Numerical Sand Box as a Tool for Hydrocarbon Exploration: Applications to the Hides Anticline and the Western Papuan Fold and Thrust belt*

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Search and Discovery Article #42520 (2020)**
Posted May 4, 2020

*Adapted from oral presentation given at 2020 AAPG/EAGE PNG Geoscience Conference & Exhibition, PNG's Oil and Gas Industry Maturing Through Exploration, Development and Production, February 25-27, 2020, Port Moresby, Papua New Guinea
 DOI:10.1306/42520Beucher2020

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Abstract

Analysing the geometry and the geological evolution of subsurface structures is fundamental to the characterisation of reservoirs and the search for hydrocarbons, particularly in fold and thrust provinces. Field data bring fundamental insights but are often insufficient to understand the geological system. Imaging techniques, such as seismic, may be limited in quality and/or have insufficient penetration to fully understand the large-scale structures. Thus it has been necessary to utilize geometrical modeling, backed up by occasional analog experiments using sand, clay and silicone to simulate the formation of large geological structures. These have proven to be very valuable but their setup is time consuming and reproducibility is often an issue. It is also difficult to run a large number of simulations to fully explore the parameter spaces and quantify the uncertainty. Darnault and Hill (AAPG in press) report the results of 17 analog modeling of the Hides anticline by IFPEN run over an 18 month period.

We present UWGeodynamics, a finite element software which facilitates numerical-mechanical and thermo-mechanical modeling in 2D and 3D at all scales. Whilst this can be for the expert user on a supercomputer, we discuss a simple setup for the desk geologist that simulates sandbox modeling. The advantage of the UWGeodynamics sandbox modeling is that over 300 2D models can be run overnight on a supercomputer (or in the cloud) or 10+ models overnight on a laptop as opposed to one analog model/month. This allows us to fully investigate the range of all inputs/variables overnight and produce a movie for each experiment. These can be compared both visually and statistically to determine not only the best outcome but also the range of reasonable outcomes. A major benefit is that we can determine which parameters are important or sensitive in the model and which have little effect.

To replicate sandbox modeling of the Hides anticlines (after Darnault and Hill in press) we ran 1050 2D models in 3 days and reproduced their simple ductile, brittle and complex ductile rheologies. We were able to produce the same outcomes with different mixes of parameters, including strain rate, the angle of the fault ramp and subtle variations in material strength and coefficient of friction. This allows a much

improved understanding of the structural evolution. Our aim now is to test many other possibilities to improve the fit to the observed structural geometries from the field. We then aim to expand the models to 3D (requiring a supercomputer or cloud computing) to test variations along strike. The same modeling can be applied to other structures along strike in PNG, such as Muruk and Kutubu, and to compressional or extensional structures elsewhere in the world.

Numerical Sand Box as a Tool for Hydrocarbon Exploration: Applications to the Hides Anticline and the Western Papuan Fold and Thrust Belt

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Margins at Melbourne, February 2020

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Acknowledgements

- The initial sandbox modelling work for this project was carried out at Oil Search as a research project with IFPEN. Many thanks to Oil Search and JV partners.
- Digital sandbox modelling using Underworld was carried out as part of Basin Genesis Hub research at the University of Melbourne.
- Many thanks to BGH partners; the Australian Research Council, Oil Search, Chevron and Equinor (Statoil).

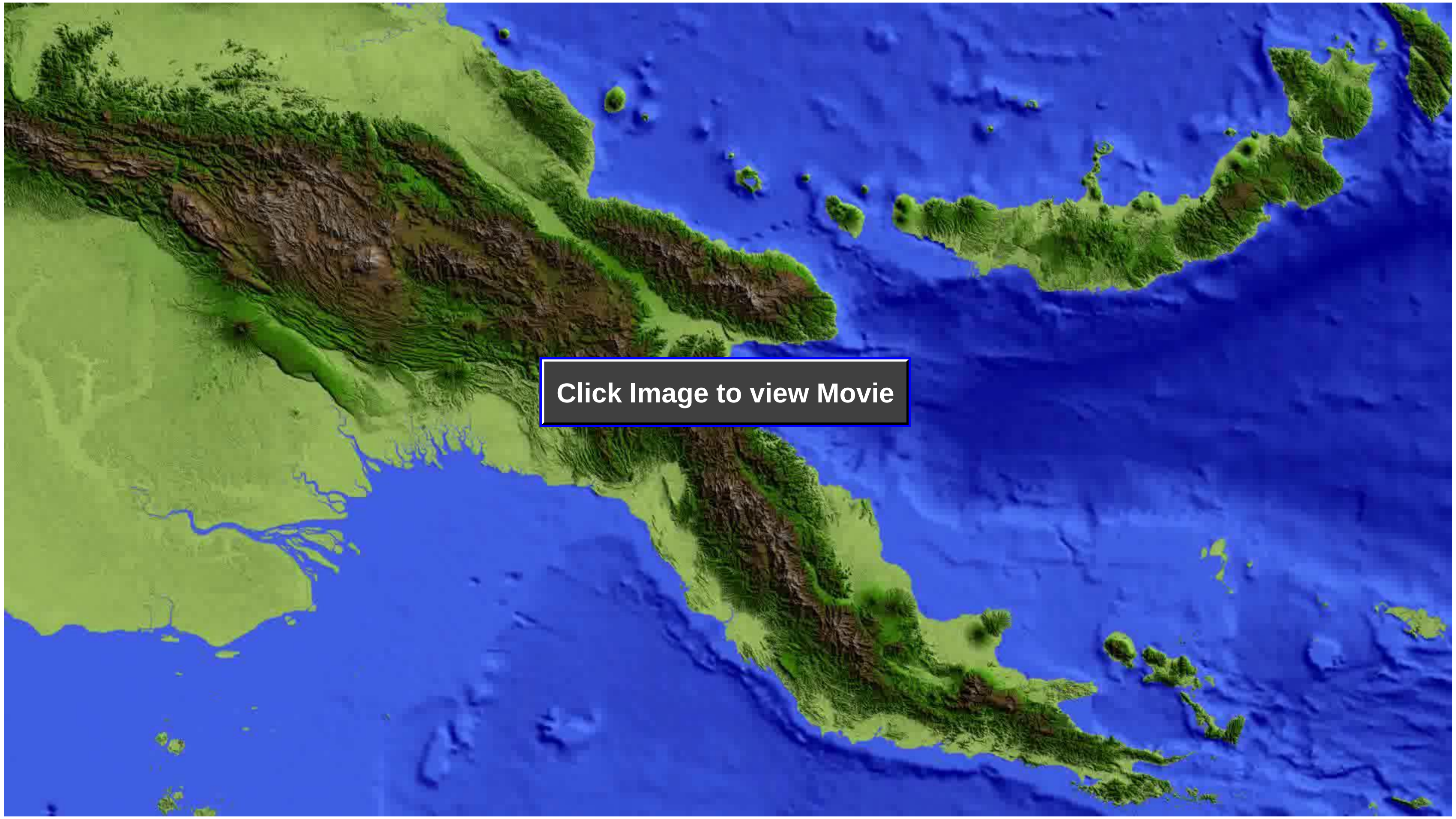
The Goal

- Seismic in PNG is not so good, often misleading
- Geometrical models are excellent, but limited by algorithms and the bias of the interpreter
- Real-Earth finite element models are good, but many variables are poorly constrained and not well understood
- Sandbox models are simple and well understood by the average geologist, but they take time
- So we aim to develop a digital desktop sandbox modelling kit where the geologist can design a model and run a dozen or more variations overnight

Outline of Talk

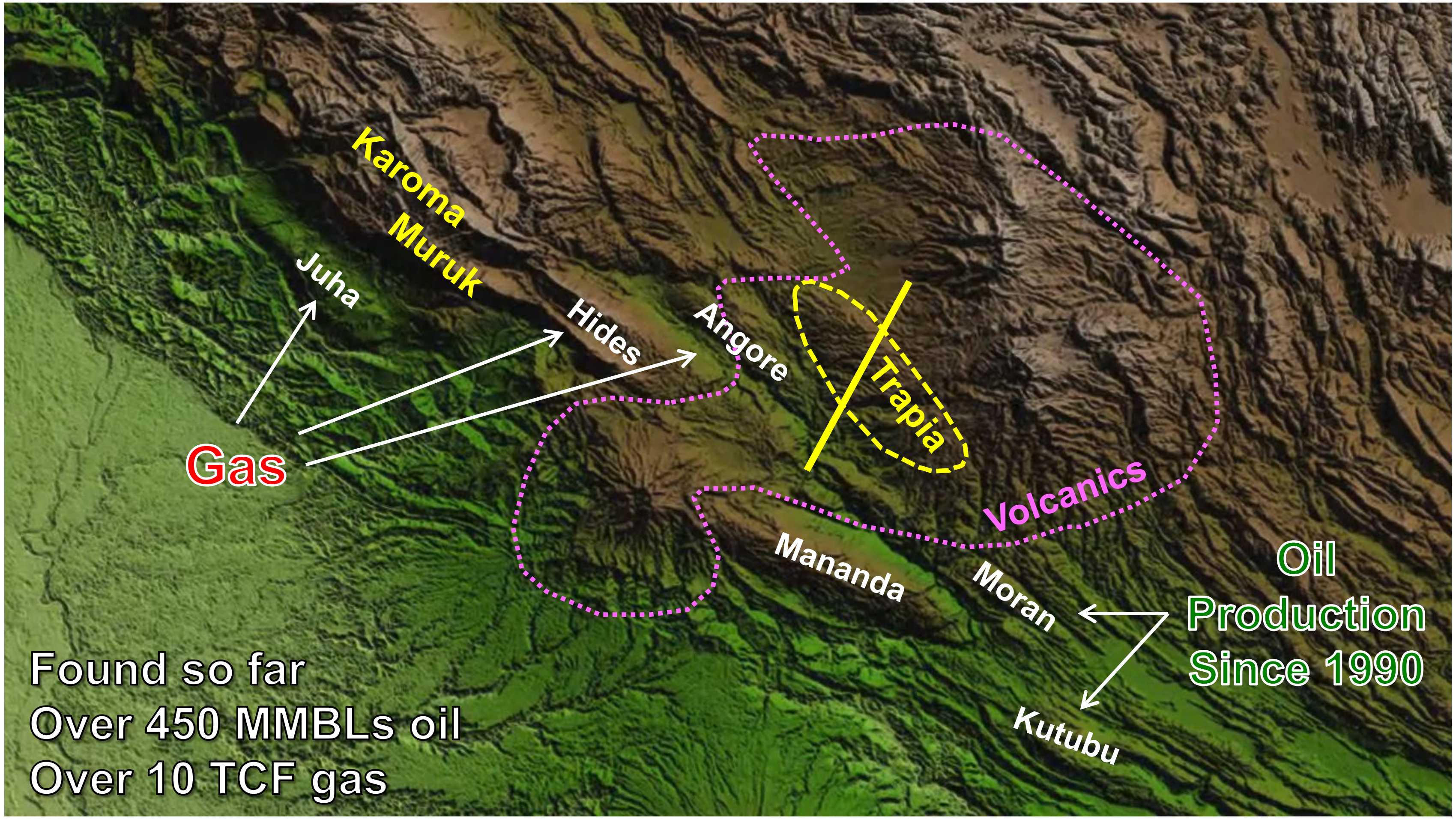
- The structure problem in PNG
- Geometrical solutions
- Sandbox models
- Digital sandbox models

West PNG Highlands



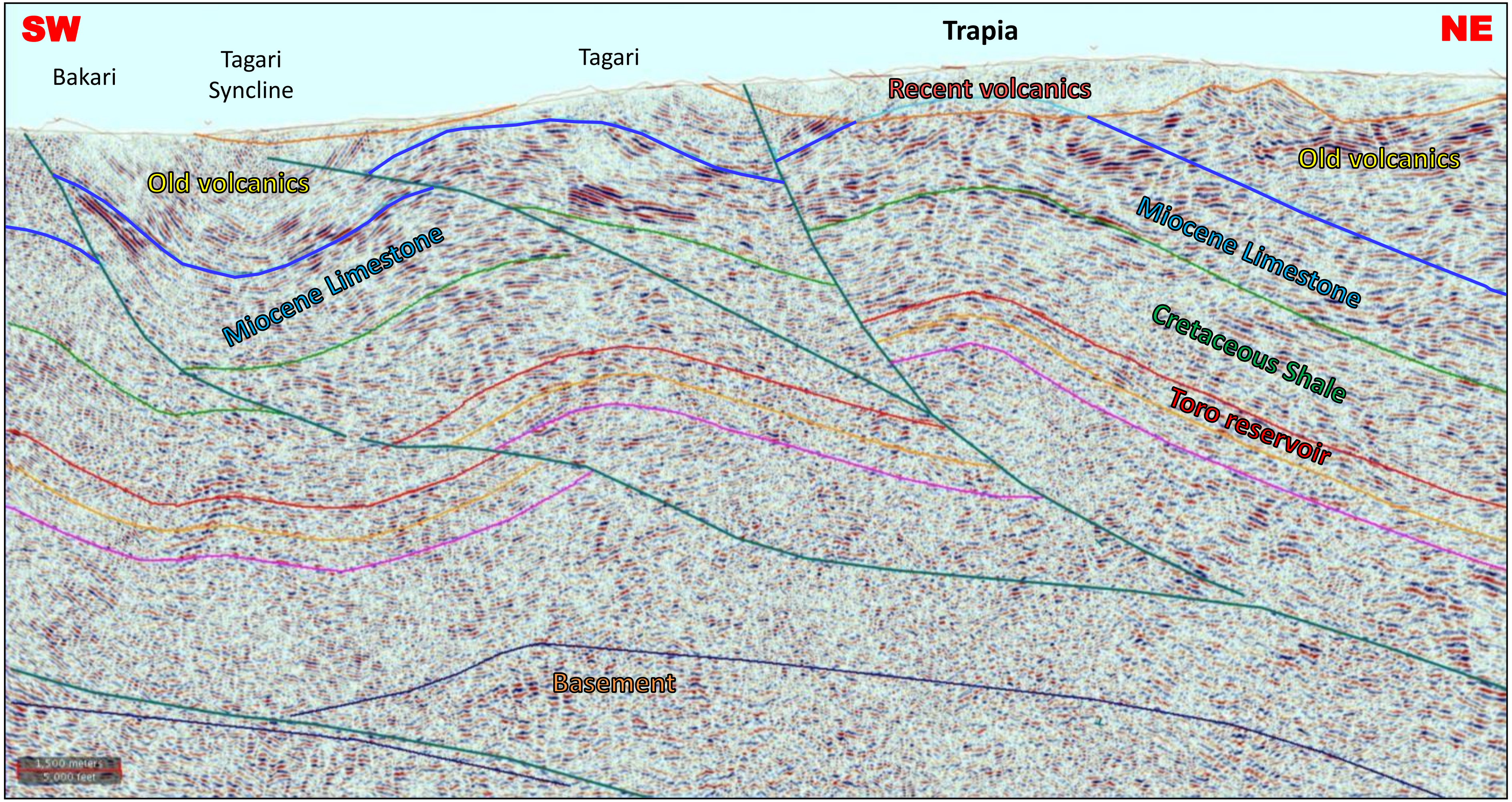
Courtesy Oil Search APPEX 2016

Fields and Trapia Seismic



Courtesy Oil Search APPEX 2016

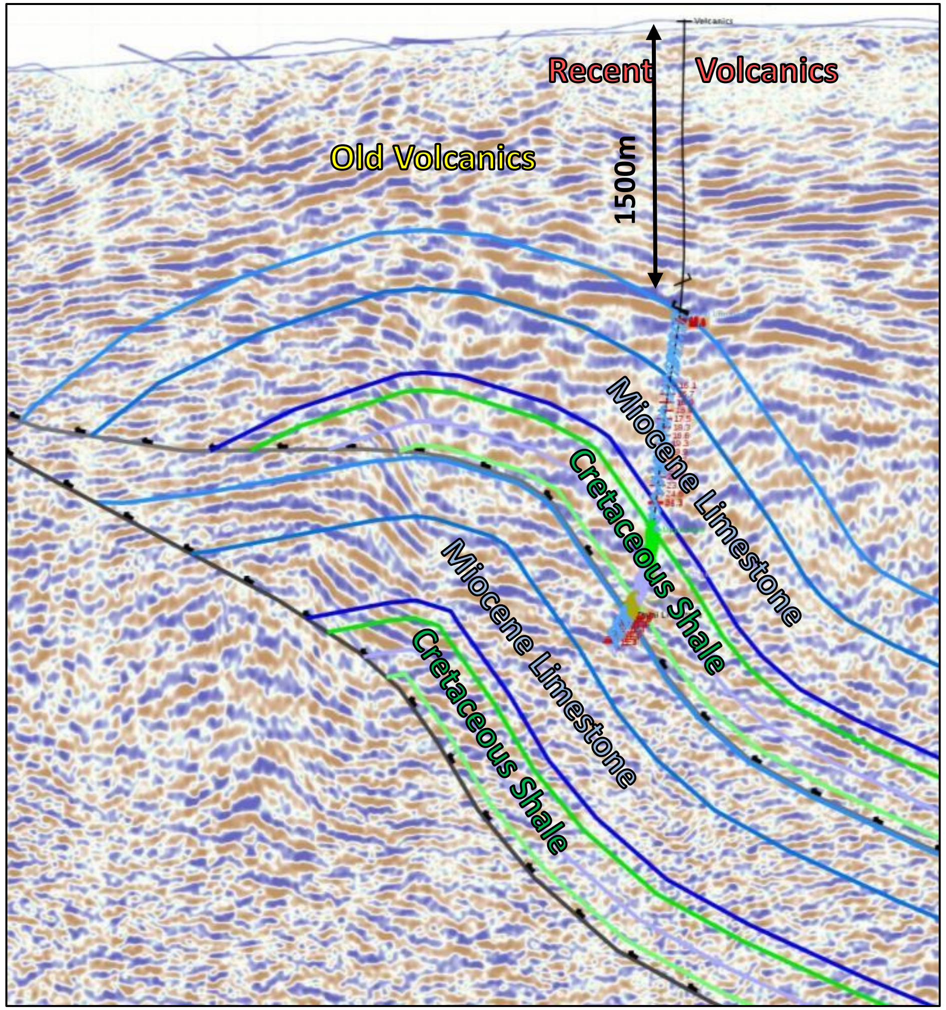
Trapia TWT seismic line pre-drill

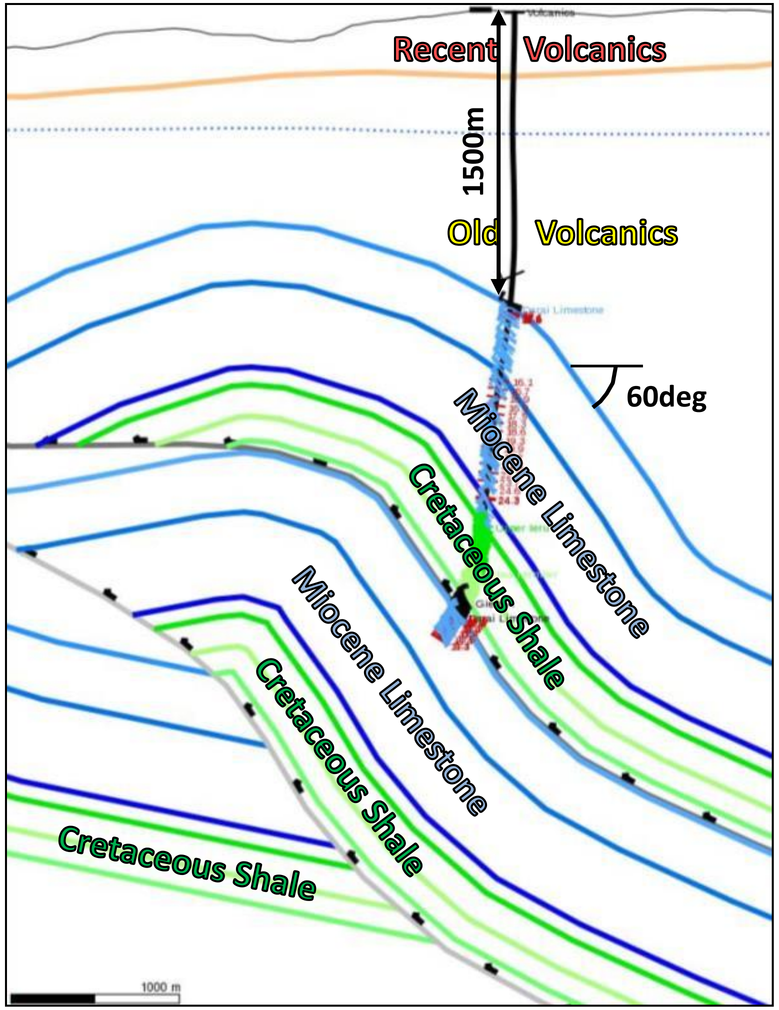


Courtesy Oil Search APPEX 2016

Trapia depth seismic line post-drill

The consistent 60^{O} dips and Darai thrust repeat recorded in the well were not observed on seismic data

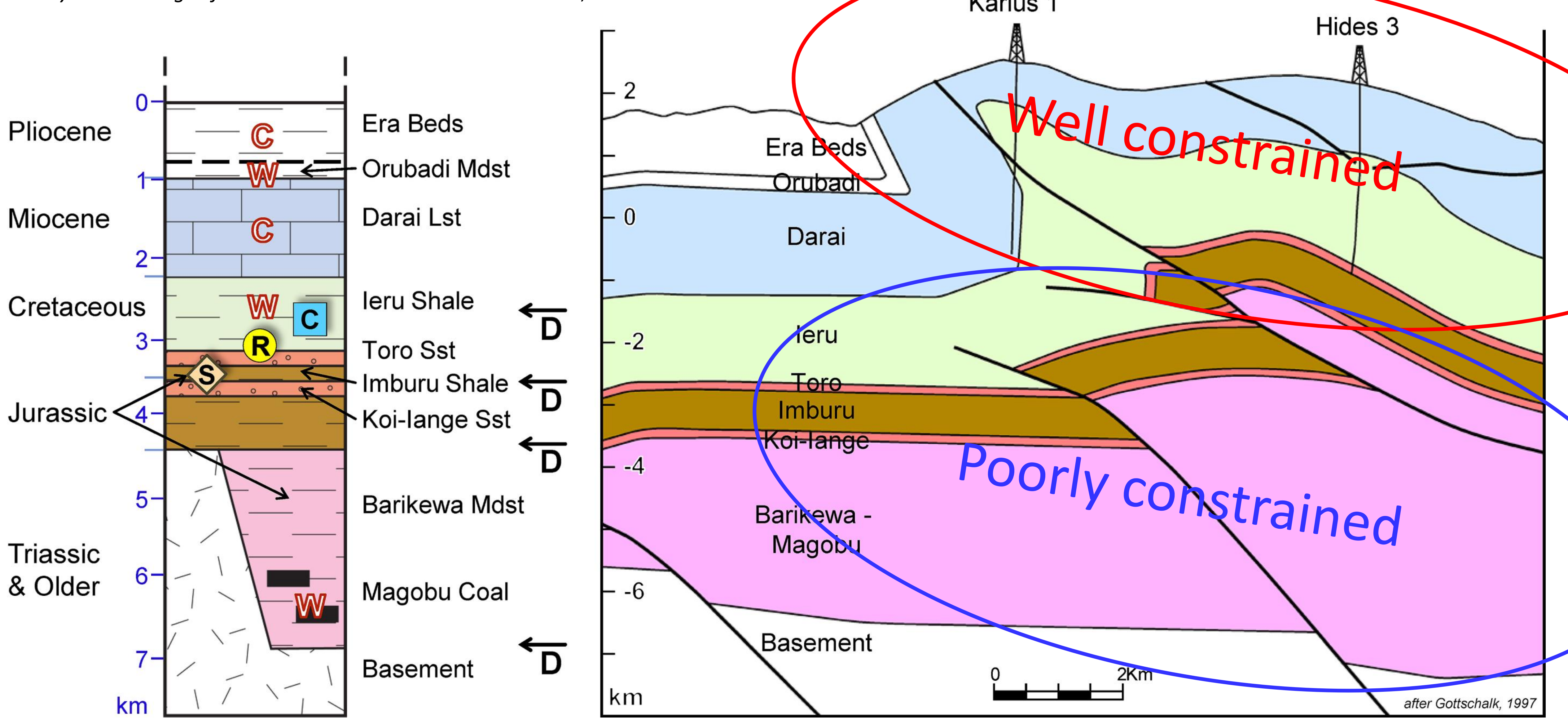




Courtesy Oil Search APPEX 2016

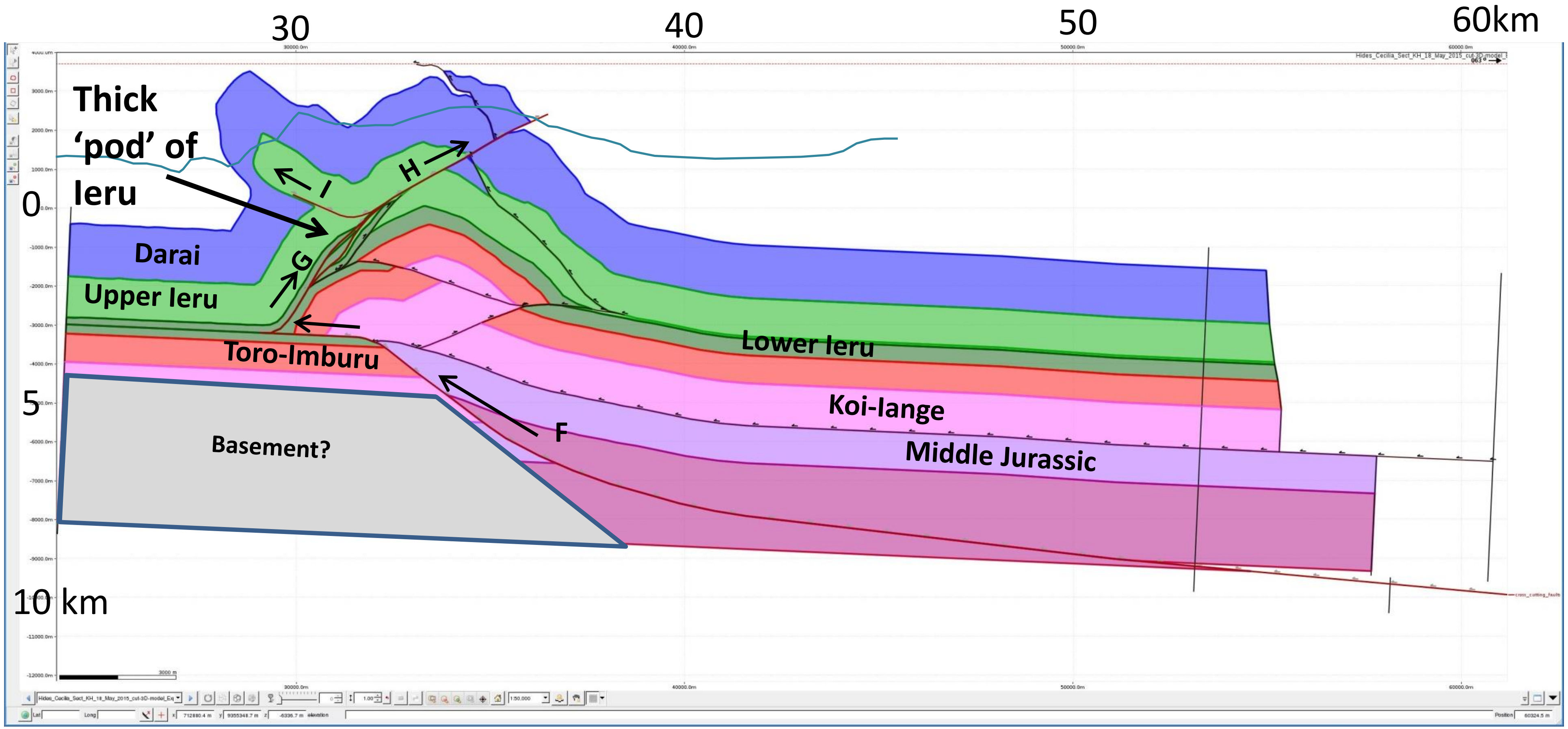
Hides Anticline-Johnstone and Emmett (2000).

Petroleum Geology of the Hides Gas Field, Southern Highlands, Papua New Guinea. In: Buchanan, P.G., Grainge, A.M. and Thornton, R.C.N. (Eds), *Papua New Guinea's Petroleum Industry in the 21st Century: Proceedings of the Fourth PNG Petroleum Convention*, 319-336.



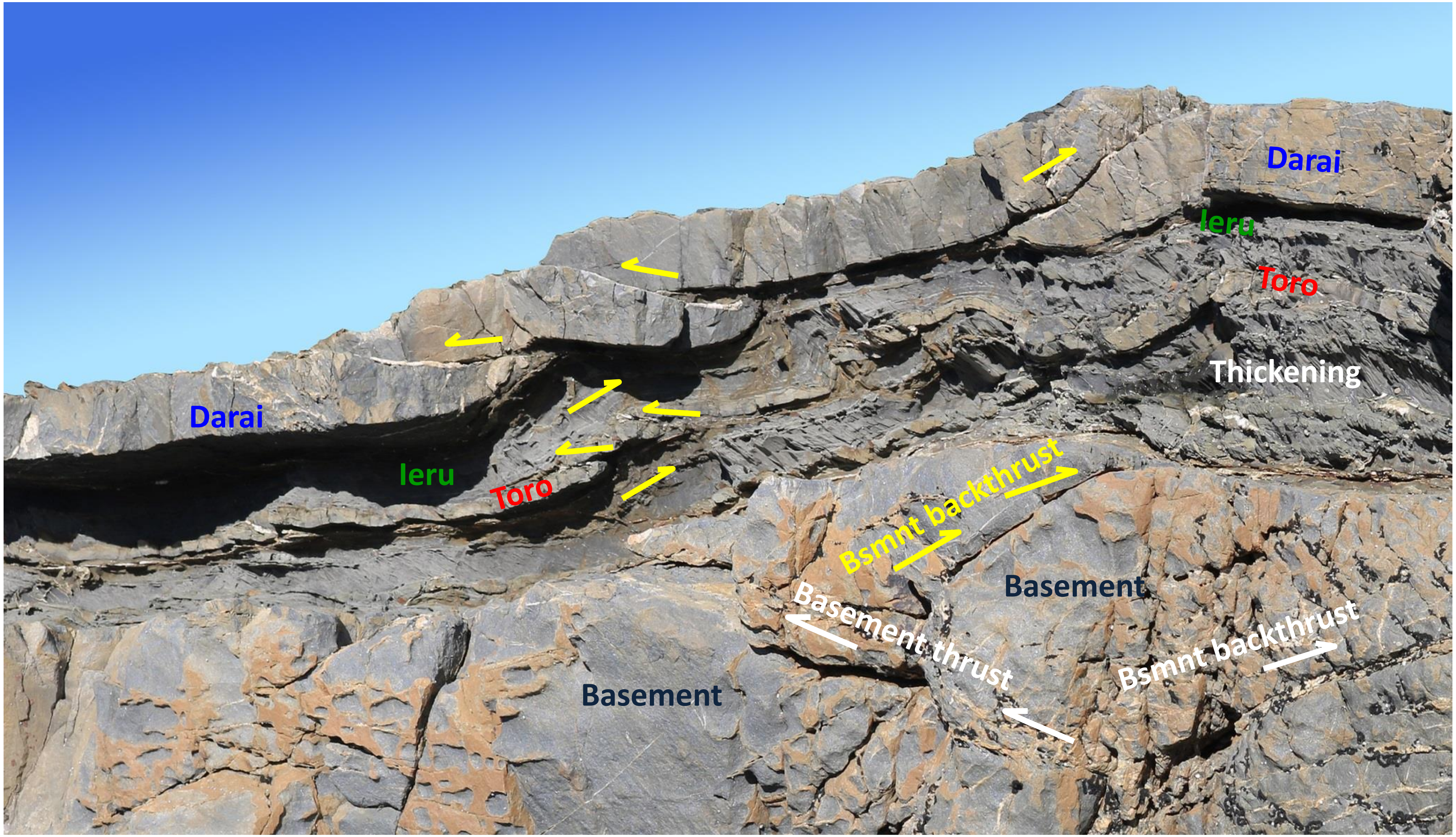
Fault-bend-fold and triangle zones

- Geometrical forward modelling using Move^{TM}, ~100 attempts

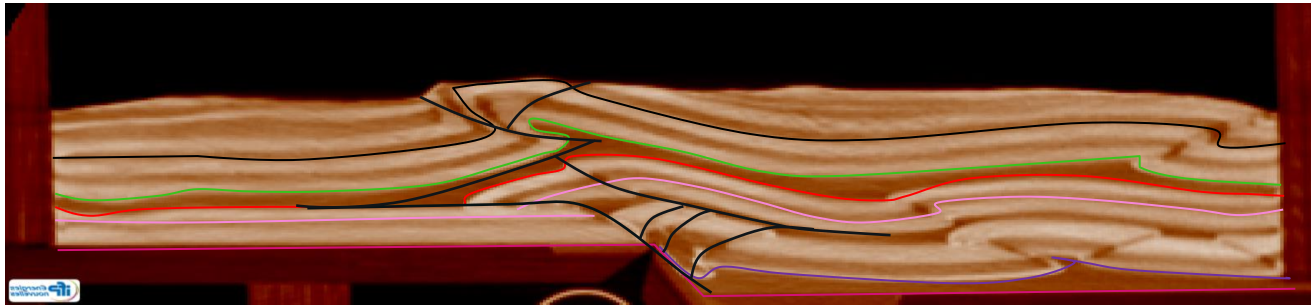


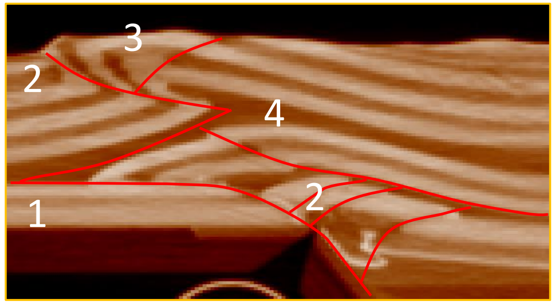
Darnault & Hill, in press AAPG Bull

Field analogue, Cape Liptrap, near Melbourne, Australia

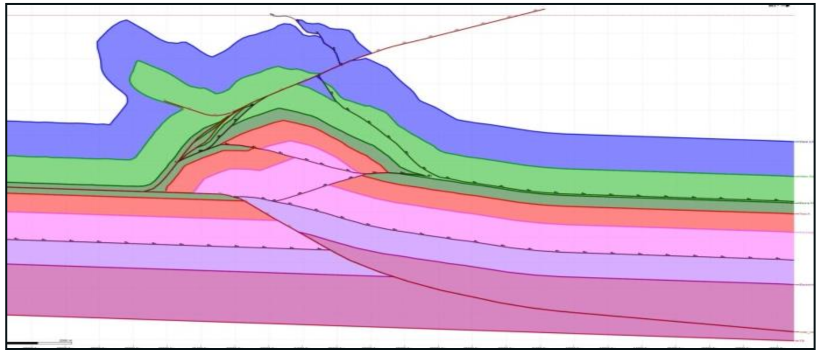


Use of X-Ray Tomography





A set of 17 sandbox experiments were carried out under an X-ray tomography device (above), which records the 3D deformation through time (Colletta et al., 1991). Brittle rheologies were simulated with alternating sand and pyrex layers, with a grain size of 100µm. Sand has a negligible cohesion, an angle of internal friction of 30° and a density of 1600kg/m^3. Pyrex is similar in terms of mechanical property but a different radiological density, which can be differentiated from the sand with a tomographic image. Ductile layers were simulated with silicone putty (SGM36), which behaves as a Newtonian fluid with a density close to 1g.cm^{-3}, a viscosity of 2.5.10^4 Pa.s at room temperature and a strain rate below 3.10^{-3}s^{-1}. See Darnault & Hill (in press) for details.

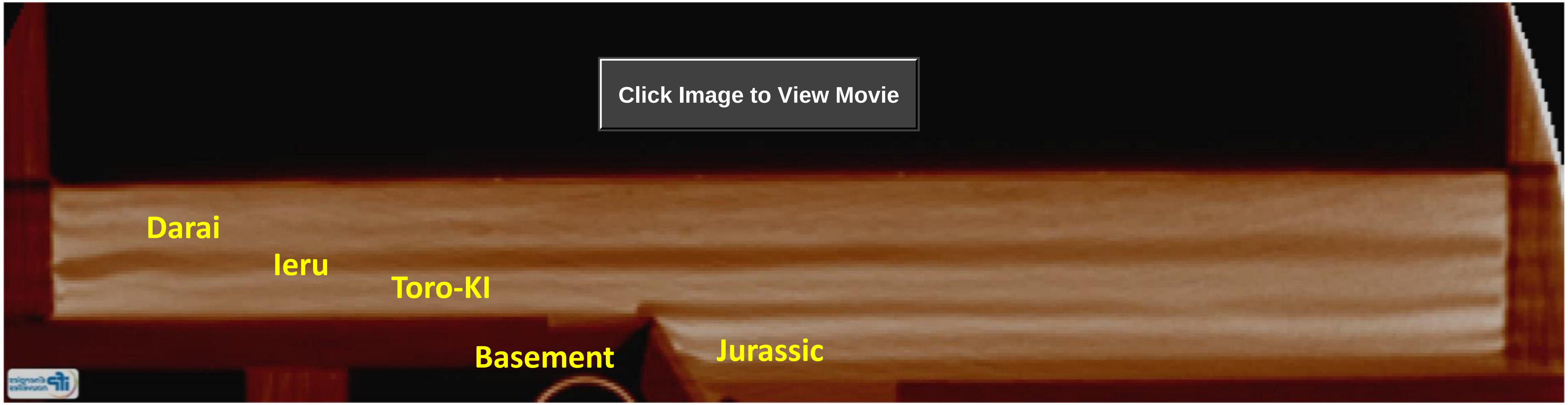


Sandbox modelling, IFPEN

~1 week to run a model

One of 17 experiments, IFPEN

The 17 experiments that OSL did with IFP took 18 months
It took one year to adjust the parameters to get close to Hides-like structures
We need something quicker, preferably at the desktop



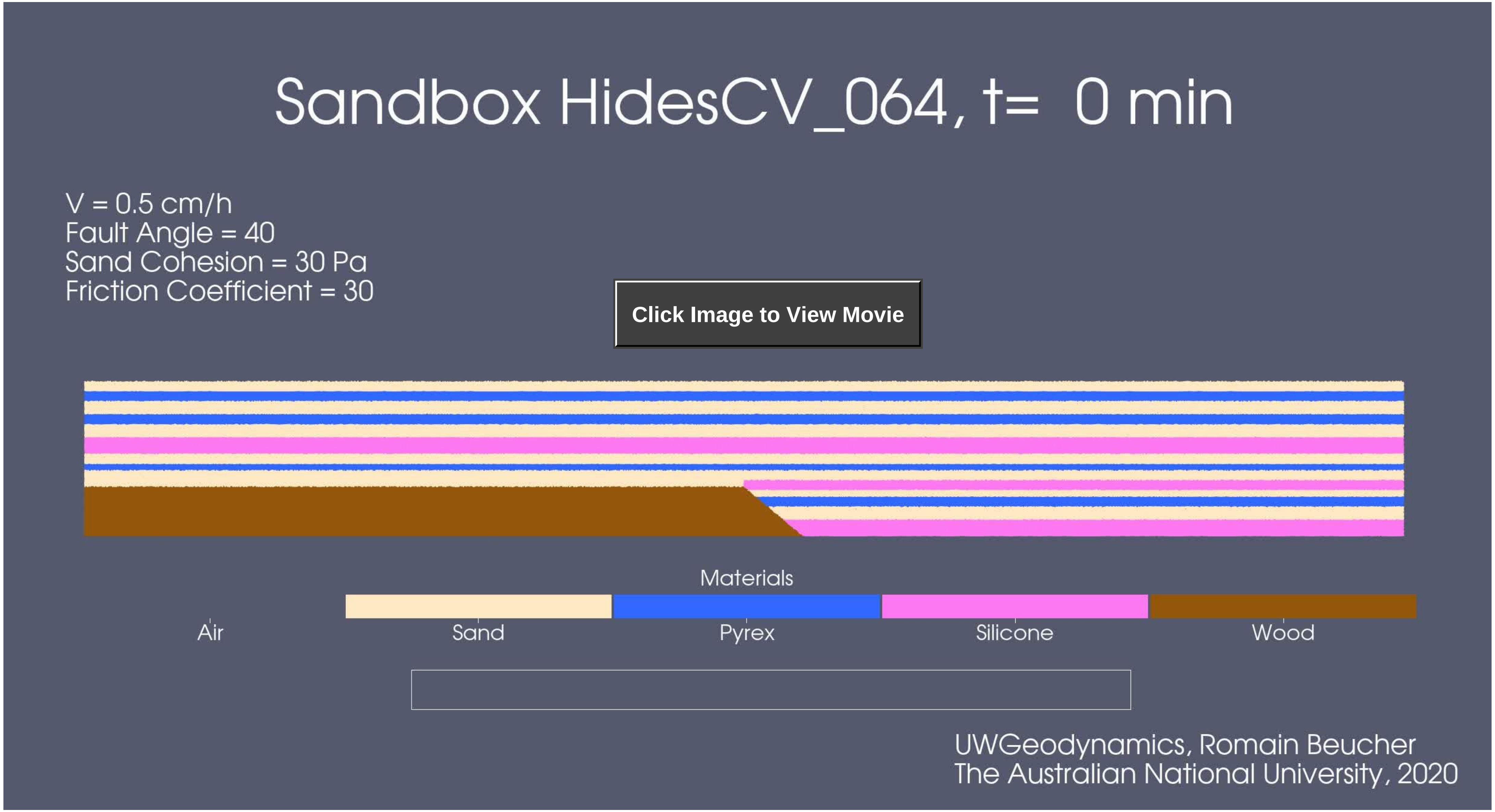
Sand (strong)
Silicone (weak)

Darnault & Hill, in press AAPG Bull

Underworld sandbox model

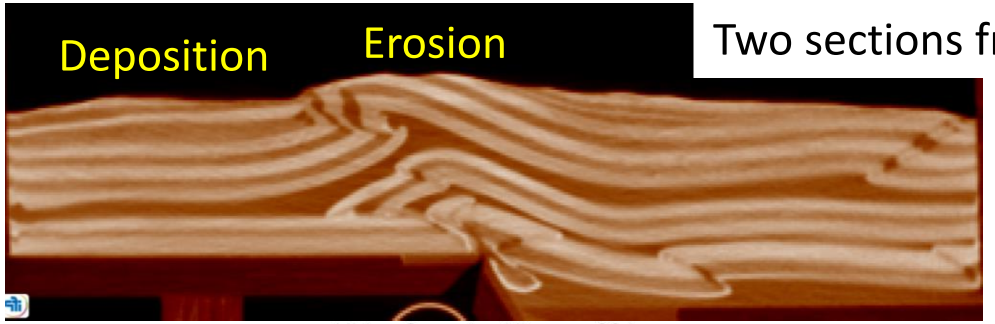
- Romain Beucher calibrated the finite element code against a number of digital calibrations of sandbox models
- He then calibrated against the IFP models that we developed (Darnault & Hill in press AAPG Bull)
- He used Brittle, Simple Viscous and Complex Viscous rheologies and varied
  - Ramp angle
  - Cohesion
  - Velocity
- He produced 1,050 models in 3 days, using a super-computer.

Hides complex-viscous 064

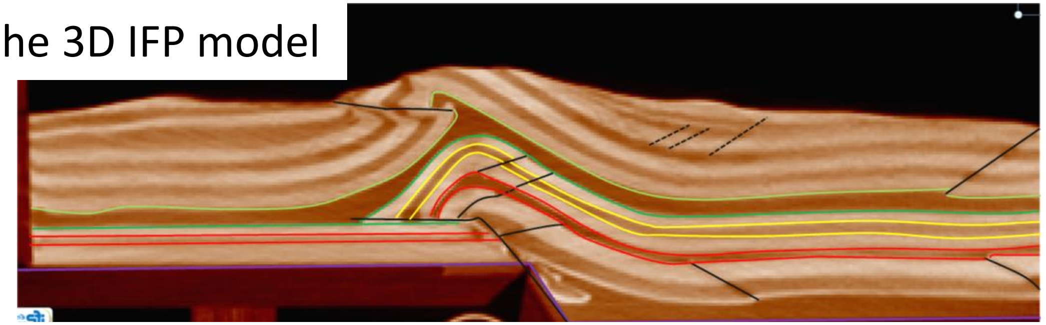


Matching IFP model 15, ductile rheology, fault 55^{o}, vel 0.6 cm/hr

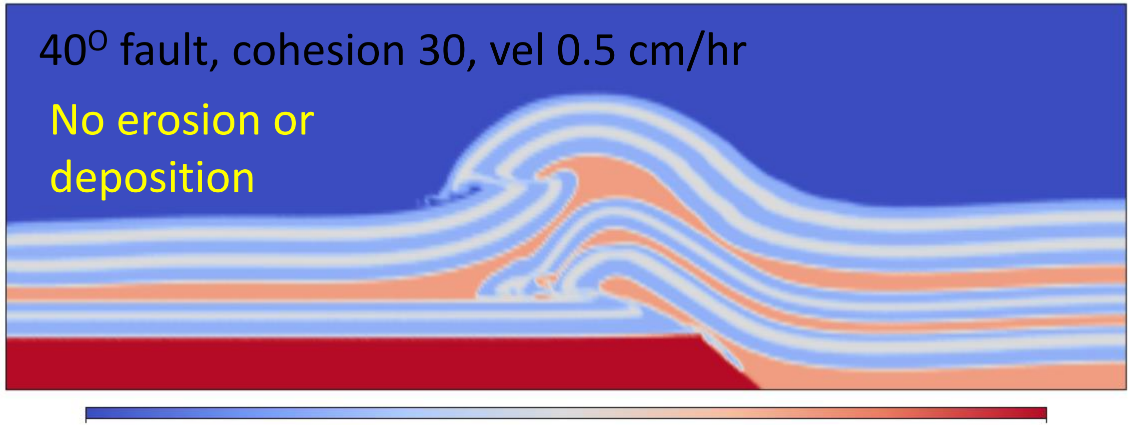
Two sections from the 3D IFP model



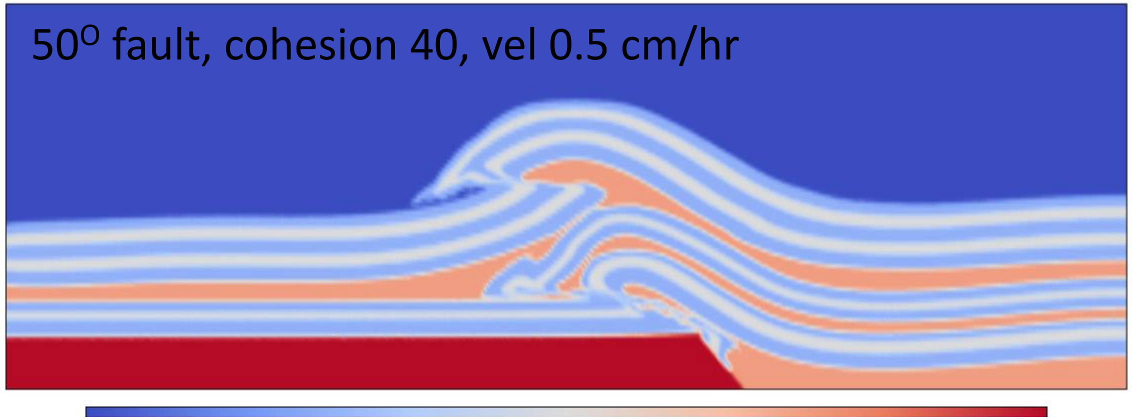
Hides Complex Viscous 064



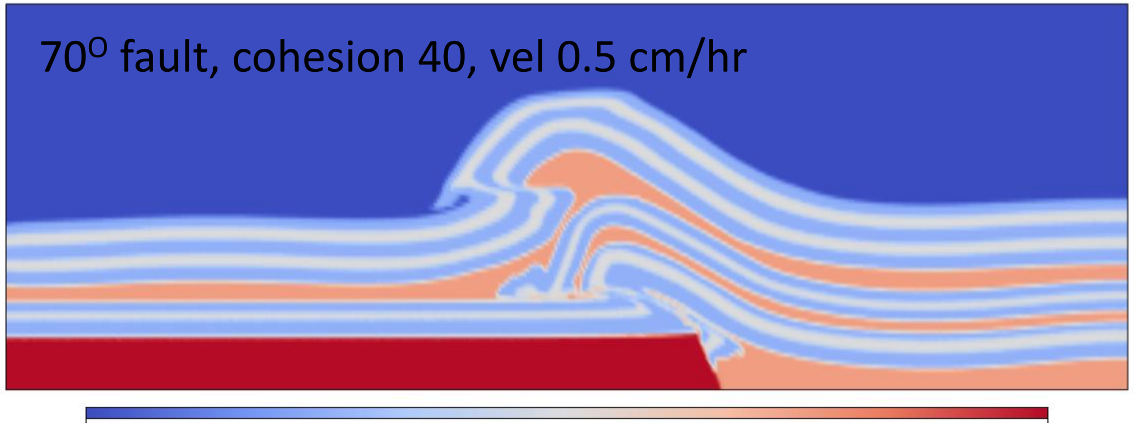
Hides Complex Viscous 119

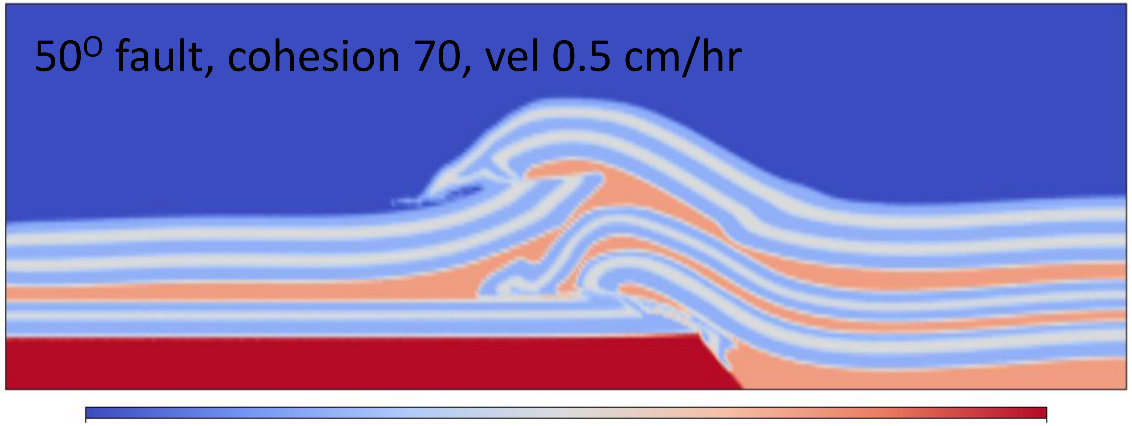


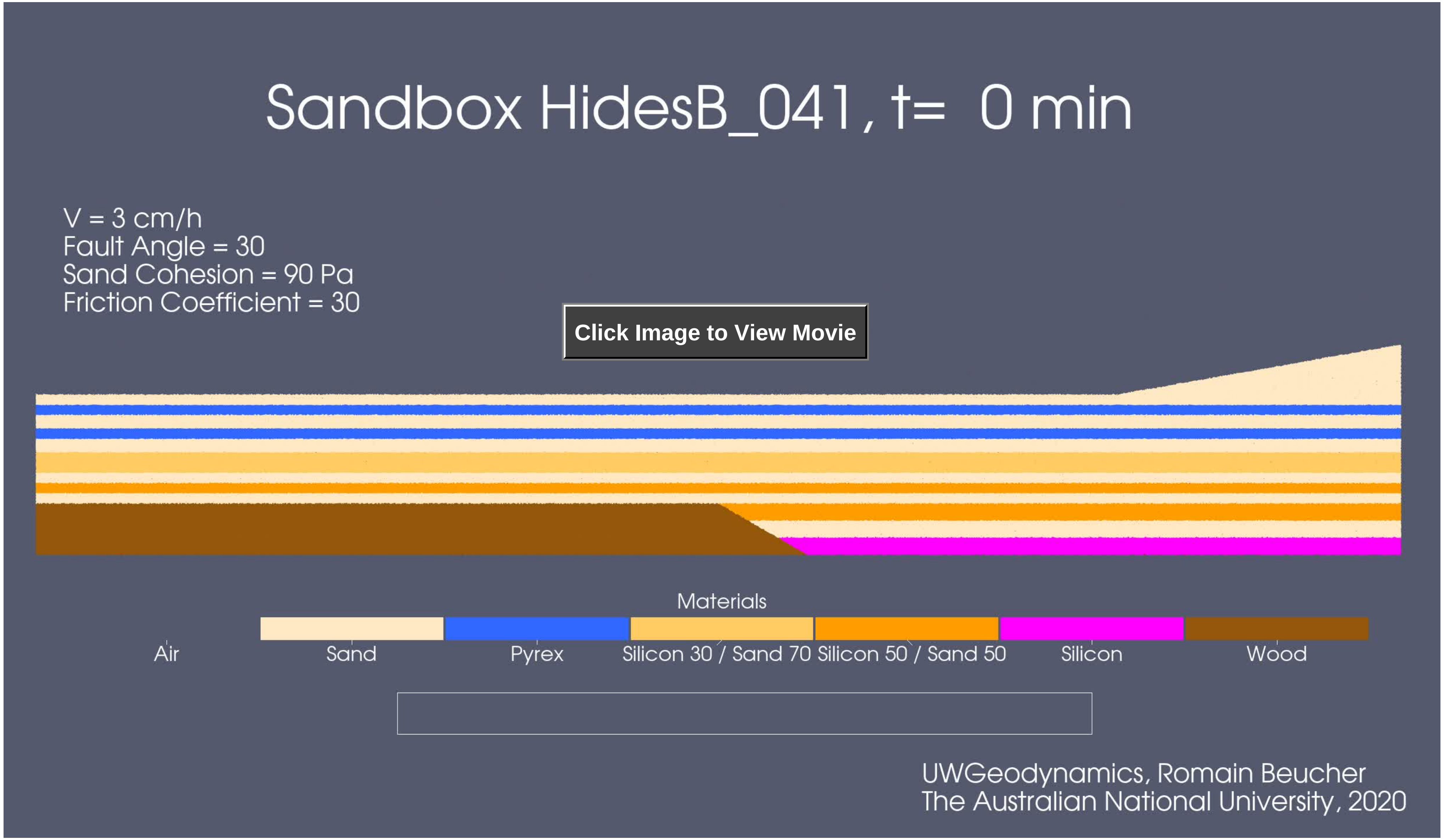
Hides Complex Viscous 219



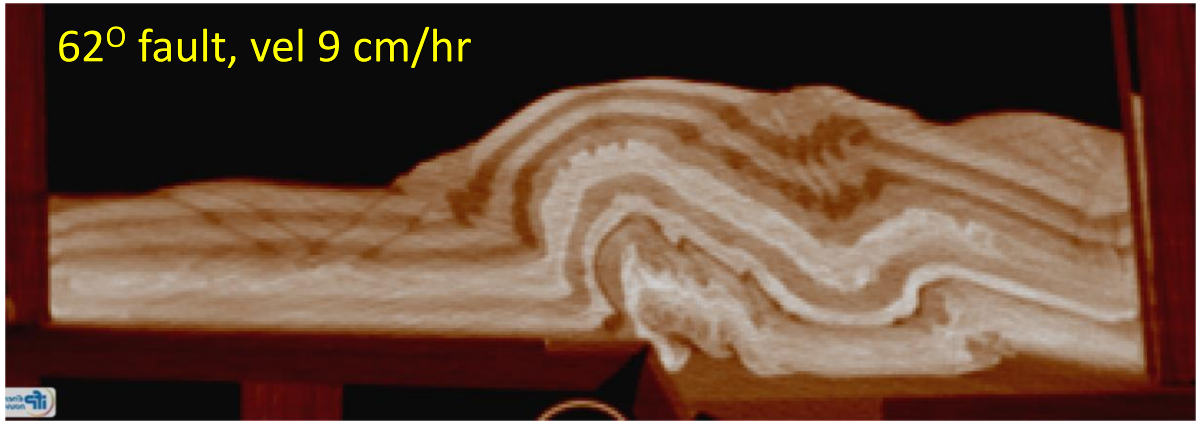
Hides Complex Viscous 134





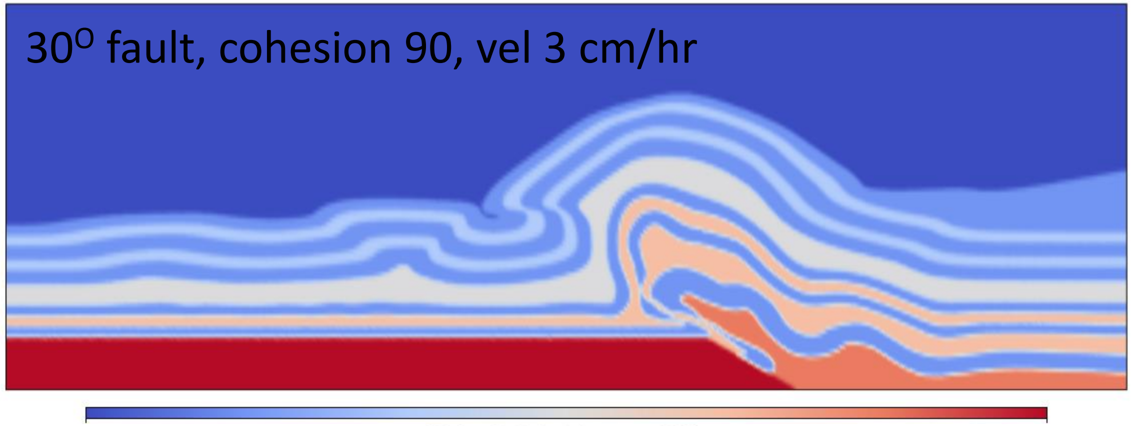

Sandbox HidesB_041 , t= 0 min
V = 3 cm/h
Fault Angle = 30
Sand Cohesion = 90 Pa
Friction Coefficient = 30
Click Image to View Movie
Materials
Air
Sand
Pyrex
Silicon 30 / Sand 70
Silicon 50 / Sand 50
Silicon
Wood
UWGeodynamics, Romain Beucher
The Australian National University, 2020

Matching IFP brittle model 12, brittle rheology, fault 62^{O}, vel 9cm/hr

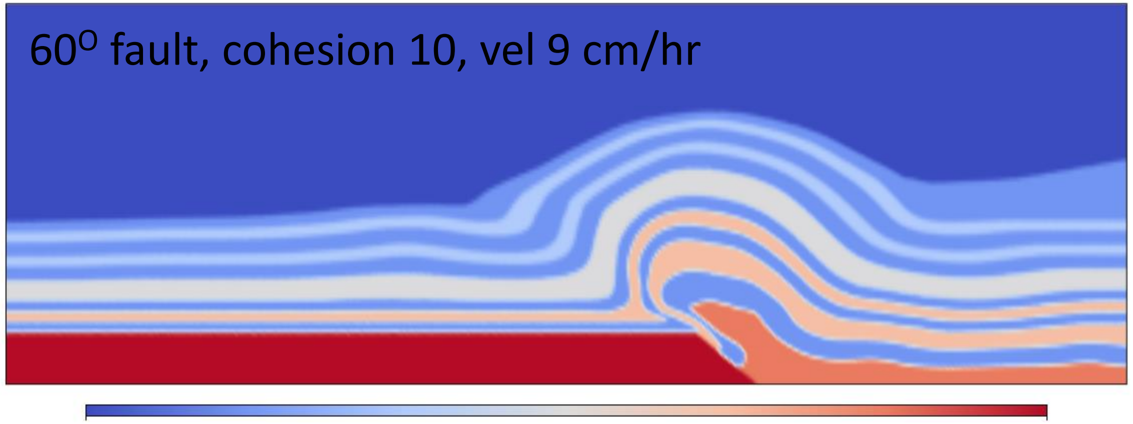


Darnault & Hill, in press AAPG Bull

Hides Brittle Viscous 041

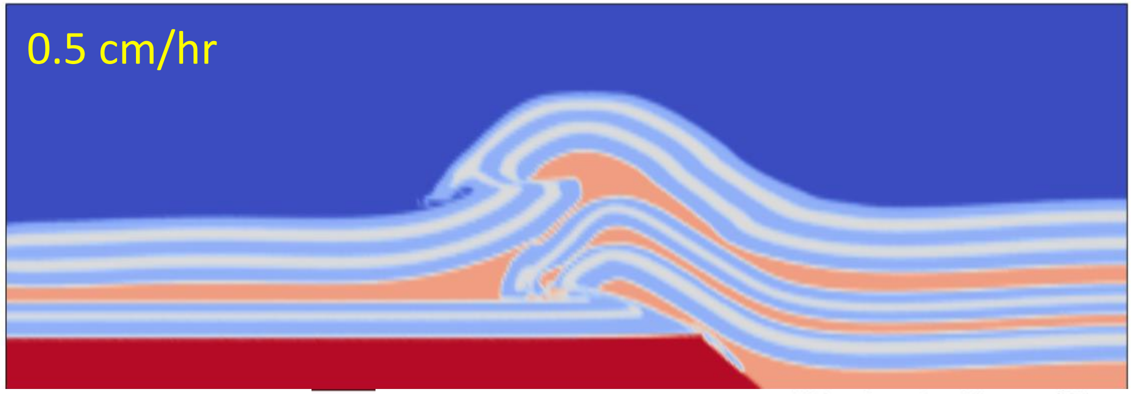


Hides Brittle Viscous 053

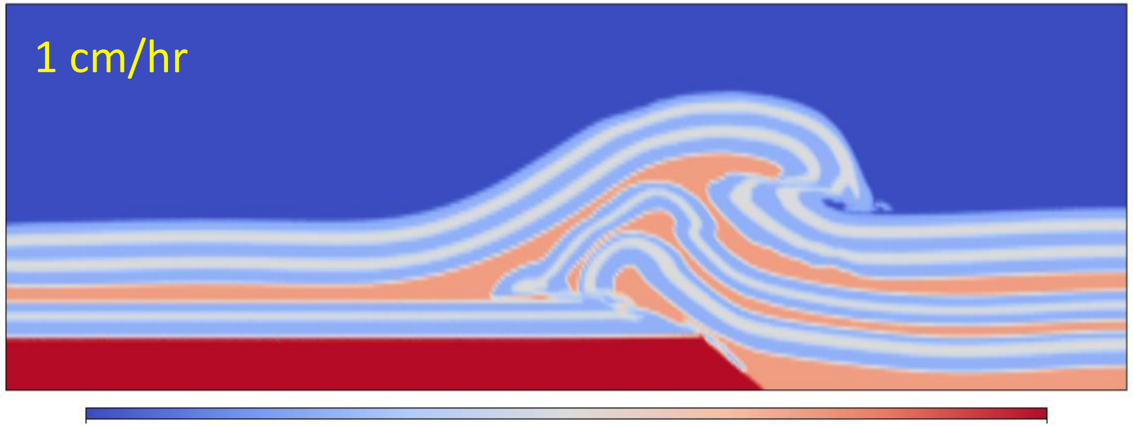


Some Complex Viscous models
Fault dip 40^{O}
Cohesion 10 =low
Velocity 0.5 to 9 cm/hour

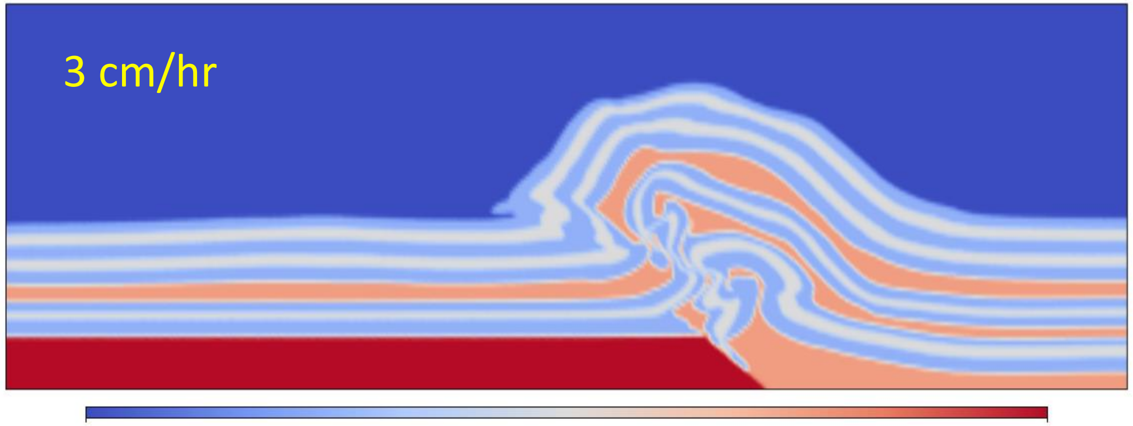
Hides Complex Viscous 054



Hides Complex Viscous 050



Hides Complex Viscous 051



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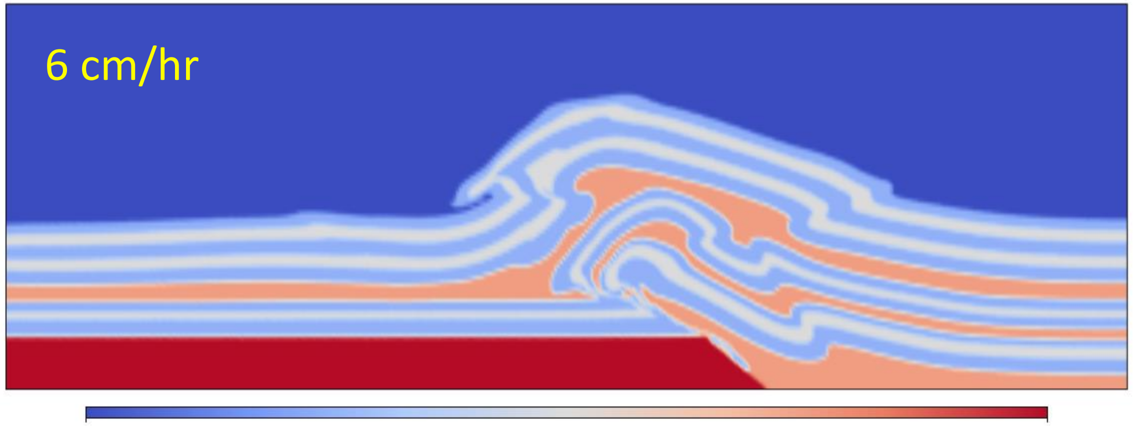

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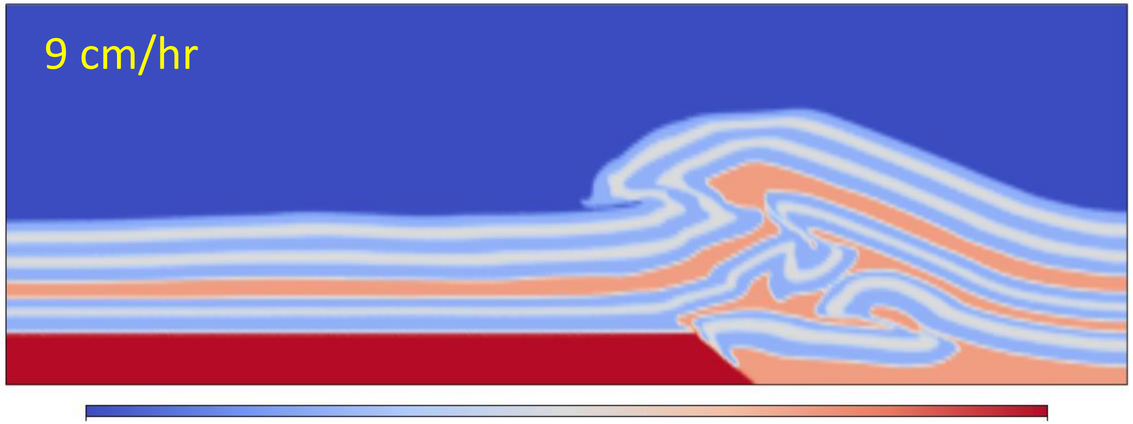
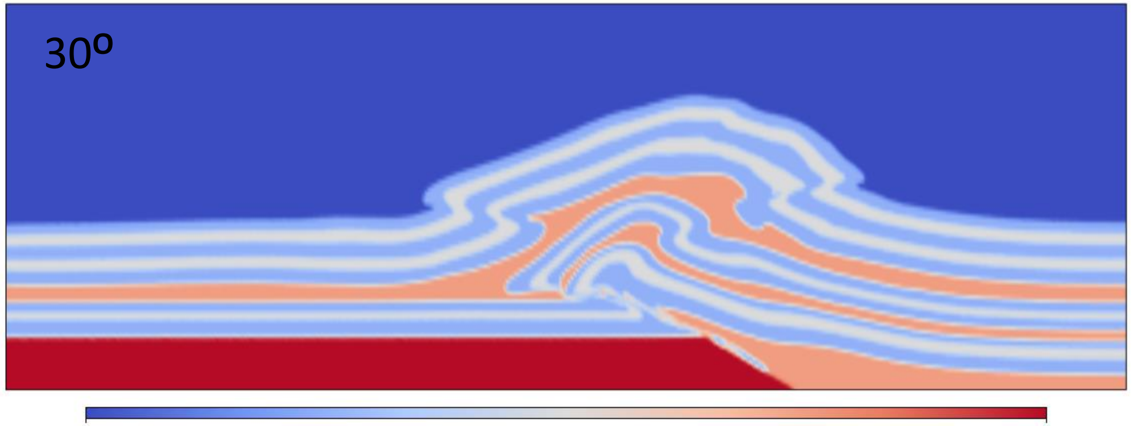
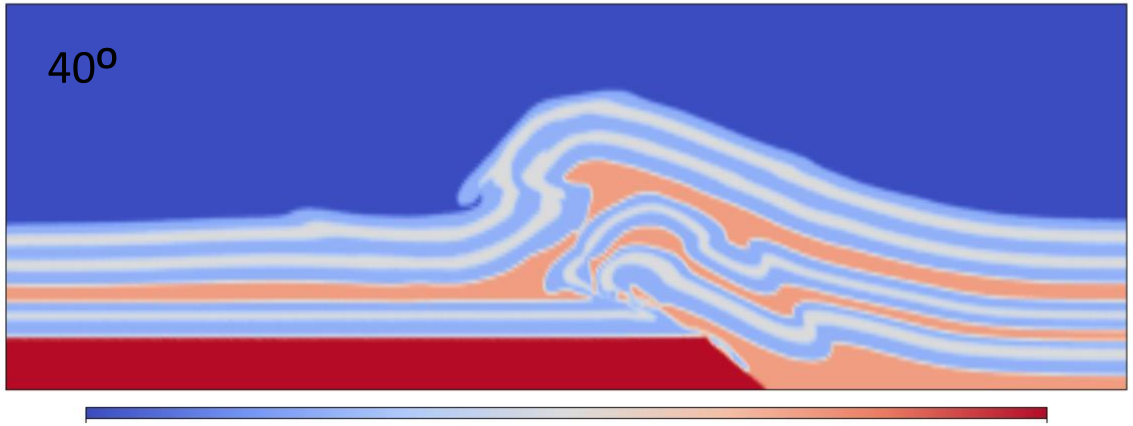


Change ramp angle (cohesion 30, Velocity 6cm/hr)

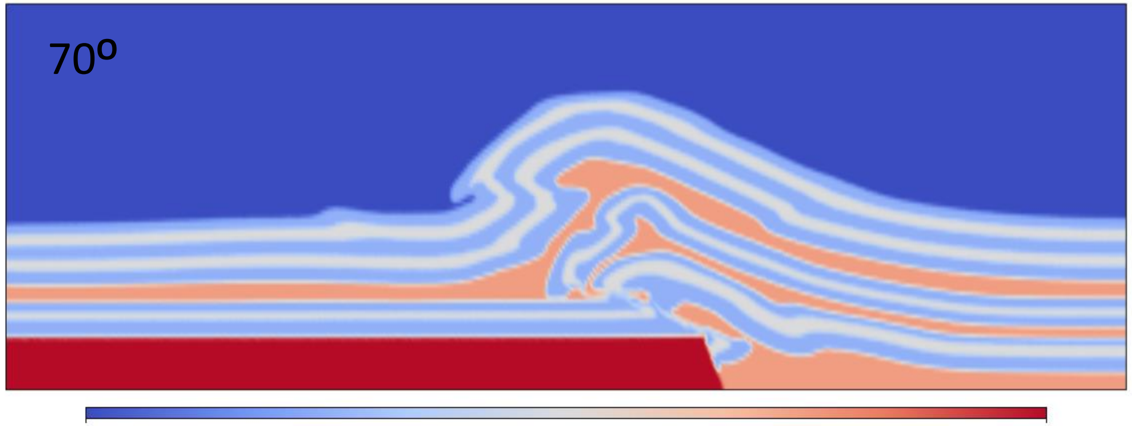
Hides Complex Viscous 012



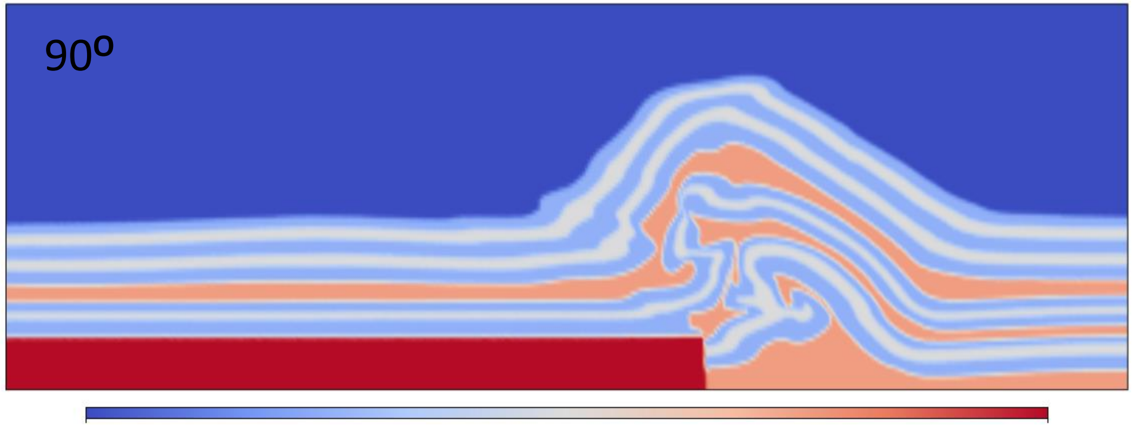
Hides Complex Viscous 062



Hides Complex Viscous 212



Hides Complex Viscous 312



The Dream

- The Geo has an idea and builds a geometrical forward model
- The starting geometry is loaded into the digital sandbox model and populated with simple rheologies from a menu
- A dozen (or more) variations are developed and run overnight on the laptop
- The results are examined in the morning

- With further work, the program will learn as it runs the models testing against observations and focussing on models that match the criteria
- Then – 3D

Hides complex-viscous 212