Structural inheritance and evolving rift kinematics in transform and oblique rift systems: A comparison of global examples

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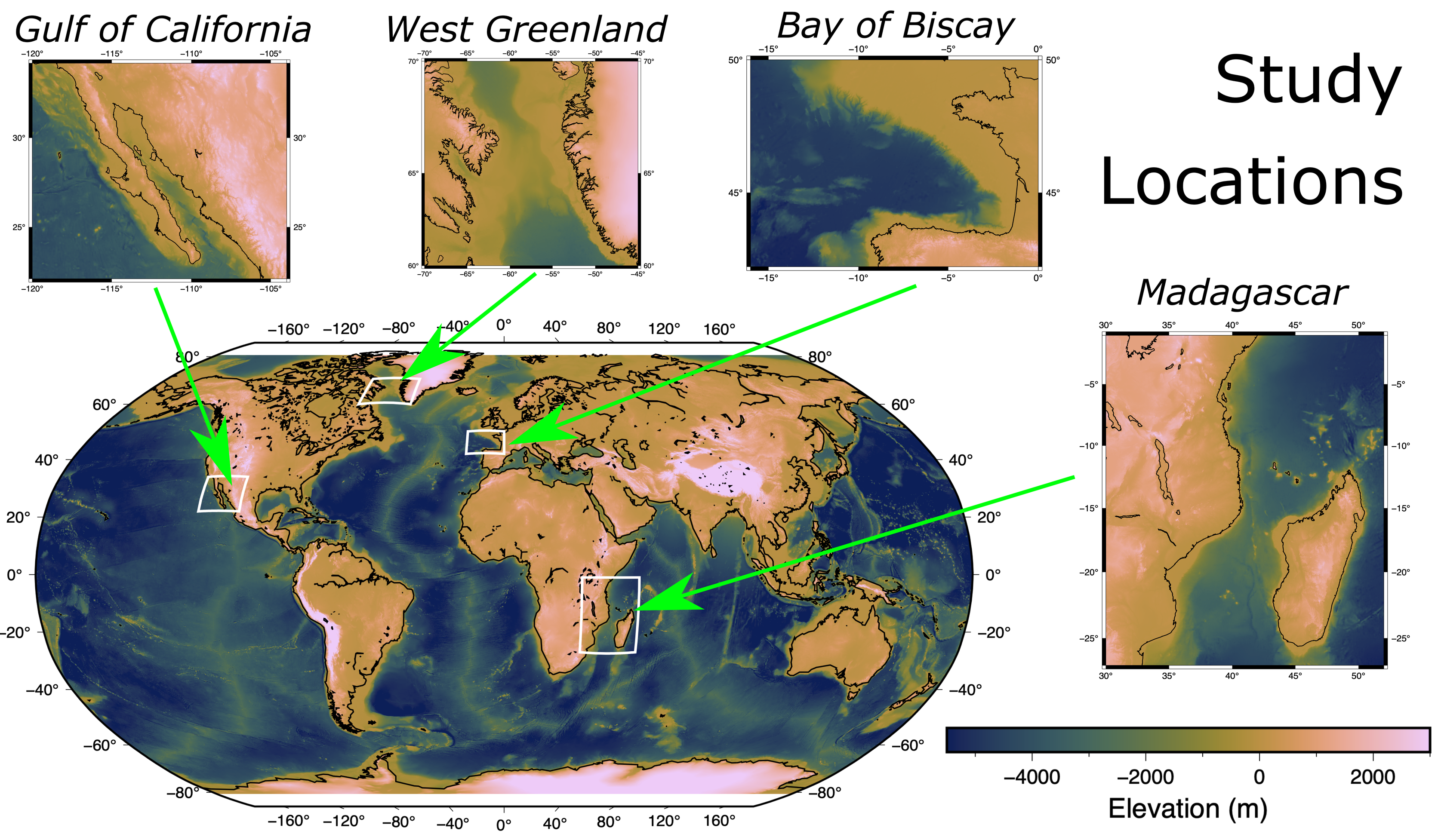
Introduction

- The development of oblique rifts and transforms is influenced by a number of interrelated factors (Brune et al., 2018; Farangitakis et al., 2019, 2020).
- The relative importance, and prevalence, of evolving rift kinematics and structural inheritance amongst rift systems globally is insufficient.
- As such, **the aim of this study is to determine to what extent these two processes prevail and answer the question–** *Is there a tectonic formula for the formation of oblique and transform rifts/ margins?*
- Structural inheritance refers to heterogeneities produced by previous geological processes that proceed to influence subsequent geological events.
- Changes in the orientation and magnitude of far-field forces mean that as a rift proceeds from inception to possible breakup.
- The kinematic regime may evolve such that the orientation of extension with respect to the rift boundary is spatiotemporally variable.
- Such changes in rift kinematics allow structures established under one kinematic regime to be subsequently reactivated, overprinting multiple rift episodes, whilst variable extension magnitude may introduce further complexities.

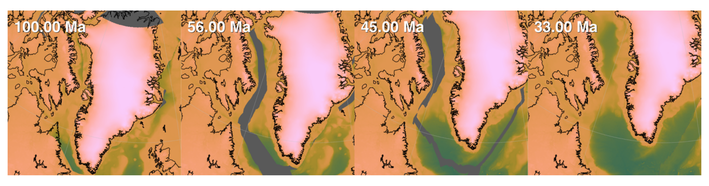
Approach

- 4 different regions with oblique rifts of various types are compared: West Greenland (Davis Strait), East Africa (Madagascar), Bay of Biscay and Gulf of California.
- Using GPlates (Müller et al., 2018) we extracted key plate kinematic parameters from published reconstructions (Matthews et al., 2016) during the dispersal of Pangaea (Frizon De Lamotte et al., 2015).
- The aim of this was to determine if any common aspects can be elucidated from the kinematic evolution of different oblique rifts.

Study Locations



West Greenland



West Greenland plate reconstruction (Matthews et al., 2016).

- Mesozoic-Cenozoic rifting between Greenland and North America created the Labrador Sea and Baffin Bay, while leaving preserved continental lithosphere in the Davis Strait, which lies between them (Peace et al., 2017).
- Inherited crustal structures from a Palaeoproterozoic collision have been hypothesized to account for the tectonic features of this rift system (Peace et al., 2017, 2018; Heron et al., 2019).

Plate model results: *Peaks in the velocity of Greenland w.r.t. N. America at ~50 and 80 Ma are coincident with significant changes in the velocity azimuth and interpretations of the timing of transform development.*

Conclusion: *Changes in plate kinematics for the NW Atlantic region transformed an originally near orthogonal rift into a oblique-transform margin that localised at a region where the rift intersected large-scale orogenic structure suggesting inheritance played a role (Davis Strait).*

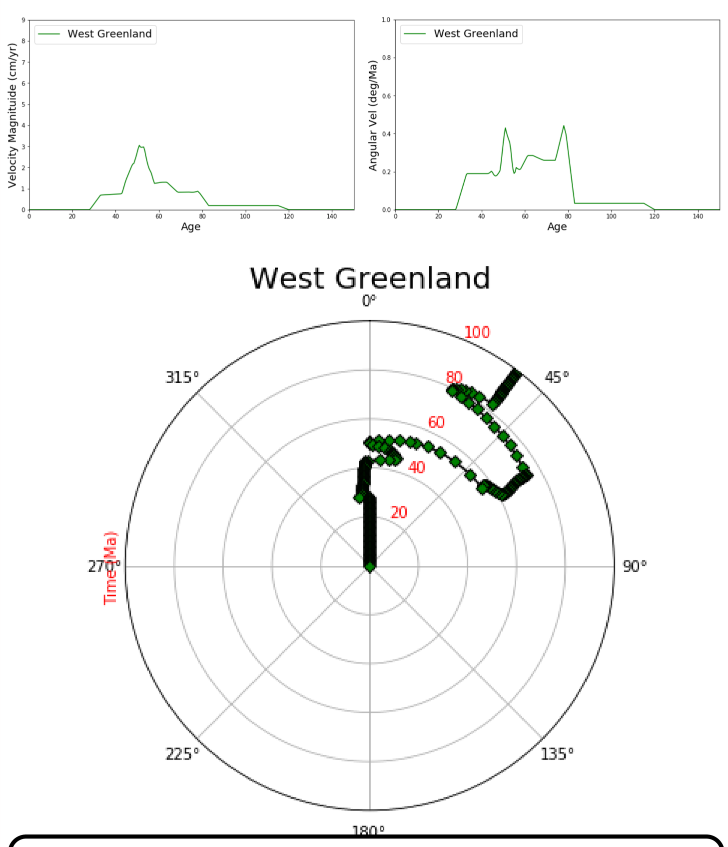
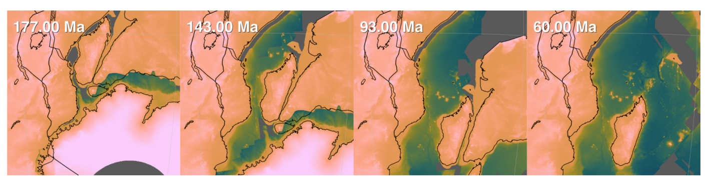


Plate kinematic parameters for Greenland w.r.t N.America during the opening of the Labrador Sea/Baffin Bay extracted from Matthews et al. (2016) in GPlates.

Madagascar



East Africa plate reconstruction (Matthews et al., 2016).

- Jurassic breakup of East and West Gondwana simultaneously opened the Western Somali and the Mozambique Basins (Peace et al., 2019). These rifts seem to follow inherited Permo-Triassic weaknesses and were linked by the Davie and/or Rovuma strike-slip systems.
- New constraints on the initial opening directions of these basins indicate shear tectonics played a substantial role (Phethean et al., 2016; Mueller and Jokat, 2017).
- The Davie and Rovuma strike-slip systems crosscut basement fabrics and do not follow the trends of older basins (Macgregor, 2018) i.e. inheritance within strike-slip zones is unapparent. However, the location of these strike slip systems was dictated by the overlap of near orthogonal rifts, which themselves followed lithospheric weaknesses.

Plate model results: *Numerous changes in velocity azimuth and magnitude for Madagascar w.r.t Africa are documented from ~180 –120 Ma which could have contributed to the oblique rifting.*

Conclusion: *Initiated as a transform/oblique rift as a kinematic necessity to accommodate nearby orthogonal rifts. Changes in plate kinematics during early evolution likely influenced development as transform/oblique region.*

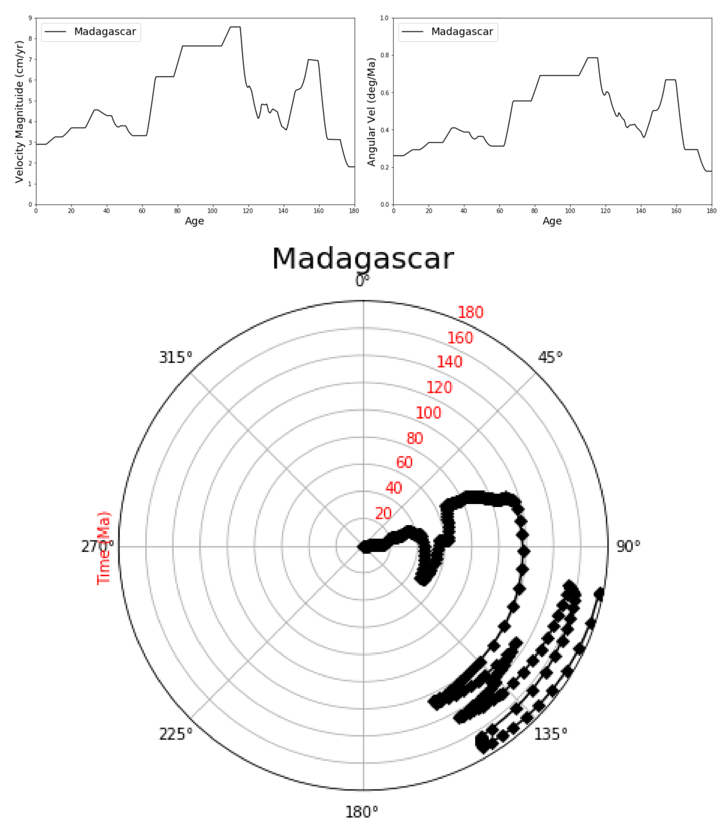
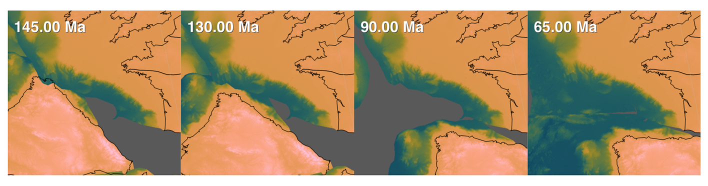


Plate kinematic parameters for Madagascar w.r.t Africa during the opening of the Indian Ocean extracted from Matthews et al. (2016) in GPlates.

Bay of Biscay



Bay of Biscay plate reconstruction (Matthews et al., 2016).

- V-shaped oceanic basin corresponding to a failed arm of the southern North Atlantic.
- Opened during several rifting periods, with extension starting in the Middle/Late Triassic and the onset of major rifting in Late Jurassic (Cadenas et al., in review; Cadenas et al., 2018; Boillot et al., 1979; Zamora et al., 2017).
- Subsequently partially closed during the Alpine orogeny.
- From the Late Jurassic to Barremian transtension dominated producing NW-SE and NE-SW oriented structures, whereas from the Late Aptian to Late Cretaceous near N-S hyperextension occurred (Tugend et al., 2014; Cadenas et al., 2018; Cadenas et al., in rev.).
- Three end member kinematic models have been proposed: a scissor-type model (Vissers and Meijer, 2012), a strike-slip model (Le Pichon and Sibuet, 1971; Olivet, 1996) and a mixed model, including a period of transtension, with the development of pull-apart basins, and orthogonal extension (Jammes et al., 2009).

Plate model results: *Numerous changes in velocity azimuth and magnitude for Iberia w.r.t NW Europe are documented from ~180 –90 Ma which could have contributed to the oblique rifting. Two variations outstand at around 150 Ma and 125 Ma, supporting kinematic variations proposed on the basis of geological and geophysical observations.*

Conclusion: *During the onset of major rifting, it Initiated as an oblique, transtensional rift with a subsequent change in kinematics leading to hyperextension. The nature of the obliquity would have evolved through time. Inheritance also probably played a key role.*

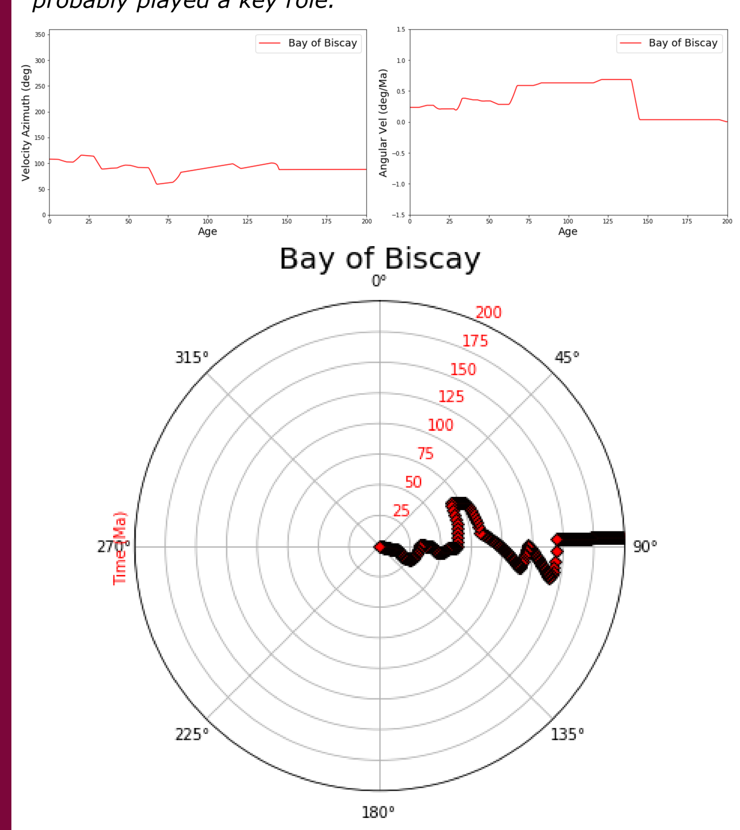
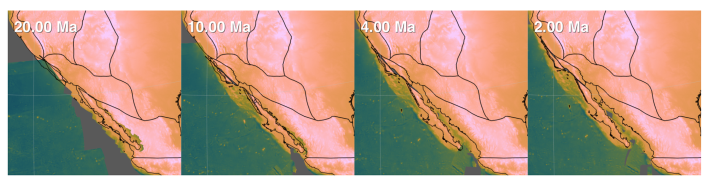


Plate kinematic parametersfor Iberia w.r.t. NW Europe during the opening of the Bay of Biscay extracted from Matthews et al. (2016) in GPlates.

Gulf of California



Gulf of California plate reconstruction (Matthews et al., 2016).

- The Gulf of California consists of 7 en-echelon dextral transform-spreading ridge systems with variable structural styles ranging from pull-apart basins to narrow rifts, to magmatic and amagmatic rifting (Lizarralde et al., 2007).
- Dextral transform motion is thought to have started about 20 Ma in the area, however the proto-Gulf extension is thought to have started around 12 Ma (Bennett and Oskin, 2014).
- A 15° clockwise rotation in the relative motion between the plates at ~8 Ma increased rift obliquity and favours strike-slip faulting (Bennett and Oskin, 2014) leading to shearing which localized in en-echelon strike-slip shear zones, which develop into nascent pull-apart basins by 6 Ma (Bennett et al., 2013) (Umhoefer et al., 2018).
- Change in plate motion 6 Ma (Bennett and Oskin, 2014) that led to the transtensional opening of the Gulf from south to north (Umhoefer et al., 2018).

Plate model results: *Global models show that from ~30 Ma the Gulf of California underwent a progressive rotation of extension direction. However, many of the smaller-scale kinematic changes inferred in previous work are not represented in the global models.*

Conclusion: *Many of the small kinematic changes that have shaped the Gulf of California Rift are not apparent in the global models but it is know from previous work that these likely influenced the oblique nature of this rift.*

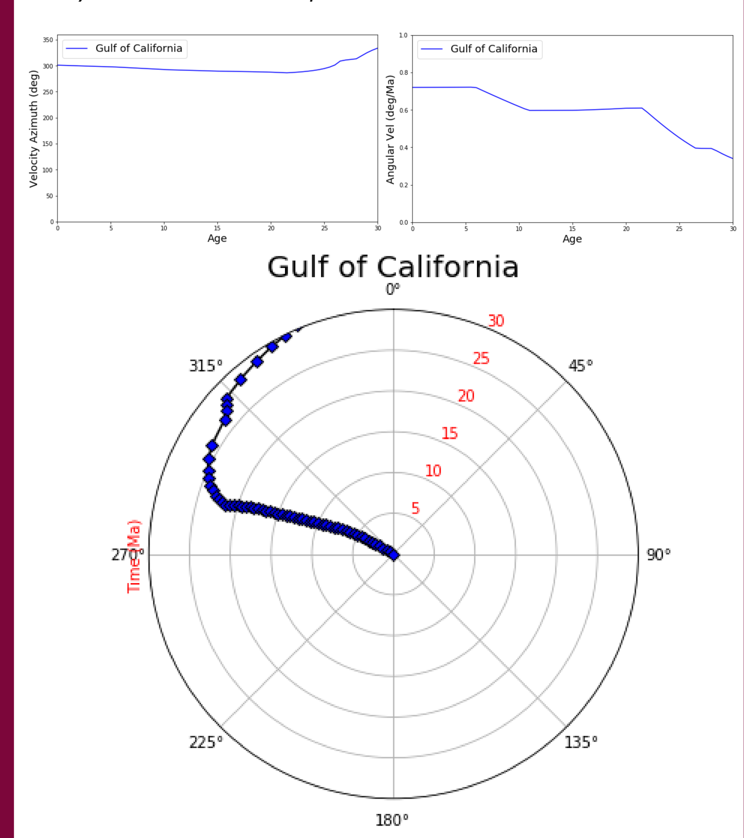


Plate kinematic parameters for Baja California w.r.t. N.America during the opening of the Gulf of California extracted from Matthews et al. (2016) in GPlates.

Common themes and conclusions

- Oblique rift and transforms are a kinematic necessity of continental breakup
- Change in rift orientation is common amongst the margins studied.

However, the magnitude, duration and orientation of such changes is not consistent or systematic.

- Structural inheritance at crustal and lithospheric scales is common for all areas considered but again the nature of this is variable
- Overall, although some common themes exist for the evolution of the studied regions, often including the role of structural inheritance and a change in extension direction, there does not appear to be a single 'pathway' to transform/oblique rift/margin formation.

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Acknowledgements: All maps are plotted with the 'Batlow' colourbar (Crameri, 2018).

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