Shear-Tensile Model - A Prospective Alternative to Moment Tensor in Seismic Detection of Fracture Mode During Hydrofracture Treatment of Oil and Gas Wells

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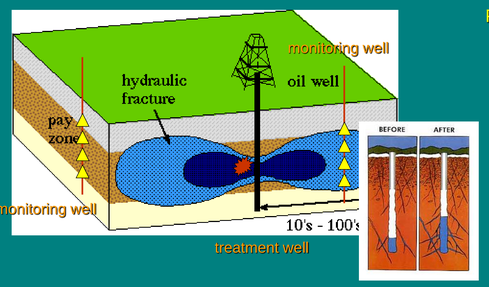
Motivation: hydrofracturing of oil/gas wells



Possibility to recover MT (6 components)

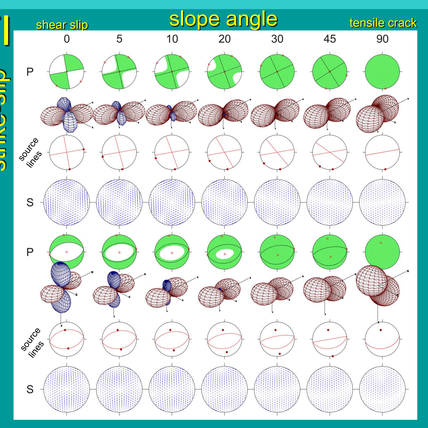
far field: Vavryčuk (2007)

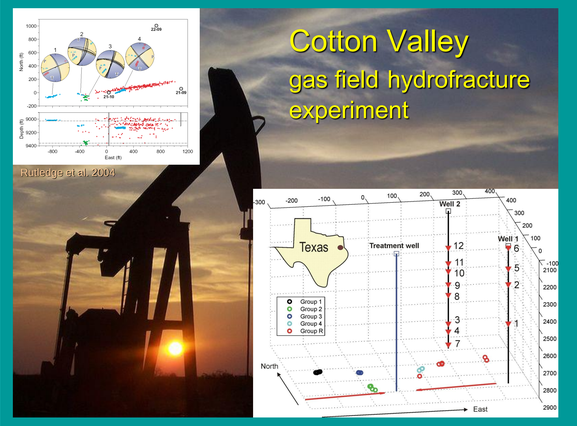
rarely / occasionally / standard: 3 (or more) wells: OK from P, P+S; 2 wells: OK from P+S; 1 well: Not enough !

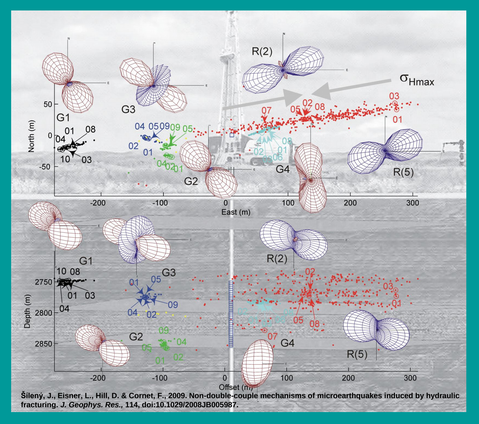
- additional constraint needed — Jechumtálová & Eisner (2008)
- near-field needed — Song & Toksoz (2011)
- a simpler source model needed — less parameters, e.g. shear +off-plane comp.

→ shear-tensile/implosion model: STI

STI







Šílený, J., Eisner, L., Hill, D. & Cornet, F., 2009. Non-double-couple mechanisms of microearthquakes induced by hydraulic fracturing. J. *Geophys. Res.*, 114, doi:10.1029/2008JB005987.

Design of shear-tensile/implosion model (STI)

Far field P+S from 2 wells
= even-determined inversion for MT
No over-determination !

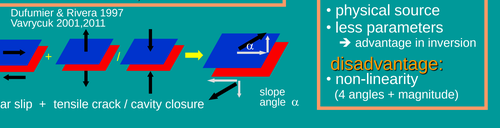
Viewpoint of fracture mechanics:
MT is unnecessarily complex

Traditional decomposition ISO+DC+CLVD

Question of particular interest:

Was permeability of the reservoir increased?
i.e, were tensile cracks created?

→ discriminate between shear and tensile modes of fracturing

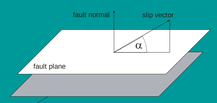


→ shear – tensile / implosion source model
Dufumier & Rivera 1997
Vavrycuk 2001,2011

benefits:
- physical source
- less parameters → advantage in inversion

disadvantage:
- non-linearity (4 angles + magnitude)

Parameters:
- DC angles dip, strike, rake
- slope angle α
- magnitude (scalar moment)



Retrieval of STI parameters:
- via MT (DC,ISO,CLVD): through 6 parameters → vulnerability of ISO,CLVD
- directly: 5 parameters → more robust → preferred in scarce configurations

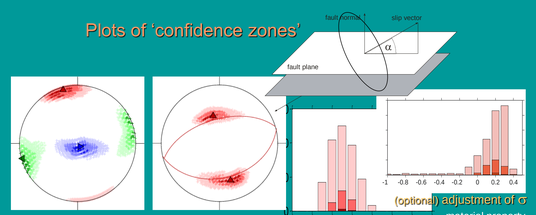
Inversion method: 2-step grid search
- coarse grid global search
- fine grid local refinement

advantageous mapping of model space: at 'each' point (in terms of the sampling) information available on the goodness of fit: chi-square

possibility of other inversion options:
- different norm (L1)
- adjustment of σ

→ possibility to construct a confidence region: subspace in the model space around estimated solution with a priori specified probability content

Plots of 'confidence zones'



Shear-slip part of the mechanism
Projection of T,P,N axes of the mechanisms with NRMS < NRMS$_{threshold}$
→ estimate of uncertainty in the orientation of shear-slip part

Source planes:
- fault plane
- plane normal to slip

→ info on fault plane (ambiguous, but…)

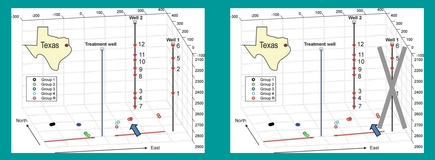
Tensile/implosion part
Histogram of values of the slope angle α of the mechanisms with NRMS < NRMS$_{threshold}$
→ estimate of uncertainty in the tensile/implosion part
α positive → tensile fracturing
negative → implosion

Synthetic testing of STI:

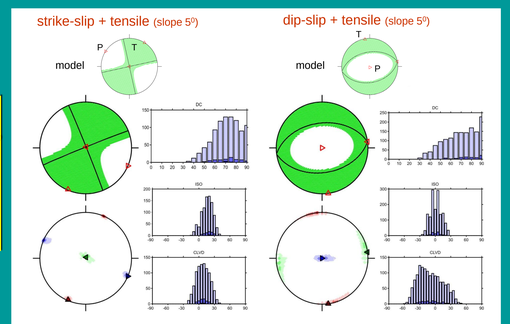
two-well vs. single well monitoring

Cotton Valley gas field hydrofracture experiment

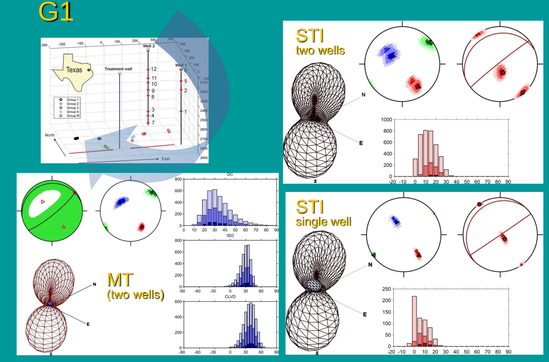
Simulation of a single-well monitoring



Source model:
- vertical strike-slip
- 45⁰ dip-slip



Re-processing of Cotton Valley



Conclusions:

MT: general description of a dipole source
but too general in case of a simple fracturing:
hydrofracturing in oil/geothermal industry:
opening/closing of tensile cracks

additional constraint helpful → STI model
less parameters than MT (5 vs. 6)
non-linear model → exploration of model space →
- advantage in estimate of uncertainty of the solution
- minimization in different norms
- estimate of Poisson constant

beneficial in deficient configurations
in particular, single-well monitoring
robust even with:
- reasonable noise in data
- realistic mislocation
- slight velocity mismodeling