Influence of the mechanical coupling and inherited strength variations on the geometry of continental rifts.

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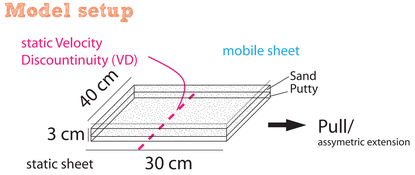
Introduction

The geometry of continental rifts is strongly controlled by the rheology of the lithosphere at the onset of rifting. This initial geometry will further control the development of ocean spreading centers and the structure of adjacent passive margins. Therefore, understanding the influence of coupling between the different layers of the lithosphere with and without laterally variable strength in the crust is key when investigating continental rifts. In this study we infer the influence of coupling in the crust on the rift geometry by means of crustal scale analogue experiments, where we characterize the response of the crust to deformation in terms of the strength ratio between brittle and ductile crust. The degree of coupling has been varied for setups containing or not a pre-existing weak zone.
We use the concept of strength ratio to compare the models to nature. The obtained geometry give then a idea of the coupling conditions under which rifting developed in nature.

Model setup

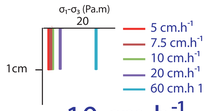


Two layers experiments consist of a lower ductile layer made of silicone putty and an upper brittle layer consisting of feldspar sand. Extension is induced by pulling a plastic sheet from under a fixed sheet in the direction of the arrow. In this way the velocity discontinuity is stationary.

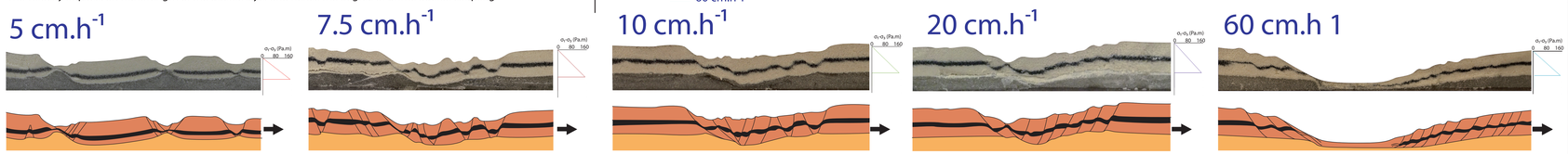
Coupling and rift geometry

Model

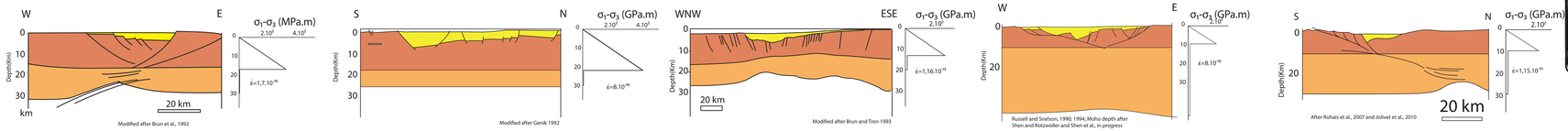
The velocity impacts on the strength of the ductile layer and hence the degree of brittle ductile coupling.



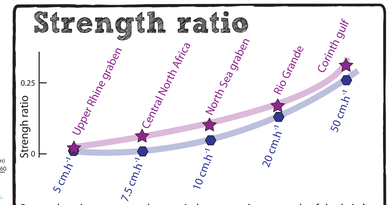
Variation of the ductile strength for the tested velocities



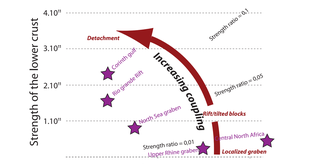
Nature



Strength ratio



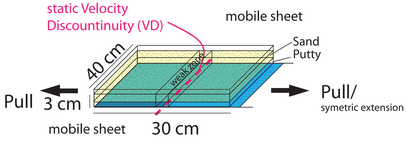
Strength ratio corresponds to ratio between the strength of the brittle and the ductile crust, thus reflects the degree of coupling Here, in the series of analogue models the strength ratio only depends of the strain rate at which the experiment has been deformed. In nature, the initial the initial thickness of the brittle and ductile crust as well as the strain rates are parameters that are a priori difficult to estimate.



Natural Analogues	Strain rate (E.s.)	Crustal Thickness (km)	Upper crust (km)	B/D Ratio	Strength Ratio
Upper Rhine graben	1.70E-16	30	17	1.3	0.009
Red Sea Rift	8.00E-16	30	22	2.8	0.015
North Sea Central graben	1.16E-15	20	15	1.9	0.060
Rio Grande Rift	8.00E-16	30	10	0.8	0.132
Corinth Rift	1.10E-15	30	10	0.8	0.298
East African Rift	4.00E-16	30	20	2.0	0.011

Coupling and activation of weak zone

Model setup

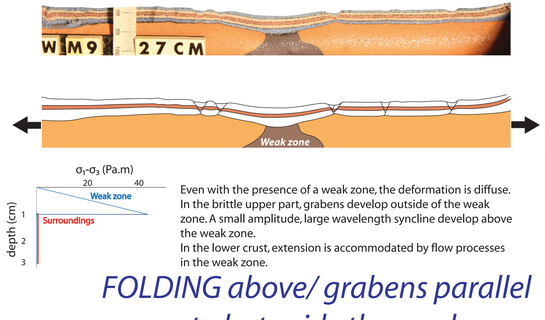


Two layers experiments consisting of a lower ductile layer made of silicone putty and an upper brittle layer consisting of feldspar sand. The model is lying on both sides on moving plastic sheets that are pulled apart. The model is dragged from below on each side and the velocity discontinuity is therefore fixed. The models contain a weak zone located above the velocity discontinuity.

With simple analogue models at crustal scale, we demonstrate that the activation of a weak zone, such as the Mozambic Ocean Suture Zone (MOSZ), required special conditions of coupling within the crust. The evolution of the coupling whitin the Afro-arabian crust is directly linked to the arrival of the Afar mantle plume.

During the mesozoic, series of parallel NNW trending grabens develop parallel to the MOSZ. Evidences for Mesozoic sedimentation above the MOSZ is given in Kalhil and Mc Clay (2001). From the deformation observed in our models, these sediments were deposited in the syncline formed above the weak zone.

During Eocene, and with the arrival in the system of the Afar mantle plume, deformation started to focus and localized above the MOSZ, leading to localized stretching in the upper crust, thinning and ultimately the formation of the Red Sea with sea floor spreading.

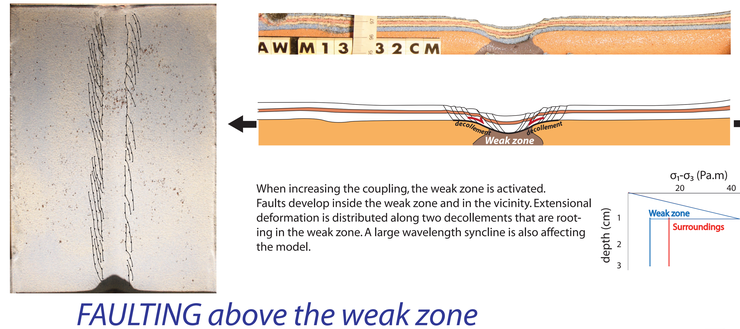


Even with the presence of a weak zone, the deformation is diffuse. In the brittle upper part, grabens develop outside of the weak zone. A small amplitude, large wavelength syncline develop above the weak zone.
In the lower crust, extension is accommodated by flow processes in the weak zone.

FOLDING above/ grabens parallel to but aside the weak zone

Syncline above/ grabens parallel to but aside the MOZS

Change in the coupling



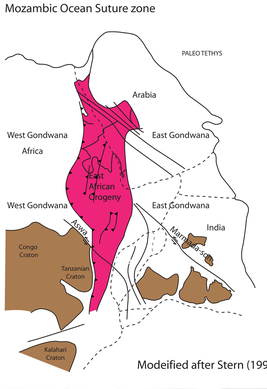
FAULTING above the weak zone

Localized deformation above the MOZS

Increasing coupling

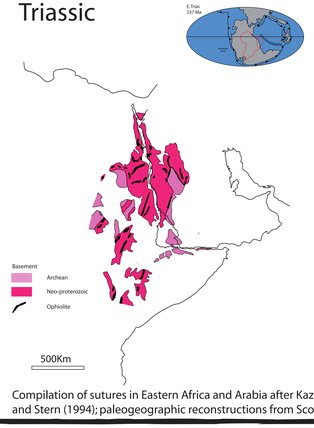
Activation of the Mozambic Ocean suture zone

Late Precambrian



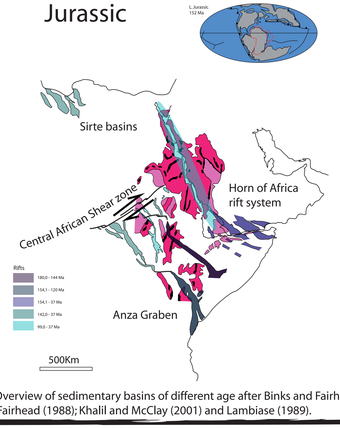
Modeified after Stern (1994)

Triassic

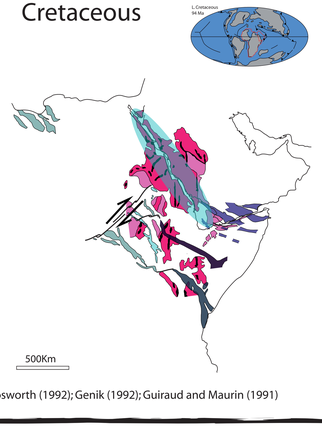


Compilation of sutures in Eastern Africa and Arabia after Kazmin (1978) and Stern (1994); paleogeographic reconstructions from Scotese (1997).

Jurassic



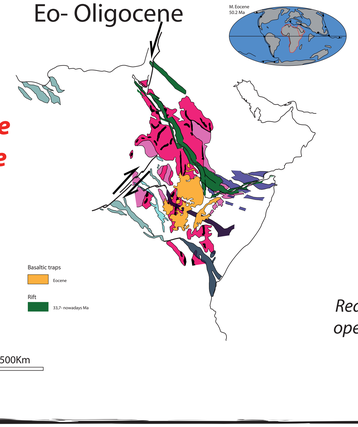
Cretaceous



Overview of sedimentary basins of different age after Binks and Fairhead (1992); Bosworth (1992); Genik (1992); Guiraud and Maurin (1991) Fairhead (1988); Khalil and McClay (2001) and Lambiase (1989).

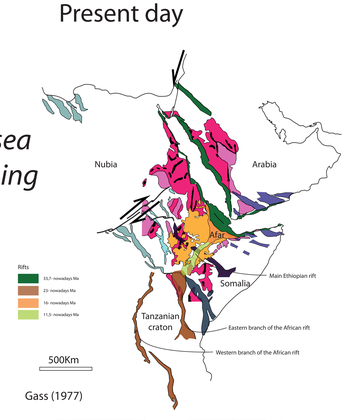
Onset of the Afar mantle plume

Eo- Oligocene



Red Sea opening

Present day



Gass (1977)

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