Interplay of near surface rift evolution and deep-seated crustal flow

New findings from fully quantified crustal-scale analogue models

EGU21-1027

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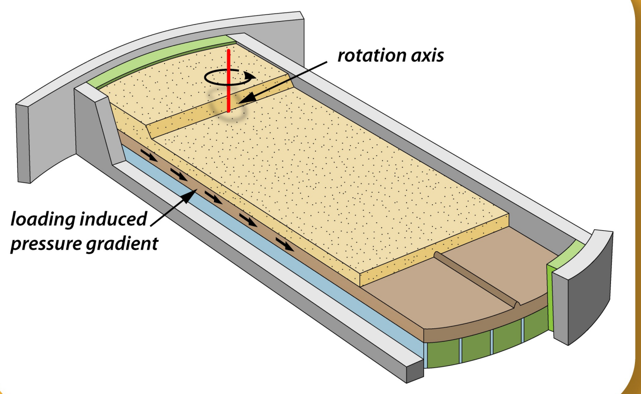
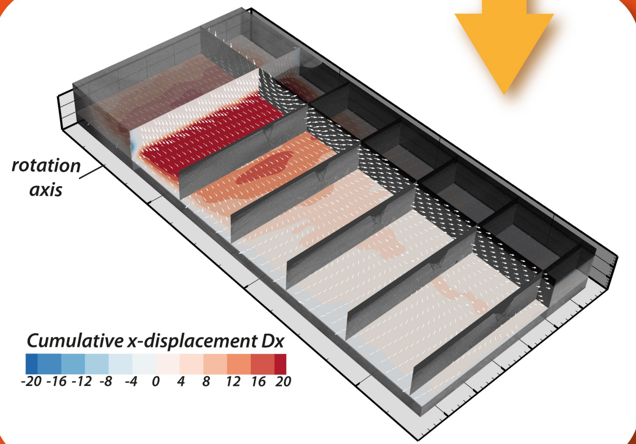
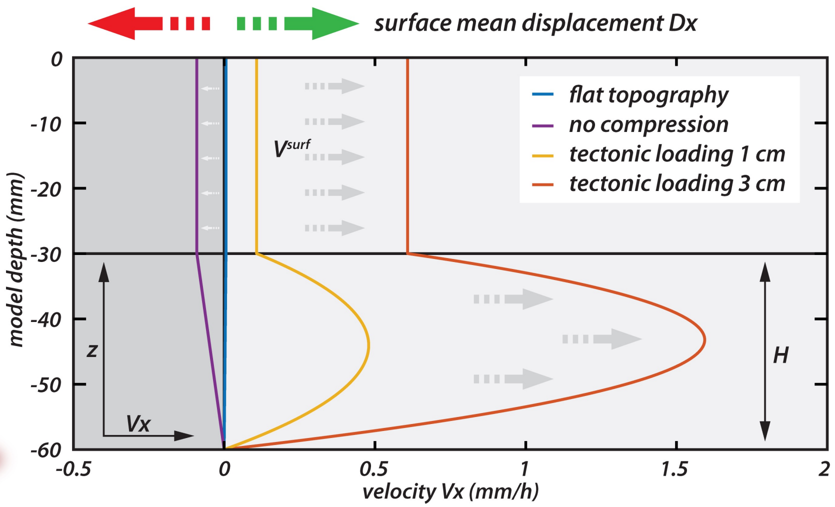
Model set up



Deformation quantification



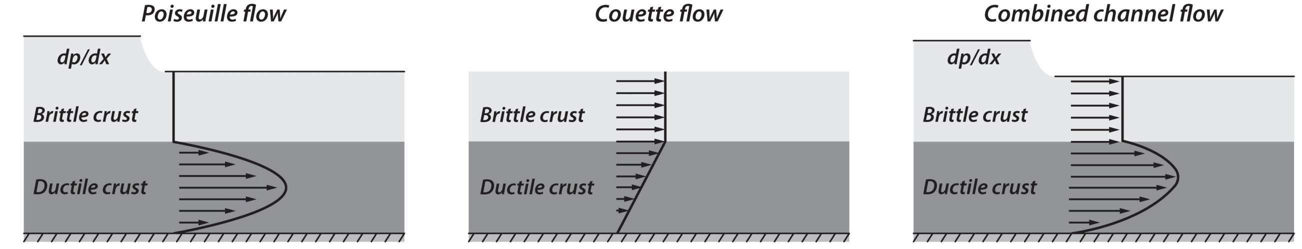
Comprehensive understanding of deformation interaction



Comb.	Poiseuille	Couette

$$Vx = \frac{1}{2\mu} \cdot \frac{dp}{dx} \cdot (z^2 - H \cdot z) + \frac{V^{surf}}{H} \cdot z$$

μ	viscosity
$\frac{dp}{dx}$	pressure gradient
H	channel thickness
V^{surf}	surface velocity
z	depth coordinate

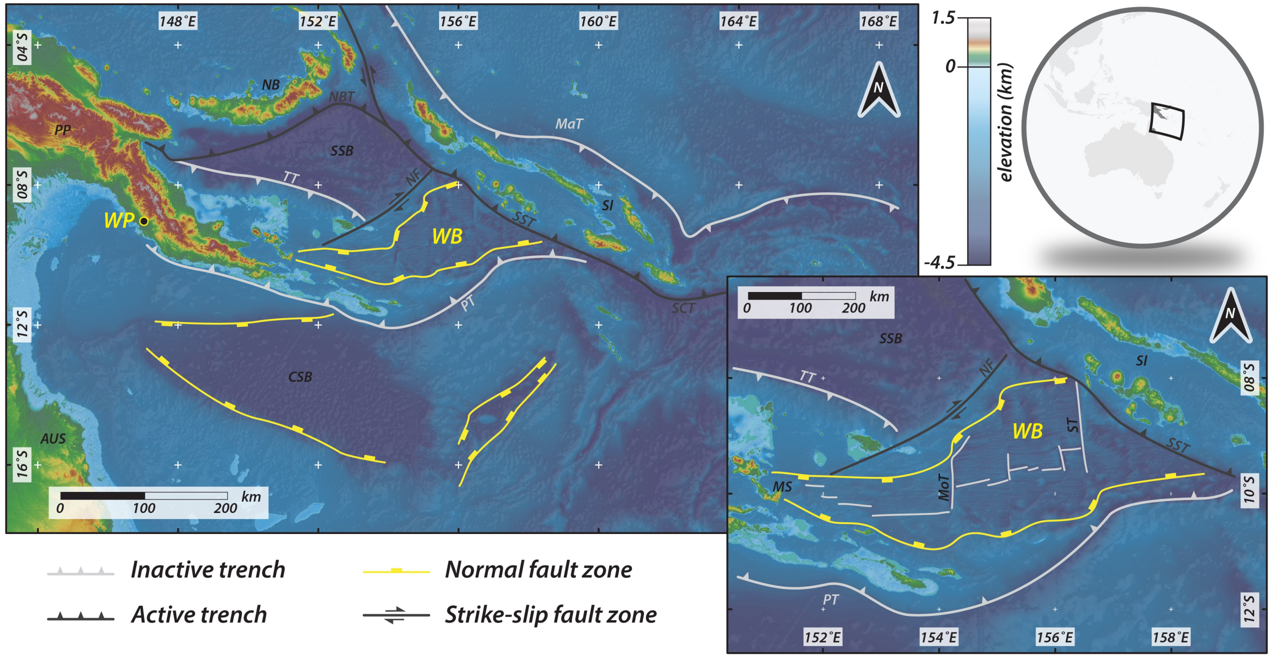


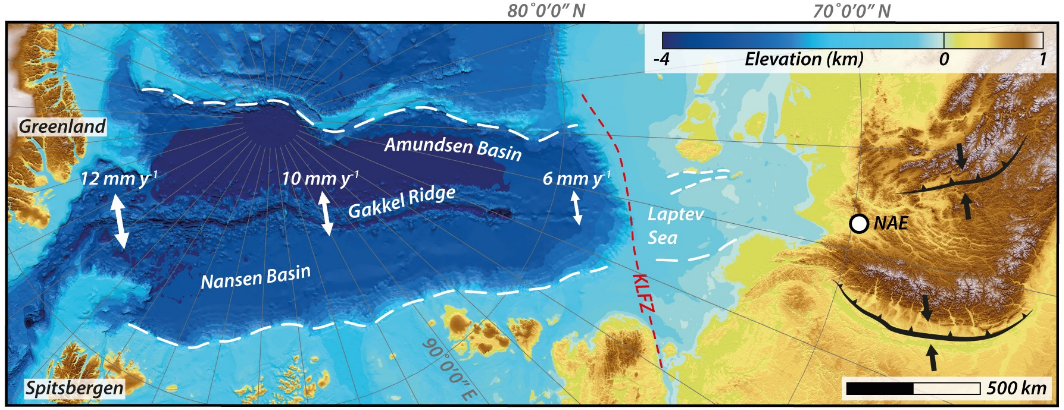
Interested...? Join me in the breakout text chat or contact me via timothy.schmid@geo.unibe.ch

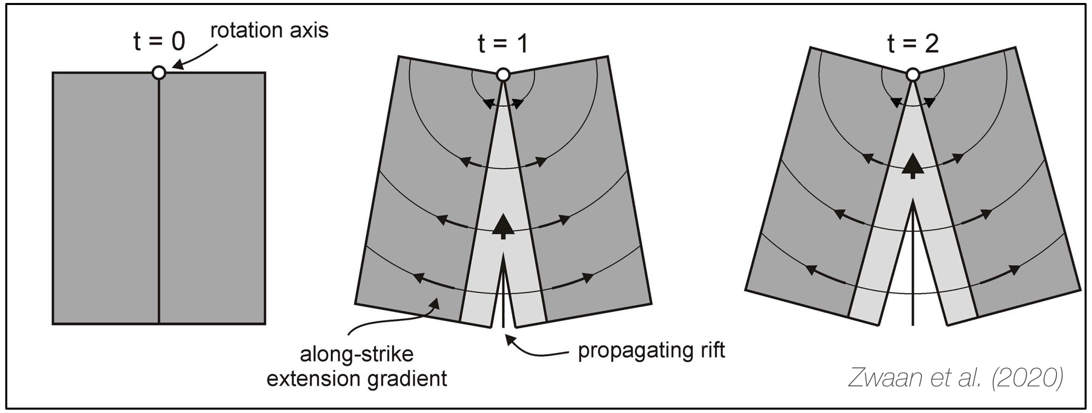
Rotational rift settings

"V-shaped basins" …

- Associated with extension gradients along strike
- Pivoting motion about a Euler pole
- Compressional setting across the Euler pole
- Rotational component on global scales

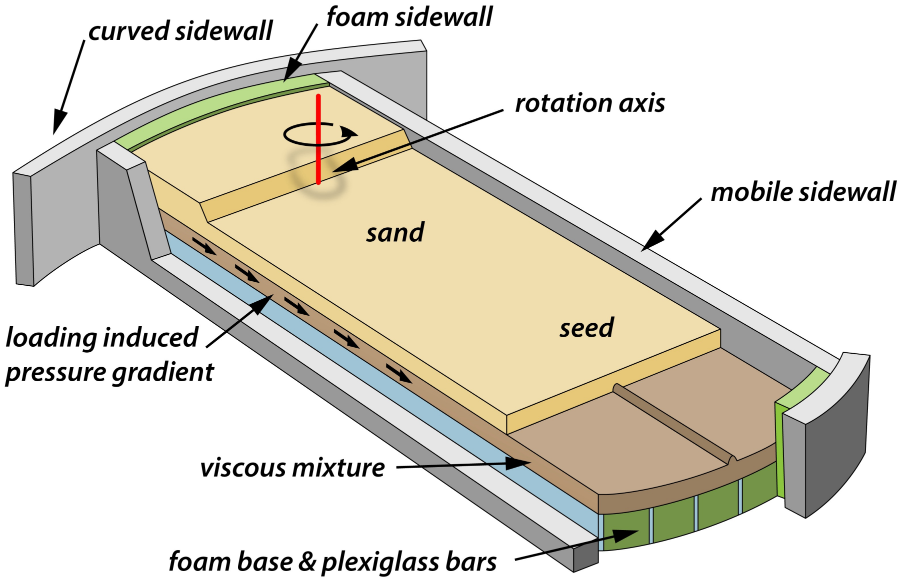


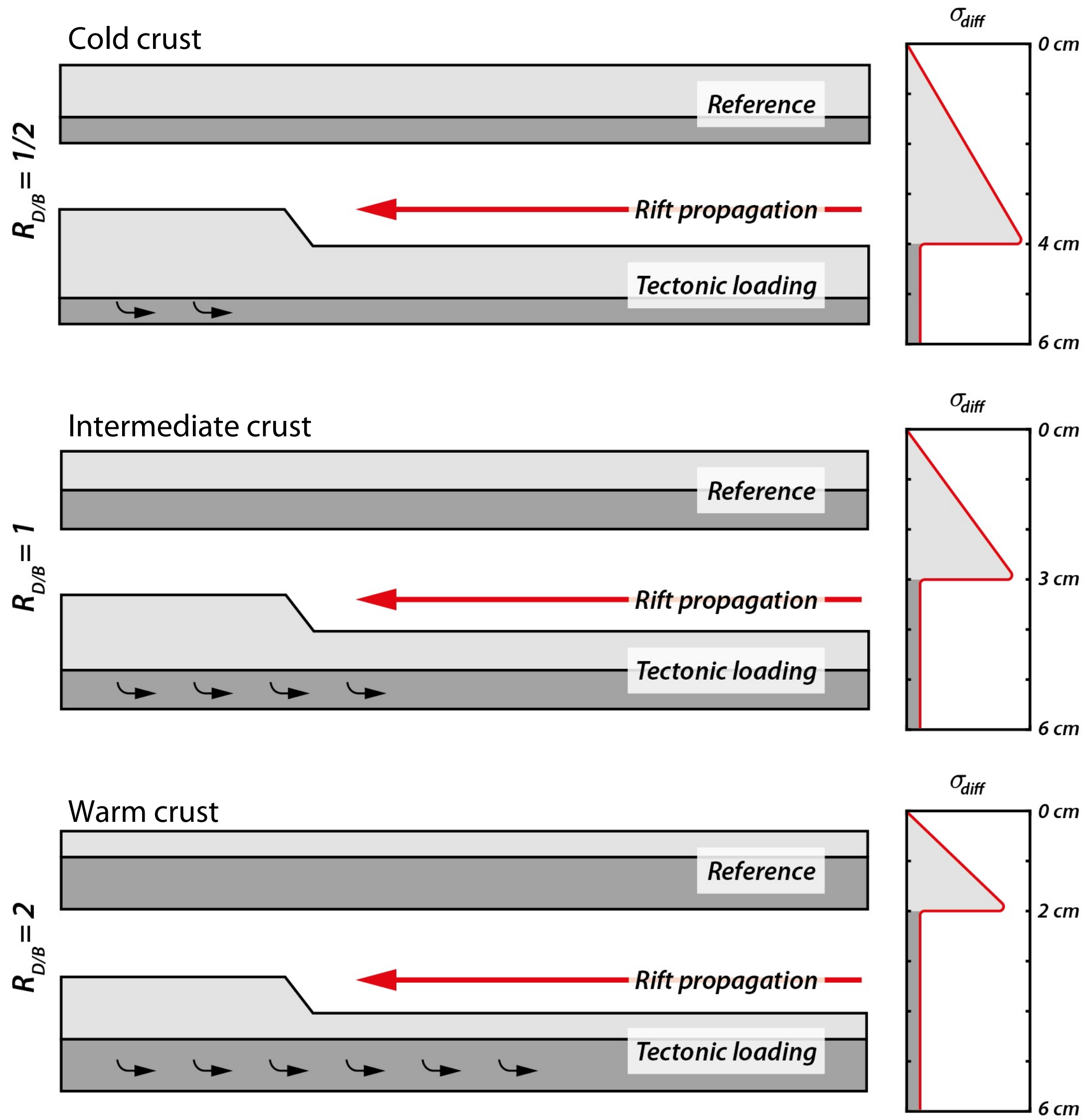




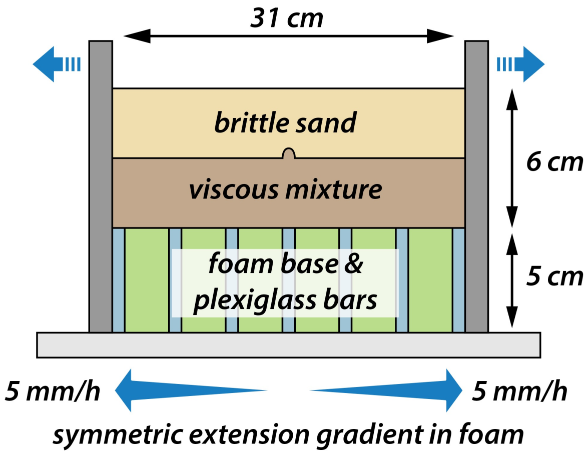
Model set up

- Rotational setting with an extensional and compressional domain
- Brittle/ductile ratio for a cold, intermediate or warm crust
- Pressure-gradient driven viscous flow, stimulated by sand package





Material properties and model scaling

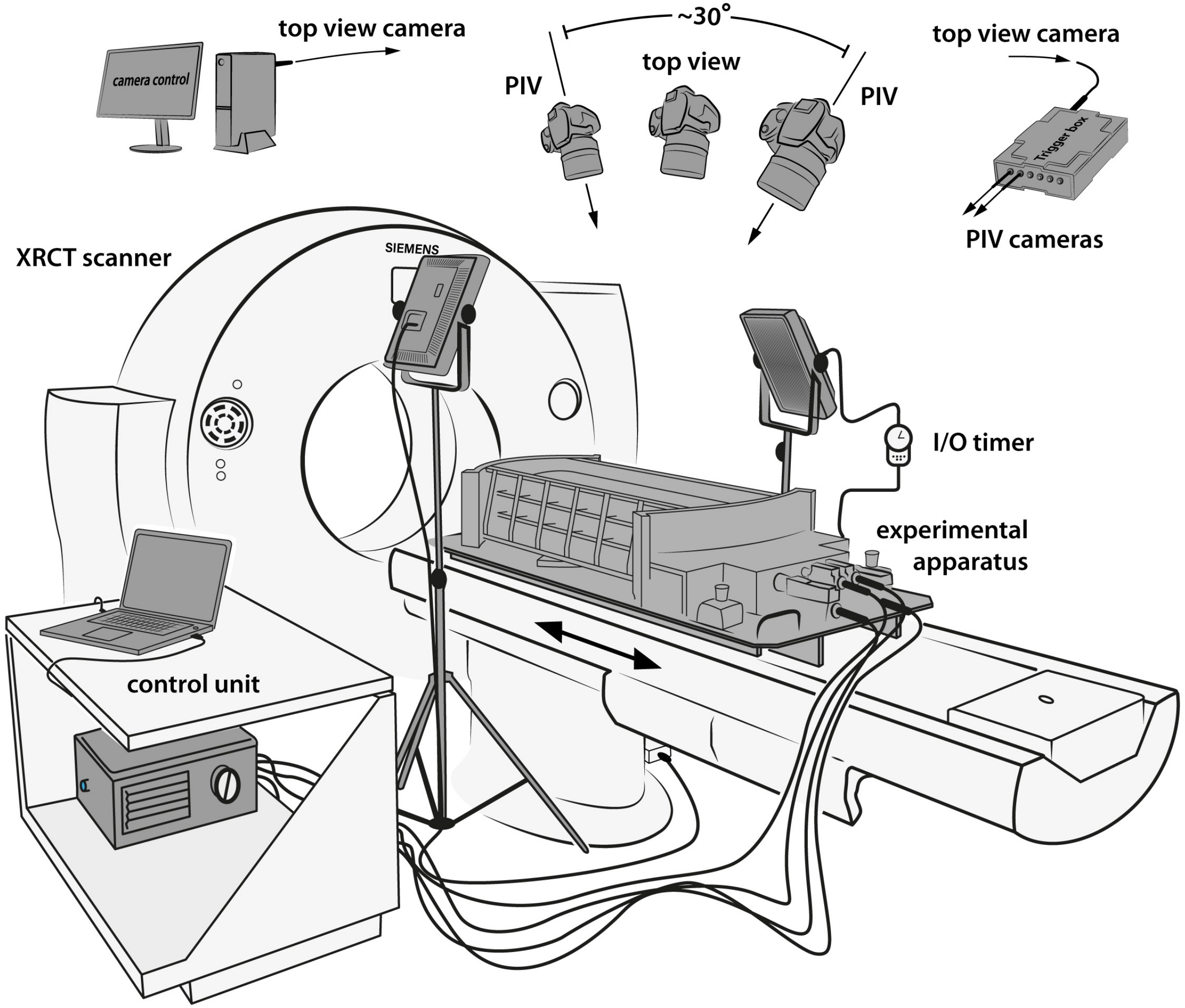


Granular materials	Quartz sand	Corundum sand	Zirshot	Viscous material	PDMS/corundum mixture
Density (kg/m^3)	1560 (30 cm)	1960 (30 cm) / 1890 (bulk)	2300 (bulk)	Density (kg/m^3)	1600
Grainsize (µm)	60-250	88-175	150-210	Viscosity (Pa s)	1.5E+5
Friction coefficient µ / (°)	0.72 / (36°)	0.78 / (38°)		Stress exponent n	1.05
Strain softening (%)	16	16			
Cohesion (Pa)	48 ± 26	55 ± 42			

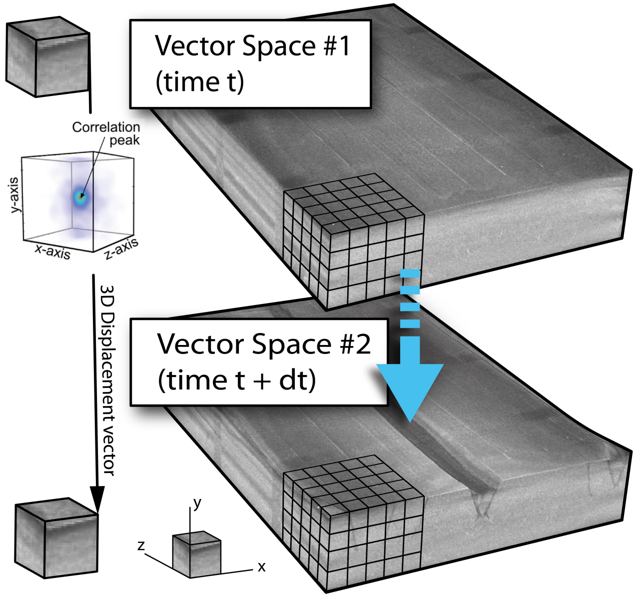
	General parameters			Brittle upper crust		Ductile lower crust		Dimensionless numbers		
	Gravitational Acceleration g (m/s^2)	Crustal thickness h (m)	Extension velocity v (m/s)	Density ρ (kg/m^3)	Cohesion C (Pa)	Density ρ (kg/m^3)	Viscosity η (Pa s)	Smoluchowski number R_s	Ramberg number R_m	Reynolds number R_e
Model	9.81	0.06	$2.8 \cdot 10^{-6}$	1560	50	1600	$1.5 \cdot 10^{5}$	1	15-60	<<1
Nature	9.81	$3 \cdot 10^{4}$	$1.4 \cdot 10^{-10}$	2700	$5 \cdot 10^{7}$	2900	$1 \cdot 10^{21}$	1	16-63	<<1

1h → 0.88 Ma
1 cm → 5 km
10 mm/h → 6 mm/a
$5\ 10^{-5}\ s^{-1} \rightarrow 6\ 10^{-15}\ s^{-1}$

Deformation monitoring and quantification

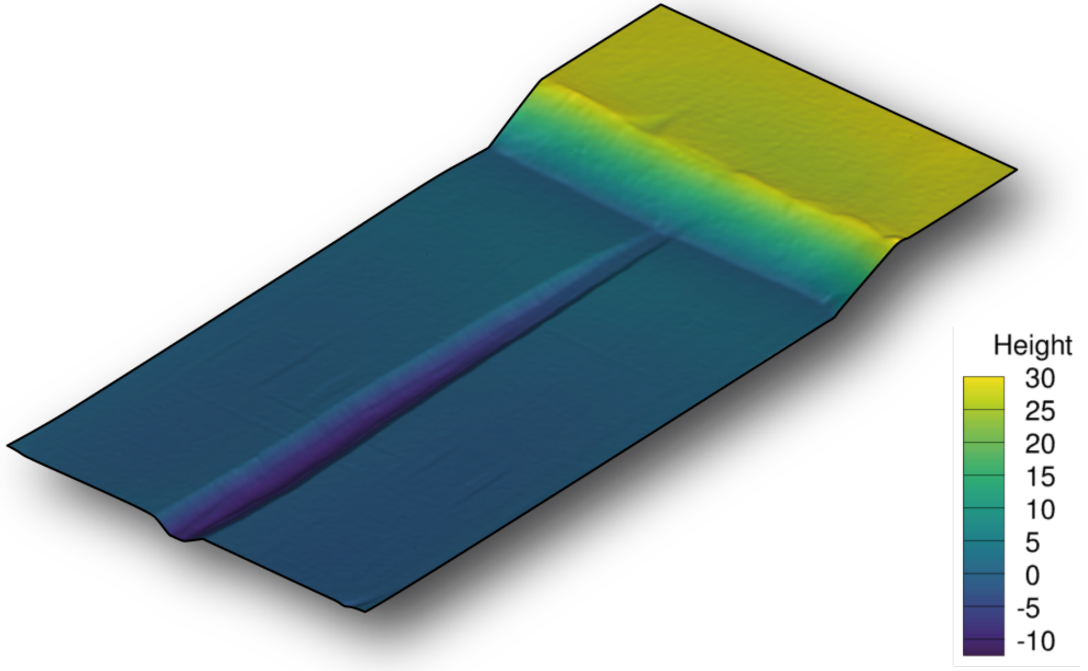


- Stereoscopic setup of DSLR cameras (3D stereo DIC)
- Medical XRCT scanner (DVC)

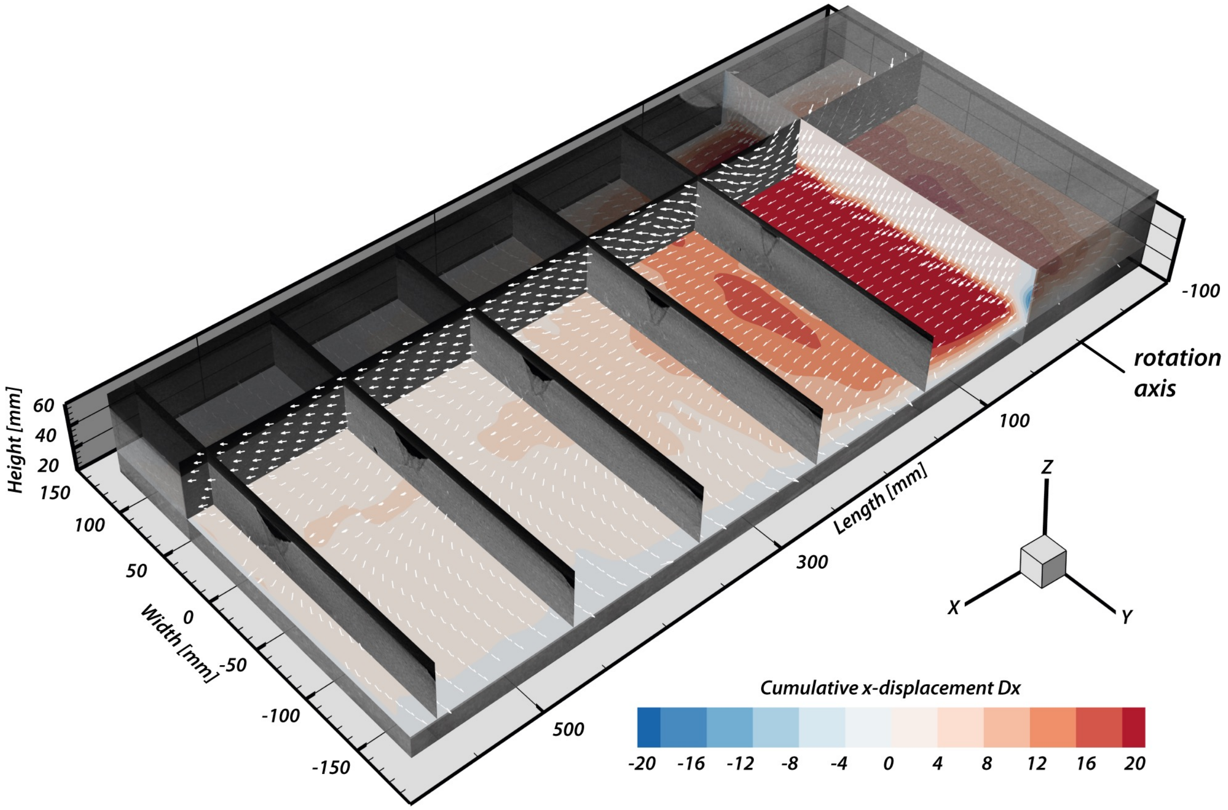


Modified after Adam et al. (2013)

3D stereo Digital Image Correlation
-
Spatially and temporally high-resolution data

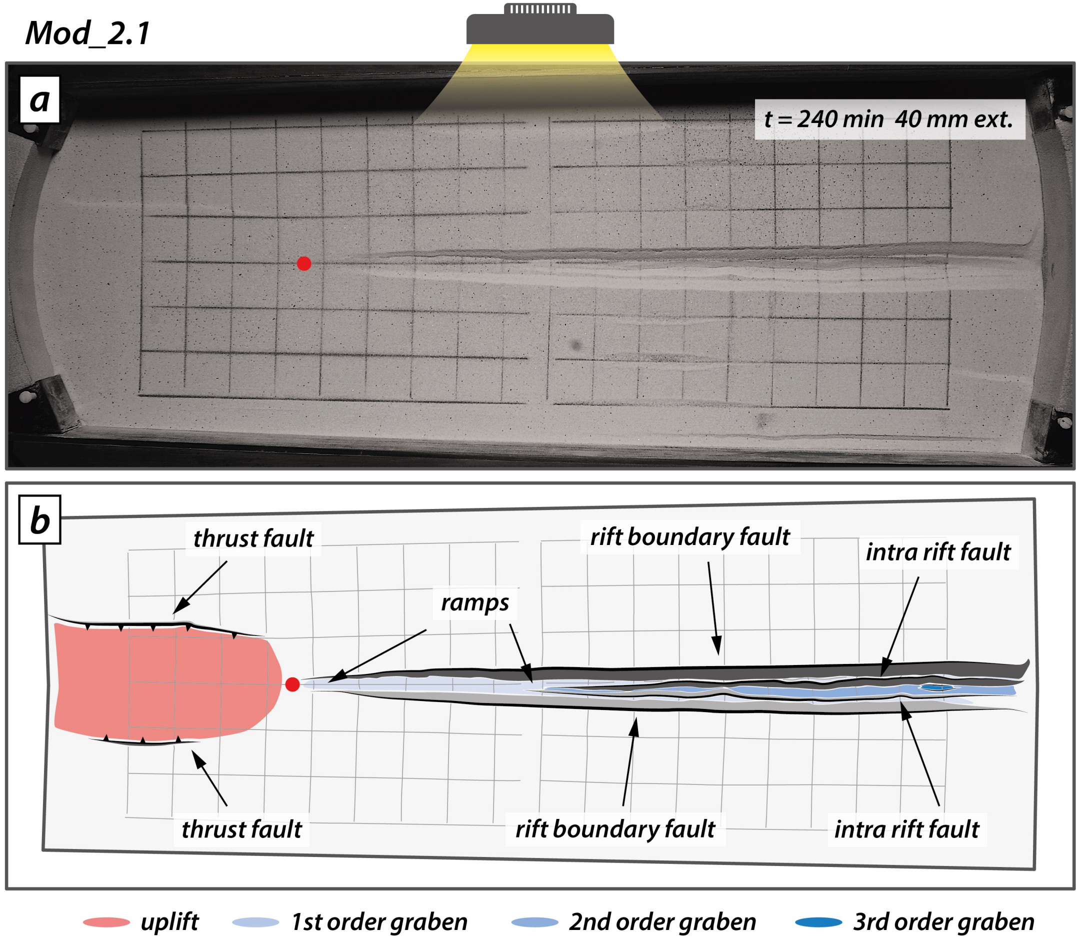


Digital Volume Correlation
-
Quantitative insights on CT scans



Surface analysis – Fault activity

Qualitative description – top view analysis



- Rift propagation towards the rotation axis
- First order conjugate normal faults (rift boundary faults)
- Subsequent inward migration forming higher order faults and associated grabens
- Thrusting in the compressional domain
- Extensional domain similar for all models

Check out movies !
https://github.com/TimothySchmid/EGU-2021.git

Surface analysis – Fault activity

- Incremental strain rate indicates fault activity
- Boundary faults develop within 90 minutes
- Intra rift faults accumulate deformation as activity along boundary faults drop
- Final state: three different fault generations active (segment-wise) at the same time due to velocity gradient

Strain-partitioning between competing fault generations

Check out movies !
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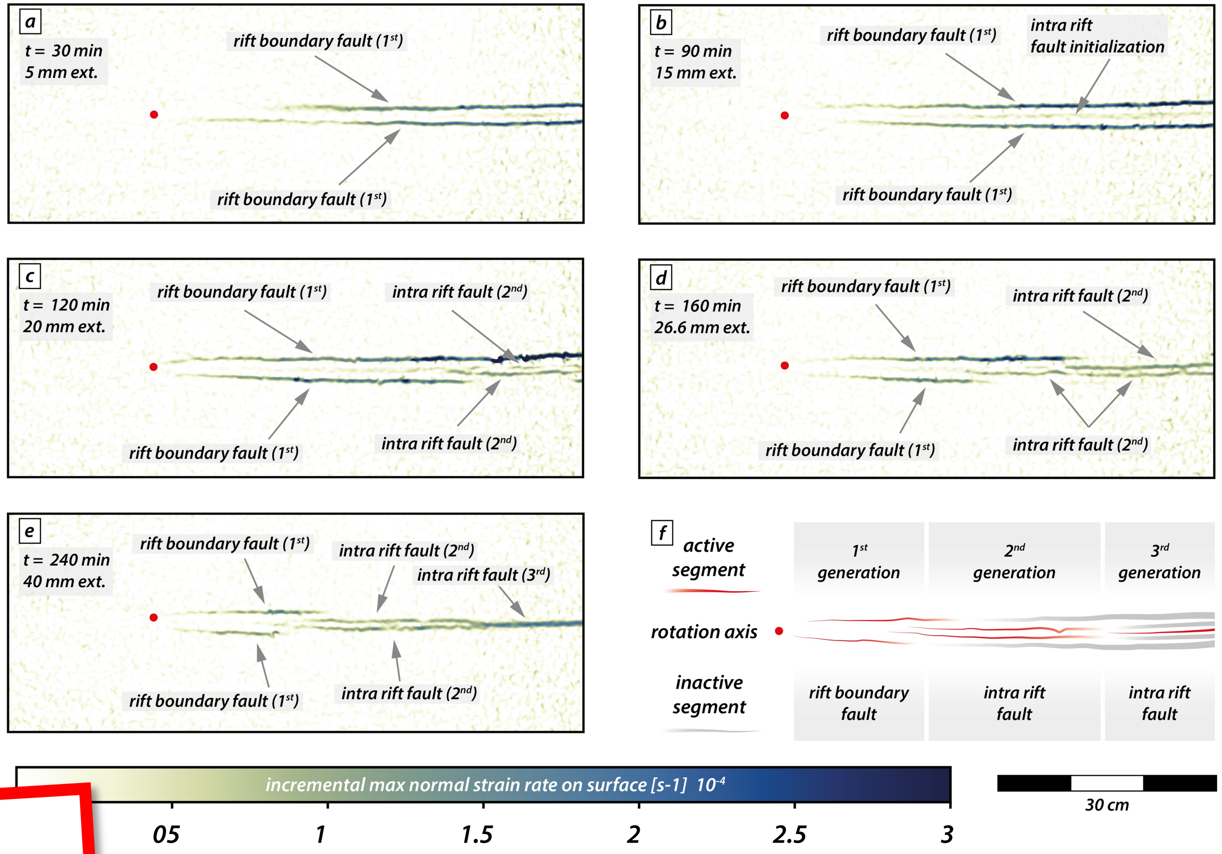
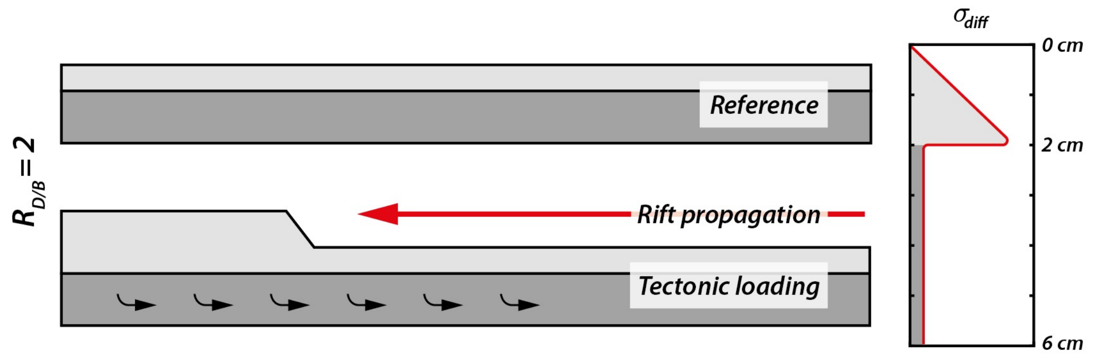
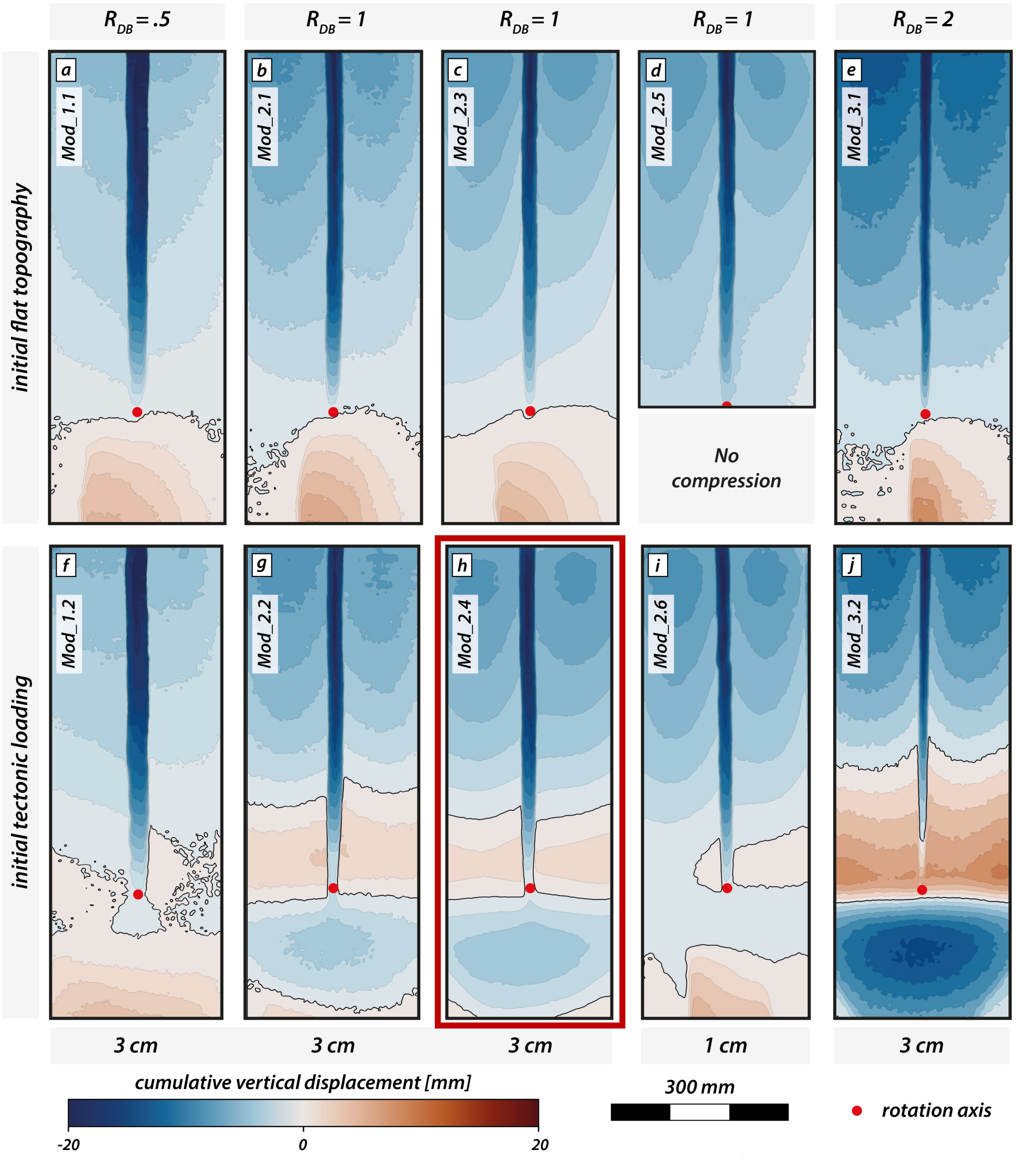
Quantitative description - incremental strain rate



Deep-seated deformation – Vertical displacement



- Increasing vertical motions with increasing R_{DB}
- Zone of subsidence in the compressional domain
- Uplift bulge in front of the topographic step

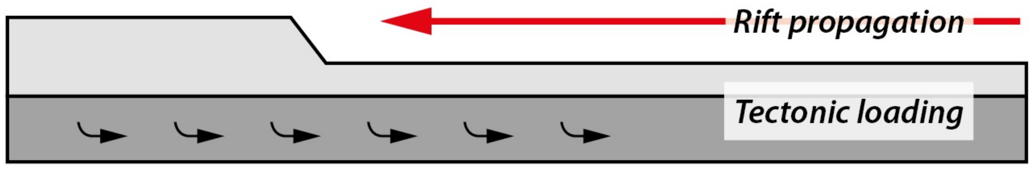


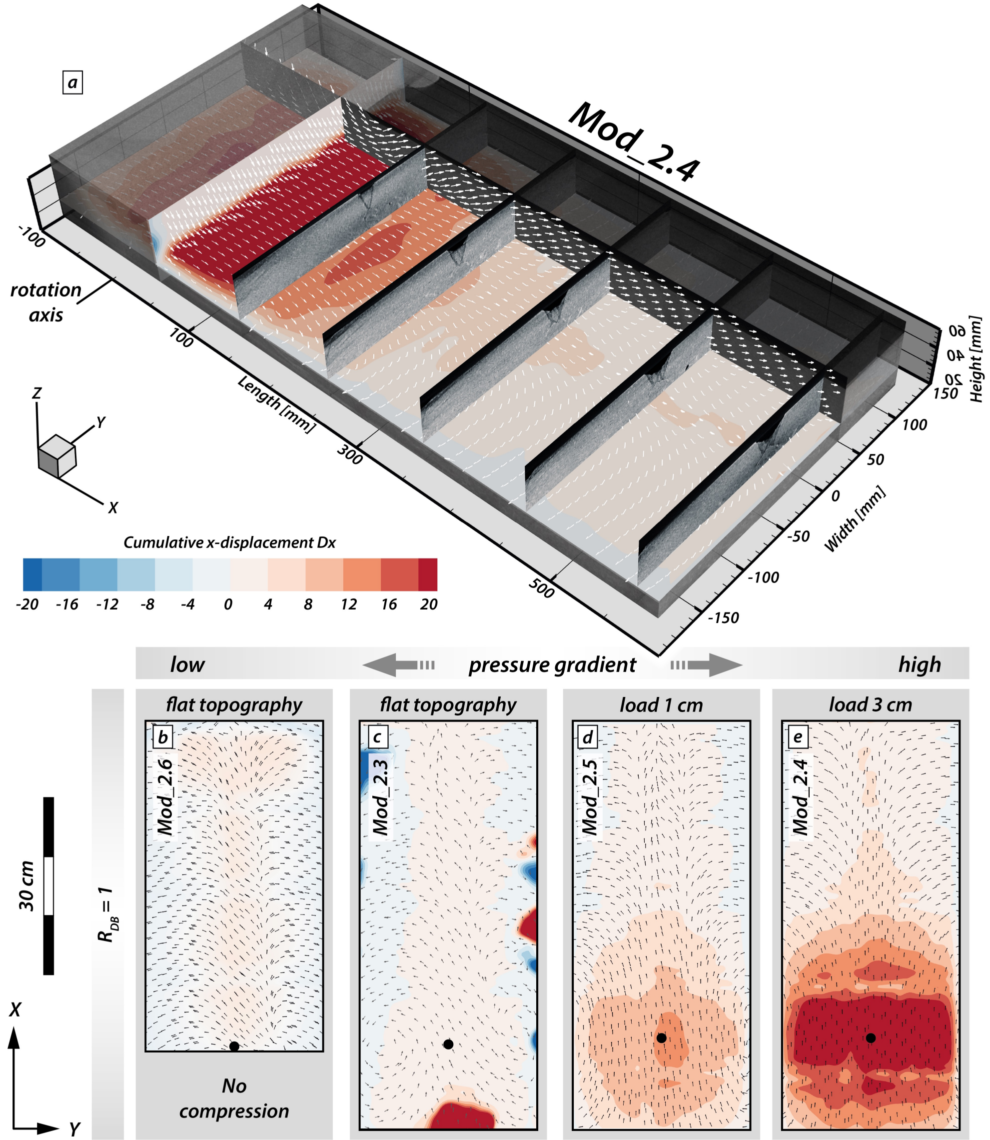
Surface expression of deep-seated flow?

Check out movies !
https://github.com/TimothySchmid/EGU-2021.git

Deep-seated deformation – Viscous flow

- Models with $R_{DB} = 1$
- Increasing horizontal, rift-parallel flow with increasing pressure gradient
- Pocket of maximum flow around the topographic step (rotation axis)
- Rift-propagation opposing flow below the rift axis



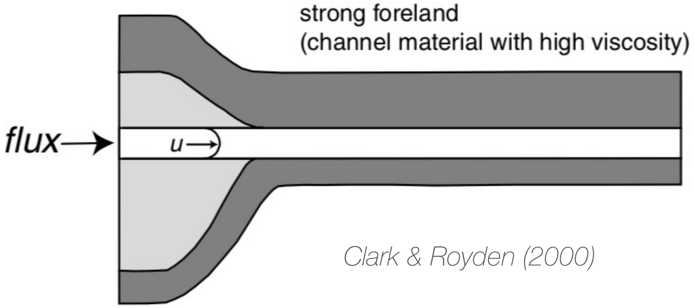


Channel flow

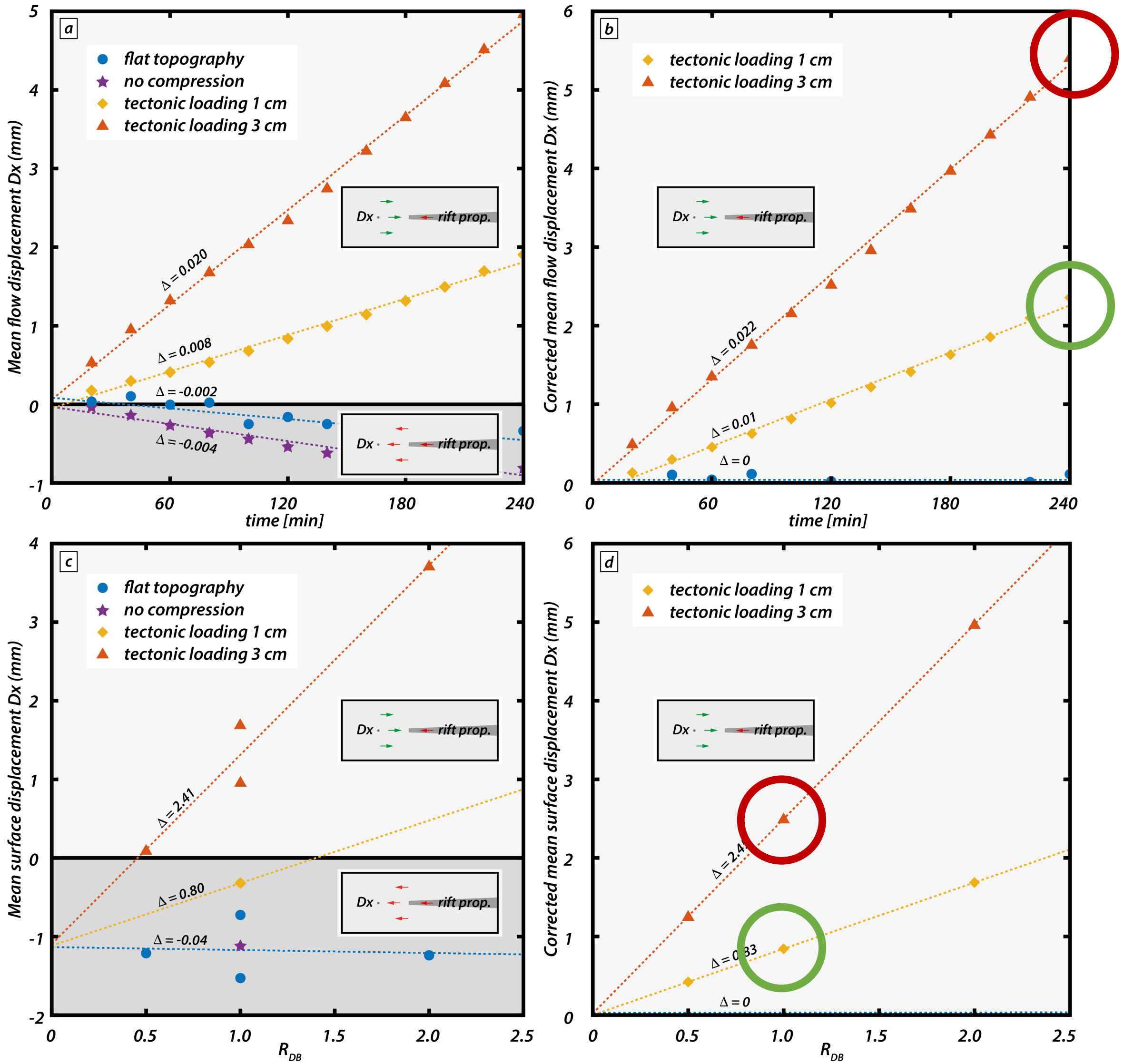
- Enhanced vertical motions with increasing R_{DB} due to increasing horizontal flow in the viscous part
- Proportionality of μ and H requires lower viscosities for smaller R_{DB} (channel thickness)

$$\mu = \frac{H^3 \rho_c g \Delta t}{3L^2} \qquad R_{DB} \approx H$$

Kruse et al. (1991)



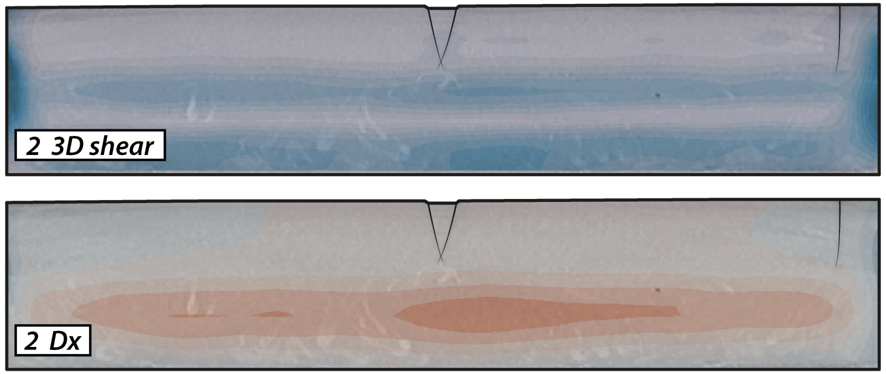
Clark & Royden (2000)

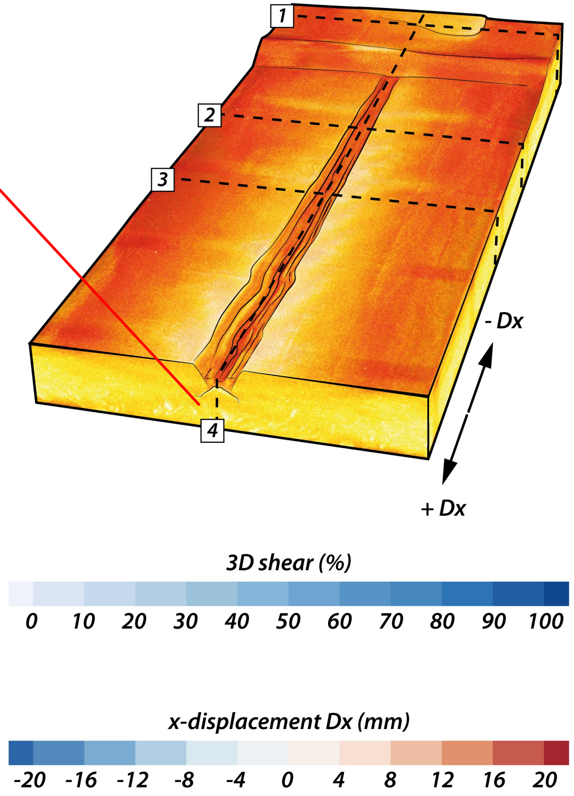


Effective flow regime

D_X Displacement

- *Combined channel flow mode*





Poiseuille flow only
→ too small

$$\bar{u} = -\frac{H^2}{12\mu}\frac{dp}{dx}$$

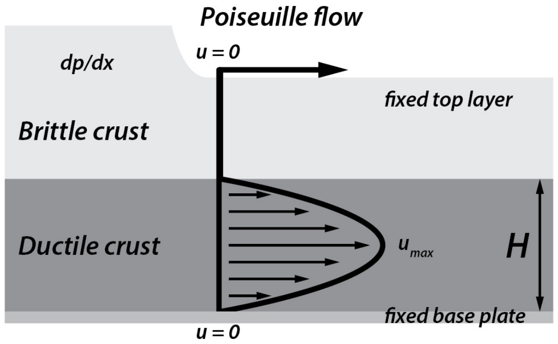
Couette flow only
→ too small

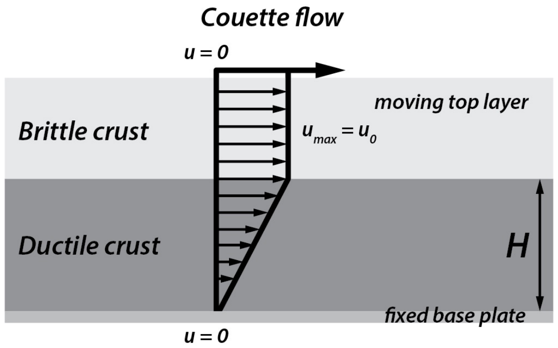
$$\bar{u} = \frac{u_0}{2}$$

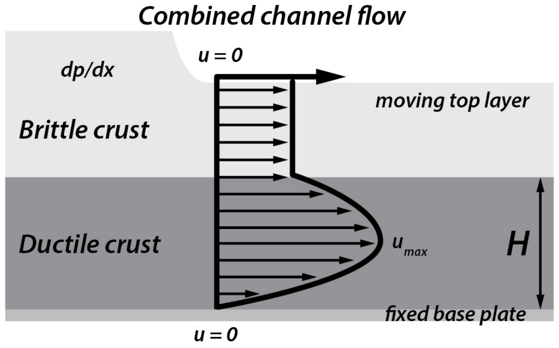
Combined channel flow
→ best fit

$$\bar{u} = -\frac{H^2}{12\mu}\frac{dp}{dx} + \frac{u_0}{2}$$

Gruijic (2006)

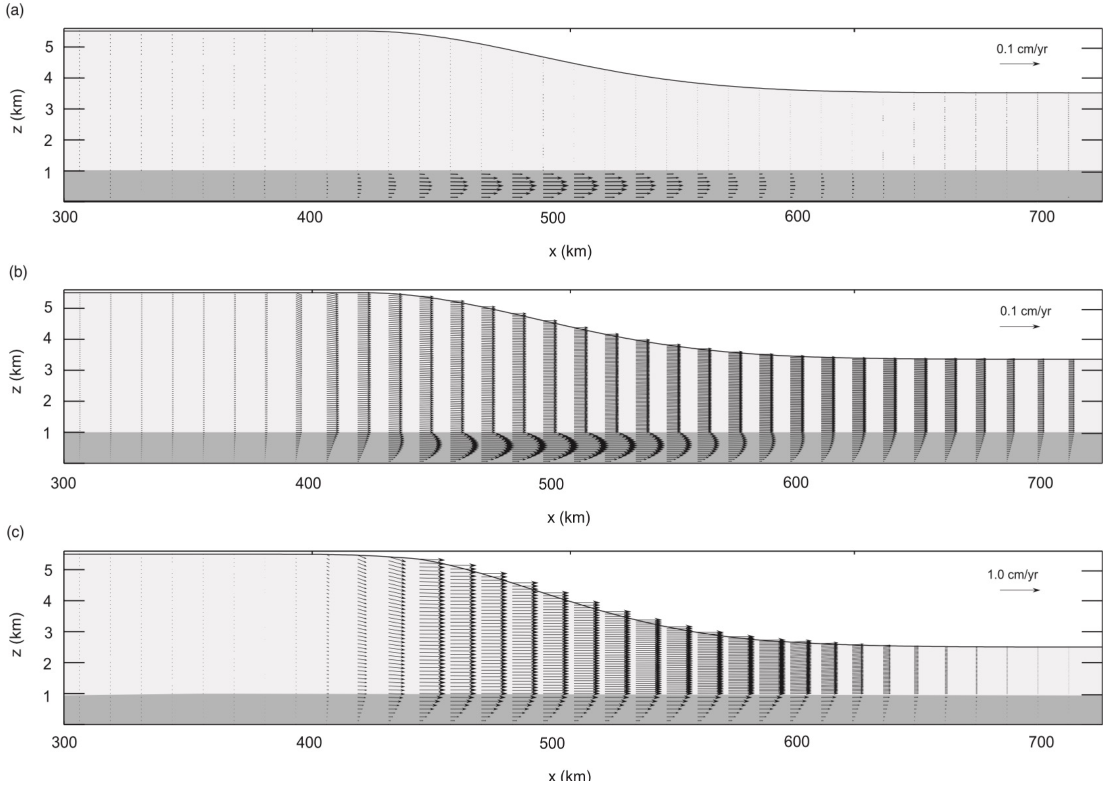






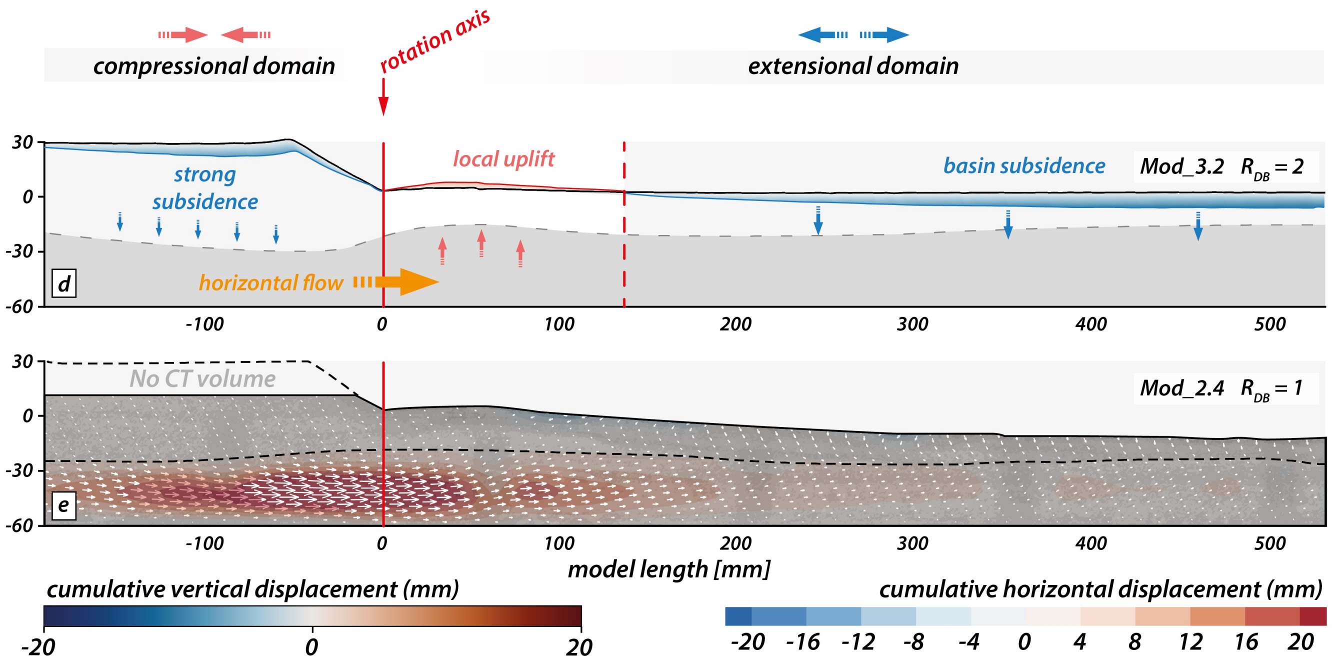
Effective flow regime

Basin-scale
Loading only (no rifting)



Gemmer et al. (2004)

Crustal-scale



Section parallel to rift-axis

Conclusion

Near-surface features

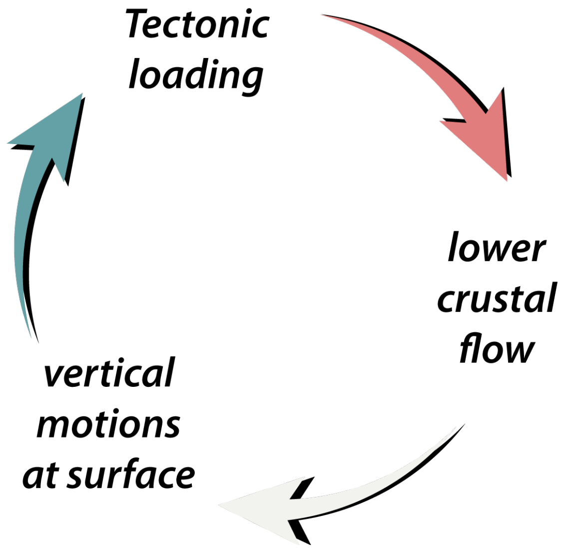
Rift propagation is accompanied by inward migration of fault activity and competing fault growth of conjugate fault pairs as the result of strain partitioning of bulk extension

Deep-seated features

Tectonic loading above the compressional domain induces lower crustal flow which increases with increasing flow channel thickness

Interaction

Horizontal flow at depth enables vertical and horizontal motions at the surface which is expressed by deformation features



Out-of-plane motions play an important role and rifting must be considered as a 3D process