

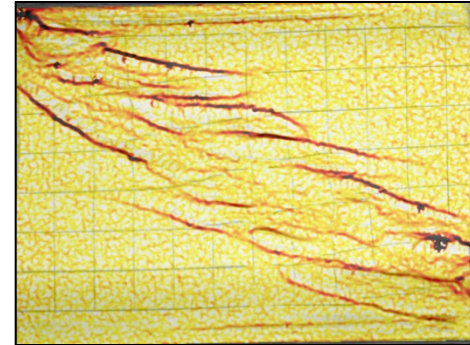
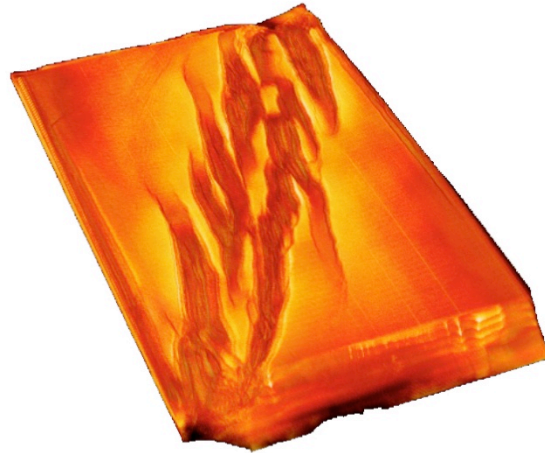
Are complex rift patterns the result of interacting crustal and mantle weaknesses, or of multiphase rifting? (An analogue modelling study)

EGU21-688

Authors:

Frank Zwaan*
Pauline Chenin
Duncan Erratt
Gianreto Manatschal
Guido Schreurs

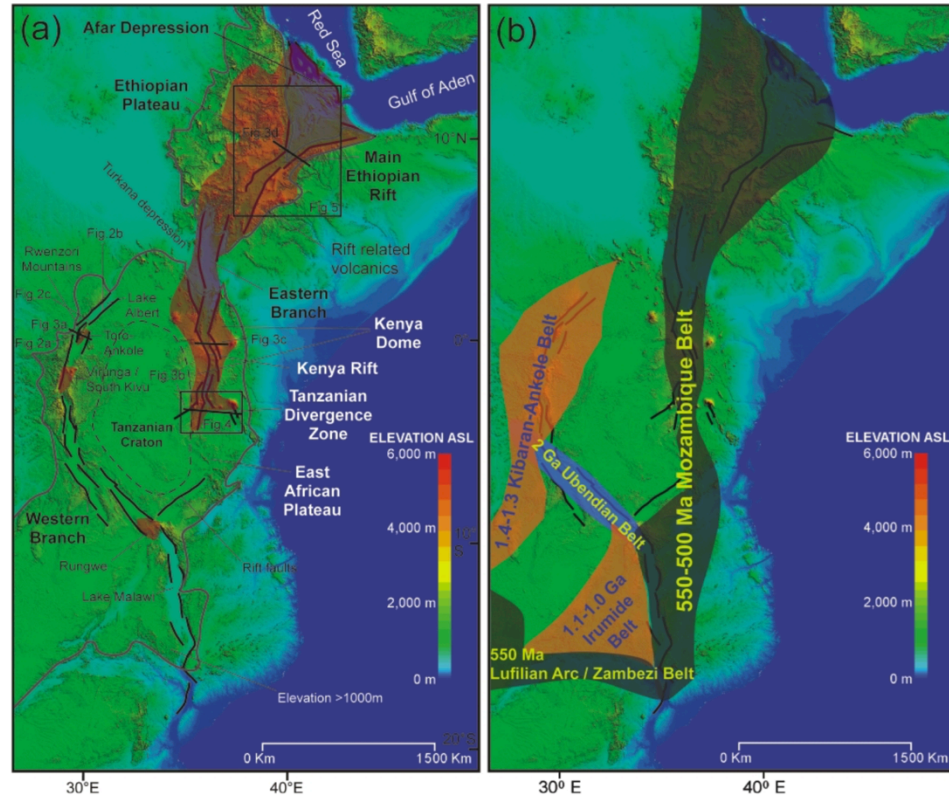
Univ. Bern
Univ. Strasbourg
*frank.zwaan@geo.unibe.ch



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Motivation: rift localization

- **Observation:**
 - Faulting occurs along pre-existing weaknesses (e.g. in the East African Rift)
- **Questions:**
 - What type of weaknesses? Crust, mantellic, or both?
 - Do these interact, how?

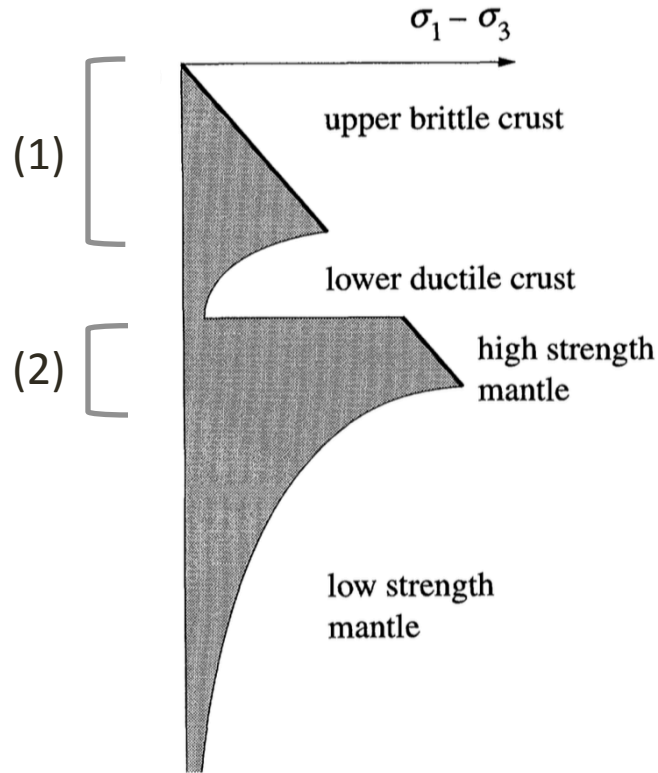


Motivation: rift localization

- **Previous (modelling) studies generally either**
 - Focus on either mantle or crustal weaknesses, or
 - Do not fully explore the 3D components of rift systems
- **Our aim is:**
 - To study the interactions between mantle and crustal weaknesses through 3D analogue models

Model design: lithospheric structure

- **Stable continental lithosphere contains two strong layers:**
 - (1) Upper brittle crust
 - (2) Strong upper mantle
- **Inherited weaknesses in these layers will control deformation**
 - Suture zones
 - Older faults
 - Etc.



Model design: basic set-up

- **Base plate configuration**

- Edge of base plate represents weakness in the upper mantle

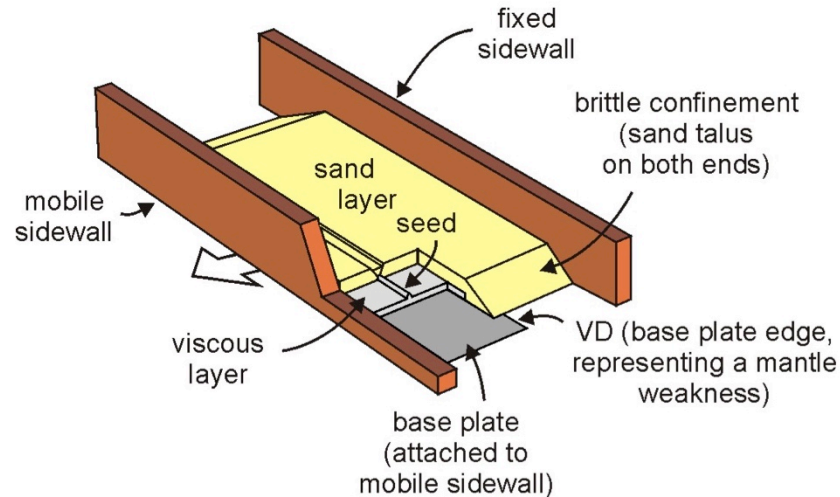
- **Brittle-viscous layering**

- 3 cm thick sand cover represents brittle upper crust
- 1 cm thick viscous layer represents ductile lower crust

- **Weaknesses in the brittle layer**

- Represent crustal weaknesses

3D cut-out sketch of model set-up



Zwaan et al. (2021) in Solid Earth Discussions

Model design: basic set-up

- **Base plate configuration**

- Edge of base plate represents weakness in the upper mantle

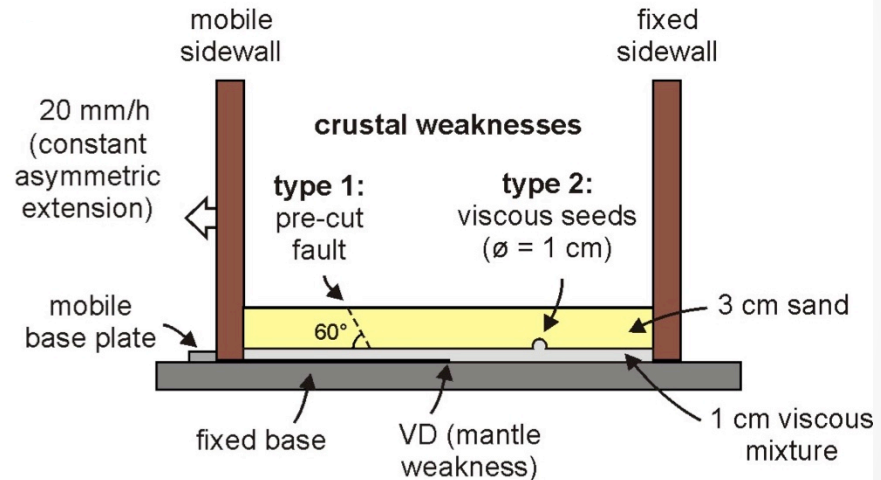
- **Brittle-viscous layering**

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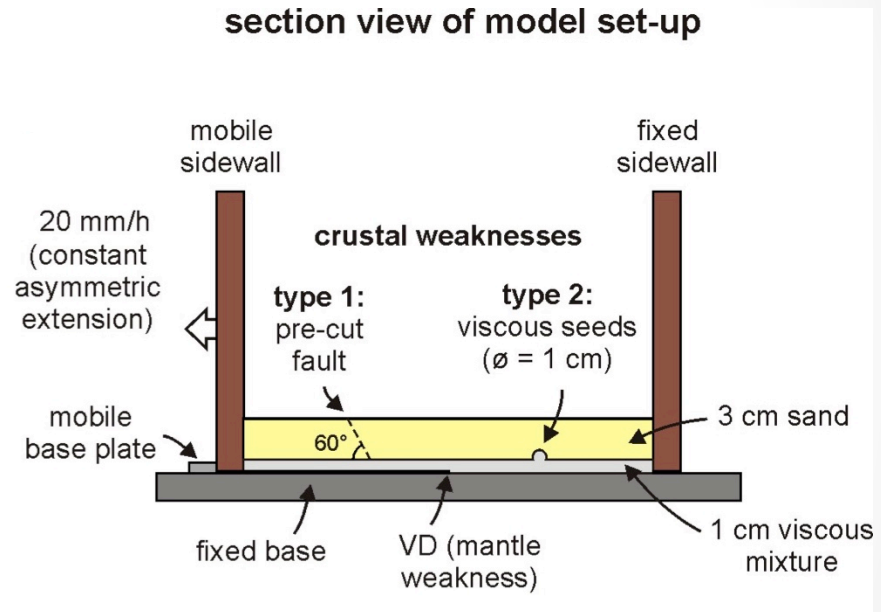
section view of model set-up



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Model design: basic set-up

- **Two crustal weakness types**
 - (1) Pre-cut faults in the brittle sand cover
 - (2) “Seeds” rods viscous material locally weakening the strong sand layer
- **Models are deformed as the (left) sidewall moves apart**
 - VD: velocity discontinuity (deformation represents a shear zone in the upper mantle)

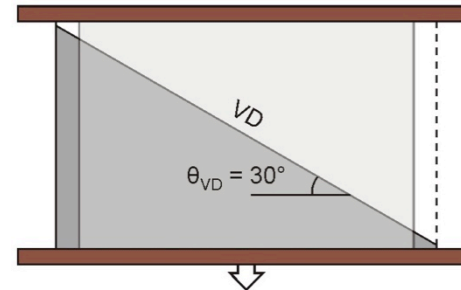
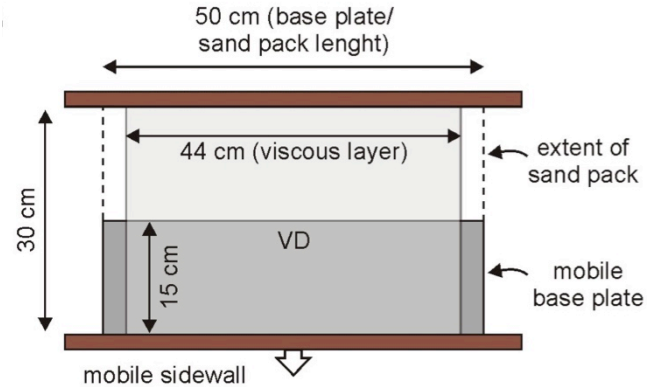


Zwaan et al. (2021) in Solid Earth Discussions

Model design: 3D weakness

- **Two model mantle weakness orientations:**
 - Parallel to model axis
 - 30° oblique to model axis

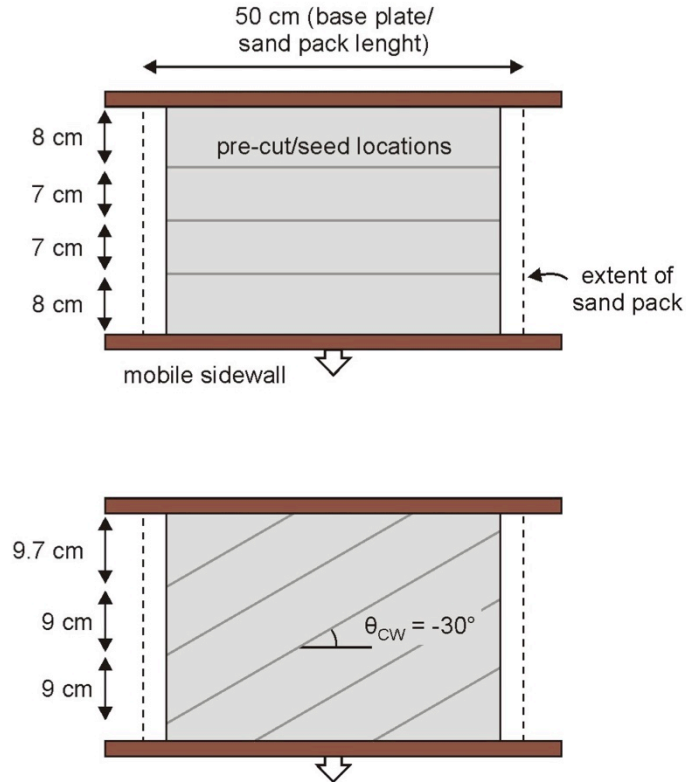
Model set-up and base plate (VD) geometries (top view)



Model design: 3D weakness

- **Three crustal weakness orientations:**
 - Parallel to model axis
 - -30° oblique to model axis
 - 30° oblique to model axis (not shown here)
- **Various 3D combinations with the two mantle weakness orientations**

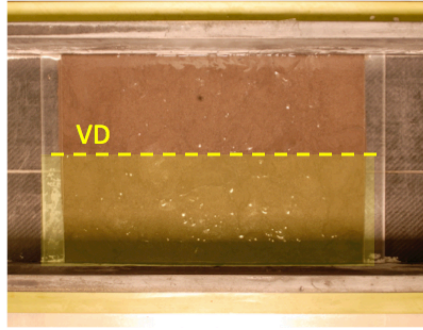
Simulated crustal weakness geometries (top view)



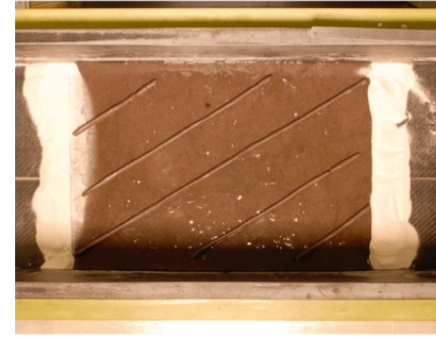
Model procedure: example of a model run

1. Prepare viscous layer
2. Add seeds
3. Add sand layer
4. Deform model

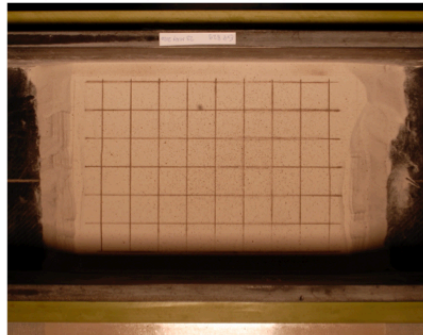
1) Base plate + lower ductile crust



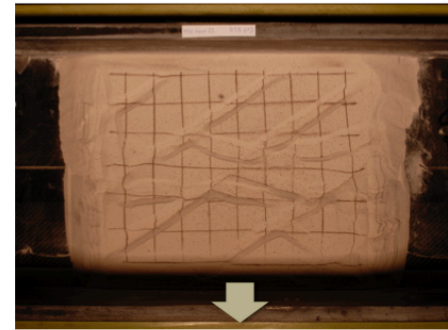
2) Upper crustal weaknesses (seeds)



2) Upper brittle crust (sand)



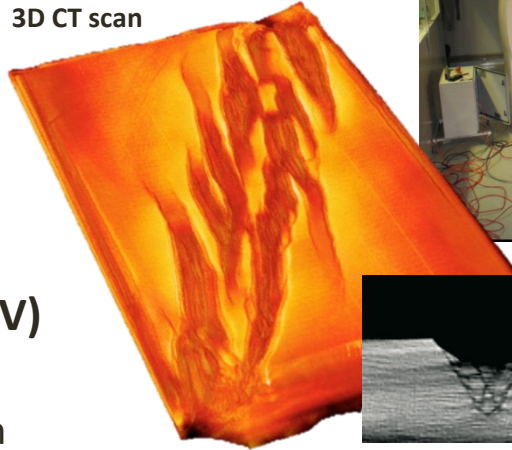
4) Deformed model



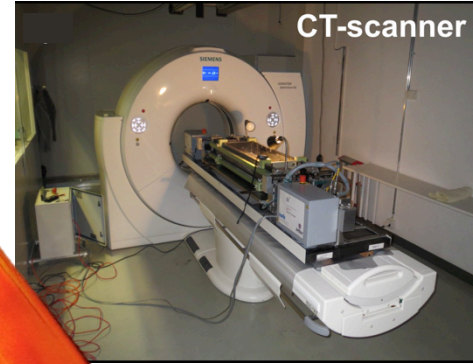
Model analysis

- **Surface photography**
 - See previous slides
- **Particle Image Velocimetry (PIV)**
 - Analysis of surface pictures to extract displacement and strain
- **X-Ray CT-scanning**
 - Unique insights into internal model evolution during a model run

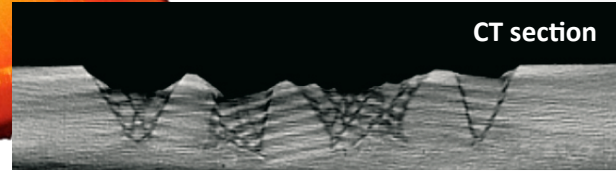
3D CT scan



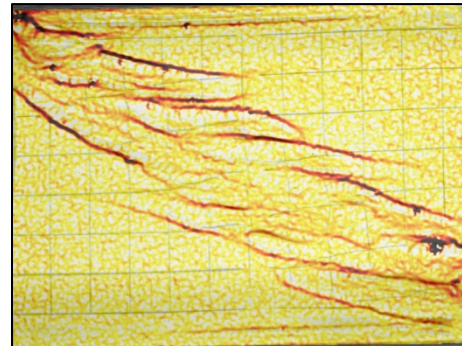
CT-scanner



CT section



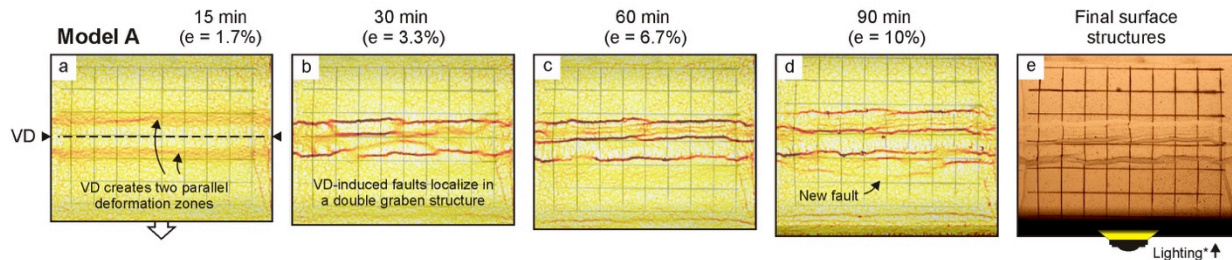
PIV analysis
(strain map
shows active
faults)



Model results: effects of crustal weaknesses (PIV)

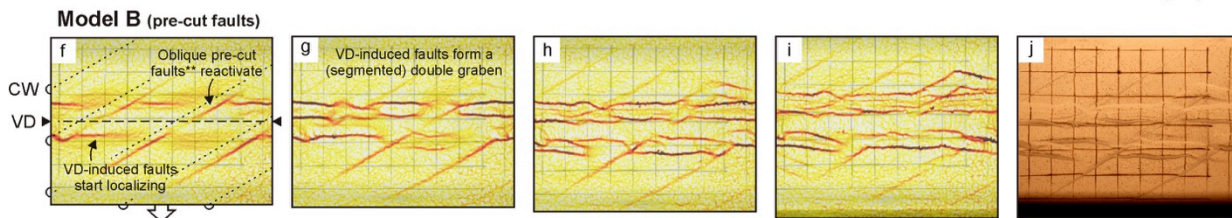
Model axis-parallel VD only

- Rift along VD



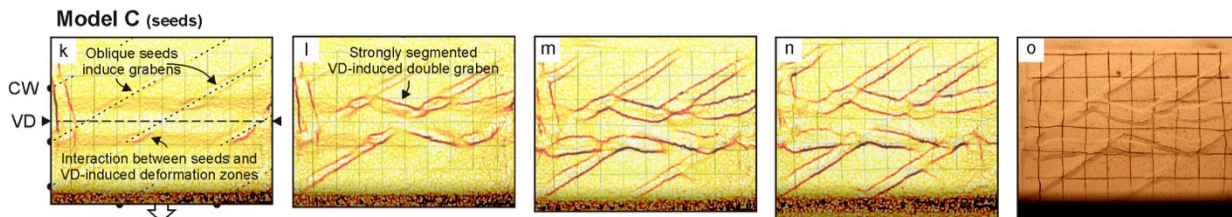
VD + oblique precut faults

- Rift along VD slightly
overprinted by oblique
structures

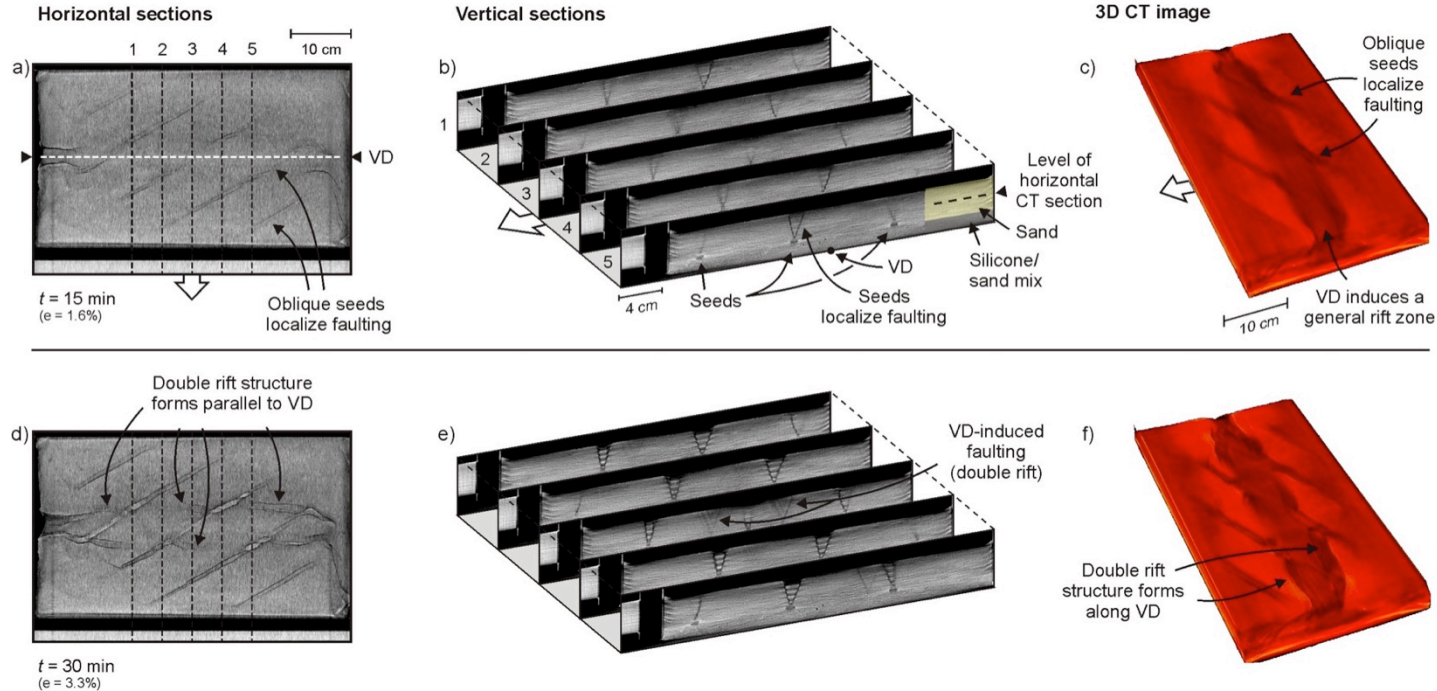


VD + oblique seeds

- Rift along VD
strongly overprinted
by oblique structures



Model results: interacting structures (CT)



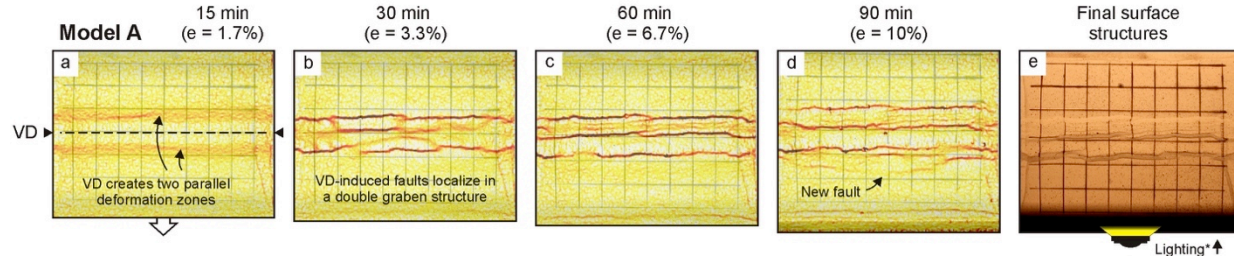
- Crustal structures activate first, followed by a VD-induced rift zone

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Model results: thicker viscous layer

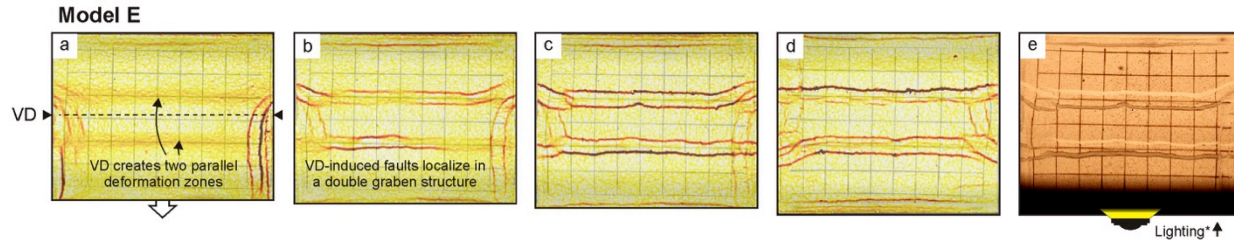
Normal viscous layer

- Rift along VD



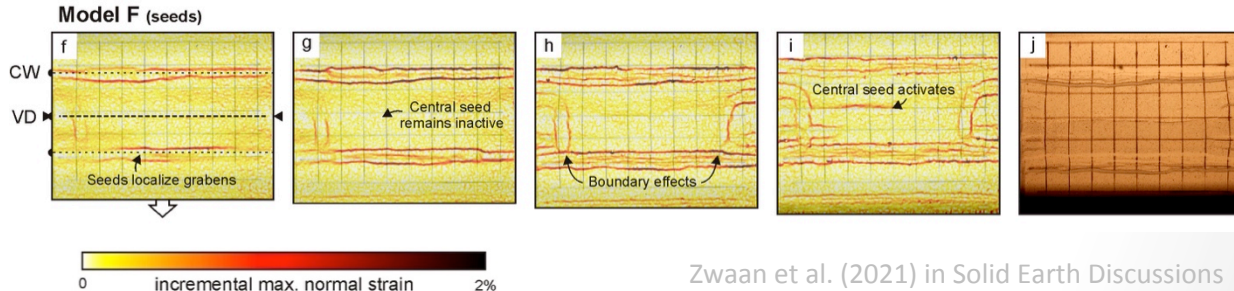
Thicker viscous layer

- Graben are farther apart



Thicker viscous layer

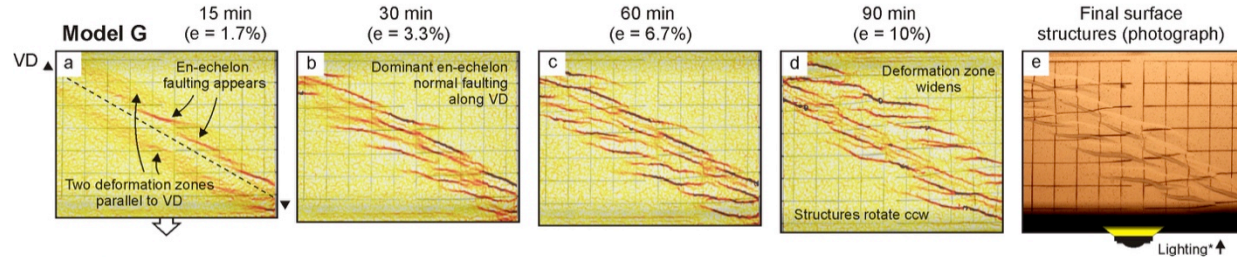
- seeds localize graben



Model results: effects of oblique VD (PIV)

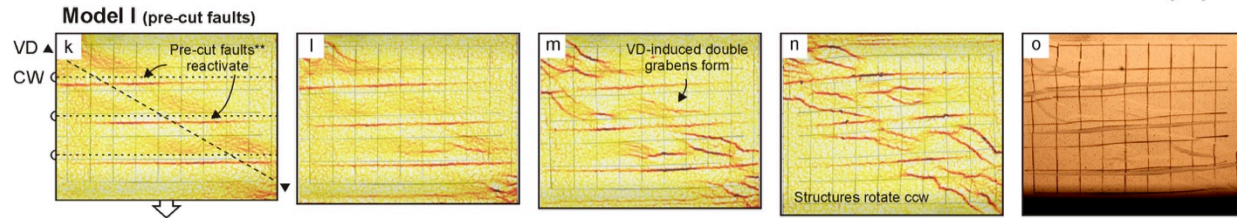
Oblique VD only

- Rift along VD
- (en echelon structures)



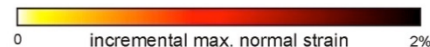
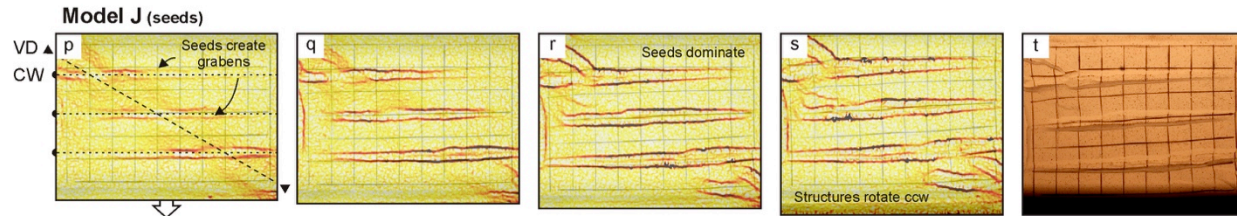
VD + pre-cut faults

- Rift along VD strongly overprinted by pre-cut-induced faults



VD + oblique seeds

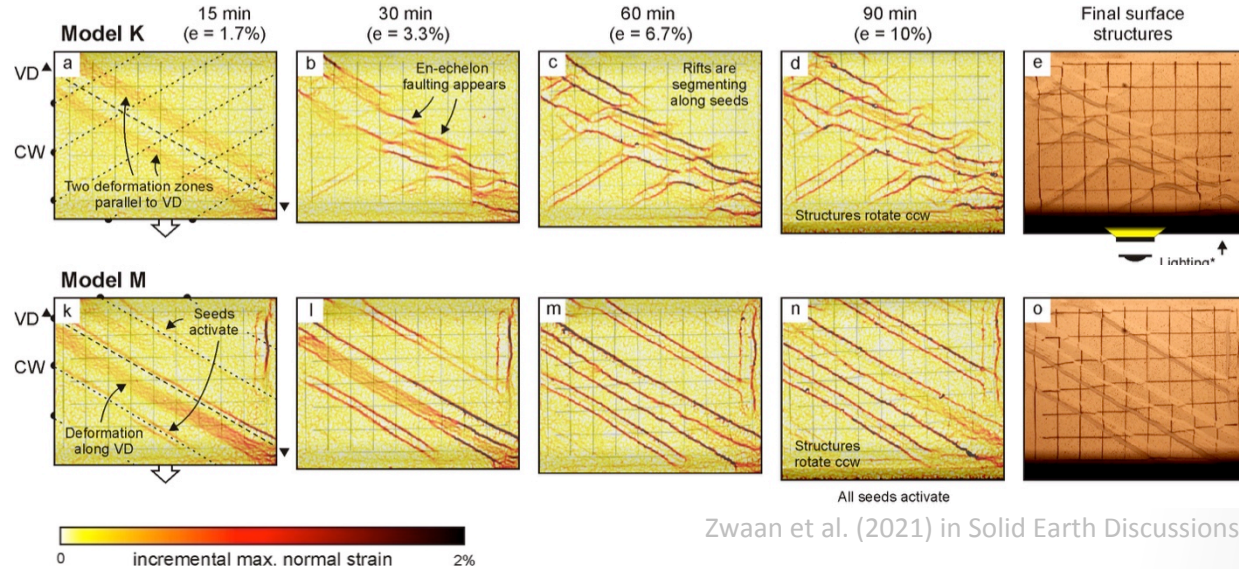
- Rift along VD very strongly overprinted by seed-induced faults



Model results: extra weakness orientations!

Oblique VD and seeds

- Complex interaction

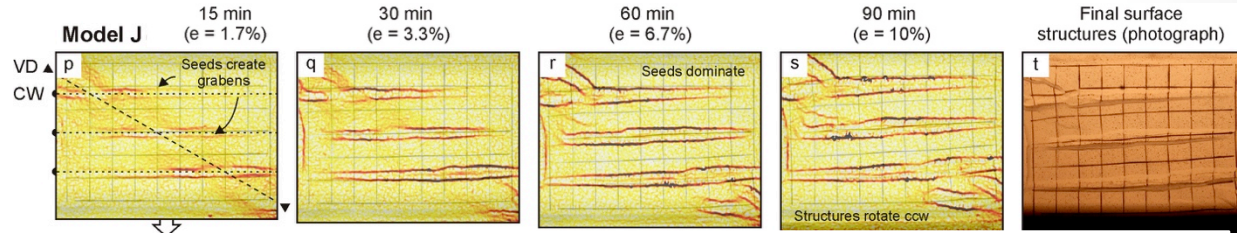


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Model results: effects of extension velocity

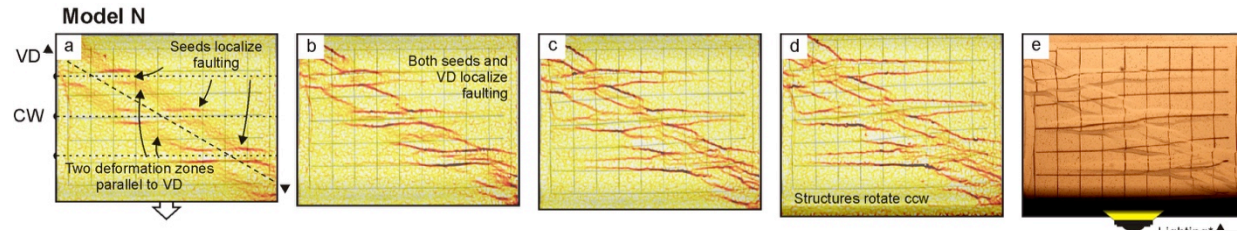
Normal extension

- Rift along VD very strongly overprinted by seed-induced faults



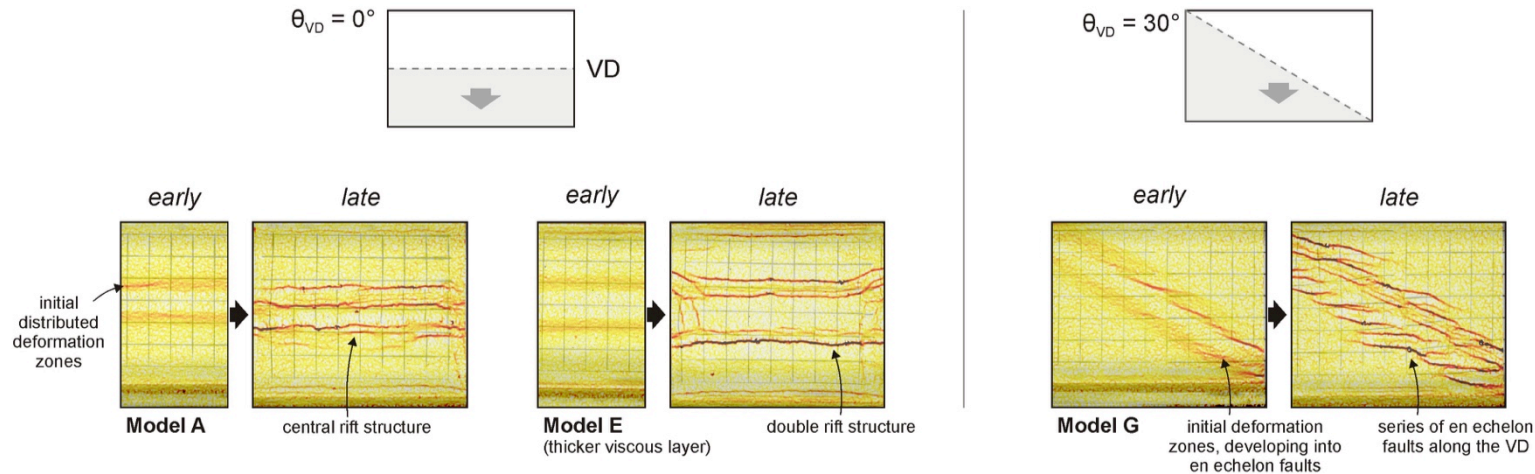
Fast extension

- Rift along VD much less overprinted by seed-induced faults



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Discussion (effect of VD only)



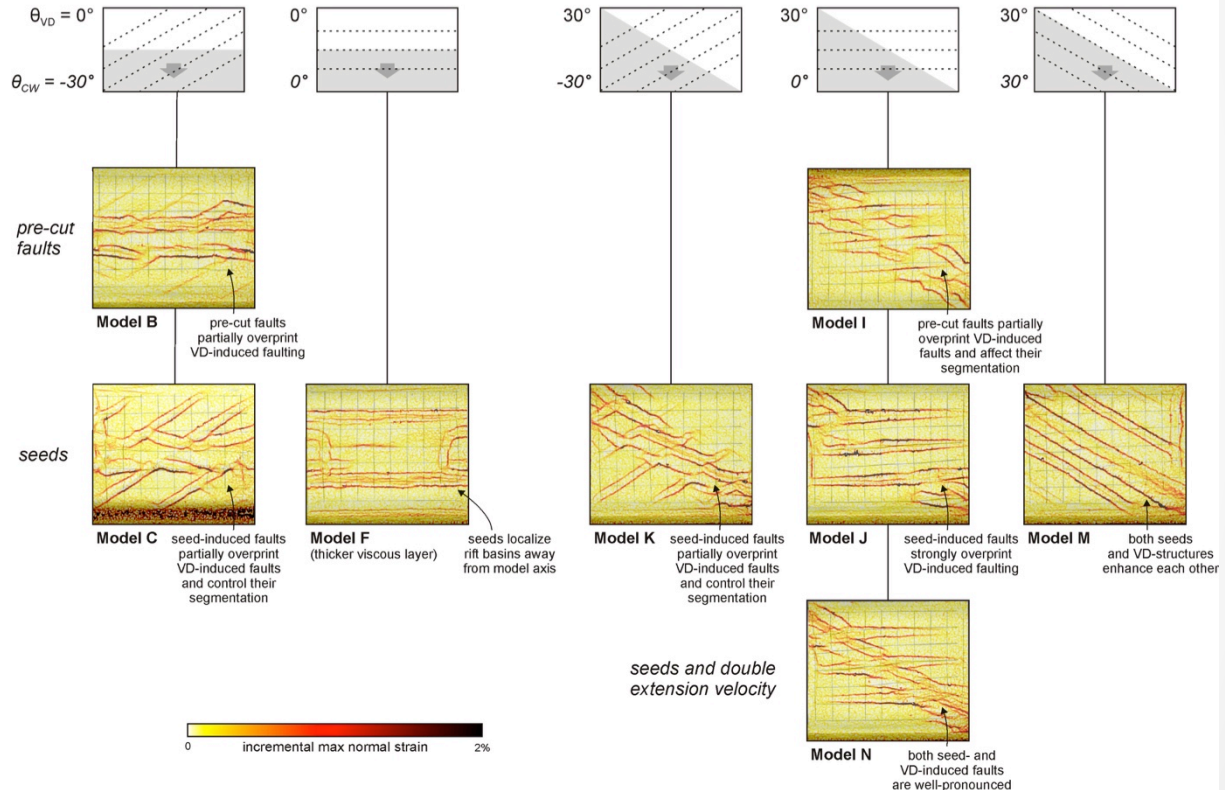
- **Orthogonal vs. Oblique extension structures**
- **Initial deformation localizes along distributed deformation zones**
- **Thicker viscous layer: more spaced-out graben (Model E)**

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Discussion (combined effects of VD and crustal weaknesses)

Complex interactions, depending on:

- Type of (crustal) weaknesses
- Orientation of (crustal) weakness
- Extension velocity



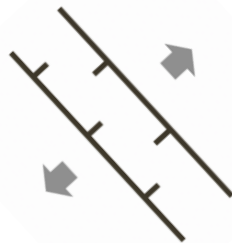
Discussion (structural weaknesses vs. multiphase extension)

Different structural graben orientations in previous models and nature might suggest multiphase extension (i.e. involving rotating extension directions during rifting)

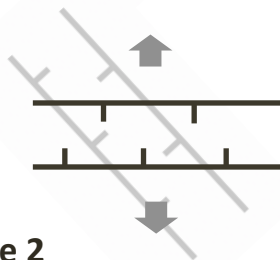
Yet our model results highlight that such structures can also develop in a single rifting phase

Multiphase extension

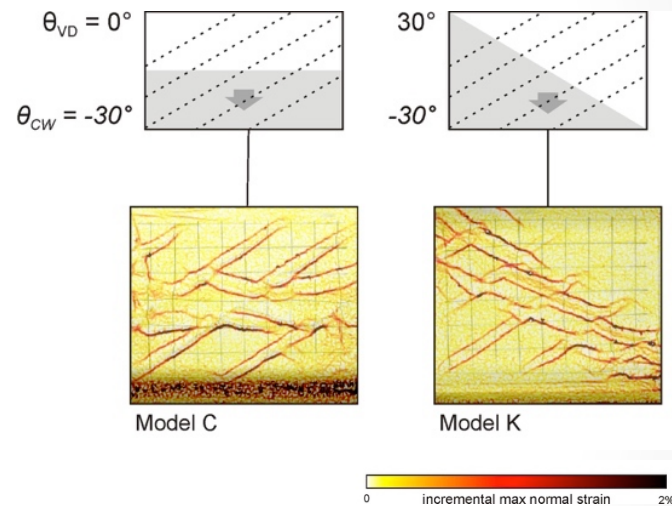
Phase 1



Phase 2



Single-phase extension (our models)



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Conclusion

- **Mantle VD orientations affect basin rift structures:**
 - Model-axis parallel VD: parallel graben along VD
 - Oblique VD: en echelon graben along VD
- **Crustal weakness type affects deformation in the crust:**
 - Pre-cut faults: moderate reactivation; Seeds: strong reactivation
- **Extra parameters:**
 - Extension velocity may change which weakness is dominant (crust vs. mantle)
 - Lower crust thickness affects style/spacing of faulting
- **Simultaneous activation of mantle- and crustal weaknesses can account for complex rift structures**
 - No direct need for multiphase extension
 - Strong motivation to reevaluate the history of natural examples

Further reading: Solid Earth Discussion paper

[Abstract](#)[Discussion](#)[Metrics](#)

08 Jan 2021

Review status: this preprint is currently under review for the journal SE.

Complex rift patterns, a result of interacting crustal and mantle weaknesses, or multiphase rifting? Insights from analogue models

Frank Zwaan¹, Pauline Chenin², Duncan Erratt², Gianreto Manatschal², and Guido Schreurs¹

¹Institute of Geological Sciences, University of Bern, Baltzerstrasse 1+3, 3012 Bern, Switzerland

²Université de Strasbourg, CNRS, ITES, UMR 7063, 5 rue Descartes, Strasbourg F-67084, France

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Questions/comments? frank.zwaan@geo.unibe.ch