



Animated reconstructions of the Late Cretaceous to Cenozoic northward migration of Australia, and implications for the generation of east Australian mafic magmatism: COMMENT

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INTRODUCTION

Chains of shield volcanoes in eastern Australia define a broad north-south trend that roughly parallels the Tasmanid and Lord Howe seamount chains in the Tasman Sea. Both the seamount chains and the shield volcanoes young to the south, and both have been interpreted as hotspot volcanoes on a north-drifting Australian plate (Wellman and McDougall, 1974; McDougall and Duncan, 1988; Cohen et al., 2007; Sutherland et al., 2012; Davies et al., 2015). A change in the age distribution of the shield volcanoes during the early Miocene and a corresponding deflection in the trends of the seamount chains were attributed by Knesel et al. (2008) to a reduction in the rate and a change in the direction of Australian plate motion caused by its collision with the Ontong Java Plateau. In their paper, Jones et al. (2017) examined changes in the significance of the age and direction trends of the eastern Australian shield volcanoes by comparing them to predictions for the absolute motion of the Australian plate defined by two competing apparent polar wander paths (APWPs) and the global moving hotspot reference frame (GMHRF) of Doubrovine et al. (2012). We believe that significant errors have been made in the plate motion analysis, expressed as inconsistencies within and between their figures 10 through 13, which also invalidate the second of their two animated reconstructions for Australian plate motion. Our concern that these invalid reconstructions might form the basis for future studies motivates our commentary on their paper. Jones et al. also contributed new ⁴⁰Ar/³⁹Ar ages for shield volcanoes and lava fields in Queensland, and we raise no issues with these data or their interpretation.

PLATE RECONSTRUCTION ERRORS

Errors in Calculation of Synthetic APWP

In their figure 10, Jones et al. showed a synthetic APWP calculated from the GMHRF. Doubrovine et al. (2012) provided a list of corresponding finite reconstruction Euler poles for the Australian plate at 10 m.y. intervals in table S3 of their auxiliary material. Rotating the geographic South Pole around each of these finite poles (but in the opposite sense to the reconstruction)

defines the synthetic APWP for the GMHRF, and we presume that Jones et al. attempted this or a similar procedure, but we cannot reproduce their results (our Table 1 and Fig. 1). The inconsistencies, in general, increase as the age of the poles increases, and instead of the relatively uniform rate of APWP implied by the GMHRF between 60 and 30 Ma, the Jones et al. poles suggest a sharp reduction in the rate of apparent polar wander between 40 and 30 Ma.

Conversion of APWPs to Plate Motion

In their figure 11 (Fig. 2 in this commentary), Jones et al. purported to show contrasting reconstructions of the movement history of an arbitrary point in eastern Australia according to the GMHRF and the APWPs of Embleton and McElhinny (1982) and Idrnurm (1985). This can be done validly for the GMHRF, using the Doubrovine et al. (2012) finite reconstruction poles, and the Jones et al. figure shows correct positions for the motion history according to the GMHRF model. Reconstructing motion of a point on a plate defined only by an APWP is another matter, however. Paleomagnetic poles, and APWPs derived

TABLE 1. COMPARISON OF GMHRF SYNTHETIC PALEOMAGNETIC POLES

Age (Ma)	Reconstruction pole			Jones et al. (2017)*		This commentary [†]	
	Latitude (°N)	Longitude (°E)	Angle (°)	Latitude (°N)	Longitude (°E)	Latitude (°N)	Longitude (°E)
10	-17.57	-140.65	6.75	-82	129	-83.5	130.4
20	-18.51	-144.95	13.55	-77	125	-77.2	127.2
30	-18.96	-145.08	20.66	-69	124	-70.5	128.3
40	-22.21	-147.68	25.82	-67.5	122	-66.1	127.3
50	-23.14	-141.87	27.37	-62.5	128	-64.9	133.6
60	-25.21	-136.60	30.01	-59.5	133	-62.9	139.6

Notes: GMHRF—global moving hotspot reference frame (Doubrovine et al., 2012). Reconstruction pole shows latitude, longitude, and counter-clockwise angle of rotation for Euler pole required to restore Australia to its position in absolute coordinates at the corresponding age.

*Our estimate of the position, from the figure 10 of Jones et al. (2017).

[†]Should be identical to Jones et al. (2017) pole.

from them, are fixed only with respect to the Earth's spin axis. They constrain paleolatitude and orientation of points on the plate, but not longitude. While a set of reconstruction poles can be calculated that will restore each mean virtual geomagnetic pole (VGP) on a path to the geographic pole, these are not unique; the range of allowable reconstruction poles corresponds to the longitudinal indeterminacy of a single paleomagnetic pole, and constitutes a continuous suite of points arranged along a great circle forming a perpendicular bisector to the great circle joining the VGP and geographic pole. Jones et al. were not explicit in their description of how their reconstructions were derived from the APWPs, but they noted that the operations were performed in the software package GPlates (<https://www.gplates.org/>). GPlates includes a routine for calculation of a reconstruction pole to restore a VGP to the geographic pole, but this restricts the latitude of the reconstruction pole to 0°, thereby reducing the solution to a single point. Completing the determination of the full reconstruction pole corresponding to the VGP is accomplished by a second step, as noted in a tutorial provided on the GPlates web site, in which the reconstructed plate is rotated around the geographic pole until the longitude of independently known points on the plate is correctly restored; the composition of the second and first rotations yields the true reconstruction pole. Failure to carry out the second step will yield plate reconstructions that place points at their correct latitude and orientation, but with an error in longitude.

We cannot definitively test how Jones et al. produced their reconstructions from the APWPs, owing to uncertainty about their method of interpolating ages (see below), but we suspect that they may have used only the first, in-built routine for calculating a VGP reconstruction, without recognizing the significance of the resulting indeterminacy of longitude. We note that in their figure 11A, the reconstructed point tracks derived from the two APWPs roughly cluster, but are displaced in longitude from the (correctly determined) track derived from the GMHRF, and that in figure 11B, which plots only latitude against age, all three tracks roughly cluster together. Longitude appears to have been incorrectly determined for the tracks derived from the APWPs, bringing into doubt the reconstruction poles used. Given these concerns, the animated reconstruction shown in their second animation, which incorporates the reconstruction poles for the Embleton and McElhinny (1982) APWP, must also be questioned.

Inconsistencies within Their Figure 11

Leaving aside concerns with how the reconstructions were generated, the latitude of the 50 Ma reconstruction point for the “Embleton” APWP in their figure 11A is inconsistent with its latitude in their figure 11B, which suggests a much smoother progression in latitude between 60 and 40 Ma. Indeed, the closeness of the 40 and 50 Ma points in figure 11A has no obvious explanation, other than error. Likewise, the relatively uniform spacing between the 50, 40, and 30 Ma points on the GMHRF track in their figure 11A does not agree with the very sharp reduction in apparent polar wander between 40 and 30 Ma implied by the synthetic poles for the GMHRF in their figure 10.

INCONSISTENCIES IN CONSTRUCTIONS OF APWPs

Construction of the “Longitudinal” (Embleton and McElhinny, 1982) APWP Motion Model

Jones et al. did not make it clear how they constructed their motion model from the Embleton and McElhinny (1982) APWP. They refer to the “dotted line” path in their figure 3B (in fact, a series of running means of scattered, undated poles from laterites and weathered profiles calculated by Embleton and McElhinny) as a “final product” that they use in their reconstruction, but the points defining this path were not assigned ages by Embleton and McElhinny, and it is difficult to see how these undated points could be quantitatively included in a reconstruction model. In the text, Jones et al. listed a series of seven dated poles purportedly compiled by Embleton and McElhinny. Of these, poles at 15, 25, 30, 50, and 60 Ma are described as being “from a corrected lateritic profile (Embleton, 1981)” (Jones et al., 2017, p. 466). In fact, Embleton (1981) did not directly assign ages to the laterite data, either before or after smoothing; rather, he approximately calibrated the age of the path defined by the smoothed laterite and weathered profile data by including

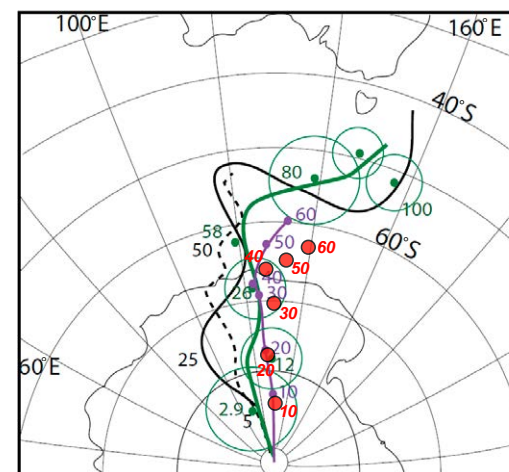


Figure 1. Reproduction of figure 10 of Jones et al. (2017), to which we have added our calculation of the synthetic apparent polar wander path derived from the global moving hotspot reference frame (GMHRF; Doubrovine et al., 2012) (red dots, with ages in Ma), for comparison with their calculated path (in purple, with ages in Ma); the two should be identical. Note the closeness of the 30 and 40 Ma poles in the Jones et al. version. Black line symbols show the apparent polar wander path (APWP) determined from smoothing of laterite and weathered profile data by Embleton (1981) (solid line) and Embleton and McElhinny (1982) (dashed line), with approximate positions of mean igneous poles for 5, 25, and 50 Ma. Green line pole positions, and confidence circles represent the APWP and dated poles of Ildnum (1985).

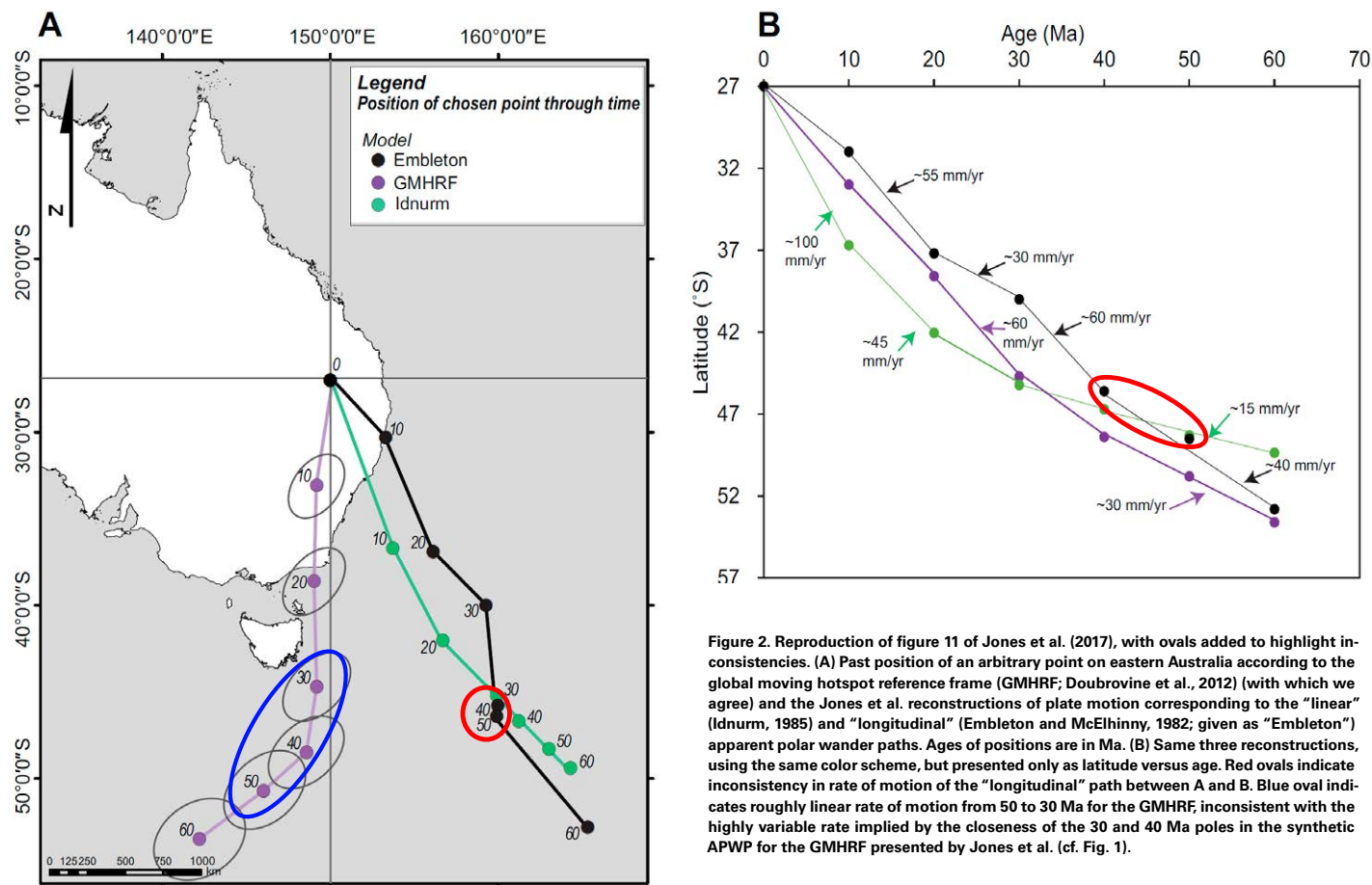


Figure 2. Reproduction of figure 11 of Jones et al. (2017), with ovals added to highlight inconsistencies. (A) Past position of an arbitrary point on eastern Australia according to the global moving hotspot reference frame (GMHRF; Doubrovine et al., 2012) (with which we agree) and the Jones et al. reconstructions of plate motion corresponding to the “linear” (Idnum, 1985) and “longitudinal” (Embleton and McElhinny, 1982; given as “Embleton”) apparent polar wander paths. Ages of positions are in Ma. **(B)** Same three reconstructions, using the same color scheme, but presented only as latitude versus age. Red ovals indicate inconsistency in rate of motion of the “longitudinal” path between A and B. Blue oval indicates roughly linear rate of motion from 50 to 30 Ma for the GMHRF, inconsistent with the highly variable rate implied by the closeness of the 30 and 40 Ma poles in the synthetic APWP for the GMHRF presented by Jones et al. (cf. Fig. 1).

independently determined mean poles derived from primary magnetizations from dated igneous rocks, with mean ages of 5, 25, and 50 Ma. How Jones et al. derived their additional 15, 30, and 60 Ma poles is not explained, although if they do come from the Embleton and McElhinny compilation, they presumably correspond to the poles with approximately corresponding ages, namely the Nandewar volcano (given as 17.5 Ma), Liverpool volcano (33.7 Ma), and (with an inappropriately old age) the combined Eocene basalts (60–40 Ma) poles. However, Embleton and McElhinny clearly indicated that data yielding these three poles were included in their 25 and 50 Ma means, so these do not constitute independent, additional constraints. The other two poles, at 4.5 and 22 Ma, would appear to correspond to poles listed for 4.5–0 Ma (younger basalts pole of Aziz-ur-Rahman [1971]) and 24–20 Ma (Tweed and Main Range pole of Wellman [1975]) in both the Embleton (1981) and Embleton and McElhinny

(1982) compilations. Again, the 24–20 Ma pole is not independent, but was incorporated in the mean for the 25 Ma calibration pole in the Embleton (1981) and Embleton and McElhinny (1982) compilations.

This suite of dated poles shows considerable scatter (see Musgrave, 1989)—indeed, the smoothed laterite path was presented by Embleton and McElhinny to demonstrate a lack of significant longitudinal motion in the Australian APWP and to argue therefore that the dated poles were not reliable as individual constraints on the path. Musgrave (1989) showed that, when both scatter of these dated poles and weighting based on their precision were taken into account, the most complex age model that could be justified on the basis of the paleomagnetic poles alone is a linear fit of age against distance along the APWP. Given this background, use of these poles to constrain stage rotations for the Australian plate is unwarranted. If the smoothed laterite path shown in figure

3B of Jones et al. was indeed used to constrain the scatter in the dated poles, how were the igneous and laterite data combined? Were the dated igneous poles assigned in some way to positions on the smoothed laterite path? Or were the dated poles used to directly generate reconstruction rotations, without direct regard to the smoothed laterite path, on the false assumption that they already embodied the “improved fit” seen in the smoothed path? There is insufficient detail in the methodology given by Jones et al. to answer these questions, but given the limitations of the dated poles, the complex changes in rates of motion shown for the “longitudinal” APWP cannot be justified.

“Longitudinal” Form of the Embleton and McElhinny (1982) APWP

Jones et al. distinguished between the Idnurm (1985) APWP, which they described as “linear”, and the Embleton and McElhinny (1982) path, which they termed “longitudinal”, presumably on the basis of the sinuous track followed by the “solid line” path shown in their figures 3 and 10 and the “westward diversion” they noted in the Miocene. This path was, however, not taken from Embleton and McElhinny (1982), as cited by Jones et al., but rather from Embleton (1981). This “solid line” path and the “dotted line” path of Embleton and McElhinny (1982) are both smoothed paths derived from the same set of undated laterite and weathered profile VGPs, but differ in the method and degree of smoothing. By the time of their 1982 paper, Embleton and McElhinny had rejected the apparent sinuosity in the laterite path and the scatter seen in the dated igneous poles as artifacts of noise, and the smoother “dotted line” laterite path was produced to emphasize this point; in fact, the two paths appear together only in a figure in Musgrave (1989). Indeed, all subsequent versions of the Australian APWP, including those of Musgrave (1989), Idnurm (1985, 1994) and Schmidt and Clark (2000), show the trajectory of the path as essentially linear along the 120°E meridian back to at least 40 Ma, with differences between the paths largely limited to the distribution of age. Given this, the contrast between a “linear” and a “longitudinal” APWP is meaningless.

CONCLUSIONS

The central premise of the Jones et al. paper appears to be incorrect: there is in reality no “longitudinal” alternate path for the Australian post-Mesozoic APWP, and the apparent sinuosity seen in the laterite curve presented in Embleton (1981) was already recognized as an artifact of poor-quality data in the Embleton and McElhinny (1982) paper that Jones et al. cited as the basis for their analysis. In addition, while a lack of detail about methodology makes it hard to be definite, the inconsistencies and errors in the reconstructions shown in their figures 10 and 11, and the unclear and inconsistent description and use of previous paleomagnetic compilations, lead to a strong suspicion that the reconstruction rotations generated in this paper are largely invalid. We

would caution against any use of or reliance on these reconstruction poles, or on the derived plots and plate motion animation.

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