Mesozoic Breakup of Southwest Gondwana and Basin Formation Along the Argentinean Atlantic Margin*

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Abstract

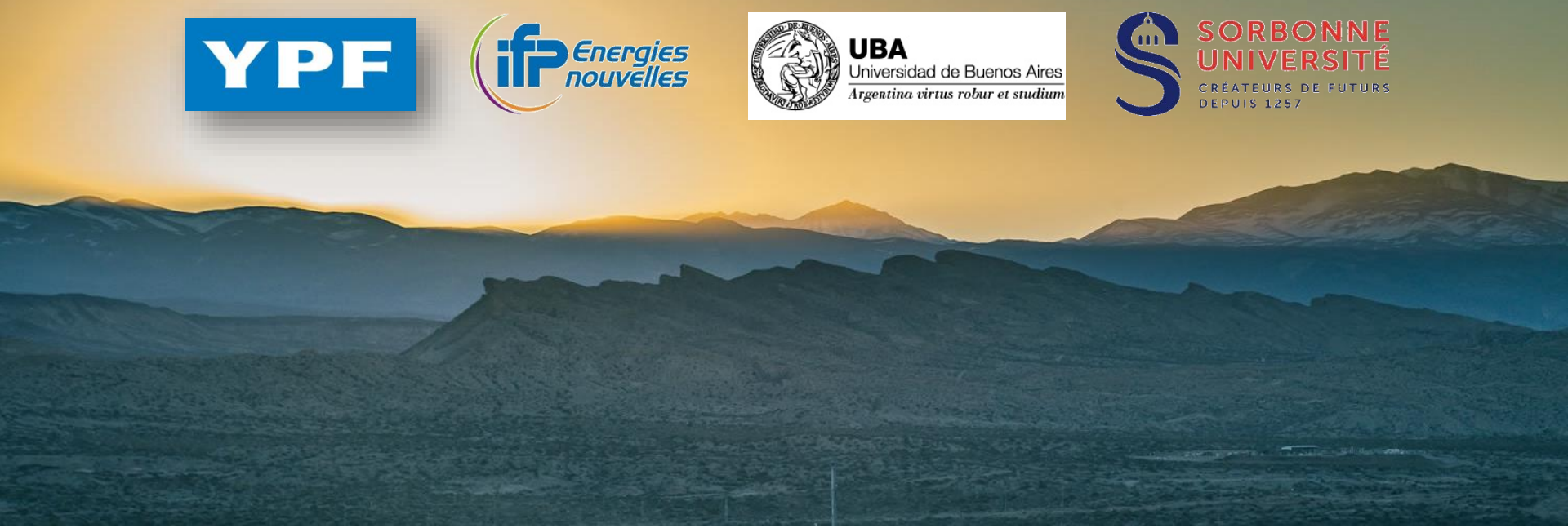
The opening of the South Atlantic in the Early Cretaceous was only the final stage of a complex rifting process that southwest Gondwana experienced throughout the Mesozoic. This work is a tribute to the pioneering efforts of Uliana, Biddle and Cerdán (1989), thirty years after the publication of their integration in AAPG Memoir 46. We followed a similar approach, but we integrated state of the art geodynamic theories and updated seismic and geochronology databases that allowed the correlation of rifting stages across southwest Gondwana. We differentiated four stages in southwest Gondwana riffing evolution.

After the Mid-Permian to Mid-Triassic Gondwanan orogeny, extensional reactivation of former compressive structures of the Cape-Ventania fold belt took place since the Late Triassic. Intracontinental rifts in Africa and South America characterize the Karoo rifting throughout the Triassic. Since the Early Jurassic, rifting on Eastern Africa was triggered by the impact of the Karoo plume, which produced the breakup of Africa from Antarctica and India and the opening of the Mozambique channel and the Weddell Sea. The results of this work suggest that the Colorado and Salado basins, offshore Argentina, are part of the Jurassic African Karoo II rift system, that later on remained perched on continental crust on the south American conjugate margin across the Early Cretaceous South Atlantic Ocean. Throughout the Mid- and Late Jurassic, retroarc extension in Patagonia and the Antarctic Peninsula is responsible for the synextensional emplacement of the Chon Aike Magmatic Province.

The Malvinas and Austral depocenters formed at this time as part of a larger system related to differential slab rollover and a vertical slab tear in the south, that introduced a thermal anomaly responsible for the successive opening of the Weddell Sea. Retroarc extension reaches a maximum in the Late Jurassic, with the opening of the Rocas Verdes back-arc Basin and the Rawson/Valdés-Outeniqua basins further inland. In the Early Cretaceous, extension largely oriented E-W and associated with far-field forces controlled the initiation of rifting and the opening the South Atlantic Ocean. The Paraná plume only reached the surface after oceanization had started in the southernmost segment of the South Atlantic. The identification of four superimposed rifting settings in the Argentinean offshore was key in the understanding of the complex Mesozoic breakup history of southwest Gondwana.

Selected Reference

Uliana, M.A., K.T. Biddle, and J. Cerdan, 1989, Mesozoic Extension and the Formation of Argentine Sedimentary Basins, Chapter 39, Analogs: AAPG Memoir 46, p. 599-614.



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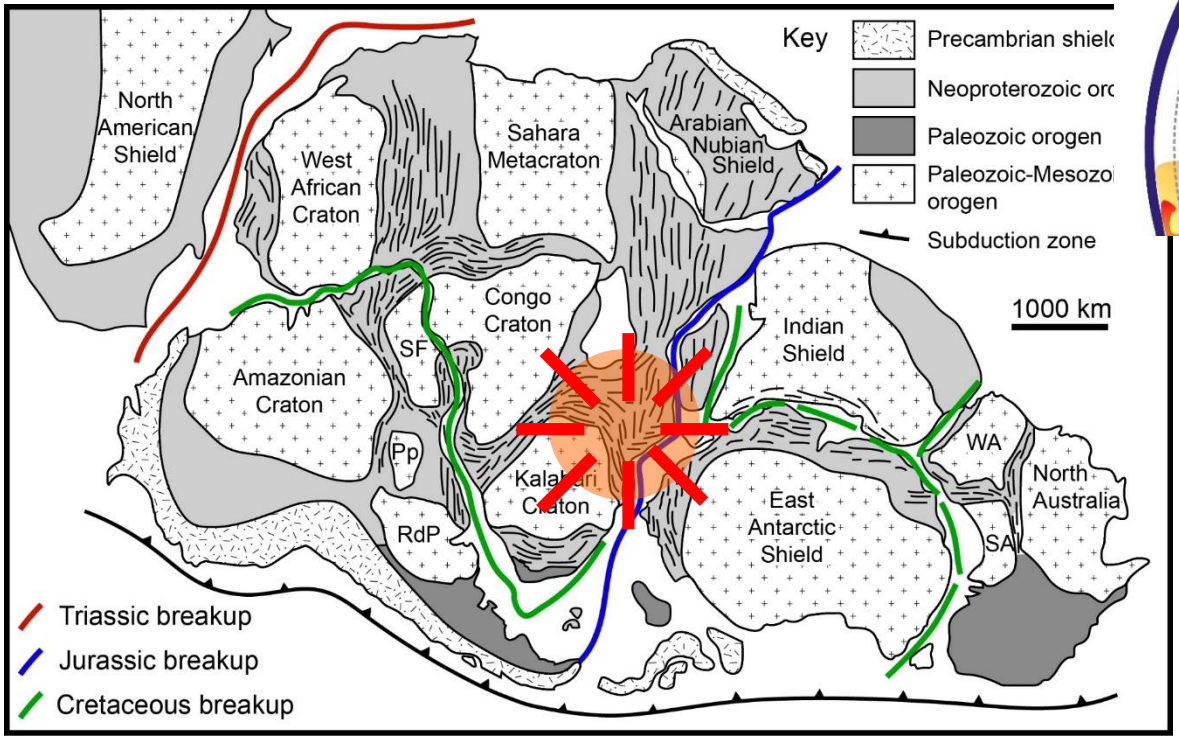
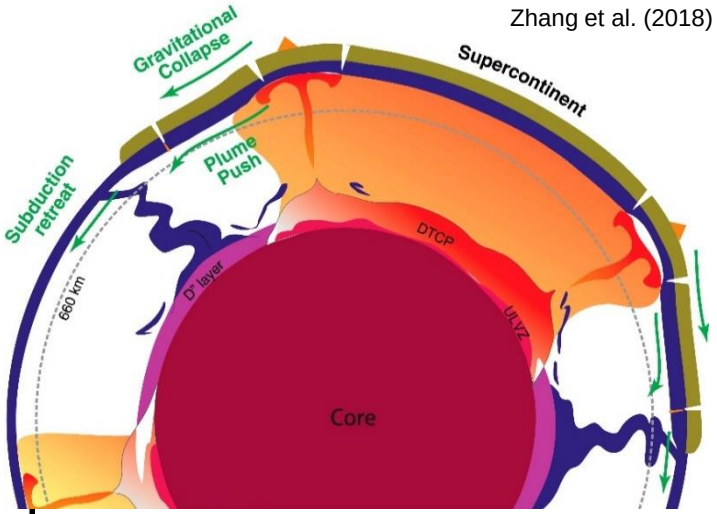
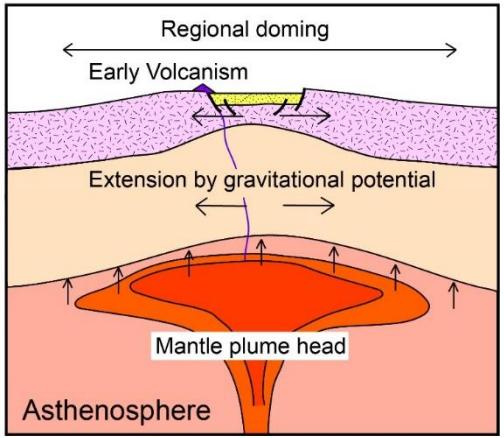
Breaking continents, breaking paradigms…

1. *Plume impingement (active rifting)*
2. *Orogen gravitational collapse*
3. ***Subduction-driven extension (passive rifting, produced by slab retreat, negative rollover, slab steepening)***



Zhang et al. (2018)





After Allen & Allen (2005) and Merle (2011)

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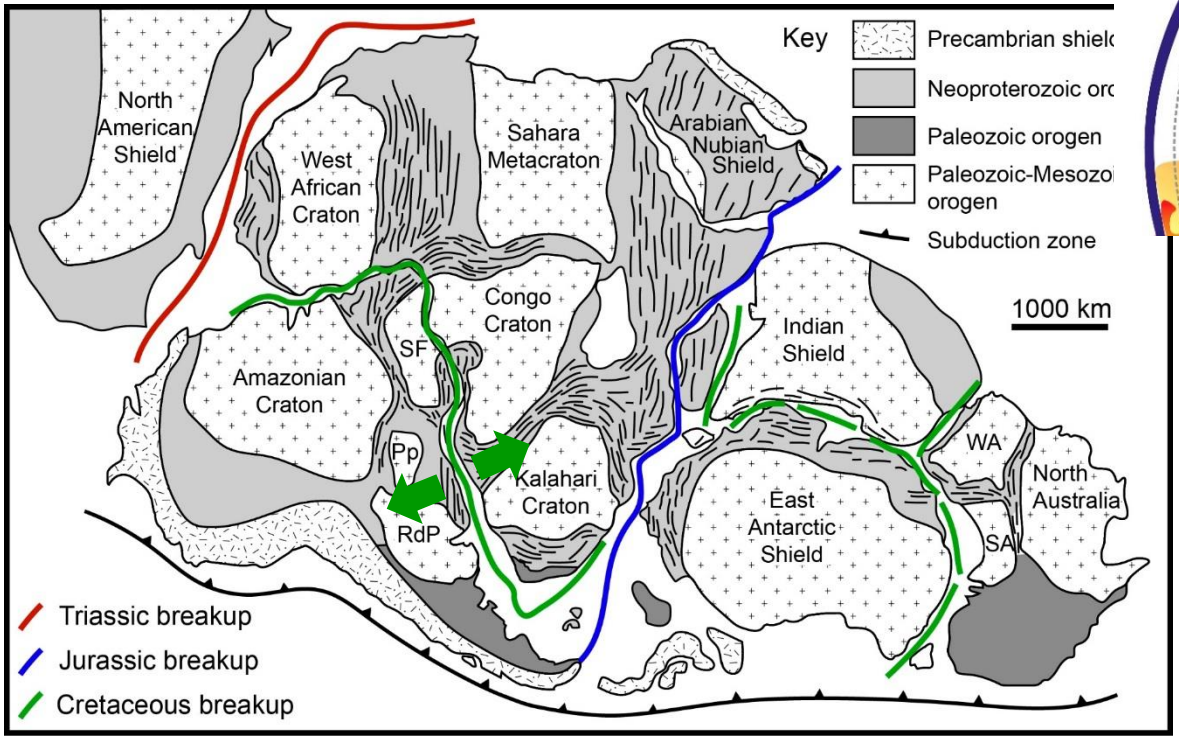

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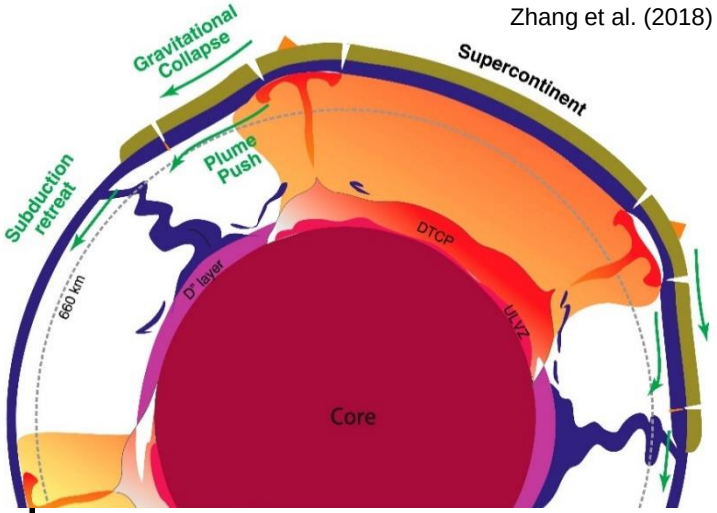
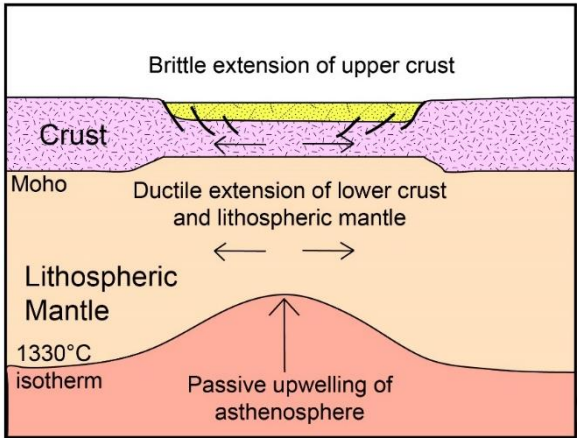




After Allen & Allen (2005) and Merle (2011)

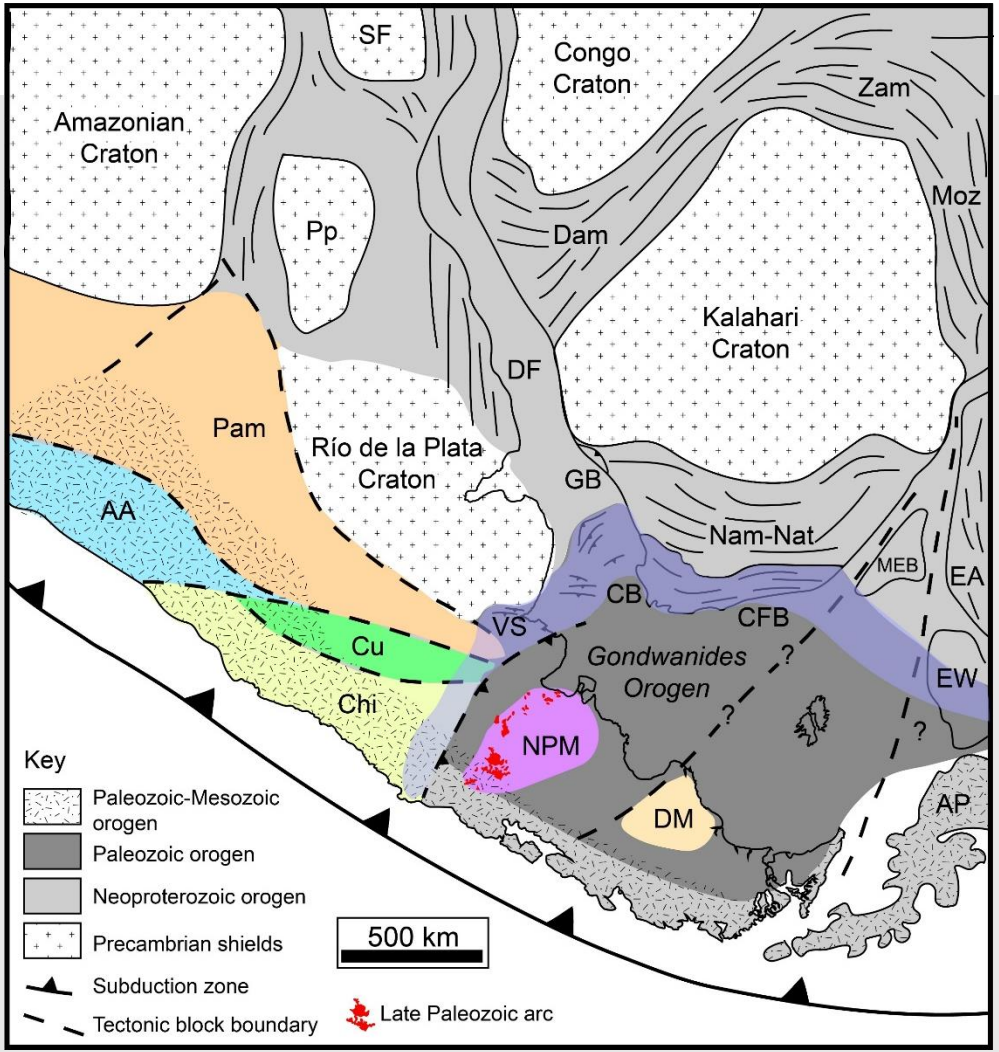
Agenda

1. *Introduction*
2. *Pre-Mesozoic configuration*
3. *Three rifting stages in the Colorado basin*
4. *Late Triassic*
5. *Early-Mid Jurassic*
6. *Late Jurassic*
7. *Early Cretaceous: The South Atlantic Rift*
8. *Conclusions*

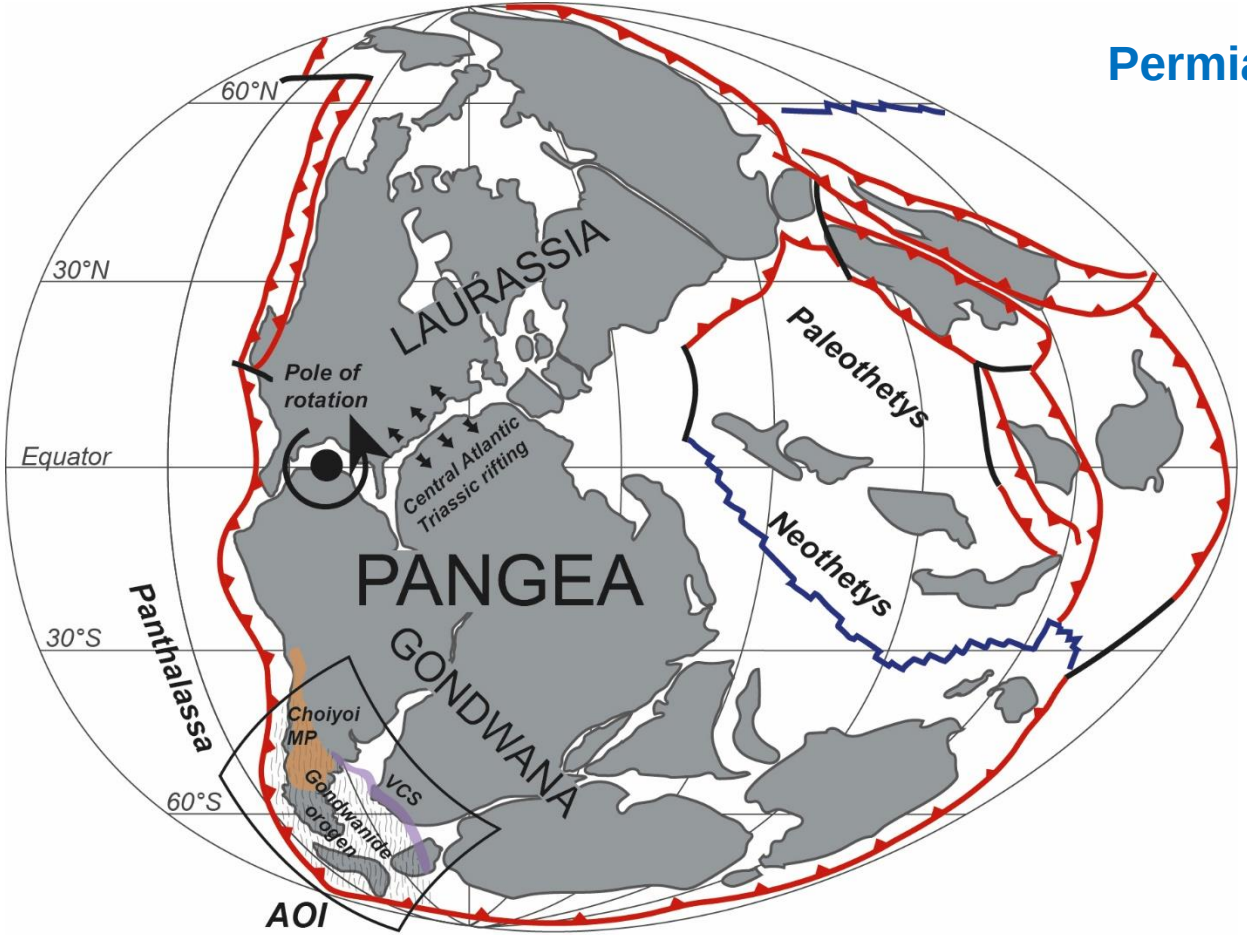
Pre-Mesozoic configuration

SW GONDWANA

- ✓ *Craton amalgamation in the Neoproterozoic,*
- ✓ *Continuous subduction from the west since the Cambrian,*
- ✓ *Terrane accretion throughout the Paleozoic (Pampia, Cuyania, Chilenia),*
- ✓ *Structural inheritance of the basement fabric (structural grain, sutures) in the formation of Mesozoic extensional basins,*
- ✓ *Reactivation of structures according to the stress regime at each stage,*



Permian-Triassic



- ✓ *Counter-clockwise rotation of Pangea.*
- ✓ *Absolute displacement of Gondwana to the NE, closure of the Paleotethys, opening of the Neotethys.*
- ✓ *Extensional emplacement of the Choiyoi silicic Magmatic Province.*

Modified from Riel et al. (2018)

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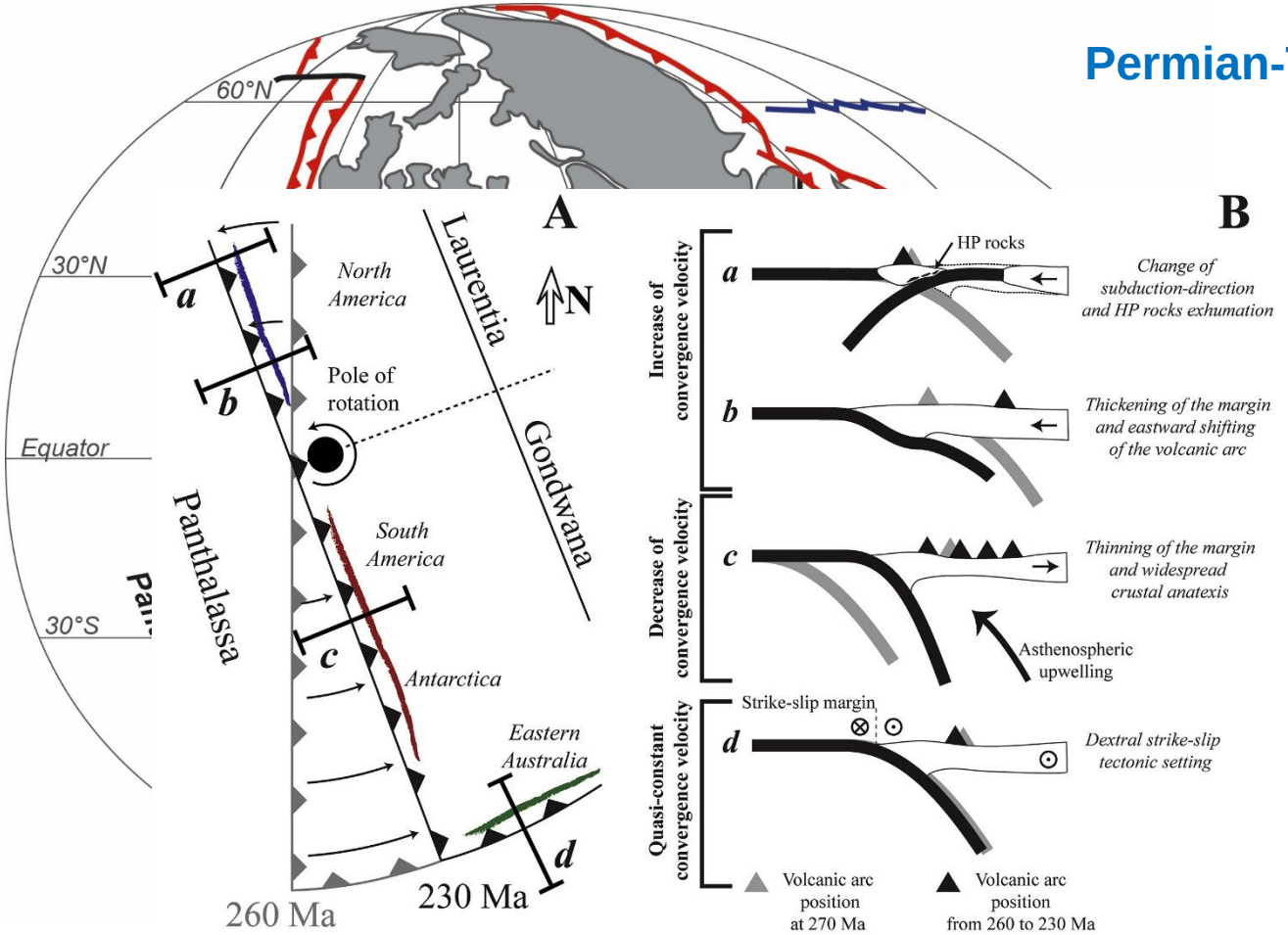

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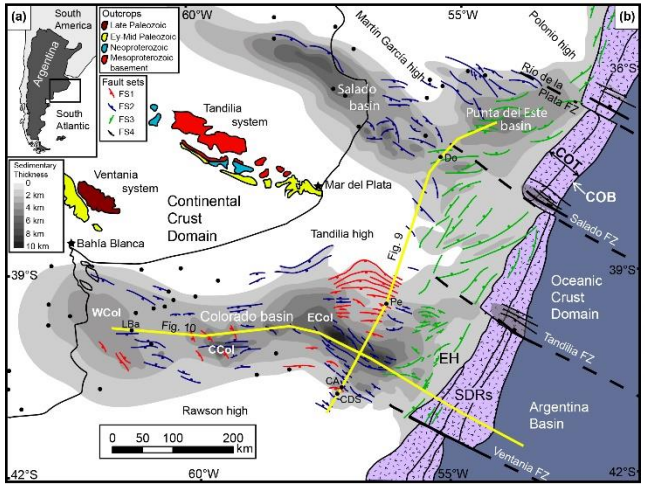
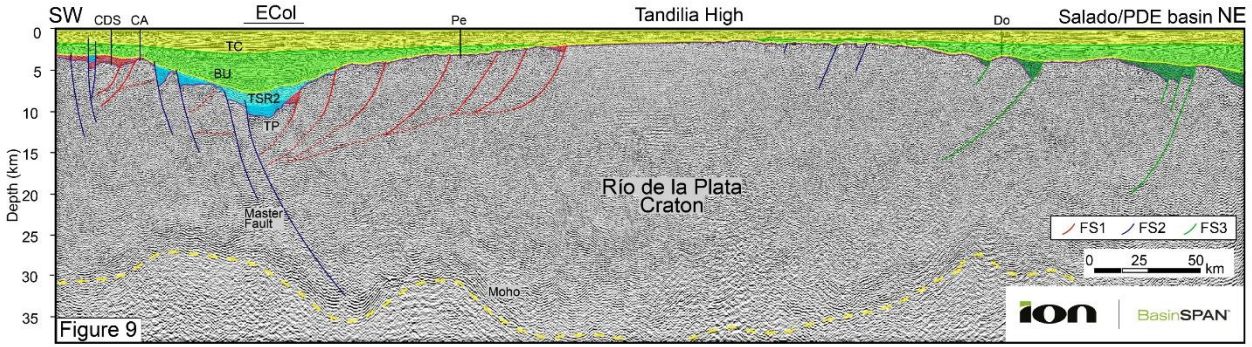
Three rifting stages in the Colorado basin

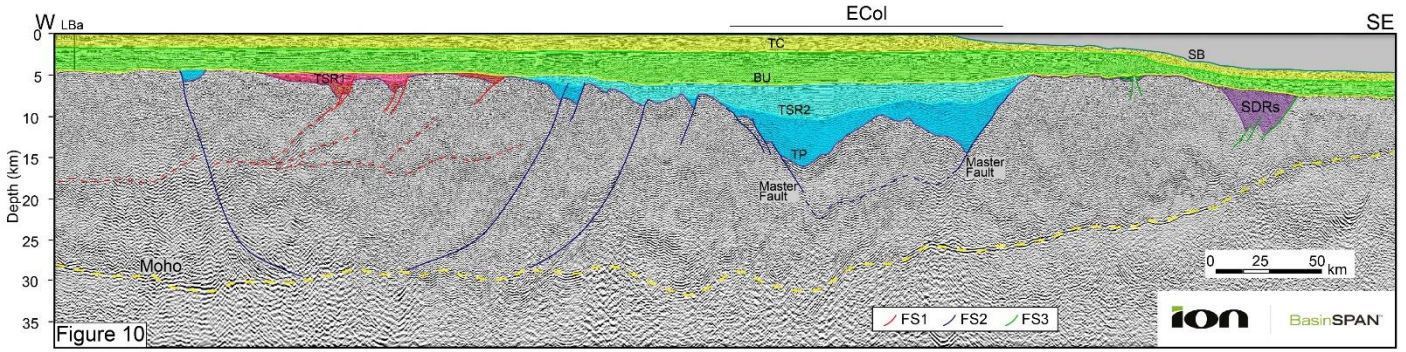


Lovecchio et al., 2018

- ✓ *A first rifting event is associated with Fault Set 1 (FS1), and the formation of tilted blocks on the northern flank of the Eastern Colorado depocenter (ECol), and half-grabens north of the CCol depocenter.*
- ✓ *FS1 faults are intersected by FS2 faults forming the main depocenters in the Colorado and Salado basins.*

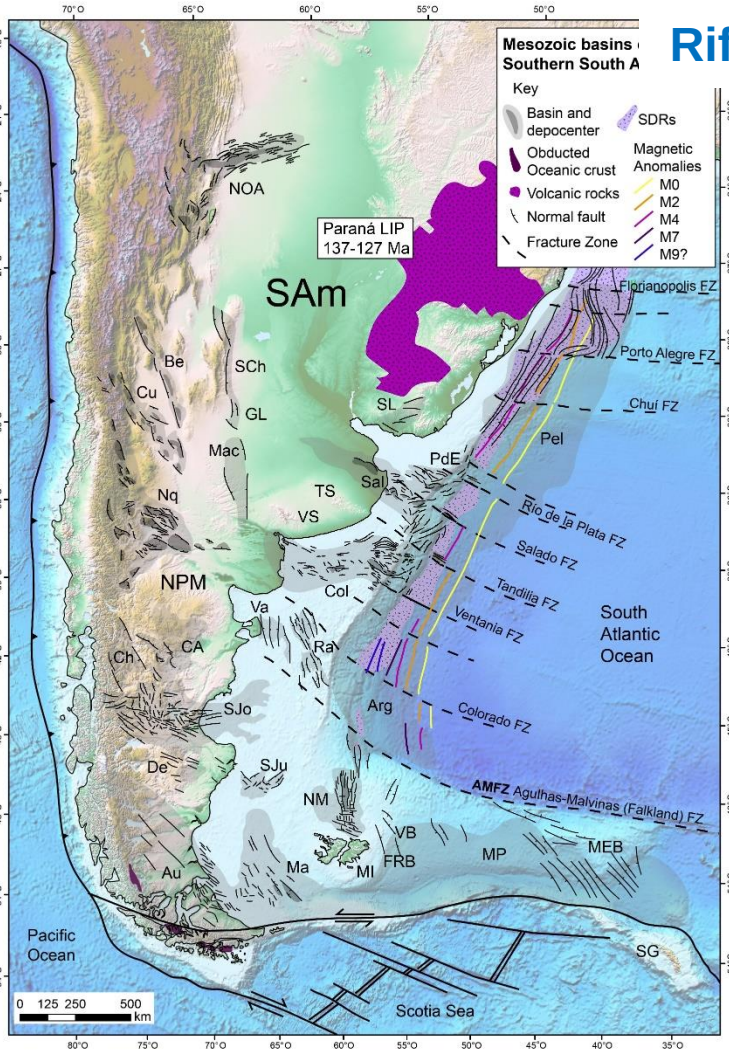


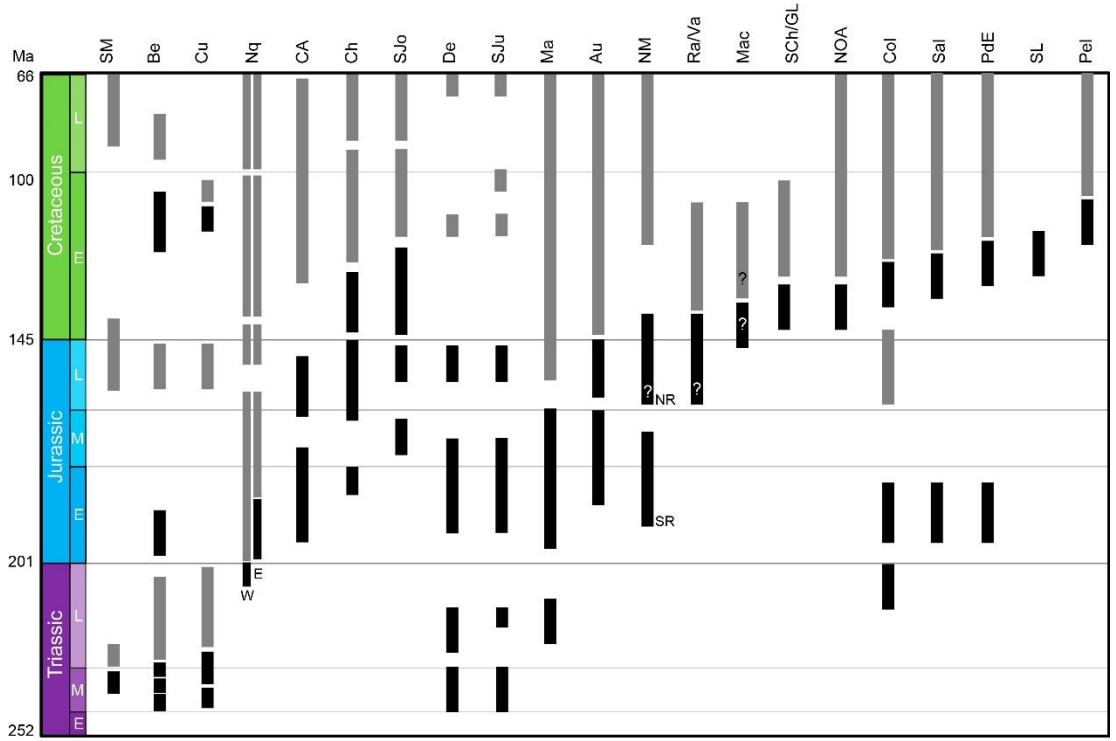
- ✓ *FS3 faults are oriented NE-to-NNE and are restricted to a 200 km wide stripe along the outer continental crust domain. Their inboard dipping character is synthetic with the surfaces bounding SDR wedges.*



Rifting Chronology: South American basins

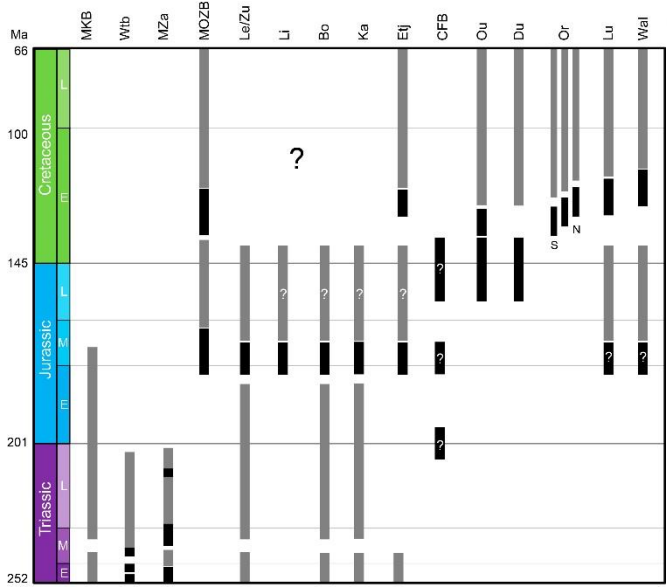
- ✓ *Triassic: Cuyo basins*
- ✓ *Jurassic: Neuquén, Cañadón Asfalto, Austral, Malvinas basins*
- ✓ *Jurassic/Cretaceous: Colorado, Salado basins*
- ✓ *Early Cretaceous: Macachín, Sierras Chicas, NOA basins*

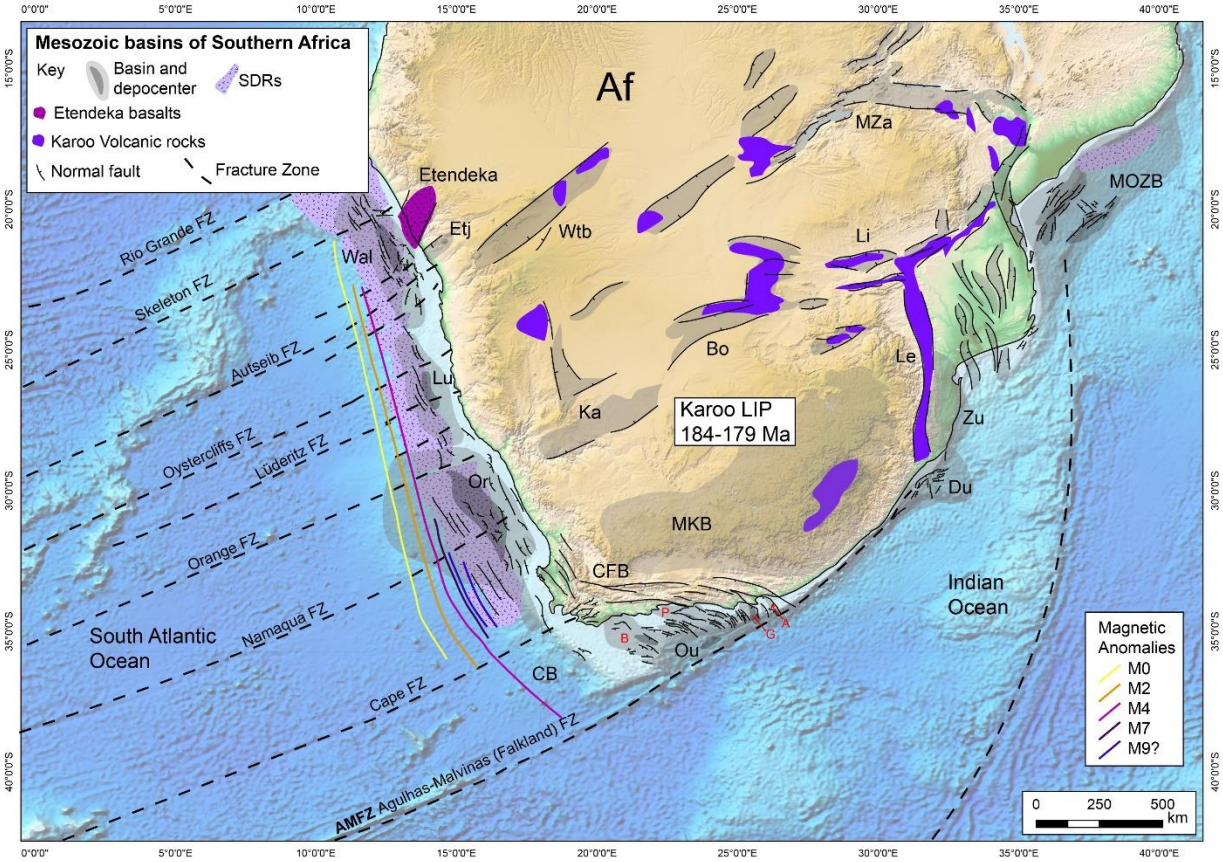




Rifting Chronology: South African basins

- ✓ *Karoo I rifting (Carboniferous – Triassic)*
- ✓ *Karoo II rifting (Early Jurassic)*
- ✓ *Mozambique basin (Mid-Jurassic)*
- ✓ *Outeniqua basin (Late Jurassic)*
- ✓ *South Atlantic basins (Early Cretaceous)*





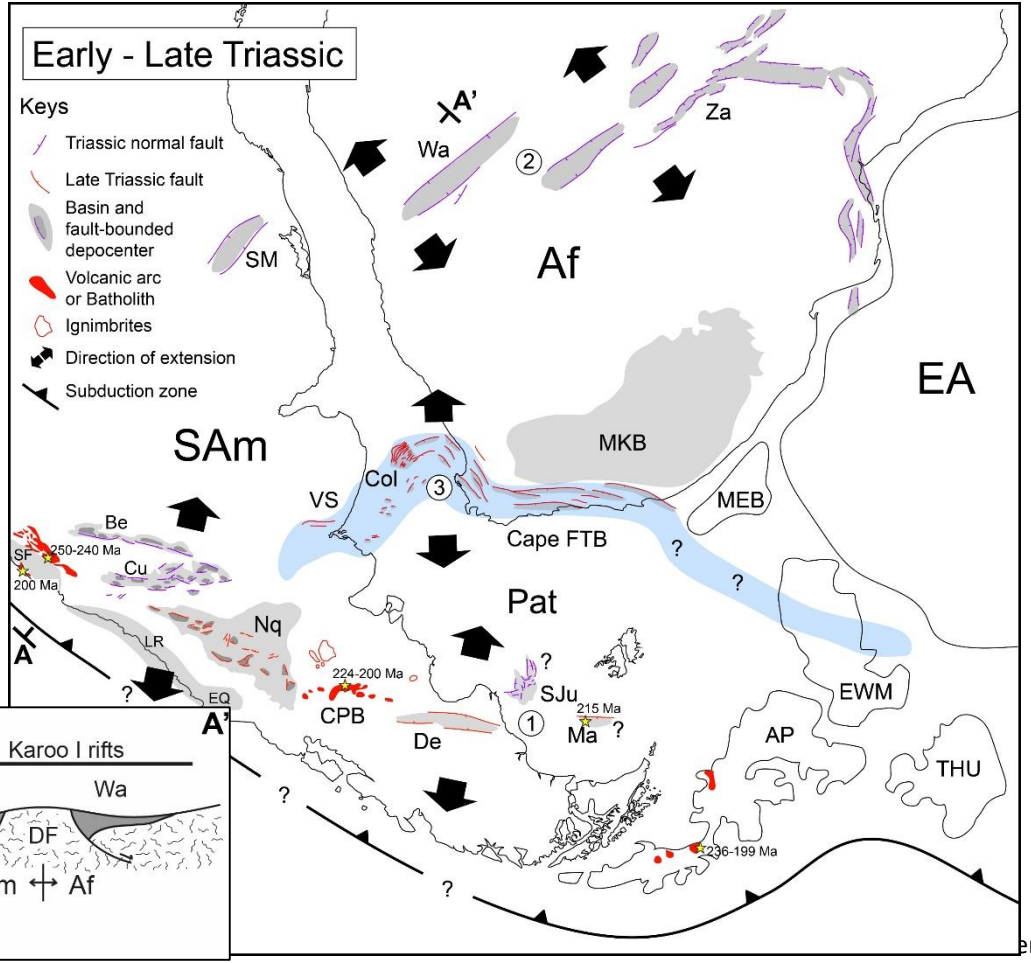
Late Triassic

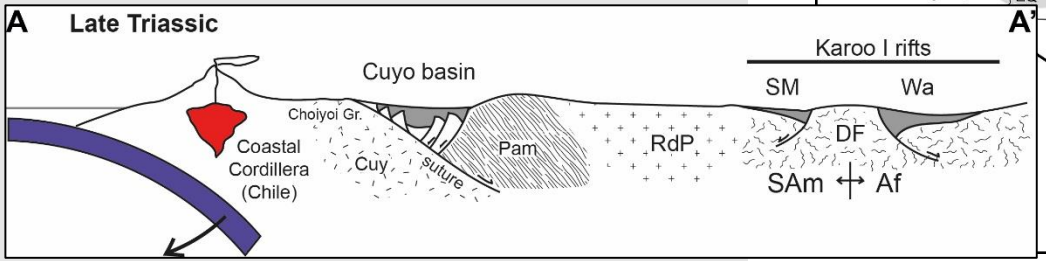
Subduction

- ✓ *Volcanic arc in Chile and Antarctic Peninsula.*

Basins

- ✓ ***1**: Retroarc extension and suture extensional reactivation along the Gondwana Margin (Cuyo basin, Precuyano of Neuquén, Deseado Massif and Malvinas basin)*
- ✓ ***2**: Triassic intracontinental rifts in Africa (Karoo I), extend into South America (Santa María basin).*
- ✓ ***3**: Negative inversion of the Ventania/Cape FTB (Colorado basin).*



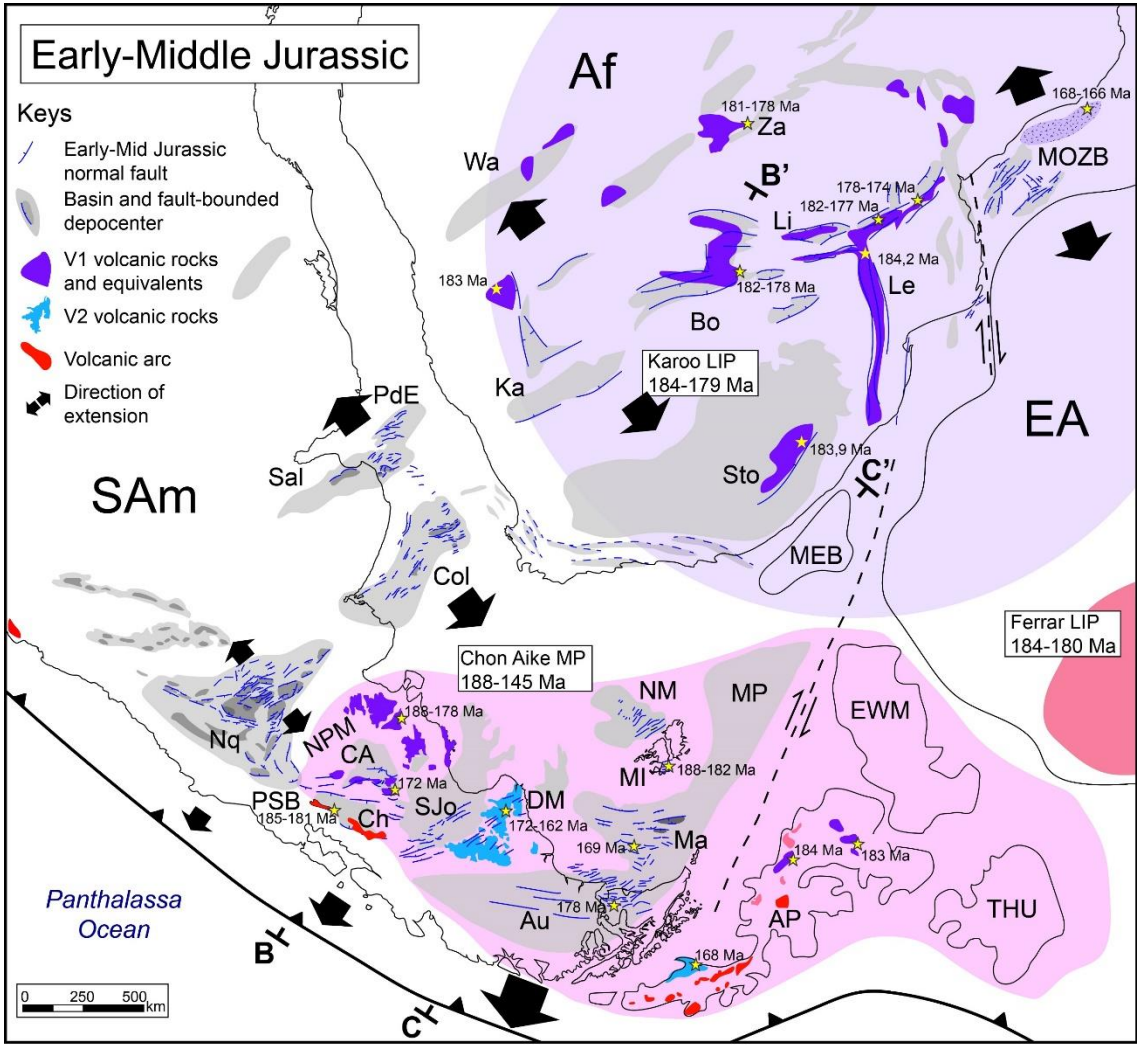


Early-Mid Jurassic

- ✓ *Karoo II rifting in Africa, **impingement of the Karoo plume** in SE Africa in the Early Jurassic. Colorado and Salado basins' main depocenters formed during this stage.*

Subduction

- ✓ *Differential trenchward arc migration: Subcordilleran Batholith → Patagonian Batholith.*
- ✓ ***Chon Aike Magmatic province**, associated with retroarc extension. Peak of magmatism in the Middle Jurassic. Formation of the Cañadón Asfalto and Chubut basin, and the Malvinas and Austral basins (Serie Tobífera).*
- ✓ *Rotational extension: differential rollback (Echaurren et al., 2017).*
- ✓ *Strike slip along the East/West Gondwana boundary.*
- ✓ *A **Slab tear** between Patagonia and Antarctica would provide a border condition for the differential rollback model (Lovecchio et al., 2019).*



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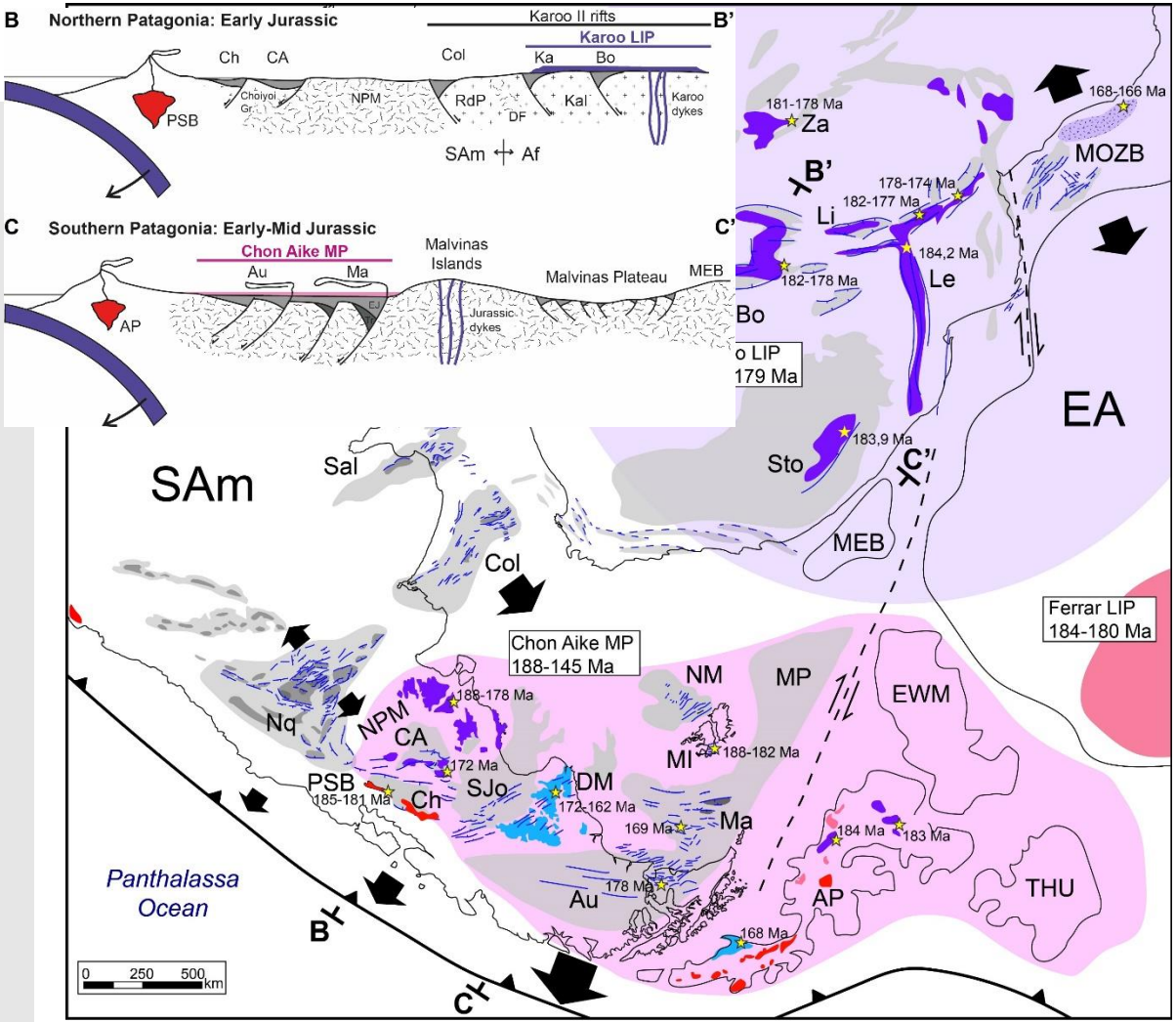
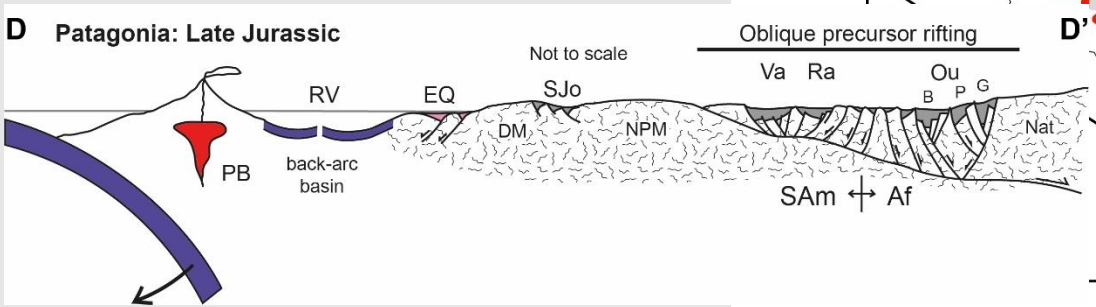
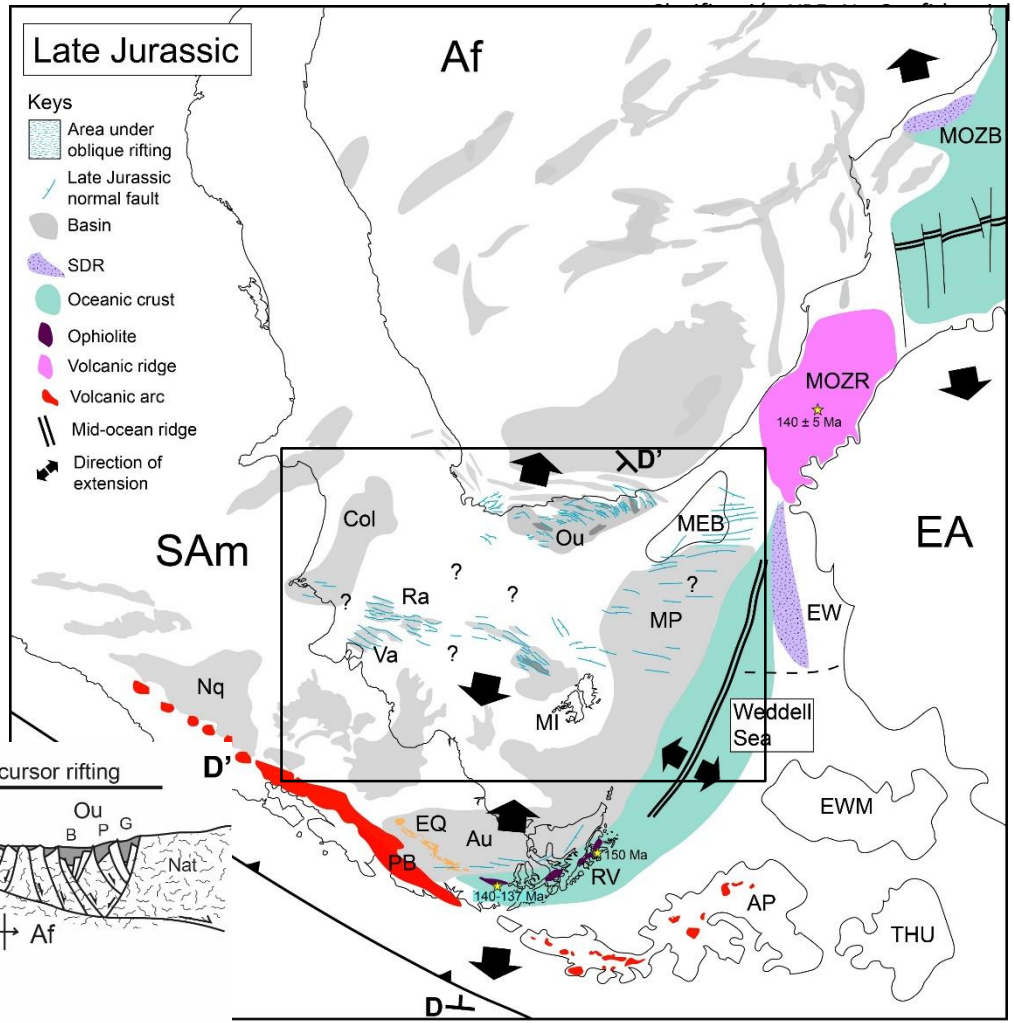


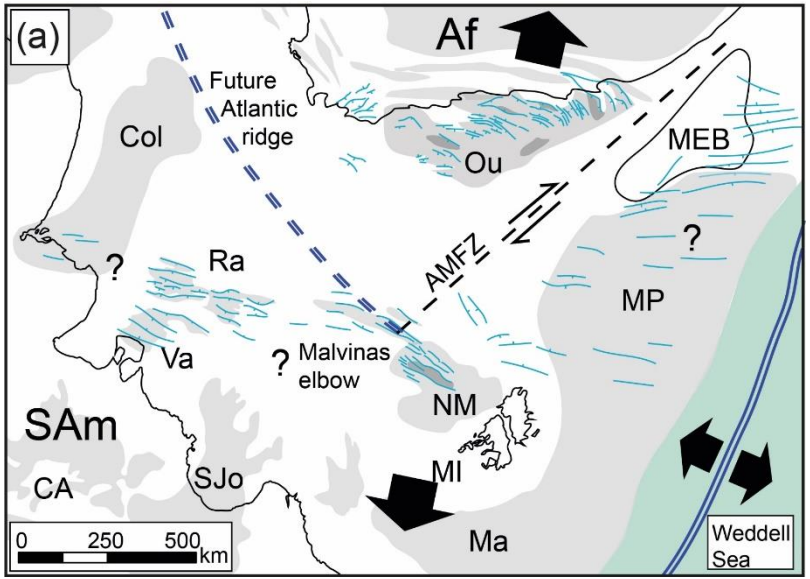
Late Jurassic

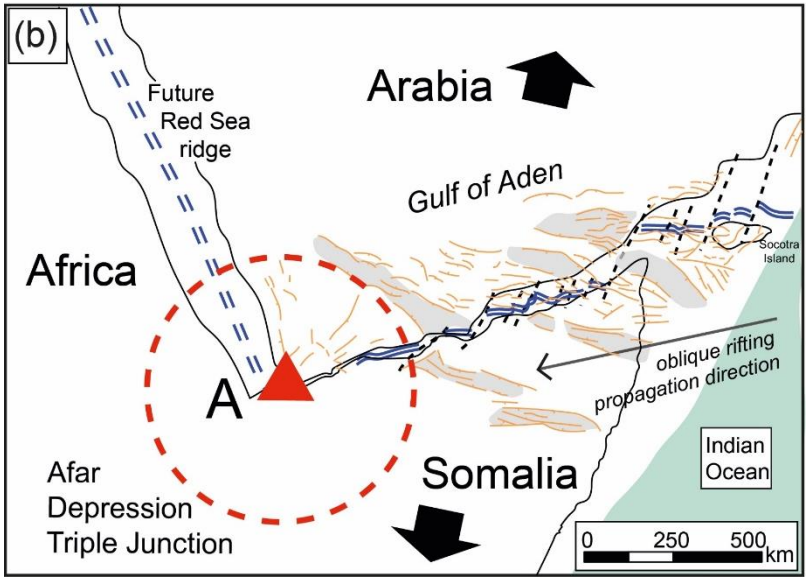
- ✓ *Opening of the Mozambique channel and the **Weddell Sea** (induced by a thermal anomaly produced by the asthenospheric window).*
- ✓ ***Oblique rifting** responsible for the formation of the Outeniqua basin, the basins in the Malvinas Plateau, and the Rawson/Valdés basins.*
- ✓ ***Retroact extension** produces a new pulse of volcanism in the Late Jurassic restricted to the Andean Region (El Quemado Complex and equivalents) and the opening of the Rocas Verdes back-arc basin.*





Oblique rifting: the Gulf of Aden vs. the southern South Atlantic





Rawson-Outeniqua segment

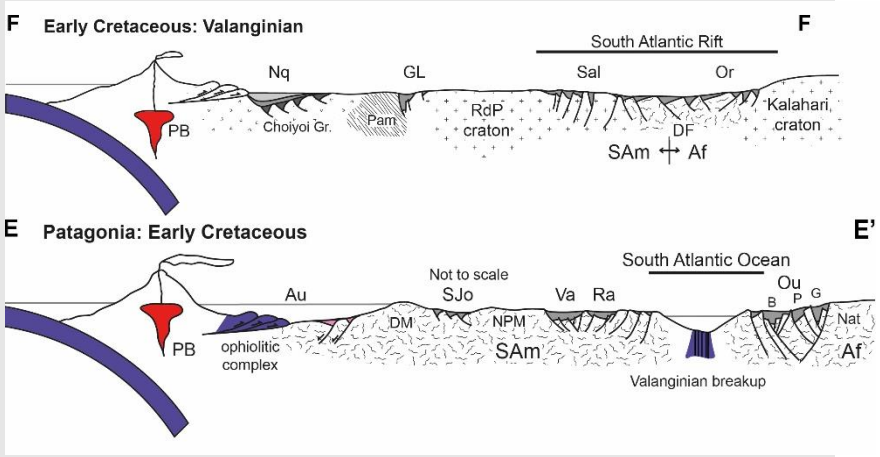
- ✓ *Core of the Gondwanides orogen (Late Paleozoic).*
- ✓ *One free border (Weddell Sea).*
- ✓ *The system evolved through a third branch: the South Atlantic Ocean.*
- ✓ *The Agulhas-Malvinas FZ evolved as a strike-slip fault system (probably due to a change in the orientation of stress to a more E-W direction).*

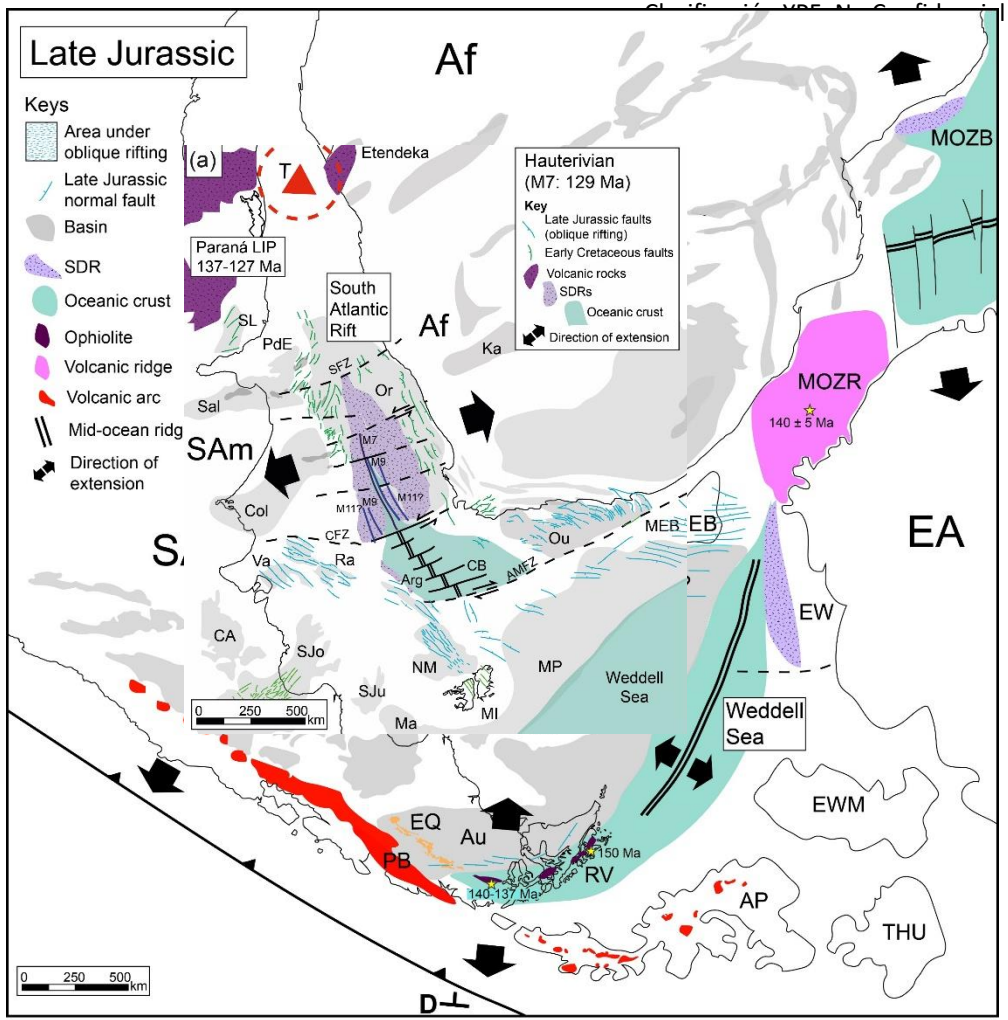
Gulf of Aden

- ✓ *Gulf of Aden, between Somalia and the Arabian plate*
- ✓ *One free border (Indian Ocean).*
- ✓ *Rifting propagates to the W (Afar plume).*
- ✓ *The system evolved through a third branch: the Red Sea. The Gulf of Aden continued to generate oceanic crust.*

Early Cretaceous

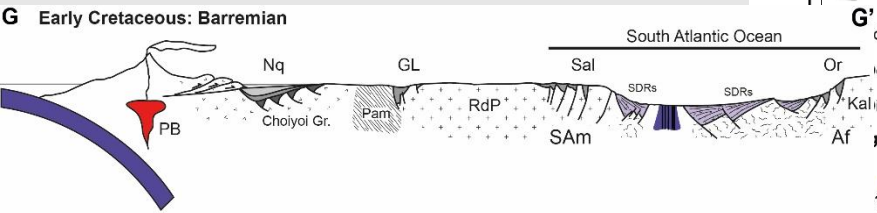
- ✓ *The **South Atlantic Rift** formed between South America and Africa, was a 500 km wide, highly-segmented rift system produced by passive rifting (the Paraná-Etendeka plume impingement occurred after onset of rifting).*
- ✓ *Some Neoproterozoic Brasiliano-Panafrican basement heterogeneities might have played a role in rift localization.*
- ✓ ***Intra-Valanginian unconformity** in the Outeniqua basin marks the onset of the Agulhas-Malvinas Fracture Zone activity (AMFZ), interpreted as the onset of oceanic crust accretion along the South Atlantic ridge (Broad et al., 2012).*

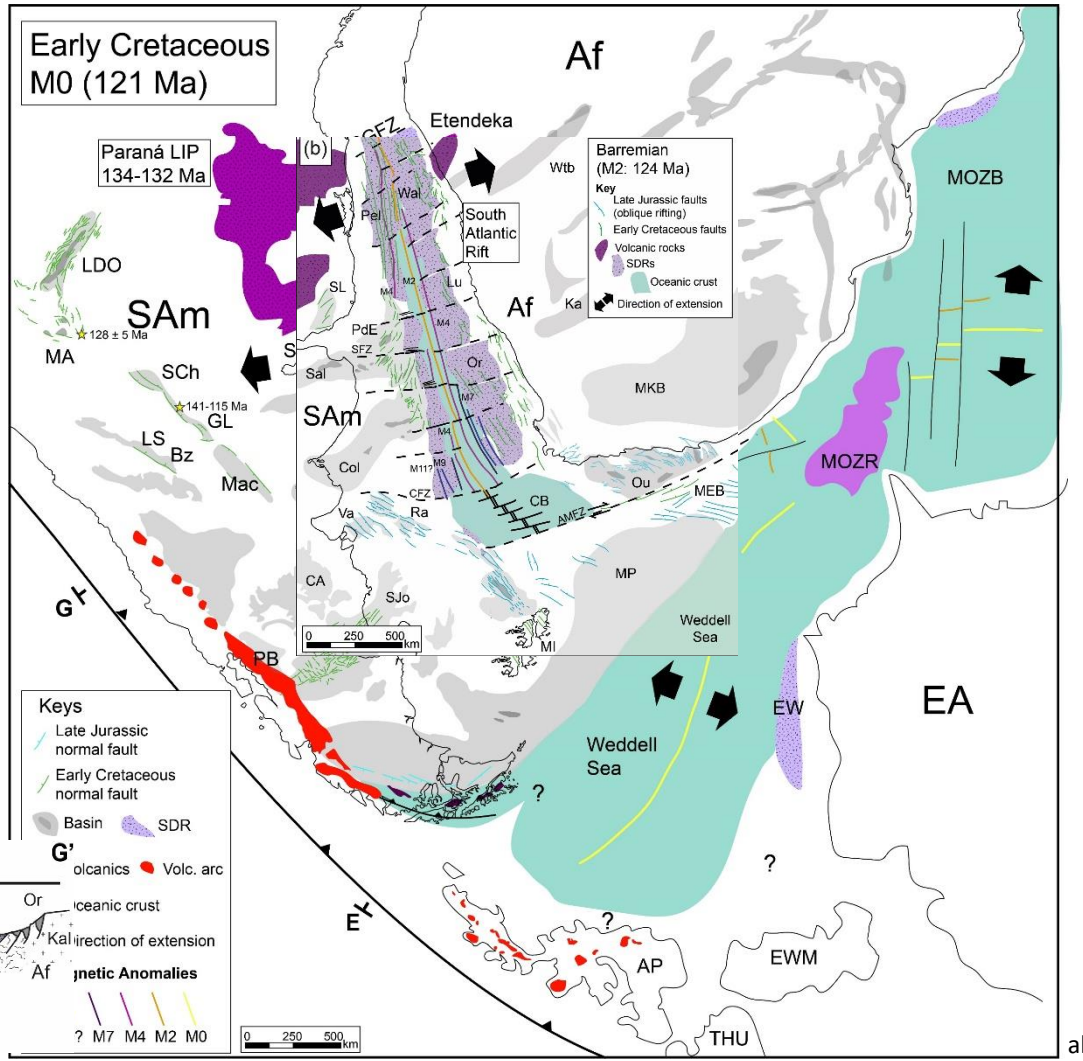




Early Cretaceous

- ✓ *Between the Agulhas-Malvinas FZ and the Colorado FZ (Rawson-Outeniqua segment), the margin is **magma-poor**.*
- ✓ *North of the Colorado/Cape FZ, the conjugate margins are **magma-rich** and characterized by SDRs on the continent-ocean transition.*
- ✓ *Paraná-Etendeka volcanism, previous to SDR emplacement in the Pelotas segment (Stica et al., 2014).*
- ✓ *In South America, extensional reactivation of sutures around the Río de la Plata craton and other structures (continental rifts).*
- ✓ *Closure of the Rocas Verdes marginal basin (120 Ma). Initiation of the foreland stage in the Austral basin.*





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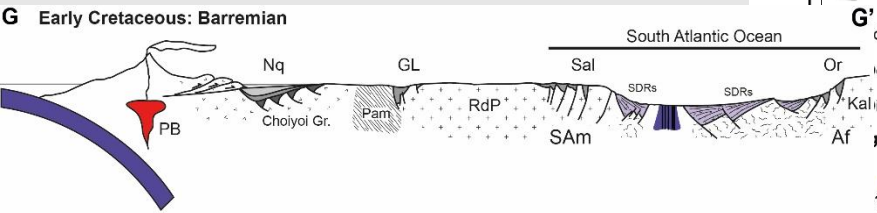

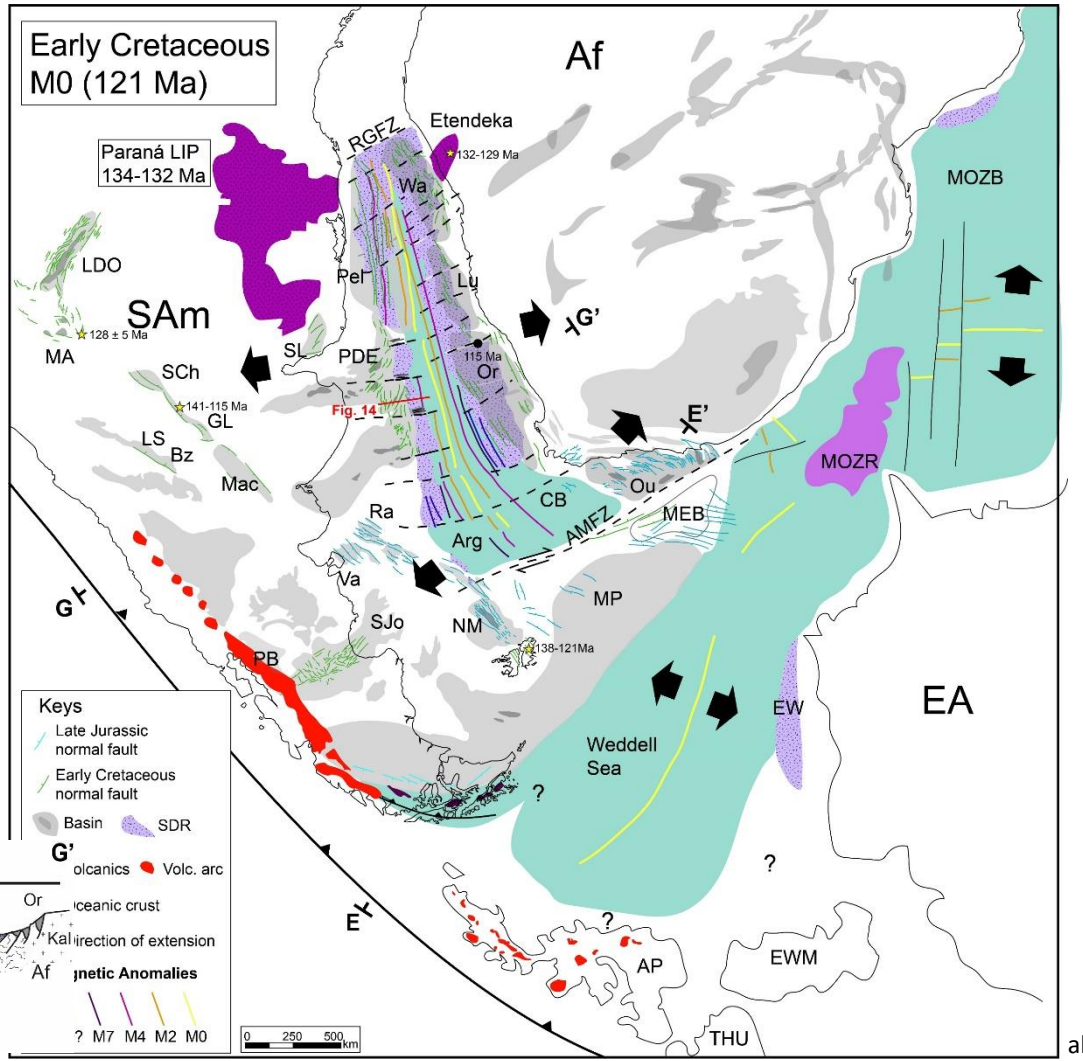

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Conclusions

1. *Mesozoic rifting in SW Gondwana was a complex, multi-episodic process strongly related to subduction dynamics.*
2. *The Colorado and Salado basins, offshore Argentina, are part of the Karoo Rift system.*
3. *The South Atlantic Rift was a highly-segmented 500 km-wide rift system emplaced between South America and Africa, along basement discontinuities.*
4. *Spreading initiated in the south, between the Colorado and Agulhas-Malvinas fracture zones, an area intensely deformed in the core of the Late Paleozoic Gondwanides orogen.*
5. *Late Jurassic oblique rifting, recorded in the Rawson/Valdés-Outeniqua and Malvinas segments, preceded formation the magma-poor southernmost segment.*
6. *North of the Colorado fracture zone, once rifting was already established, magma-rich margins formed product of the interaction with the Paraná-Etendeka LIP.*