ADAPTING US FRACTURING TECHNOLOGY TO UK SHALE EXPLORATION

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European shale completions

E & A return depends on optimising completions & we cannot simply replicate the approach to multi-stage hydraulic fracturing (MSF) developed in the US

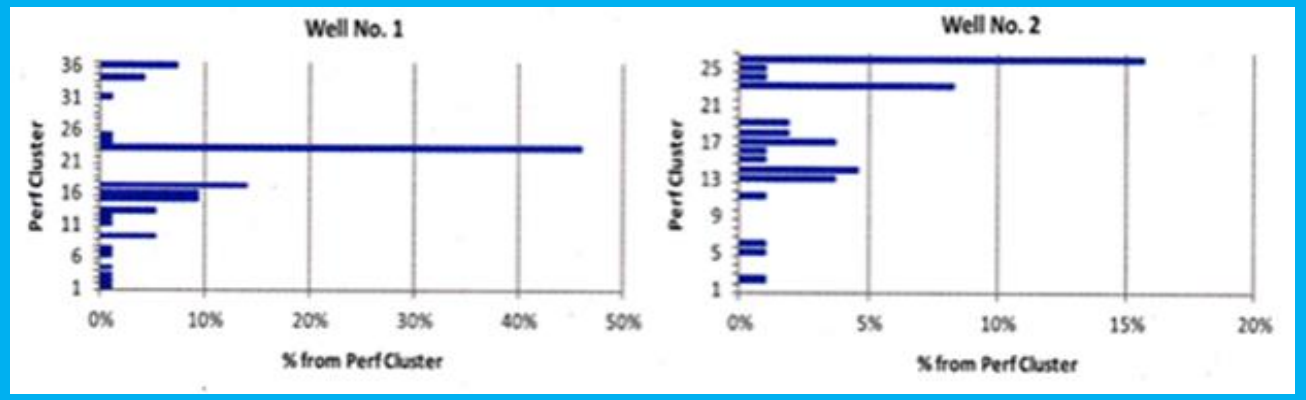
- licence to operate, D & C costs, land availability, population density etc. dictate that we must strive for greater efficiency

<u>Questions</u>

1. What is the potential for improving multi-stage hydraulic fracturing (MSF)?
2. Can geomechanics, notably reservoir stress state, help us understand the US experience?
3. Why is reservoir stress state relevant to E & A?
4. Is there an inexpensive means to characterise stress state before drilling?

The potential for improvement: US experience

Production per stage, **2010**



Ganguly & Cipolla, JPT, 2012

The potential for improvement: US experience

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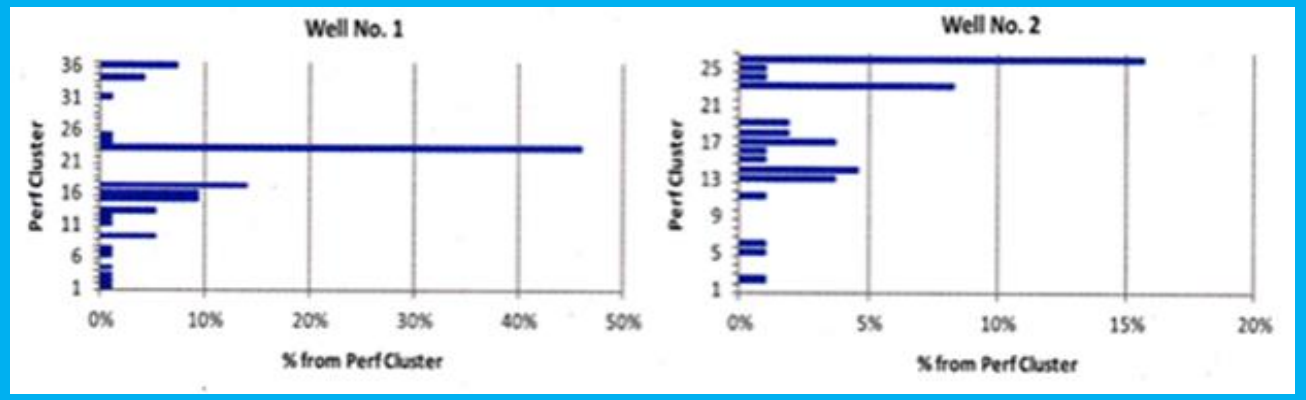
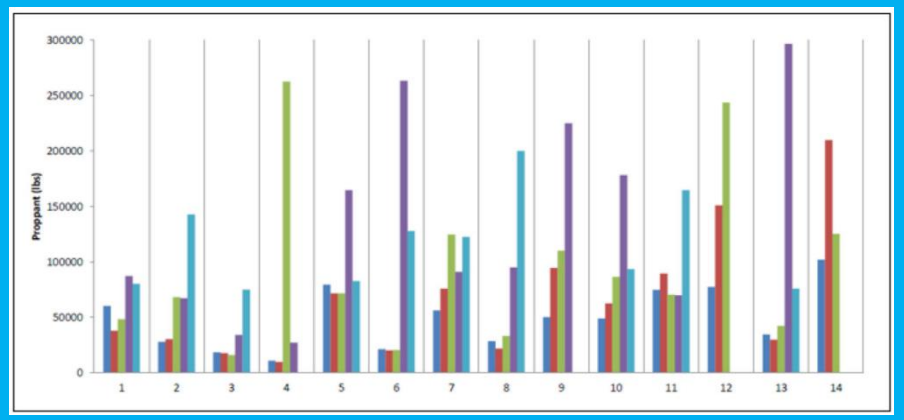


Ganguly & Cipolla, JPT, 2012

Wheaton et al., 2016 SPE 179149

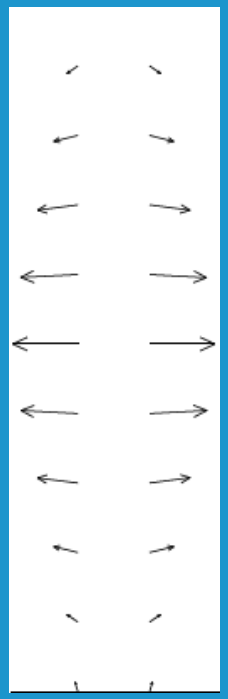


Proppant mass

Heel

Proppant mass per cluster, **2016**

Can geomechanics help us understand the US experience?

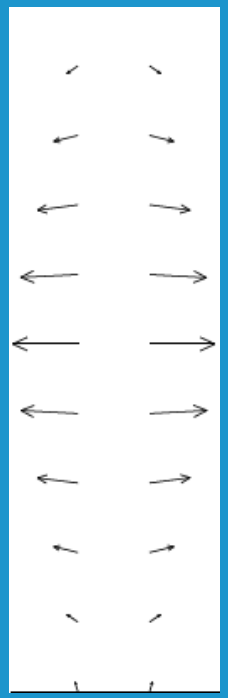


Elastic medium, homogeneous stress

Displacements around hydraulic fracture

We typically think of hydraulic fractures as elliptical openings which open according to a largely uniform distribution of displacements

Natural & hydrofracturing strains superpose



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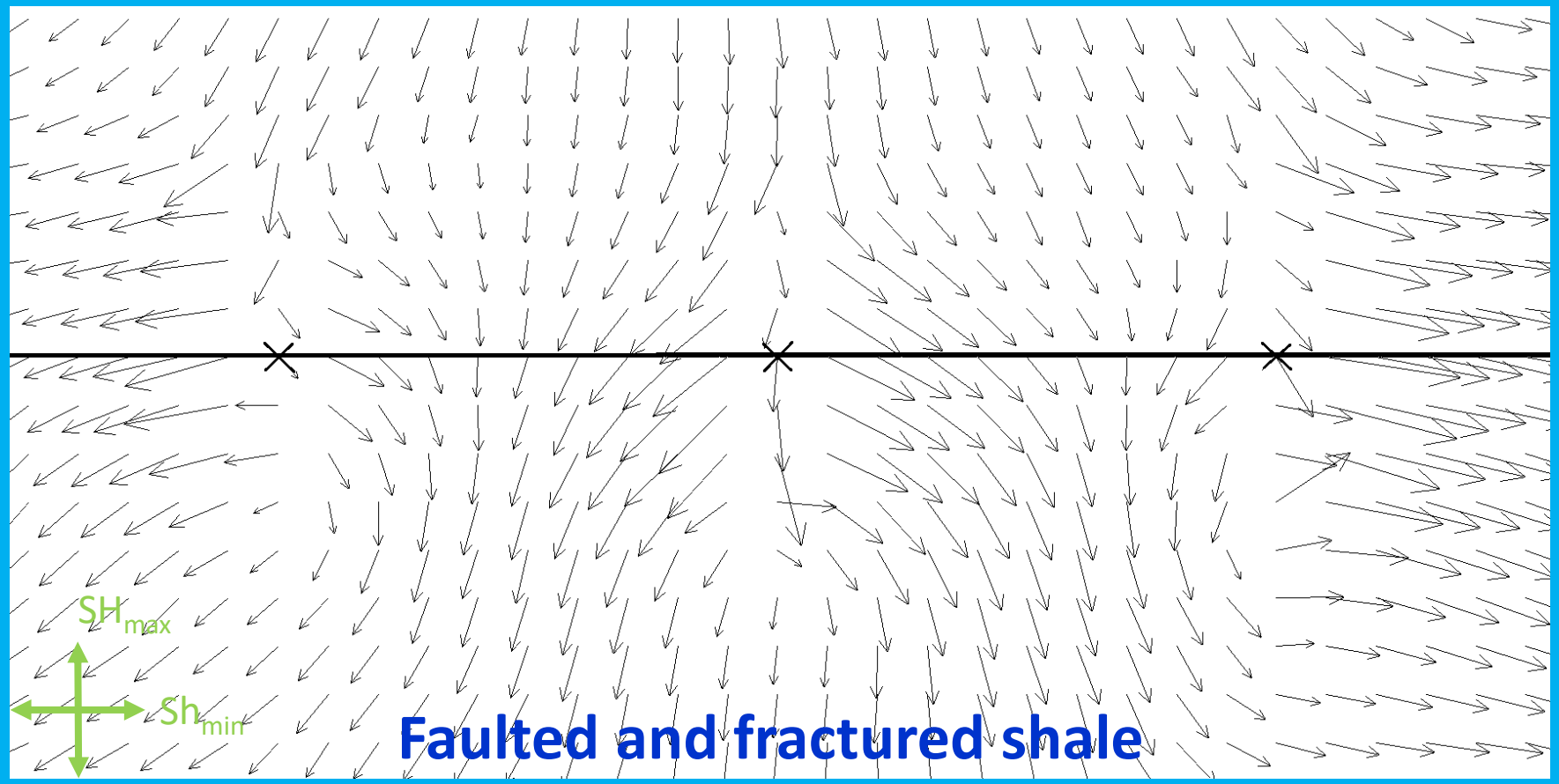
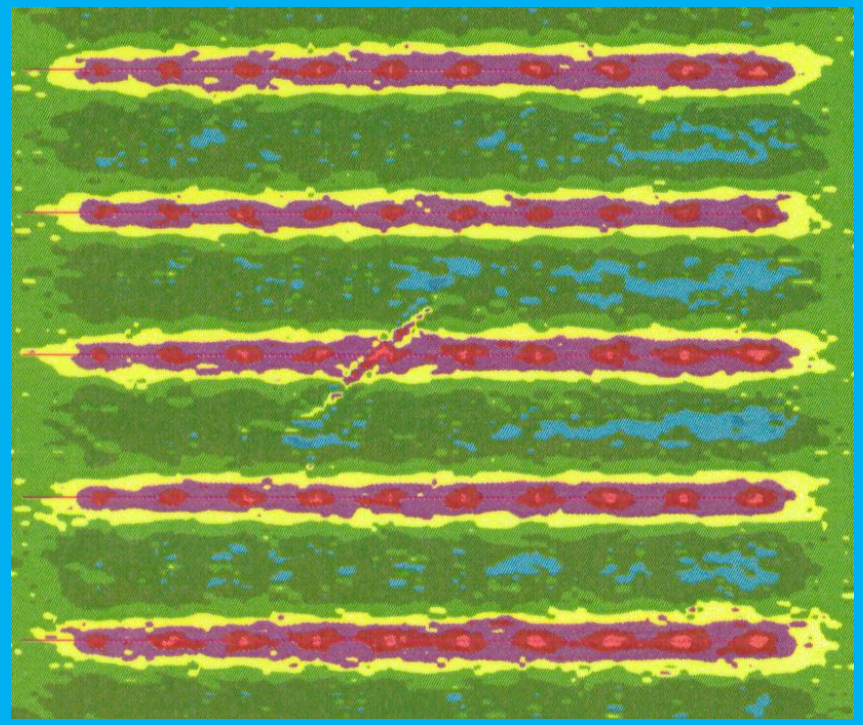


Perforations (crosses) 100m apart; frac half-length ~100m

Interaction with other hydrofractures

Effective S_{xx} stress after MSF 5 wells

Filled contours, 3.5 MPa (500 Psi) interval



10 hf, 1 km

y

x

Plan view, 5 wells, 10 hf each =50 hf, x_f=100m; net pressure 1500 psi

Interaction with other hydrofractures

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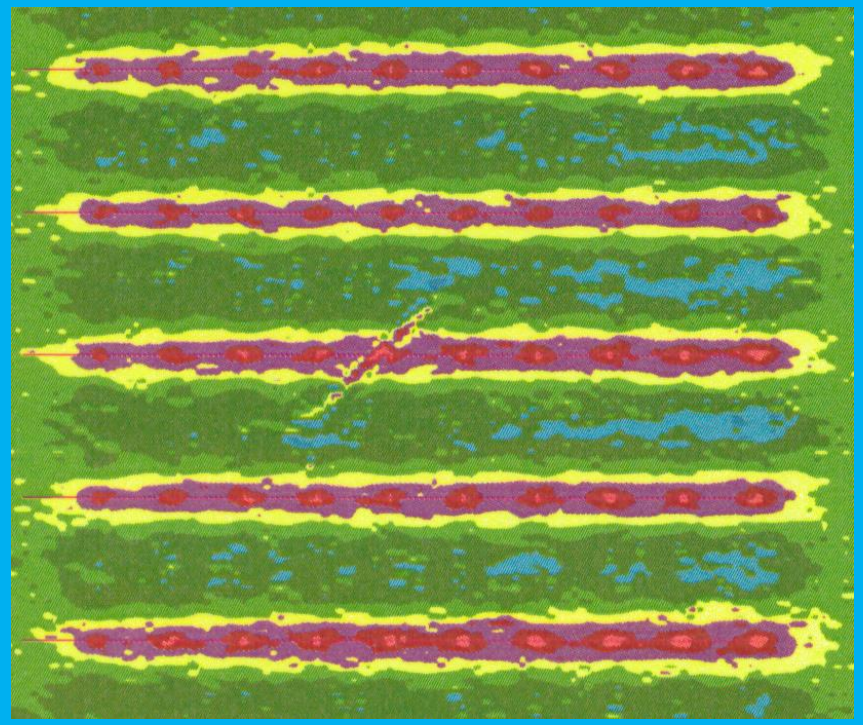
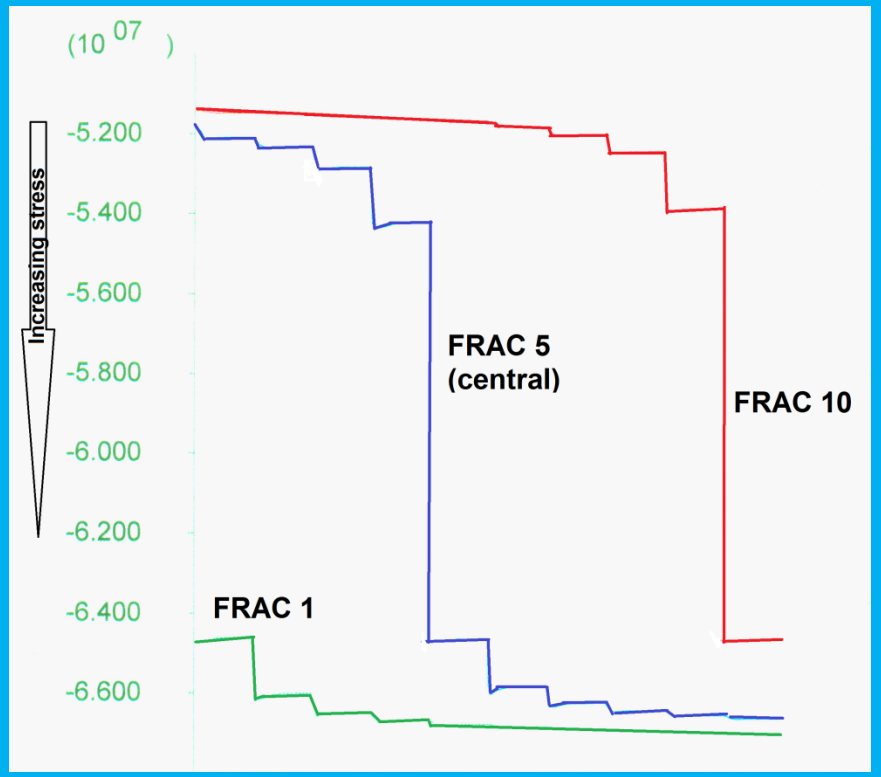


10 hf, 1 km

Plan view, 5 wells, 10 hf each =50 hf, x_f=100m; net pressure 1500 psi

Principal stress changes at perfs, one well

MPa, net pressure 2000 psi



Lowest stress increase nearest heel

How is reservoir stress state relevant to E & A?

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- Starting aim: the magnitudes of 3 principal stresses, their orientation and the pore pressure

How is reservoir stress state relevant to E & A?

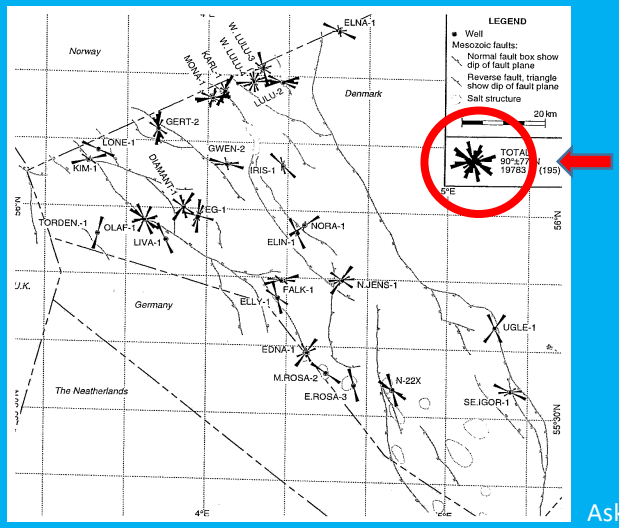
- Heterogeneous or homogeneous?
- Starting aim: the magnitudes of 3 principal stresses, their orientation and the pore pressure:

    1. Orientation and planning the well azimuth
    2. Relative magnitudes & regions to be avoided
    3. Magnitude of the minimum horizontal stress and the fracture pressure window
    4. The risk of induced seismicity
    5. Extrapolation of production from single fracs to single MSF wells to multiple MSF wells

Inexpensive pre-drill characterisation of stress state

1. Orientation of the minimum horizontal stress & well azimuth

- Usually plan horizontal section // minimum horizontal stress
- In UK the regional SH_{max} orientation ~ NNW-SSE
- BUT should anticipate change in the vicinity of faults & other structures
  - e.g. Preese Hall-1 departs from regional (008^0-188^0 in the Hodder Mudstone) and varies with depth



Ask, 1997

Sh_{max} orientations in the Danish Central Graben

Sh_{max}

E Midlands breakouts

Brereton et al., 1993

Inexpensive pre-drill characterisation of stress state

2. Faulting environment and regions to avoid

- In many areas of the UK
  - the faulting environment changes with depth from reverse to strike slip

Thrust fault in Bowland Basin

Inexpensive pre-drill characterisation of stress state

2. Faulting environment and regions to avoid

- In many areas of the UK
  - the faulting environment changes with depth from reverse to strike slip
- Avoid reverse/thrust faulting environments!
  - fracs don't work

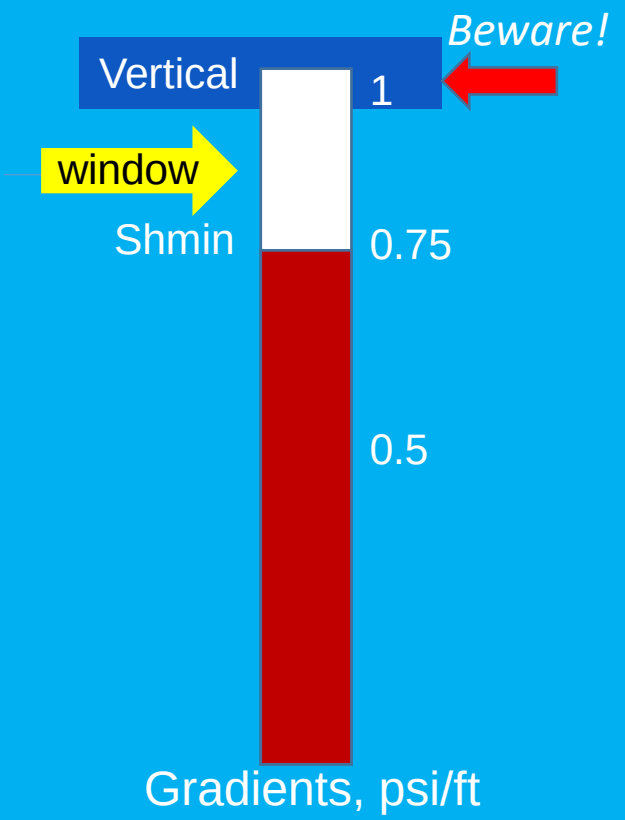
Thrust fault in Bowland Basin

Inexpensive pre-drill characterisation of stress state

3. Minimum horizontal stress & the fracture pressure window

The gradient of the minimum horizontal total stress (Sh_{grad}) onshore UK is mostly 0.6 - 0.85 psi/ft in strike slip and normal faulting environments

- the higher values limit fraccing net pressure window*
- variability of the fracture pressure window across licences?
  - areally?
    - relatively uniform, smoothly varying or strongly affected by structure?
  - with depth?



* up to 3500 psi net pressure in US

Inexpensive pre-drill characterisation of stress state

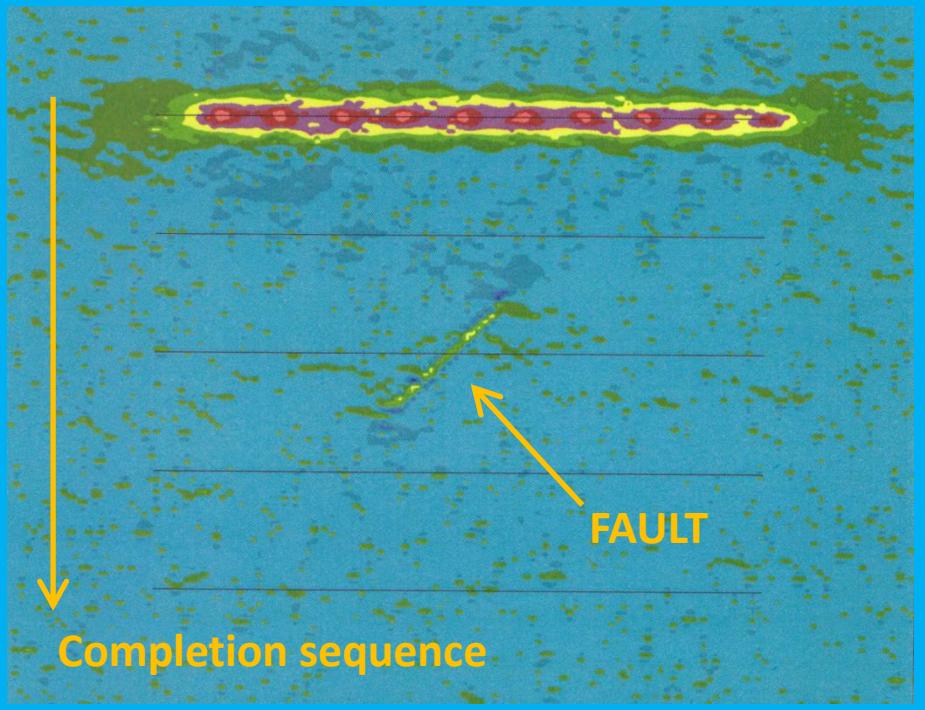
4. The risk of induced seismicity

Why are some areas more prone to induced seismicity than others? Can we rank areas in terms of greater or lesser risk of induced seismicity?

Conventional thinking says ‘critical faults’ are unstable.

- *this ignores stress history*
- *previous slip may have relieved the disturbing forces (destressed the fault)*

Established geologic methods can identify the trends of changing effective stress



Minimum stress after fracturing 1st well of 5, contour interval 2.5 Mpa (360 psi)

Inexpensive pre-drill characterisation of stress state

5. Extrapolation of well performance

- Extrapolation from single well fractured completion performance
  - Single fracture vs MSF
  - Single well vs multiple wells
- Changes of stress state
  - From one location to another
  - Induced by
    - MSF
    - Multiple wells

Inexpensive pre-drill stress characterisation

- Data are essentially free
  - Onshore well database

Our Ref. EXP/1/PS.472 Your Ref. Date 17th September 1958

Subject Hydraulic Fracturing Operations at Egmanton No.35 on 16th September 1958

  - Geoscience
    - analytical and numerical interpretation
  - Mining rock mechanics
- Progressively construct the geomechanical model