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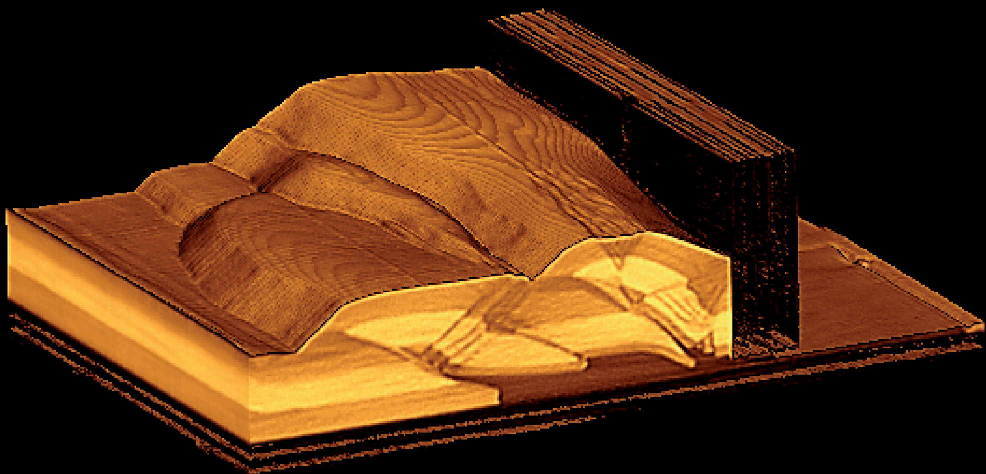
INSTITUTE OF GEOLOGICAL SCIENCES, UNIVERSITY OF BERN

Tectonic Laboratory



Analogue modelling and X-ray computed tomography (XRCT) at the Tectonic Laboratory in Bern

Analogue modelling is a well-estabishled technique to investigate the evolution of tectonic structures in the Earth's crust and lithosphere. Scaled analogue models offer the opportunity to determine the relation between imposed boundary conditions and resulting structures. The strength of such models lies in stimulating the conception of testable hypotheses about the development of tectonic structures in nature.

The Tectonic Laboratory at the University of Bern offers innovative and state-of-the-art facilities to model and analyse in detail a large variety of tectonic settings. Our analogue models are analysed by X-ray computed tomography (XRCT) using a 64-slice Siemens Somatom Definiton AS. XRCT is a technique which permits visualisation of the interior of a model without destroying it, hence allowing an in-depth analysis of the 3-D geometry of the model and of the kinematic evolution of model structures with time.

Digital volume correlation (DVC) techniques on XRCT volume data are used to quantify the 3D spatial and temporal strain patterns inside analogue models. Strain quantification of analogue experiments is of great importance when comparing analogue models with numerical studies.

Analogue modelling applications for the petroleum industry

- Analogue models offer the opportunity to test different tectonic scenarios and make it possible to investigate the 3-D geometry and evolution of structures, such as faults and folds, at a spatial and temporal resolution that can not be attained in natural field examples.

- Full 3-D imaging of analogue models using XRCT allows the reconstruction of any desired section, be it horizontal, vertical or oblique and provides constraints for seismic analysis of complex tectonic zones where seismic data are often fragmentary and difficult to interpret.

- XRCT analysis of analogue models at regular time intervals makes it possible to understand the 3-D evolution of structures in time (4-D) and is especially important when determining the potential for migration and trapping of hydrocarbons.

- 4-D XRCT data sets obtained from analogue models provide the opportunity to re-run the experiment on the computer screen and thus represent a valuable database for seismic interpreters to see realistic 3-D simulations of tectonic structures

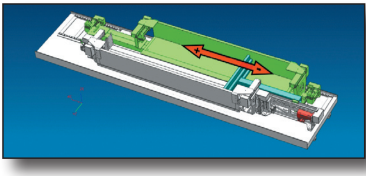
- A detailed analysis of analogue models by XRCT and DVC techniques provides quantitative data sets that can serve as input not only for seismic interpretations, but also for basin modeling and petroleum systems modeling.

Analogue model experiments are run within the investigation field of a 64-slice X-ray computed tomographer allowing a full 4-D analysis of the entire model (3-D geometry with time)

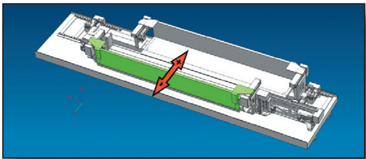
3-D view of analogue model investigating faulting in extensional transfer zones. The model consists of a basal viscous layer overlain by sand layers. Image is constructed from 2268 serial cross-sectional XRCT slices each spaced 0.3 mm apart. Longest dimension of model is 80 cm.

Experimental apparatus

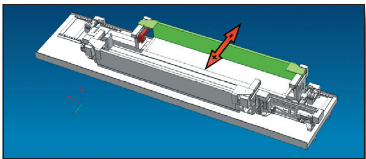
An innovative experimental apparatus is used to investigate a wide variety of tectonic settings. Computer-controlled stepper motors permit the combined displacement of baseplate and sidewalls (see figures below) hence also allowing oblique movements.



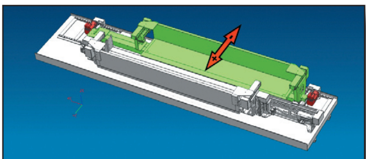
Lateral translation of baseplate and vertical sidewall



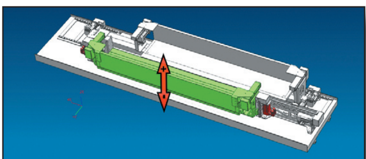
Inward or outward displacement of vertical sidewall



Inward or outward displacement of vertical sidewall



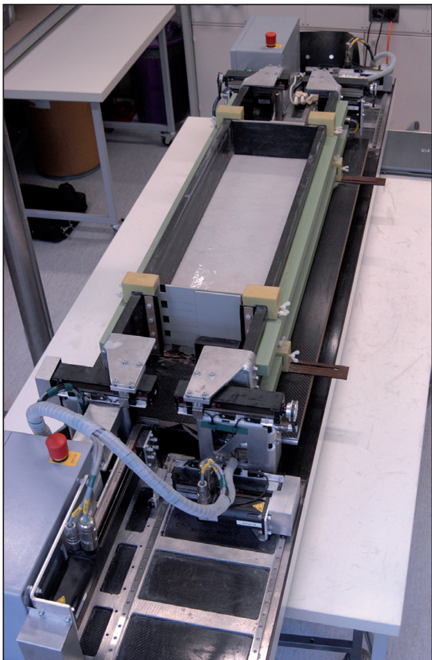
Inward or outward displacement of baseplate and vertical sidewall



Upward or downward displacement of vertical sidewall

Well-characterized analogue materials (see Panien et al., 2006) including viscous silicone and brittle granular materials (e.g., quartz sand, corundum sand, microbeads, and glass powder) are used to model structures in tectonic settings, such as:

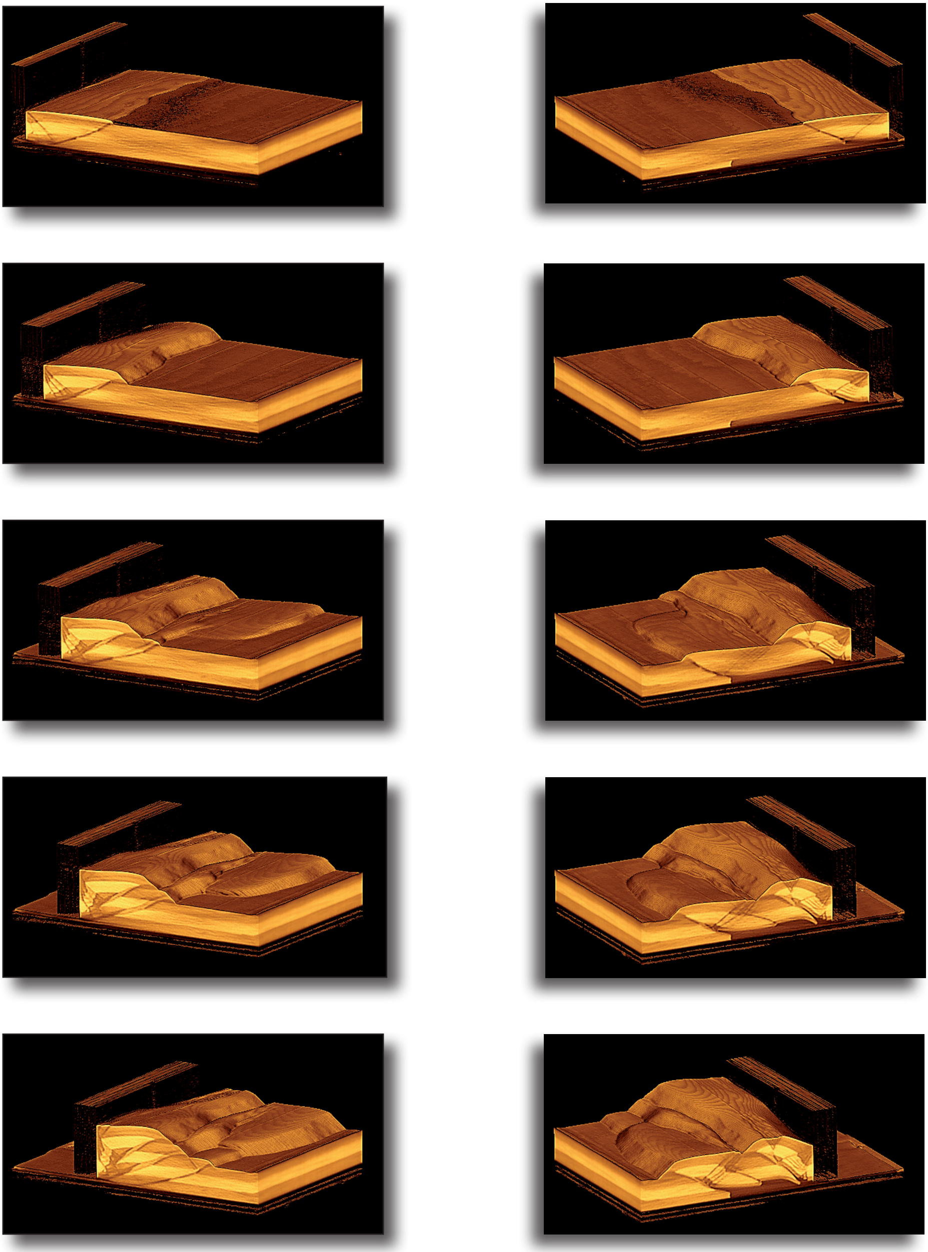
- extension
- shortening
- strike-slip
- inversion
- oblique extension (transtension)
- oblique shortening (transpression)
- oblique inversion
- sub-salt tectonics



Experimental apparatus. Displacement of base-plates and sidewalls is driven by computer-controlled stepper motors.

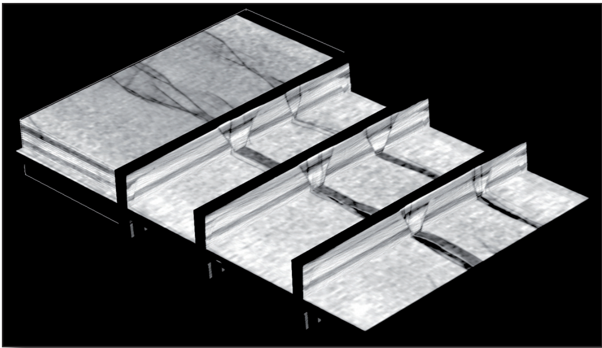
4-D Analysis of analogue models

Animations created from XRCT data sets allow us to replay the analogue experiment on the computer screen and to investigate the 3-D geometry of each recorded stage in detail. The 3-D views below show consecutive stages of deformation for a thrust experiment.

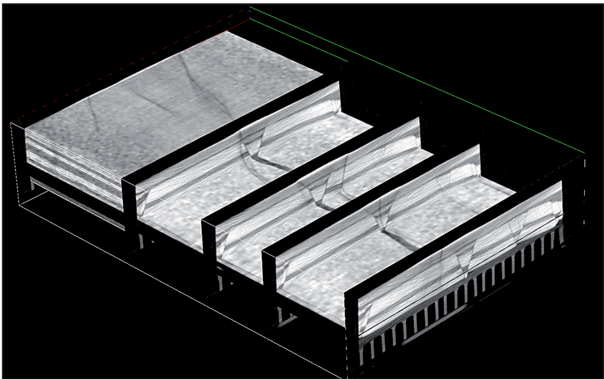


Examples

Rift reactivation



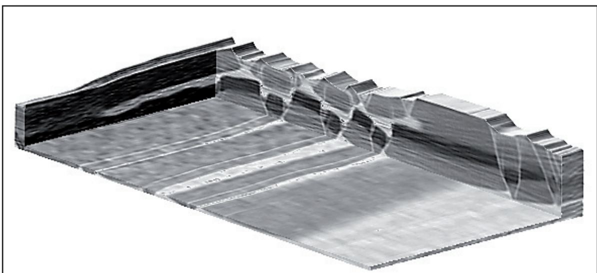
3-D view of model simulating strike-slip reactivation of rift structures. Figure shows horizontal sections near top (left-hand side) and at depth (right-hand side) and three vertical sections. Longest dimension of model is c. 70 cm.



3-D view of model simulating oblique reactivation of rift structures. Figure shows horizontal sections near top (left-hand side) and at depth (right-hand side) and four vertical sections. Longest dimension of model is c. 70 cm.

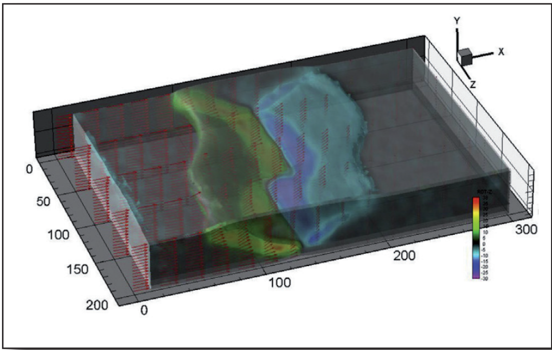
Sub-salt tectonics

3-D perspective block diagram of a model simulating extension in a multi-layer model consisting of a basal "salt" layer (viscous silicone) overlain by brittle sand layers and and interbedded upper "salt" layer. XRCT analysis allows visualisation of sub-salt structures. Height of model is c. 4 cm.



3-D view with horizontal and vertical sections showing fault structures in a model with a salt layer (light-grey) sandwiched between brittle sand layers. Longest dimension of model is c. 25 cm.

Strain quantification of analogue models analysed by XRCT



3-D strain results of analogue model simulating pop-up structure. Digital image correlation techniques applied on successive 3-D volumetric XRCT data allow to quantify the 3D spatial and temporal patterns of strain. Cumulative displacement vectors indicate total material transport. Iso-surfaces of constant shear strain outline extent and geometry of thrust faults. Cold and warm colors refer to forward and back thrust, respectively (see Adam et al., 2013).

Selected publications

Adam, J., Klinkmüller, M., Schreurs, G., Wienecke, B. 2013. Quantitative 3D strain analysis in analogue experiments: Integration of X-ray computed tomography and digital volume correlation techniques. Journal of Structural Geology, 55, 127-149

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Buiter, S., Schreurs, G. and Ellis, S. 2008. Numerical and analogue models of the formation of parallel-dipping normal faults. Boll. di Geofisica, 49, 311-313.

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Panien, M., Schreurs, G. and Pfiffner, O.A. 2006. Mechanical behaviour of granular materials used in analogue modelling: insights from grain characterisation, ring-shear tests and sandbox tests. Journal of Structural Geology, 28, 1710-1724.

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Schreurs, G. & Colletta, B. 1998. Analogue modelling of faulting in zones of continental transpression and transtension. In: Holdsworth, R. E, Strachan, R.A. and Dewey, J.F. (eds.): Continental Transpressional and Transtensional Tectonics, Geological Society London, Special Publications, 135, 59-79.

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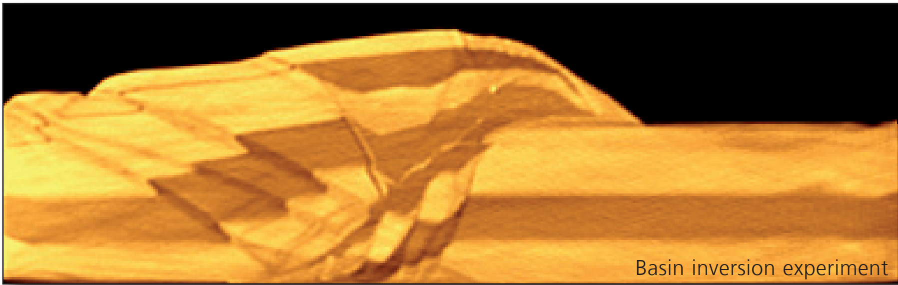

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