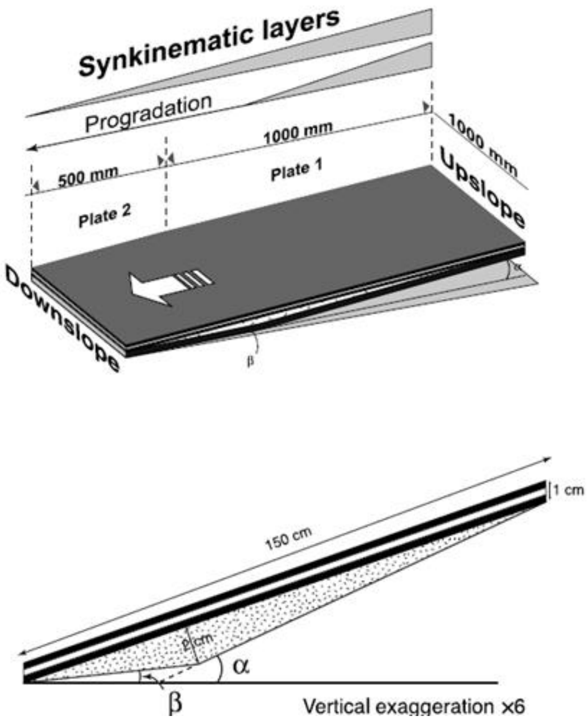
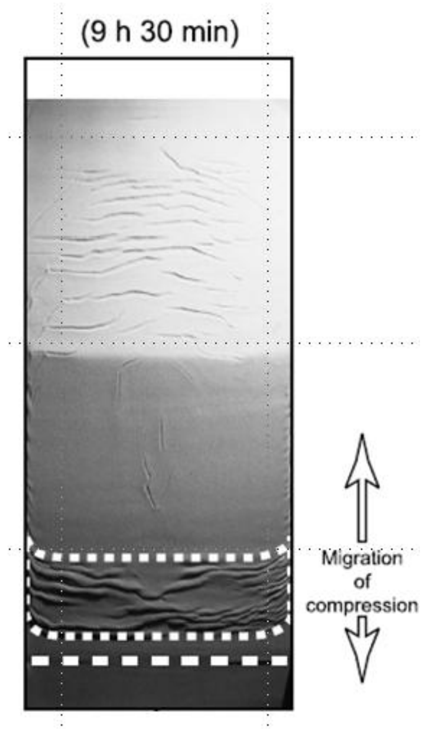
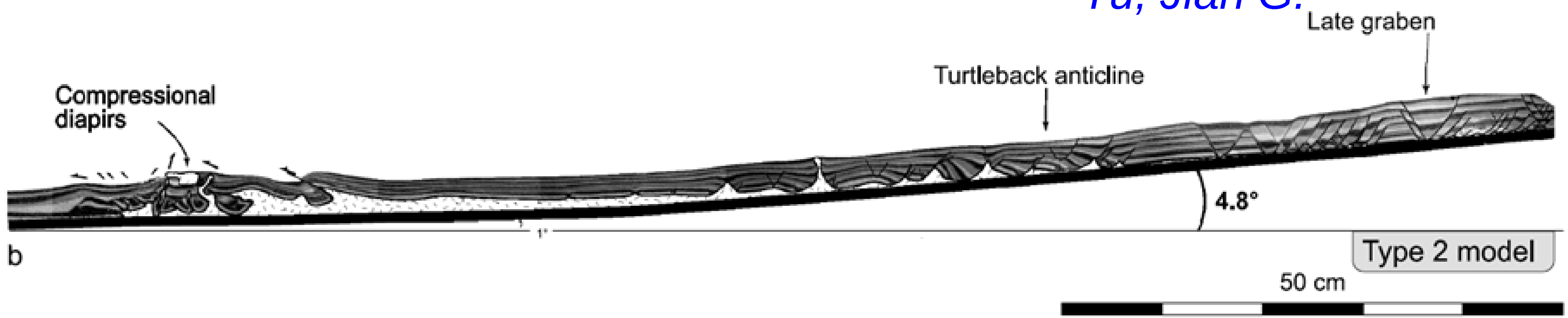




Regional-Scale Salt Tectonics Modelling:

Bench-Scale Validation and Extension to Field-Scale Predictions

Thornton, Dean A.,
Roberts, Daniel T.,
Crook, Anthony J.L.,
Yu, Jian G.



Acknowledgements

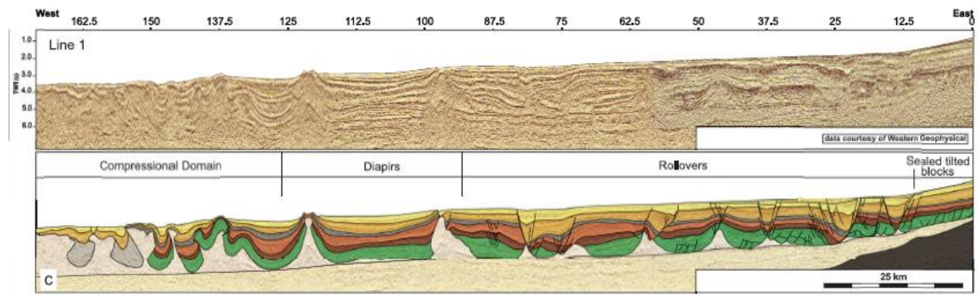
- Special thanks to:
- European Social Fund (Kess Scholarship);
- Joe Cartwright – Seismic 3D Labs, Cardiff University
- Rockfield Software Ltd.

Main Goal: **Determine main controls on structural styles and reservoir properties in a gravity driven system underlain by a mobile sub-strate**

Structural questions:

Major controls on structural style:

a. timing of activity of structures (basement subsidence vs. sedimentary loading)
b. spacing and style of extensional rafts
c. transition to compressional regime
d. influence of basement geometry

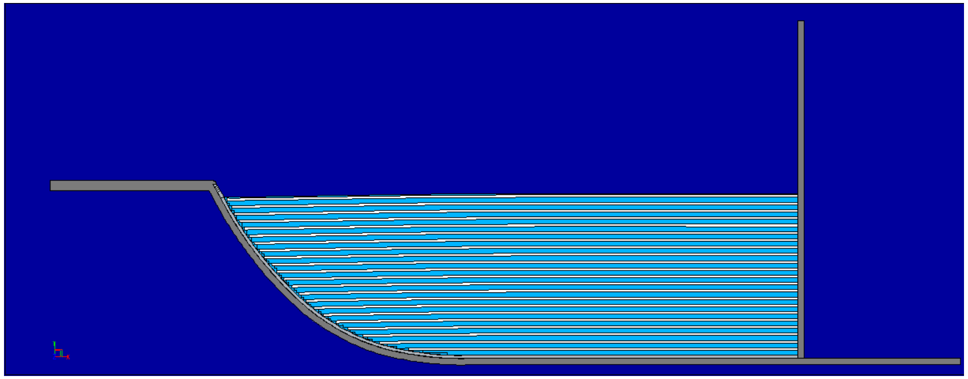


Rationale

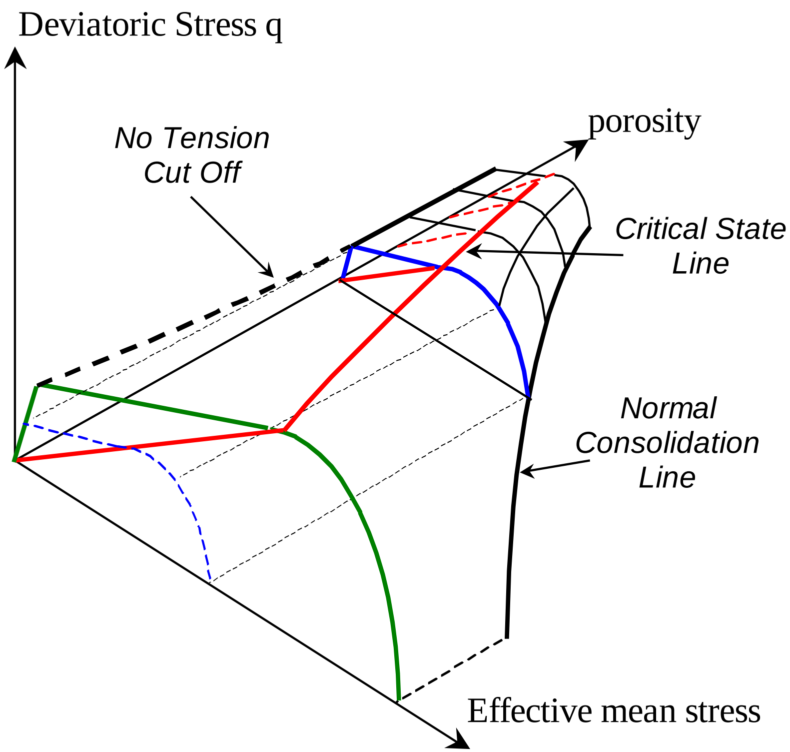
- Fort et al, 2004 performed laboratory experiments on brittle-ductile models to study thin-skinned deformation above the salt at margin scale
- The experiments are designed with the salt basin wedging out, both landward and seaward, and entirely covered by sediments at the onset of gravity driven deformation.
- They show that the experiments capture the main mechanisms observed in the seismic images

ELFEN – Modelling Approach

- **Finite Element Method**
- **Physics** based approach incorporating **large strain**
- Enhanced **rheological models** (constitutive models) for **rocks** and **salt**
- Enhanced **fault** and **localisation prediction**
- Includes **Sedimentation** and **Erosion**

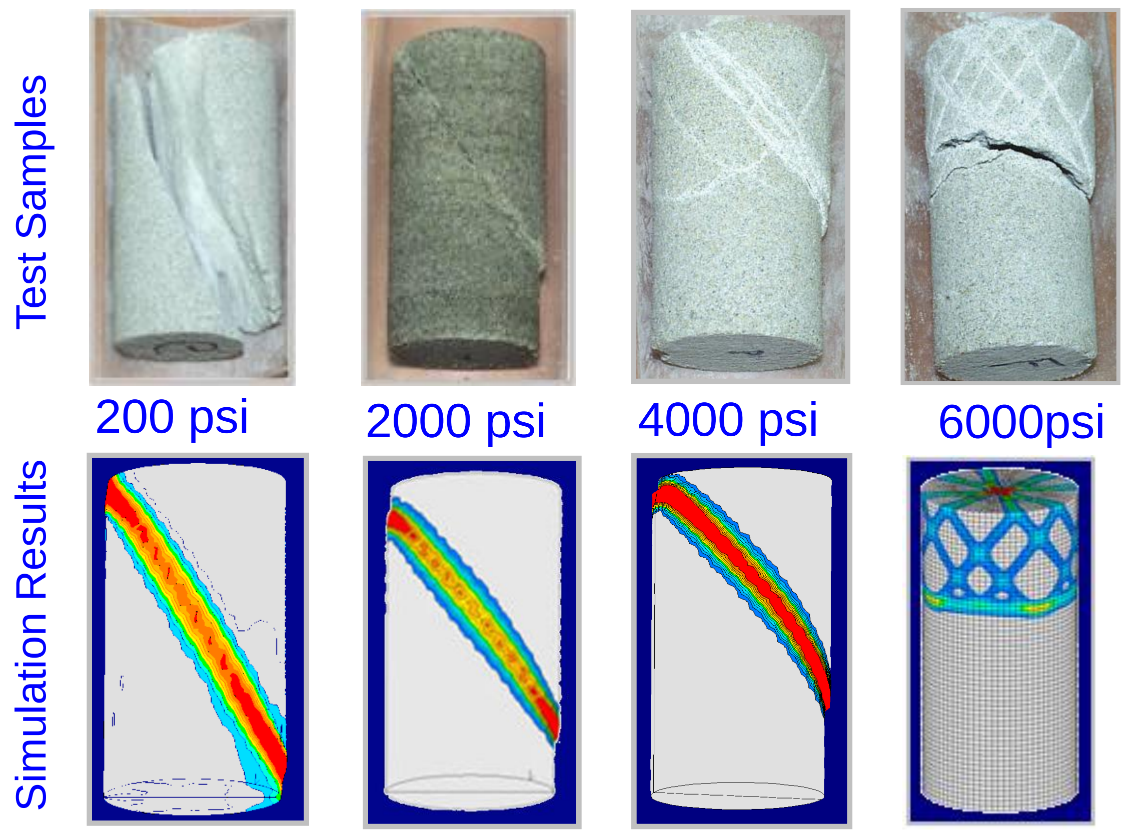


Rockfield's SR3 Constitutive Model



- State Boundary Surface Based on Critical State Theory.
- Represents Increased strength due to Mechanical Compaction and Strength Reduction due to Shear Failure
- Fracture Mechanics Concepts facilitate scale-up from experimental to field scale
- Localisation Identification Algorithms enable the prediction of the formation and evolution of new faults

Dependence of fracture angle on confining pressure



SR3 Model - Characterisation

- The constitutive model is has been shown to provide a good prediction of the response in sandbox tests in a number of different stress regimes.

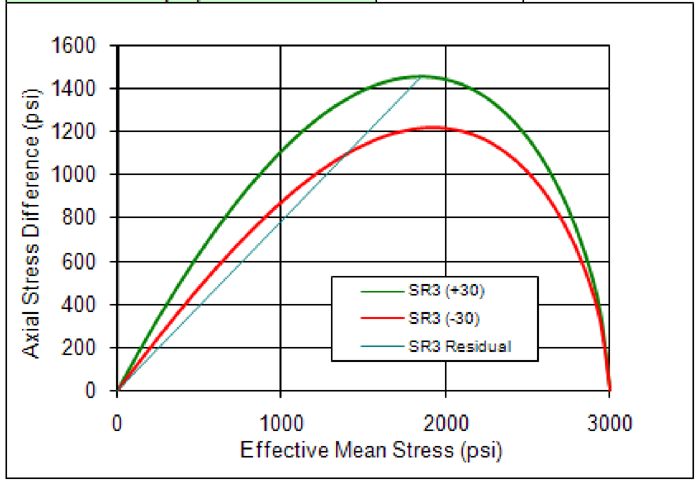
- **Elastic Properties:**
  Young's Modulus (E) = 75,000 Pa
  Poisson's Ratio (υ) = 0.3
- **Initial Porosity**
  ϕ_0 = 0.45
- **SR3 Plasticity:**
  Residual Friction M = 0.79 ϕ_{cs} = 20.34°

Yield Surface Definition

Soft Rock 3 Model

Yield Surface Definition Parameters	
Pre-Consolidation Pressure p_c	3000
Friction Parameter ϕ (°)	55.00
Tensile Intercept p_t	-1.00
Exponent n	1.6
Friction Parameter ψ (°)	45.00
	0.785
Deviatoric Correction (alpha)	0.25
Beta 0	0.6
Beta 1	3.00E-04

Residual Friction Angle ϕ_{cs}	20.34
q_{cs}/p_{cs}	0.79



Herschel-Bulkley Model

- The silicone is represented using a Herschel-Bulkley material model. This relates the shear stress with the shear strain rate via

$$\tau = \tau_0 + k\dot{\gamma}^n$$

where τ_0 is the initial shear strength, k is the consistency parameter and n is an exponent.

- When $\tau_0 \rightarrow 0$ and $n = 1$ then this becomes a Newtonian fluid where the consistency parameter (k) is the fluid viscosity (μ)

- The silicon is defined as being Newtonian with
 μ = 10000 Pa.s (2.778 Pa.hrs).

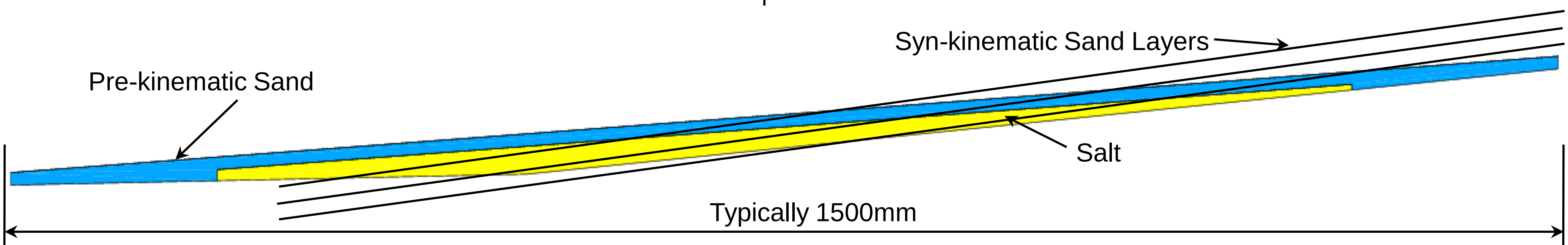
- This is achieved in ELFEN by setting
 τ_0 = 0.2Pa
 n = 1
 k = 2.778 Pa.hrs

Geometry

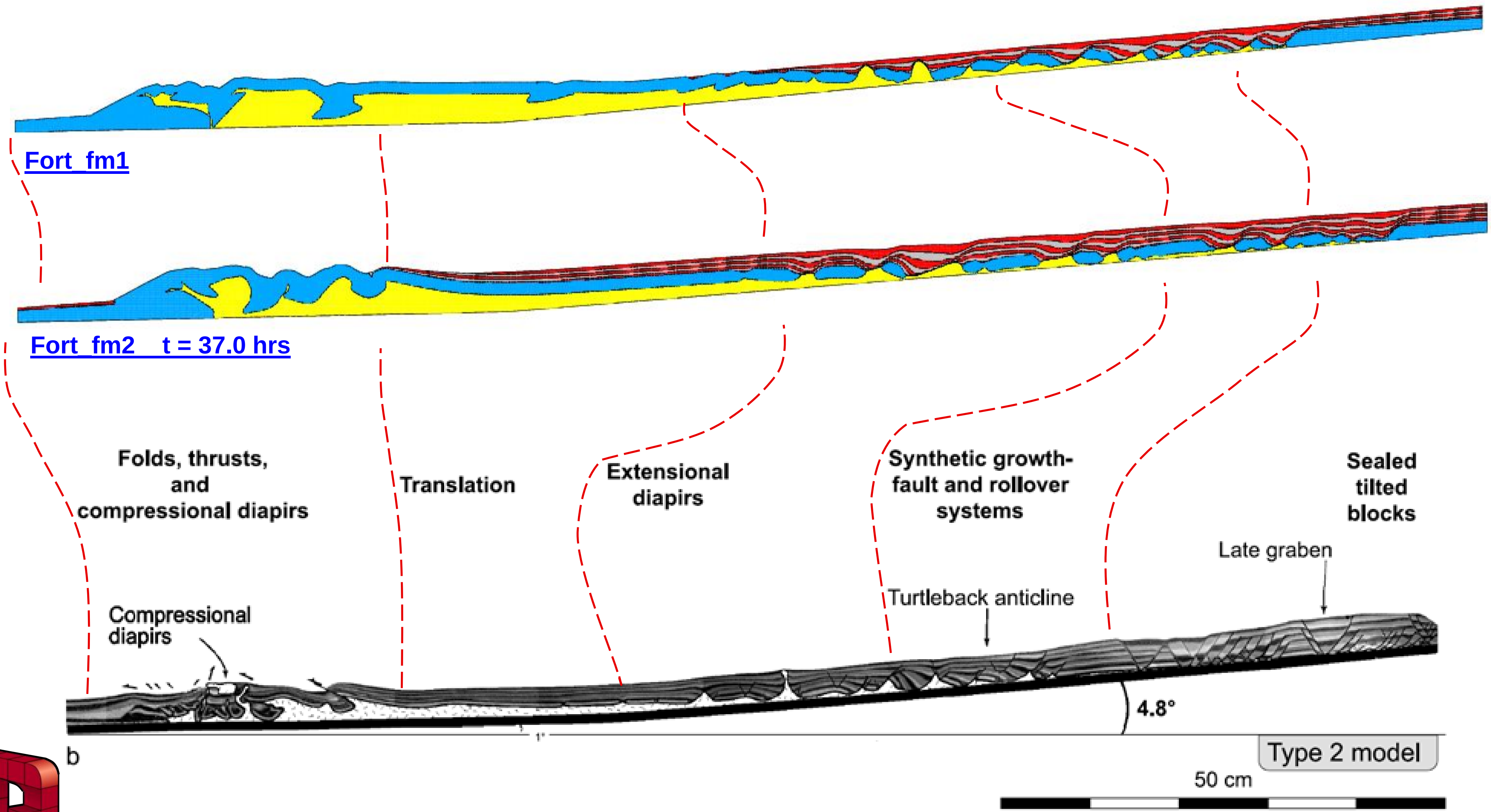
- Parametrically Defined to allow modification slopes, pre-kinematic sediment and salt thickness, syn-kinematic layer thickness and extent, sedimentation rate
- The pre-kinematic layer is 5mm thick in the extensional zone and may be either constant thickness or tapered towards the toe of the slope

Loading and Boundary Conditions

- Multi-stage analysis comprising
- Gravity initialisation of the salt and pre-kinematic sand
- Sedimentation of the syn-kinematic layers after a specified time (typically 5hrs)
- No slip at the sediment/sandbox and salt/sandbox interfaces.

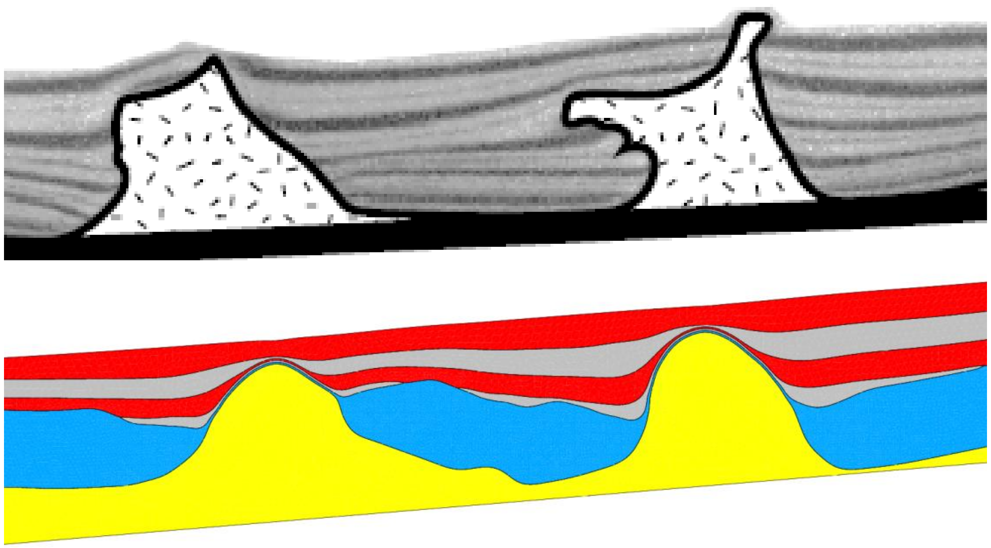


Fort_fm1 - Distal slope angle 1º. Proximal slope angle 4.8º.
Fort_fm2 – Distal slope angle 1º. Proximal slope angle 3.8º.



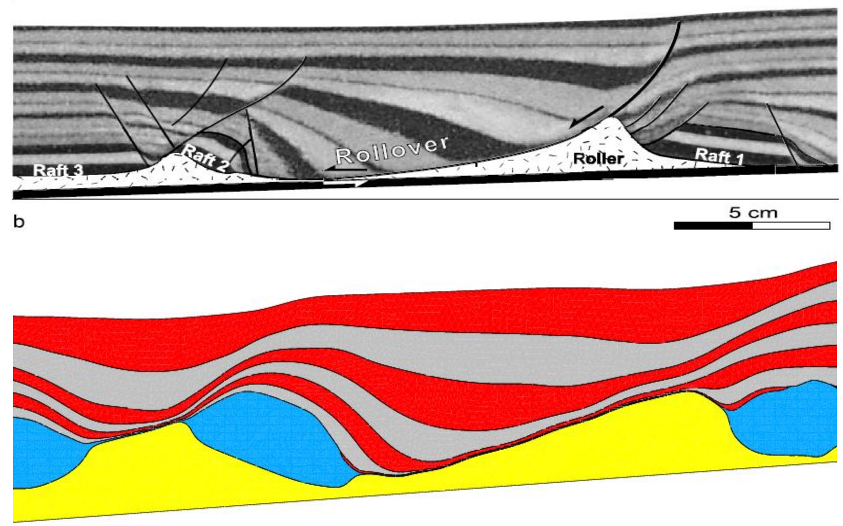
Comparison of Structural Styles

Fort_fm1



Diapirs in the proximal extension zone

Fort_fm2

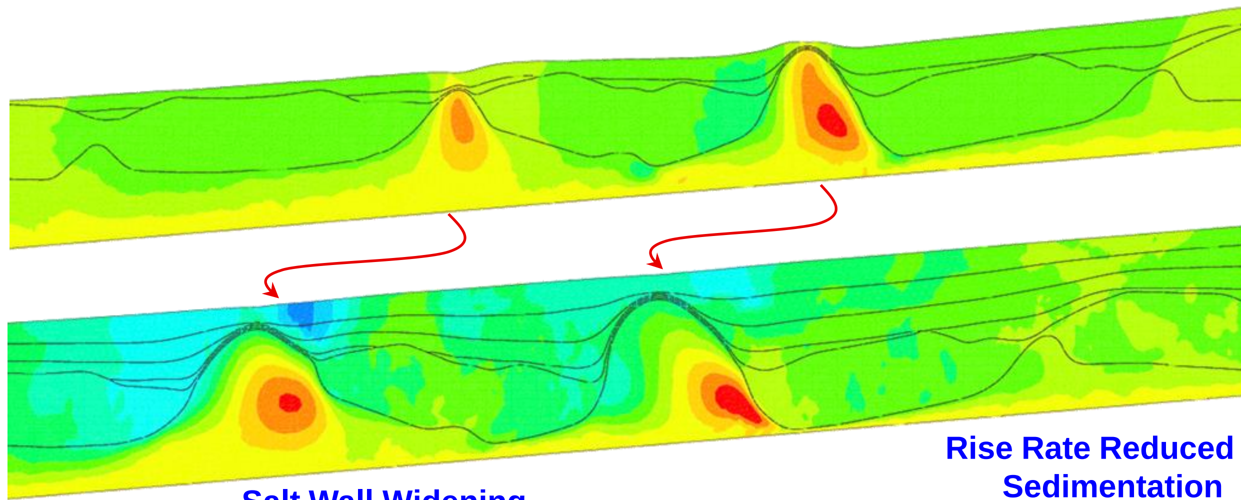


Salt rollers in the proximal extension zone

Version 1.0

Regional-Scale Salt Tectonics Modelling
Diapiric Rise Rates

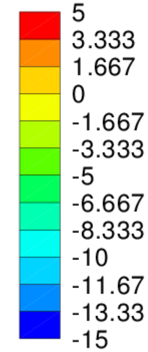
Fort_fm1



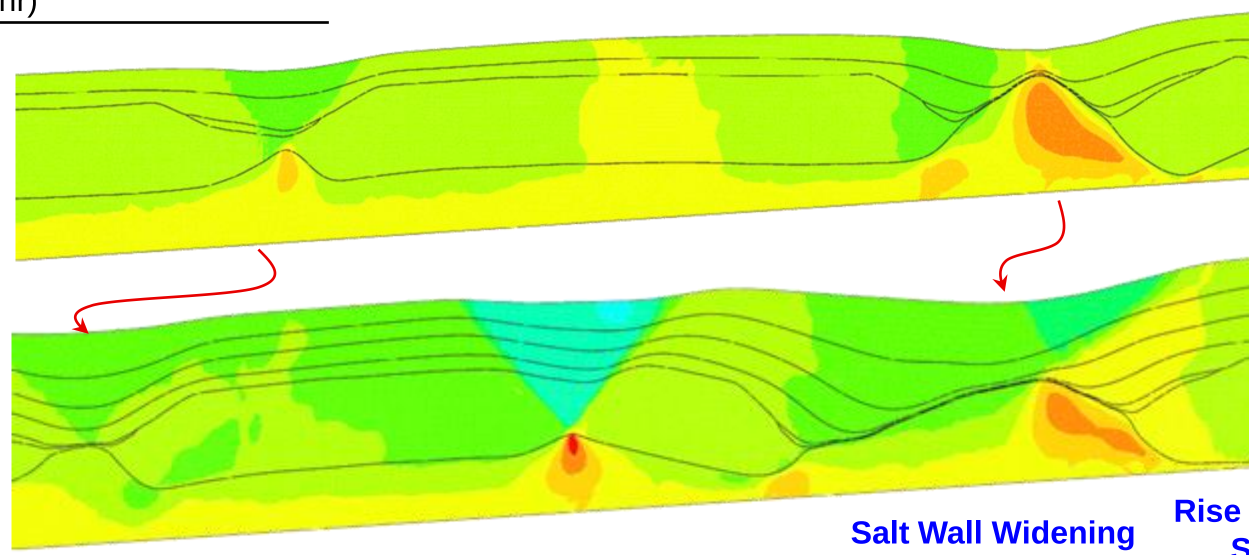
Rise Rate Reduced by Sedimentation

Salt Wall Widening

Vertical Velocity (mm/hr)



Fort_fm2

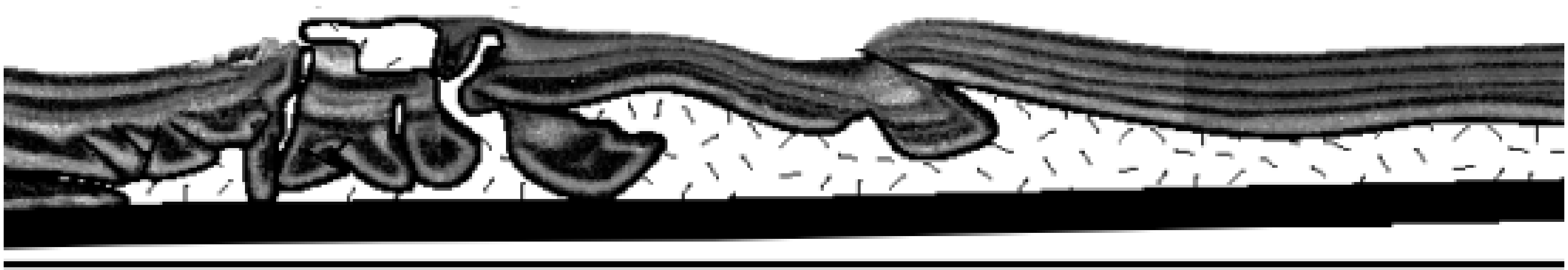


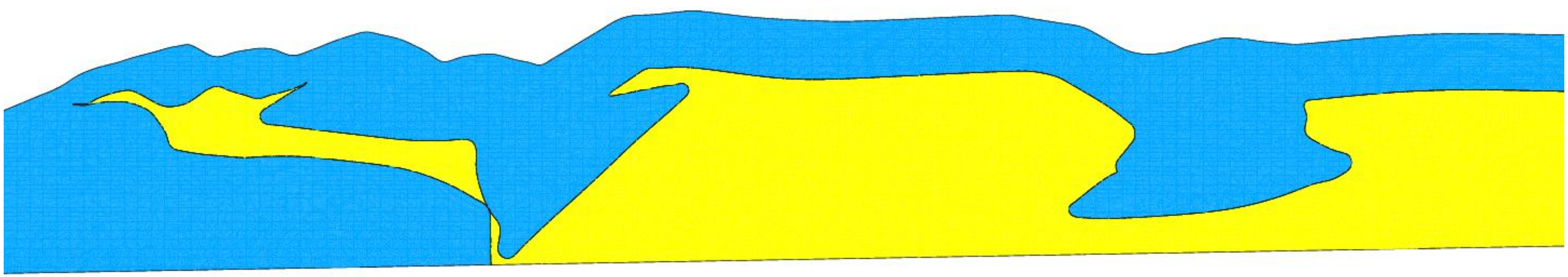
Salt Wall Widening

Rise Rate Reduced by Sedimentation

Vertical Velocity(mm/hr)

Comparison of Structural Styles





Fort_fm1

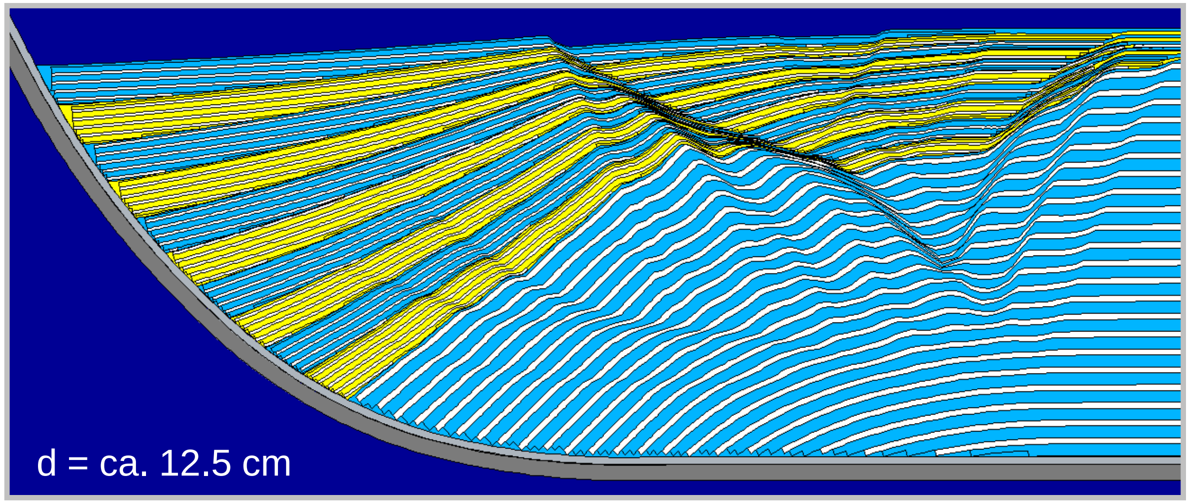
Enlarged view of compressional deformation in the physical and computational models

Regional-Scale Salt Tectonics Modelling

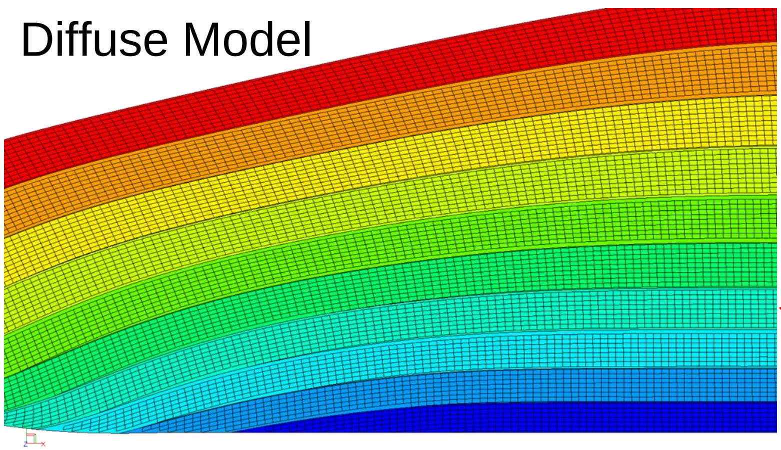
McClay E30/E37 Listric Fault Experiment and Prediction

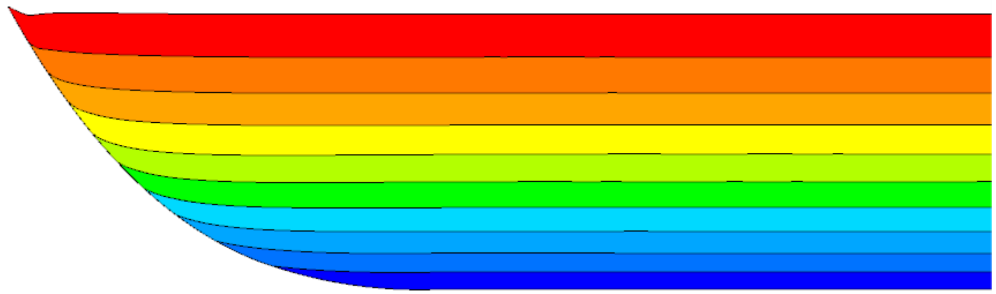
Bench-scale Simulation

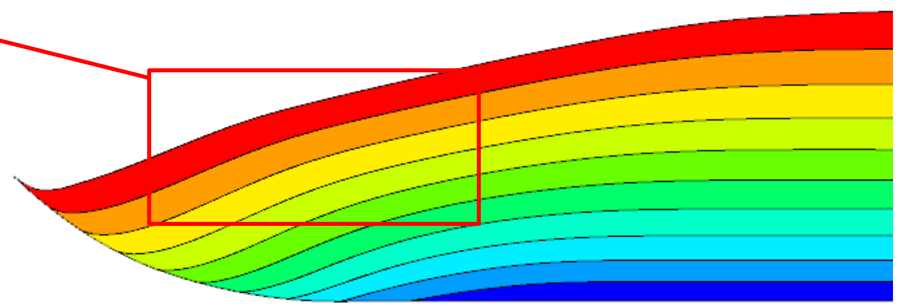
Collapse graben develops due the increase in the bed lengths of the upper region of the pre-rift sand.



Shear in Field-Scale Diffuse Model



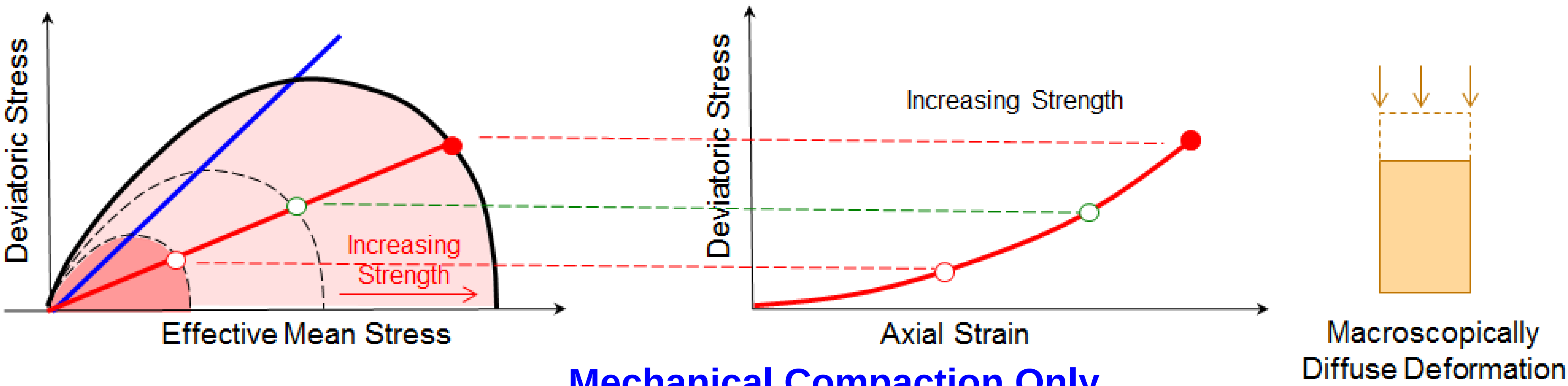




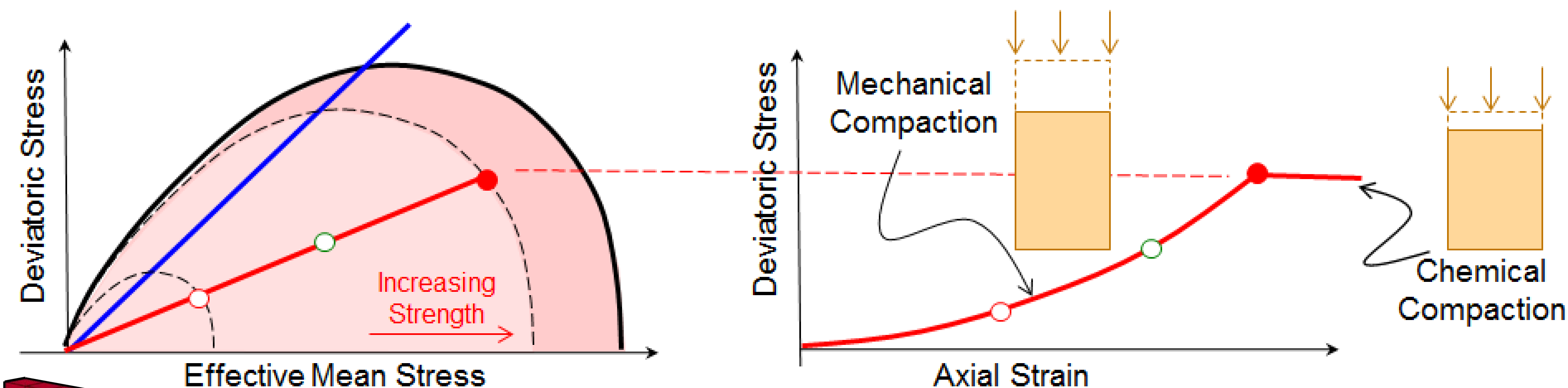
Field-scale Simulation including Deposition

(Mechanical Compaction Only)
Hydrostatic Pore Pressure

Regional-Scale Salt Tectonics Modelling
Critical State Based Model Uniaxial Compaction



Mechanical Compaction Only



Mechanical and Chemical Compaction

Status and Further Work

- Good correlation between structural styles of experimental and numerical models as been observed..
- Better correlation can be achieved by improved calibration of numerical rheologies relative to experimental materials.
- Knowing more about the physical experimental set-up and design would allow for a more specific, rather than generic, comparison.
- Extension to the field-scale can be accommodated via consideration of rheological upscaling via thermal and chemical compaction processes.
- Parametric investigation of field scale processes and behaviour will be performed.