Characterization of reservoir using microseismicity induced during stimulation tests:

Contribution from tomographic analysis and faulting mechanisms

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Outline

1/ Introduction

2/ Tomographic analysis

- Methods
- Results for the stimulation tests of 2000 and 2003
- Implication for the reservoir properties

3/ Faulting mechanisms

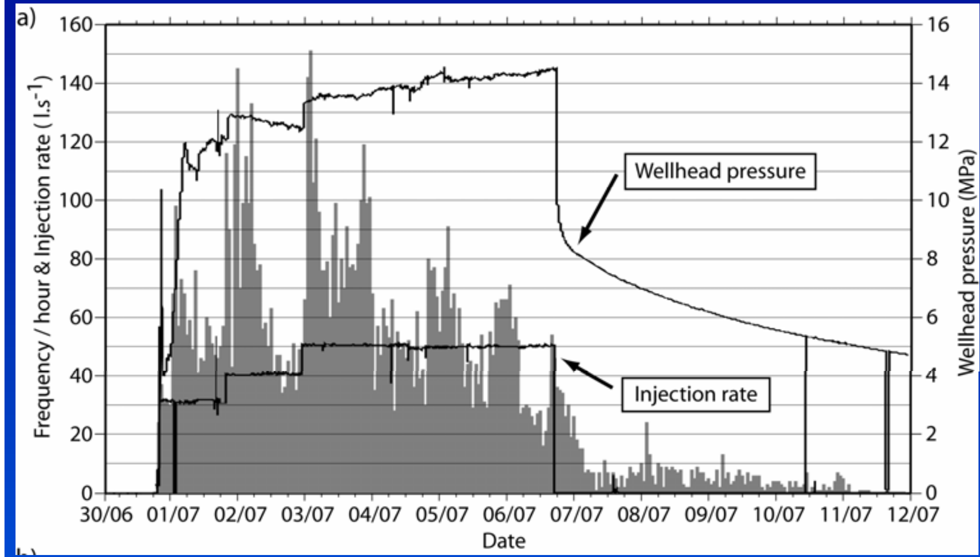
- Fault plane solutions
- Double couple / Non double couple
- Stress regime

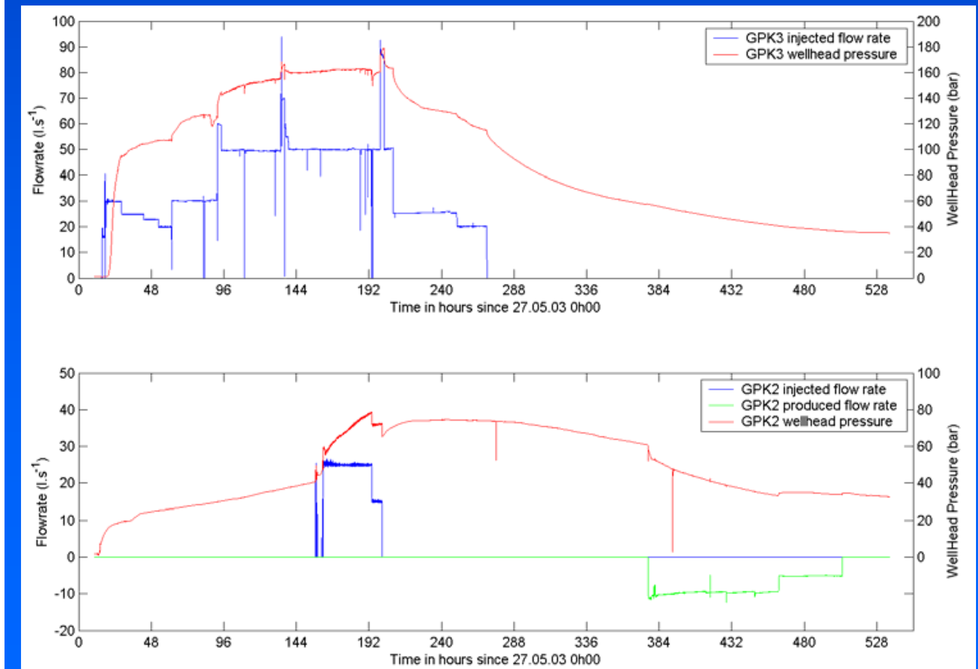
4/ Conclusions

Introduction (1/2)

- Seismic methods used for:
  - observing pressure and/or fluid propagation
  - following the fracture network improvement
  - delineating active seismic structures
- Tools usually used:
  - JHD, Collapsing, Multiplets, Precise picking,..
- Tomographic analysis
  - Precise relocation of microseismic events
  - Velocity structure → reservoir properties
- Faulting mechanisms
  - Orientation of fault planes
  - Stress regime

Introduction (2/2)





Stimulation of GPK2 in 2000

- 30, 40 & 50 l.s^{-1} (6 days of injection)
- overpressure up to 14 MPa
- 10000 events detected on surface, 7200 located

Stimulation of GPK3 in 2003

- rates up to 90 l.s^{-1} (11 days of injection)
- overpressure up to 18 MPa
- 6000 events detected on surface, 2250 located

Tomographic analysis – Method & Data

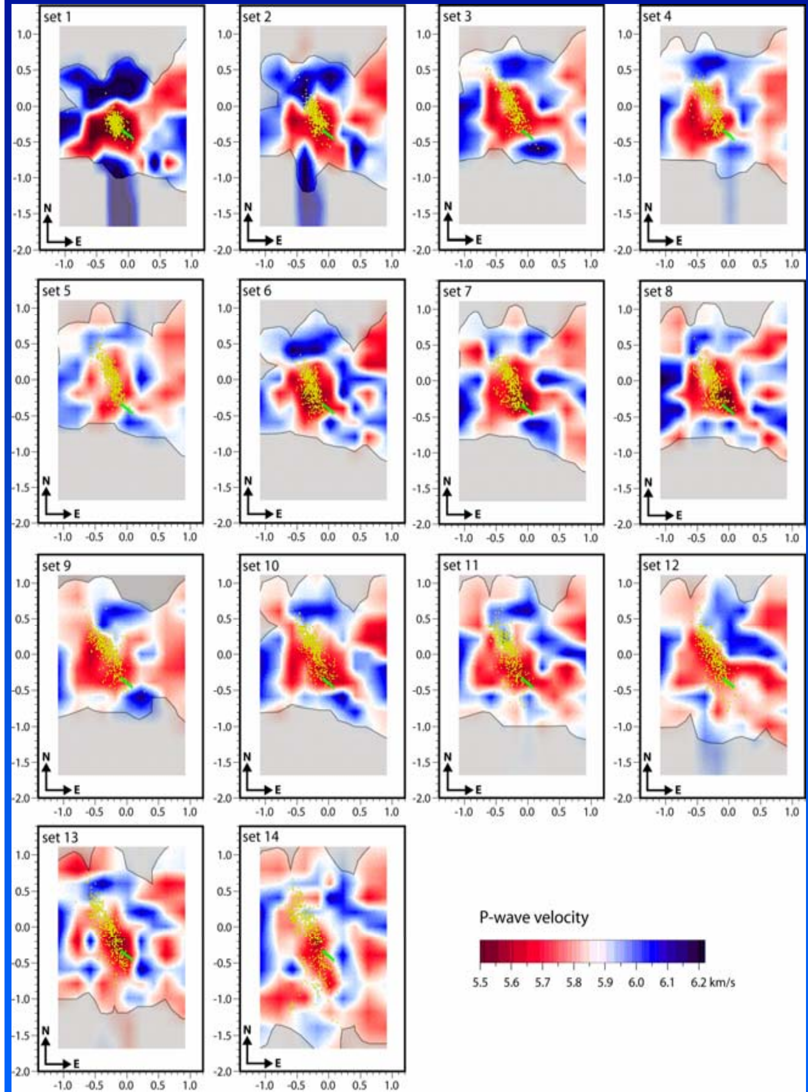
Stimulation of GPK2 in 2000

- Algorithm *SIMULPS* (Thurber, 1983)
- inversion of arrival times by an iterative, damped least square method
- Simultaneous estimates of the 3D velocity structure and earthquakes locations
- Temporal evolution of the velocity structure (14 sets of 500 events)

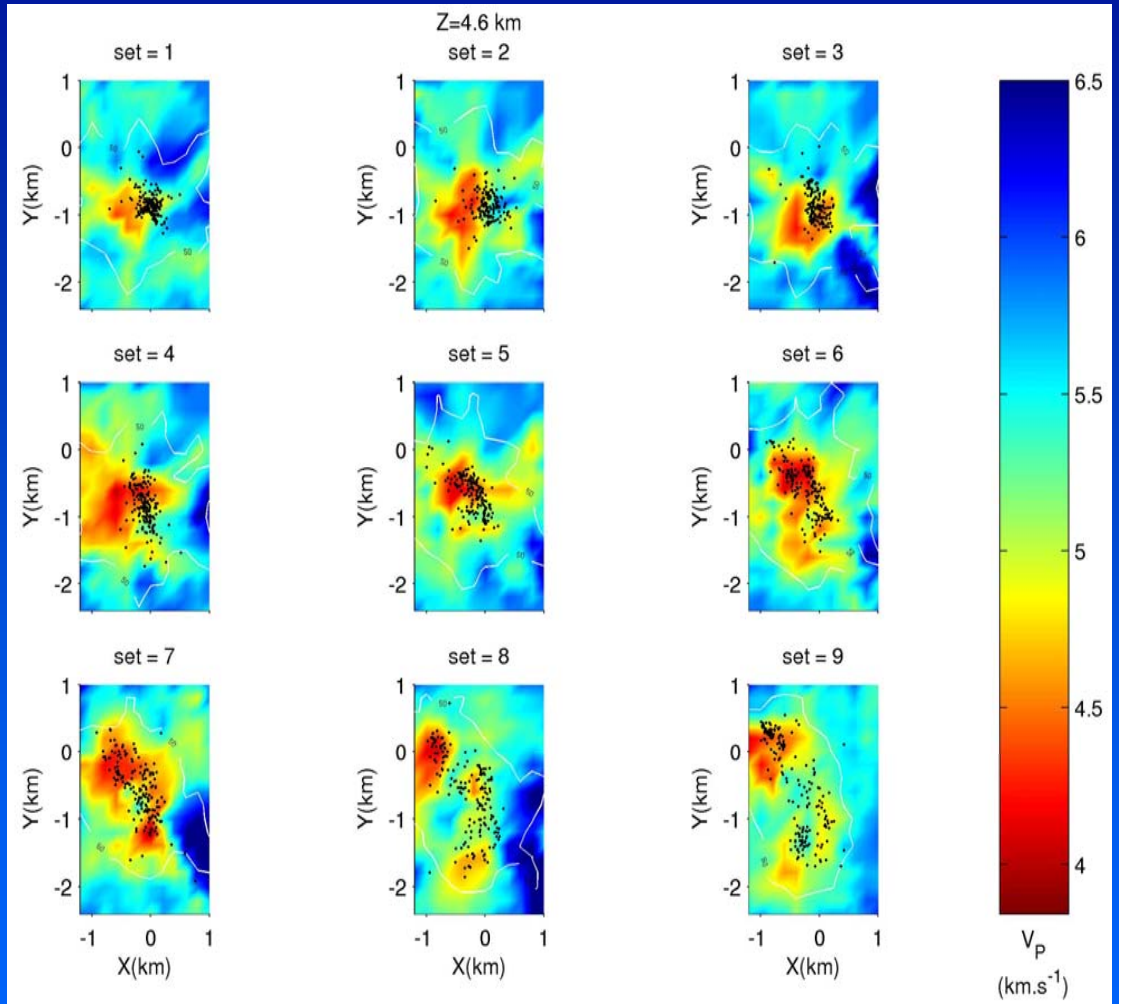
Stimulation of GPK2 in 2003

- Algorithm *TomoDD* (Zhang & Thurber, 2003)
- Combination of absolute and relative arrival times for the inversion
- Simultaneous estimates of the 3D velocity structure and earthquakes locations
- Temporal evolution of the velocity structure (9 sets of 250 events)

Tomographic analysis – Results



Stimulation of GPK2 in 2000



Stimulation of GPK2 in 2003

Tomographic analysis – Interpretation

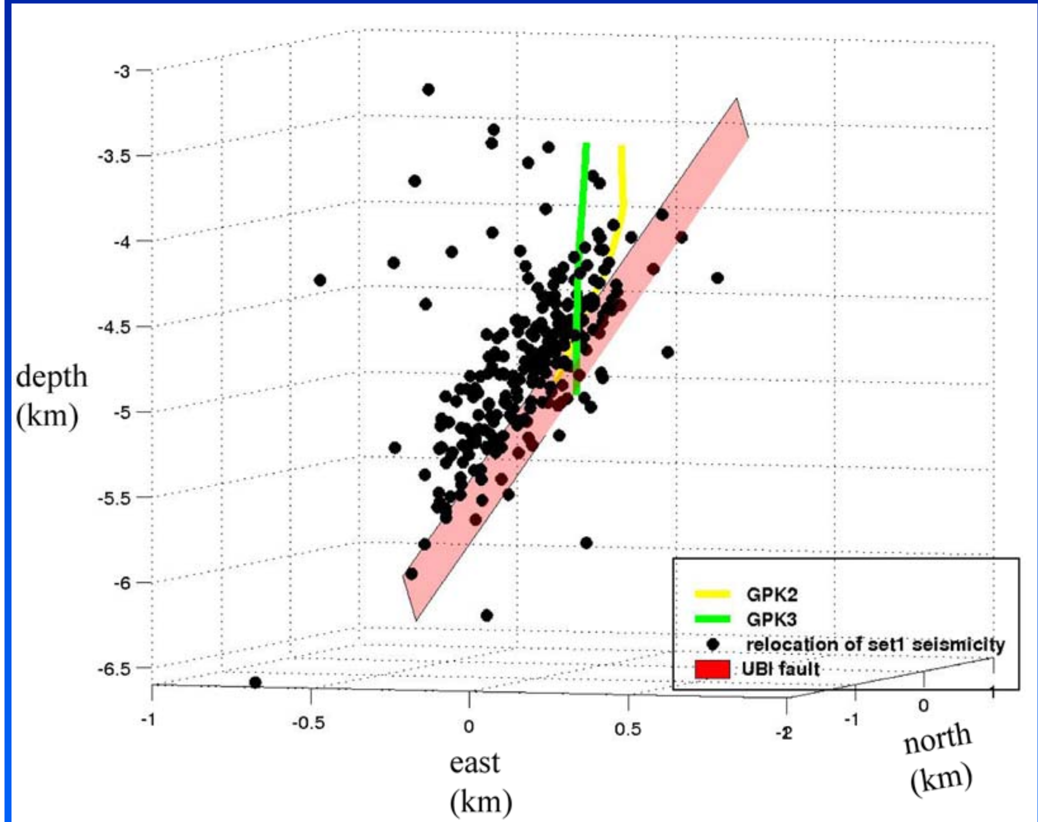
Velocity structure:

- *Parameters that are likely to induce a decrease of V_P*
  - increase of pore pressure
  - increase of porosity (by microcracking for example)

- *Parameters that are likely to induce an increase of V_P*
  - cooling of the medium (injection of cold water)
  - increase of water saturation in the medium

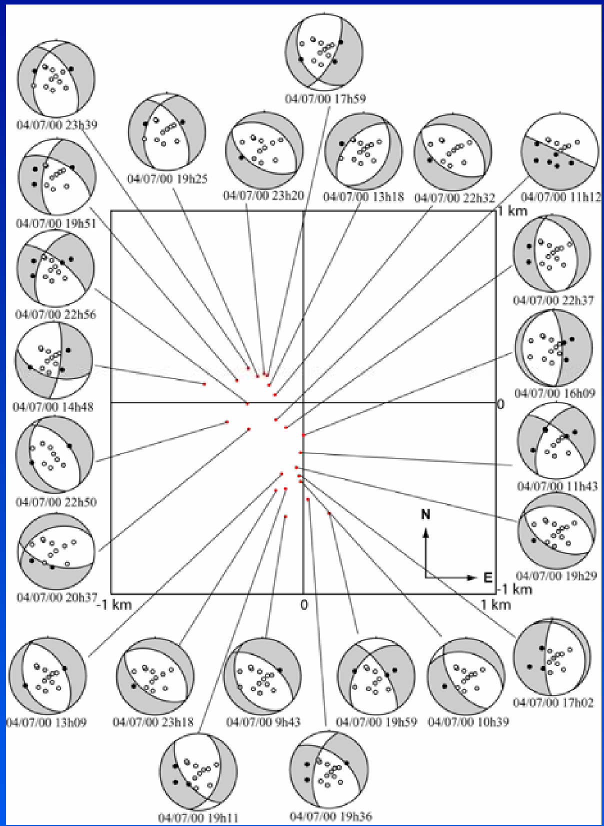
Tomographic analysis – Interpretation

Location of microseismic events:

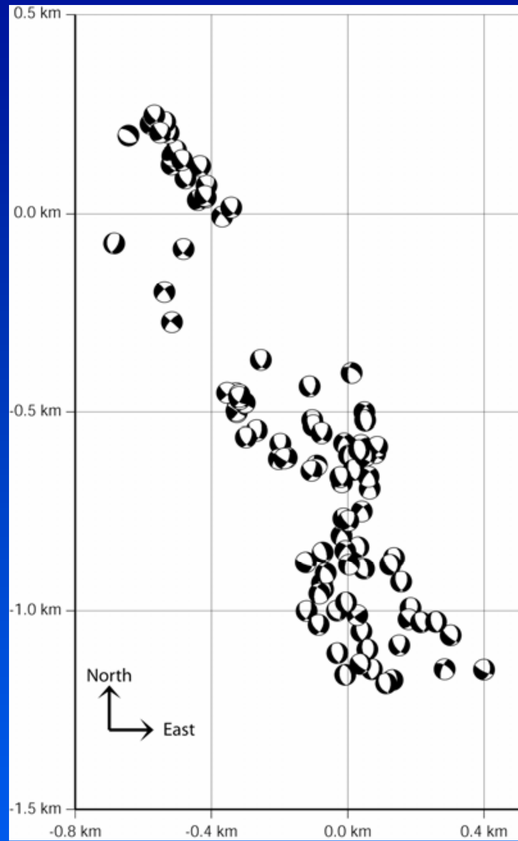


- ➢ First 250 events recorded during the test
- ➢ Seismicity fits with the major fracture plane that was observed with UBI images
- ➢ Characteristics of the fracture: azimut 167°N; dip 75°
- ➢ 80% of the total flow absorbed by the fracture
- ➢ Location of some larger magnitude events

Faulting mechanisms – Fault plane solutions



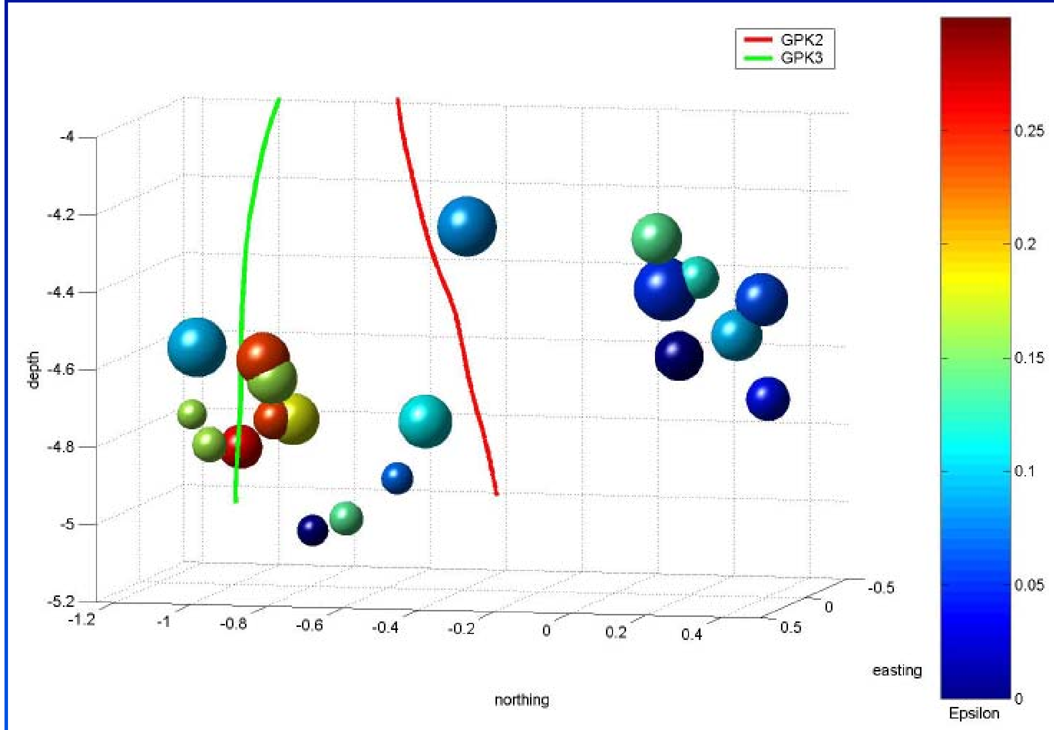
Stimulation of GPK2 in 2000



Stimulation of GPK2 in 2003

- Predominance of normal-faulting solutions, with a more or less pronounced strike-slip component
- Observation of pure strike-slip movements which propotion increases with depth

Faulting mechanisms – Non Double Couple Component



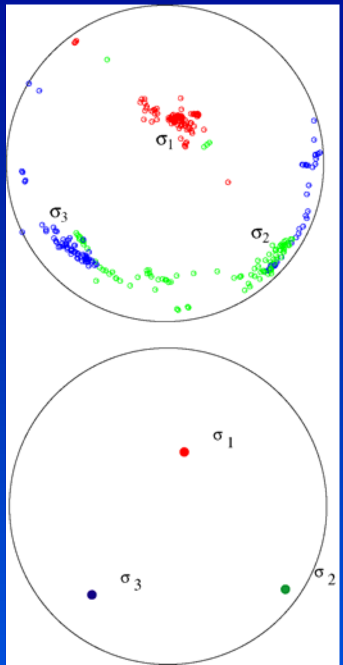
NDC component expressed as ε (-0.5< ε <0.5)

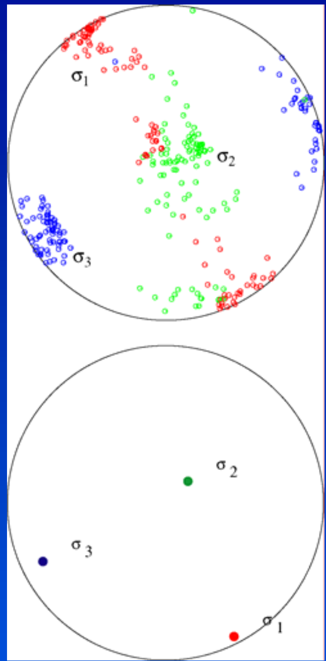
- if ε < 0 → compressive movements
- if ε < 0 → tensional opening
- if 0 < ε < 0.25 → DC dominates
- variations of ε give the proportion of NDC in the movement

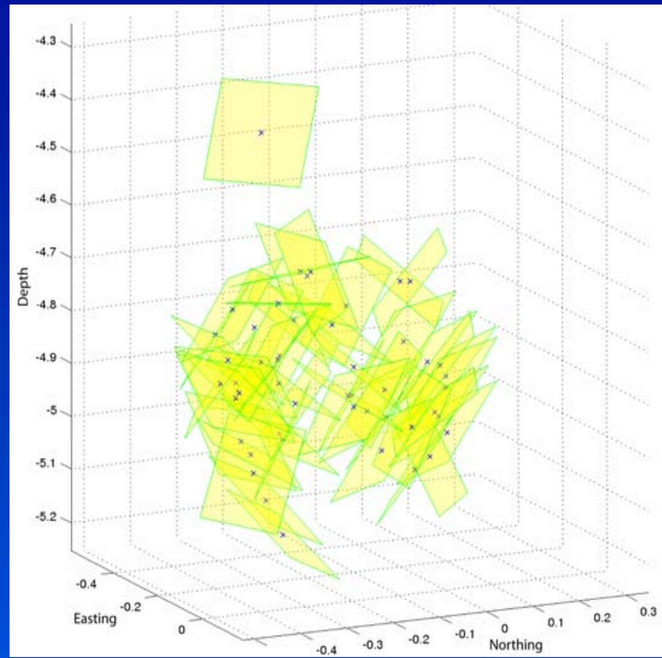
Results:

- always a DC solution for each focal mechanism
- events in the vicinity of the injection well show a high NDC component
- events far away from the injection well show a null or low NDC component
- Effect of the overpressure induced by injections
- indication of tensional opening in addition to shearing

Faulting mechanisms – Stress regime







- NNW-SSE orientation of S_H
- stable orientation of S_h
- S_H becomes major stress at depth, S_V dominant in the shallower part of the medium
- Normal-faulting regime to strike-slip regime
- Scatter of solutions:
  - stress heterogeneities?
  - close value for S_H and S_V magnitude?

- NNW-SSE to NW-SE orientation of the fractures, with dip either to W or E
- Planes dipping to W are subvertical, planes dipping to E subhorizontal
- En echelon fracture system

Conclusions

<u>For stimulation monitoring purpose:</u>

➢ ***tomographic methods can help:***

- viewing the variations of the velocity structure during injections

- linking these changes with variations of rocks properties

- observing the effect of the stimulation process

- relocating precisely the microseismic events

➢ ***Faulting mechanisms bring information on:***

- the type of movements on fault planes

- the stress regime (orientation of the components of the stress field)

- the geometry of the fracture network