**The dispersal of the Pangea supercontinent, associated magmatism and its relationship with proposed ‘hot-spots’**

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**Abstract**

Despite the prevalent idea that continental rifts are triggered by thermal anomalies, rising from the deep mantle, there is increasing evidence that hot-spots are found at locations where rifting was hindered and often considerably delayed by a barrier to rift propagation. These locations often coincide with series of aborted rift basins, major, rift-orthogonal shear zones, or triple junctions. The breakup of Pangea was accompanied by extensive, episodic, magmatic activity. Several Large Igneous Provinces (LIPs) formed onshore and widespread volcanic rifted margins developed offshore. Hots-spots that were active during the dispersal of Pangea comprise; Iceland, Tristan da Cunha, Kerguelen, and Bouvet. In this contribution, we demonstrate that throughout the dispersal of Pangea, the commonly assumed hot-spots are found distal from the locus of rift initiation and the subsequent first oceanic crust accretion. There is no location where extension propagates away from the postulated hot-spots, and typically at the location of hot-spots major lithosphere-scale shear movements, aborted rifts and splinters of continental crust rifted far out into the oceanic domain are found. Here, we consider the chronological order of the breakup of Pangea and briefly discuss the Triassic formation of the Central Atlantic Ocean, the breakup between East and West Gondwana in Middle Jurassic times, the separation of India from Antarctica with the Kerguelen hot-spot, the opening of the South Atlantic and its relationship to the Tristan da Cunha hot-spot, and finally the formation of the North Atlantic, when rifting switched over from the magma-poor Labrador Sea/Baffin Bay system to the volcanic North Atlantic system and the initiation of the Iceland hot-spot.

**Introduction (AP)**

Supercontinents represent assemblies of all or nearly all of the Earth’s continental lithosphere (Rogers and Santosh, 2003). Throughout geological time there have been multiple occasions where the majority of continental lithosphere was assembled together into either supercontinents such as Pangea (Rogers, 1996; Stampfli et al., 2013; Frizon De Lamotte et al., 2015) or other large accumulations of continental lithosphere that are termed by some pervious work as ‘semi-supercontinents’ (Santosh et al., 2009) such as Gondwana, Laurasia and Rodinia. The amalgamation and disintegration of these large continental accumulations has been demonstrated to have had one of the most significant influences on the development of the Earth’s geosphere, hydrosphere, atmosphere and biosphere (e.g. Hames et al., 2003; Cawood and Buchan, 2007; Murphy et al., 2009; Nance and Murphy, 2013; Rolf et al., 2014; Nance et al., 2014).

However, despite the momentous role that supercontinent cycles are considered to have had upon the development of the Earth, the processes that governed the assembly and drove subsequent dispersal remain the subjects of scientific discussion (Santosh et al., 2009; Audet and Bürgmann, 2011; Murphy and Nance, 2013). The debate primarily revolves around whether continental dispersal was driven by deep-rooted mantle plumes in ‘active’ models or whether ‘passive’ plate tectonic processes drove the disintegration process (Storey, 1995; Dalziel et al., 2000; Santosh et al., 2009; Pirajno and Santosh, 2015; Yeh and Shellnutt, 2016). Advocates of the active model in which supercontinent dispersal is driven by a deep-rooted mantle plume, or plumes, often look to the apparent temporal relationship between LIP’s that are considered to be the products of the mantle plumes that drove breakup (e.g. refs). However, consideration of the spatial-temporal and geometric relationships between LIP’s and breakup reveals significant issues with this simplistic model of continental breakup. Furthermore, large volumes of magmatism occur even on continental margins and rifts categorized as ‘non-volcanic’ or ‘magma poor’ (Peace et al., 2017b), as magmatism to some extent invariably accompanies continental breakup (White, 1992). This suggests that a continuous spectrum exists between volcanic and non-volcanic rifting (White et al., 2003), not a bimodal distribution, and that the relationship between rifting and magmatism is not as simple as suggested by a two end-member models (Geoffroy, 2005). For this reason the role of the mantle and its relationship with magmatism during continental breakup is a subject of debate (e.g. Peace et al., 2017a). Furthermore, an undisputed seismic detection of a Morgan-type mantle plume has yet to be made (Hwang et al., 2011) given the limitations of seismic tomography and other methods (Foulger et al., 2013).

In this contribution we therefore systematically consider the chronology and geometry of dispersal of Gondwana and Laurasia, the principle constituents of the supercontinent Pangea, in relation to the multiple postulated hot-spots that are attributed by an abundance of previous work to be the products of mantle plumes that drove supercontinent dispersal (Gill et al., 1992; Santosh et al., 2009; Gerlings et al., 2009). Our analysis reveals significant spatial-temporal mismatches between the chronology of breakup and the locations of the hot-spots demonstrating that irrespective of the existence of the postulated plumes leading to the hot-spots they alone cannot explain the dispersal of Pangea. Furthermore, it can be seen that hot-spot magmatism is often associated with regions where rift propagation was hindered or prevented due to a significant, large-scale barrier such as a transform fault or terrane boundary, a tectonic setting where numerical modelling and geological obsrvations indicates that significant melt generation is possible (e.g. Koopmann et al., 2014; Peace et al., 2017a).

**The assembly and dispersal of Pangea (AP + input required from others)**

This review does not aim to summarise the amalgamation and dispersal of the supercontinent Pangea as this is covered in detail by previous work (e.g. Stampfli et al., 2013), and thus only the most salient points are provided here. The supercontinent of Pangea existed from the Late Paleozoic, and reached its final shape at the end of the Triassic (Rogers, 1996). Pangea represents the single largest accumulation of continental lithosphere into a single entity at any point in the history of the Earth (Stampfli et al., 2013). However, to comprehend the formation of Pangea it is essential to understand the formation of its constituent blocks; principally Gondwana (or Gondwanaland) in the south and Laurasia in the north.

The making of Pangea is the result of large-scale amalgamation of continents and micro-continents, which started at the end of the Neoproterozoic with the formation of Gondwana (Stampfli et al., 2013).

The Neoproterozoic formation of Gondwana has been dealt with extensively in the literature but remains a matter of continued scientific discussion.

The development of Gondwana is complicated by the simultaneous accretion of terranes on the south-American, Antarctic and Australia sides whilst microcontinents were detached from the African and southern-Chinese side.

Laurasia

Amalgamation history

Gondwana, or Gondwanaland in some previous work, formed prior to and eventually became part of the supercontinent Pangea.

The dispersal of Pangea occurred through an extended period of Earth’s history and is sumarized by several previous works (Frizon De Lamotte et al., 2015)

**Proposed ‘hot-spots’ in proximity to the disintegrating supercontinent (GF?)**

As previously described the dispersal of Pangea was a multiphase affair with the separation of different constituent parts occurring at both simultaneous and separate times (e.g. refs).

The North Atlantic – Iceland plume

Baffin Bay plume

South Atlantic – Tristan

Afar

**The opening of the South Atlantic (DF)**

In Early Cretaceous times, West Gondwana broke up to form South America and Africa, with the continuous spreading resulting in the continued expansion of the South Atlantic Ocean. The contemporaneous Paraná–Etendeka continental flood-basalt provinces in Brazil and Namibia, respectively, are frequently referred to the influence of the Tristan da Cunha hot-spot with the Walvis Ridge and Rio Grande Rise as the expression of the plume tail (Morgan, 1981). As discossed herein there remains significant spatial and temporal mismatches between the proposed hotspots and these magmatic provinces.

## *Rifting and magmatism*

Regardless of the remarkable geometrical fit between the rifted continental margins of South America and Africa, first recognized by Wegener (1915), both the rift and breakup phases were complex. Continental extension may have begun in isolated centers in South America during the Late Triassic (at about 210 Ma) when almost all of south and west Gondwana was affected by magmatism resulting in a very high heat flow (Macdonald et al., 2003). In addition to this Late Triassic to Early Jurassic rifting phase, there was a Middle Jurassic extensional phase and it took almost 40 Ma, from Valanginian to late Albian time, for Africa and South America to separate completely (Keeley and Light, 1993; Szatmari, P., 2000). The line of continental separation and the position of the principal failed rifts were controlled by both, the position of boundaries between different ages of basement and the structural grain of the basement (Macdonald et al., 2003). Tough breakup is reasonably well understood, the location and magnitude of continental intraplate deformation during rifting, particularly affecting South America is an open question and widely discussed (see e.g. Eagles, 2007; Heine et al., 2013; Moulin et al., 2009; Torsvik et al., 2009)

Continental breakup and initial seafloor spreading in the South Atlantic were accompanied by extensive transient magmatism as inferred from sill intrusions, flood basalt sequences, and voluminous volcanic wedges and high-velocity lower crust at the present continental margins. Voluminous volcanism affected both Mesozoic intracratonic basins onshore (Paraná-Etendeka flood-basalt province; (Peate, 1997; Renne et al., 1992; Trumbull et al., 2007) and the rifted crust offshore (Bauer et al., 2000; Franke et al., 2007; Gladczenko et al., 1997; Gladczenko et al., 1998; Hinz et al., 1999; Koopmann et al., 2014; Mohriak et al., 2008; Paton et al., 2016; Stica et al., 2014).

Menzies et al. (2002) and Moulin et al. (2009) compiled published geochemical data and radiometric dates for the dikes and the lava flows in the Paraná–Etendeka flood-basalt provinces. According to these compilations volcanic activity peaked in the late Hauterivian–early Barremian (133-129 Ma and 134–130 Ma, respectively). Apart from the age of the basalts, there is much controversy about the source of magmas in the Paraná–Etendeka province and it’s origin (see e.g. Renne et al., 1992; Peate, 1997; Hawkesworth et al., 1999; Trumbull et al., 2007; Rocha-Júnior et al., 2013; Comin-Chiaramonti et al., 2011; Will et al., 2016; Foulger, 2017).

The Early Cretaceous opening of the southern South Atlantic took place between 137 to 126 Ma ([Heine et al., 2013](#_ENREF_25); [Macdonald et al., 2003](#_ENREF_32); [Moulin et al., 2009](#_ENREF_40); [Rabinowitz and Labrecque, 1979](#_ENREF_43)). From multichannel seismic and potential field data, Koopmann et al. ([2016](#_ENREF_31)), confirming Moulin et al. ([2009](#_ENREF_40)), conclude that the oldest magnetic chron in the southern South Atlantic, related to oceanic spreading is M9 (c. 135 Ma). Older anomalies, previously identified as M11 (c. 137 Ma) are found within the SDRs ([Corner et al., 2002](#_ENREF_10); [Koopmann et al., 2016](#_ENREF_31)). There is still some uncertainty about the age of the first oceanic crust in the proximity of the Falkland Plateau, where strike-slip deformation in the proximity to the Falklands-Agulhas fracture zone hampers the identification of the earliest spreading anomalies. In a recent study, Collier et al. ([2017](#_ENREF_8)) identified M10r (134.2 Ma, late Valanginian) as the oldest recognisable chron at the southern tip of the South Atlantic. However, Becker et al. ([2012](#_ENREF_3)) suggested that the breakup unconformity, identified in rift basins at the northern edge of the Falkland plateau, is a time-equivalent to the well dated rift-to-sag unconformity in the North Falkland Basin, indicating a Valanginian (~137 Ma) age for the first oceanic crust in the southern South Atlantic.

Most of the southern South Atlantic continental margins are of the volcanic type ([Gladczenko et al., 1997](#_ENREF_20)), however, the southernmost, about 400 km long portion lacks SDRs ([Becker et al., 2012](#_ENREF_3); [Franke et al., 2010](#_ENREF_16); [Koopmann et al., 2014b](#_ENREF_30)). Thus, from the magnetic anomalies interpreted seaward of the SDRs there was an abrupt onset of volcanic rifting at shortly before 137 Ma (Koopmann et al., 2016). From this point on towards the north the progressive continental breakup was accompanied by large-scale transient magmatism with the formation of voluminous SDR wedges, accompanied by high-velocity lower crustal bodies over the ~1.800 km to the Florianopolis/Rio Grande fracture zones offshore Namibia/Brazil ([Becker et al., 2014](#_ENREF_4)). The SDRs were emplaced consecutively northward, as indicated by the progressively termination of the pre-M4 magnetic seafloor spreading anomalies within the volcanic wedges. Only from magnetic chron M4 (c. 130 Ma) onward oceanic crust was formed in the entire southern South Atlantic (Koopmann et al., 2016).

At the latitude of the Paraná–Etendeka flood-basalt provinces, the rift was stuck. At this position, one of the fundamental structures in the South Atlantic development ([Moulin et al., 2012](#_ENREF_39)), the Florianópolis (or Rio Grande) fracture zone is found. This fracture zone had an remarkable offset during breakup (150 km; ([Elliott et al., 2009](#_ENREF_12)) and delayed breakup by 10- 20 My. Immediately to the north, the central South Atlantic is characterized by the presence of an approximately 1–2 kilometre-thick Aptian salt layer ([Mohriak et al., 2008](#_ENREF_36)). Minor SDRs reveal an age, very close to the salt deposits. A number of aborted rifts developed (Campos, Santos, Esperito Santos Basin) along the Brazil margin and the crust was extremely stretched and thinned before the two spreading axis in the central and southern South Atlantic connected ([Evain et al., 2015](#_ENREF_13); [Mohriak et al., 2002](#_ENREF_37)).

Sporadic but widespread magmatic activity continued well after breakup (80 Ma and younger) in southern Africa and Brazil (Comin-Chiaramonti et al., 2011). The most common expression of this are alkaline intrusions, which are locally numerous (e.g., kimberlite fields) but involve smaller volumes compared with the Early Cretaceous activity.

## *Timing of rifting and magmatism*

A key question is the relative timing of extension and the emplacement of the large-volume magmatic flows, both onshore (Paraná–Etendeka flood-basalts) and offshore (SDRs). From plate tectonic reconstructions and based on dating of the continent–ocean transition it is believed that rifting adjacent to the Walvis Ridge/Rio Grande Rise initiated at about 134 Ma ([Moulin et al., 2009](#_ENREF_40)) or 135 Ma ([Bradley, 2008](#_ENREF_6)). Thus, as pointed out by Foulger ([2017](#_ENREF_14)), extension occurred where the Paraná and Etendeka basalts were emplaced. This is well in line with the magma flow directions of both, the basaltic rocks from the Etendeka igneous province of Namibia and from the Paraná province in Brazil. In both provinces, the basalts were deposited in north-south–trending rift basins, revealing that rifting even preceded flood volcanism, at least in the portion of the magmatic province within 100 km of the nascent spreading ridge ([Clemson et al., 1997](#_ENREF_7); [Glen et al., 1997](#_ENREF_22)).

The peak magmatism (~132 Ma) predated the seafloor-spreading stage at the latitude of Paraná–Etendeka flood-basalt by about 20 million years. Final breakup in the central South Atlantic occurred at the Aptian–Albian boundary (112-113 Ma; ([Heine et al., 2013](#_ENREF_25); [Moulin et al., 2009](#_ENREF_40); [Torsvik et al., 2009](#_ENREF_51))), when seafloor spreading commenced north of the Walvis Ridge–Rio Grande Rise. According to the Global Time Scale 2012 ([Gradstein et al., 2012](#_ENREF_23)), the emplacement of SDRs occurred prior to the peak activity of the Paraná–Etendeka flood-basalts. This is certainly the most widespread used time-scale, however, when considering the M-sequence geomagnetic polarity time ([Malinverno et al., 2012](#_ENREF_33)) the SDRs would have been emplaced simultaneously (Koopmann et al., 2016). As the SDRs mark the final stage of the continental rifting phase it is evident that the complete extensional phase and likely also earliest seafloor spreading in the southern South Atlantic predate the emplacement of the Paraná and Etendeka basalts (Franke, 2013).

## *Kinematics of the South Atlantic rift*

A South to North propagating opening of the southern South Atlantic is commonly accepted ([Austin and Uchupi, 1982](#_ENREF_1); [Gaina et al., 2013](#_ENREF_19); [Heine et al., 2013](#_ENREF_25); [Jokat et al., 2003](#_ENREF_27); [Macdonald et al., 2003](#_ENREF_32); [Moulin et al., 2009](#_ENREF_40); [Rabinowitz and Labrecque, 1979](#_ENREF_43); [Seton et al., 2012](#_ENREF_48)). As pointed out by Franke (2013), this opening direction contradicts the hypothesis that rifting migrated away from the Paraná–Etendeka flood-basalt provinces. In the contrary, rifting migrated towards it, which is at odds with a continental breakup being triggered by the Tristan da Cunha hotspot. What else then could have resulted in continental separation?

When reconstructing the South Atlantic the Cape fold belt in South Africa aligns nicely with the Ventana (or Sierras Australes) Hills in Argentina. By identifying the South African Cape fold belt offshore South Africa, Paton et al. (2016) propose that initial rifting along western Gondwana was a consequence of the extensional reactivation of the western Gondwanan Fold Belt. As these rift basins are thought to have formed through a gravitational collapse of the fold belts, the rift basin geometry was controlled by the underlying fold belt geometry, resulting in a broadly SW-orientated (with respect to Africa) extension in the area of Argentina/South Africa. According to Paton et al. (2016), during the mid-Cretaceous, the rift configuration changed significantly and extension now was merely following a north–south trend, i.e. perpendicular to the fold-belt. This geometry fits well with the earlier proposed clockwise rotation of the extensional deformation throughout the Early Cretaceous (Franke, 2013), based of structural data from the continental margins.

The structure and shape of the continental margins show considerable deviations from symmetric structures as would expected by active rifting, triggered by a source centred below the rift. With respect to extruding lava volumes, high-velocity lower crust, dyke orientations, and fault patterns, the complementary southern South Atlantic passive margins experienced a distinct asymmetric evolution during breakup ([Becker et al., 2014](#_ENREF_4); [Becker et al., 2016](#_ENREF_5); [Koopmann et al., 2016](#_ENREF_31); [Salomon et al., 2017](#_ENREF_47)). The asymmetry in offshore magmatism with considerably more SDRs and volume of high-velocity lower crust on the African margin is surprising, given the opposite asymmetry in the onshore Paraná–Etendeka flood-basalt provinces. The possible explanation of a greater extent of postrift uplift and erosion on the African margin has been ruled out by Becker et al. ([2014](#_ENREF_4)), because fission-track and denudation studies on both margins do not support this. In their view, South America offered more favourable structures for magma ascent and extrusion than South Africa. All this providing evidence for mainly passive rifting, as earlier proposed by Maslanyj et al. ([1992](#_ENREF_34)).

The highly asymmetric subequatorial margins of Brazil and West Africa almost certainly did not rift apart in a pure-shear fashion, and an evolution model assuming simple-shear–type rifting mechanisms is suggested (Mohriak et al., 2008).

A seismic refraction study at the easternmost Walvis Ridge, including the junction with the Namibian coast found a small intruded area around the Walvis Ridge (Fromm et al., 2015). Also onshore, in the landfall area of the Walvis Ridge at the Namibian coast a narrow region (<100 km) of high-seismic-velocity anomalies in the middle and lower crust, interpreted as a massive mafic intrusion has been identified by seismic reflection and refraction data (Ryberg et al., 2015). From these data, it appears likely that at least no broad plume head existed during opening of the South Atlantic.

To the north of Walvis Ridge, a sudden absence of SDRs ([Elliott et al., 2009](#_ENREF_12)) comes along with a dramatic decrease in crustal thickness from 35-km-thick crust below Walvis ridge to 5–6-km-thick oceanic crust in the central South Atlantic (Fromm et al., 2015). A similar sudden absence of SDRs occurs south of a major transfer zone in the southern South Atlantic ([Becker et al., 2012](#_ENREF_3); [Koopmann et al., 2014a](#_ENREF_29)). These abrupt changes in emplaced magmatic volume question the hypothesis of a major influence thermal variations in the sublithospheric mantle as origin for the magmatism. Gradual variations of mantel properties and dynamics are expected to generate smooth transitions over at least a hundred or a few hundreds of kilometers rather than sharp transitions.

The architecture of the SDRs, in addition implies an episodic emplacement with multiple magmatic phases alternating with magma-starved phases (Franke et al., 2010). The South Atlantic unzipped in jumps from south to north and the SDRs were emplaced consecutively along the successive northward propagating rift zones (Clemson et al., 1997; Franke et al., 2007; Koopmann et al., 2014; Stica et al., 2014).

Between the Falkland-Agulhas fracture zone and the Walvis Ridge/Rio Grande Rise, this process lasted for approximately 10 Ma, as derived from the earliest magnetic chrons adjacent to the SDRs (Koopmann et al., 2016)

## Opening of the Northeast Atlantic, the Labrador Sea and Baffin Bay (AP)

The opening of the North Atlantic, including the Labrador Sea and Baffin Bay represents the dispersal and thus end of the Laurasia continental amalgamation that formed the northern constituent of the Pangea supercontinent (e.g. refs). The breakup of the North Atlantic and the Labardor Sea – Baffin Bay involved multiple rift phases (Lundin, 2002).

The North Atlantic Igneous Province (NAIP) is a classic LIP (Hansen et al., 2009) that comprises the voluminous Paleogene igneous rocks on the conjugate East Greenland and Northwest European margins including the British isles and Ireland as well as those to the west of Greenland surrounding the Davis Strait and also on Baffin Island. The opening of the north Atlantic, as well as the formation of NAIP are often attributed to a mantle plume. However,

*Rifting and Magmatism*

Although evidence for pre-breakup rifting in the Labrador Sea and wider North Atlantic region has been documented in the form of sedimentary basins and magmatism of Jurassic and possibly Triassic age (Larsen et al., 2009) it is not until the Late Aptian, when spreading reached the Galicia Bank, having propagated from the Central Atlantic (Boillot and Malod, 1988; Lundin, 2002).

The northwest Atlantic rift, transform and extinct spreading system comprises the Labrador Sea in the south, which is connected to and offset from Baffin Bay in the north via the Ungava Fault Zone, a transform fault system running through the Davis Strait bathymetric high (Fig. x). The Labrador Sea, Davis Strait and Baffin Bay formed due to multiphase, divergent motion between Greenland and North America (e.g. Chalmers and Pulvertaft, 2001; Hosseinpour et al., 2013). The first extensional stage from at least the Early Cretaceous, but potentially earlier (Larsen et al., 2009) to magnetic chron 25 (56 Ma) is characterised by regional NE-SW extension (Abdelmalak et al., 2012). This NE-SW extension culminated breakup and the propagation of seafloor spreading in the Labrador Sea from south to north in the Early Tertiary from 61 to 56 Ma (magnetic chrons 27 to 25; Chalmers and Laursen, 1995). During this stage the Davis Strait underwent continental rifting but not breakup (Suckro et al., 2013; Peace et al., 2017b). In Baffin Bay oceanic spreading also occurred simultaneously during this first stage, although probably not as extensively as in the Labrador Sea (Jackson et al., 1979; Hosseinpour et al., 2013). During the second stage, between magnetic chron 20 (45 Ma) and chron 13 (36 Ma) (Roest and Srivastava, 1989), the regional extension direction changed to NNE-SSW (Abdelmalak et al., 2012). This resulted in seafloor spreading becoming oblique and slowing in the Labrador Sea, and probably Baffin Bay (Hosseinpour et al., 2013), until it entirely relocated to the east of Greenland at 36 Ma (Roest and Srivastava, 1989). This reorganization coincided with transform development in the Davis Strait which may have also resulted in small amounts of oceanic crust being produced on leaky transform faults (Funck et al., 2007).

The North Atlantic Igneous Province (NAIP) is a classic LIP (Hansen et al., 2009) that comprises the voluminous Paleogene igneous rocks on the conjugate East Greenland and Northwest European margins including the British isles and Ireland as well as those to the west of Greenland surrounding the Davis Strait and also on Baffin Island.

*Timing of magmatim*

The relationship between the opening of the Labrador Sea - Baffin Bay rift system and its relationship to postulated hotspots was considered in detail by (Peace et al., 2017a)

*Implications for breakup mechanisms*

Some recent numerical modelling suggests that duel rifts could still be explained by rifting response to a mantle plume (Beniest et al., 2017)

**Opening of the Central Atlantic (GM)**

Content to be provided by GM

**The separation of India and Antarctica (SR)**

Content to be provided by SR

**The breakup of East and West Gondwana (JP)**

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## Afar

## May or may not include this section depending on the length of the others.

## A plate tectonic model for supercontinent dispersal (AP/GF/DF/CS?)

## All authors as contributors

## This review has highlighted the spatial-temporal mismatches between the predictions of plume driven dispersal of Pangea and geological observations. Given the spatial, temporal and geometric mismatches between supercontinent dispersal and hot-spots outlined herein consideration of mechanisms capable of achieving supercontinent breakup in the absence of hot-spots must be considered.

Magmatic occurrences at barriers to rift propagation

(Koopmann et al., 2014)

(Peace et al., 2017a)

**Conclusions**

## All authors as contributors

Overall, our analysis of the previous work has revealed significant spatial-temporal mismatches between the chronology of breakup and the locations of proposed hot-spots. This demonstrates that irrespective of the existence of the postulated plumes leading to the hot-spots they cannot explain the dispersal of Pangea. Thus, we suggest that breakup was facilitated by plate tectonic processes.

Furthermore, it can be seen that hot-spot magmatism is often associated with regions where rift propagation was hindered or prevented due to a significant, large-scale barrier such as a transform fault or terrane boundary, tectonic settings where numerical modelling indicates that significant met generation is possible (Koopmann et al., 2014).

**Acknowledgements**

North Atlantic group

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**Figures?**

Paleogeographic reconstruction of Gondwana and Laurasia

Possibly include reconstructions of breakup

Hotspot locations

