Reservoir Dynamics & the New Geophysics

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on behalf of:

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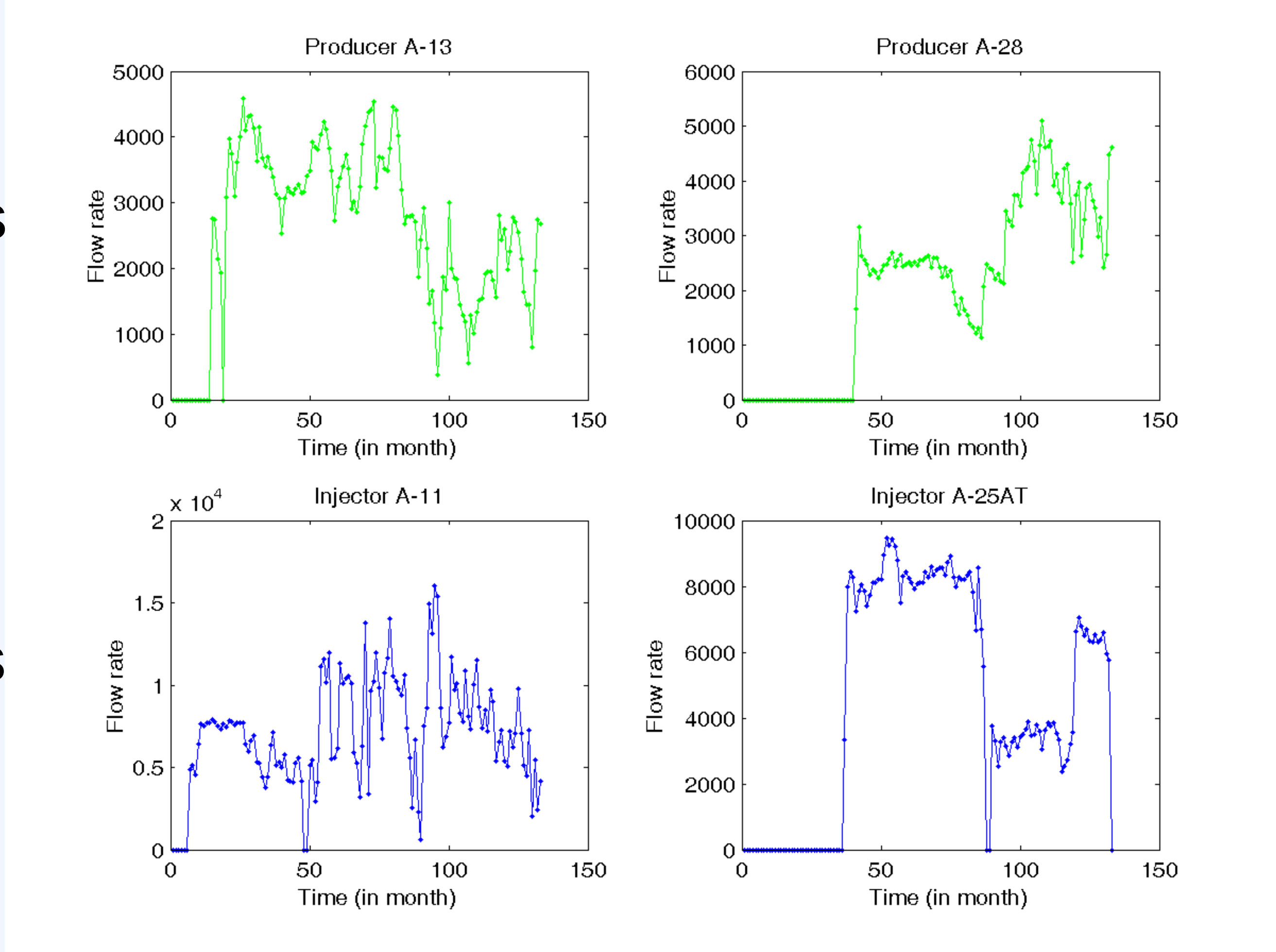
Talk outline

1. Observations in oil & gas reservoirs
    - Interwell rate correlations
    - Flood directionality
    - Reservoir Physics
2. Observations in ground water reservoirs
3. Seismic observations
    - How Aligned Cracks Occur
    - Seismic Conseqeunces of Diltancy
    - Rock Physics
    - Seismic Summary
4. Conclusions

1.1 Flow rate fluctuations

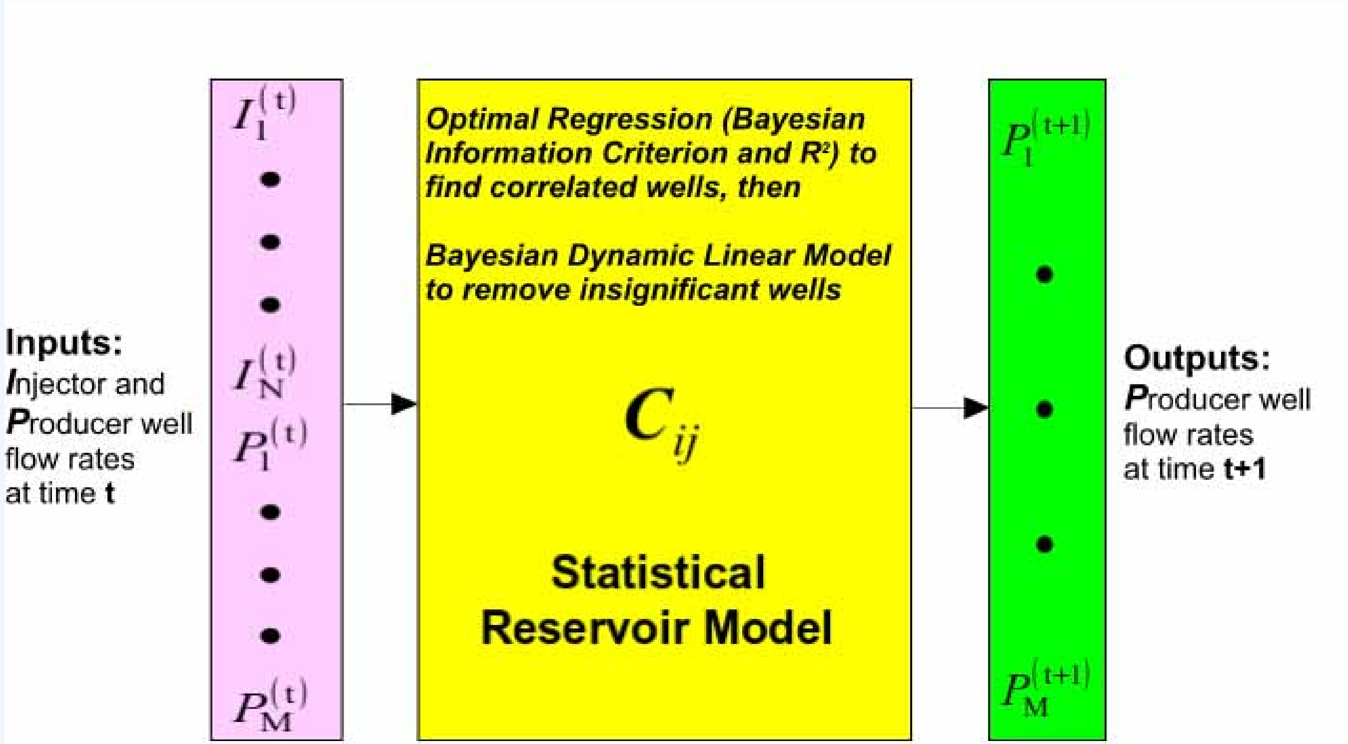
Producers

Injectors



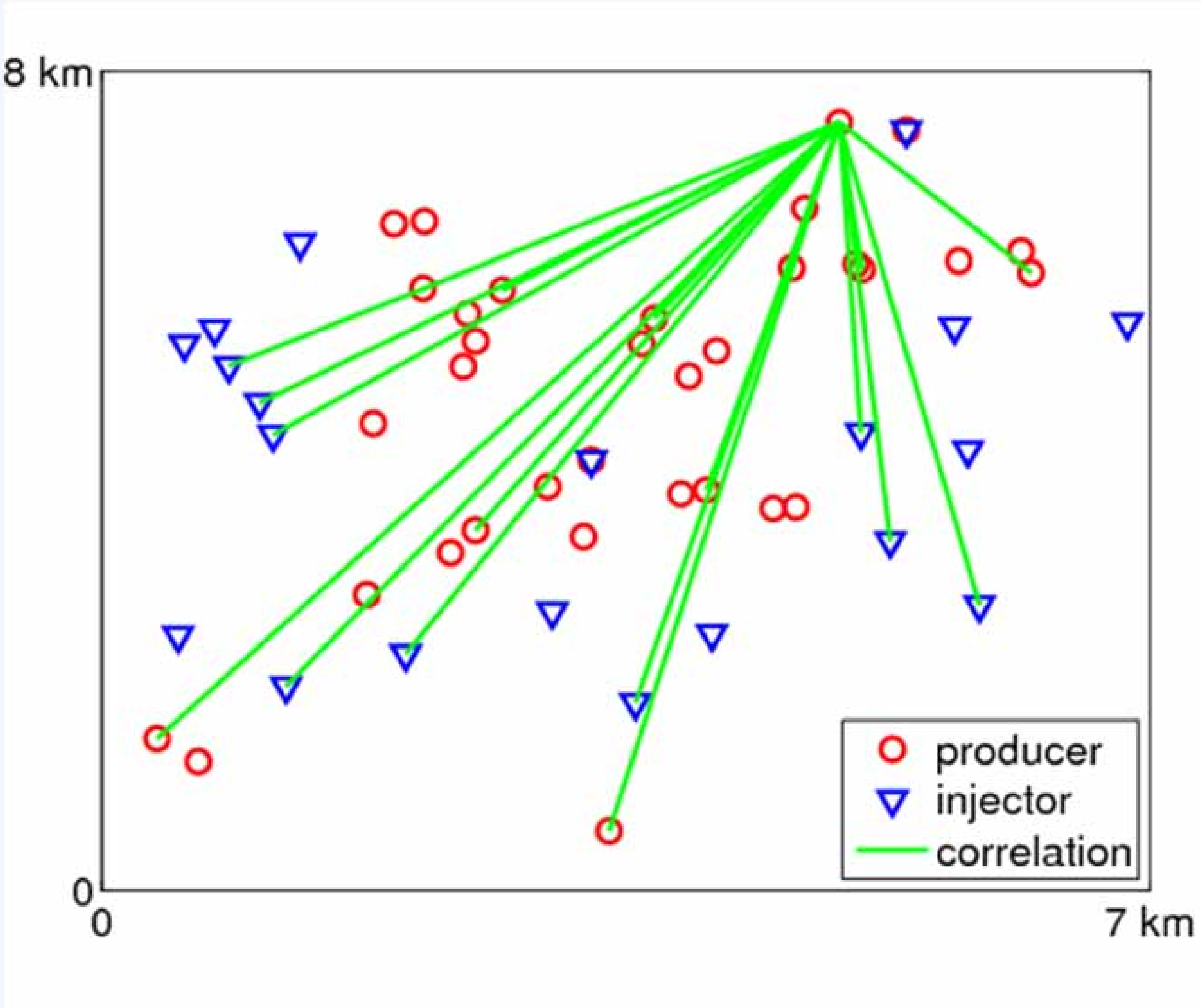
1.2 Correlation measures:
Standard (Pearson, Spearman, Kendall)
or Statistical Reservoir Analysis (SRA)

(developed & patented by the University of Edinburgh)

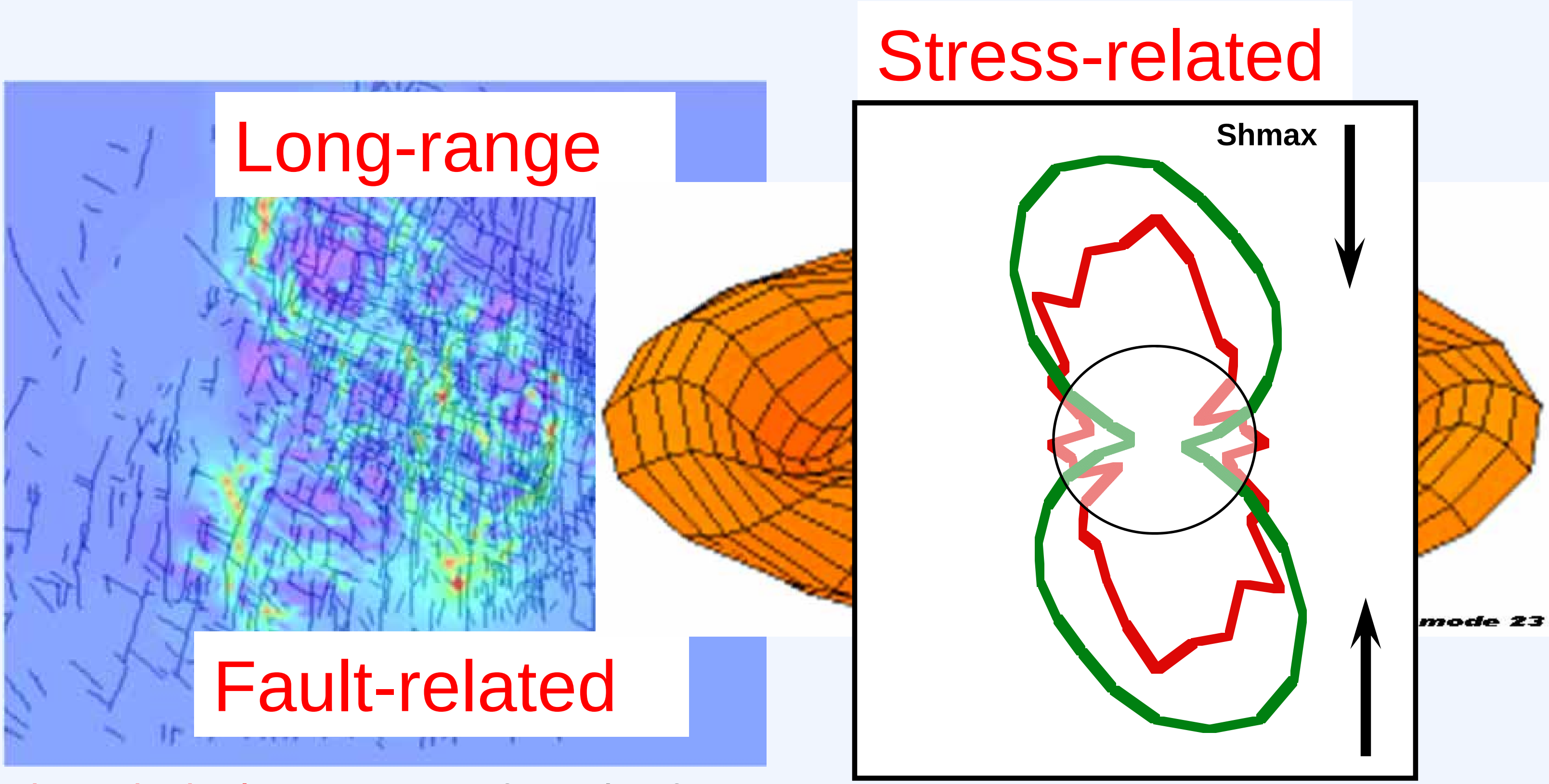


- Finds best small group of wells to model flow rate of any well of interest

1.3 Statistical Reservoir Analysis
Example of correlated wells



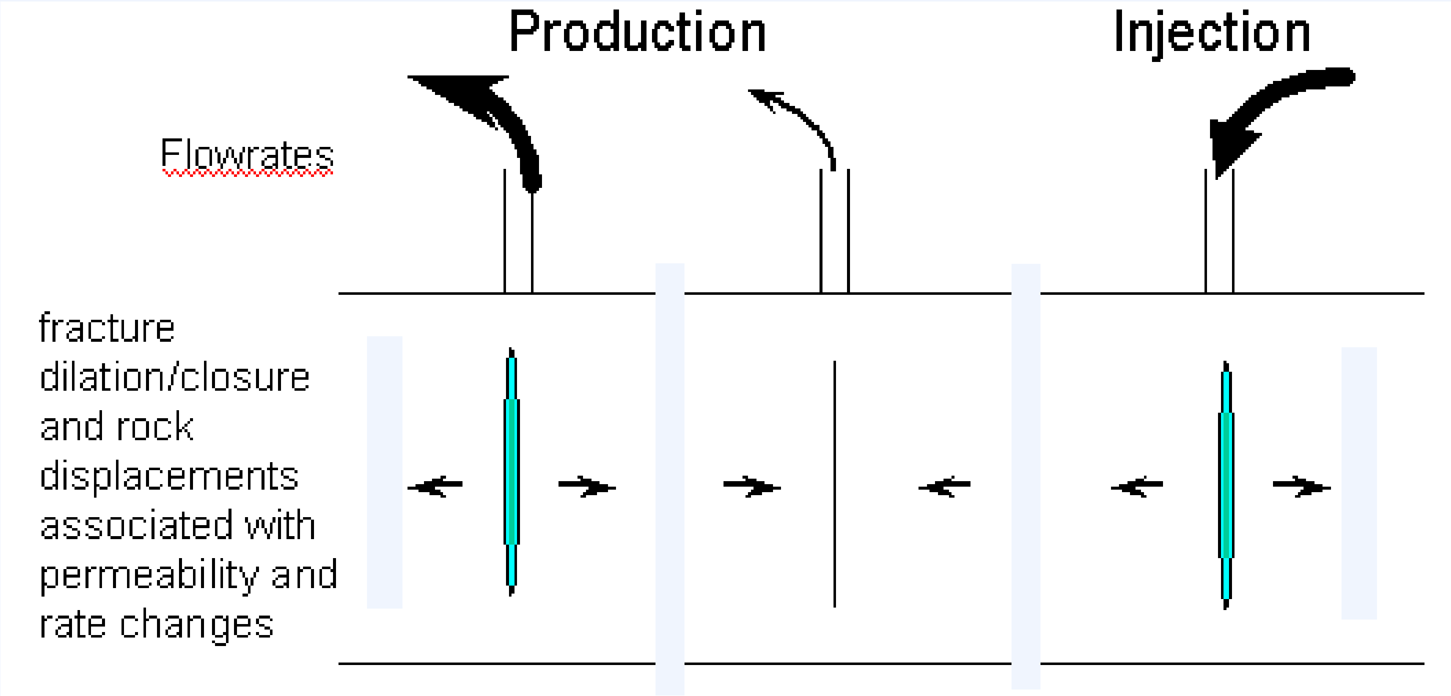
1.4 General characteristics of rate correlations



First principal component of matrix of rate correlations between all wells in field B – independent mode ‘explaining’ largest proportion of fluctuation variance

Injector-Producer pairs only
broadband fluctuations
high frequency fluctuations
__ zero correlation

1.5 Basic concept



1.6 Long history of flood directionality

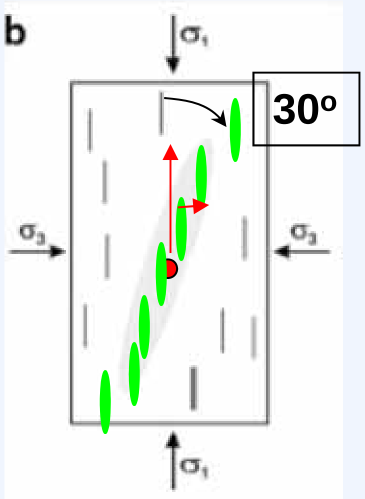
Classic papers appeared in 1959/1960:

- Analytical modelling of 5 spot well patterns
- Demonstrated relationship between areal sweep efficiency and anisotropic permeability

Orientation of well pattern relative to permeability axes can change recoveries by 10's of % points

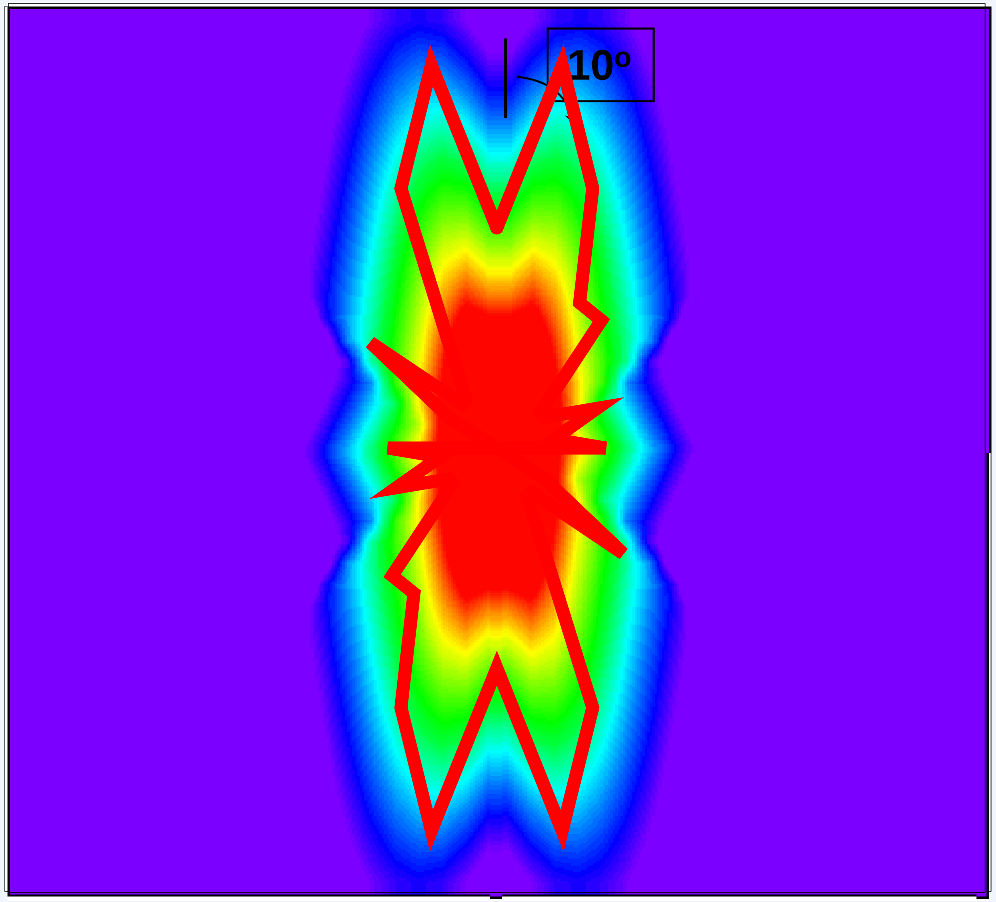
1.7 Flood progress through interacting fractures in matrix of medium permeability

permeability



Healey et al, 2006

Fracture dilation



most favoured breakthrough directions for injected fluid in 47 ‘unfractured’ fields worldwide

Min. path distribution around a well ~ isobars of pressure field. Equivalent to flood progression.

1.8 Reservoir physics

- Communications are not just Darcy fluid flow, but…
- …coupled fluid flow and geomechanics
  - incorporating pre-existing faults and/or fractures
  - influenced by modern-day stress state
- … near a critical point
  - long-range interactions = heavy micro-cracking

2.1 Groundwater reservoirs

- Significant literature on the impact of oriented micro-cracks/fractures on groundwater production
- In particular, monitoring and predicting the movement of pollutants

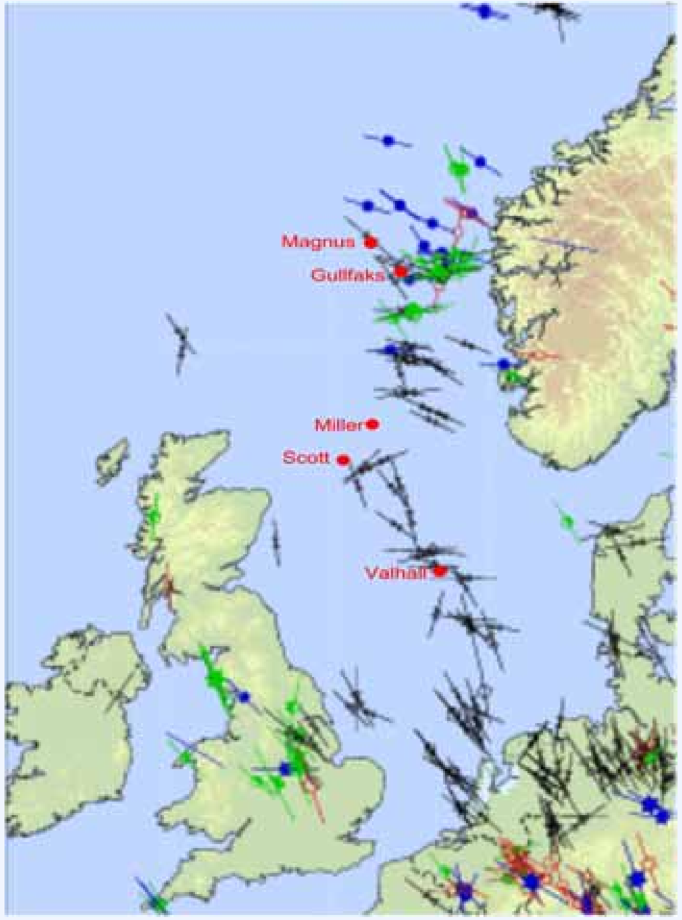
2.2 Some simple geophysical observations……

1. Relatively simple measurements of seismic velocity anisotropy and electrical resistivity anisotropy. Typically show:
2. Alignment with maximum horizontal stress, and
3. Relatively large % anisotropy, indicative of high crack densities

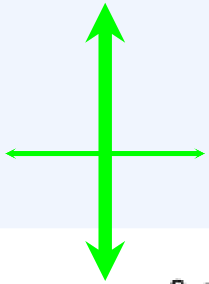
	Seismic Velocity Anisotropy	Electrical Resistivity Anisotropy
Chalk Site 1	+/- 10%	+/- 6%
Chalk Site 2	+/- 10%	+/- 4%
Chalk Site 3	+/- 6%	+/- 1%
Limestone Site 1	+/- 24%	Not measured
Limestone Site 2	+/- 15%	Not measured
Limestone Site 3	+/- 29%	Not measured

3.0 Case studies in North Sea with neotectonic setting

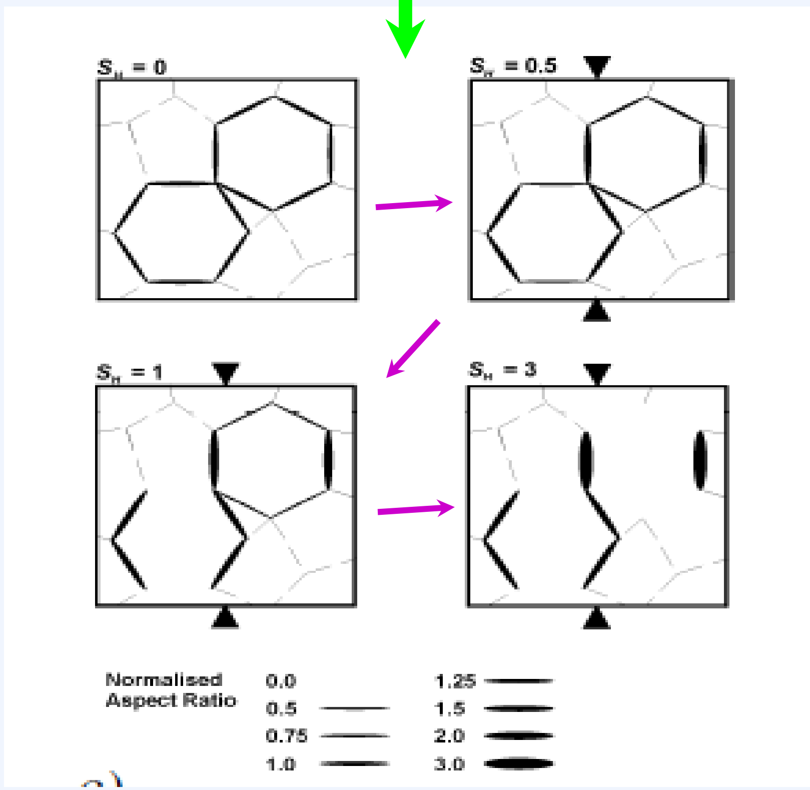
Maximum horizontal stress axes
(World Stress Map Heidbach et al (2008))



3.1 How aligned cracks/fractures occur



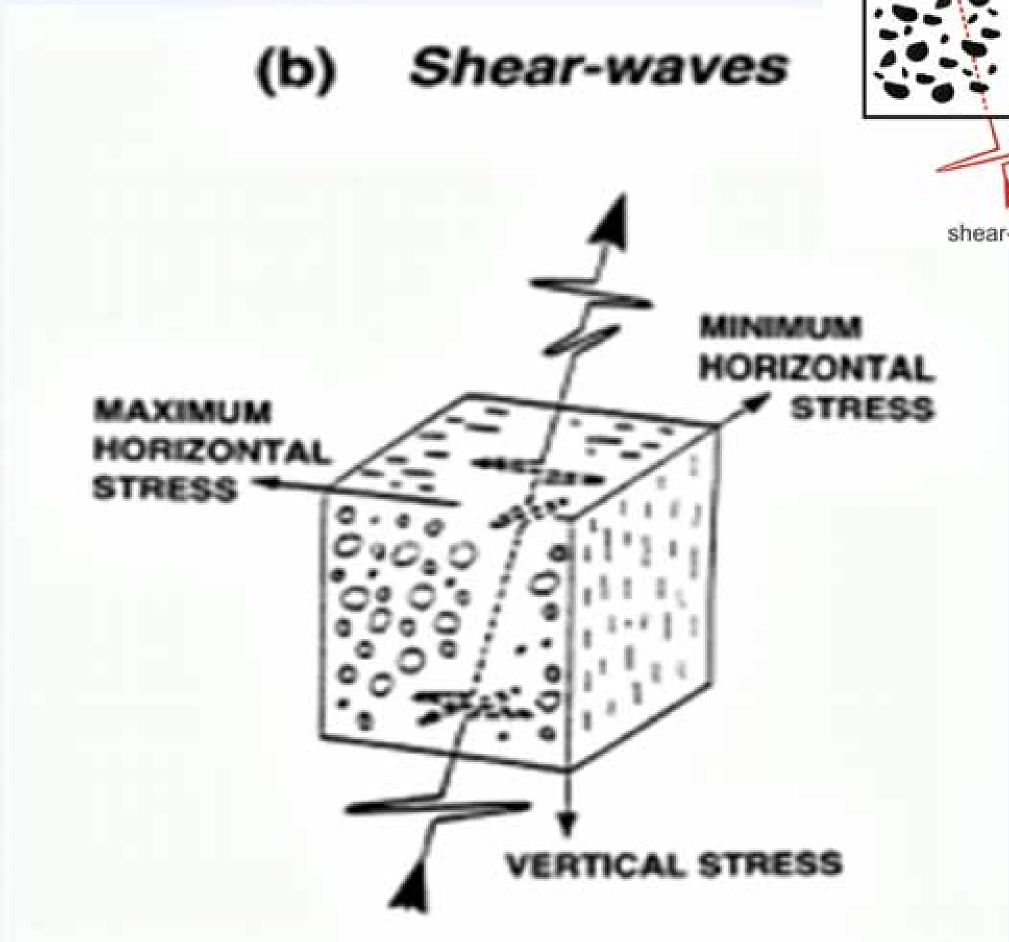
1. Beginning, with hexagonal crack distribution in the conventional 'billiard ball' model of grains and porosity…….
2. Increasing differential horizontal stress progressively results in aligned crack/fracture sets

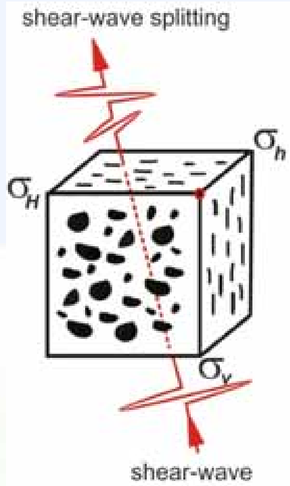


Increasing differential horizontal stress

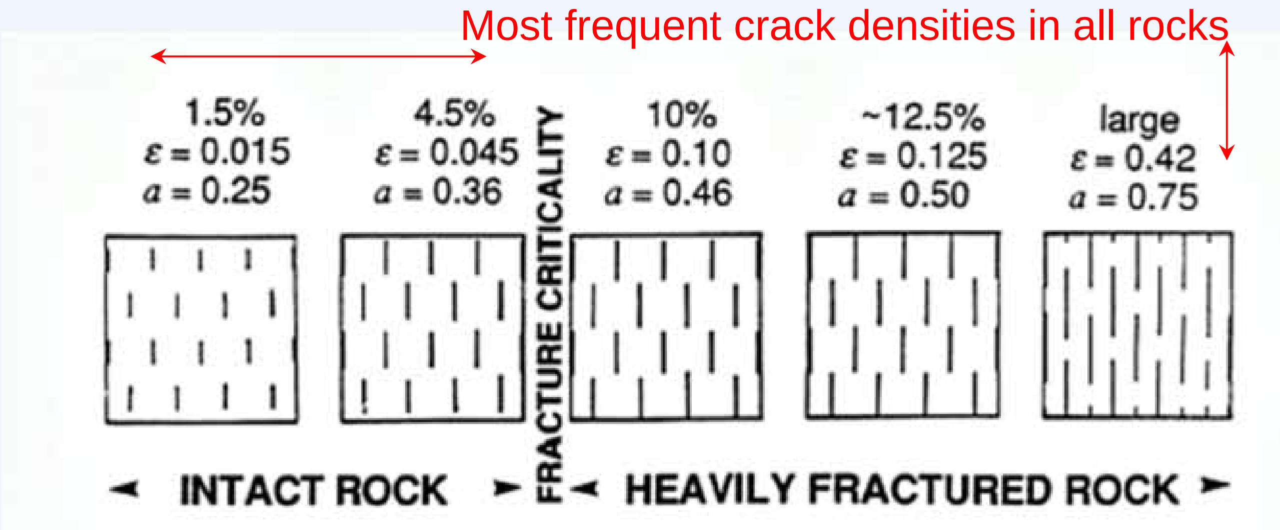
3.2 Seismic consequences of Dilatancy

1. P wave reflectivity is relatively insensitive to systems of aligned cracks/fractures.
2. S waves are much more sensitive.
3. In particular, Shear Wave Splitting (aka Shear Wave Bi-refringence) can be used to fully describe anisotropic, dilatant, rock bodies





3.3 Summary of observations of seismic anisotropy



Based on some in situ observations and lab work, Shear Wave Splitting implies that rocks are so heavily microcracked that they verge on 'criticality'

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This implies:

For truly *predictive* reservoir monitoring, seismic measurements need to be 3-component………..

4.0 Conclusions

- Coupled geomechanics-flow near a critical point is an integral part of reservoir physics
- Reservoir deformation in response to production appears to involve fracture interactions. Modes of deformation can change during the life of a field
- Analysis of inter-well correlations in rate histories offers a low cost means of interpreting faults or fractures between wells, complementary to other techniques; also allowing time-lapse monitoring
- 3C, probably permanent, seismic reservoir monitoring is what’s needed – as opposed to towed streamer.