Earthworks

- global thinking in exploration geoscience

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Some thoughts on plume-heads and fixed reference frames

Rotation model CR20ABJG

(CR20AAJG has Africa fixed)

The movement of any one continent has to be referenced to some other continental fragment and this has no direct relevance geometrically to any other pair of fragments. It follows that there is a hierarchy from the most important fragments to the least significant ones. Africa, as the heart of Gondwana, I have always taken as my starting point. The constituent fragments of Africa are mostly related to Africa (strictly Congo/438) directly, if not by way of some fragment lower in the chain (e.g. Seychelles to Madagascar and then Madagascar in its turn to Africa). In the same way, smaller fragments of South America are related to South America and hence to Africa, and so on. I have been looking again at Africa's relation to a fixed geographical reference frame that then impacts on the movement of all the fragments lower in the hierarchy. As usual, this has been a learning experience that provokes the few remarks that follow below, in no particular order.

A 'hotspot reference frame' is well-known and relates supposedly to a convection pattern in the earth's mantle that remains fixed with respect to the axis of rotation, i.e. the north and south geographical poles. This frame has limitations since the reference points it relies upon are only hotspot or (strictly speaking) plume-head trails left as volcanic islands and guyots on the oceanic crust. These appear to become better-focused as a plume ages but evidently impact over a large area (often more than 1000 km in diameter) when the plume first 'strikes'.

__Figure 1.__ Green dots (dated) show the trail of the Bouvet plume head at intervals since the Paleozoic with respect to Africa in model CR20ABJG. The shorter trail of Doubrovine et al. (2012) is shown by pale blue squares.

It must be imagined that crustal geology will have an important influence on precisely where, within this large area, the first manifestations of volcanicity appear and this may differ by hundreds of km from the locus of the older, mature and well-focussed plume head. A degree of uncertainty therefore exists.

The oldest well-defined and generally accepted plume trail is no older than about 130 Ma and is provided by the Walvis Ridge in the South Atlantic. This, I now believe, has its own idiosyncrasies (as, probably, do all the others). The trail of the Emperor plume, leading to the present day location of Hawaii, is perhaps the best-defined trail on earth (with its abrupt change of direction at about 43 Ma) but ocean older than about 80 Ma with the record of the trail before that time is already lost to subduction off Kamchatka.

Doubrovine *et al.* (2012) provide a careful analysis of evidence from all the world's plume trails to define a single global reference frame. Unfortunately, for the above reasons, this does not extend further back in time than 124 Ma and appears to be highly influenced by the Walvis Ridge track. Along with many other authors, they do not appear to recognise the central role of the Bouvet plume in Gondwana disruption and dispersal. In my modelling of Gondwana disruption I have found the position of the Bouvet plume (sometimes known as the Karoo or Nuanetsi/Mwenezi plume) to be of pre-eminent importance. It may be traced back to an initial plume strike off southern Mozambique at about 183 Ma and the widespread and

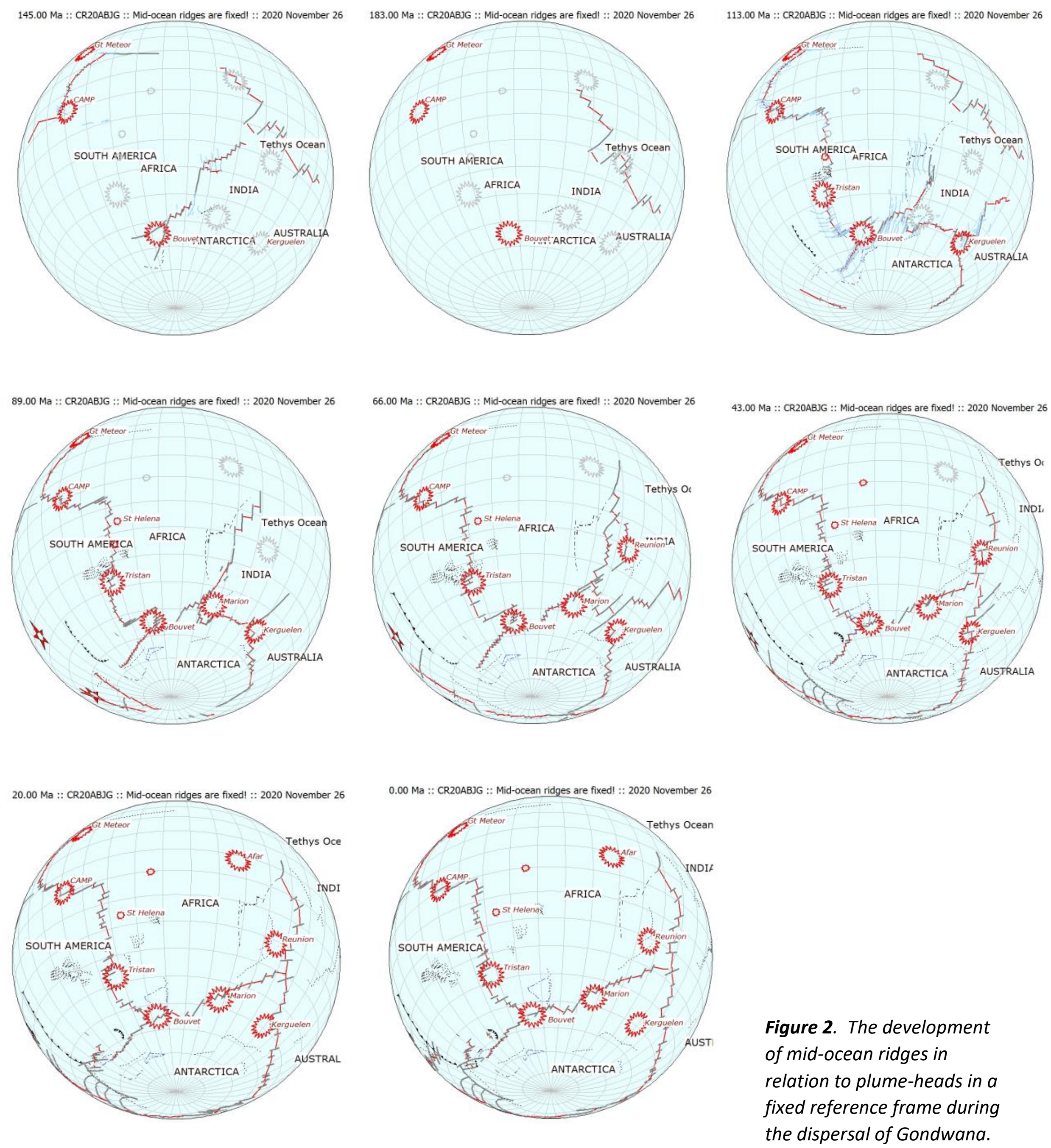

***Figure 2**. The development of mid-ocean ridges in relation to plume-heads in a fixed reference frame during the dispersal of Gondwana.*

punctual eruption of the Karoo basalts. My model presents a trail for the Bouvet plume head that strays by no more than a few hundred km from the reference frames proposed by others for later years. On the way it explains crustal extension between the Malvinas Plateau and the Maurice Ewing Bank (until about 140 Ma), the emplacement of the Agulhas plateau (at about 100 Ma) and, after tracking the Bouvet triple junction closely, to the present day location of Bouvet Island itself. This story lends a central theme to Gondwana disruption and therefore merits at least qualitative acknowledgement in the grand scheme of any reference frame.

The path of Africa with respect to the Bouvet plume in the fixed reference frame I have therefore adopted most recently is shown in Figure 1, alongside that for Doubrovine *et al.*(2012). Before 180 Ma, my path is defined by only paleomagnetic evidence which means that a greater level of uncertainty has to be accepted than simply the 1000 km diameter of the supposed plume head. Without paying a great deal of attention to this issue, I have adopted a position for Africa near the south geographic pole at about 300 Ma, corresponding to the widely-recognised position for Gondwana at the time of the Permo-Carboniferous glaciation (recorded at the base of the Karoo succession). It is now accepted that some ice-ages have engulfed the whole planet so this conclusion may be somewhat suspect. Nevertheless, it does represent a simple extrapolation into the past of Africa's more recent and long-lived travels towards the NE with a late Carboniferous geographic south pole lying in present-day east Africa (Figure 1).

Watching Gondwana dispersal in animation is rather convincing of a rather general observation: **Geodynamics is not so much about continents drifting as about oceans – or at least their mid-ocean ridges – staying fixed with respect to the plume-head reference frame.**

This is illustrated by a sequence of stills in Figure 2. I have arbitrarily adjusted the post-break-up position of Africa in reference-frame coordinates to ensure that the most obvious plume trails lie above the positions of their plumes at a number of key times. This is not precise but follows my philosophy of it being more important to be broadly correct (and prepared to improve!) than to be precisely wrong. With uncertainties of the order of 1000 km, it proved easy to be always approximately 'right', as illustrated (Figure 2).

The maps for 183 and 145 Ma in Figure 2 give reason to speculate that a much earlier period of activity of the Reunion and Afar plumes was responsible for Cimmeria rafting off the northern margin of Gondwana. Any thoughts?

Finally, satellite-based position fixing is now sufficiently precise

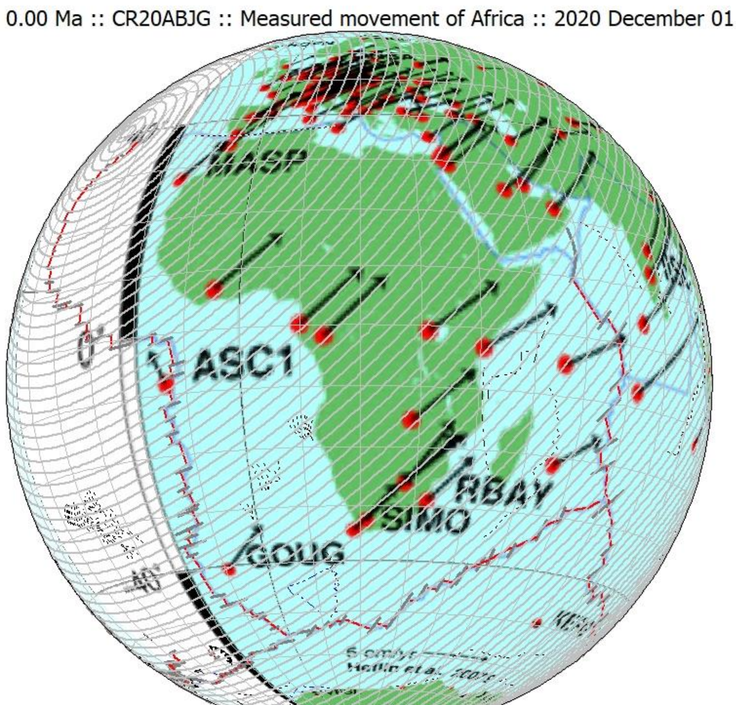

Figure 3. Small circles around the 0-46.54 Ma interval pole NW of Africa (grey) show the direction of movement of Africa with respect to a fixed reference frame. The arrows show the direction of movement from geodetic GPS measurements and their length the rate of measured movement. Agreement is good west of the Rift Valley but betrays a more easterly-directed movement to the east of it.

that the movements of continents can be measured directly from year to year using geodetic GPS techniques. It is natural to explore how the measured movements compare with those used in my geodynamic model. The earliest of these measurements shows that a limited number of stations on the Africa plate (Johannesburg, Dakar and Gough Island) are moving NE at 25, 28 and 28 mm/yr respectively (Drewes, 1998). Model CR20ABJG has these same points moving NE at a speed of 21.5, 11.7 and 21.7 km/myr, averaged over the past 46 myr. (NB 1 mm/yr ≡ 1 km/myr). Gough Island appears anomalous.

Figure 3 shows some more recent measurements (NASA: Heflin *et al*., 2007) at a larger number of stations in relation to the interval rotation pole (shown by Euler latitude lines on the globe) in model CR20ABJG for Africa against the fixed reference frame in the time between present day and 46.54 Ma. Note here that the GPS stations east of the East African Rift (including those in the western Indian Ocean) show a more easterly movement direction than the main body of Africa through present-day rift opening. Many more recent observations are now available (e.g. Prawirodirdjo & Bock, 2004) but I have been unable to find them in a format that is easily understandable or a map/figure that can be easily imported into Atlas.

Be aware, of course, that GPS motions refer only to present-day **instantaneous** plate rotations. It is a testimony to my assertion that such rotations remain approximately constant over long intervals (e.g. 45 Ma!) and it may therefore be appropriate to use **interval** poles (as opposed to the more commonly used **finite** poles) to describe plate motions in a way that tells us more about tectonics at plate boundaries during the interval to which they apply..

It is notable that Antarctica is currently *measured* to be rotating very slowly about a fixed point in the reference frame somewhere between Kerguelen and Enderby Land and so displays very little movement at all at the present time in the vicinity of this point.

Colin Reeves

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