Integrated Characterisation of Fractured Reservoirs

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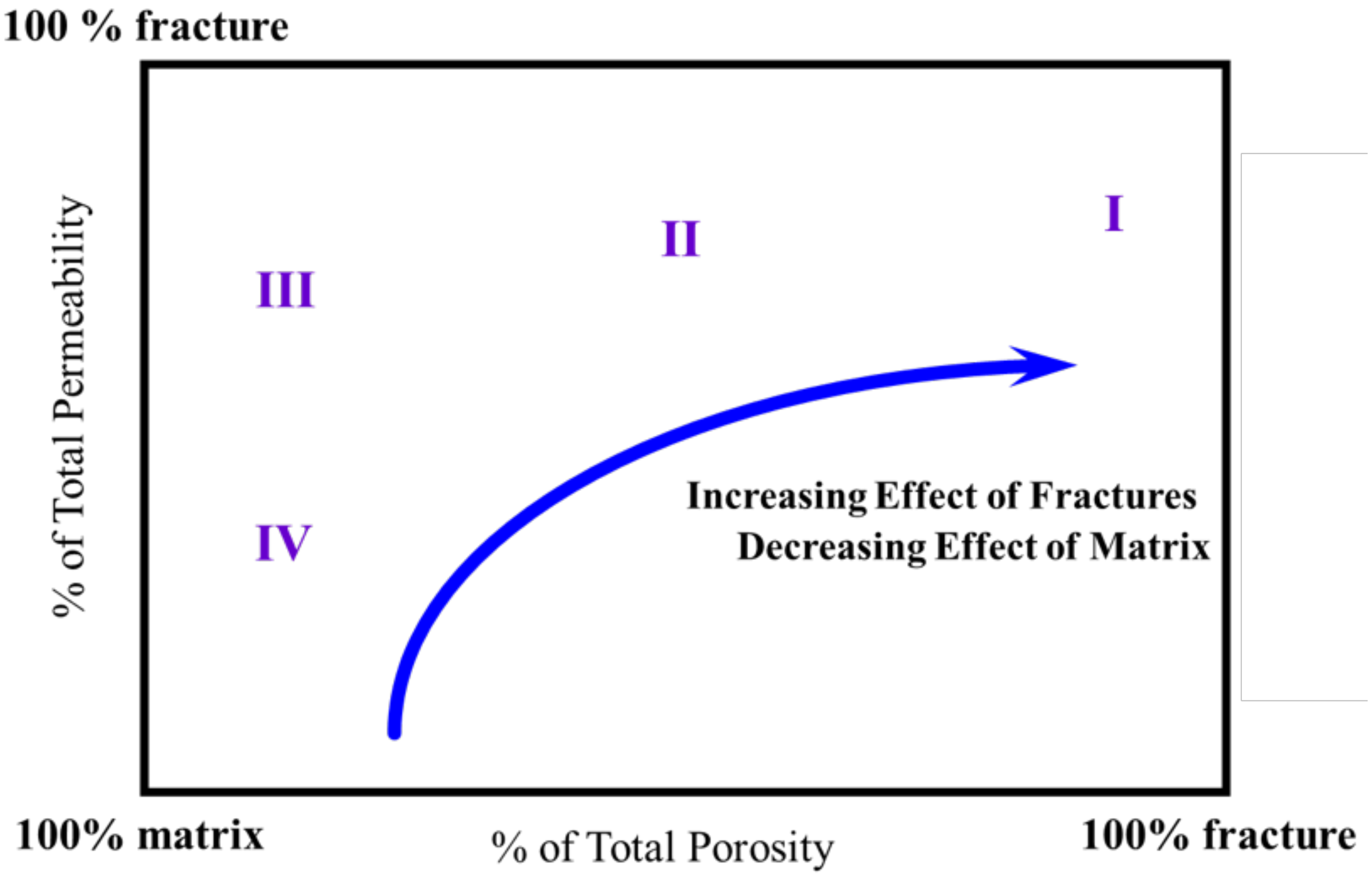
NELSON CLASSIFICATION

- Fractured reservoirs have some or all of their production from naturally occurring rock fractures
- Knowing which type is key to development strategy
- Knowing the conductive direction is a significant value-add to field development



COMPONENTS

- Fractures
- Integrated workflow
- Examples
- Conclusions

FRACTURES

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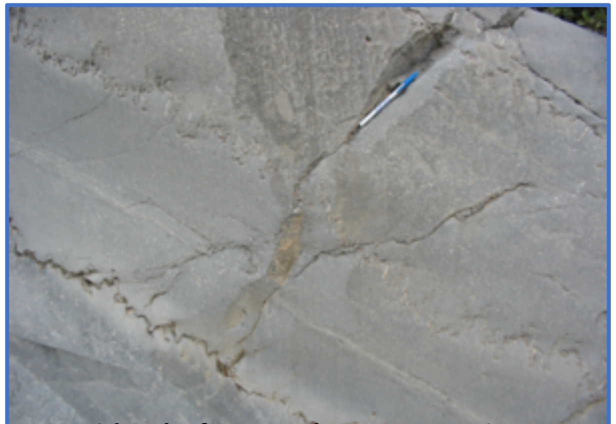
Stylolites



Cupido Platform Carbonates Mexico

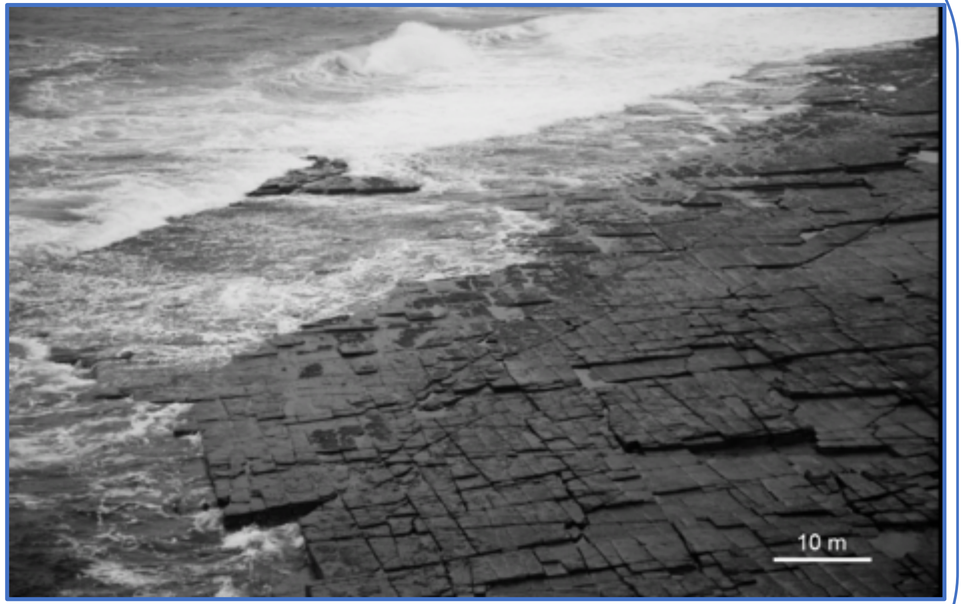
Deformation Bands

Hopeman Sandstone, UK

Faults

Devonian Sandstones, Arbroath, UK

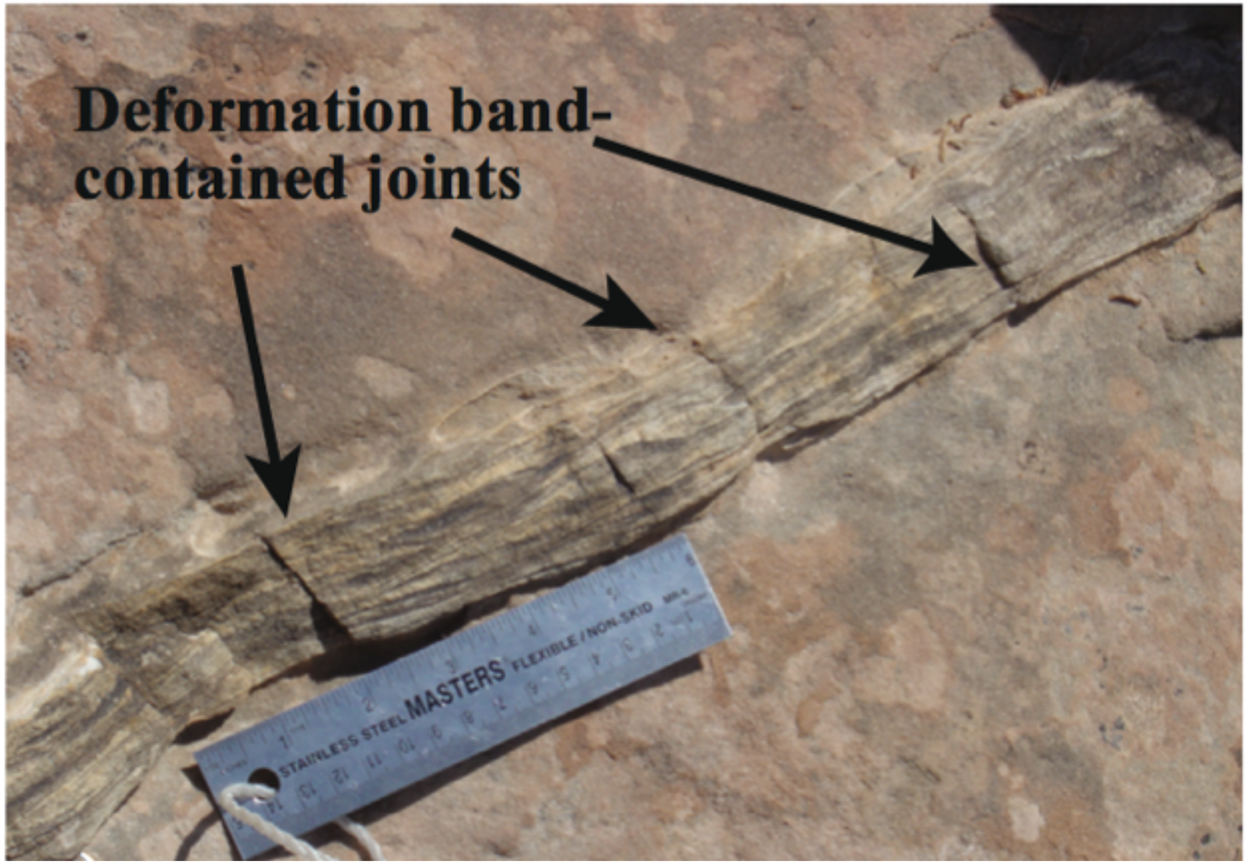
Joints



Devonian Sandstones, Caithness, UK

COMBINATIONS

Early formed deformation bands cut by open fractures



Sandstone, Colorado Plateau (*Tindall & Eckert, 2015*)

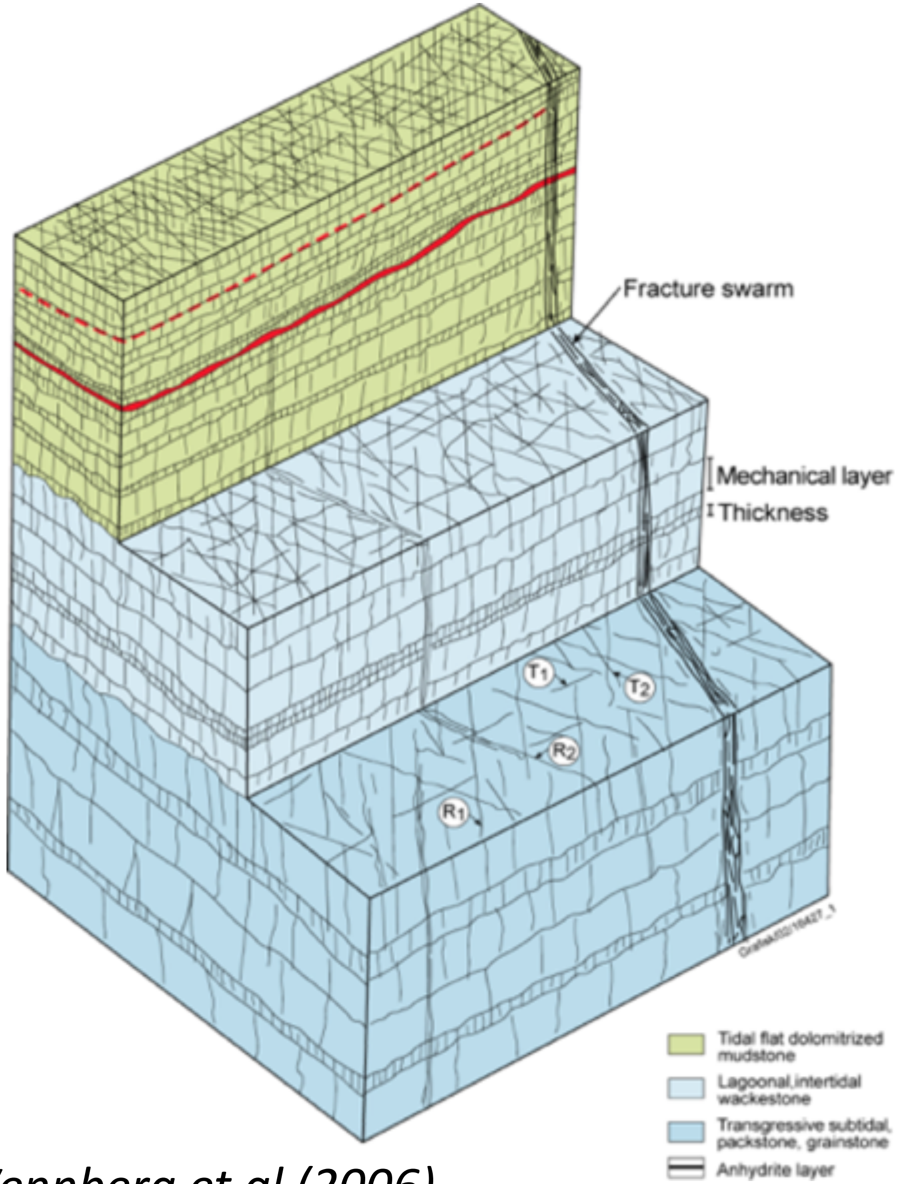
Tension gashes from stylolites

Sandstone, Barents Sea

BED THICKNESS

- Diffuse Fractures often strata-bound
- Fracture Swarms more through going

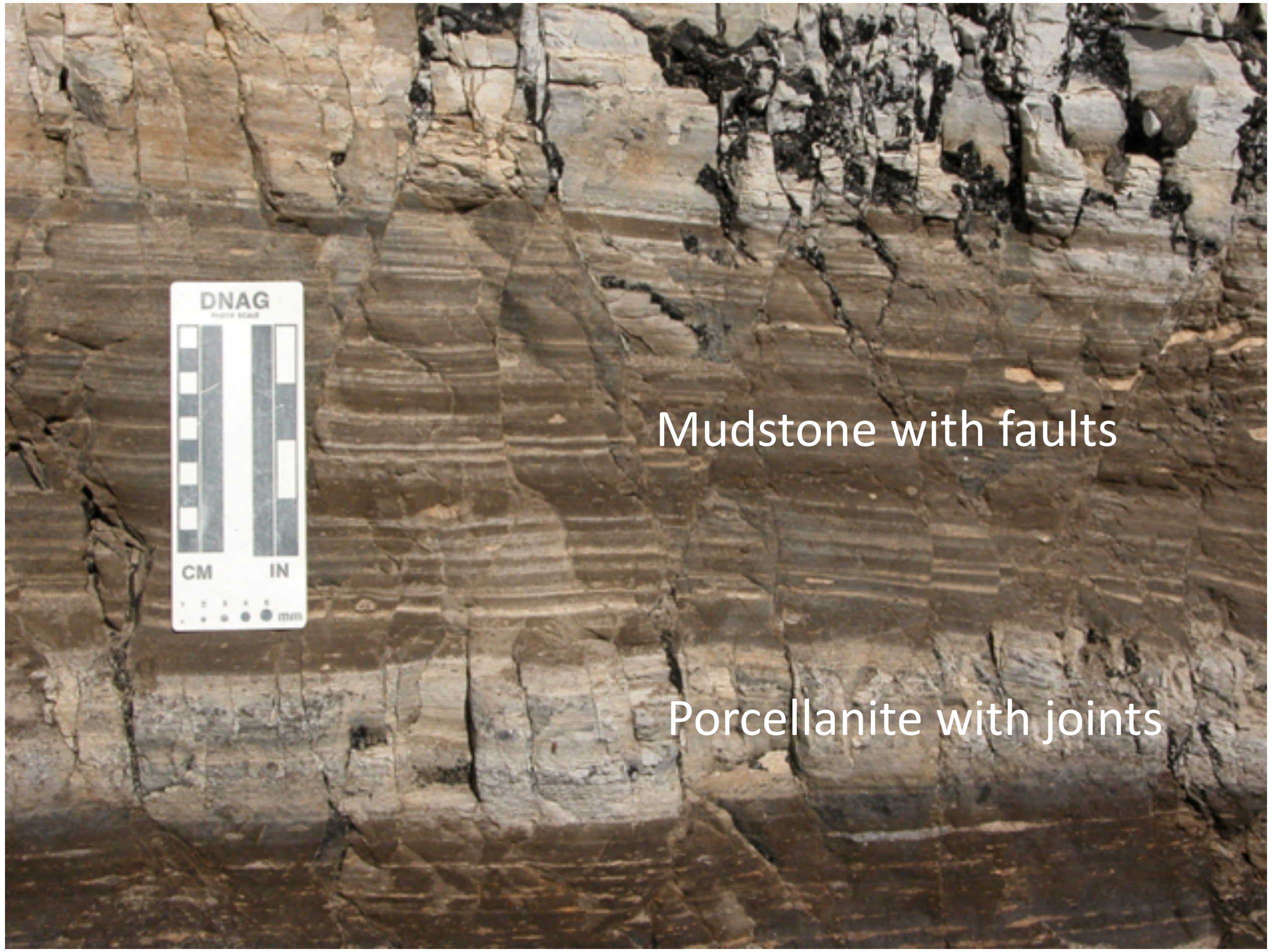
Carbonates, Asmari Fm, Iran *(OP Wennberg)*



Wennberg et al (2006)

LITHOLOGY

Cupido Platform Carbonates, Mexico



Monterrey Formation at Arroyo Burro Beach, Santa Barbara, CA (*M Gross*)

INTEGRATED WORKFLOW

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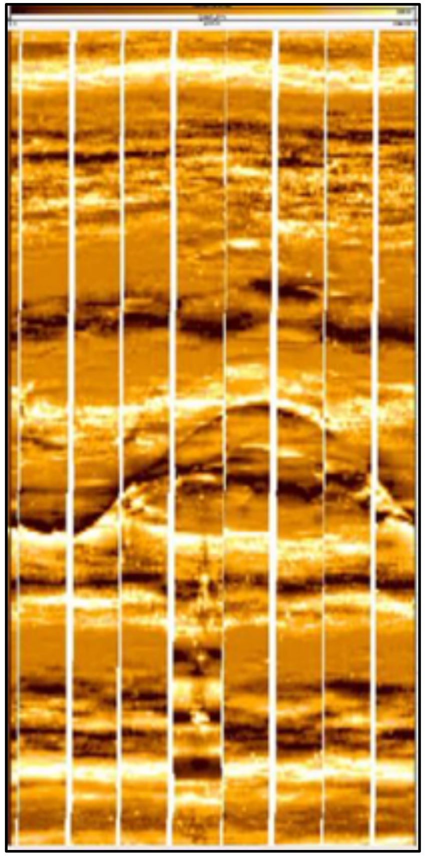
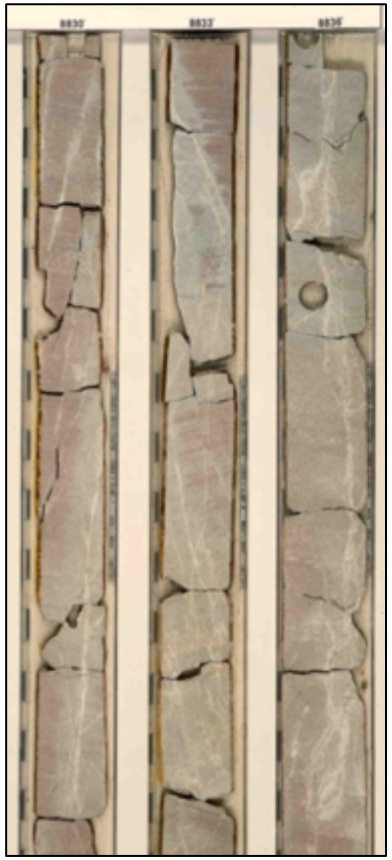
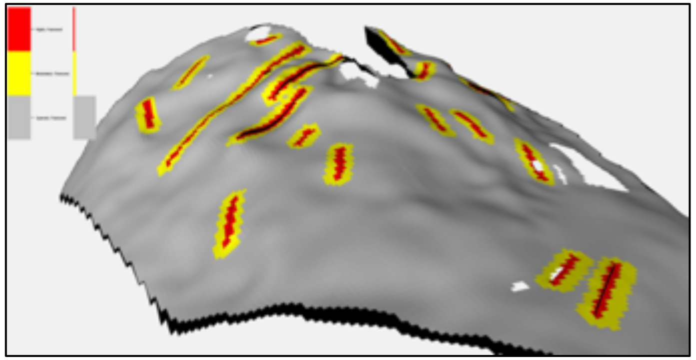
Wells





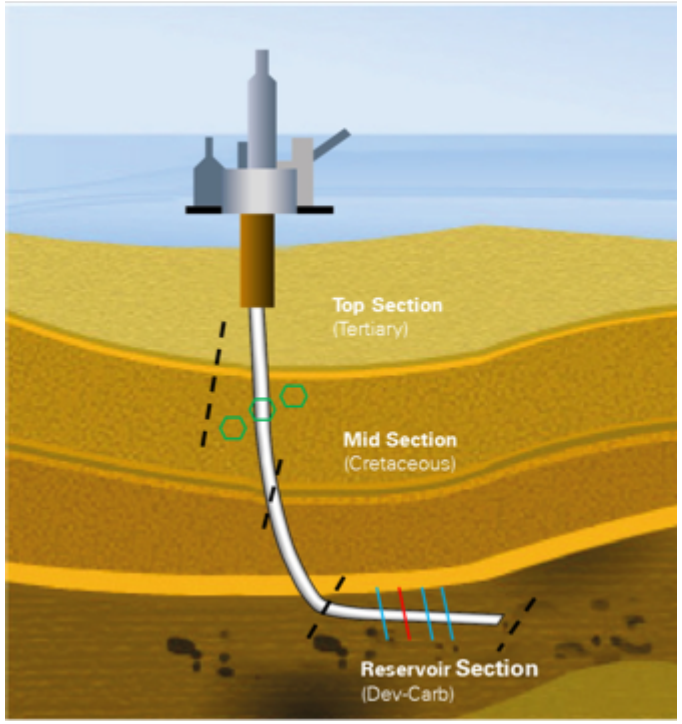
Fracture type, density, orientation, fracture sets

Integrate



Type of Fractured Reservoir
Different descriptions

Development



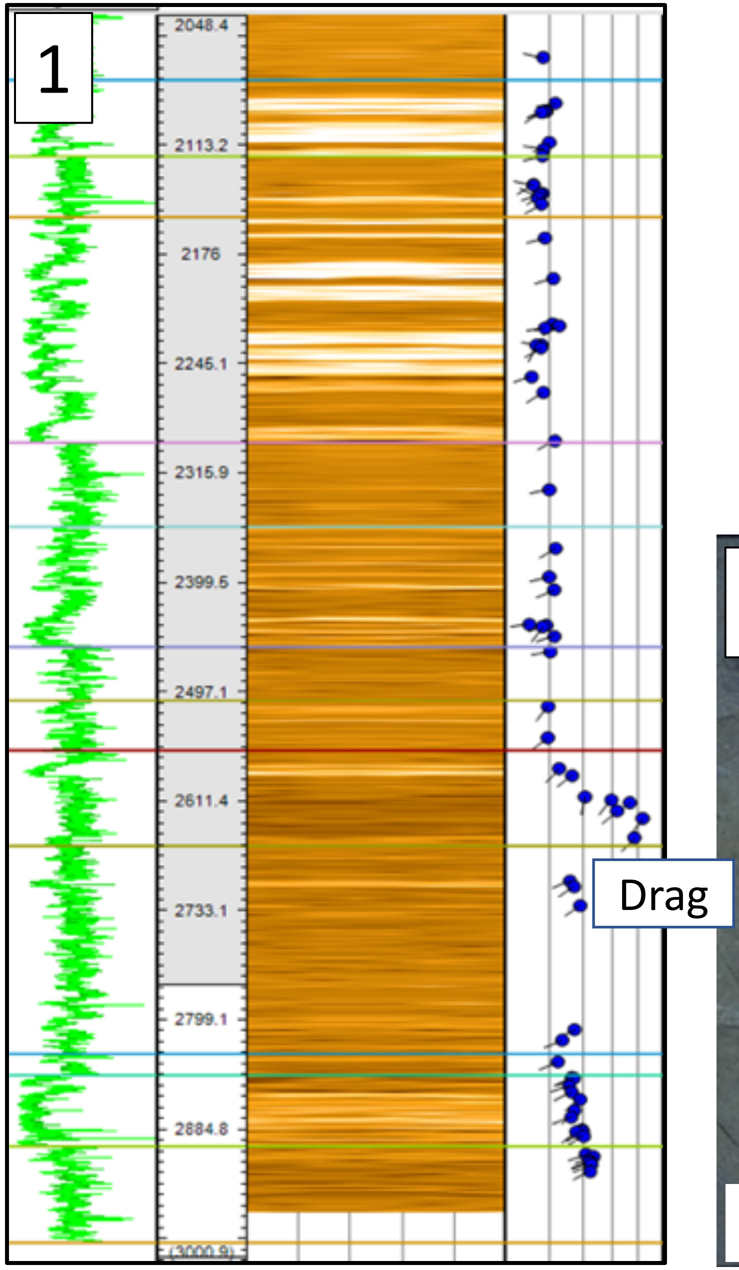
Number of wells, Rate, drainage pattern etc.

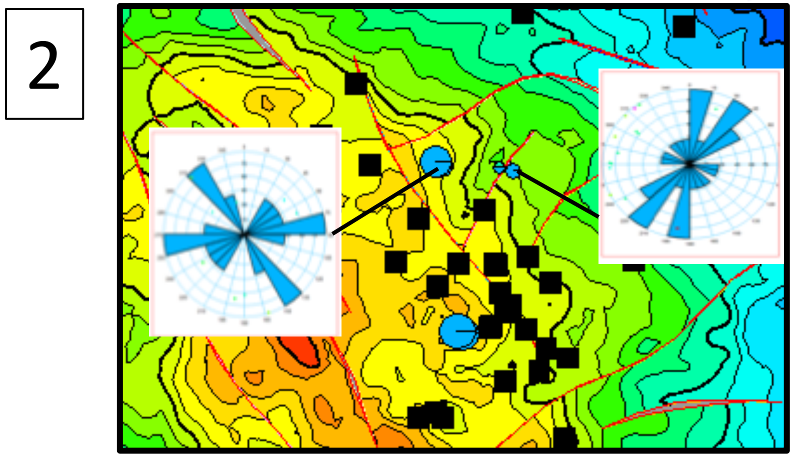
WELLS

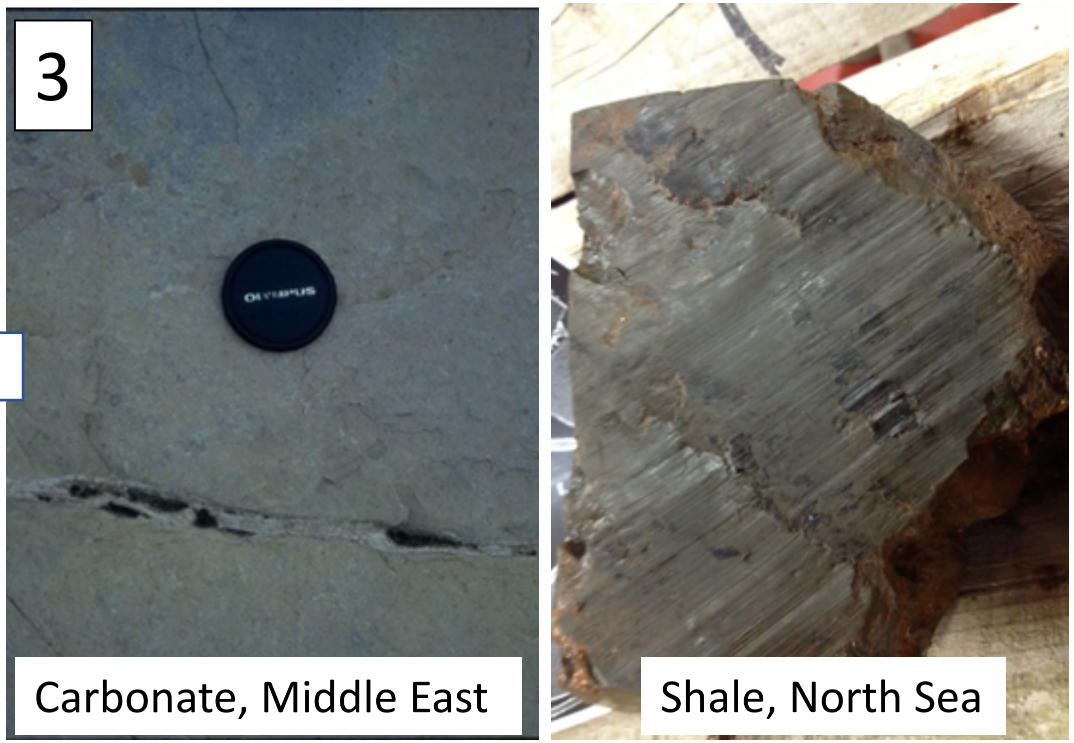
1. Picking fractures/faults & inferring from bed dip changes

2. Creating sets based upon fracture dip/strike

3. Cross-check with core for cementation, slickenlines

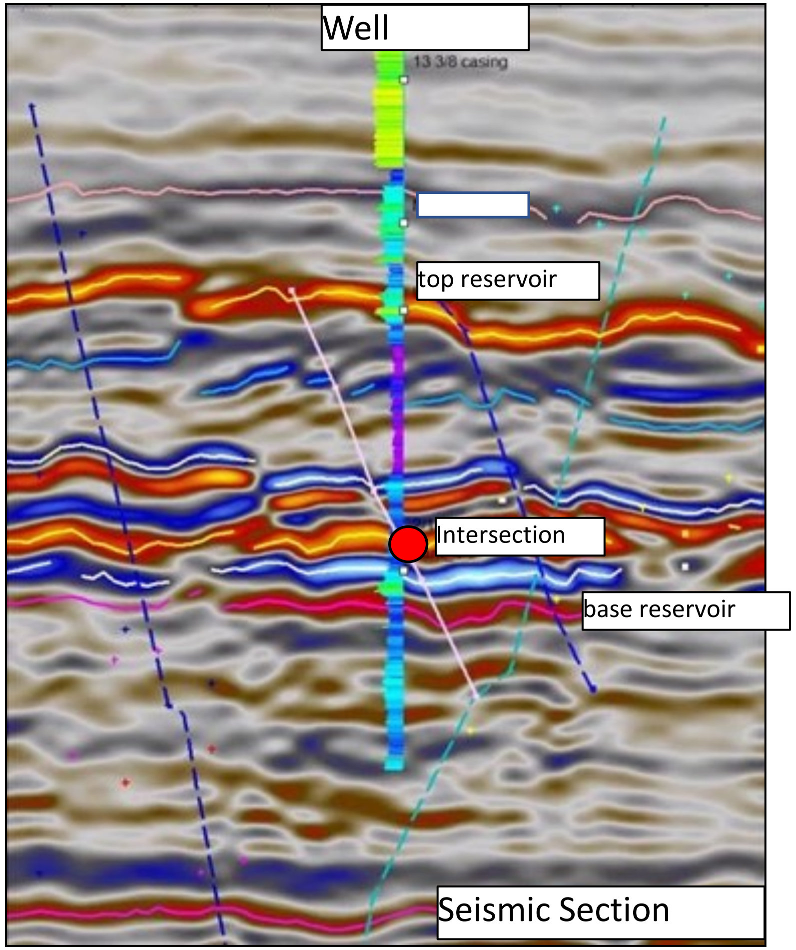




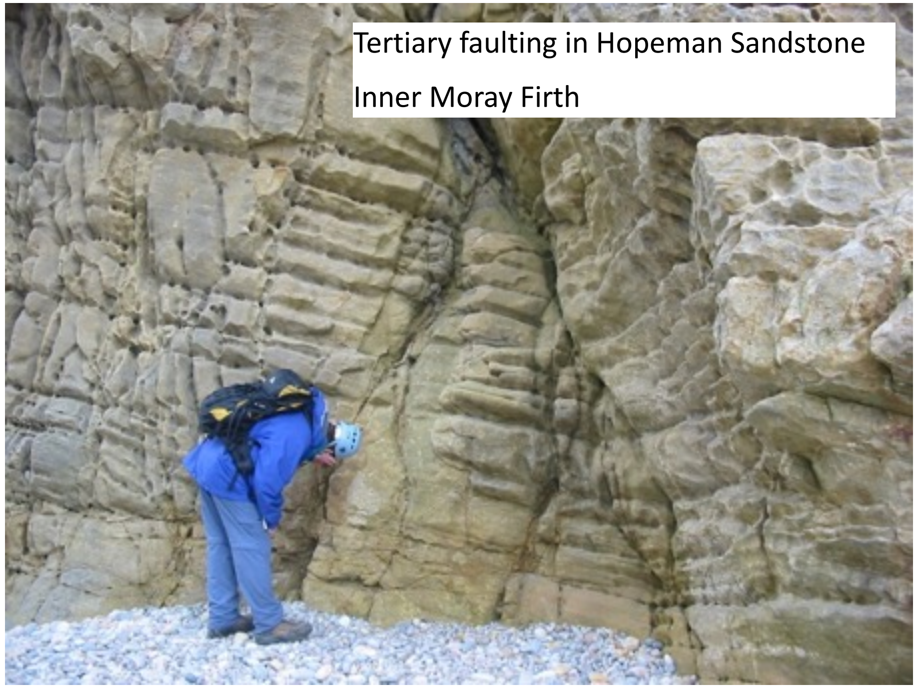


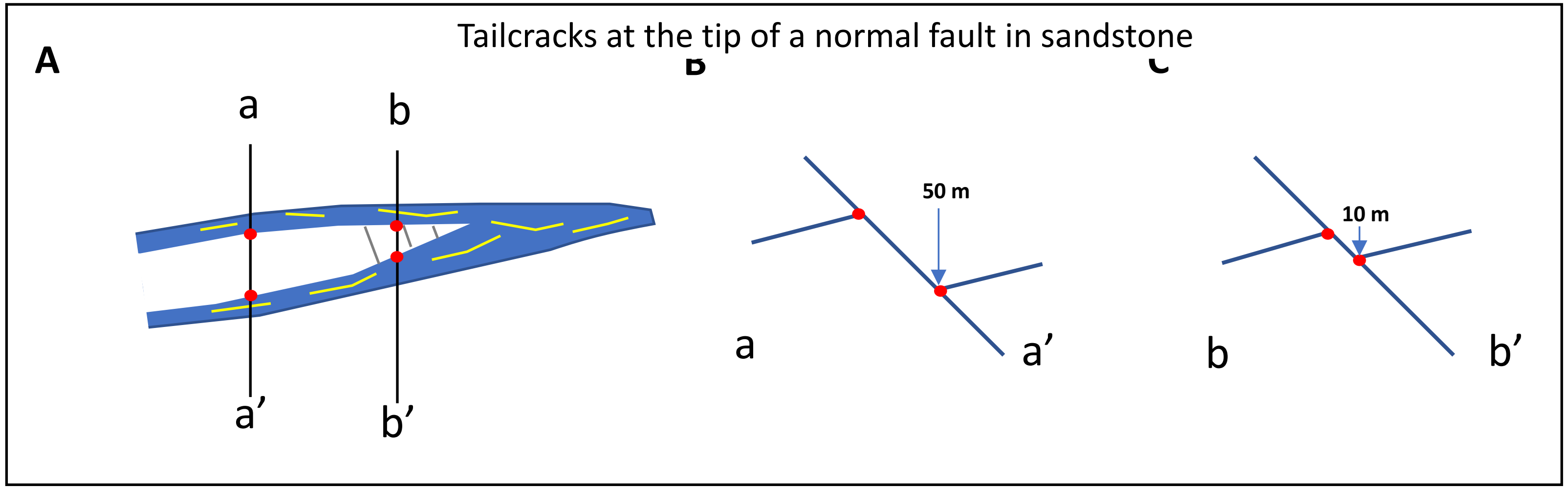
INTEGRATE STATIC DATA

Check seismic for fault(s)



Factor in tailcracks ahead of fault tips





INTEGRATE STATIC DATA

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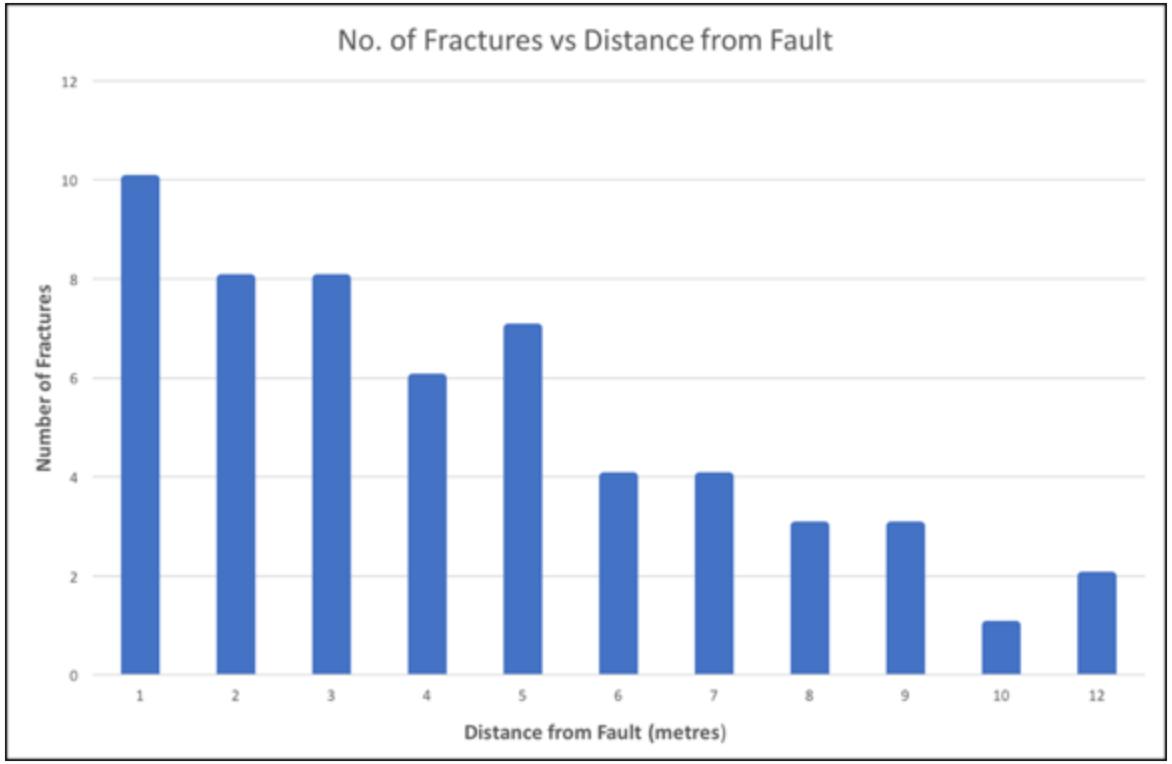
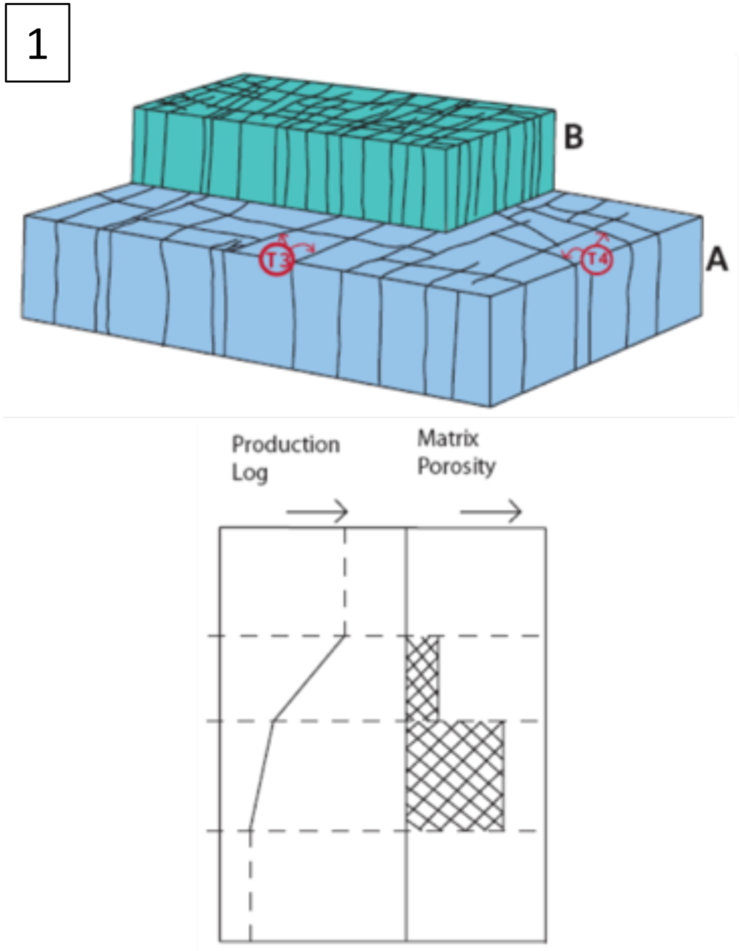
- Outcrops invaluable for fracture properties such as length, spacing, distance to faults

Jointed limestone, Kilve Pill, Somerset, UK

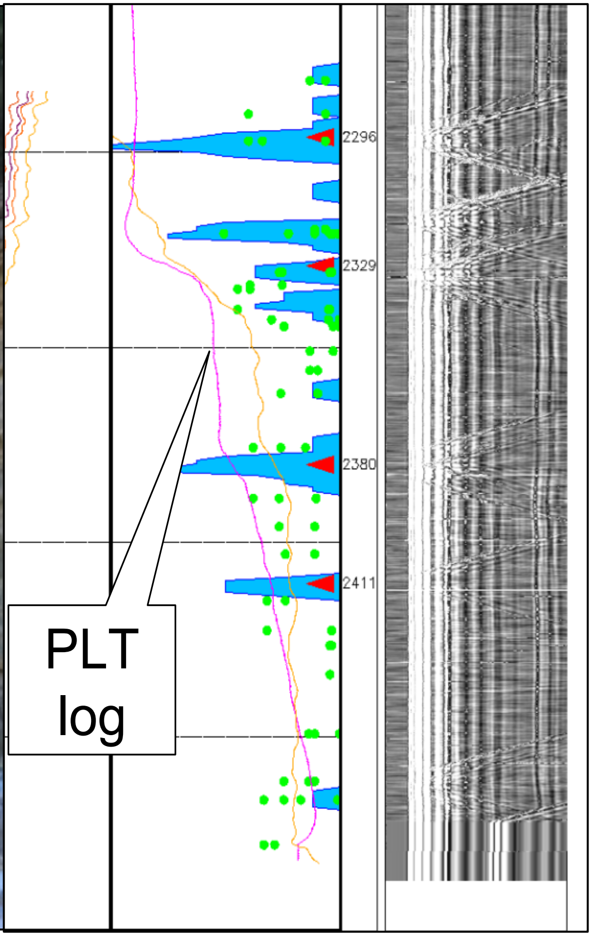


INTEGRATE DYNAMIC DATA

- Welltest perm > matrix perm ? Dual porosity response ? Egya et al (2017) – cannot rely upon it !
- Production Log Tests (PLTs) have quite different response in fractured reservoirs [1] Big flow contribution over small intervals can indicate fracture swarms, and other data such as mudlosses [3] can help distinguish them from diffuse fractures [2]. Stoneley waves to distinguish open from closed fractures [4]



Fractured Dolomites, Marsden Bay, NE England



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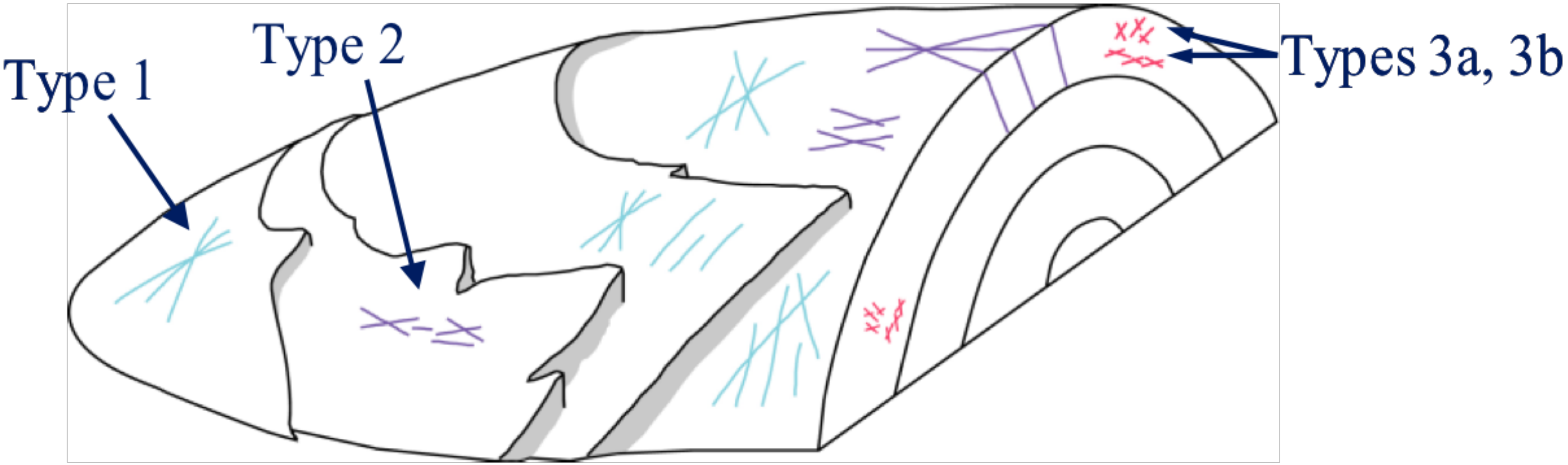
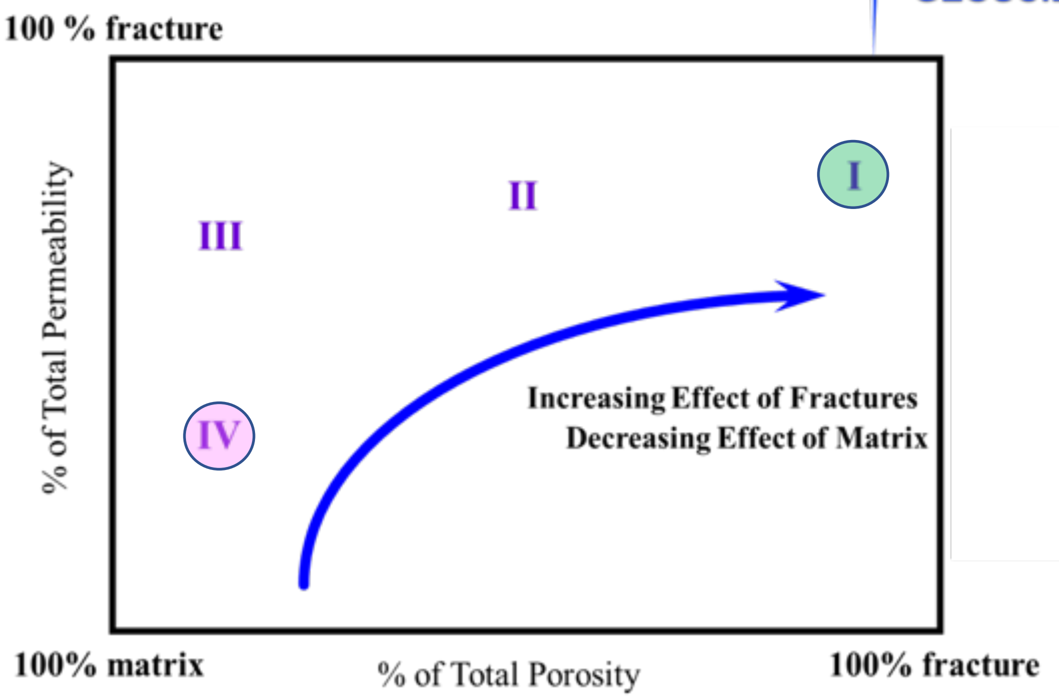
MODELS

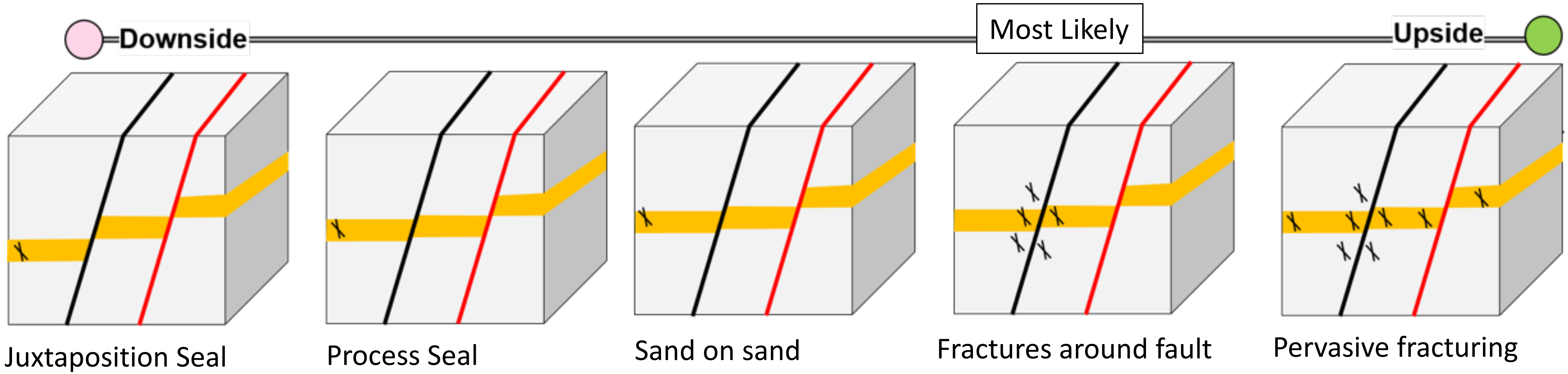
- Conceptual Model e.g., based upon Stearn's study on Teton Anticline, Wyoming



DEVELOPMENT

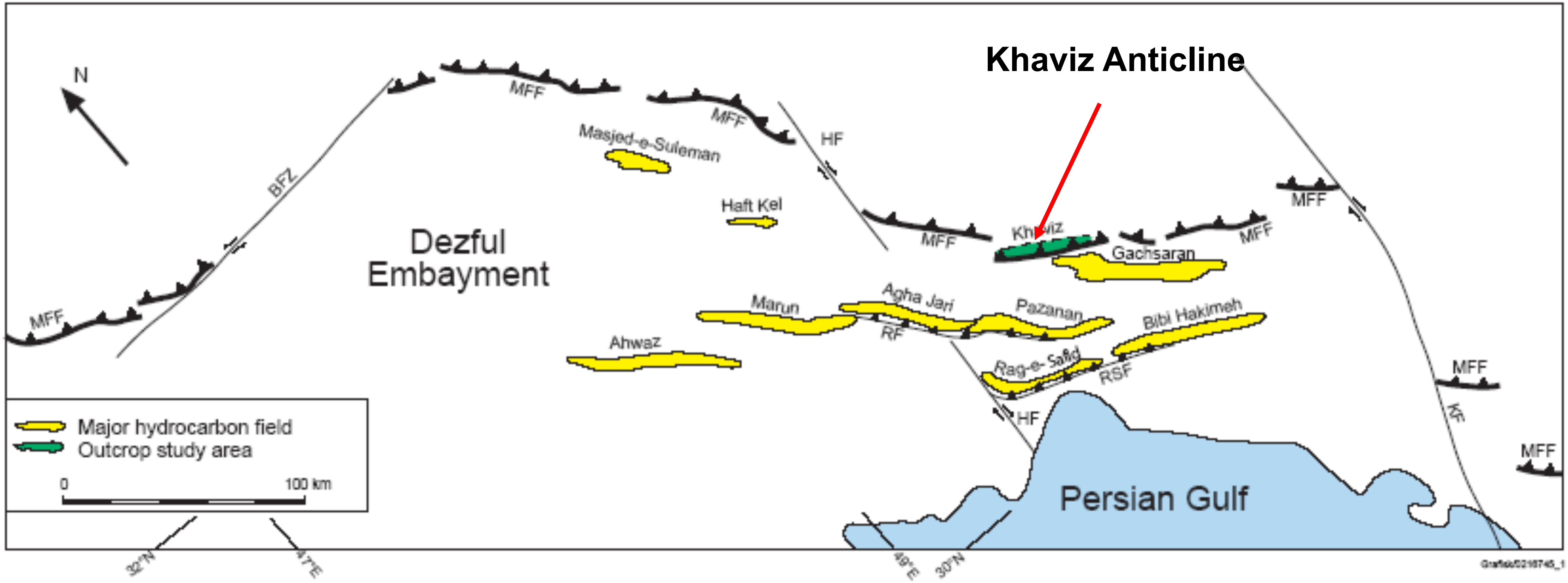
- Carry a range of reservoir descriptions
- Assign probabilities





MIDDLE EAST ANTICLINE
ELEMENTALS

- Giant fault propagation folds in Zagros mountains, Iran

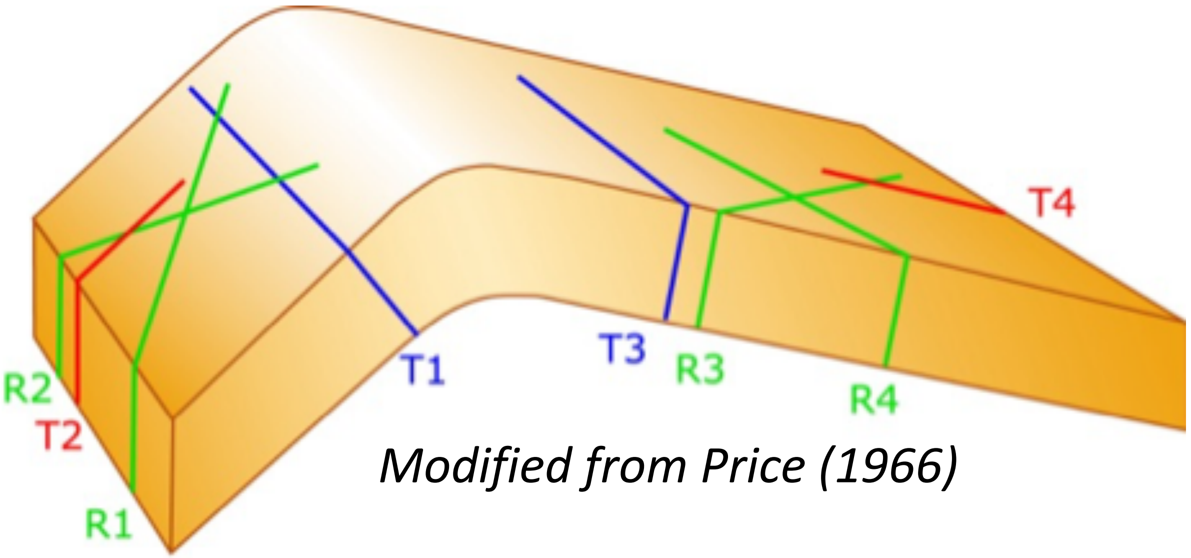


Wennberg et al (2006)

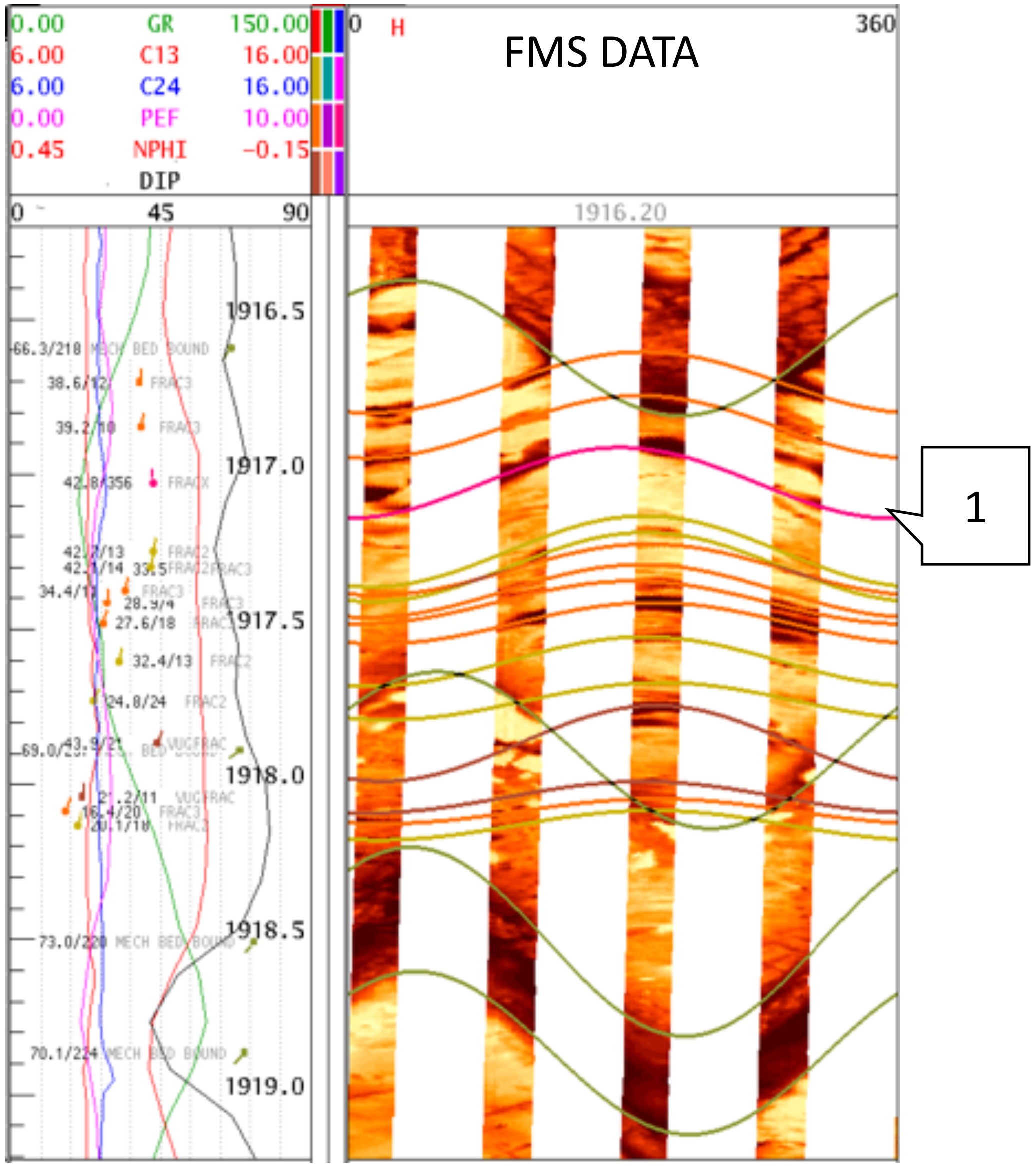
MIDDLE EAST ANTICLINE

WELLS & INTEGRATION

- Definition of fracture sets from image logs and from outcrop, consistent with the Price (1966) model.
- Tensional (T) fractures related to outer-arc extension and driven by curvature
- Shear (R) fractures abundant on flanks caused by flexural slip and driven by dip.



Modified from Price (1966)



MIDDLE EAST ANTICLINE
WELLS & INTEGRATION

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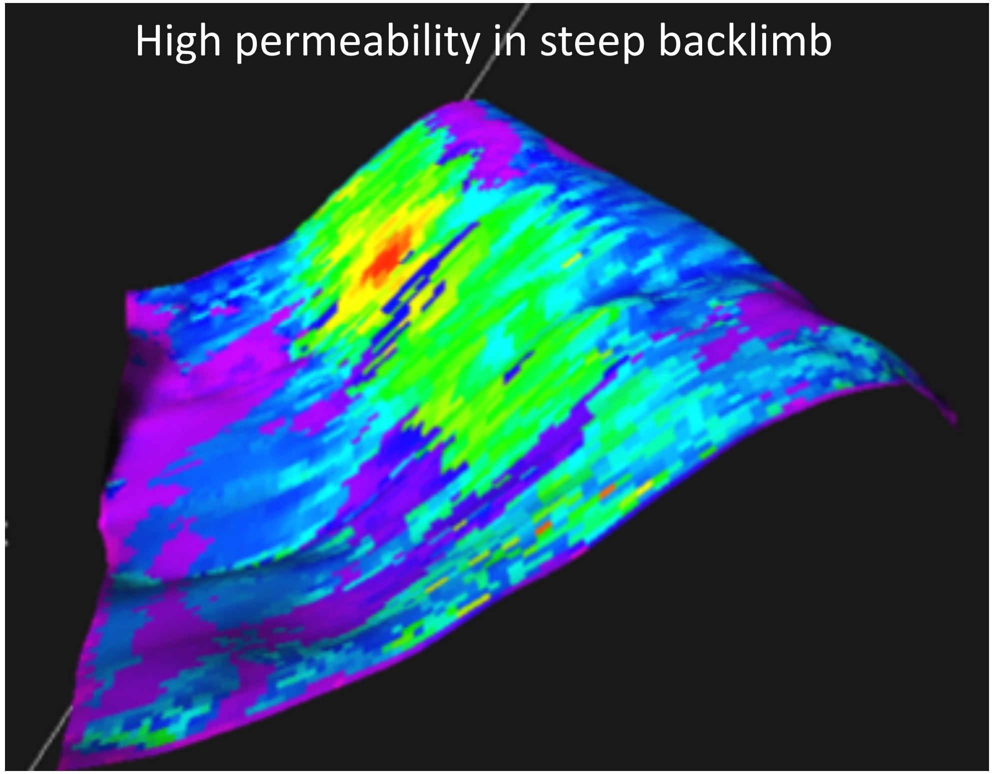
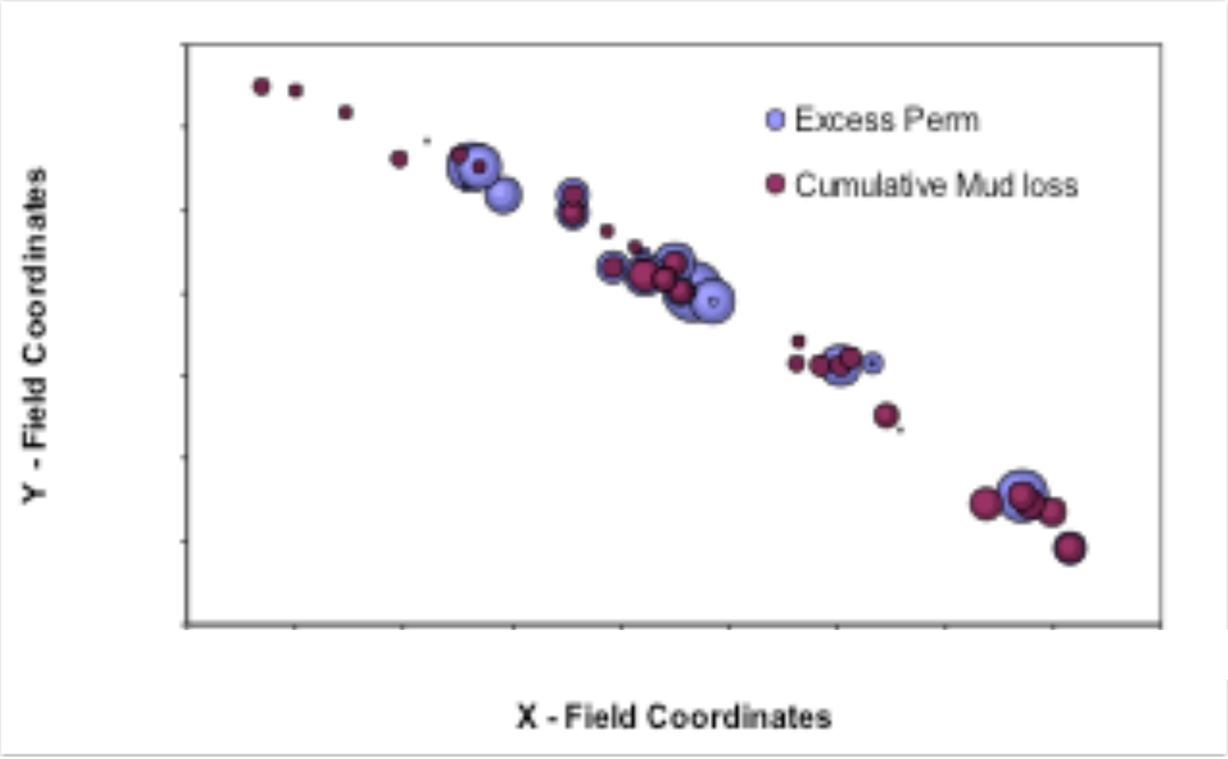
- Where these fractures intersect (mid flank position) as a result of high strain = high productivety.
- Consistent with dynamic data e.g., mudlosses, PIs



From Wennberg et al (2006)



MIDDLE EAST ANTICLINE
WELLS & INTEGRATION

- Forelimb often more fractured as experienced higher strain

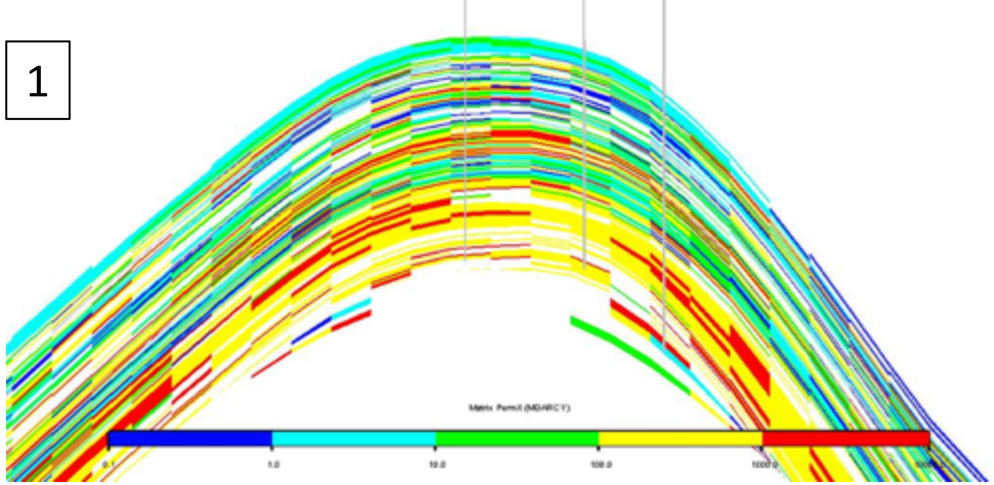

Fault propagation fold in dolomite, Marsden Bay, England

MIDDLE EAST ANTICLINE

DEVELOPMENT

- Large uncertainty handled by 2 models in highly fractured sector [1] Single porosity all layers, [2] Dual porosity carbonate layers

1



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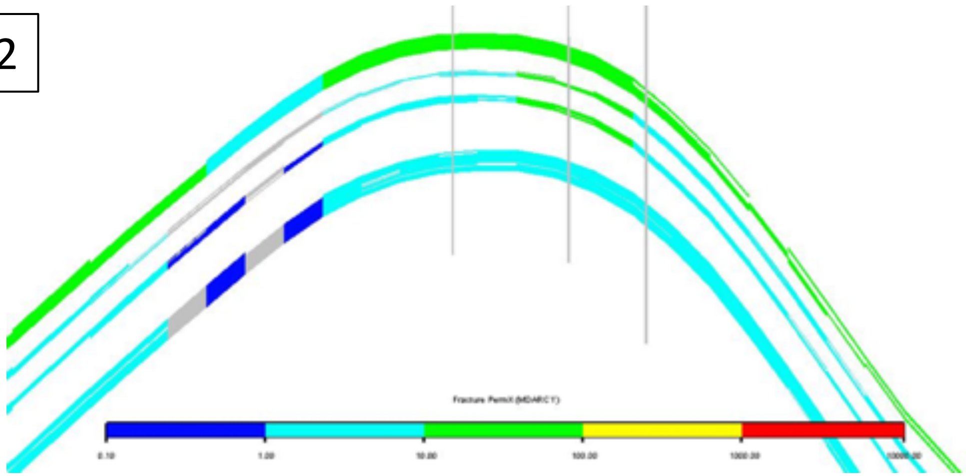
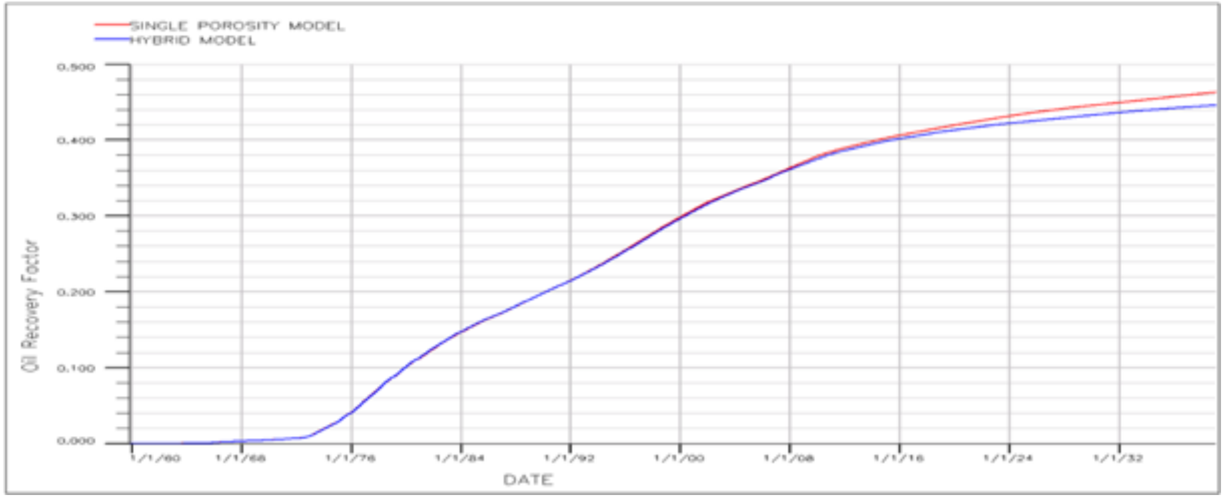


- Good history match can also be obtained with a hybrid formulation and this may influence predicted performance of new drainage strategies.

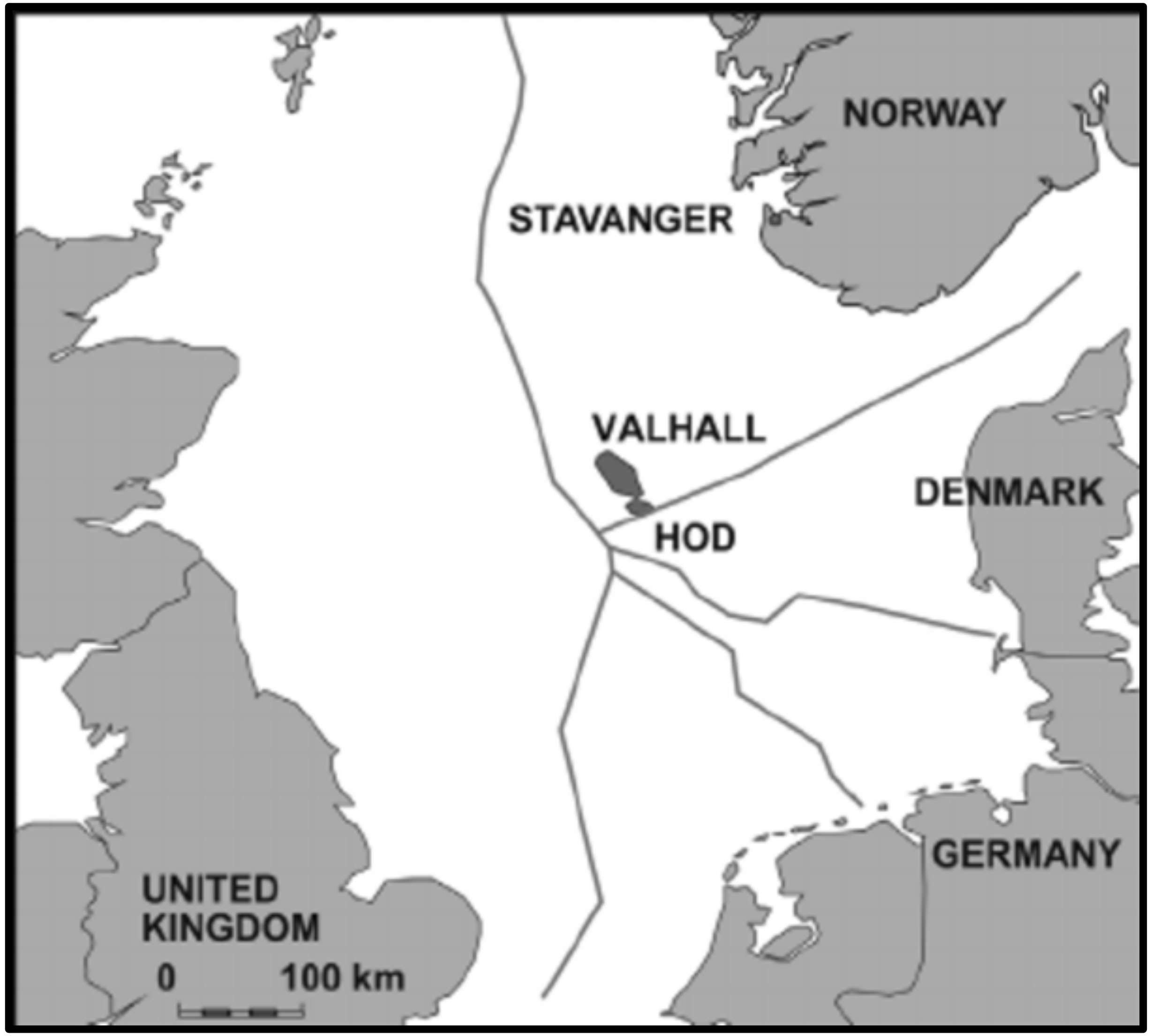


- *From Haugse & Ogilvie (2004)*

NORTH SEA MUDSTONE
ELEMENTALS

- Oil-bearing (Miocene) diatomaceous mudstone in shallow section of the Valhall Field

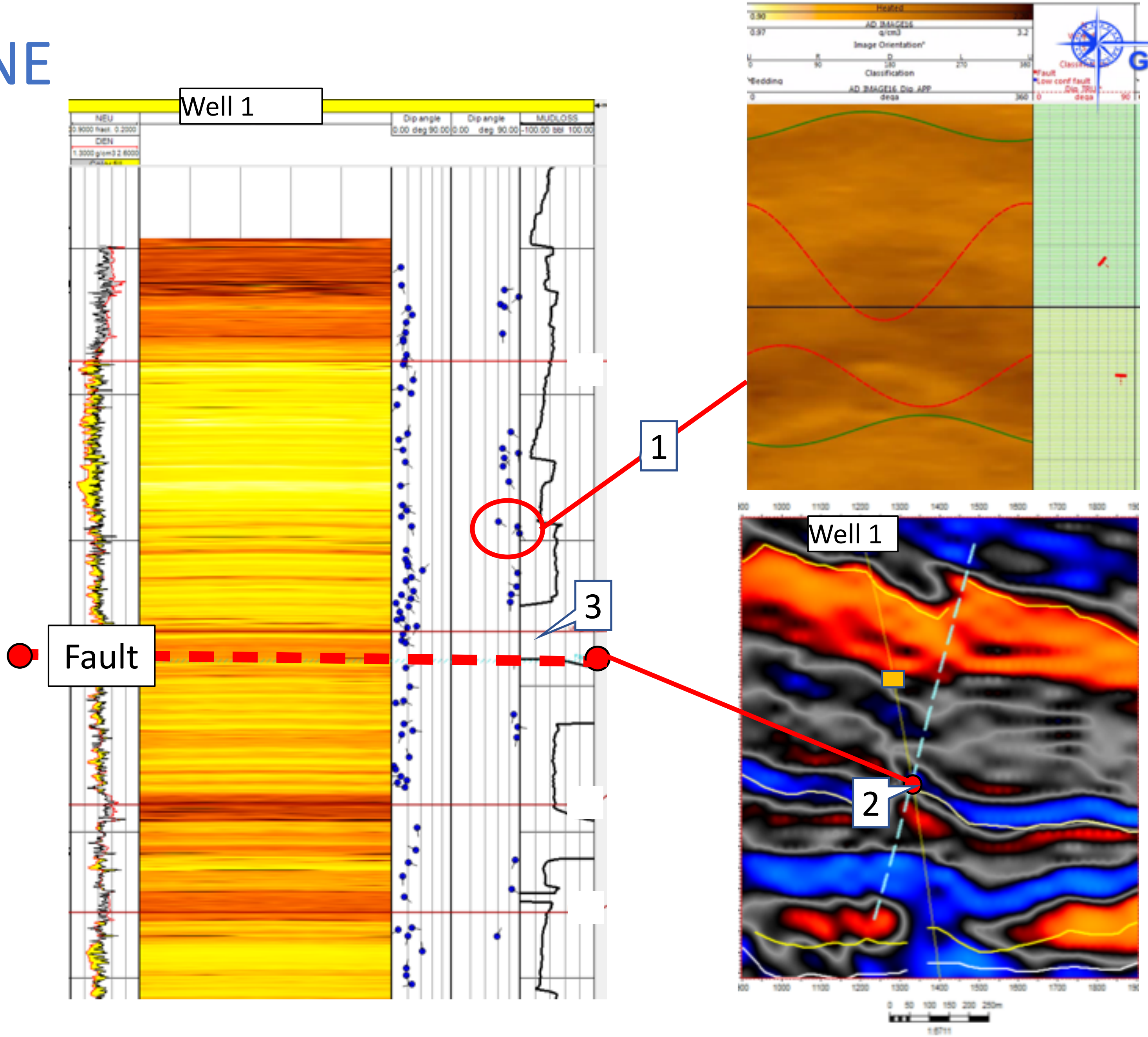
- Whose main development unit are variably fractured Cretaceous chalks



NORTH SEA MUDSTONE
WELL 1

- Highest confidence fractures from ALD image [1] related to fault with clear seismic offset (c. 20 m throw), [2].

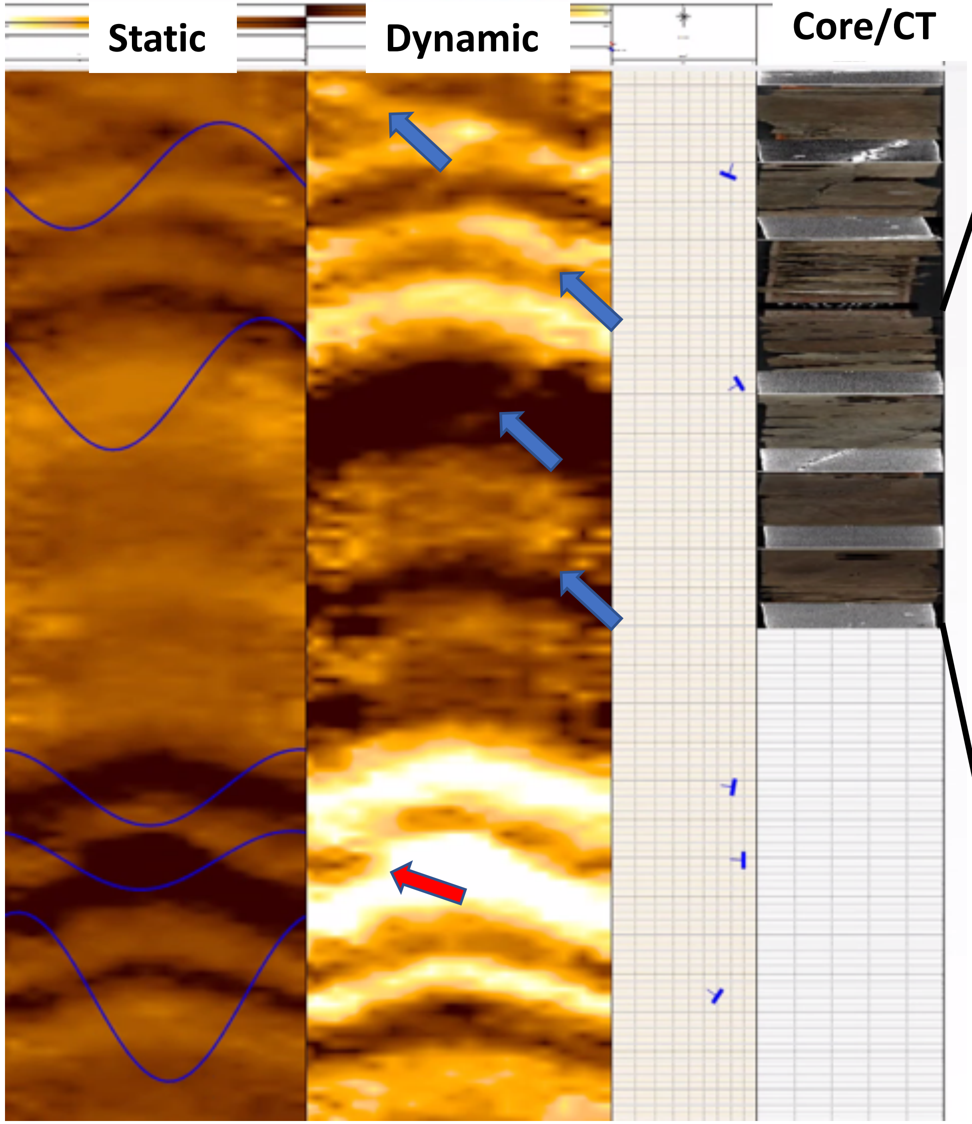
- Mudlosses significantly increase [3]



AkerBP

NORTH SEA MUDSTONE

WELL 2 INTEGRATION



CORE NOT SCRIBED, CHALLENGING TO ORIENTATE WITH THE IMAGES

NORTH SEA MUDSTONE

WELL 2, INTEGRATION

19 m Fault Core Zone

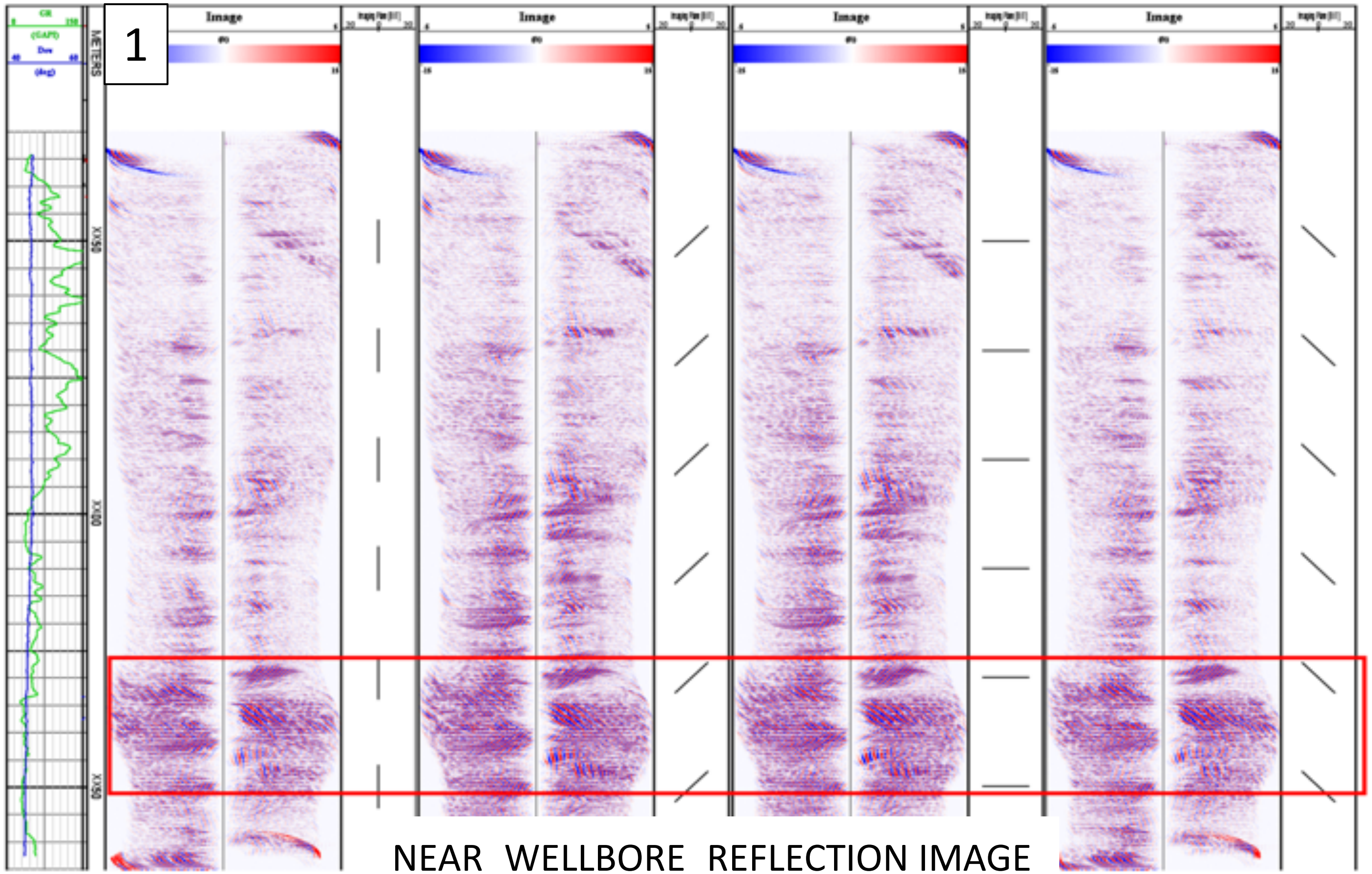
8 m Damage Zone

Slickenlined Shear Fractures in intact core

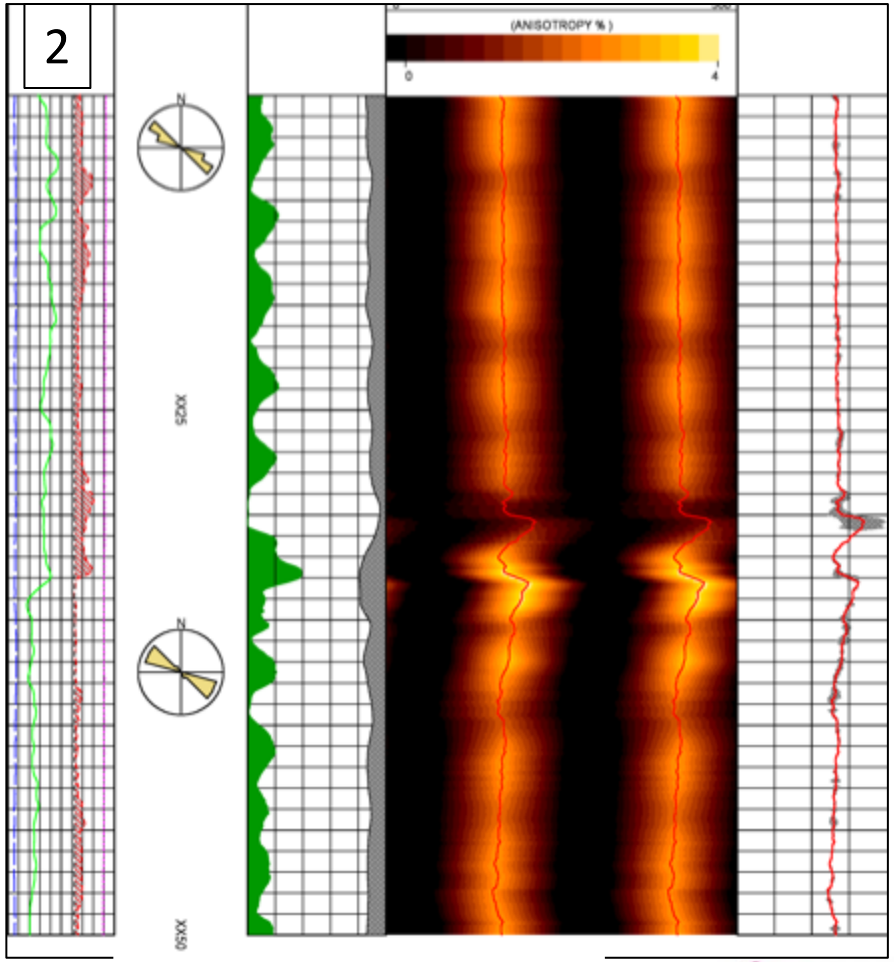
Extends below cored section (image log)

NORTH SEA MUDSTONE
WELL 2, INTEGRATION

- Strong reflection observed in all planar orientations [1]
- Fast wave direction 120 degrees [2] consistent with Shmax from wellbore breakouts



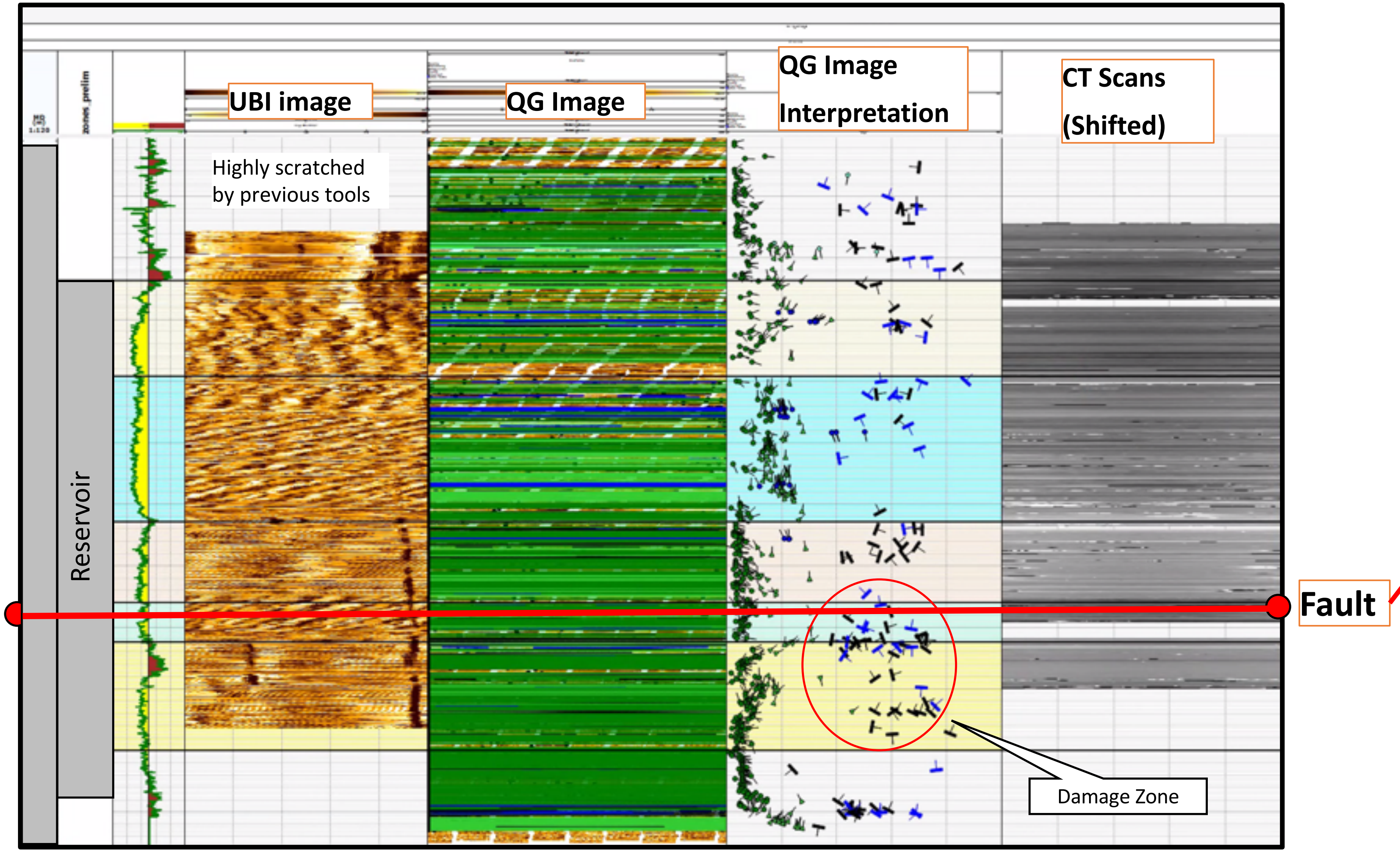
NEAR WELLBORE REFLECTION IMAGE

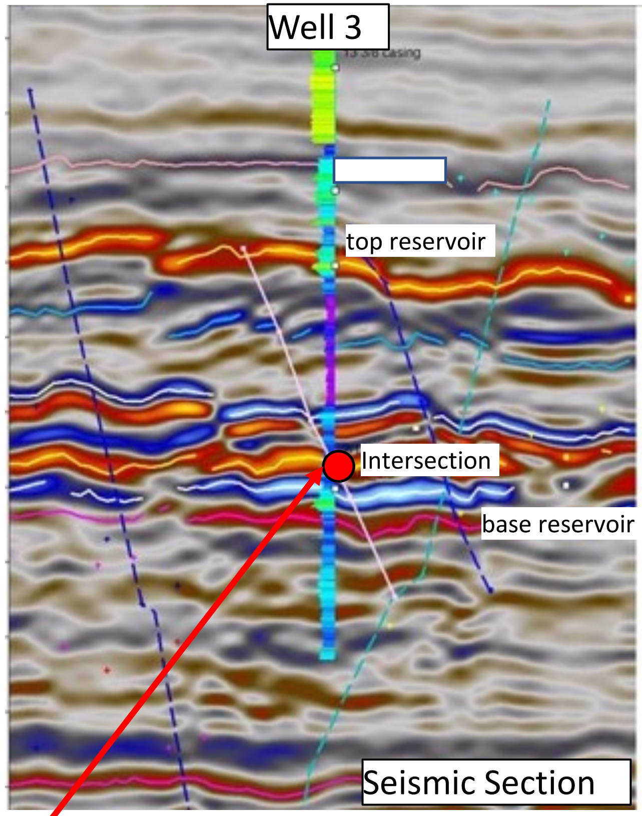


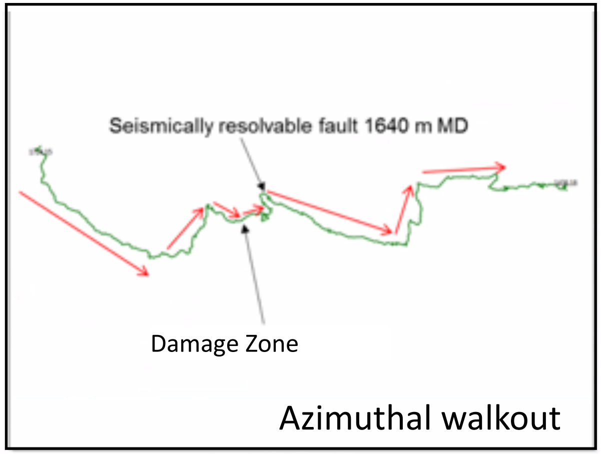
AZIMUTHAL ANISOTROPY

NORTH SEA MUDSTONE

WELL 3, INTEGRATION





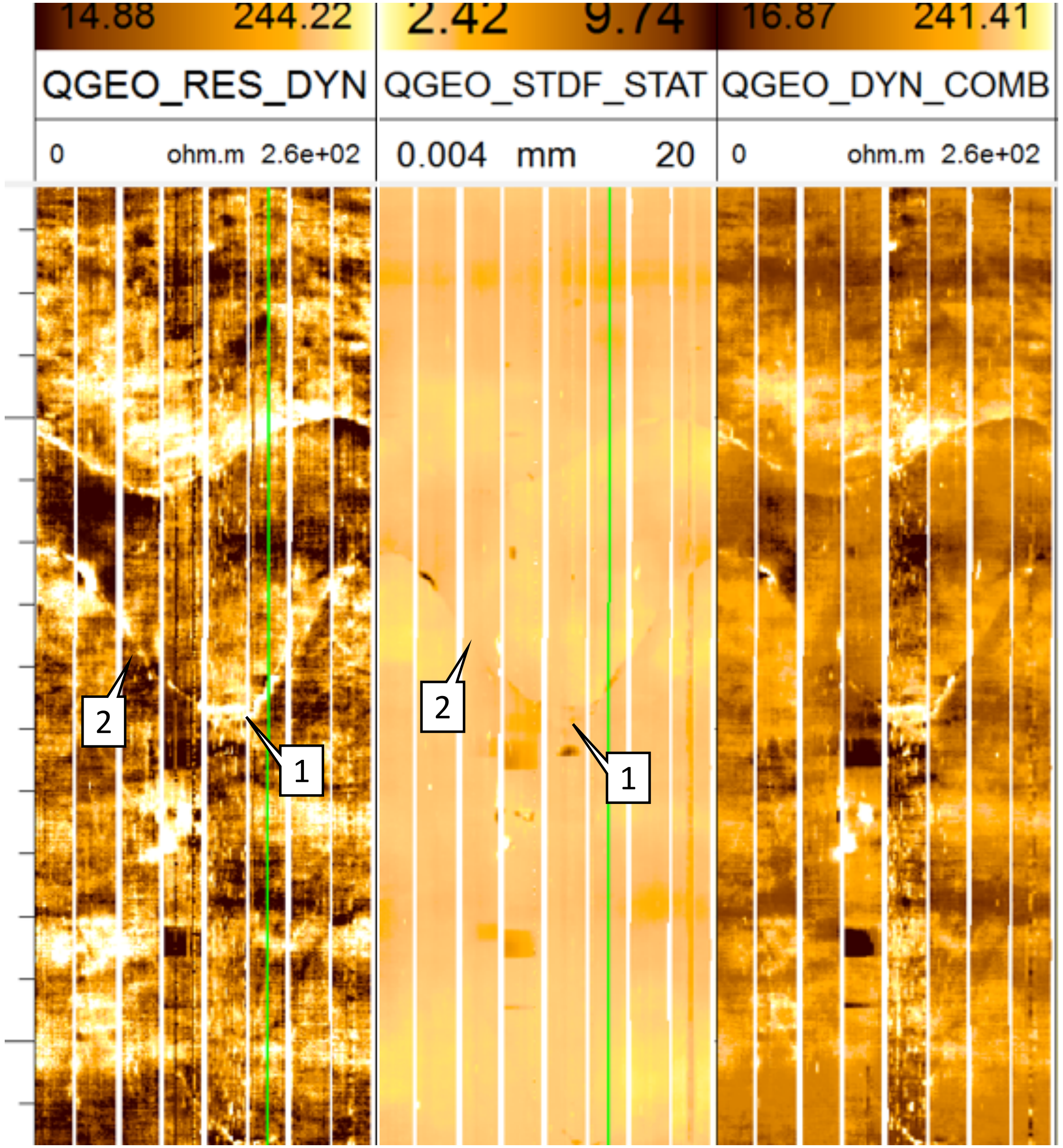


NORTH SEA MUDSTONE

WELL 3, INTEGRATION

- If standoff from pad to formation is high and fracture is resistive, then likely open fracture (mud filled) [1]
- Initial results suggest this fracture could be partially filled with minerals as the standoff is low in places [2]
- Minor open fault (cf. to partially filled open fracture) as slickenlines in core [3]

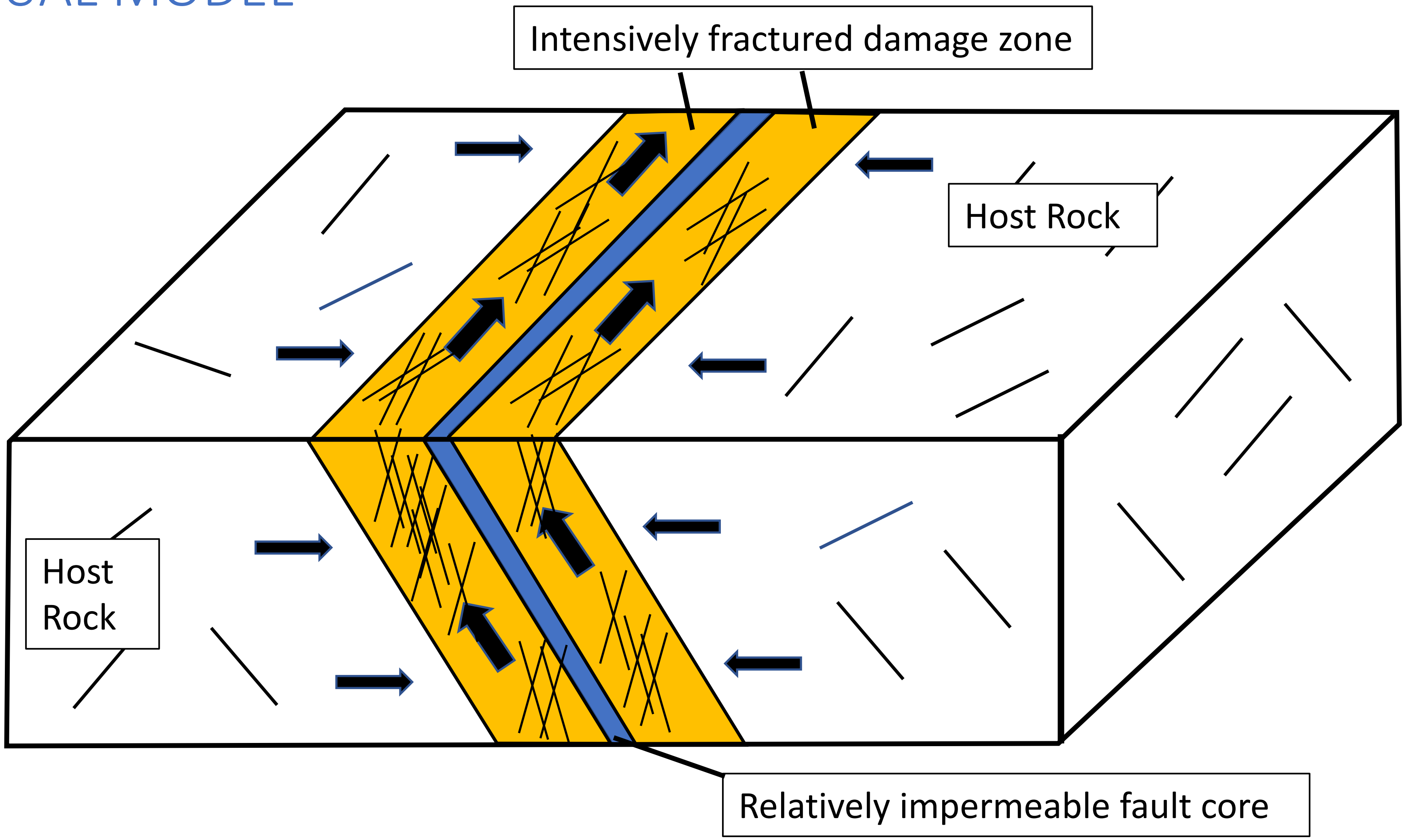
Images used to orientate the core



Inverted Dynamic Image | Standoff Image | Dynamic Image

NORTH SEA MUDSTONE

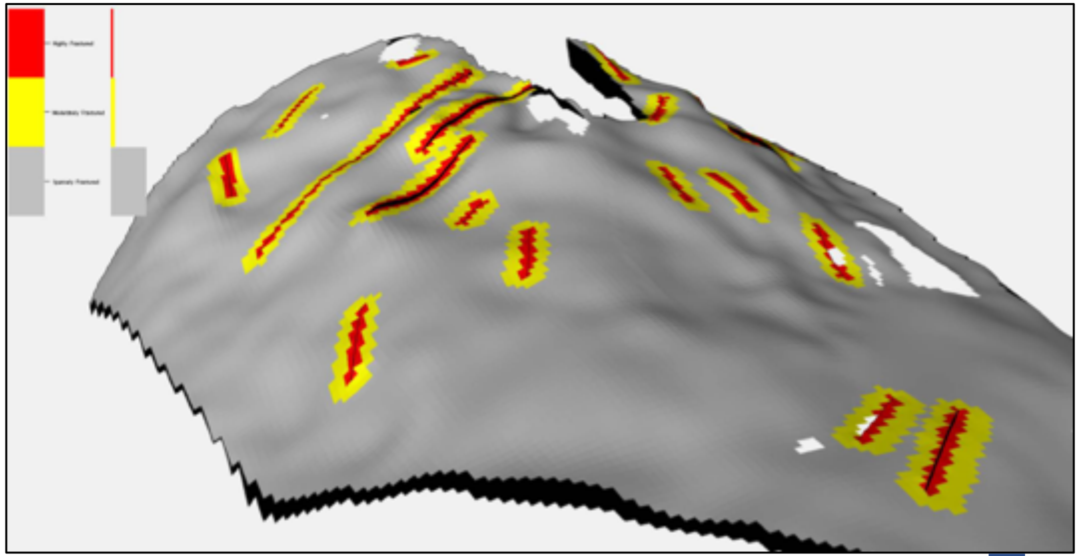
CONCEPTUAL MODEL

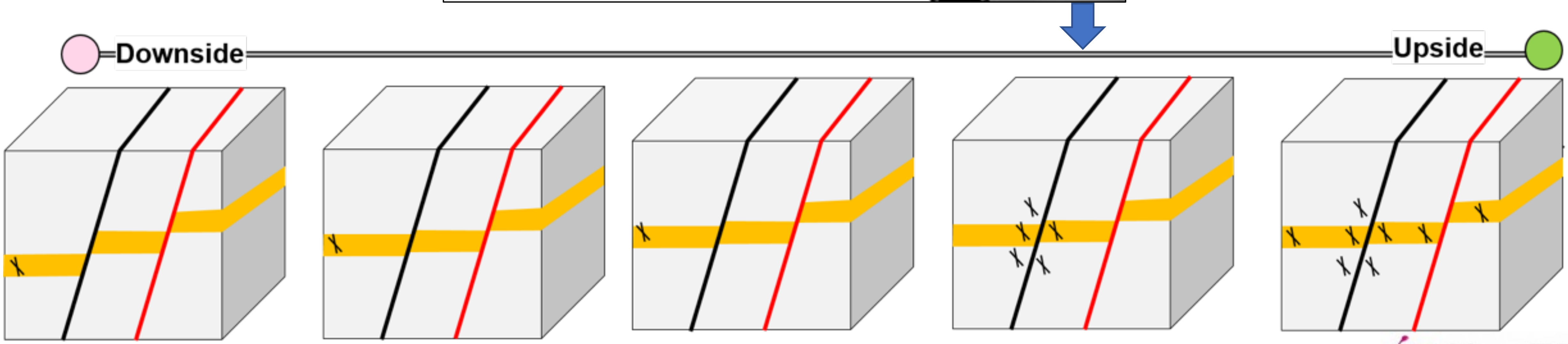


Modified from Johri et al (2014).

NORTH SEA MUDSTONE

GEOCELLULAR MODEL/DEVELOPMENT





CONCLUSIONS

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- Knowing whereabouts of natural rock fractures in a reservoir very valuable for development planning

- Successful line of evidence and integrated approach – rarely a silver bullet !

- Spending time on conceptual models has considerable value – this will save lot of time during the geocellular modelling process

- The often large uncertainty in fracture contribution needs handling through series of geologically realistic models