Earthworks

- global thinking in exploration geoscience

Research Update No. 21, July 2022

A pragmatic mantle-plume reference frame for Gondwana dispersal

Model CR22BBBI

(and CR22ABBH – Africa fixed)

1. How precise can we be?

While acknowledging published work on the topic (Schettino & Scotese, 2005; Doubrovine et al., 2012; more?) we have developed independently a mantle-plume reference frame that satisfies both the geological evidence and our particular geometrical model of Gondwana re-assembly and dispersion. We note that the central location of any plume head will be ill-defined since its effect, at the time of a plume strike at least, is often recorded a thousand km or more distant from its notional centre and that any local geological expression of eruption or extrusion is likely to be influenced by pre-existing crustal structure in the area at the scale of hundreds of kilometres. By the same token, a second error of this magnitude may well be introduced by assuming that the present-day expression of a plume head (e.g. an isolated oceanic island) is truly representative of the plume's centre of activity over its entire lifetime.

2. Three key plumes: Bouvet, CAMP and Kerguelen

Our argument starts with the assertion that the present-day Bouvet plume (centred on Bouvet Island in the southern South Atlantic Ocean) is one and the same plume that caused the widespread 'Karoo' igneous episode at 182 +/- 1 Ma (Cox, 1988; more recent refs?) in southern Africa with a centre off southernmost Mozambique and the Ferrar igneous events in Antarctica (ref). We identify its subsequent track on the Africa plate by the extrusive rocks of the Mozambique Ridge/Rise, 125-130 Ma (ref) and the Agulhas Bank (100 /Ma, ref). A smooth curve through these points shows Africa moving NE at an average rate of about 18 km/myr since 183 Ma. This trail differs by only a few hundred km from the curve of Doubrovine et al. (2012) for the interval 0-124 Ma, which was based on a global analysis of hotspot trails that appears not to include Bouvet. We have arbitrarily extended the track back to 300 Ma at which time we place the (future) Bouvet plume head in the vicinity of the present-day Lake Malawi, placing southern South America, southern Africa and Antarctica in high southern latitudes with the south geographic pole in West Antarctica at the end of Carboniferous times.

A second (or third) plume trail is necessary to orient Africa as a whole with reference to this Bouvet trail. For this purpose we have employed the CAMP and Kerguelen plume heads at the NW and SE extremities of reassembled Gondwana respectively. The 200 Ma outbreak of the CAMP plume should fall in the vicinity of the triple junction North America-Africa-South America. We have pivoted Gondwana about the Bouvet plume at this time to make this happen.

With this configuration, the (future) Kerguelen plume head is located below the Great Australian Bight at 200 Ma. Australia within reassembled Gondwana then moves slowly eastwards until the Kerguelen plume approaches the India-Australia-Antarctica triple point at about 140 Ma. This places the Kerguelen plume head within a few hundred km of the Bunbury Basalts (125 Ma) in Australia and the Rajmahal Traps (115 Ma) in India as well the subsequently-developed Broken Ridge (Australia plate) and the Kerguelen Plateau (Antarctica plate) more generally.

The traces of the plume-head location for each of these three plumes is indicated at intervals of 10 myr in Figure 1 for each of the three continents that departed from the initial plume location. Figure 1 may be seen as an animation for the period 200-0 Ma at: https://www.reeves.nl/gondwana/large-igneous-provinces/. In addition, the output making up the large igneous provinces for all Gondwana plumes is shown in the figure. A position for the Kerguelen plume about 450 km west of Kerguelen itself would follow the Ninety-East Ridge more precisely but the remainder of the igneous record is well reproduced. The Kerguelen plume below the India plate follows the trace of the Investigator FZ,

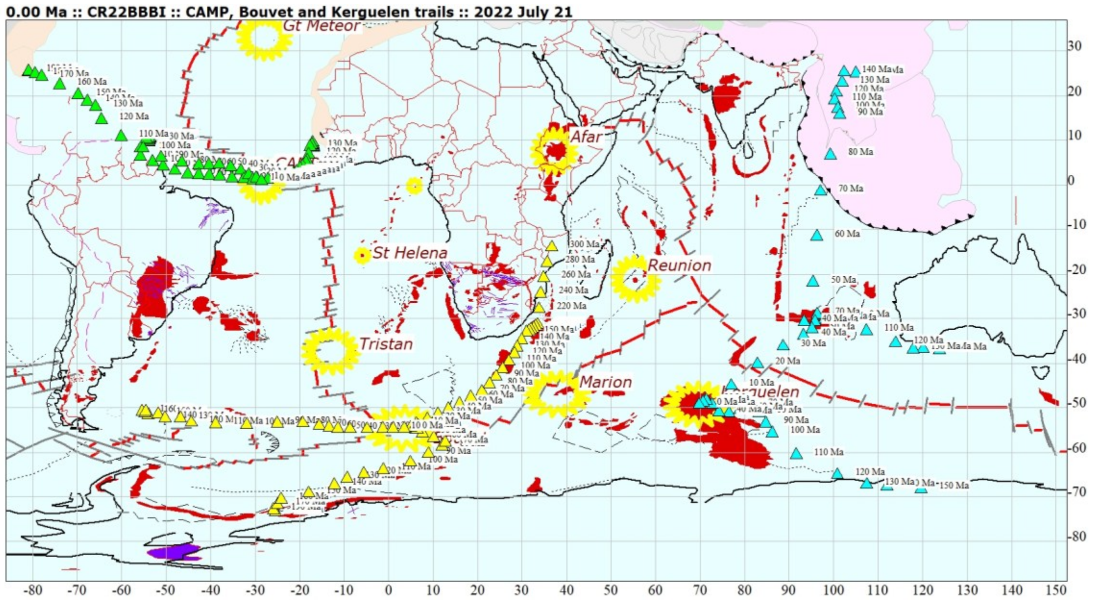

Figure 1. *The trails of the CAMP (green triangles), Bouvet (yellow triangles) and Kerguelen (blue triangles) plume-heads with respect to the continents departing from their respective triple junctions since 200 Ma at intervals of 10 myr. The main volcanic edifices attributable to plume activity are shown in reddish-brown. This figure may be seen in animation at: https://www.reeves.nl/gondwana/large-igneous-provinces/*

one of two big transform offsets in the India-Australia spreading system active from 100 Ma to 45 Ma. The trails of the Tristan, Marion and Reunion plumes are all within the likely errors mentioned above, as well as the St Helena, Cameroon line and Afar events. The finite Euler rotations for Africa with respect to our reference frame are given in Table 1.

3. Africa and Antarctica in this reference frame

Figure 2 shows the movement of Africa with respect to our fixed mantle plume reference frame for the period 200 Ma to the present day. Note that there is a steady movement towards the NE, the eastern coast of Africa (Kenya) lying about 3500 km distant from the equator at 200 Ma, the west coast (Gabon) about 2500 km distant. The rate of northward progress appears to be much slower before about 150 Ma. After this time it averages about 20 km/myr.

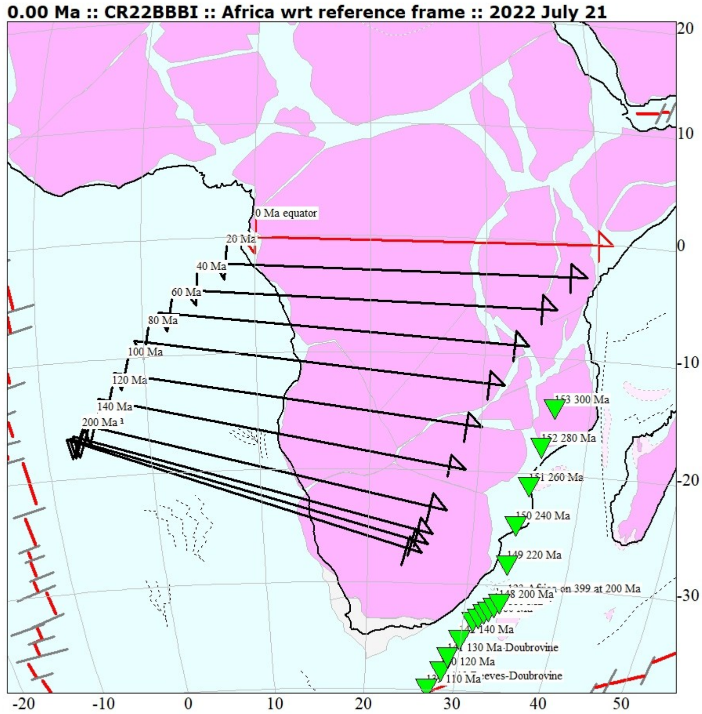

Figure 2. *The movement of Africa within the mantle-plume reference frame, 200 to 0 Ma. Black fiducials of the present-day equator (red) shown at intervals of 20 myr.*

The movement of Antarctica relative to Africa is central to our Gondwana dispersal model (Research Update No.20). Using our model we can now, therefore, predict the movement of Antarctica with respect to the mantle-plume reference frame in the interval 200-0 Ma. The result is shown in Figures 3a and 3b.

Figure 3(a) shows the position of a token for Antarctica at intervals of 20 myr from 200 to 0 Ma in the mantle reference frame. Here it is seen that the continent's movement may be divided into three distinct periods: (1) From 200 to 155 Ma the movement is minimal; (2) from 155 to 72.5 Ma there is rapid movement towards the south geographic pole; (3) after 72.5 Ma Antarctica once again holds its position with respect to the south pole fairly consistently, perhaps even within the limits of accuracy of our modelling.

Between 155 and 72.5 Ma the velocity of Antarctica's movement may again be divided into three phases: (1) 155 to 125 Ma, slow movement (23.4 km/myr); 125 to 100 Ma, rapid movement (48.7 km/myr) and (3) 100 to 72.5 Ma, renewed slow movement (27.0 km/myr) (Figure 3(b)). In all three

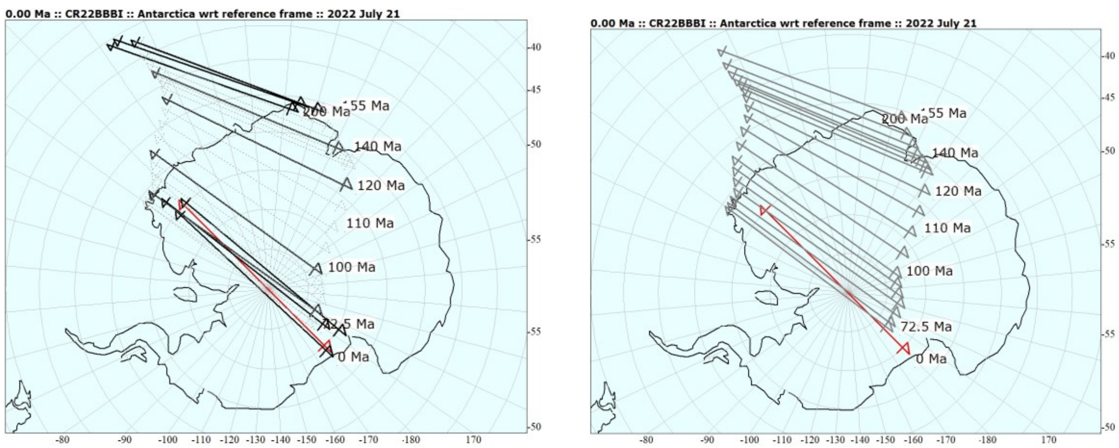

***Figure 3**. (a) Antarctica versus the global reference frame 200 to 0 Ma at intervals of 20 myr; (b) Antarctica versus the global reference frame 155 to 72.5 Ma at intervals of 5 myr.*

cases, movement is directed towards the south geographic pole. The rapid movement 125-100 Ma (Barremian, Aptian, Albian) coincides with the main ocean-growth-onset events of Gondwana dispersal.

4. Ridge push?

Figure 4 demonstrates that the rapid southward movement of Antarctica, 155-72.5 Ma, is mostly achieved by the growth of new ocean between the continent and the line joining the Bouvet, Marion and Kerguelen plume heads.

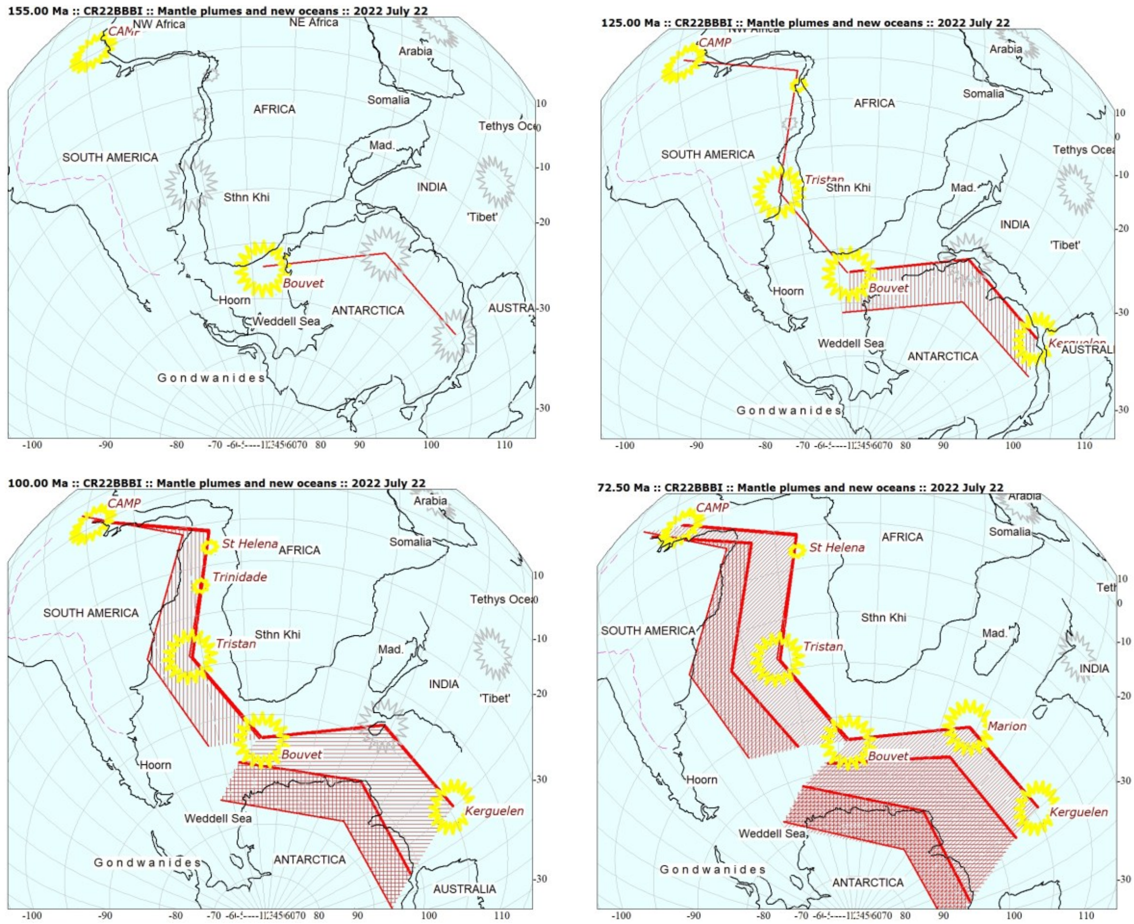

***Figure 4**. The absolute movement of Antarctica in the Late Jurassic and Early Cretaceous. (a) 155 Ma; (b) 125 Ma; (c) 100 Ma; (d) 72.5 Ma. For explanation, see text.*

At 155 Ma (Kimmeridgian - Figure 4(a)) the only ocean growth is a result of separation of East and West Gondwana, promoted by the activity of the Bouvet plume within the AAC. The future Kerguelen and Marion plumes lie below continental Antarctica.

By 125 Ma (Barremian – Figure 4(b)) the Kerguelen plume has become active and rifting, crustal extension and limited growth of new ocean has occurred between India and Antarctica-Australia.

By 100 Ma (Cenomanian – Figure 4(c)) the growth of new ocean between Antarctica and India is in full swing and the outbreak of the Marion plume is imminent.

By 72.5 Ma (Campanian – Figure 4(d)) the rate of displacement of Antarctica to the south has slowed and India departing the Kerguelen and Marion plumes has taken a more important role.

In the Equatorial and South Atlantic there is a parallel series of events happening at somewhat later times - South America moves away from the CAMP-Tristan-Bouvet plume chain. Before 125 Ma there is only limited rifting with ocean growth limited to the southernmost South Atlantic, facilitated there by articulation of platelets within southern South America and perhaps also within southern Africa. By 100 Ma, the mid-ocean ridge has become continuous through the South and Equatorial Atlantic and the direction of movement of South America is approximately normal to the mid-ocean ridge in the South Atlantic with South America putting distance between itself and the CAMP-Tristan-Bouvet plume constellation.

While the potential role of ridge push is evident for the movement of both Antarctica and South America in these intervals, there is also potential for slab-pull on the Pacific/Panthalassic margin of both continents.

CVR

2022 July 25

Table 1 (next page) revised 2025 July 28.

Table 1. (2022 July 25): Finite rotations, Africa versus Plume-Head Reference Frame

Model CR22BBBI

400	46.540	-40.880	139.310	9.000
400	72.500	-35.597	144.888	14.524
400	100.500	-32.108	141.884	20.008
400	150.000	-25.602	143.511	29.606
400	200.000	-23.455	147.324	32.508
400	380.000	-33.890	110.833	66.106

Table 1 (revised to 2025 July 28)

Finite Rotations, Africa versus plume-head reference frame

Model CR25BAKA

400	10.000	-40.880	139.310	1.950
400	20.000	-40.880	139.310	3.900
400	30.000	-40.880	139.310	5.850
400	40.000	-40.880	139.310	7.800
400	46.540	-40.880	139.310	9.000
400	72.500	-35.597	144.888	14.524
400	100.500	-28.461	145.638	21.691
400	130.000	-23.340	145.152	30.294
400	200.000	-14.554	146.585	41.021
400	270.000	-12.754	142.409	54.561
400	300.000	-16.161	135.487	61.424
400	340.000	-17.010	121.112	76.978

0.00 Ma :: CR25BAKA :: Mid-ocean ridges in a fixed reference frame :: 2025 July 28