Integrated Fault Interpretation in Reservoir Models

Force Seminar “Challenges related to fault modelling workflows

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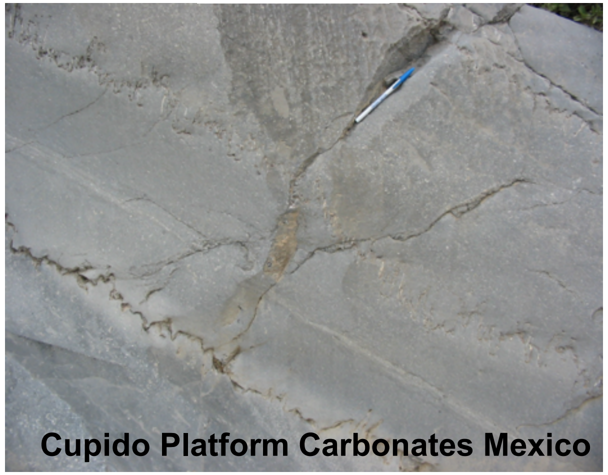
TALK COMPONENTS

- Talk Objectives:
  - Key factors that need to be considered when building and QCing a fault model,
  - Their material impact upon all aspects of petroleum value chain
- Types & Importance of Fractures
- Big vs. Small Faults
- Well cuts
- Structural Geology
- QC of Fault Framework

TYPES OF FRACTURES

Stylolites



Cupido Platform Carbonates Mexico

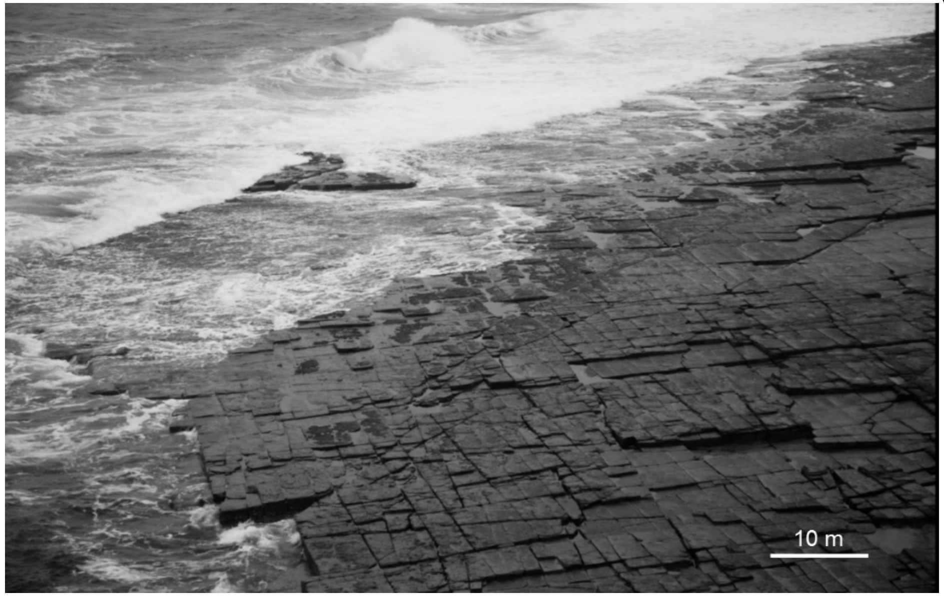
Deformation Bands

Hopeman Sandstone, UK

Faults

Devonian Sandstones, Arbroath, UK

Joints

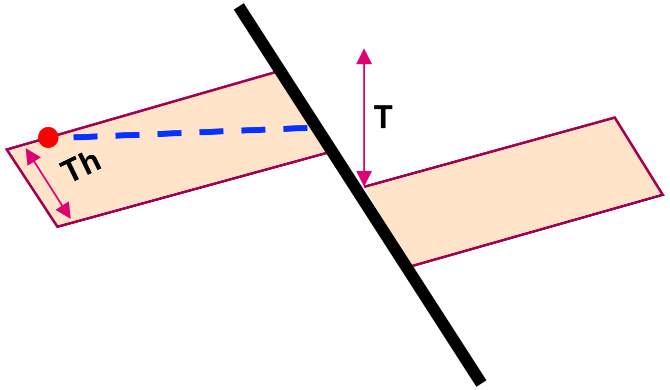


Devonian Sandstones, Caithness, UK

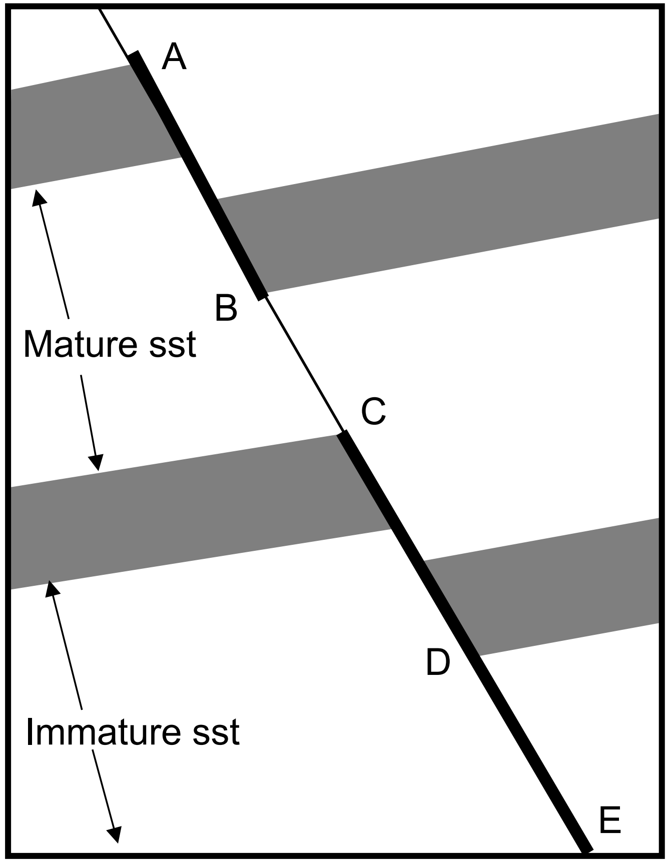
Faults are the focus of this seminar but other fractures need to be considered in the Geomodel

IMPORTANCE OF FAULTS

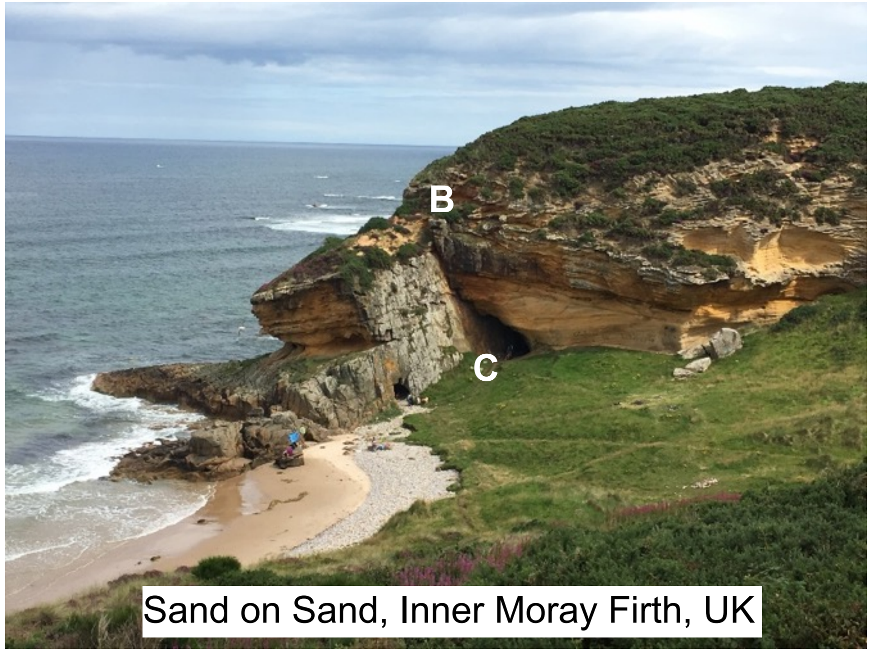
(a) Juxtaposition Seal



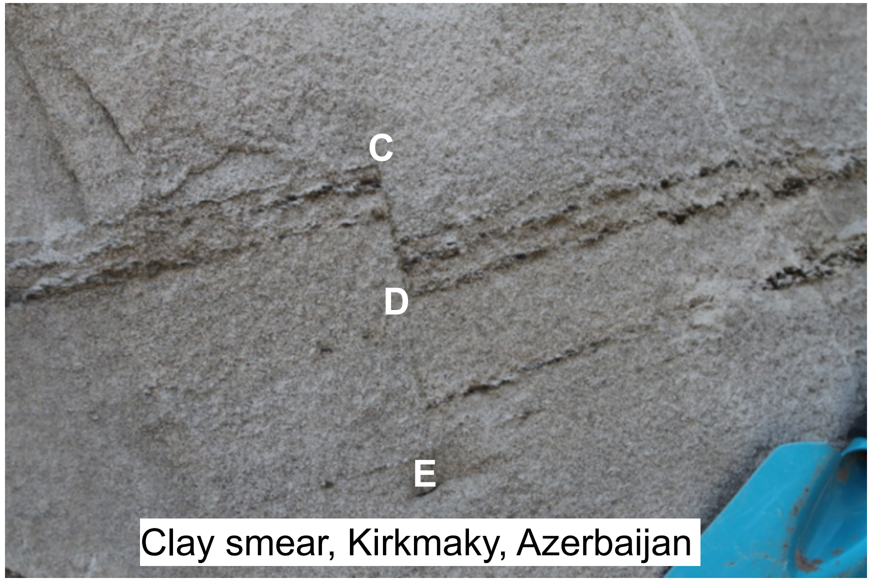
(b) Process seal



After Gibson (1998)



Sand on Sand, Inner Moray Firth, UK

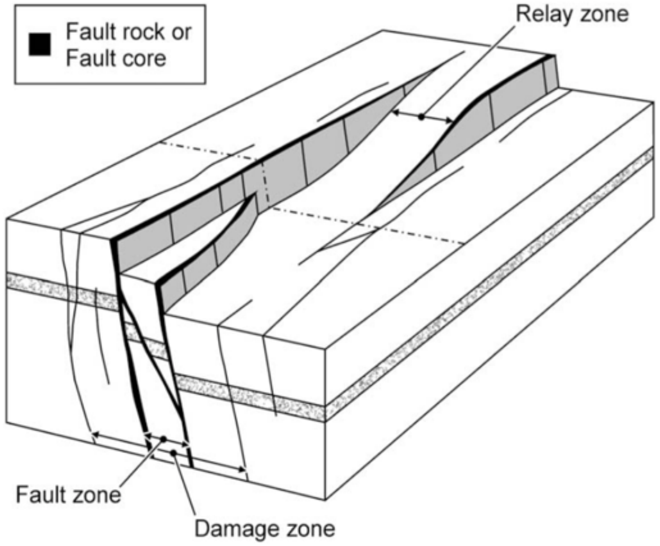


Clay smear, Kirkmaky, Azerbaijan

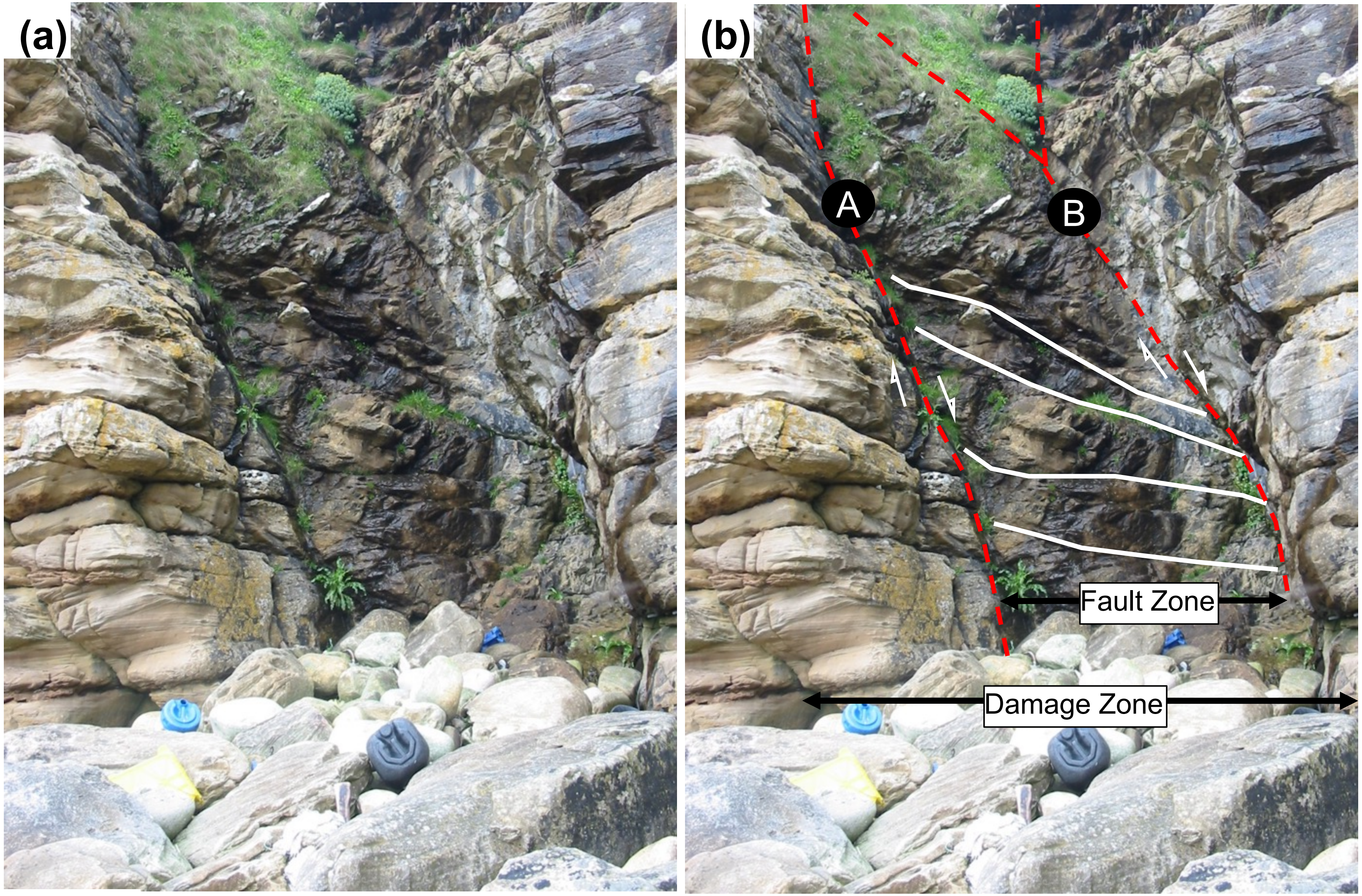
- Sealing of hydrocarbons over geological time
- Barriers during production

MULTIPLE SLIP SURFACES

- More than 1 slip surface, A + B

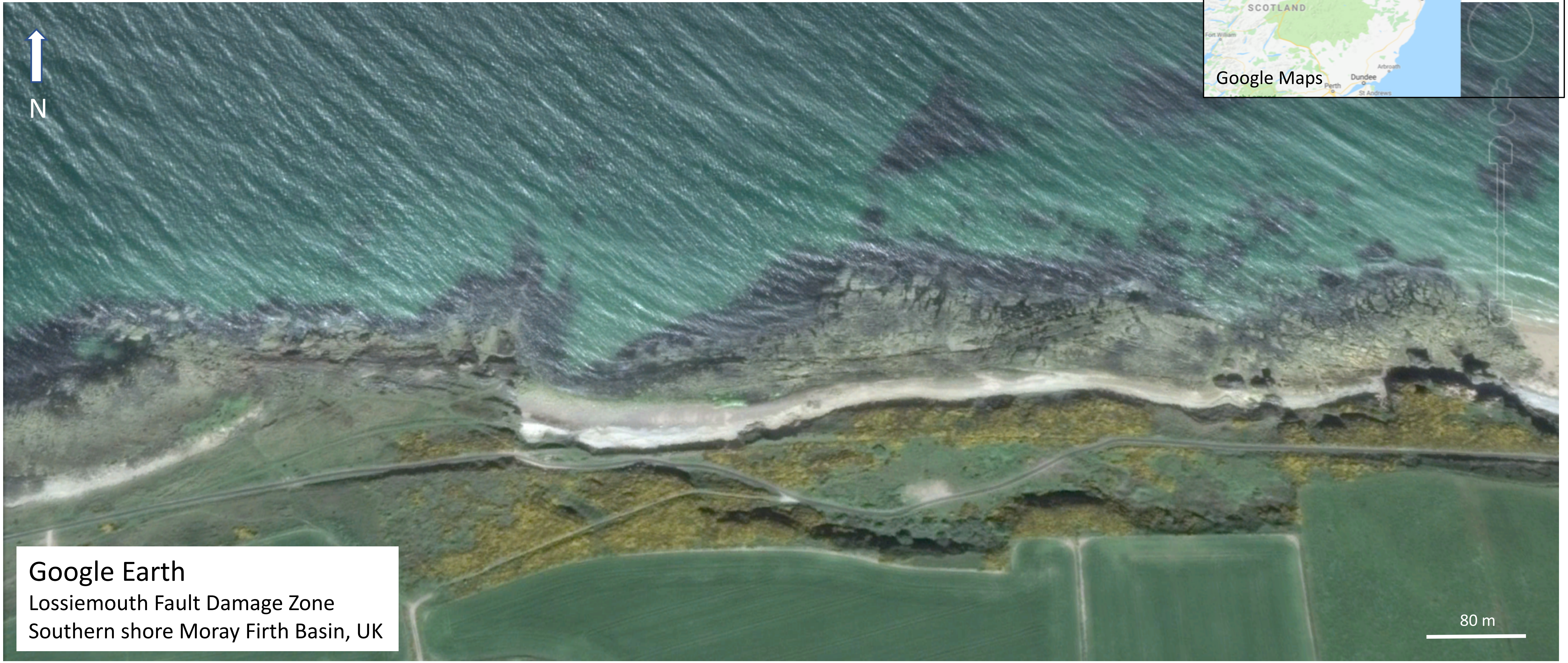


Childs et al (2009)

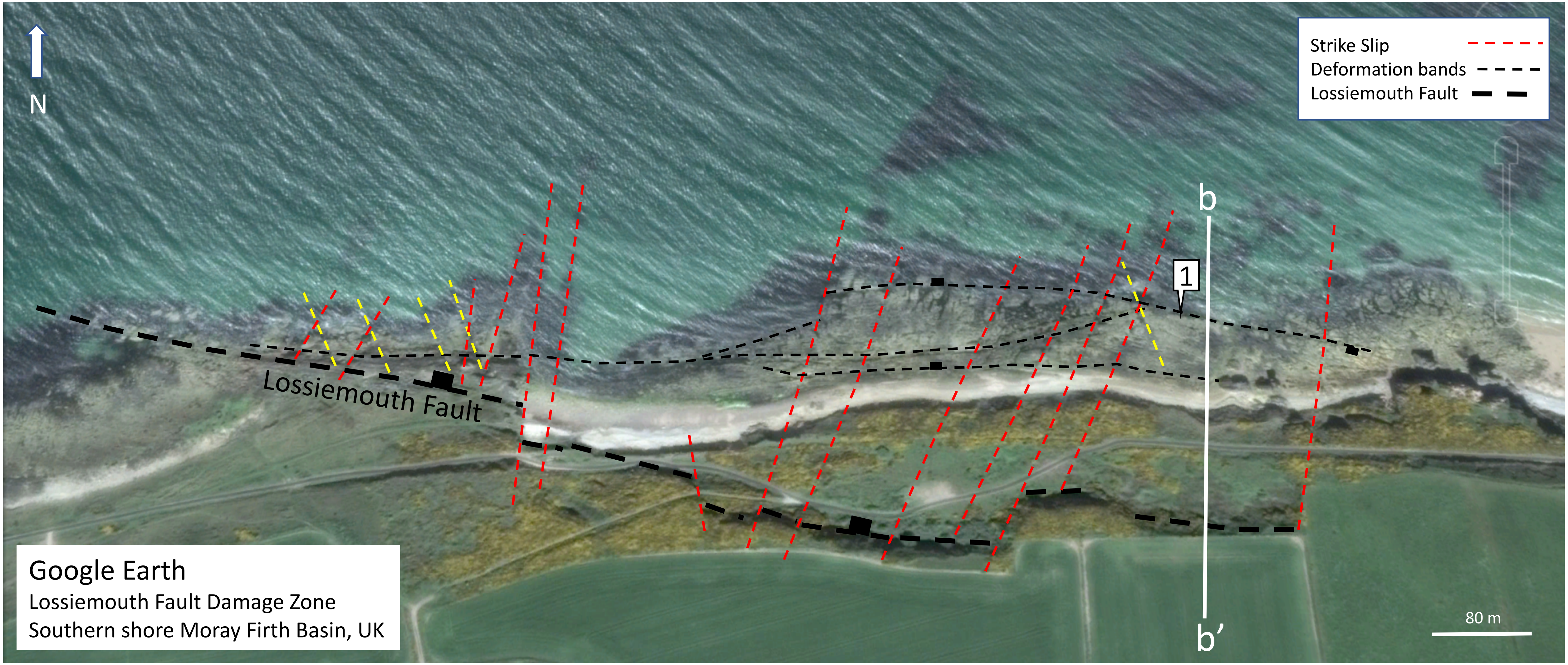


Fault in Devonian Sandstone, (Dwarick Head) Caithness, UK

SAND ON SAND – INNER MORAY FIRTH



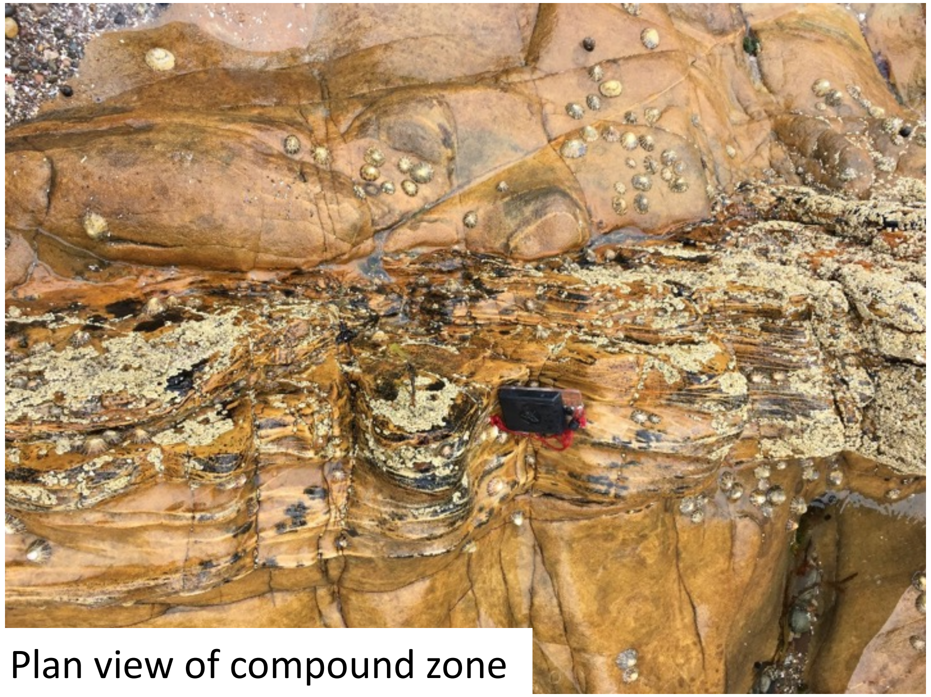
SAND ON SAND – INNER MORAY FIRTH



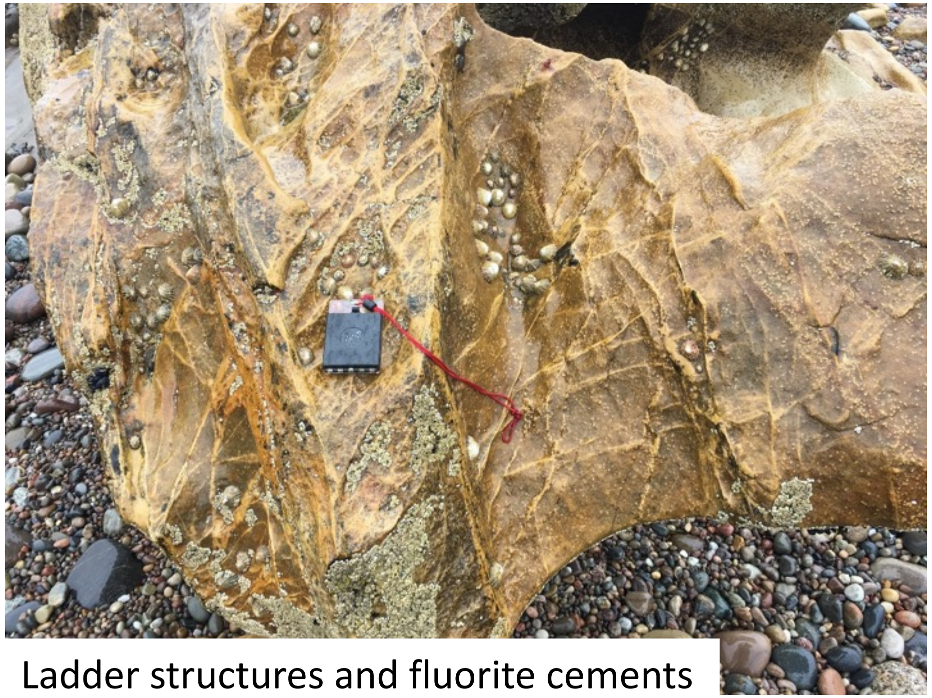
SAND ON SAND – INNER MORAY FIRTH

- Damage zone is a large splay fault with compound zones and ladder structures

Compound zone of deformation bands at location 1



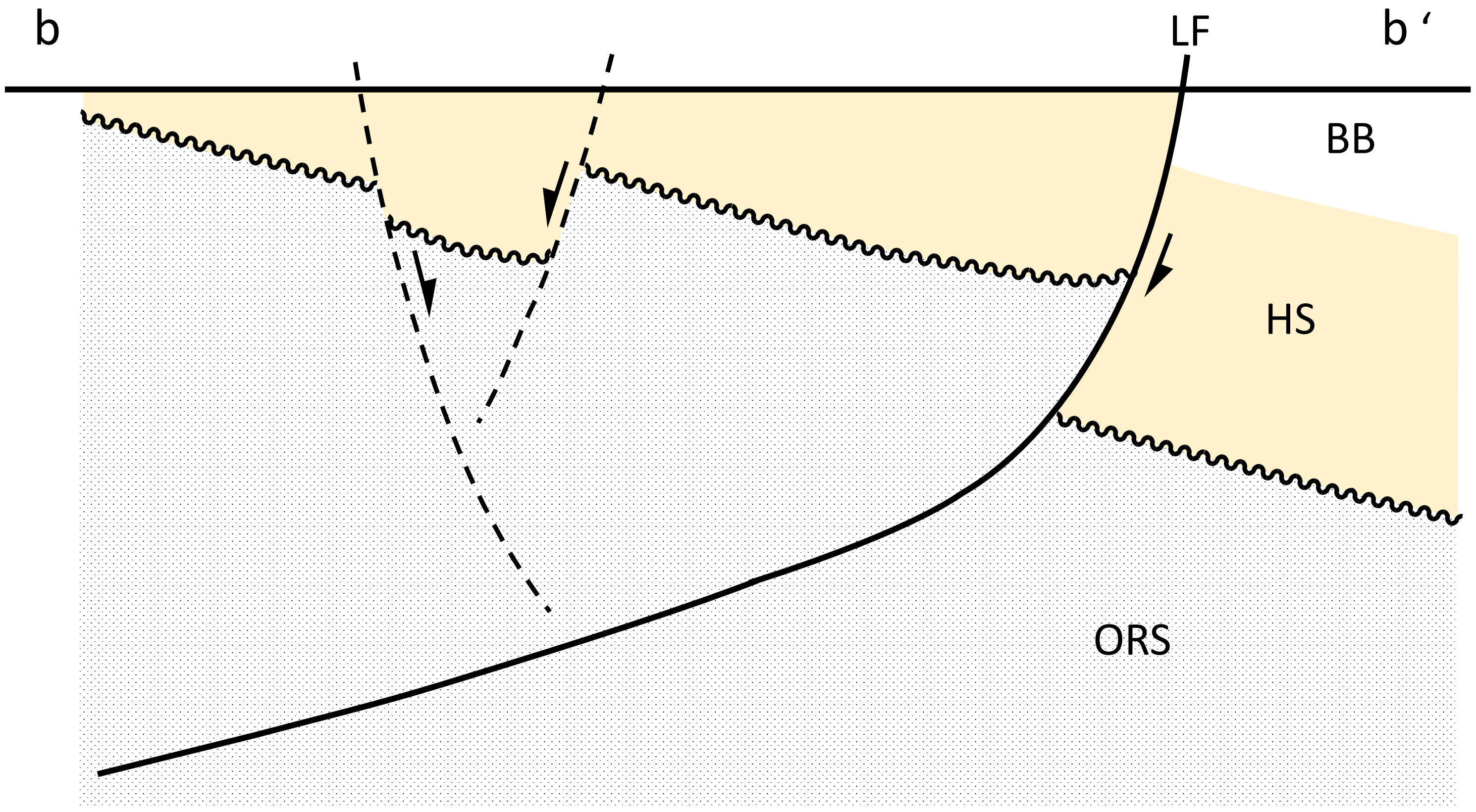
Plan view of compound zone



Ladder structures and fluorite cements

SAND ON SAND – INNER MORAY FIRTH

Cross-Section b - b’



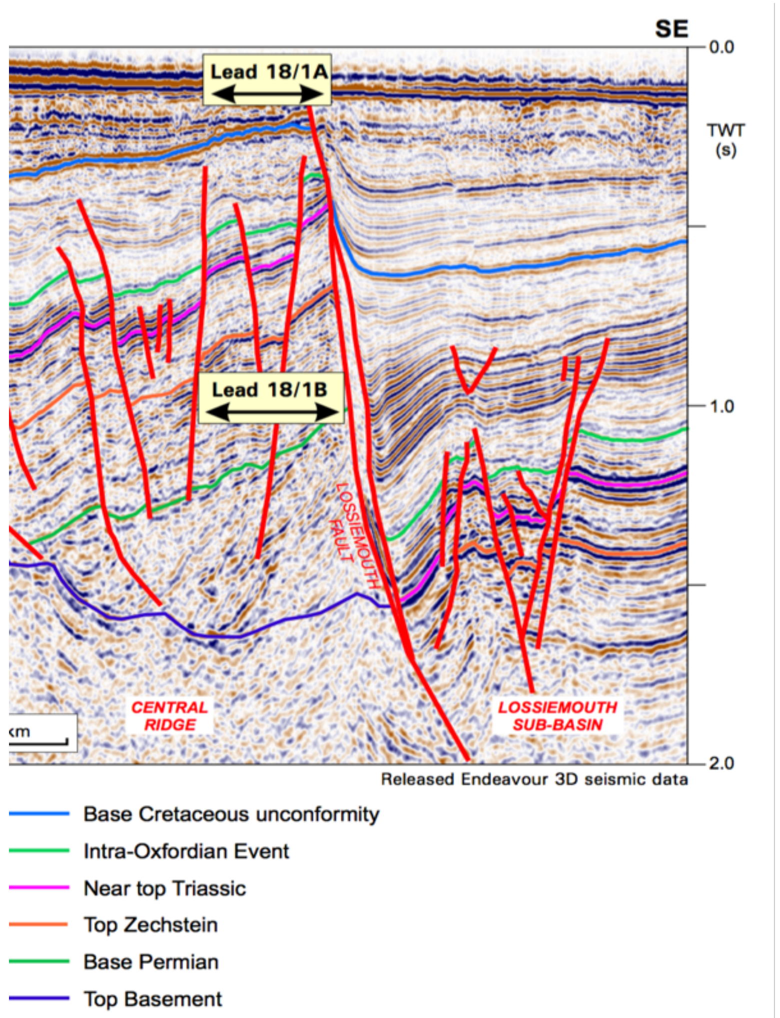
BB : Burghead Beds

HS : Hopeman Sandstone

ORS : Old Red sandstone

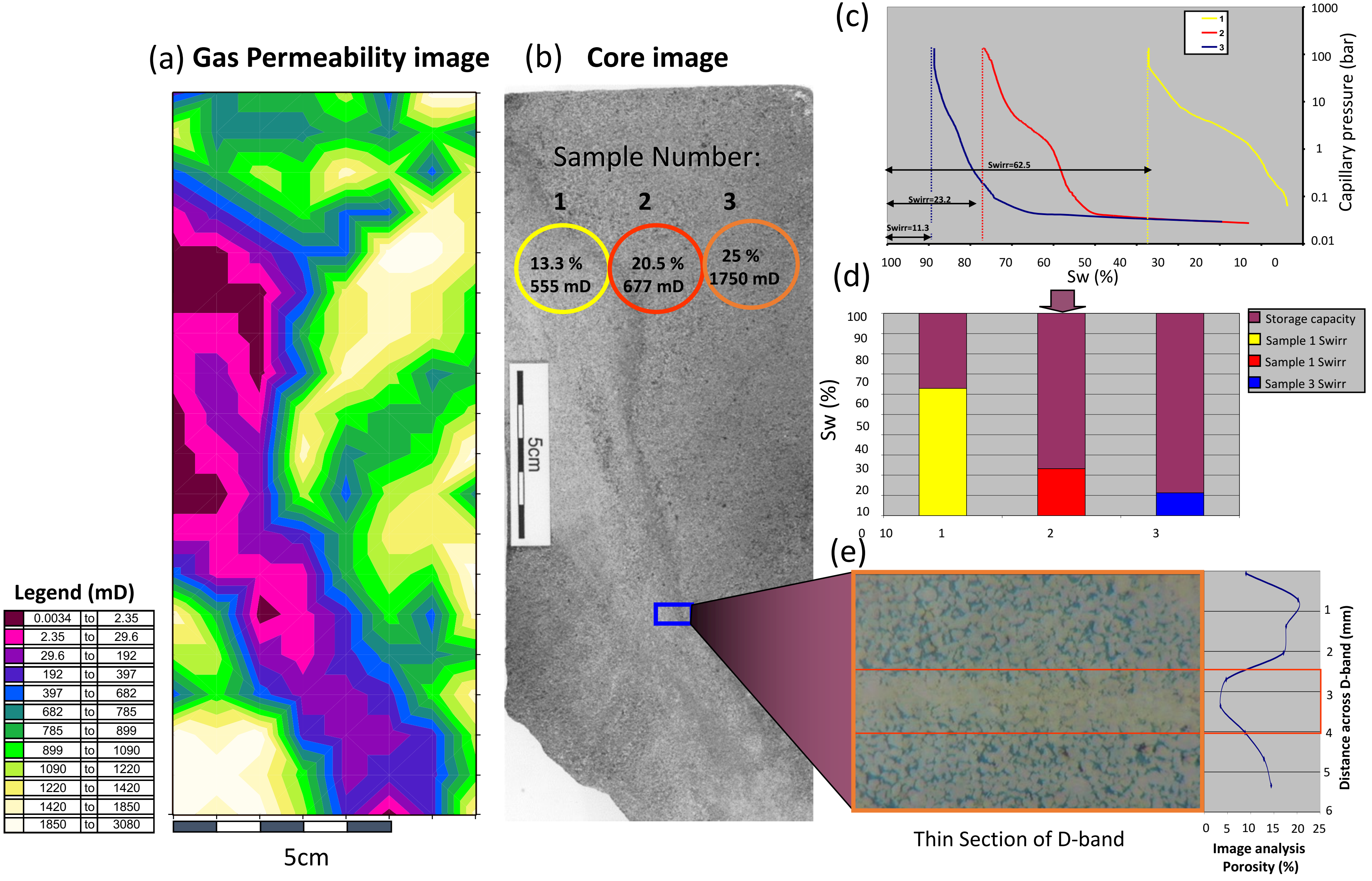
LF : Lossiemouth Fault

Moray Firth Prospect



SAND ON SAND – INNER MORAY FIRTH

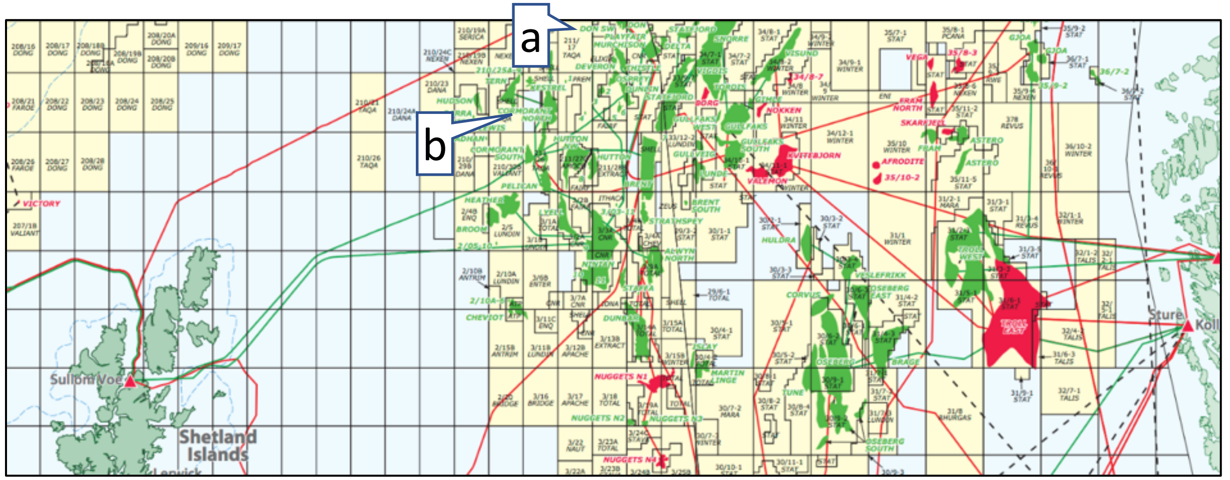
- Slabbed sample with deformation bands from damage zone
- Significant reductions in permeability and porosity (a,b)
- Increase in Sw (c), reduction in storage capacity (d)
- Driven by burial at time of faulting
- Although shallow burial faults can seal also



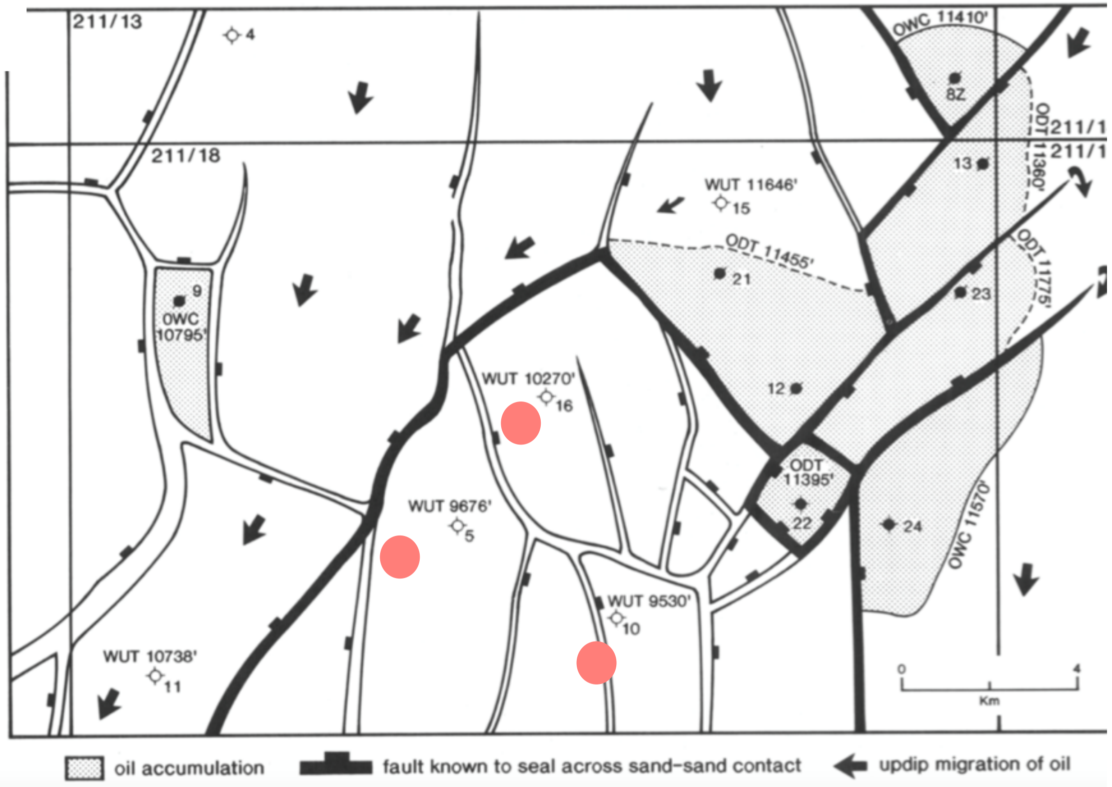
From Ogilvie et al (2001)

SAND ON SAND - BRENT PROVINCE

- Excellent examples in N Viking Graben in Brent reservoirs
- **Don Field** [a]: Oil migrated into area from North, sealing faults (not large enough to offset entire Brent Gp) have deflected migrating oil, explains dry holes
- Field development issues with small faults (<10 m throw) in **Cormorant Field** [b], (Stiles & Mckee, 1986)

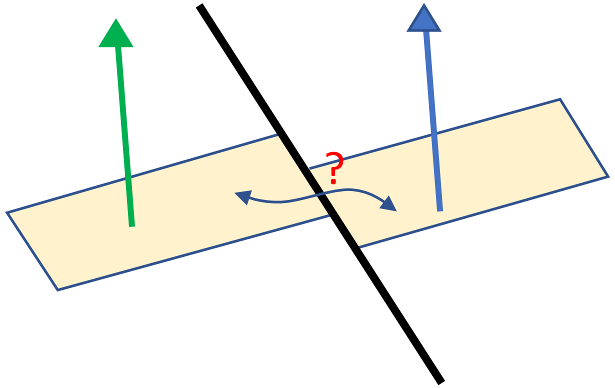


(a)



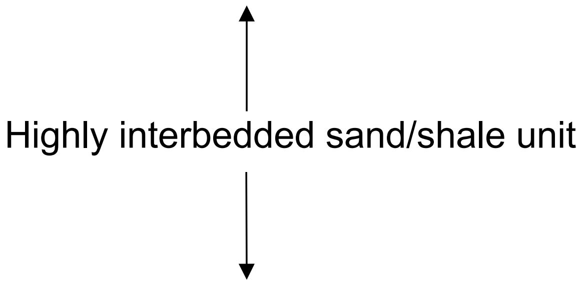
Oil migration map of Don Field, North Sea
(Hardman & Booth, 1991)

(b)



SELECTING FAULTS

- Where throw < thickness, rely upon process
- 1D sensitivity plots very useful if clay-rich
- Small faults in highly interbedded (sand/shale) often seal
- Can be used to support throw criteria for inclusion of faults in grids

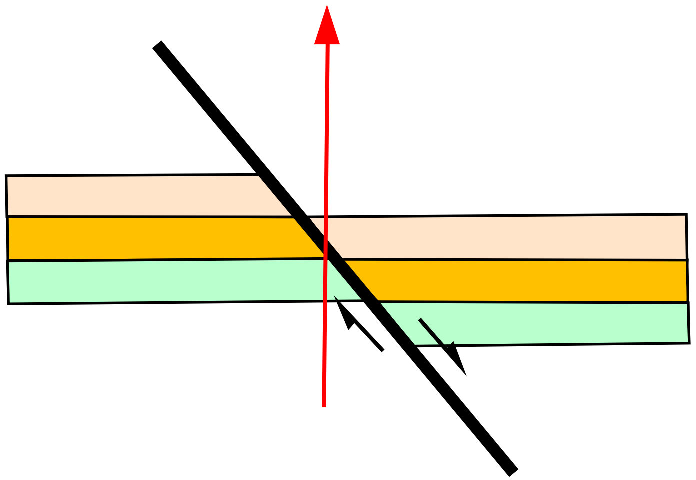


Highest NTG well chosen as worst case

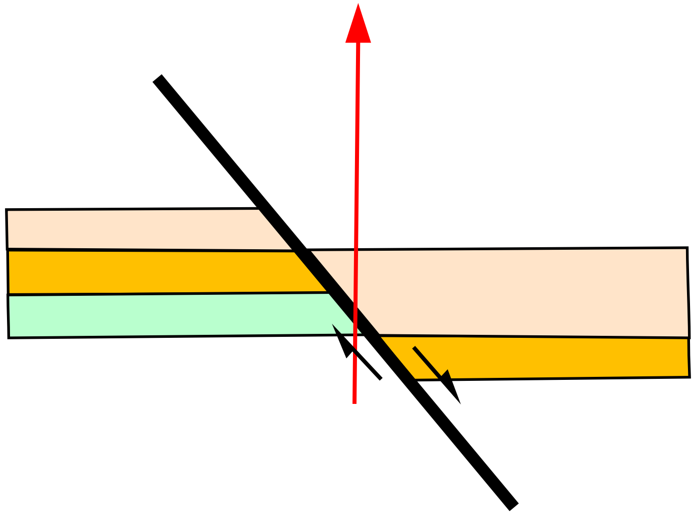
SELECTING FAULTS – WELL DATA

- Wells should be checked for evidence of faults
- Thickness in vertical wells is a good place to start
- Reduce seismic uncertainty and detect sub-seismic faults

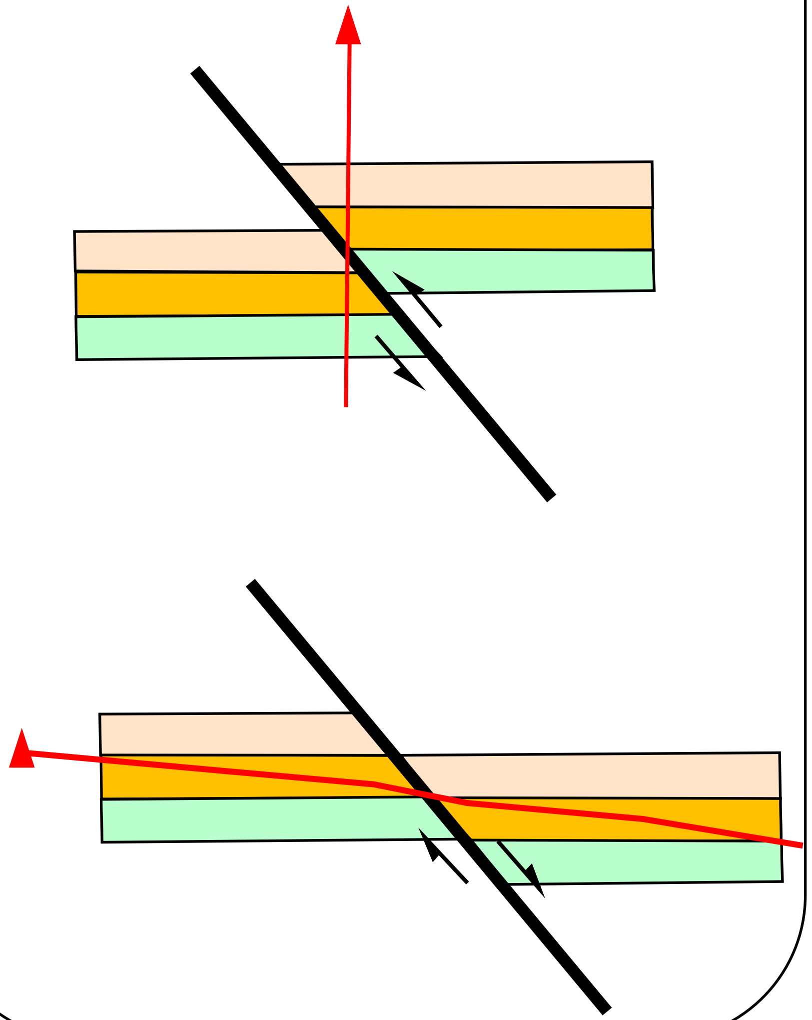
Missing section



Growth



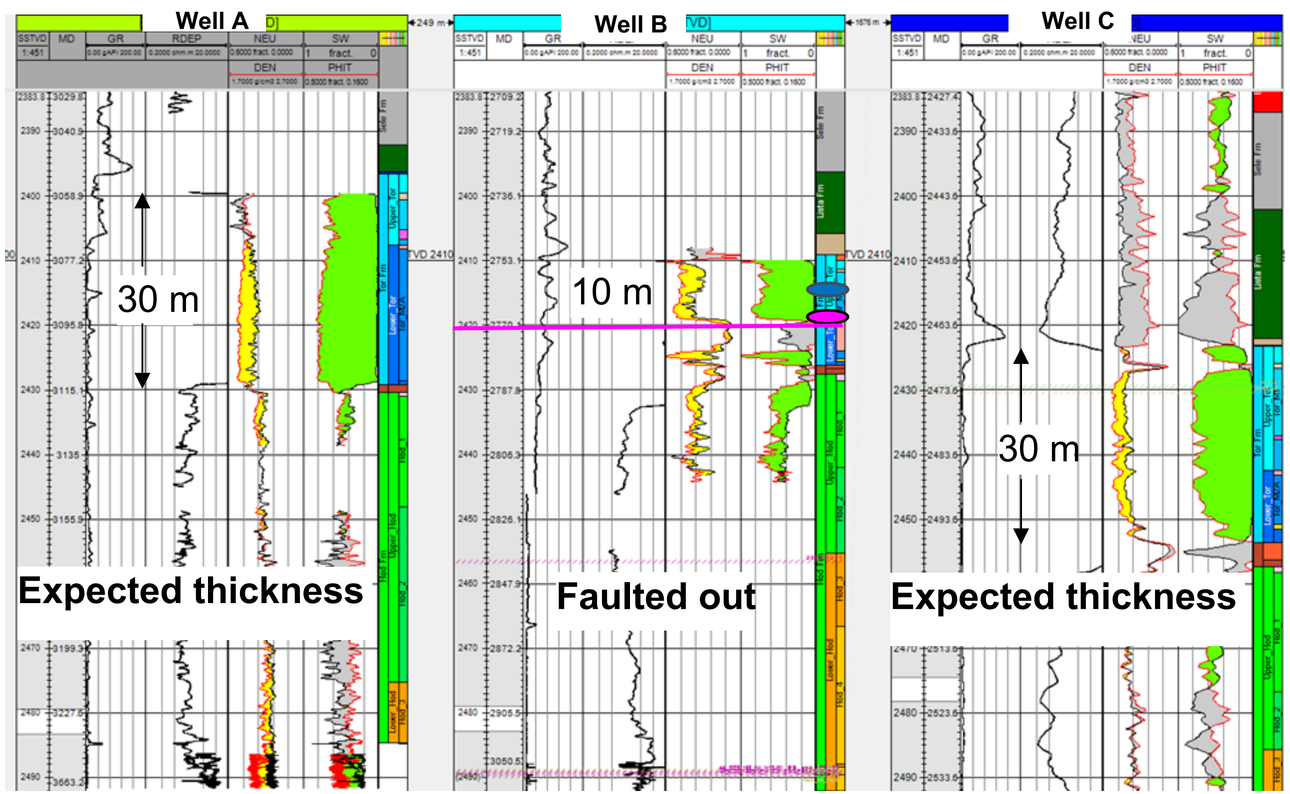
Repeat section



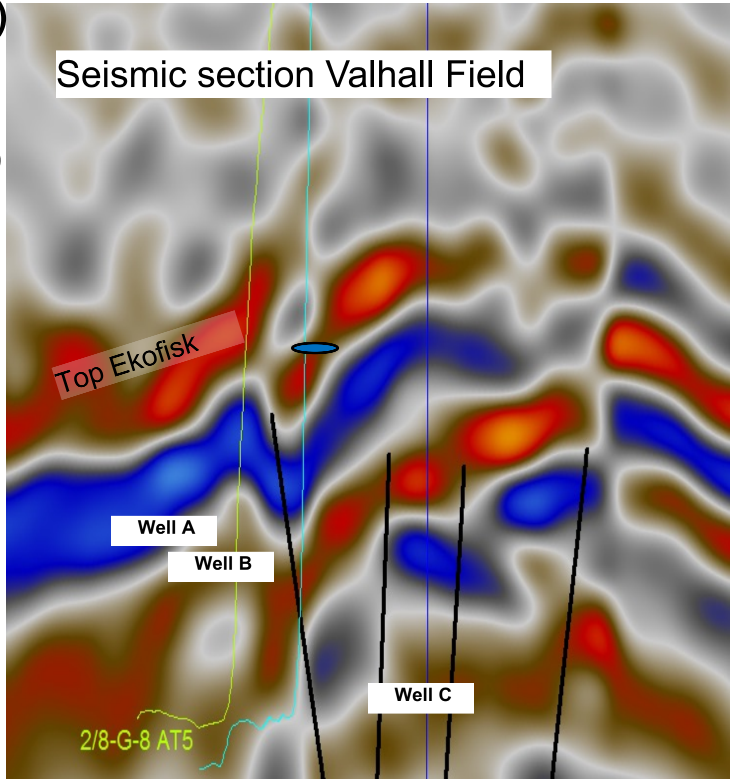
SELECTING FAULTS – WELL DATA

- Thickness variation across 3 wells (a) can be explained by a normal fault interpreted on seismic (b)
- Is bottom of chalk at fault plane (c) or does well enter fault or related fault sooner (d)
- Biostrat indicates that (d) is correct ✓

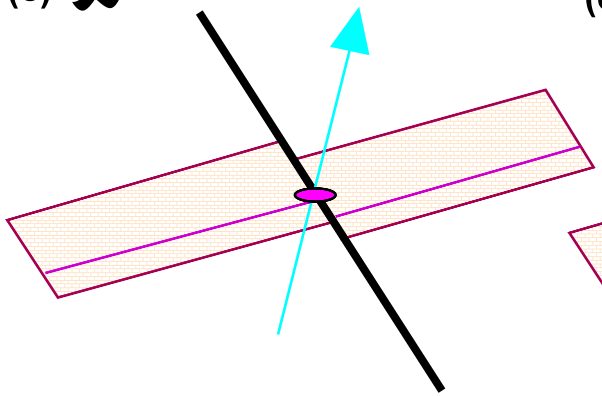
(a)



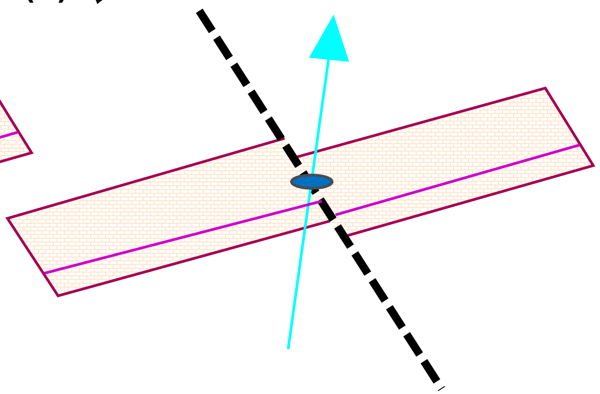
(b)



(c) ✗



(d) ✓



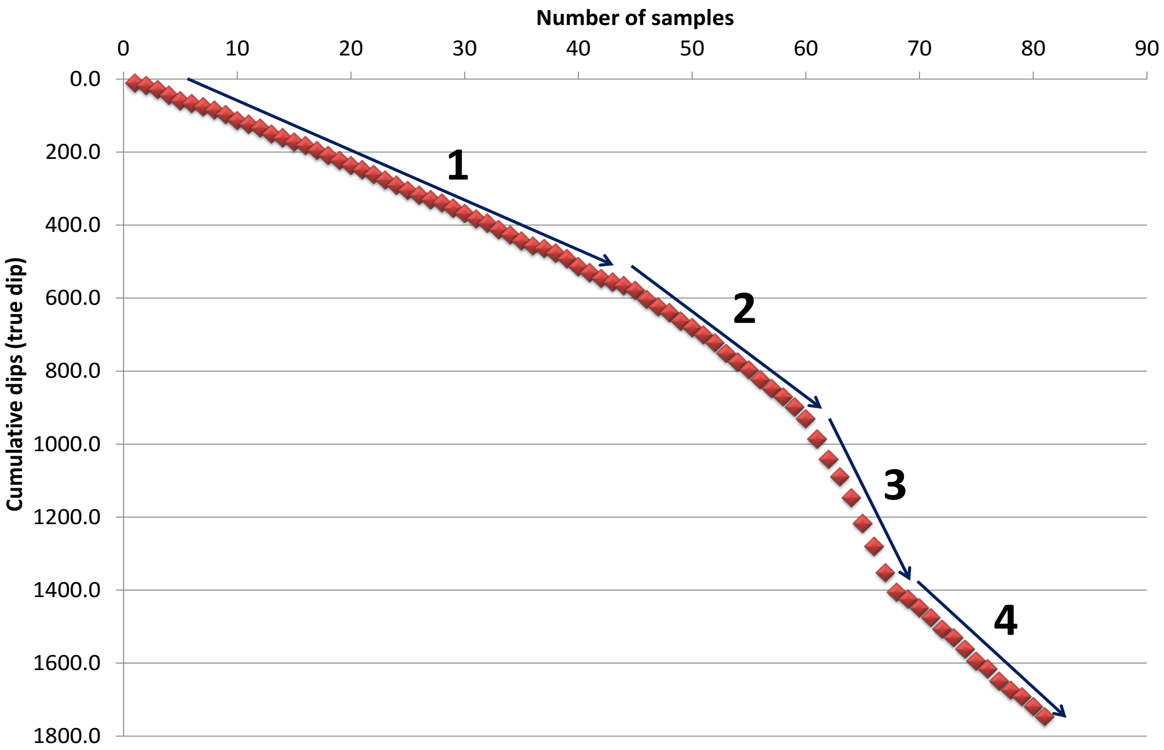
SELECTING FAULTS – WELL DATA

- Faults can also be detected from changes in bedding dip [1] and azimuth [2]
- And directly from image logs (c)

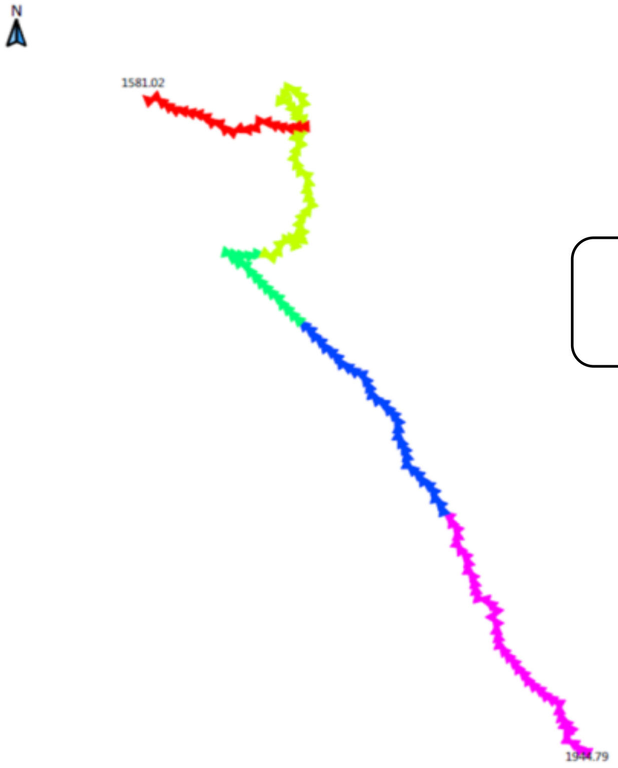
(c) Image log

Fault

(a) Cumulative Bedding Dip Plot



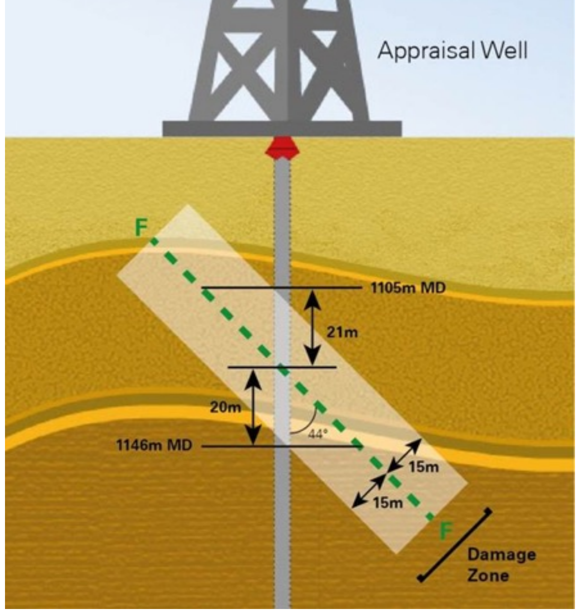
(b) Azimuthal Walk out Plot



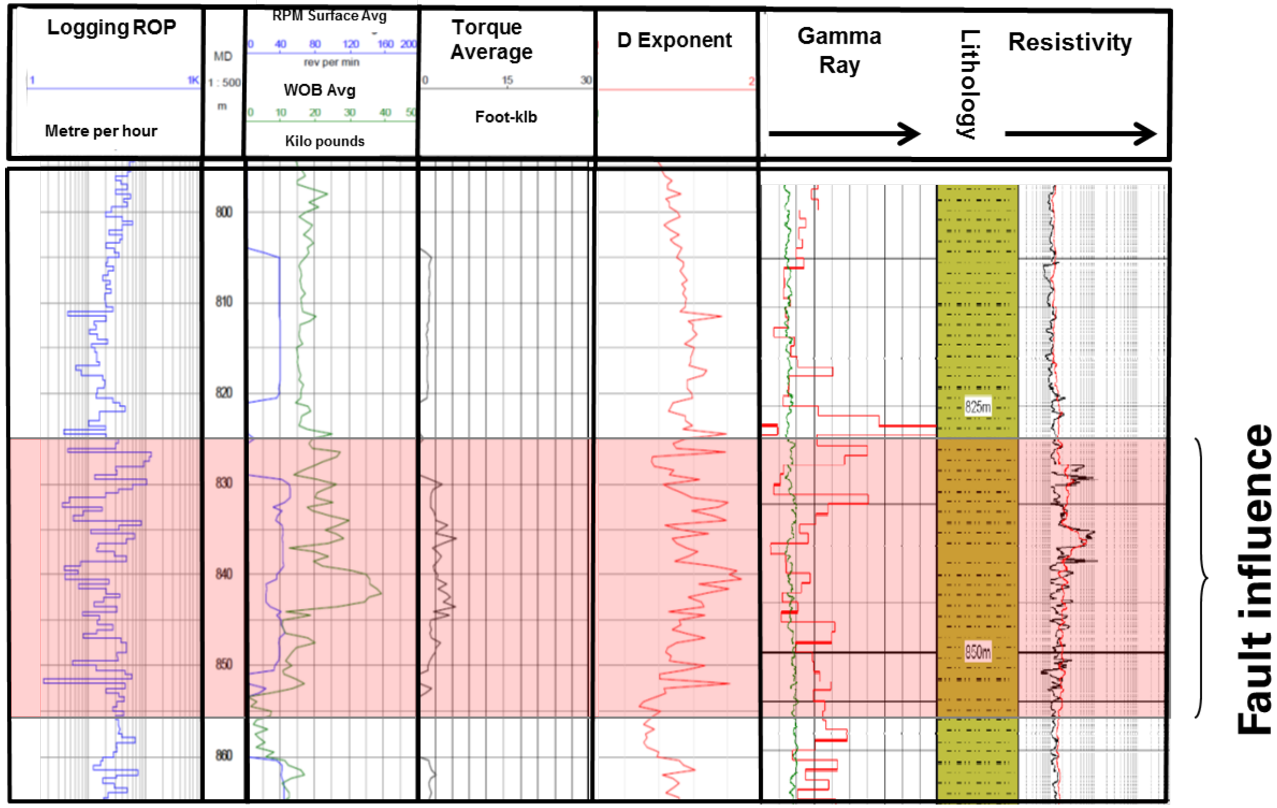
SELECTING FAULTS – WELL DATA

- Zone of disturbance or ”Damage Zone” width calculated (a, b) from appraisal wells
- Data used for planning stand off to fault for future development wells (c)

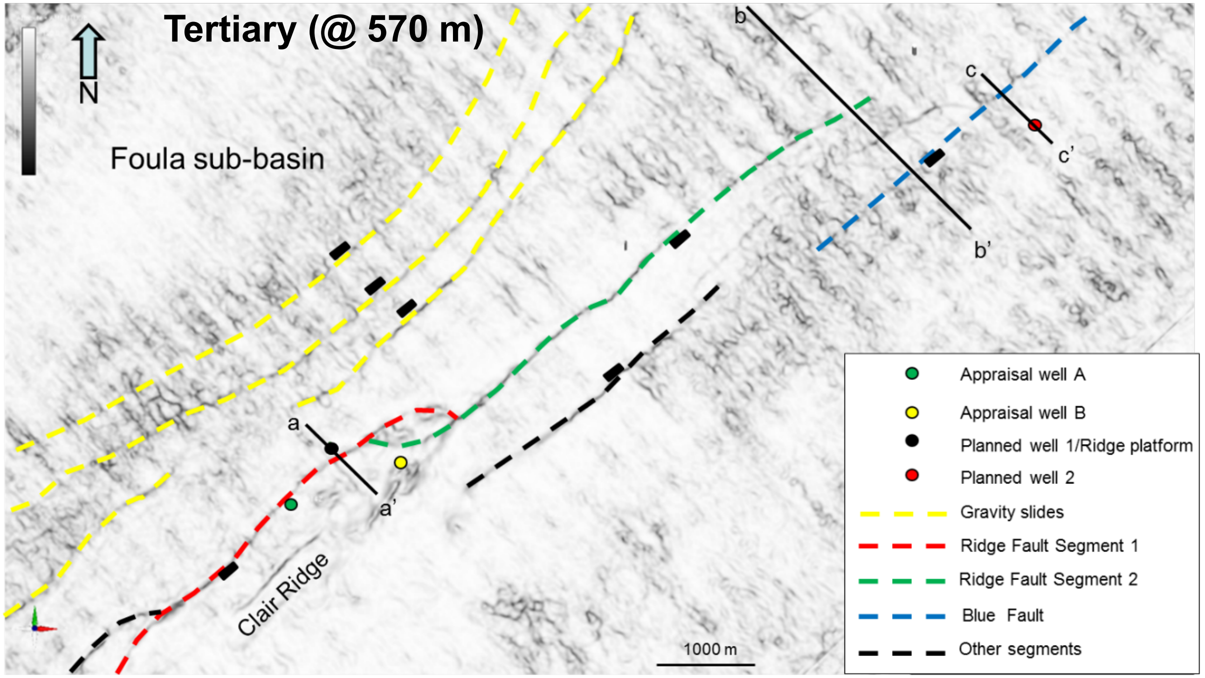
(b)



(a)



(c)



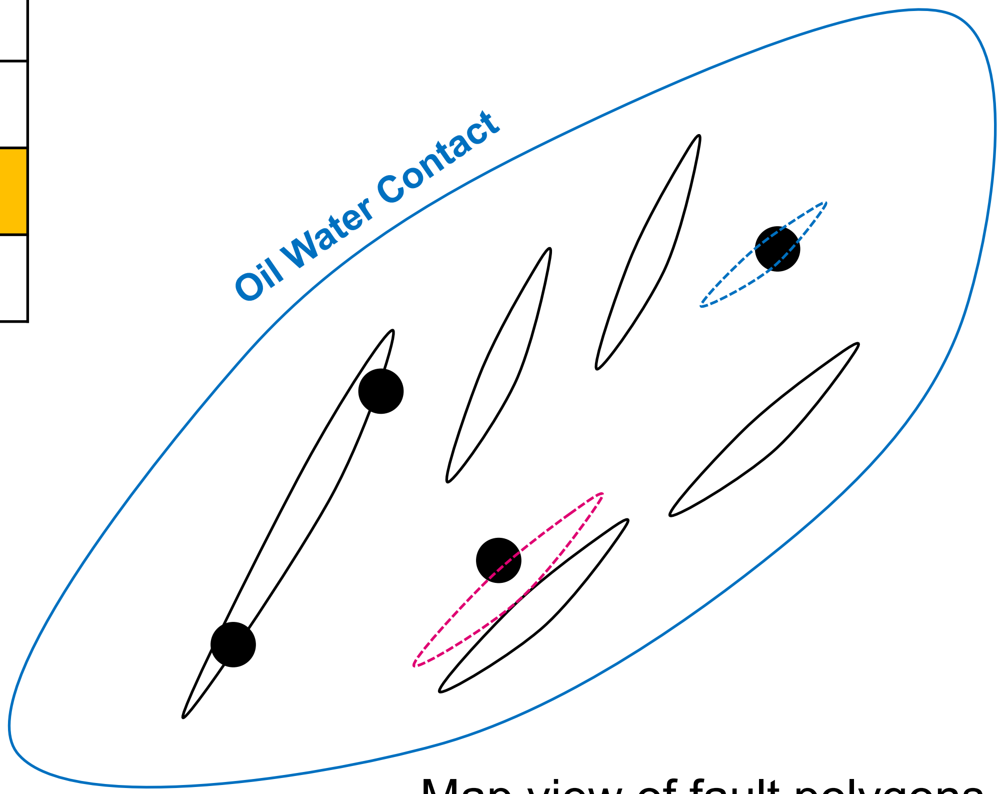
Clair Field data (Ogilvie et al, 2015)

SELECTING FAULTS – WELL DATA

- Line of evidence approach

Confidence Level	1. Seismic	2. Thickness	3. Log responses	4. Bedding dip/azimuth changes	5. Fault description comp log	6. Image logs	7. Rate of penetration	8. Mudloss
High								
Medium								
Low								

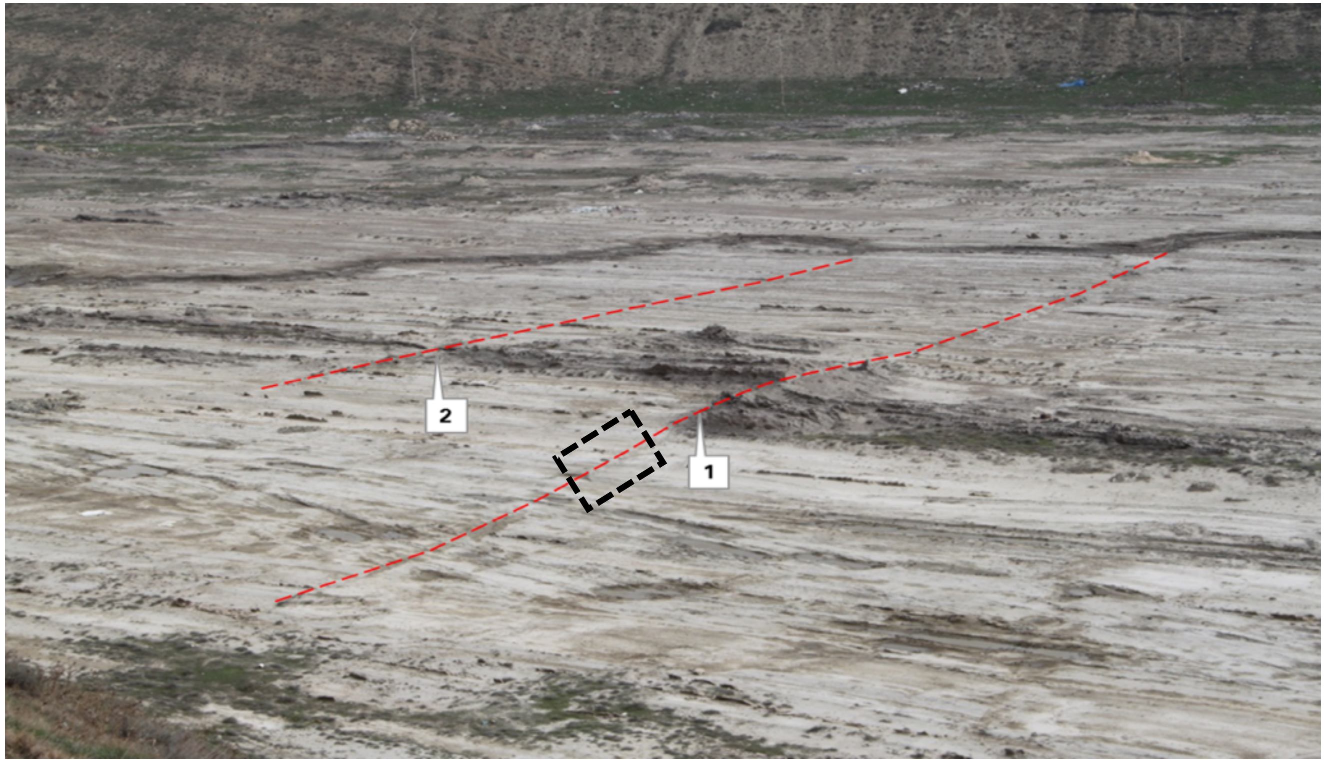
- Ideally marked on map once drilled a well
- Identify sub-seismic faults
- Handles different seismic interpretations



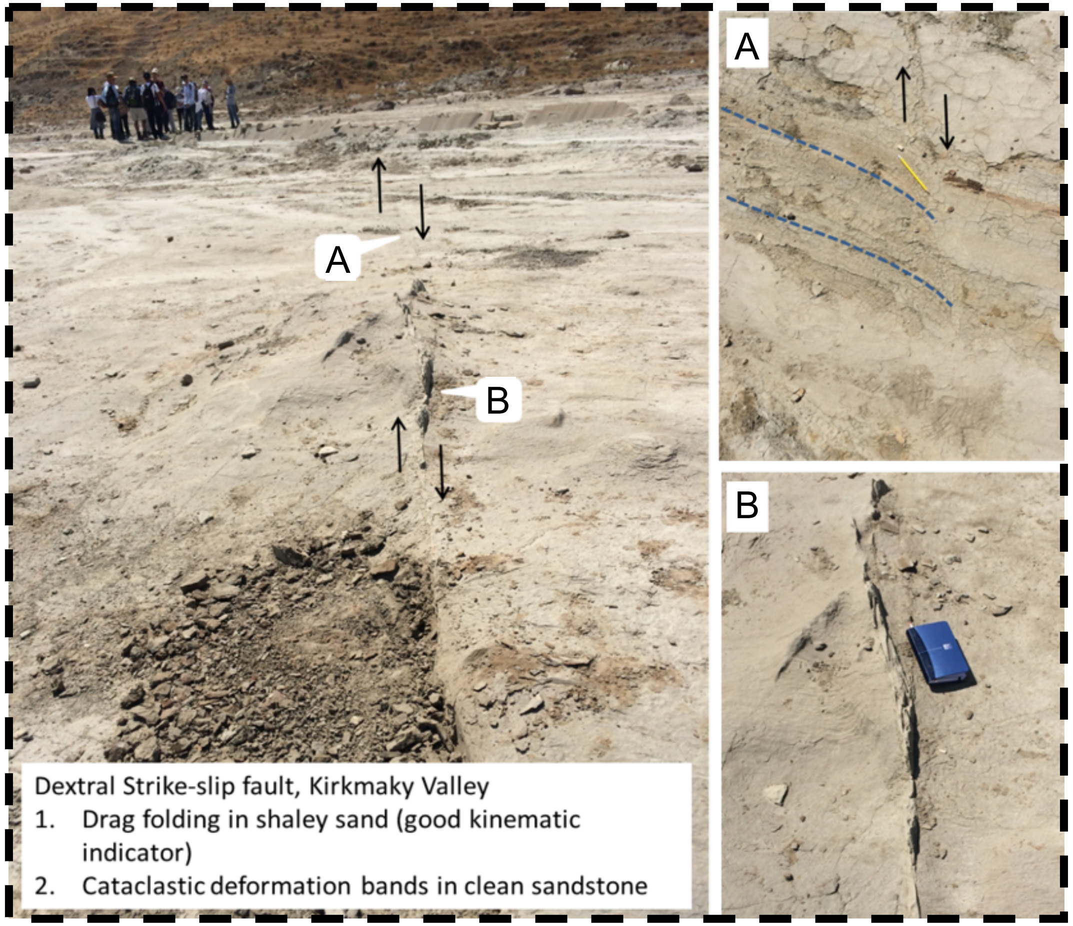
Map view of fault polygons

STRUCTURAL MODEL – STRIKE SLIP

- Often not interpreted on seismic as interpretation in dip sections
- As with dip slip faults, can be significant barriers to flow



Strike – Slip Faults on the floor of Kirkmaky Valley, Azerbaijan



Dextral Strike-slip fault, Kirkmaky Valley
1. Drag folding in shaley sand (good kinematic indicator)
2. Cataclastic deformation bands in clean sandstone

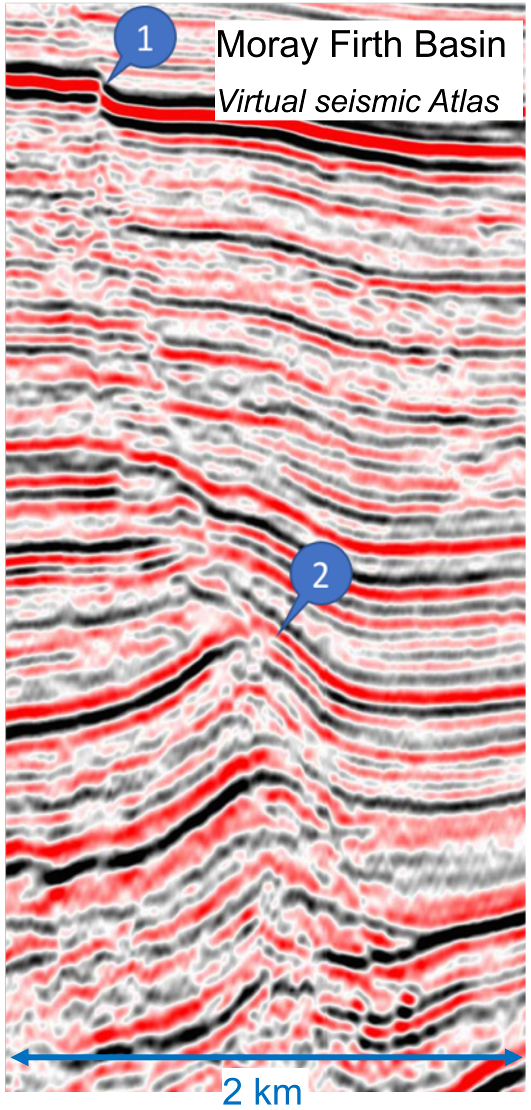
QC - FAULT DRAG

- Normal drag (a, b) – common in ductile rocks like shale
- Material impact of drag (c) drag scenario from seismic, (d) non-drag
- Drag from bedding dip tadpoles (e).

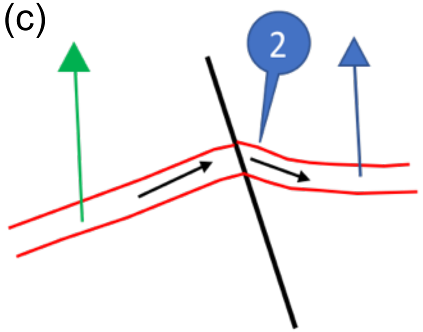
Jurassic Limestones/Shales, Kilve, UK.

http://www.ogilviegeoscience.co.uk/blog/2017/7/10/implications-of-fault-drag-1

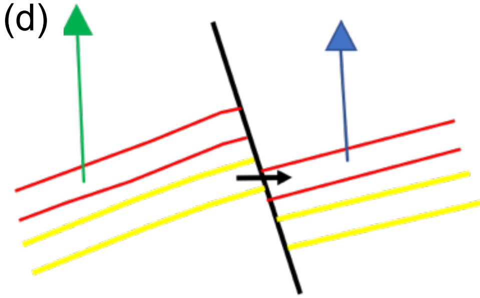
(b)



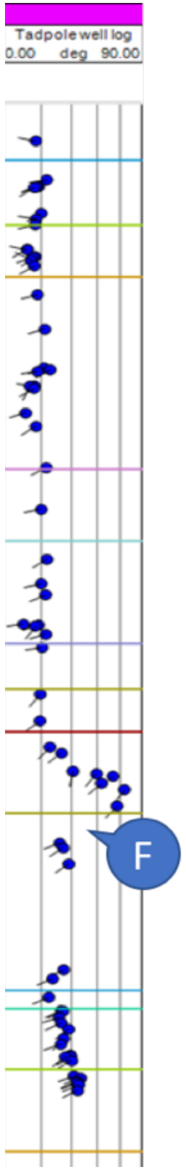
(c)



(d)

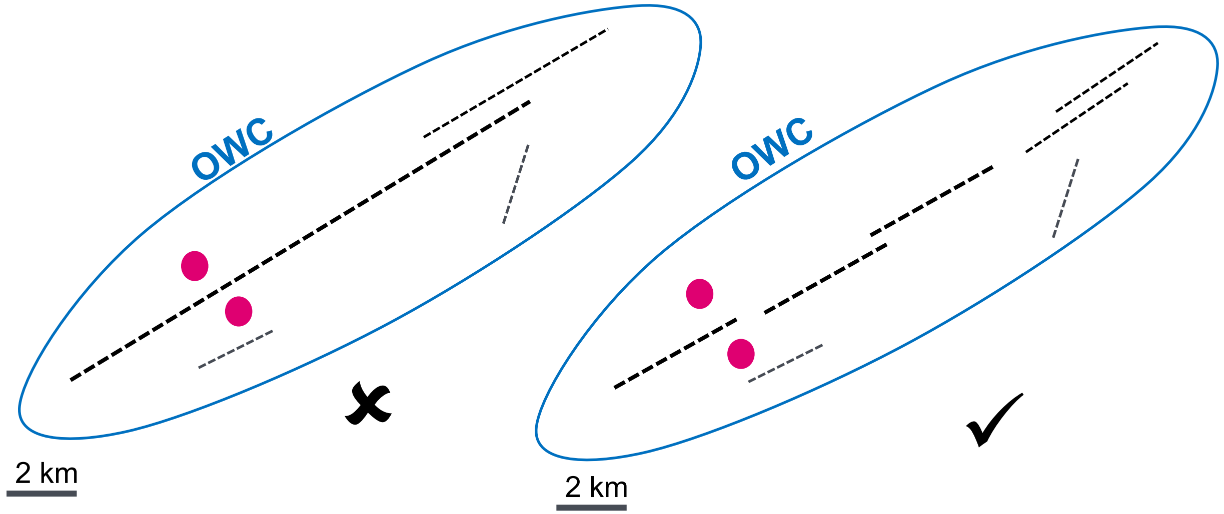


(e)



QC - FAULT THROW/LENGTH

- Implications for fluid communication
- Faults often mapped longer than they should be
- In reality are shorter segments
- Consistent with well performance ?



Map view of different fault interpretations on giant anticline

Short faults linked by relay ramps at Kilve, Somerset

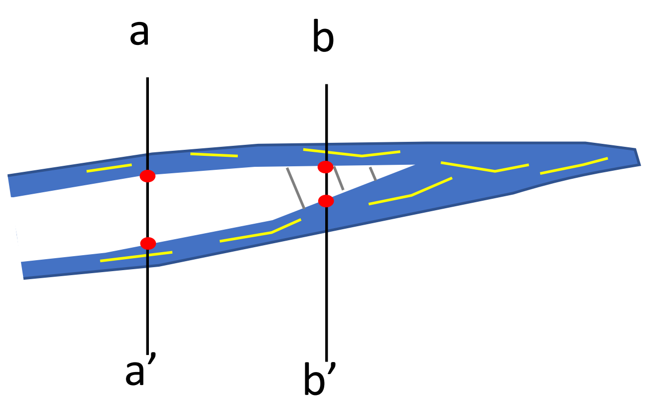
http://www.ogilviegeoscience.co.uk/blog/2017/6/17/fault-framework-qc

QC - FAULT THROW/LENGTH

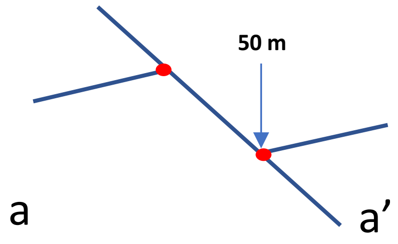
- Implications for well planning and drilling
- On seismic, only throws > c. 20m can be resolved (A, B)
- Fault tip position can be misjudged (A,C) – ahead of it is a process zone (A)
- These weak zones may be prone to mud invasion, try avoid drilling there
- Blank out fault where throw close to resolution
- Continue it based upon throw gradient knowledge, add process zone

Tertiary faulting in Hopeman Sandstone
Inner Moray Firth

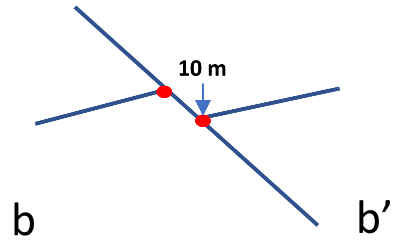
A



B



C



http://www.ogilviegeoscience.co.uk/blog/2017/6/17/fault-framework-qc

CONCLUSIONS

The following should be considered when building a fault model

- Faults which completely offset the reservoir should be included in simulation grid
- Seismic data is a primary data set but is limited by resolution
- Smaller faults can be important, creating large pressure differences across them
- May need to be included, perhaps at a later stage
  - Use 1D fault throw diagrams in clay rich rocks
  - Sand – on sand needs geohistory
- Fault cuts on maps with key cross sections (vertical wells) should be starting point for structural interpretation
- Use all available data (e.g., Google Earth, wells) and underpin by structural geology
- Fault model needs QC for fault length, throw and consider drag as all can impact dynamic simulation and well planning

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