The creation of the African margins and the Mesozoic demise of Gondwana

Colin Reeves, Earthworks & **Jon Teasdale**, Geognostics
reeves.earth@planet.nl

New marine magnetic anomaly data (Mueller and Jokat, 2019) and our repeated iterations within a set of plate tectonic working constraints have led to further refinements of our Gondwana disruption model. Early Jurassic rifting led to initiation of the East Africa margin in the Turonian, starting at 182.7 Ma – the first Gondwana disruption event (GDE-1). After about 25 myr (i.e. by 157.5 Ma) the way was clear for north-south (i.e. largely strike-slip) movement between East and West Gondwana that was to prove long-lived. Within the Africa-Antarctica corridor (AAC), we recognise a minor but significant deviation from this direction over a 6 myr interval (135-129 Ma, Valanginian to Barremian). This 'sidestep' was wrongly attributed to the early Aptian by Reeves (2017). The sidestep was (a) the culmination of Madagascar+India beginning to separate from Antarctica+Australia and (b) the start South America breaking out from the eastern margin of Africa in the northern part of the South Atlantic. We call this the second Gondwana disruption event (GDE-2). By 129 Ma, 12 000 km of new proto-ocean was continuous all the way from West Africa to Australia.

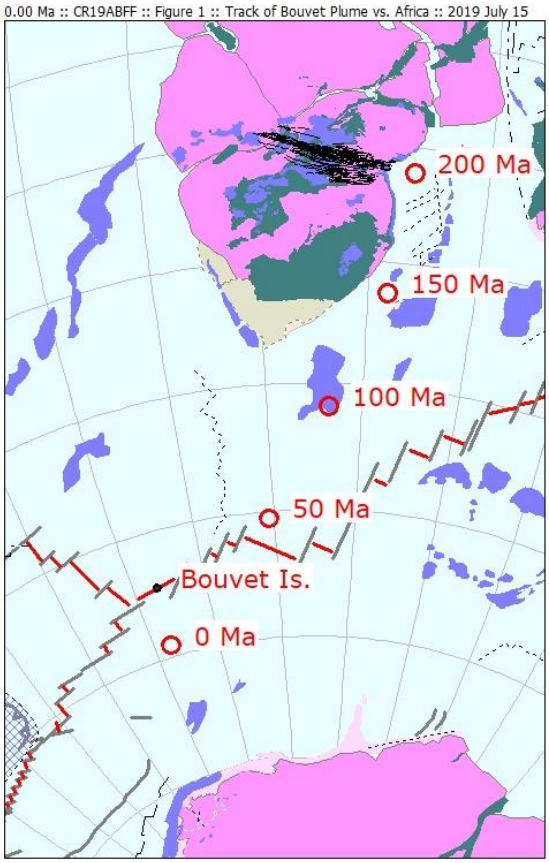

Figure 1. *Track of the Bouvet plume with respect to Africa*

The Bouvet plume and the Falkland Islands/Malvinas Plateau (FIMP)

We advocate a slightly revised track for the Bouvet mantle plume (Figure 1) that places it off southern Mozambique at its initial outbreak (182.7 Ma – (post-)Karoo/Ferrar volcanism). Our track differs but little from that of Torsvik *et al.* (2008) but gives the plume-head a constantly-central position between Africa and Antarctica in their long history of separation and tracks the Africa-Antarctica-South America triple junction precisely once it is established, including below the Agulhas Plateau at the time of its eruption (about 100 Ma, Figure 1). This gives a new dimension to the development of the southern margin of South Africa, the FIMP, the structure of southernmost South America/Patagonia and the tectonic history of the Weddell Sea.

East Gondwana (EGO), West Gondwana (WGO)

A feature of the early EGO-WGO relative movement is the change in spreading direction from NW-SE to N-S (Figure 2) that we now place at 157.5 Ma (*ct* 167 Ma, Reeves, 2017). By this time the FIMP had been dislodged from an initial position against both Africa and Antarctica. The plateau had already started to move westward as a third fragment, separate from both EGO and WGO by strike-slip along the Agulhas fault, following the 'Okavango' pole (Figure 3). A modest (<100 km) dextral displacement of Madagascar from the rest of EGO at about this time (Figure 2b) permitted the first pure strike-slip geometry between EGO and WGO with long N-S transforms off eastern and

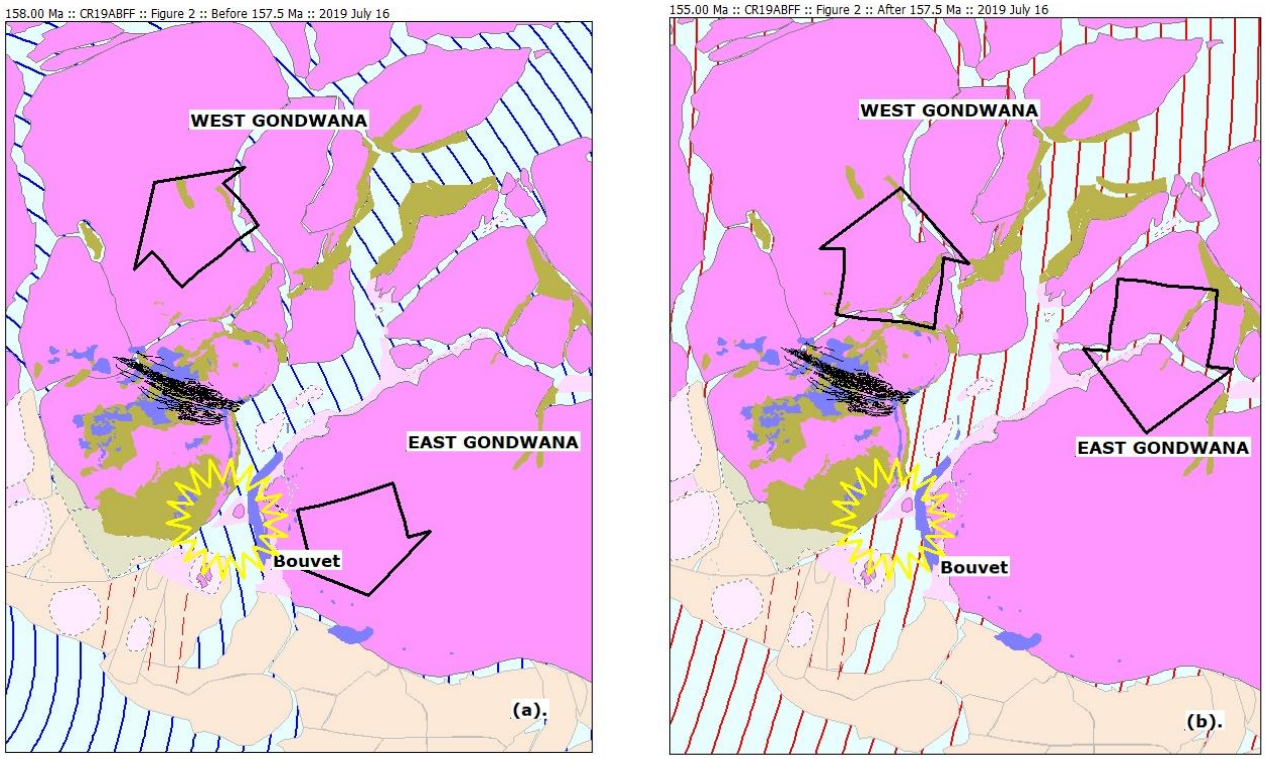

Figure 2. ***(a)*** *After 25 myr of NW-SE extension, by 157.5 Ma (Oxfordian) the way is clear* ***(b)*** *for East Gondwana to begin its long journey southwards against Africa by way of long strike-slip faults (transforms). The geometry of the two transform systems is shown as small circles for the respective Euler interval poles, blue in (a), red in (b).*

southern Africa. There is then no need to invoke renewed movement between Madagascar and India until much later.

East Gondwana break-up

The outbreak of the Kerguelen plume, at or near the Greater India-Antarctica-Australia triple point, we place at about 145 Ma and is thus the first manifestation of the 'Second Gondwana Disruption Event' (GDE-2). Locally this initiated the separation of Greater India+Madagascar from Antarctica+Australia. Off East Africa this caused a slight but growing divergence of the track of Madagascar against Africa from that of Antarctica against Africa, Madagascar+India eventually tracking the arcuate Davie Fracture Zone (DFZ) as a pure transform until Madagascar reached its present position. The configuration of EGO in just these two fragments can account for the Early Cretaceous marine magnetic anomalies off Western Australia without further relative movement of Madagascar and India in this interval. In our model, India and Sri Lanka fully 'escape' from the now well-defined gap between

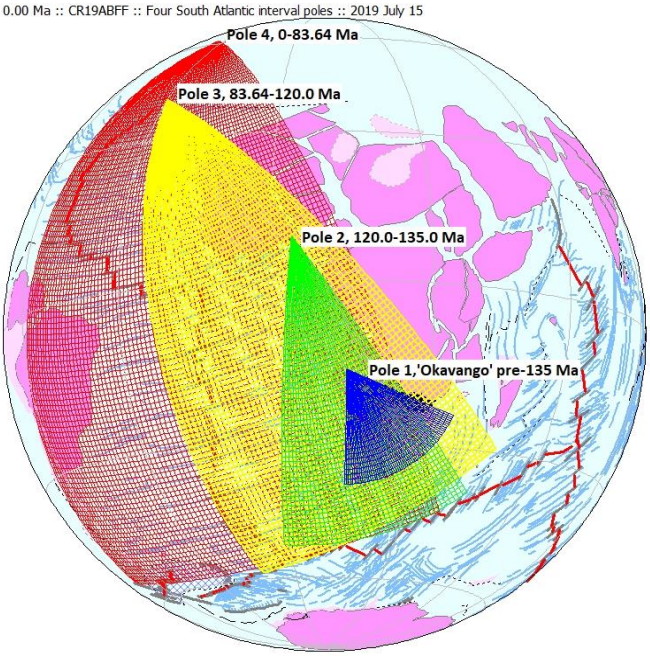

Figure 3*. Four interval rotation poles describe the evolution of the South Atlantic Ocean, including the oldest which fits both the Agulhas fault (strike-slip) and the Okavango dyke swarm (extension) dated at 178 Ma. (Le Gall et al., 2005)*

Madagascar and Antarctica only after Madagascar has come to rest as part of the Africa plate, a few myr into the Aptian and the earliest part of the Cretaceous Quiet Zone devoid of marine magnetic anomalies.

West Gondwana break-up – a new model for the South Atlantic

We define four points A, B C and D on the conjugate margins of Africa and South America (Figure 4). We advocate renewed vigour in the Bouvet plume initiating a new ridge between the FIMP and Africa as early as 145 Ma. This construction fits geometrically with the ongoing spreading regime between EGO and WGO and the location of the Bouvet plume in the AAC at this time. The new ridge had penetrated as far north as C by 135 Ma, articulating Patagonia by means of reactivation of the Salado and Colorado rift basins using the Okavango pole (Figure 4). A ridge-jump in the AAC at 135 Ma then dislodged the Maurice Ewing Bank (MEB) from Africa, starting a corridor of new ocean to its east and an ocean development regime that was to prove long-lived.

Further north, dextral movement on the 3200 km Mwembishi shear zone across Africa delayed the opening of the South Atlantic over the 1000 km length between B and C during 2-3 myr of the subsequent sidestep in the AAC. The outbreak of the Tristan plume we now time at 135 Ma. Hence, by about 132 Ma, the early South Atlantic opening south of C had joined the new proto-ocean north of B. After about 129 Ma, South America as a rigid whole (except for the MEB) was pivoting about a point in Africa near Nigeria (pole 2, Figure 3).

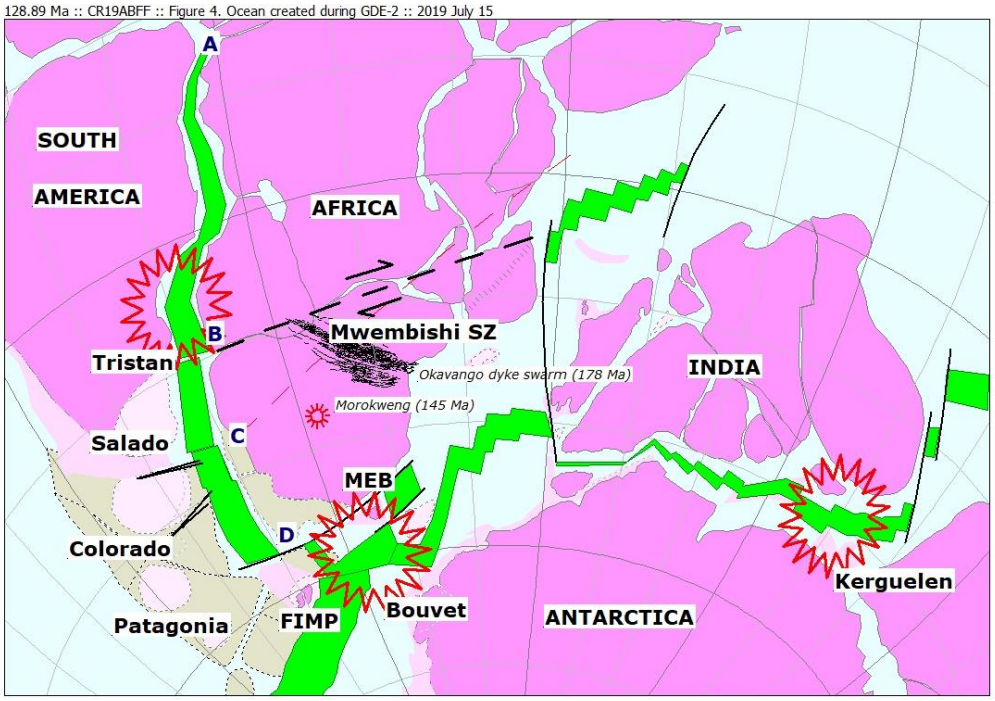

Figure 4: *The new ocean (green) created in the interval 135-129 Ma (Valanginian to Barremian), with the onset of disruption within both East and West Gondwana (GDE-2). Between B and C, the opening of the South Atlantic is delayed 2-3 myr by possible dextral movement on the Mwembishi SZ. The location of the (unrelated?) Morokweng meteorite impact, dated as coincident with the Jurassic-Cretaceous boundary (145 Ma), is indicated in central southern Africa.*

The MEB tracked continuously westwards along the Agulhas fault until firmly attached to the FIMP and the rest of South America in its present orientation by about 120 Ma. This is the time we assign to the transition of growth in the South Atlantic Ocean from a pivot point in Nigeria (pole 2, Figure 3) to coast-normal ocean growth (pole 3, Figure 3). A later pole change led to the movement still in progress today (post-84 Ma pole 4, Figure 3). Already by early Barremian time (129 Ma), however, a mid-ocean ridge system was continuous from Nigeria to Western Australia from its beginnings just 6 myr previously (Figure 4).

A visual summary of events in the interval 145-115 Ma is shown in detail from the model CR19ABFC in the animation: http://www.reeves.nl/upload/BouvetMovieTwoanigif.gif A recent global animation is available for viewing and download at http://www.reeves.nl/gondwana

The Mwembishi shear zone

We introduce the Mwembishi shear zone into our model for the first time to account for observed (50-70 km) offsets in the Precambrian margins revealed by global gravity and national aeromagnetic data at both ends of its length across Africa. Much of its central path follows fault offsets mapped over a wide swathe of central Zambia having their origin in the closing, brittle phase of collision of the Kalahari craton with the Congo craton in the Ediacaran (c. 550 Ma). These could have been reactivated during GDE-2. The alignment must pass north of the Okavango dyke swarm which shows no post-178 Ma offsets. Known alkaline intrusions in Malawi, Mozambique and Namibia, remote from known tectonic activity, as well as dykes in Namibia, date in the 135-129 Ma interval we propose. The dextral offset in the outline of Lake Malawi could also be attributable to this reactivation. Note (Figure 4) that its alignment is also a continuation of the mid-ocean ridge system between Madagascar and Africa at the time proposed for reactivation.

All the rotation poles for this latest model are available on request. The work forms part of IGCP-628, the Geological Map of Gondwana, which should be completed in 2019.

References

Le Gall, B., *et al.,* 2005. ^{40}Ar-^{39}Ar geochronology and structural data from the giant Okavango and related mafic dyke swarms, Karoo igneous province, North Botswana. Earth and Planetary Science Letters, **202**, 595-606.

Mueller, C.O., and Jokat, W., 2019. The initial Gondwana break-up: A synthesis based on new potential field data of the Africa-Antarctica Corridor. Tectonophysics, **750** , pp. 301-328 . doi: 10.1016/j.tecto.2018.11.008

Reeves, C.V., 2017. The development of the East Africa margin during Jurassic and Lower Cretaceous times: a perspective from global tectonics. Petroleum Geoscience, **24**, pp 41-56. doi: 10.1144/petgeo2017-021

Torsvik, T.H., *et al.,* 2008. Global plate motion frames: toward a unified model. Reviews of Geophysics, **46**, No.3, 1-44. doi: 10.1029/2007RG000227.