Double-saloon-door seafloor spreading: A new theory for the breakup of Gondwana

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Summary The double-saloon-door seafloor spreading model was developed in the Western Mediterranean. During subduction rollback, opposite rotational torques are driven by the pull of a sinking slab with a curved hingeline. This propels simultaneous opposite rotations of terranes in a backarc environment. The process also occurred in the Pannonian, Aegean, Caribbean and Japan Sea basins. Unlike previous models, this novel theory, when applied to Gondwana breakup, explains arc-orthogonal rifting and seafloor spreading, clockwise and counterclockwise rotations of the Falkland Islands Block and the Ellsworth Whitmore Terrane, the separation of these terranes in a northwest southeast direction, and their eventual accretion to South America and East Antarctica respectively. As in other cases, the Gondwana terranes comprise parts of a pre-existing retroarc fold / thrust belt (the Permo-Triassic Gondwanide Orogeny). Extension and microplate rotations in the backarc are accommodated by rollback and simultaneous crustal shortening at the adjacent subduction zone / accretionary wedge.

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Introduction

Seafloor spreading anomalies in the Weddell Sea which are perpendicular to the reconstructed subduction zone in southwest Gondwana do not match backarc models which envisage arc-parallel seafloor spreading. Similarly existing breakup models (eg. Dalziel & Grunow, 1992; Storey, 1995; Vaughan & Storey, 2007) do not provide geodynamic mechanisms for opposite rotations of the Falkland Islands Block and the Ellsworth Whitmore Terrane. Here it is proposed that Gondwana breakup was caused by double-saloon-door rifting and seafloor spreading thereby resolving the above and other issues, and fully explaining breakup geodynamics.

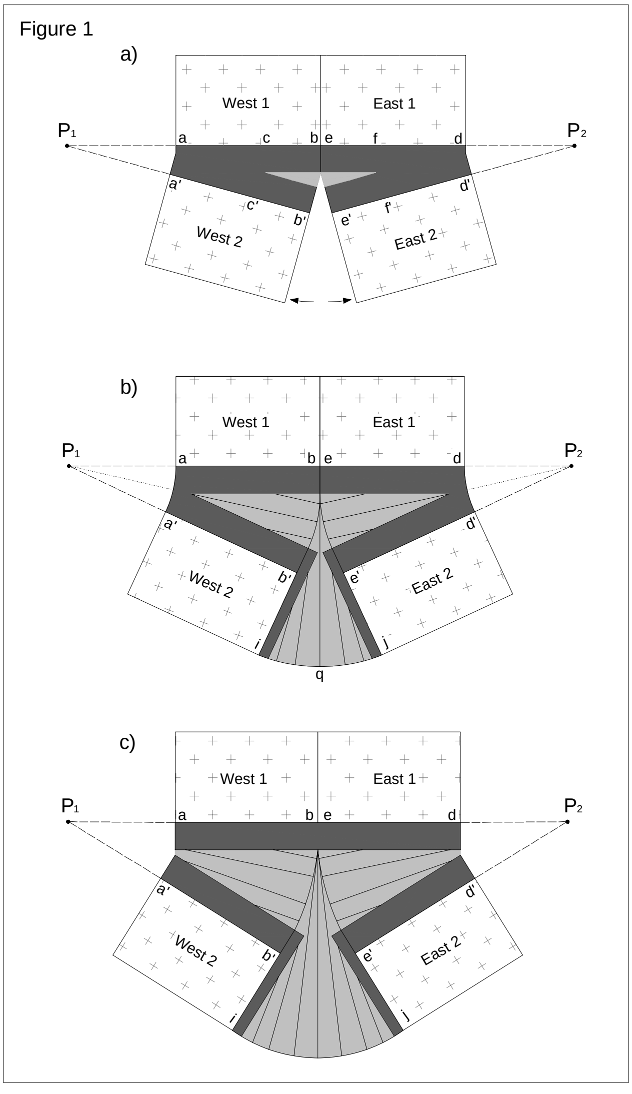

Figure 1. Double-saloon-door seafloor spreading model. See text for further explanation.

Double-saloon-door seafloor spreading model

A double-saloon-door seafloor spreading model has been developed in the Chattian to Langhian Western Mediterranean where two arc-parallel rifts propagate in opposite directions from an initial central location during backarc seafloor spreading and subduction rollback (Martin, 2006). The resultant geometry causes pairs of terranes (in this case the Balearic Peninsula and the Sardinia / Corsica Block) to simultaneously rotate clockwise and counterclockwise like double-saloon-doors revolving about their hinges. In Fig. 1, plate West 2 rotates clockwise about pole P1, whereas plate East 2 rotates counterclockwise about pole P2. Movement is driven by a centrally located force pulling in the direction of subduction rollback (b towards q in Fig. 1b). Between a and c as well as d and f, movement is accommodated by extension of thinned continental crust (dark shading) whereas from c to b and from f to e, oceanic accretion occurs (light shading). With further rotation, (Figs. 1b and c) rifts propagate towards the rotation poles, as demonstrated by seafloor spreading isochrons (dark lines within light shaded oceanic crust) which successively abut thinned continental crust. As the rotated terranes separate, a third rift opens between them which is orthogonal to the subduction zone on the southern flanks of the rotated terranes. This rift propagates in the opposite direction to subduction rollback.

In addition to being documented in the Western Mediterranean, it is postulated here that this process was active during the Serravalian phase of the evolution of the Gibraltar Arc, the Tortonian – Recent Tyrrhenian Basin, the Burdigalian to Recent Carpathians, the Serravalian to Recent Aegean, the Oligocene to Recent Caribbean, and the Burdigalian – Langhian Japan Sea. Pairs of oppositely rotated terrranes have been documented in all these cases (eg. Otofuji, 1996; Lonergan and White, 1997; Pindell et al., 1999; Duermeijer et al., 2000; Gattacceca and Speranza, 2002; Mann et al., 2002; Wenzel et al., 2002). Rotated terranes comprise parts of pre-existing retroarc fold / thrust belts, associated in each case with an accretionary wedge intruded by a magmatic arc. A synthesis of the development of these areas suggests a two-stage process: initially terranes revolve about rotation poles, before accreting, in some cases, to adjacent buoyant continental material either on the subducting or over-riding plate. Where terrane docking occurs, it reduces the width of the subduction rollback zone, leading to the breakup of the original terranes into sub-terranes which rotate about late-stage rotation poles and become caught up in strike slip fault zones. The clockwise rotated terrane is affected by dextral strike slip, whereas the counterclockwise rotated terrane becomes involved in a sinistral strike slip fault system.

Double-saloon-door Gondwana breakup

Guided by the above model, while honouring available paleomagnetic, isotopic, stratigraphic, marine magnetic and gravity data, (eg. Watts and Bramall, 1981; Mitchell et al., 1986; Grunow, 1993; Pankhurst et al., 2000; Ghidella et al., 2002; Jokat et al., 2003), an amended dispersal model for Early Jurassic to Early Cretaceous Gondwana breakup is proposed in which three plates always separate about a single triple rift or triple junction in the Weddell Sea area. Seven characteristics are considered symptomatic of double-saloon-door seafloor spreading:

i) initial breakup involves a pair of oppositely rotated microplates – the clockwise rotated Falkland Islands Block and the counterclockwise rotated Ellsworth Whitmore Terrane;

ii) microplates comprise parts of a pre-existing retroarc fold thrust belt (the Gondwanide Permo-Triassic orogeny), associated with a nearby accretionary wedge / magmatic arc; the Falkland Islands Block was initially attached to Southern Patagonia and the West Antarctic Peninsula, whereas the Ellsworth Whitmore Terrane was combined with the Thurston Island Block;

iii) paleogeographies show that these rotations are associated with widespread rifting and extension in a backarc environment relative to an accretionary wedge / subduction zone on the Pacific margin of Gondwana, where contemporary crustal shortening occurs, thereby accommodating rotations of the microplates;

iv) a ridge jump towards the subduction zone from east of the Falkland Islands to the Rocas Verdes Basin demonstrates subduction rollback; Early to Late Jurassic Pacificward migration of magmatic activity in the Chon Aike igneous province has already been documented (Pankhurst et al., 2000);

v) this ridge jump and / or backarc extension separated off the Falkland Islands Block from southern Patagonia; this process is similar to that occurring in the Western Mediterranean where areas of continental crust were isolated by plate re-organisations related to terrane docking during episodic subduction rollback;

vi) the model-predicted rift propagating in a direction opposite to subduction rollback is represented by east-trending (in an Antarctic reference frame) magnetic anomalies in the Weddell Sea; propagation is demonstrated by anomalies M19 – M13 successively abutting the Explora Wedge off west Dronning Maud Land during the Latest Jurassic and Earliest Cretaceous, 146 – 138 Ma (Jokat et al., 2003);

vii) the rollback zone is bordered by the documented dextral Gastre and sub-parallel faults in Patagonia, and by inferred sinistral strike-slip between the combined Thurston Island / Ellsworth Whitmore Terrane and Marie Byrd Land / East Antarctica in the Pine Island Bay area.

5-phase Gondwana dispersal

1) Assuming simultaneous opposite rotations as documented in other areas, the time constraints on the rotations of the Falkland Islands Block and the Ellsworth Whitmore Terrane can be combined, implying that initial movement occurs between 190 and 175 Ma. - Phase I (Fig. 2).

2) Phase II extends from docking of the Ellsworth Whitmore Block (175 Ma) until first seafloor spreading between Africa and East Antarctica (165 Ma by extrapolation from identified anomalies). The combined Falkland Plateau / Outeniqua Basin forms a rift propagating northwest (in an African reference frame) from pre Callovian time (pre – 165 Ma), whereas the Filchner Rift extends in the opposite direction. The graben under the Evans Ice Stream between West Antarctic Peninsula and Thurston Island and or the Central Rift in the Weddell Sea Embayment off eastern Ellsworth Land may represent the third rift orthogonal to the previous two. The backarc Latady Formation in Ellsworth Land dates from 183 Ma.

3) Phase III (165 – 150 Ma) The combined Falkland Plateau / Outeniqua Basin continues to extend as the combined Falkland Islands South Patagonia Block rotates clockwise, whereas the stalled Filchner Rift is replaced by seafloor spreading between Africa and East Antarctica. The third rift in the Weddell Sea reaches the oceanic accretion stage as documented by east-trending (in an Antarctic reference frame) M29 (157 Ma) and younger seafloor spreading anomalies.

4) Phase IV (150 – 134 Ma). Extension in the combined Falkland Plateau / Outeniqua Basin stalls and is replaced by a new rift in the Rocas Verdes Basin which propagates north northwestwards in Patagonia from 150 – 138 Ma. This ridge jump from east of the Falkland Islands to the west was likely driven by gradual docking of the combined Southern Patagonia / Falkland Islands Block with northern Patagonia at the transpressional Gastre and sub-parallel faults. The docking process initially caused breakup of the terrane into sub-terranes, leading to tighter rotation of the Falkland Islands Block, and finally the initiation of the Rocas Verdes Basin. The Weddell Sea spreading ridge propagated further east northeast (in an Antarctic frame) with anomalies M19 – M13 (146 – 138 Ma) successively abutting the Explora Wedge off west Dronning Maud Land.

5) Phase V (post - 134 Ma). The Rocas Verdes Basin stalls and is replaced by opening of the South Atlantic where a rift propagates northwards from anomaly M10 onwards (134 Ma). The Weddell Sea rift has propagated farther towards Mozambique and joined with an RRR triple junction off the tip of the Falkland Plateau which now includes the Maurice Ewing Bank. (Fig. 2). Matching conjugate seafloor spreading anomalies show that the Falkland Plateau begins to move as a rigid part of the South American plate from this time.

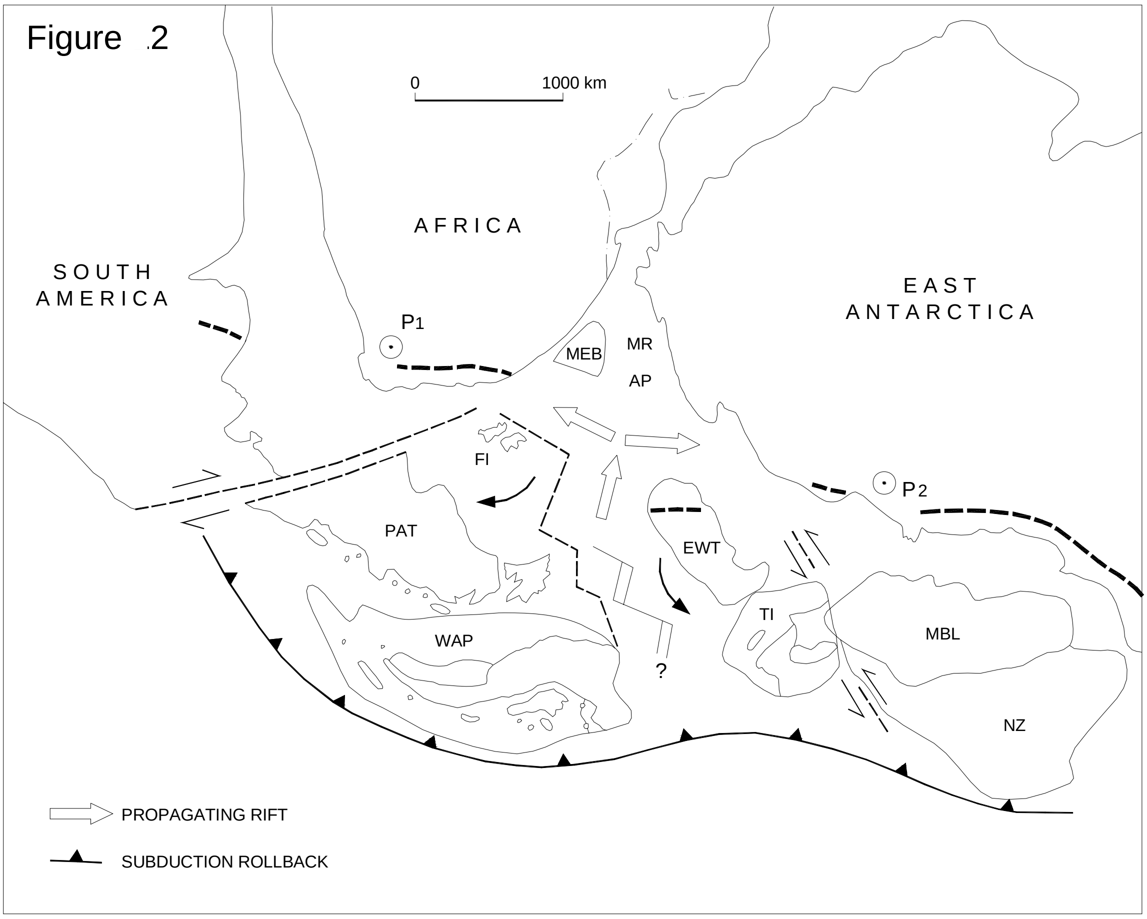

Figure 2. Initial breakup of Gondwana. Phase I (190 – 175 Ma). The Falkland Islands Block (FI), combined with Patagonia (PAT), and the West Antarctic Peninsula (WAP) rotates clockwise about a notional pole P1. Simultaneously the Ellsworth Whitmore Block (EWT) combined with Thurston Island (TI), rotates counterclockwise about pole P2. On the Pacific margin of Gondwana, subduction rollback and crustal shortening at an accretionary wedge accommodates these rotations. Southern Patagonia moves relative to northern Patagonia along the dextral transpressive Gastre Fault (light dashed lines). Conjugate motion of the Ellsworth Whitmore Terrane and Thurston Island relative to East Antarctica and Marie Byrd Land may occur along a previously postulated (Grunow, 1993) sinistral strike-slip fault. Heavy dashed lines = Permo-Triassic Gondwanide orogeny. MR = Mozambique Ridge. AP = Agulhas Plateau. MBL = Marie Byrd Land. NZ = New Zealand. In the backarc, rifting and extension occurs between the Falkland Islands and the Maurice Ewing Bank (MEB) forming the combined Falkland Plateau / Outeniqua Basin shown as a propagating rift (open arrow) pointing northwest. Sedimentary fill here is at least pre-Callovian (pre 165 Ma). A second rift is shown propagating to the southeast, representing the Filchner Rift between the Ellsworth Whitmore Terrane and East Antarctica. The third model-predicted rift propagates north northeast (in an African reference frame), and may be formed by the Evans Ice Shelf and Central Graben in the Weddell Sea Embayment off Ellsworth Land, southern West Antarctic Peninsula. Later, in Phases III and IV of Gondwana dispersal (see text above) this rift likely evolved into the spreading ridge demonstrated by the Weddell Sea herringbone, which did propagate as the model predicts, at least from anomaly M19 to M13 (Jokat et al., 2003).

Driving mechanism

Although initial Gondwana breakup occurs when the Karoo, Ferrar and the first phase of the Chon Aike Large Igneous Provinces erupt (184 – 179 Ma, 184 – 180 Ma, and 188 – 178 Ma respectively - eg. Pankhurst et al., 2000), invoking a plume-related mechanism for breakup (eg. Storey, 1995; Vaughan & Storey, 2007) explains neither the breakup geometry nor the dispersal details. The driving mechanism for double-saloon-door seafloor spreading is the pull of a sinking slab, where the curved hingeline of the subduction zone produces a pair of opposite rotational torques. In contrast to previously postulated geodynamic scenarios, the double-saloon-door theory provides a mechanism which drives opposite rotations of the Falkland Islands Block and the Ellsworth Whitmore Terrane. It furnishes a cogent argument for the separation of these blocks in a northwest southeast direction, and explains their eventual accretion respectively to South America and East Antarctica. The implication is that, in addition to being the agent which *forms* continental crust, subduction, related arc volcanism, and the associated double-saloon-door mechanism is the engine which *breaks up* continents too.

Potential tests

This novel theory for Gondwana breakup provides a new framework within which fresh research might develop. The Western Mediterranean, Alboran, Tyrrhenian, Aegean, Pannonian, Caribbean and Japan Sea examples cited above provide analogies which suggest a series of questions with which to test the theory.

- Does extension within backarc basins occur on low angle extensional detachments which may have acted as thrust faults in a preceding fold / thrust belt episode?
- Does such extension expose HPLT rocks which formed in an earlier compressional orogen?
- Is there a progression from extension-related silicic volcanism to subduction-related calc-alkaline magmatics and thence to alkaline volcanism? Such a progression has been observed in the Western Mediterranean and Pannonian Basins and related to sub-crustal heating and extension, subduction, eventual slab detachment and asthenospheric upwelling. Further study of Zuurberg volcanics in South Africa, Sweeney Formation basalts and Hjort Formation mafics and ultramafics in West Antarctica, and alkali basalts on Alexander Island may be revealing.
- Can teleseismic tomography image subducted oceanic crust over 100 Ma old, which by now may have pierced or be ponded at the 660 km transition, and thereby address the geometry of Jurassic / Cretaceous subduction in southwest Gondwana?
- Is there any evidence to suggest that significant strike slip faults such as the Gastre Fault system formed subduction transform edge propagators (STEPS)?
- Would a re-appraisal of paleomagnetic data (Grunow, 1993), calibrated against a modern reconstruction of Gondwana, influence the conclusions regarding microplate rotations in southern South America and West Antarctica?
- Can new paleomagnetic studies, particularly in Patagonia and West Antarctica, delineate all the terranes and sub-terranes involved in early and late-stage rotations?

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