegman (2011) presented better-resolved (–1–

3 m.y.) evidence from the divergent IND-AFR and IND-ANT plate boundaries, both recording sharp increases in plate divergence rates at times coincident with plume arrival. They also used lower-resolution (3–6 m.y.) models of seafloor spreading data between Africa and Antarctica (AFR-ANT) and South America (AFR-SAM) to show decelerations in the 70–45 Ma period. Cande and Stegman (2011) also suggested that these relative plate-motion changes had wider consequences, by triggering a cascade of regional plate-tectonic events in the Indo-Atlantic circuit.

Here, we test in greater detail the proposal that the introduction of plume-related forces in the Indian Ocean led to large accelerations and decelerations in Indian and African plate motions. We do this by examining plate divergence rates calculated from a set of models of higher temporal resolution than those used by Cande and Stegman (2011). In turn, we discuss whether or not such plume-triggered divergence rate changes are necessary to explain the regional plate-tectonic reorganization around the Cretaceous-Paleogene boundary.

DATA AND METHOD

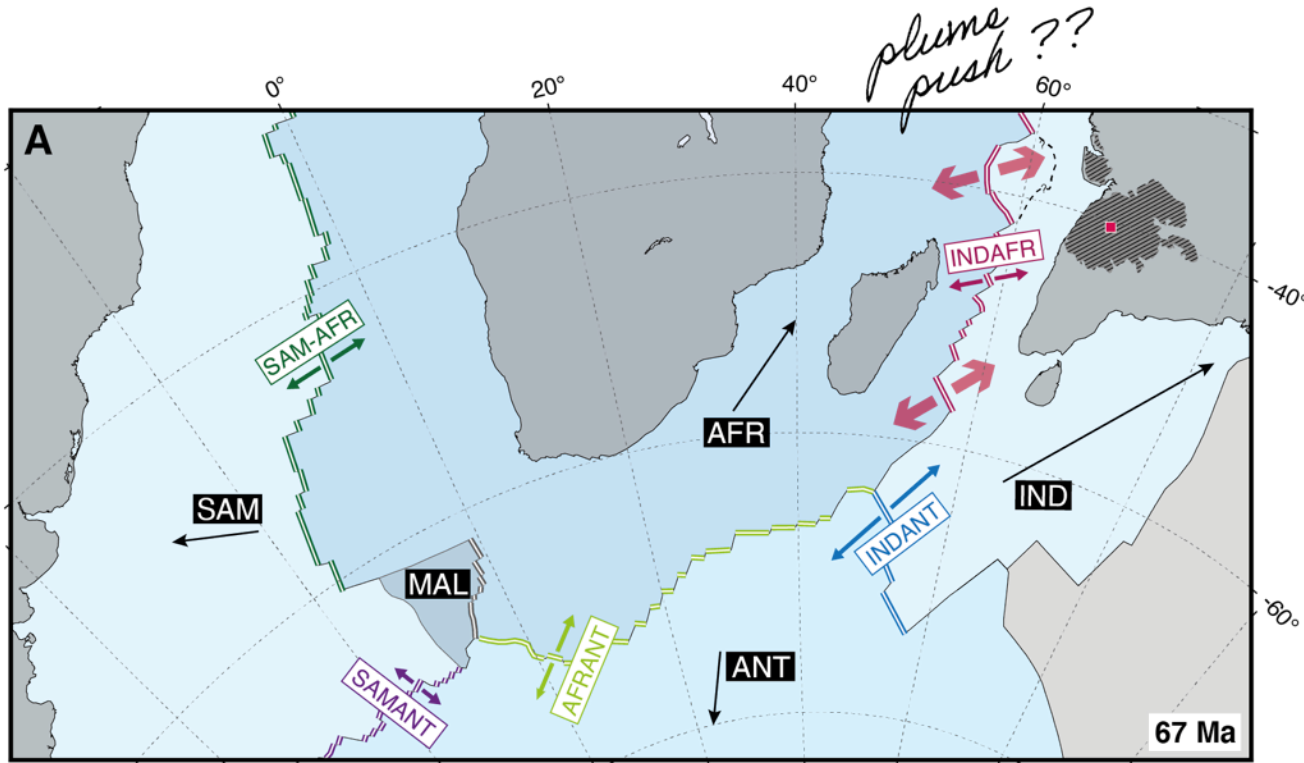
Seafloor spreading rate variations can be estimated from the spacings of magnetic reversal isochrons on individual ship-track profiles, but these are exposed to local variability and possible isochron misinterpretations. A more robust picture can be generated by calculating plate divergence rates from quantitative plate-motion models, which unite conjugate pairs of the isochrons identified in hundreds of ship profiles. The spreading rate curves presented by Cande and Stegman (2011) were derived from a set of models built using two differing techniques, here termed “Hellinger-Chang” (Hellinger, 1981; Chang et al., 1990), and “Shaw-Nankivell” (Shaw and Cande, 1990; Nankivell, 1997). In



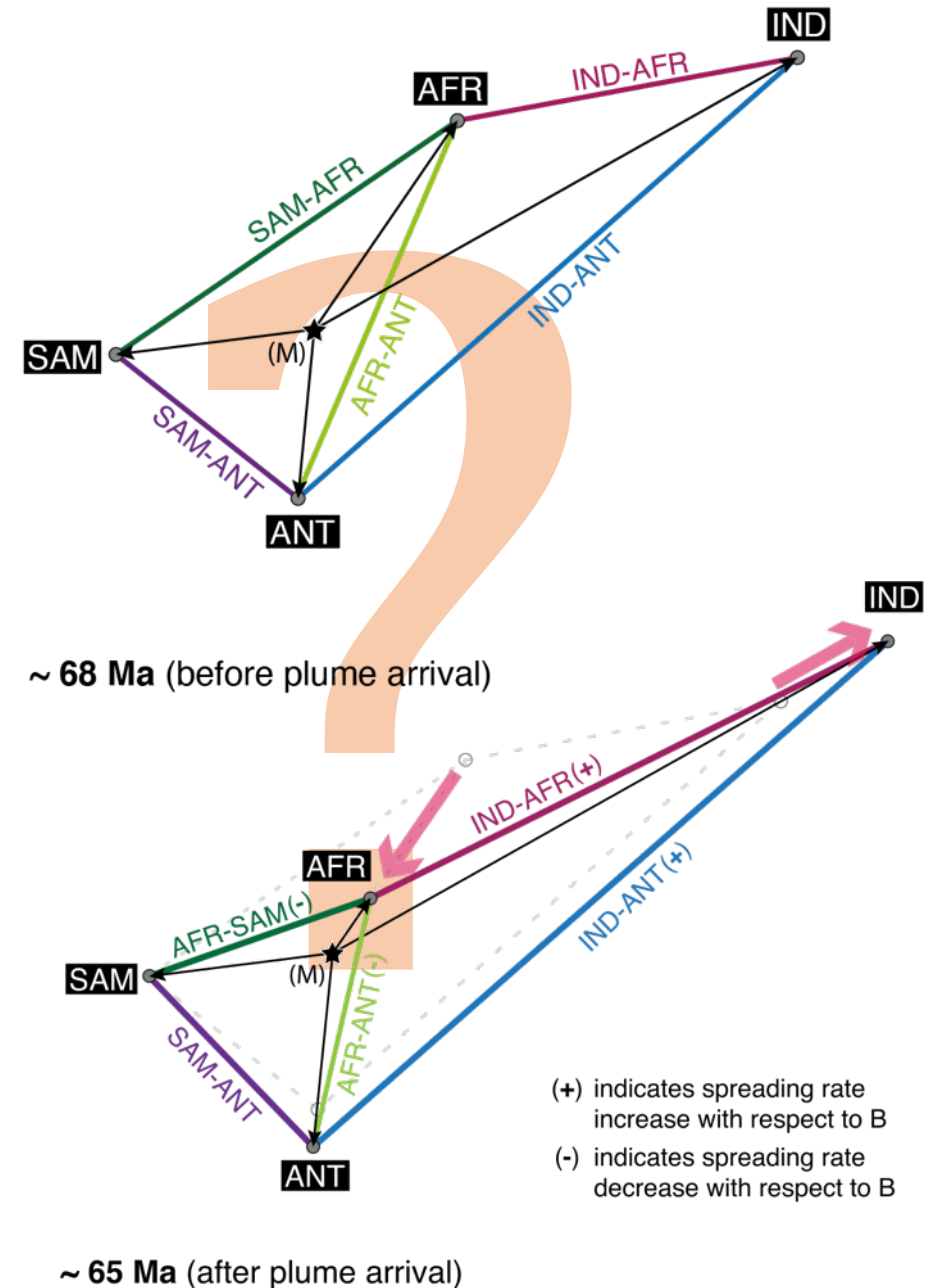
*E-mail: lucia.perezdiaz@earth.ox.ac.uk

Did the arrival of the Deccan-Réunion plume...

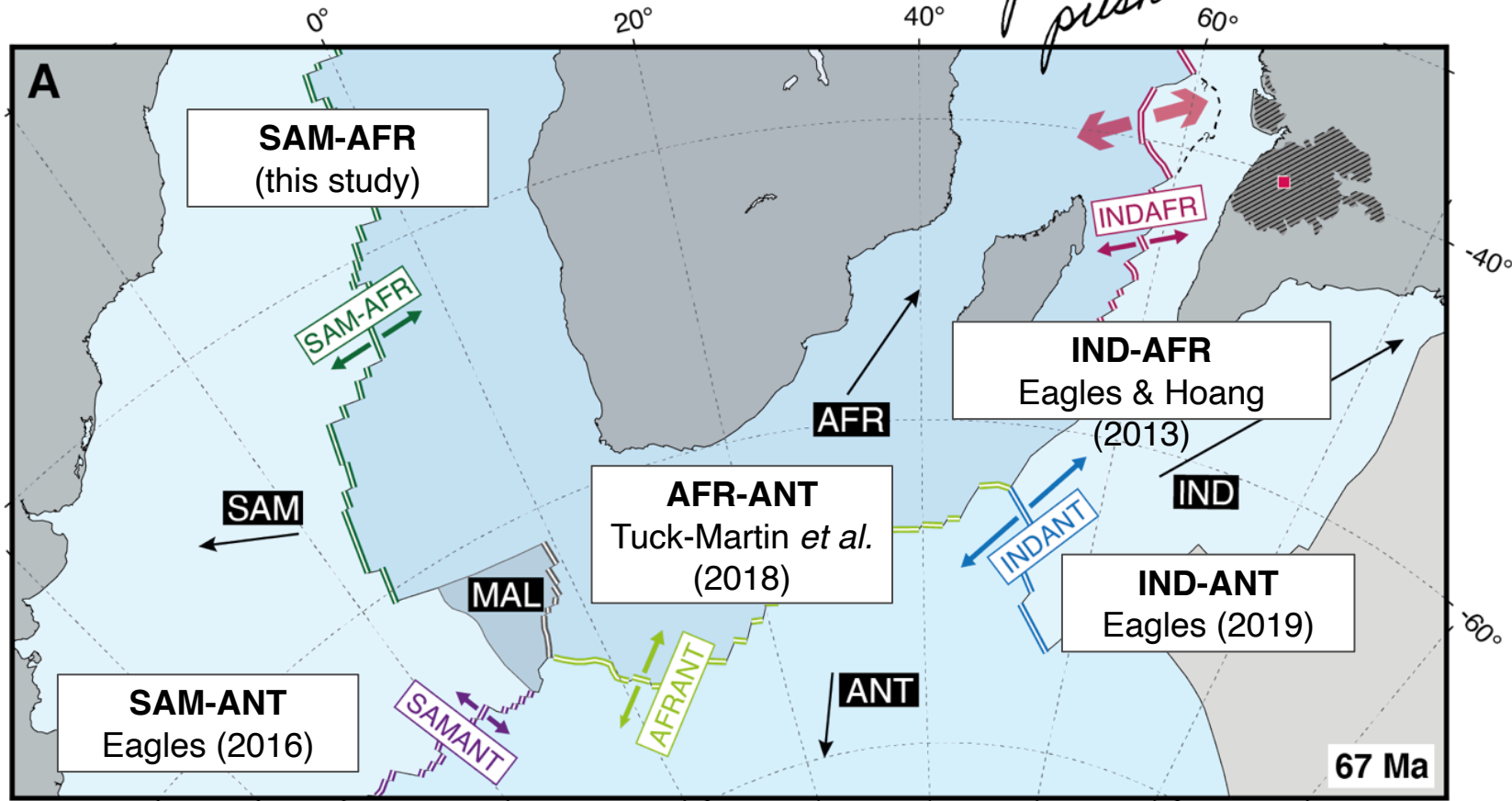
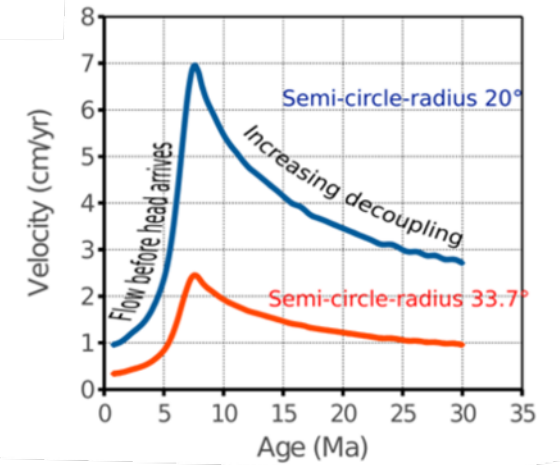
introduce a significant plate driving force to synchronously retard Africa's northeastwards progress over the mantle whilst enhancing India's?



Our test uses existing and new high-resolution models of relative plate motion records from five divergent plate boundaries around Africa and India and **concludes there is no signal consistent with a plume push force** before, during, or after the Deccan event.



The test:



Speed of two model plates under tangential plume push forces
(CitcomS model presented by van Hinsbergen *et al* 2011; doi:10.1029/2010JB008051)

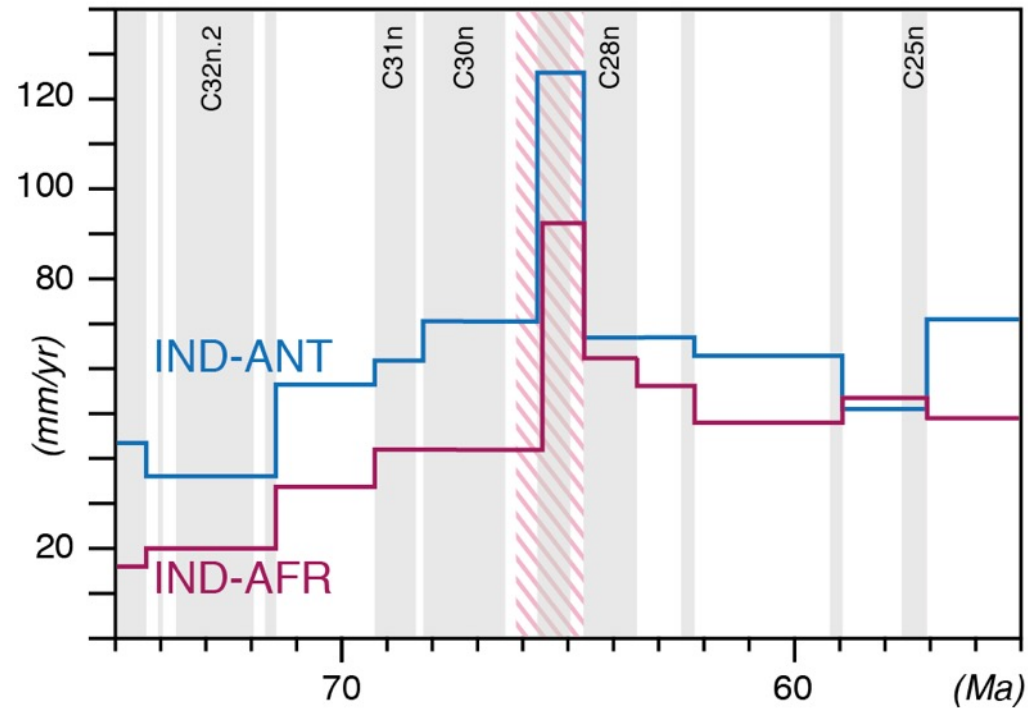
Late Cretaceous: Synchronous sharp-onset INDAFR & INDANT accelerations and AFRANT & SAMAFR decelerations as plume rises in upper mantle

Paleogene: synchronous longer-period decay (i.e. INDAFR & INDANT deceleration and AFRANT & SAMAFR acceleration) as plume material suffuses away at base of lithosphere

(+) Regional plate boundary reorganisations / tectonic events

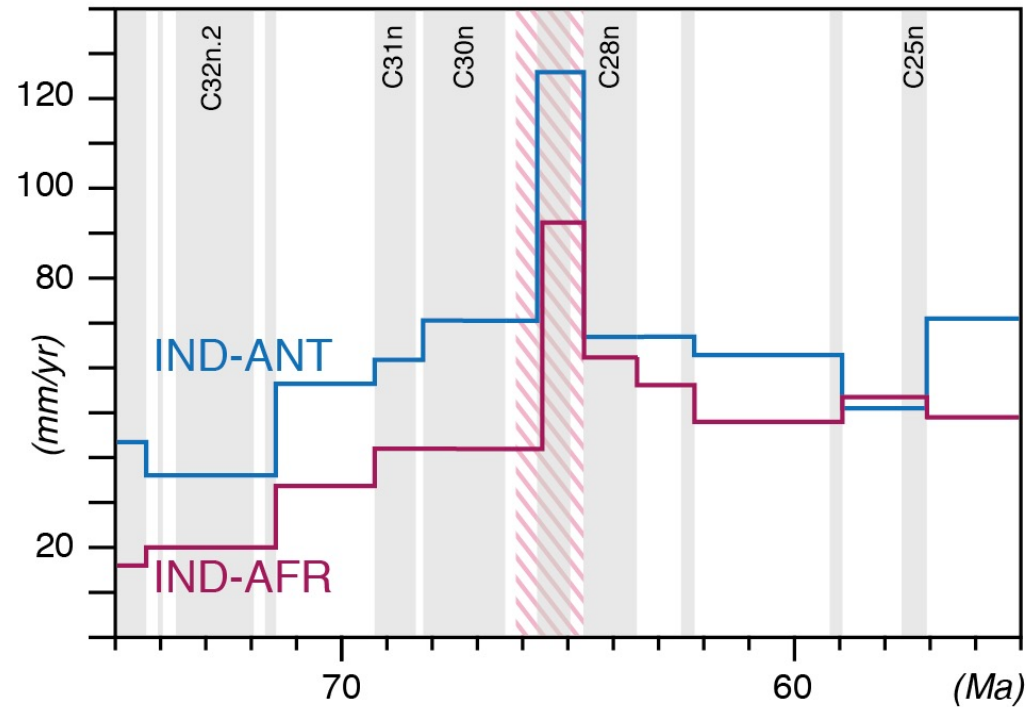
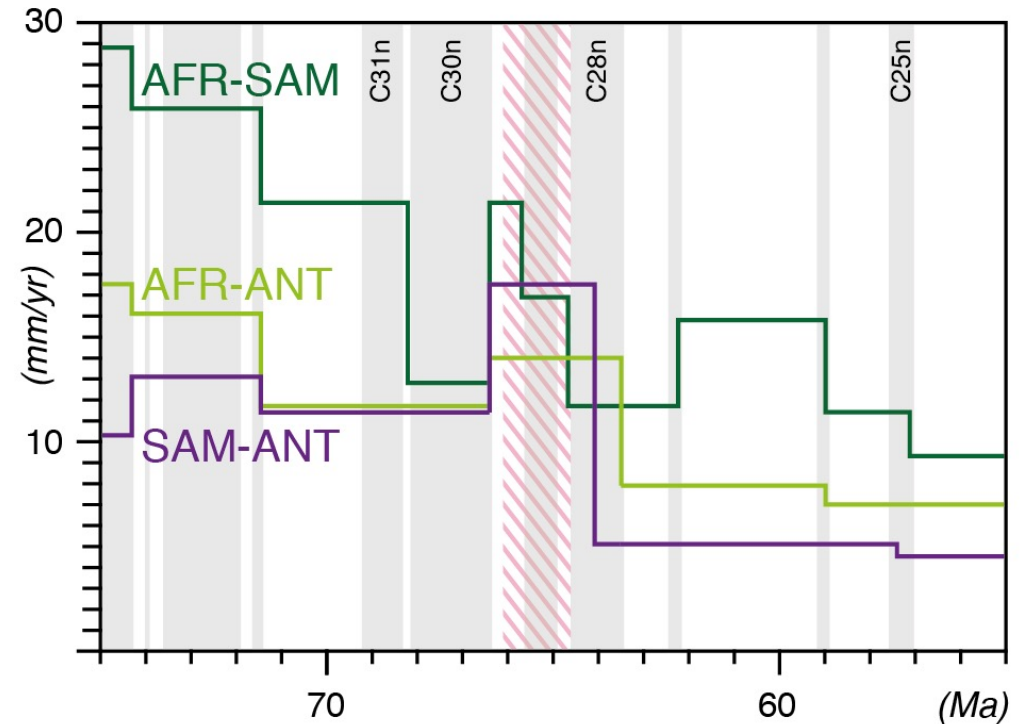
Expected plume-push signals in the models

Results: Modelled spreading rate changes through late Cretaceous and into Paleogene



As previously suggested, a short-lived divergence rate spike does indeed occur for the IND-AFR and IND-ANT plate pairs at ~65 Ma (the time of plume arrival)...

Results: Modelled spreading rate changes through late Cretaceous and into Paleogene

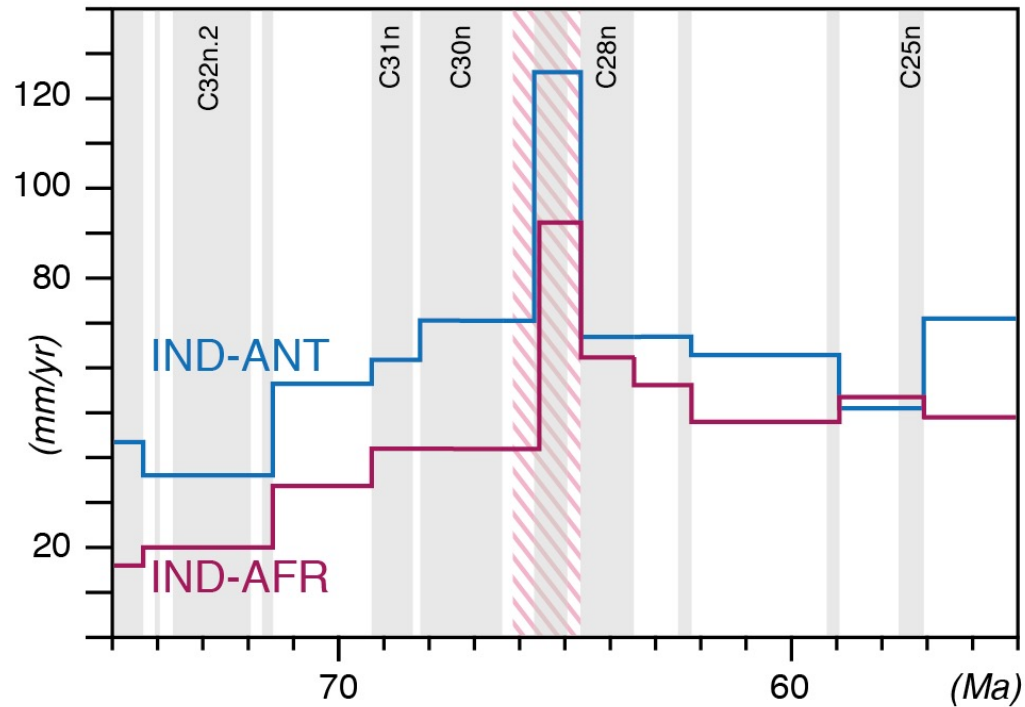
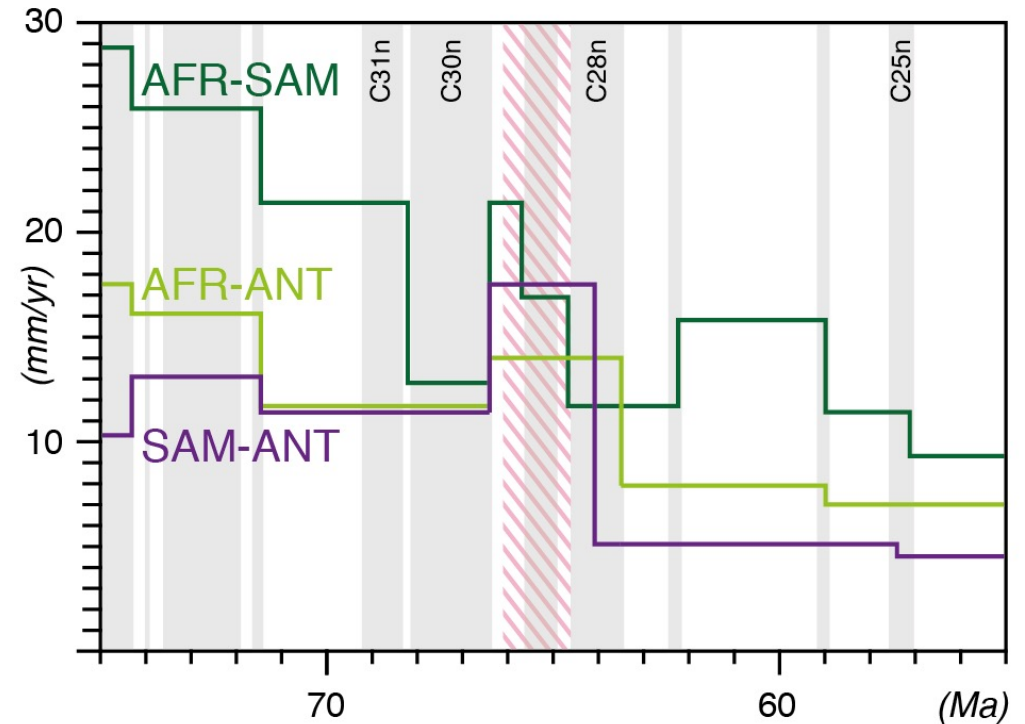


As previously suggested, a sharp-onset divergence rate spike does indeed occur for the IND-AFR and IND-ANT plate pairs at ~65 Ma (the time of plume arrival)...

...but it coincides with similar divergence rate increases between every other plate pair! The expected synchronous decreases do not occur on SAM-AFR or AFR-ANT – or indeed anywhere in the circuit!

... and most of the spikes do not give way to long-period decays during Paleogene times

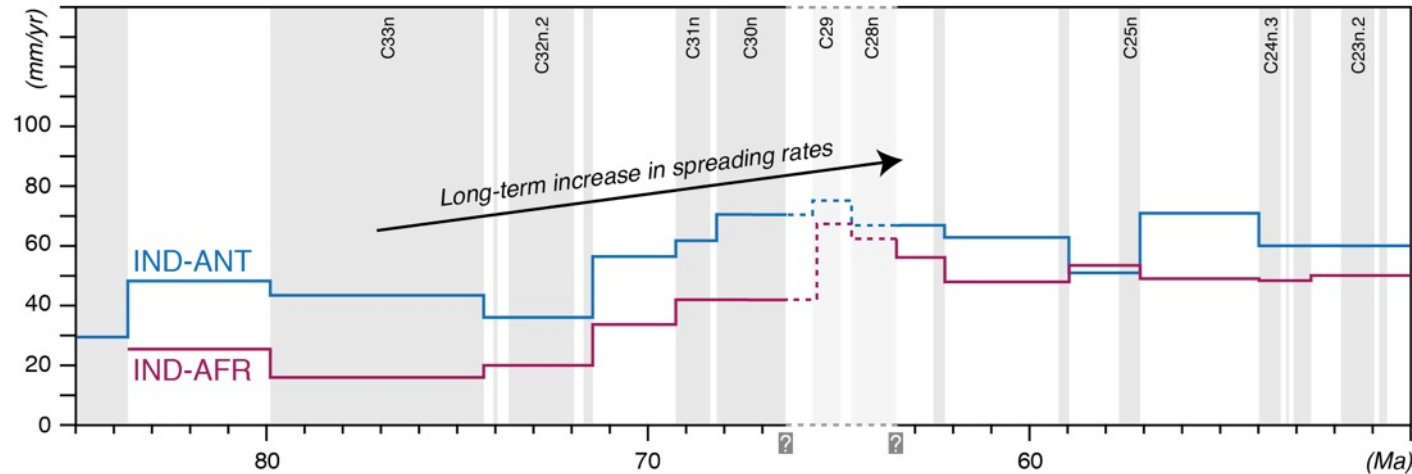
A different explanation for the observed variability:



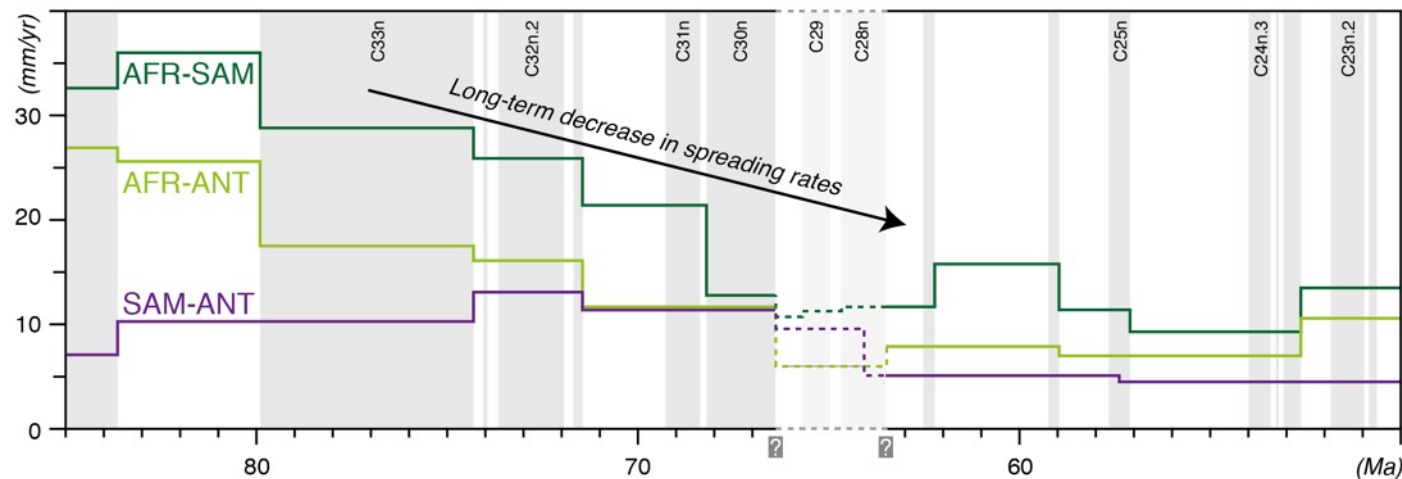
Starting hypothesis: Synchronous occurrence of a pulse of superfast spreading with the maximum of Deccan flood basalt volcanism links the onset of ~~India's fast motion to the Réunion plume head.~~

The ubiquitous spreading rate spikes are more plausibly **artefacts of timescale error** around the K-Pg boundary

Results: divergence rates corrected for the average acceleration (i.e. the 'spurious' signal) on all five divergent plate boundaries



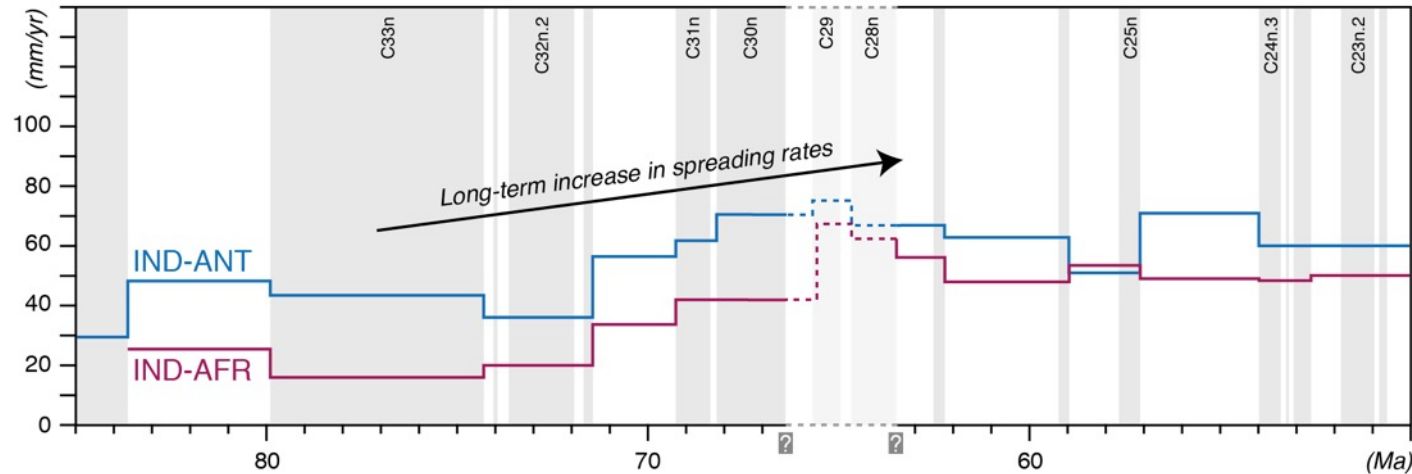
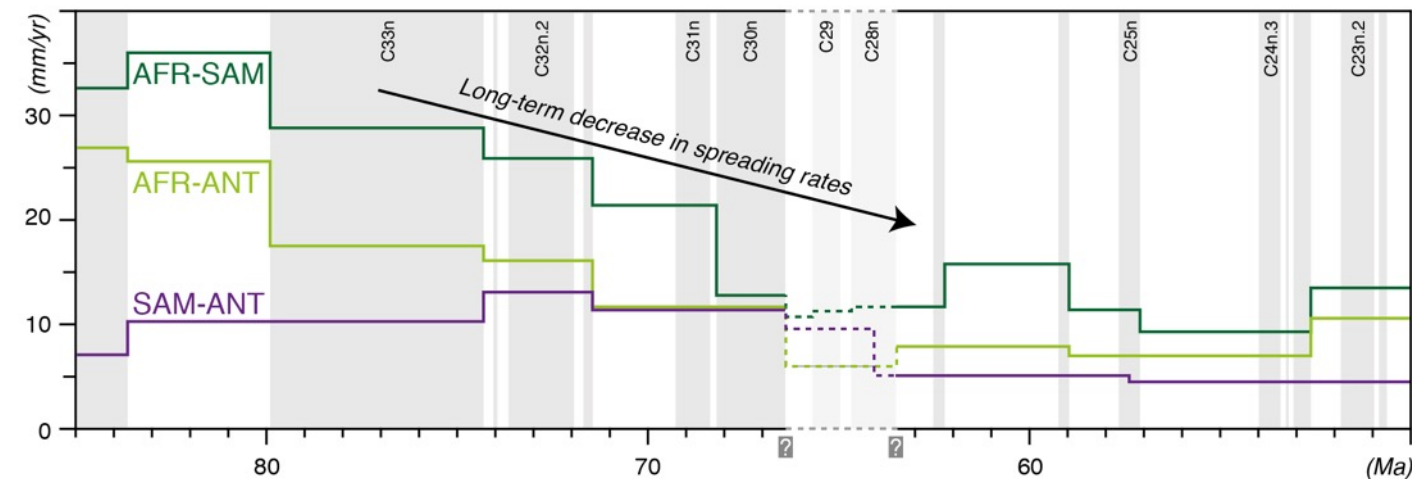
Starting hypothesis: the introduction of a plume-push force from the Deccan-Réunion at 67 Ma led seafloor spreading rates on the southern and western margins of the Indian plate to accelerate



and on the southern and western margins of the African plate to decelerate.

>> plume related???

Results: divergence rates corrected for the average acceleration (i.e. the ‘spurious’ signal) on all five divergent plate boundaries



Starting hypothesis: the introduction of a plume-push force from the Deccan-Réunion at 67 Ma led seafloor spreading rates on the southern and western margins of the Indian plate to accelerate

and on the southern and western margins of the African plate to decelerate.

~~>> plume related???~~

more consistent with **gradual changes to the African torque balance** by the maturing IND-AFR ridge.

No room for the plume

“The synchronous occurrence of a pulse of superfast spreading between 66 and 63 Myr ago with the maximum of Deccan flood basalt volcanism links the onset of India’s fast motion to the Réunion plume head.” (Cande & Stegman, 2011).

We show that...

Contemporaneous **spreading pulses** are recorded by data across the entire Indo-Atlantic plate circuit...

... best explained as artefacts of a timescale error affecting C29-C28

Anticorrelating spreading rates (accelerating in the Indian Ocean / decelerating in the South Atlantic) exist for a period starting long before plume arrival...

... and can easily be explained by the rebalancing of African torques resulting from a maturing IND-AFR ridge

