Beyond Geometry: 2D Structural Thermo-Kinematic Models of the Papuan Fold and Thrust Belt*

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Abstract

The Papuan Fold Belt (PFB) exploration took off in 1986 with the Kutubu and immediately after with the Hides discoveries. About 7bboe later, it continues to deliver today with the Muruk discovery. Exploration has advanced on the back of extraordinary surface-related challenges, with an almost exclusively helicopter-supported operation. Mapping using remote sensing images calibrated by field geological campaigns and, to some extent, sparse 2D seismic data, delineated the first drilling targets. Surface information is hindered by topography, thick forest and heavy precipitation, making it difficult to access. Seismic data in the fold belt continues to deliver mixed results in terms of subsurface imaging, which translates to problematic identification of subsurface traps. The PFB depicts thin-skinned, thick-skinned and combined thick/thin-skinned related structural geometries generated by multiple detachments. The stratigraphic pile behaves mostly as a harmonic mechanical beam, but recent discoveries and appraisal/development wells indicate strain partitioning occurs particularly at the Ieru Formation level. The implication of the latter is that in some instances surface structures do not directly relate to subsurface structural culminations. Furthermore, the linkage – geometric and kinematic – between the thick-skinned and thin-skinned structures continues to be an evolving matter of discussion amongst specialists. The kinematic story is faced with an additional obstacle: synkinematic sediments are rarely preserved in the fold belt. This discussion would be of academic interest if not for the fact that surface anticlines that involve our target reservoirs are being drilled-out and we are faced with finding hydrocarbons in deeper structural targets. We are relying on these deep targets to be the new frontier – not to mention the hinterland. Our more complex structures near or along the trend of a developed resource are ever more challenged in terms of defining them with our current seismic data and thus fall in the realm of "sound" structural interpretations or models. A compounding issue to the challenges previously mentioned relates to the economic viability of the discovered resource. There are two main drivers here: gas for LNG; and the geologic (and geographic) extent of the liquids "play" as it relates to existing facilities. There is a large uncertainty related to geological controls that yield gas-rich versus liquid-rich traps. This is where testing the thermo-kinematic history of our models and interpretations can provide insight into the controls of the hydrocarbon phase. Additionally, we could test alternate kinematic models, synkinematic/erosional models and these could be calibrated to known discoveries. This presentation will illustrate, via calibrated and uncalibrated 2D case studies, the effect of structural evolution on maturation, charge and hydrocarbon phase in the PFB.

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Why Bother….

- **Most Toro-Play surface anticlines and in commercial fairway have been drilled.** *Its only getting technically more challenging…*
- **Trap definition continues to be a major risk. Seismic imaging has improved-*mostly*- but our petroleum systems knowledge is all but stalled.** *The latter constrains us to remain in the world of what we 'know' , 'don't know' or 'don't care to know'*
- **Deeper targets conceived using seismic data- *near our producing assets*- can be 'pre-tested' for charge and phase.** *Q: will we be able to hook up a particular potential resource to deliver the $?*
- **There are relatively low cost propositions that could advance our understanding of the PNGFB Petroleum System** *and thus enable us to optimize our exploration Portfolio*

Presentation Road Map

PART 1.

Bad News: It is more complicated than just geometry

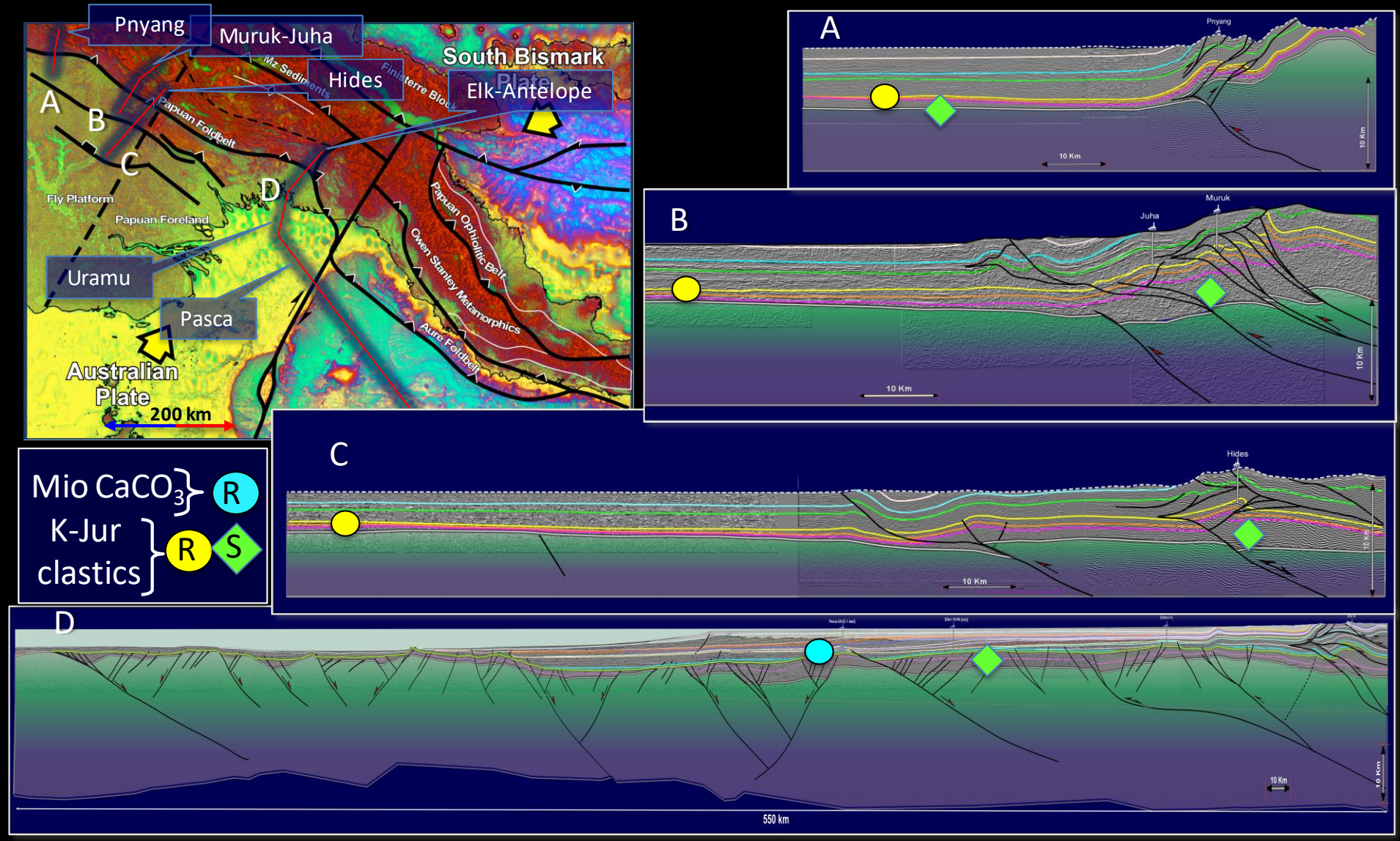
Example 1. HC phase as a function of thrust timing

Example 2. Charge of deeper targets under lean or rich conditions

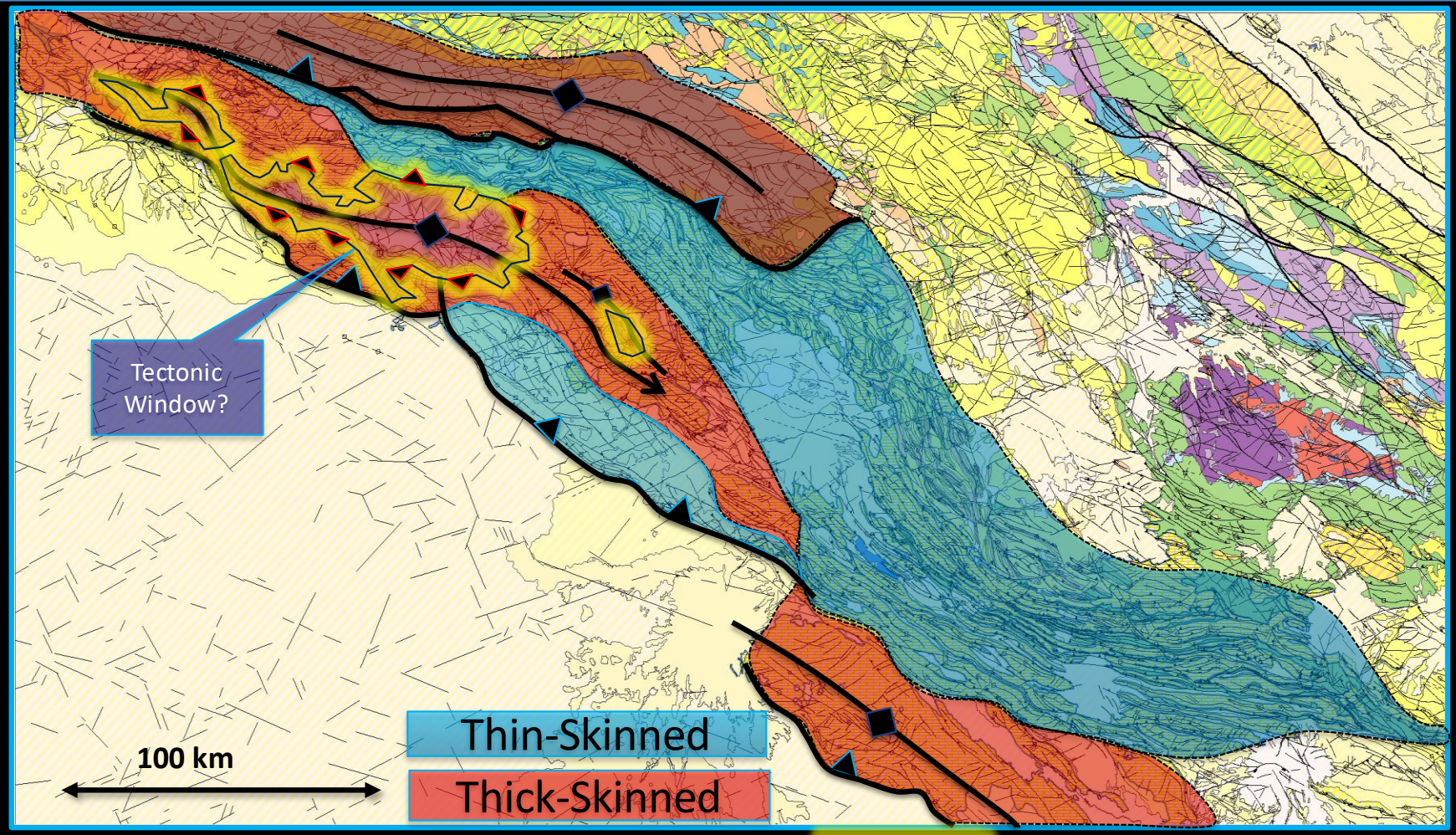
PART 2.

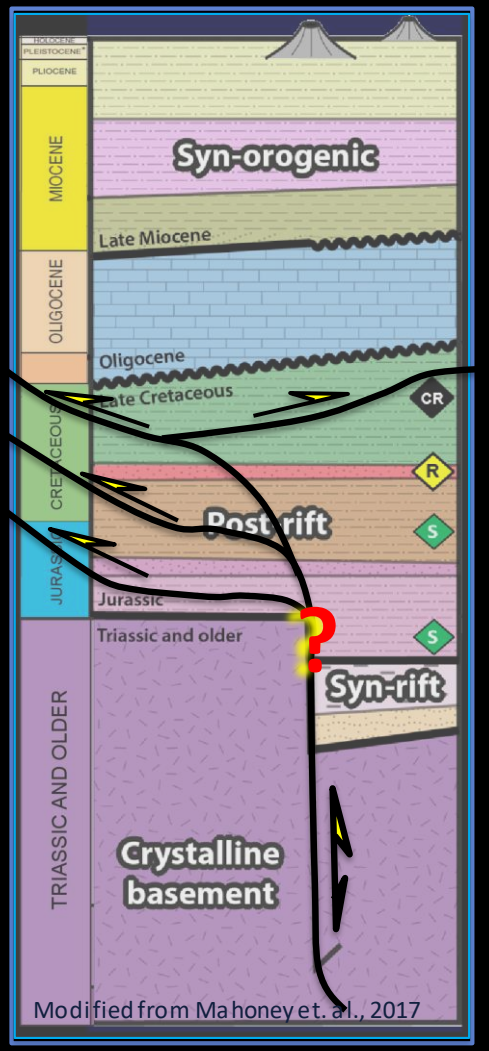
Good News: we can improve on our predictions by applying adequate modelling tools and gathering data to constrain such models, at relatively low cost

PNG Overview Petroleum System

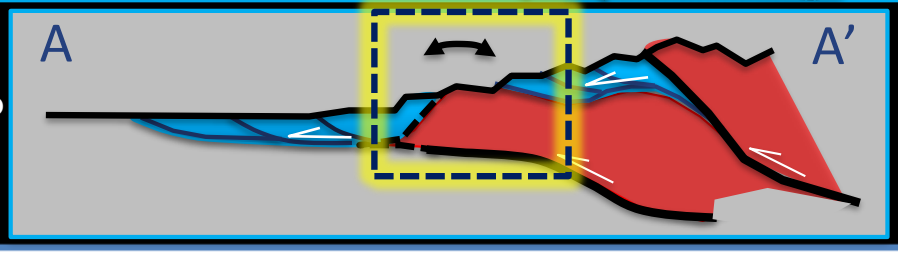


Geometry : Thin, Thick or Mixed?

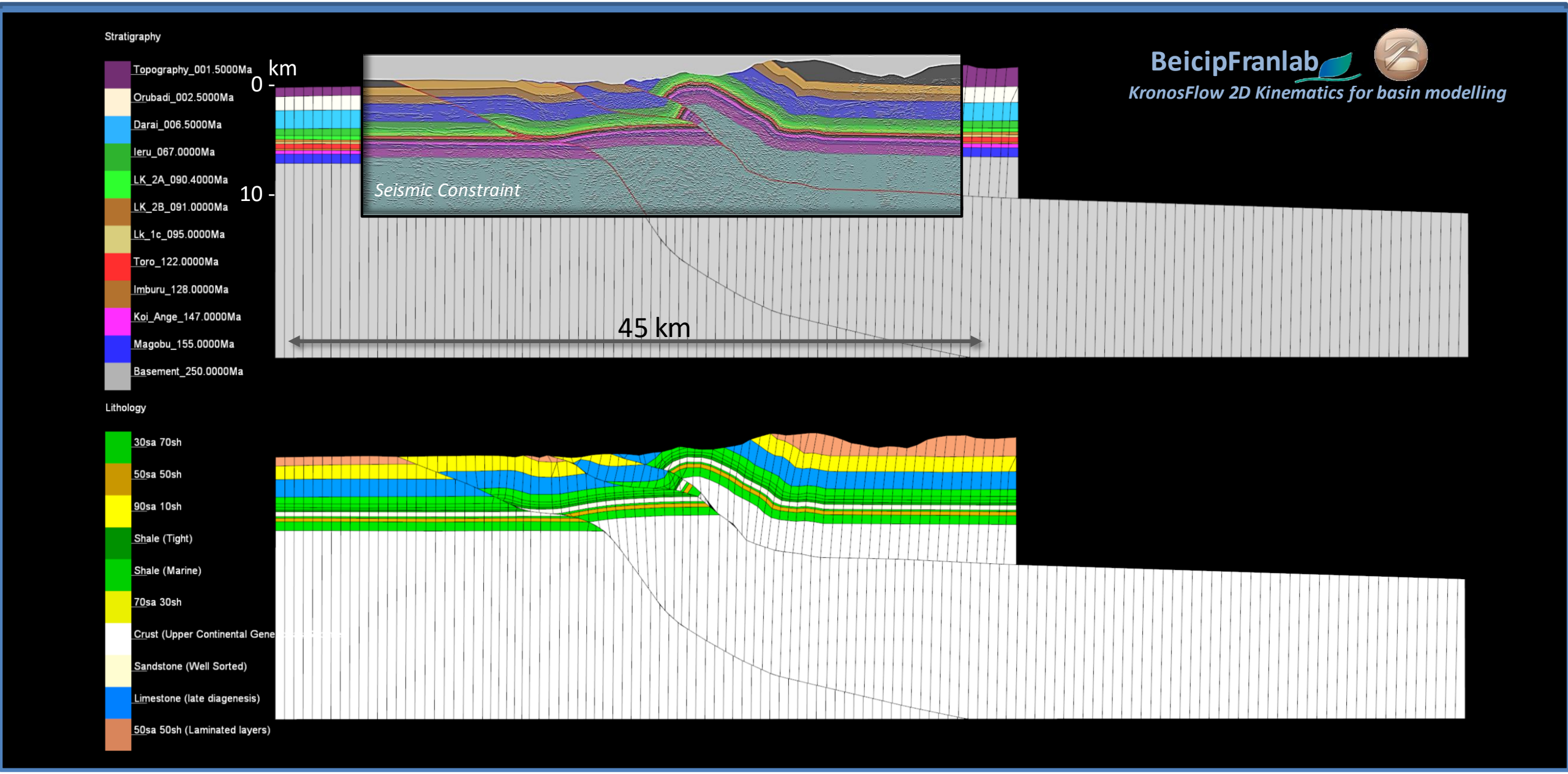




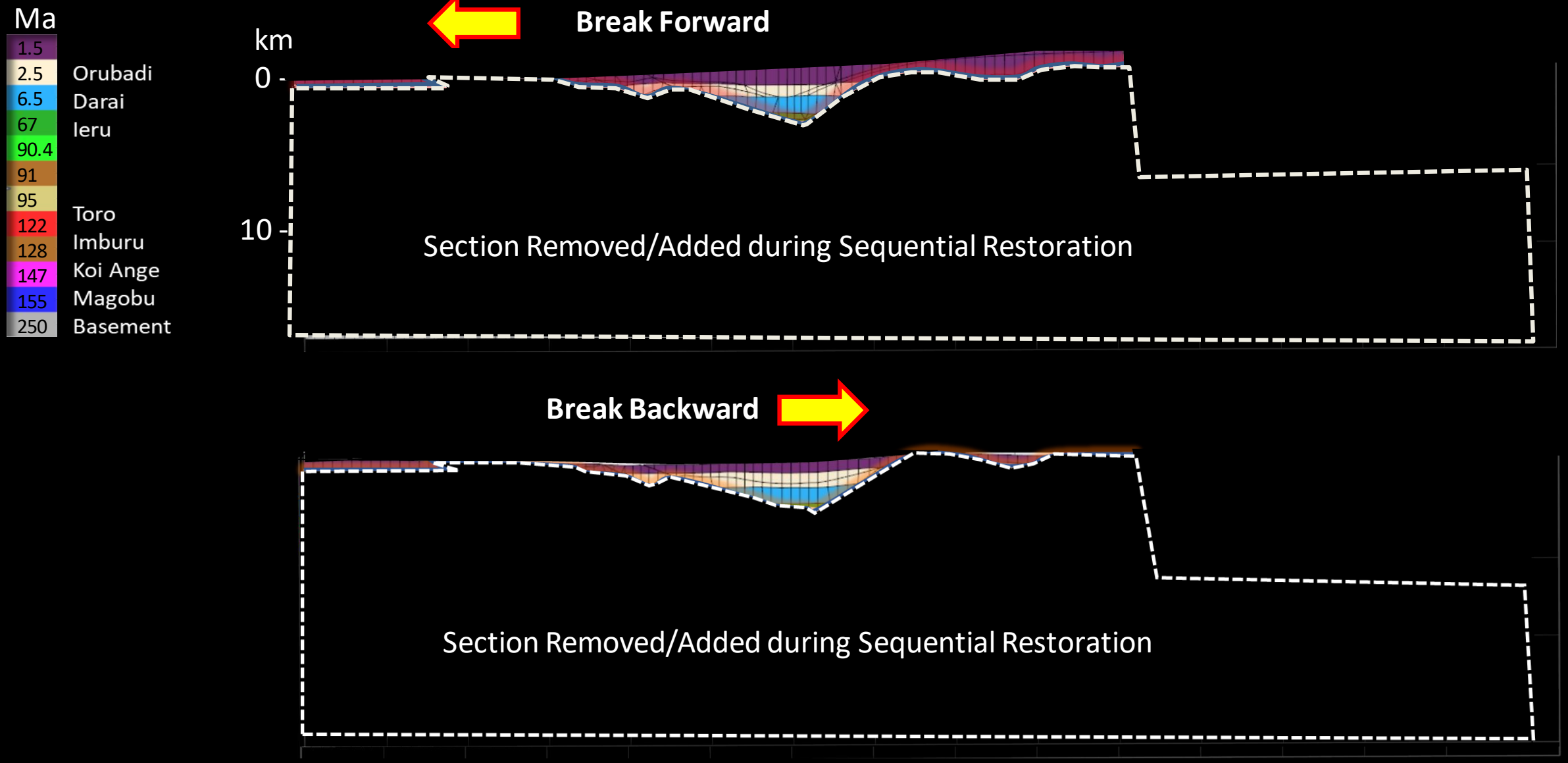
Kinematics: relevant to our de-risking?



Case 1 : Kinematics vs. HC Phase

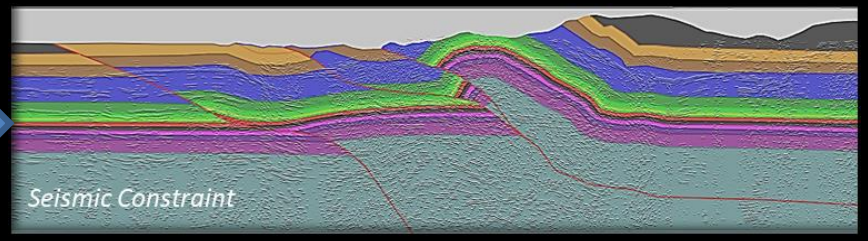


Faulting Sequence-Thrust Timing: Two Simple Scaled-Models

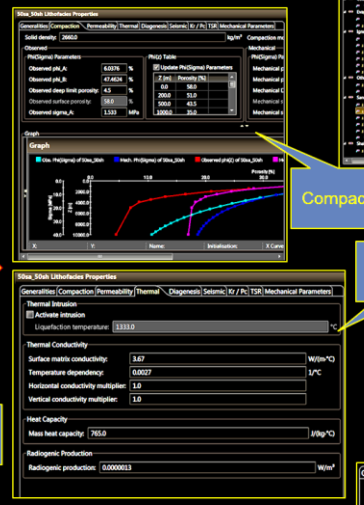


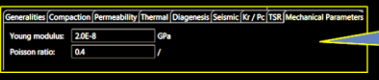
Model Constraints: keep all equal, merely change fault sequencing

Present Day Geometry **Fixed**

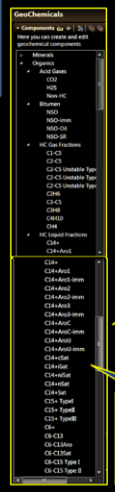


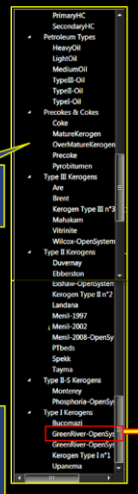
Facies- Thermal Mechanical Properties **Fixed**

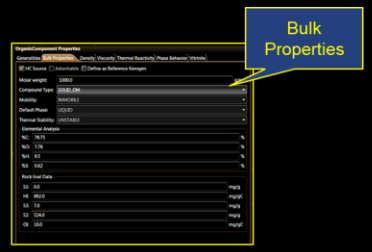


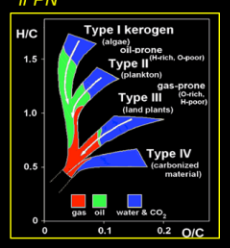


Petroleum System Parameters **Fixed**

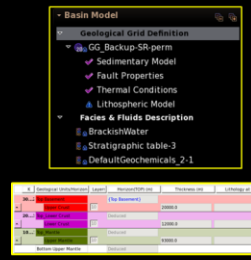


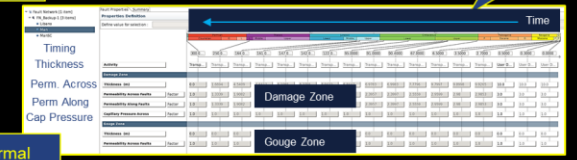


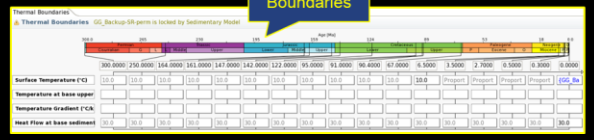




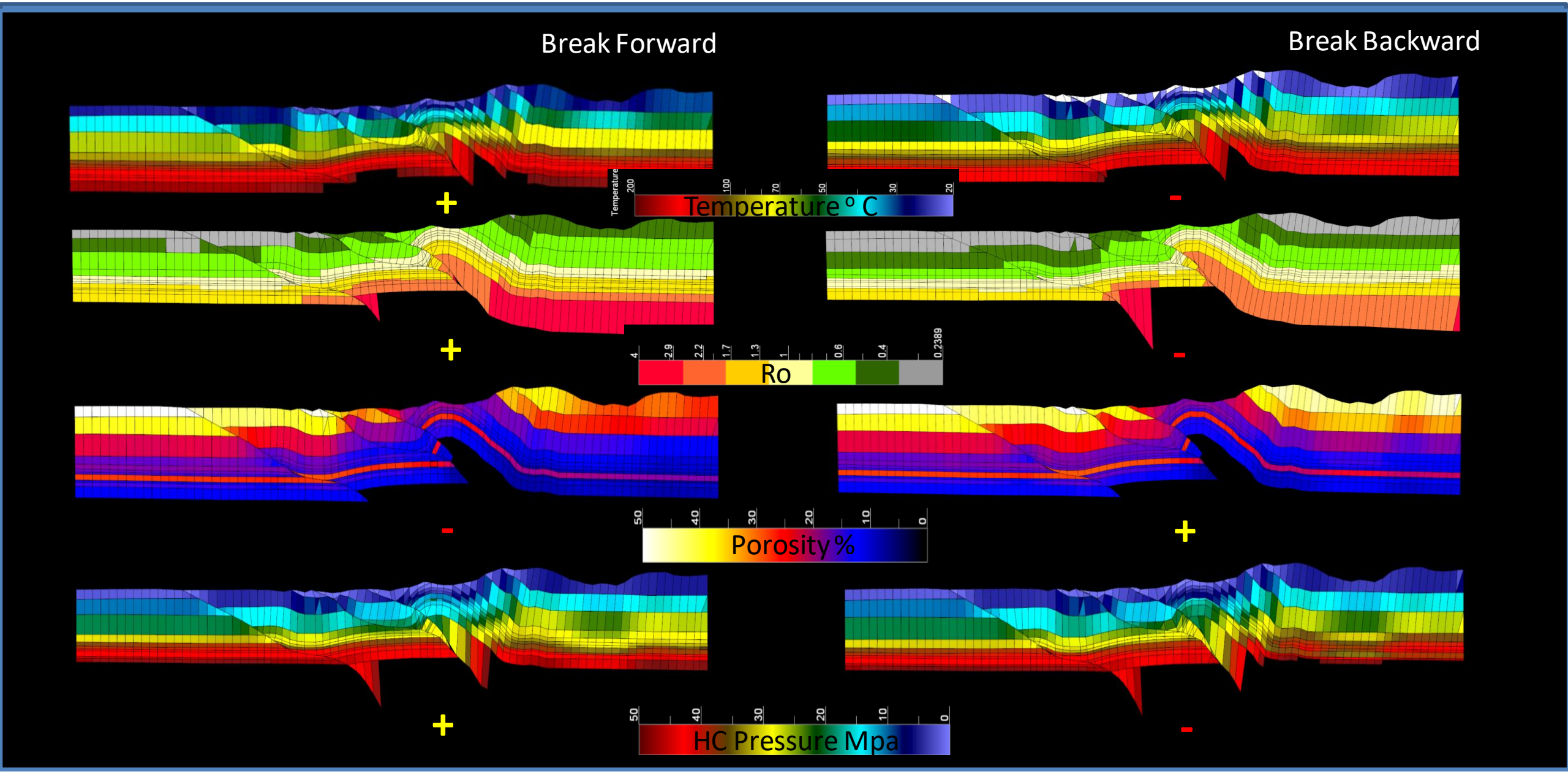
Boundary Conditions **Fixed**



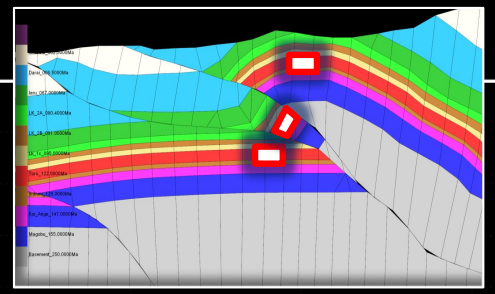


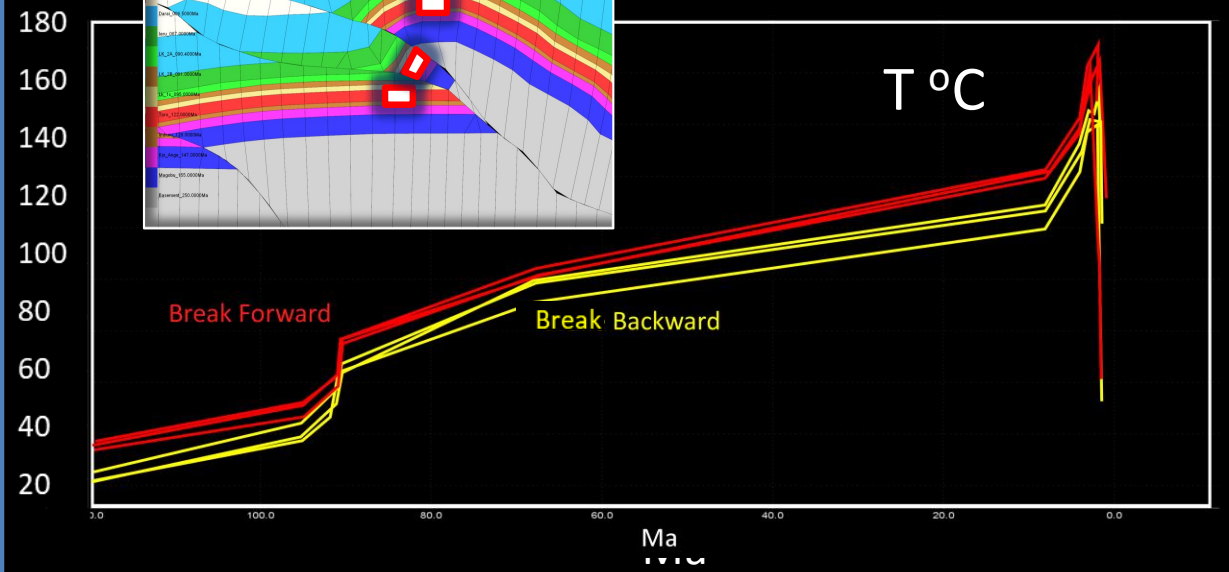


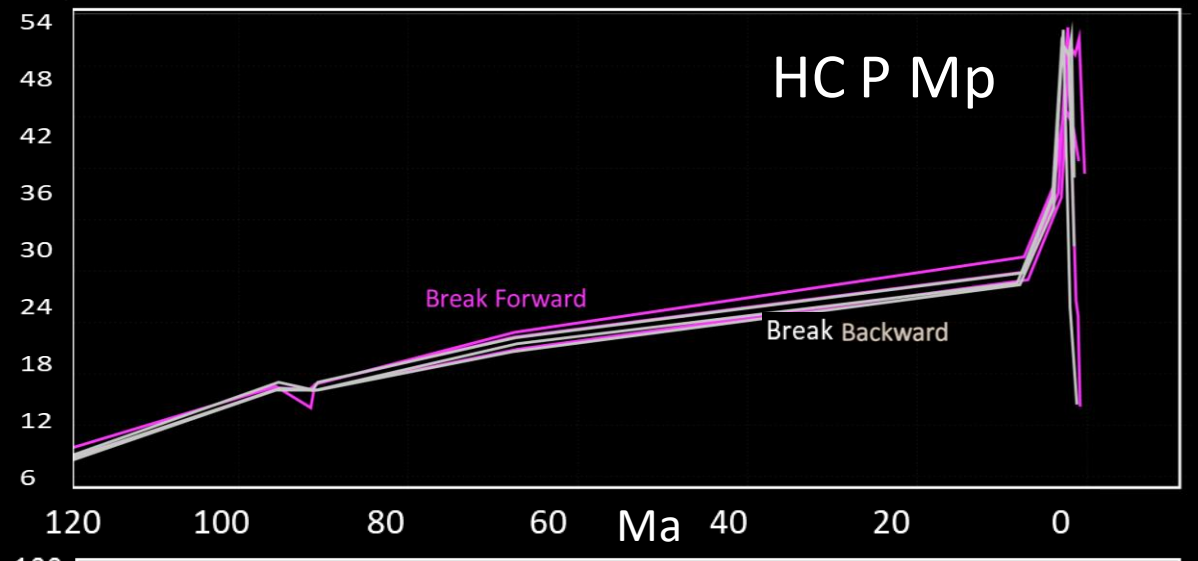
Qualitative Comparison T, ϕ, Ro and P

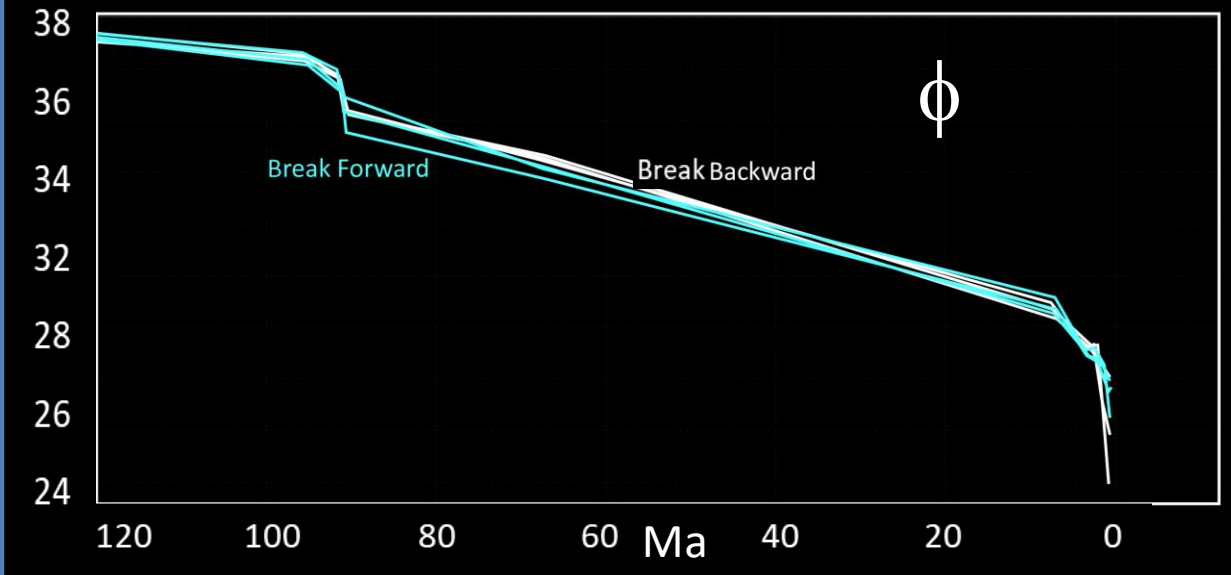


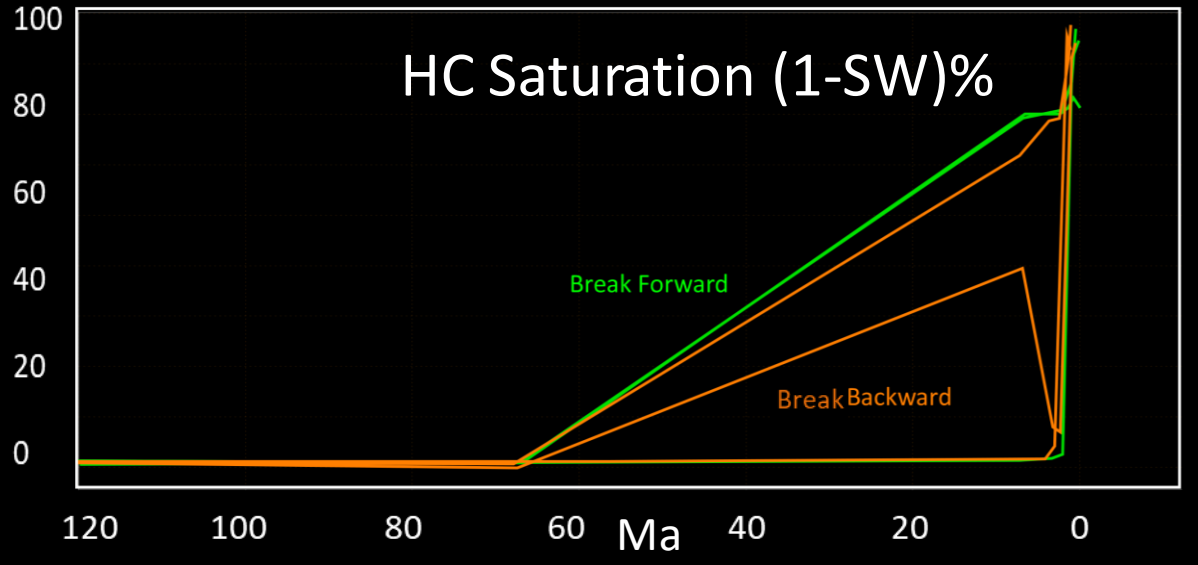
T, P, ϕ & HC Saturation *f*(time)



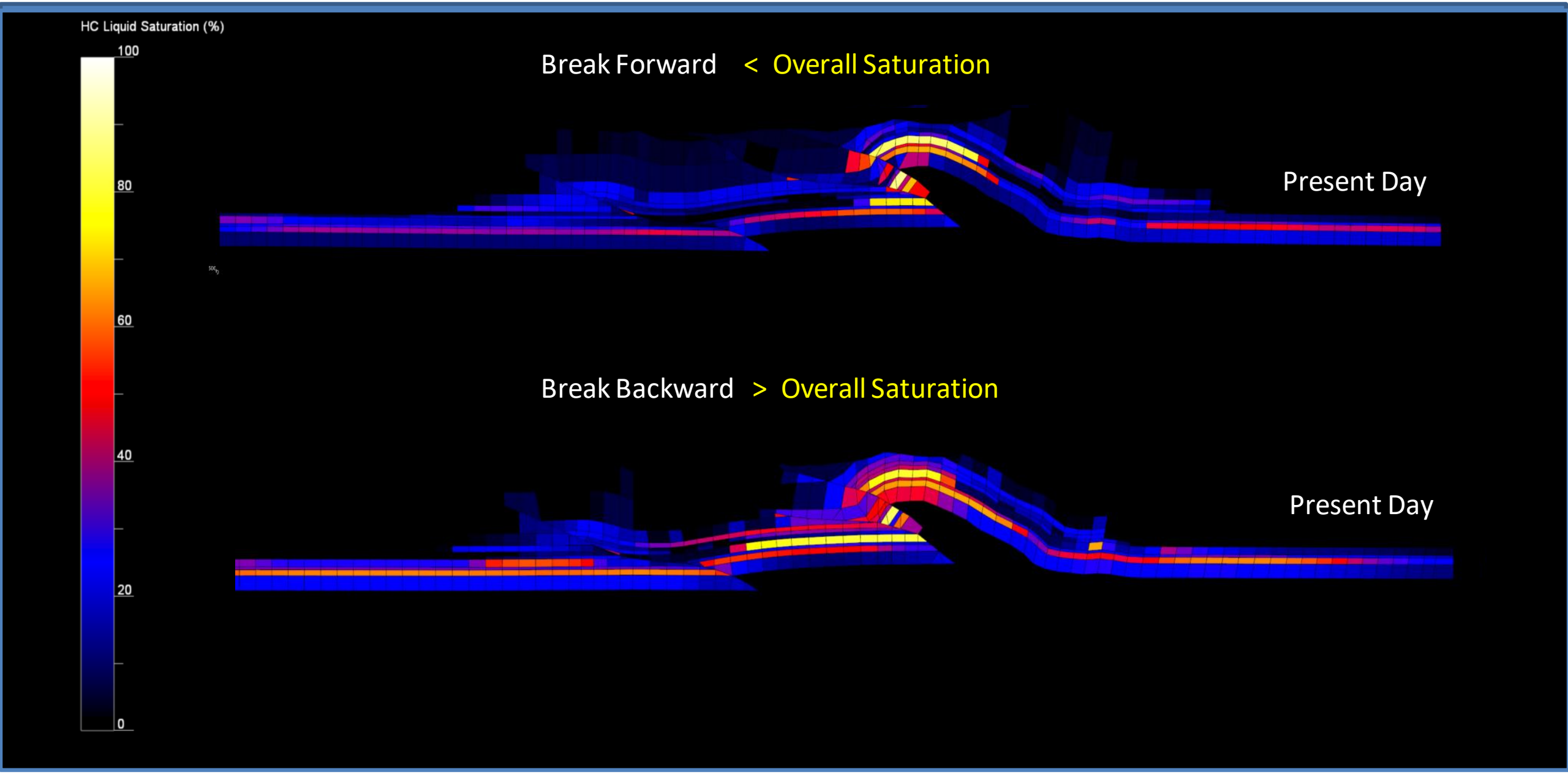




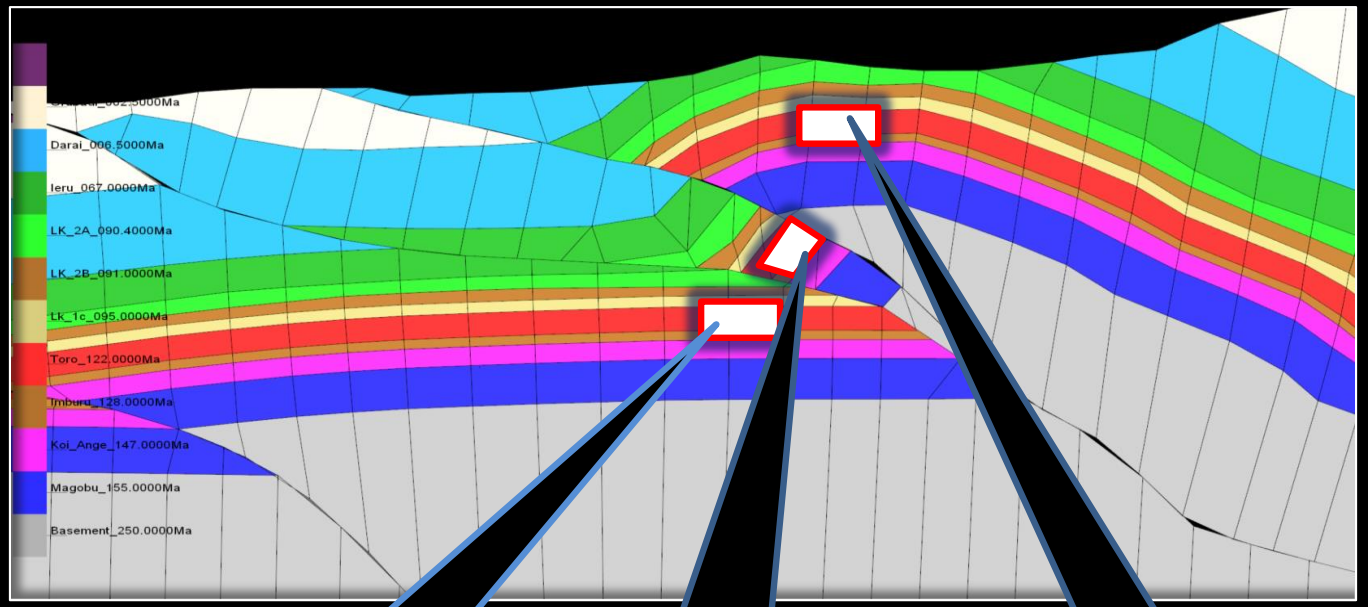




HC Saturation – Final Stages



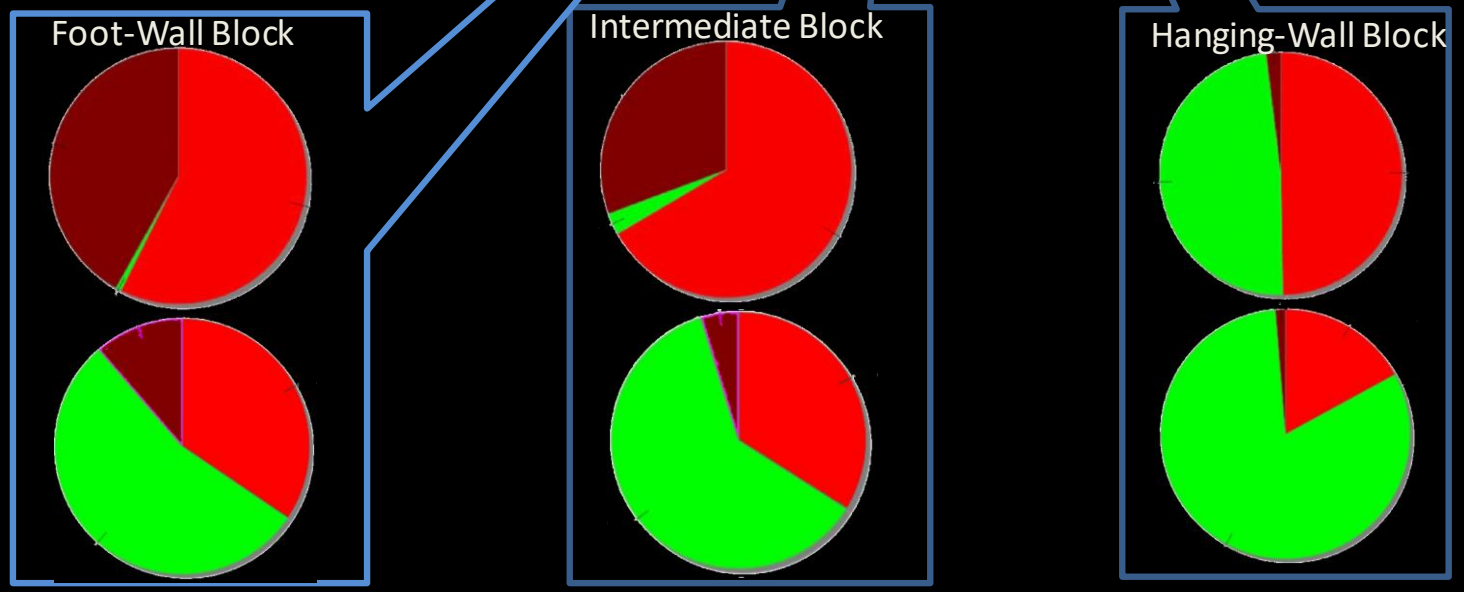
HC Phase



Outcomes

Gas Rich

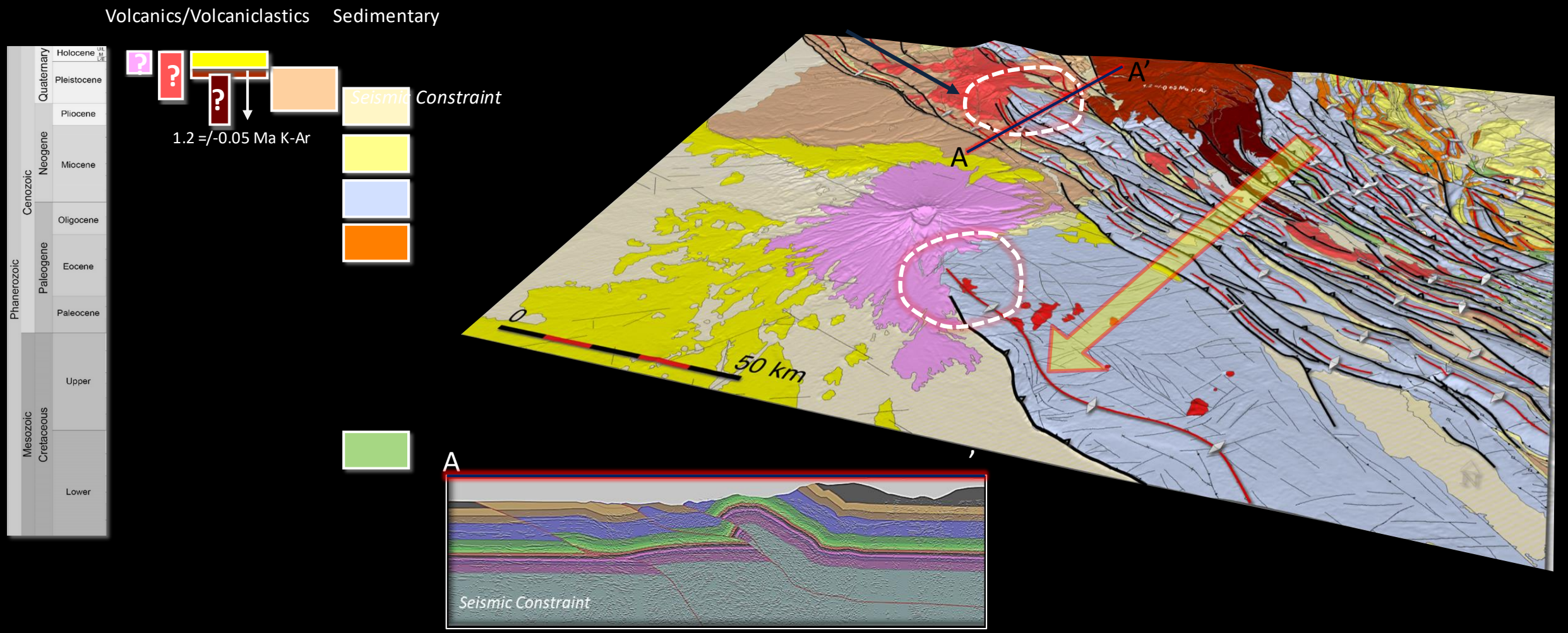
Oil Rich



Break Forward

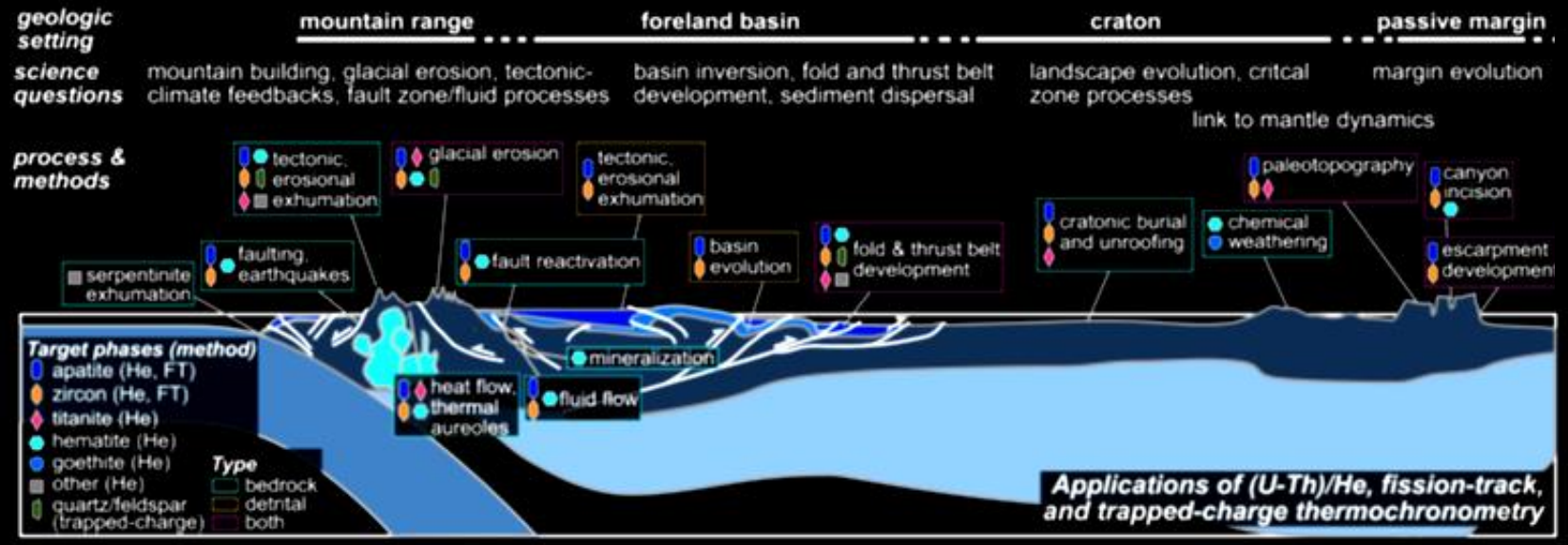
Break Backward

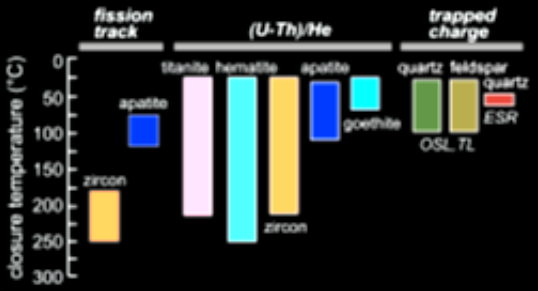
The Constraints on Faulting Sequence Could be derived from Geological Maps..



Cross cutting relationships favours a break forward model……

Low Temperature Thermochronology can provide better timing constraints

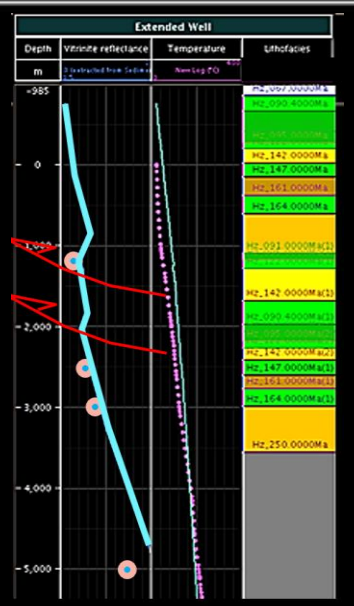




Innovations in (U–Th)/He, Fission Track, and Trapped Charge Thermochronometry with Applications to Earthquakes, Weathering, Surface-Mantle Connections, and the Growth and Decay of Mountains

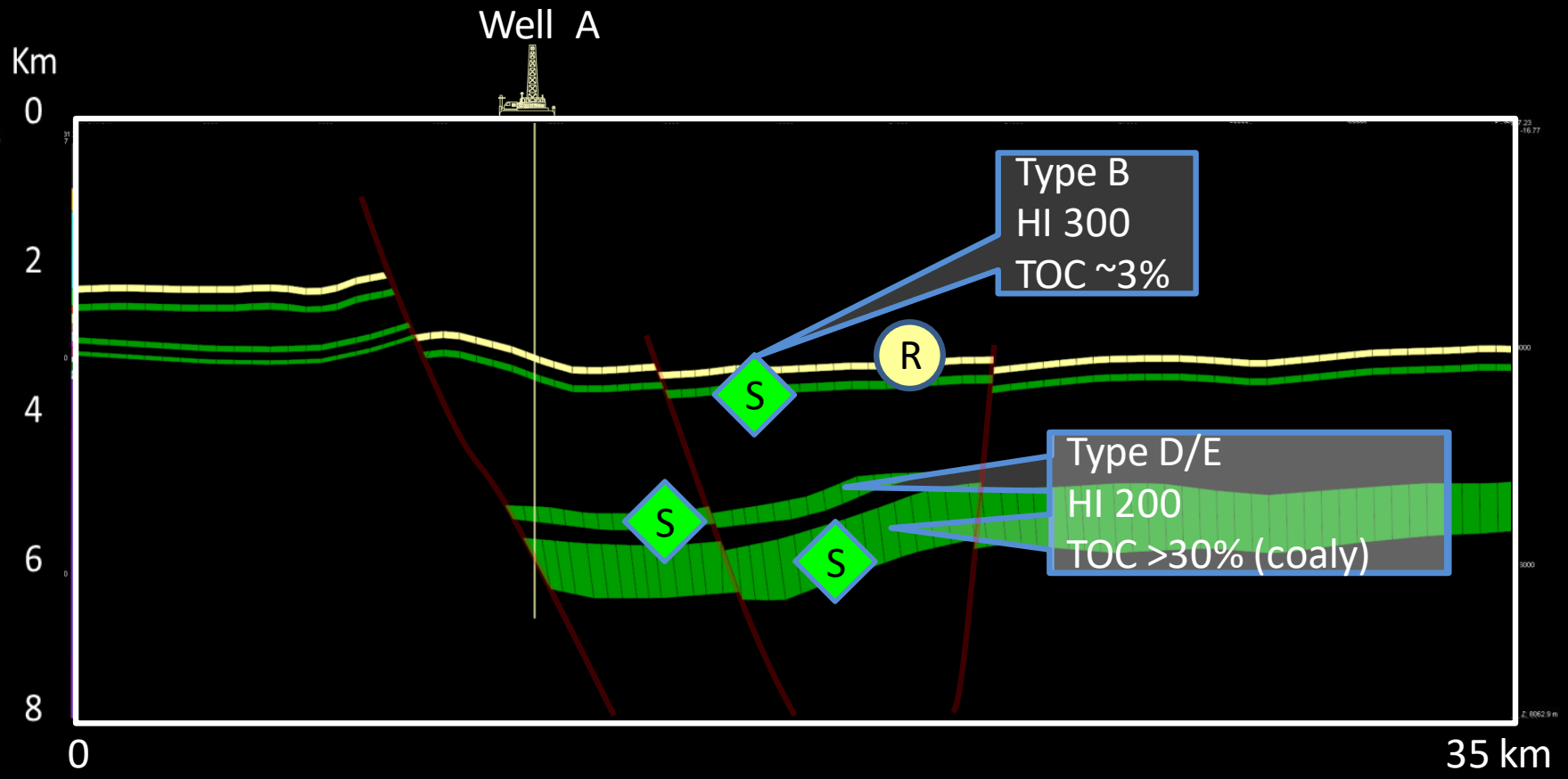
Alexis K. Ault[1], Cécile Gautheron[2], and Georgina E. King[3]

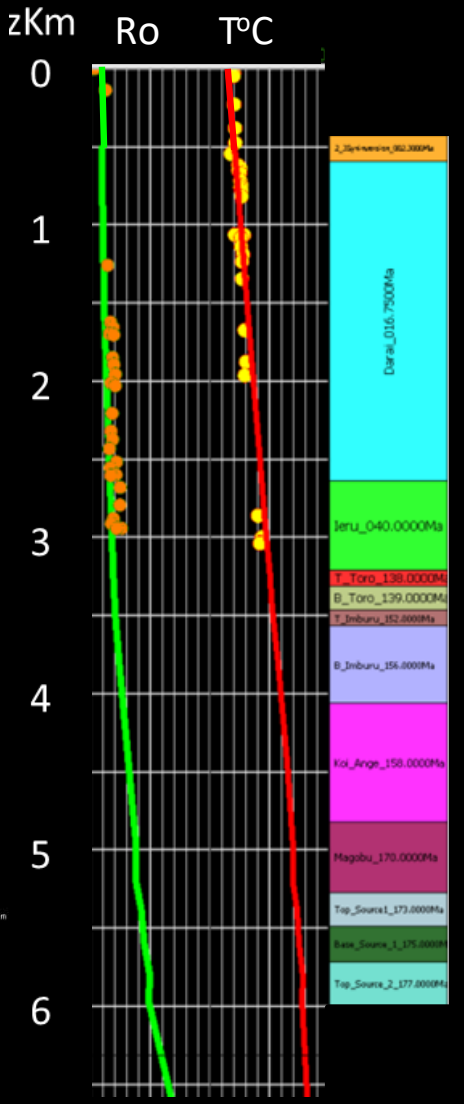
- Structural Timing
- Erosion, Exhumation
- Onset of Deformation (LPS)
- Temperature, Paleotemperature
- Paleobathymetry
- Burial, Unroofing Topography/Evolution
- Source Rock –Expulsion Timing
- Migration
- Reservoir – Sediment Dispersal
- Reservoir Diagenesis
- Fault Ages…..and more



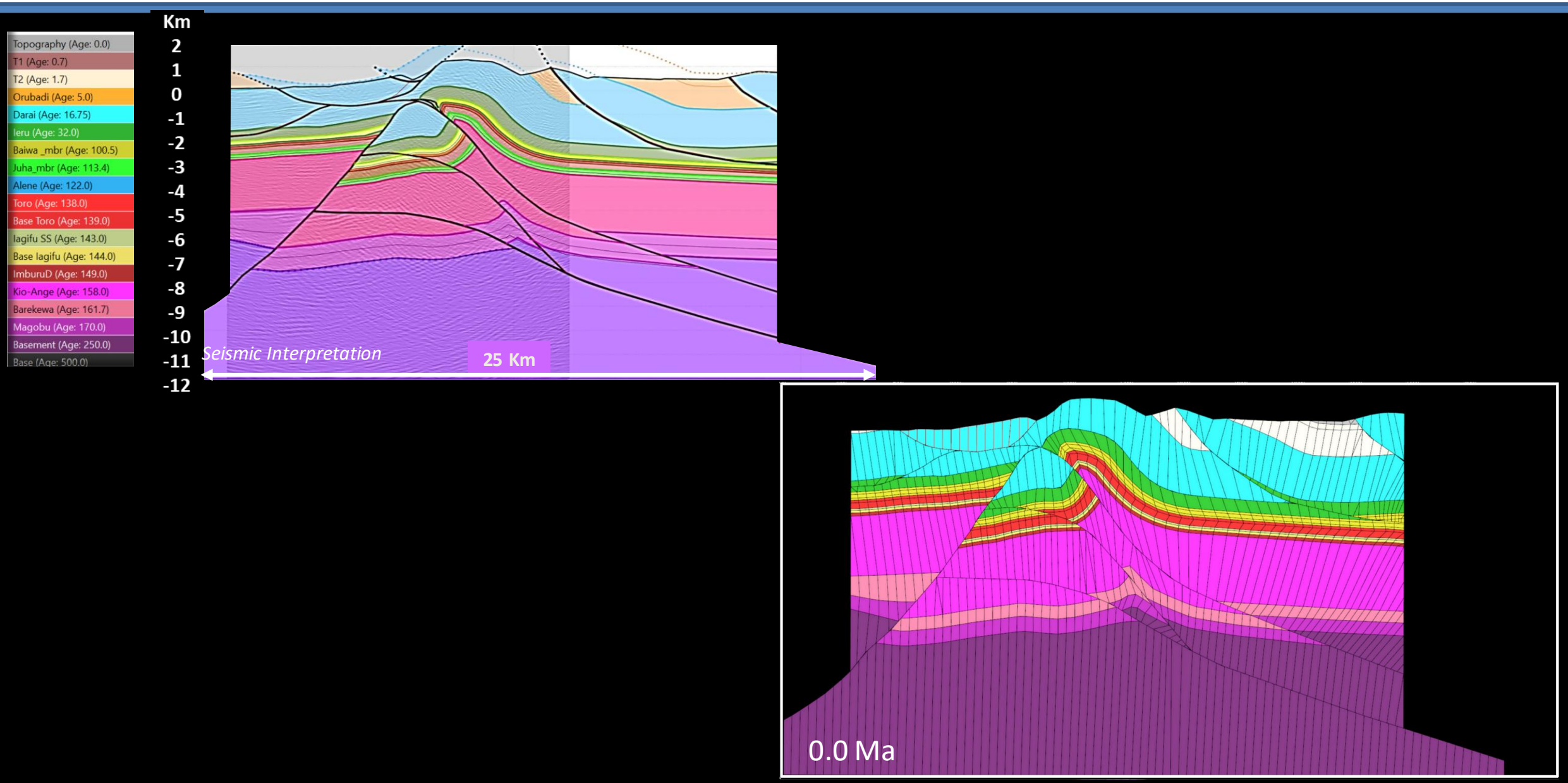
- Outcrop
- Wells

Deep Foreland Basin Wells Source Rock Calibration

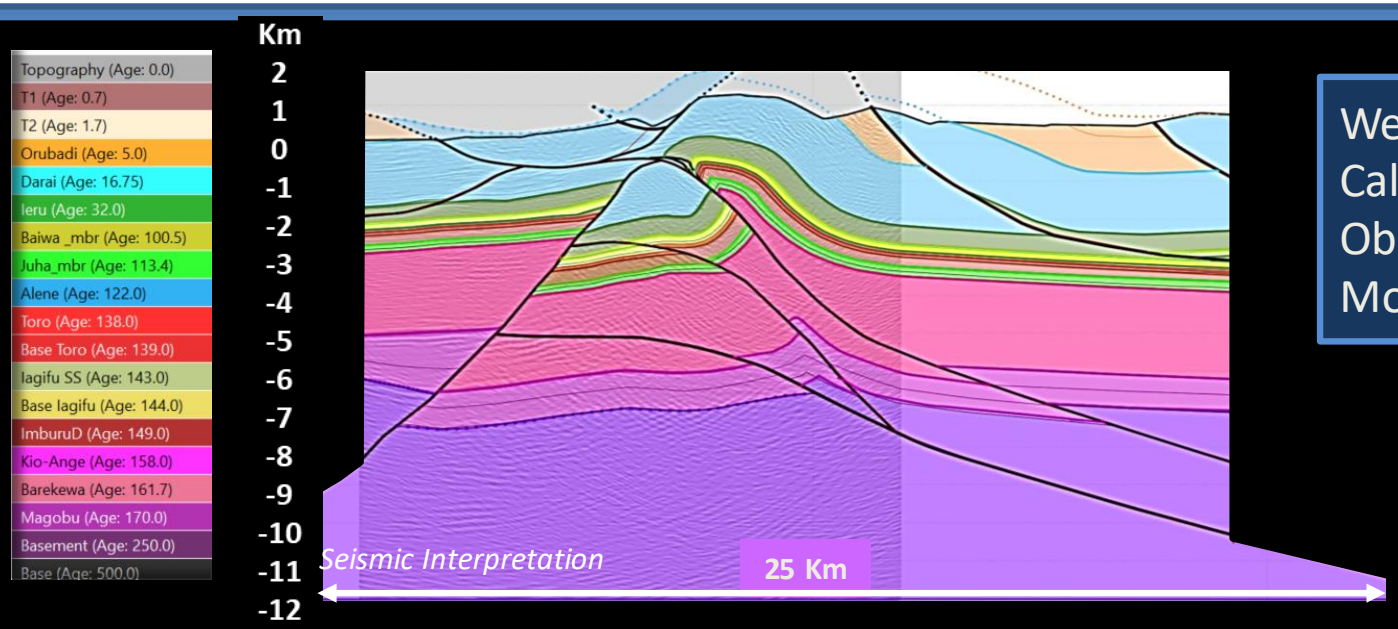




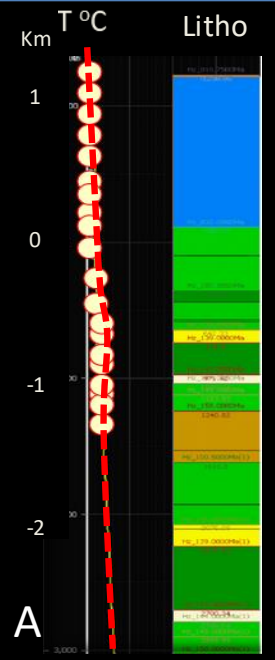
Case 2 : Source Rock Sensitivity Test

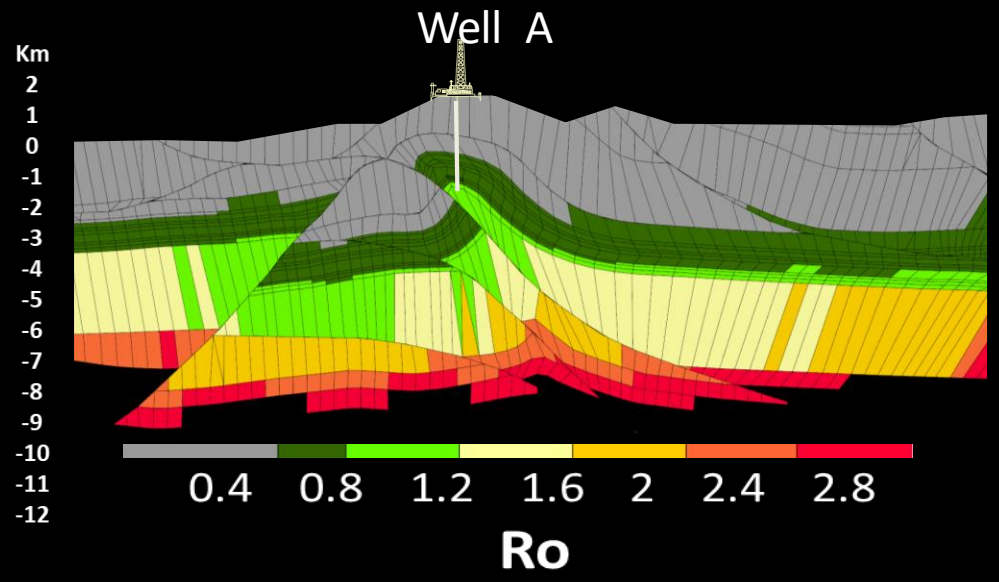


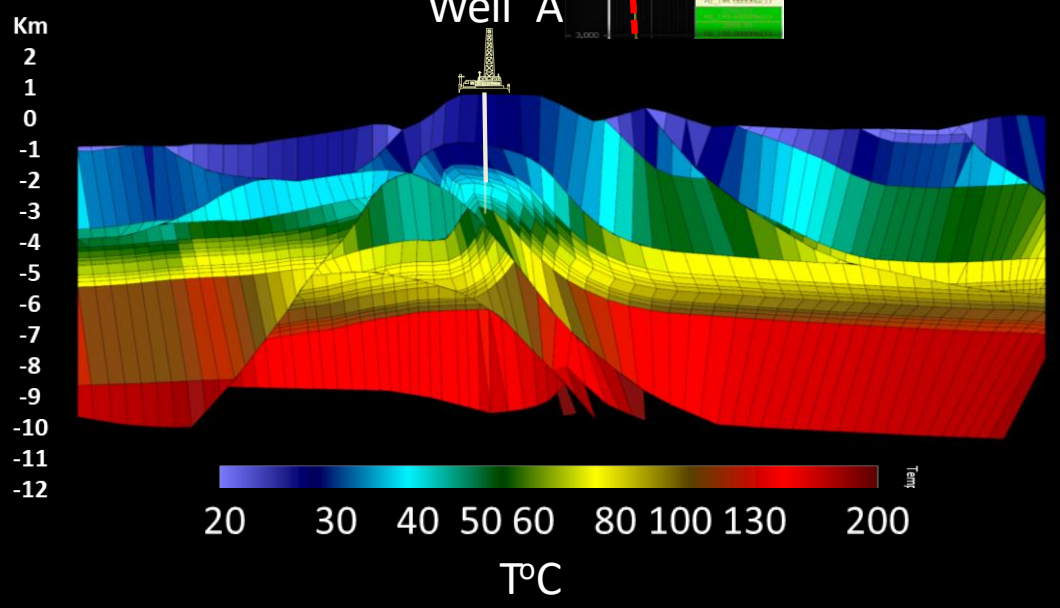
Source Rock Sensitivity Test



Well 'A' Temperature Calibration
Observed
Modelled







Lean & Rich Systems

149 Ma : Imburu
- Marine B
- 100 m
- N/G: 100%
- TOC 5 %

Well A

- Underfilled
- Lower Reservoir Charge Only
- Oil/Gas Cap

- < 30 % HC Saturation in Lower reservoir

149 Ma : Imburu
- Marine B
- 100 m
- N/G: 100%
- TOC 5 %

+

161 Ma : Barikewa
- Deltaic D/E
- 300 m
- N/G: 30%
- TOC 30 % (Coaly)

Well A

- Underfilled
- Top and Lower Reservoir Charged-fault Dependent Oil/Gas Cap

- Top and Lower Reservoir Charged

R

R

HC Saturation %

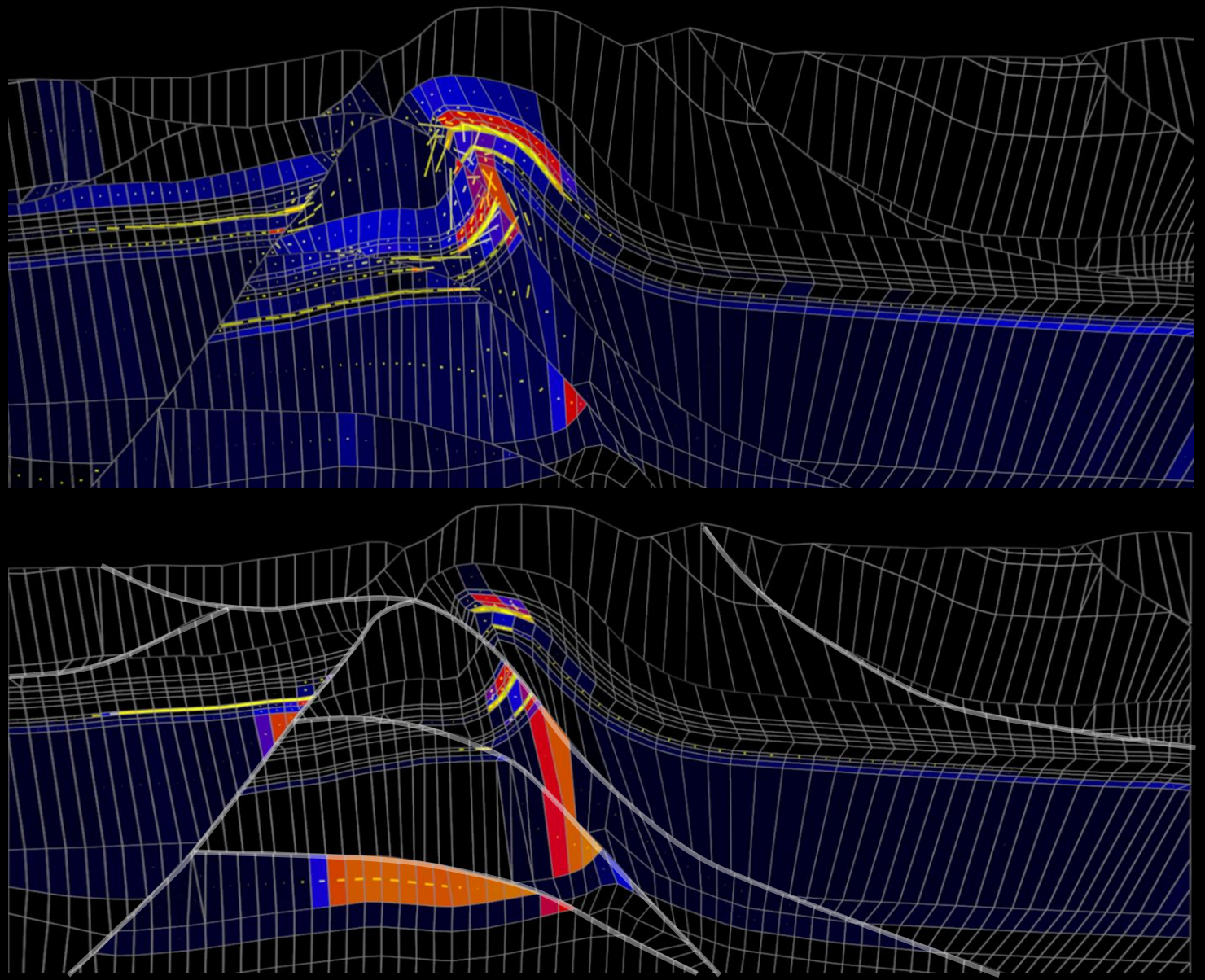
10 20 30 40 50 60 70 80

‘Rich” Model & Fault Permeability

Transmissive Faults

Impermeable Faults

Mean HC Liquid Flow



HC Liquid Saturation %

80

60

40

20

0

Conclusions

- Deeper and more complex structural targets are becoming more challenging to define and drill.
- Exploration is largely tied to add resources to declining fields and to fill existing pipelines. The latter constraining the exploration fairway.
- Standalone Exploration targets require multi MMbo or multi Tcf to be viable

- Therefore, the evaluation of our structural targets require more holistic de-risking methods; one that places our structural interpretation in a Petroleum System Context
- OSL has implemented thermo-kinematic (Kronos) modelling as a routine de-risking workflow. In order to constrain these models, we are re-initiating a campaign of targeted data acquisition in the field and from well samples e.g. rock-fluid Geochem and low-temperature geochronology…