

# De la mécanique des roches à la géomécanique crustale : l'étude des champs de contrainte naturels

François Henri Cornet, Institut de Physique du Globe de Paris

De l'origine des contraintes dans les terrains sédimentaires, au dessus des zones de découplage mécanique ?

Les massifs rocheux sont-ils juste à l'équilibre et qu'en déduire pour la sismicité induite ?

L'expérience de mesures dans le granite de Forsmark (Suède) : la notion d'assurance qualité et la difficulté posée par les variations rapides, non linéaires.

# Variation verticale des contraintes principales sur le site de Bure

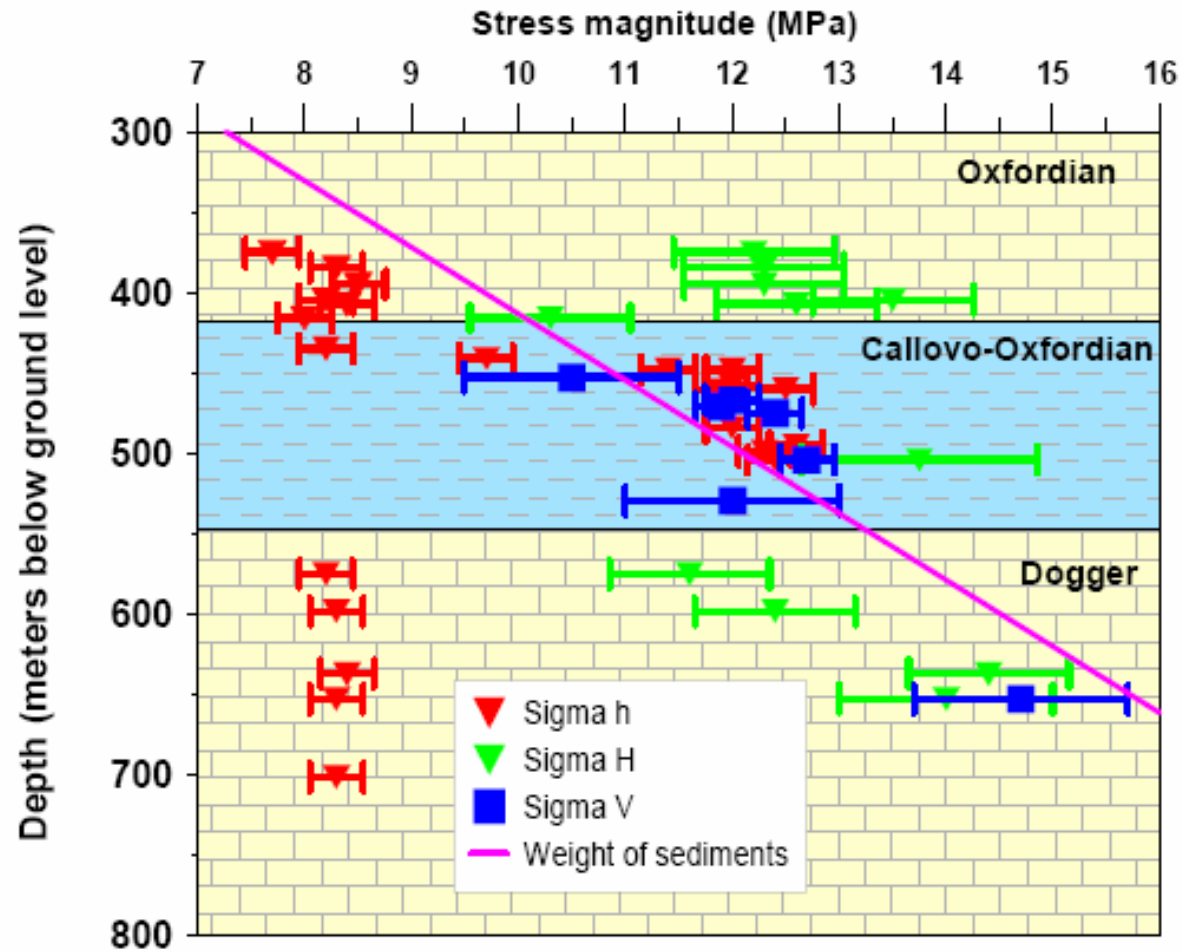
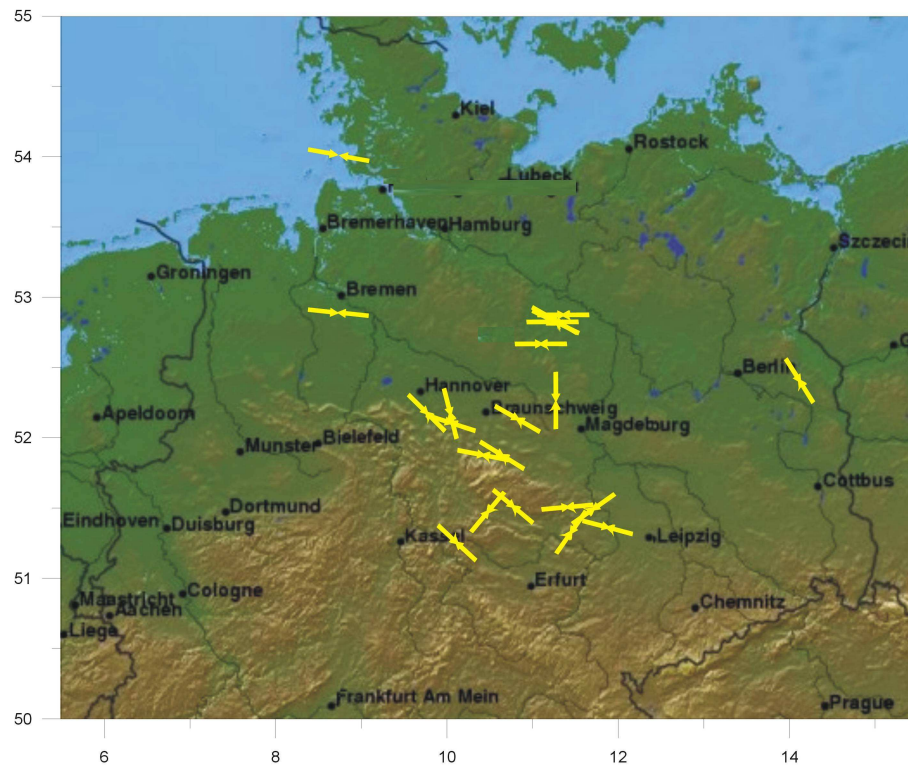


Figure 13 : Profile of magnitude of the in situ stress at the Bure Site

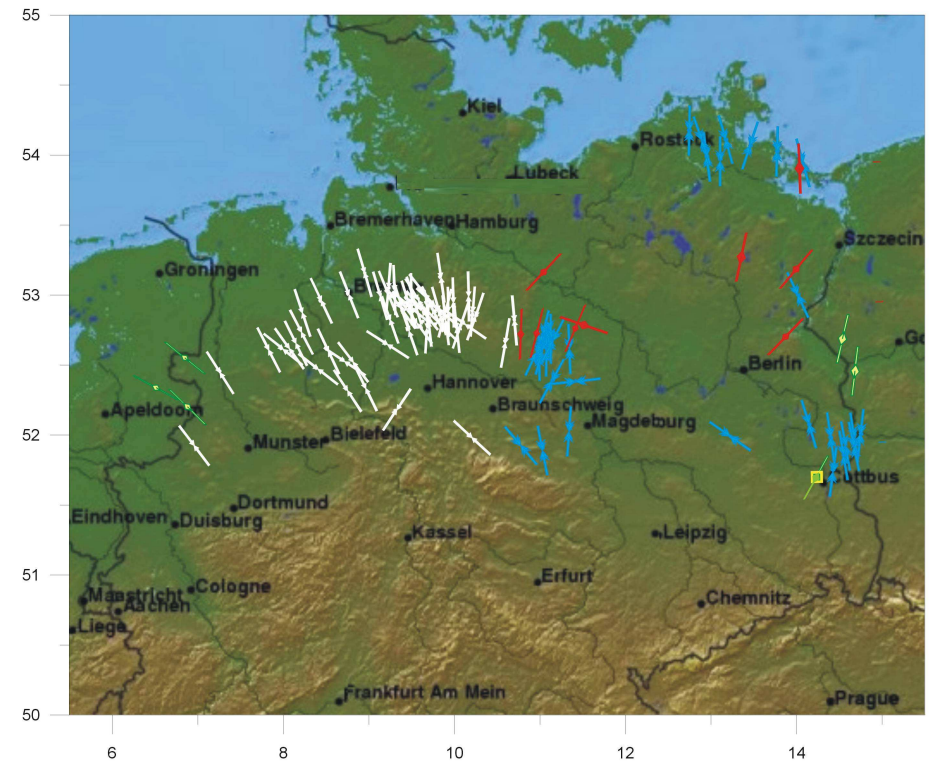
# De l'effet du Keuper évaporitique sur le champ de contrainte en Allemagne du nord

Direction de la composante maximum horizontale

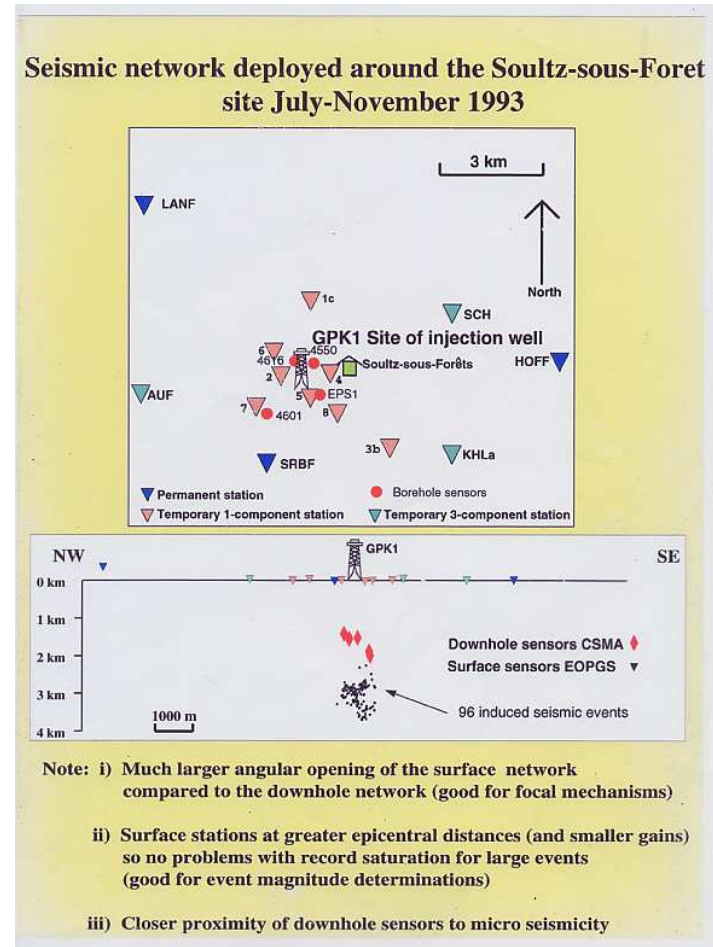
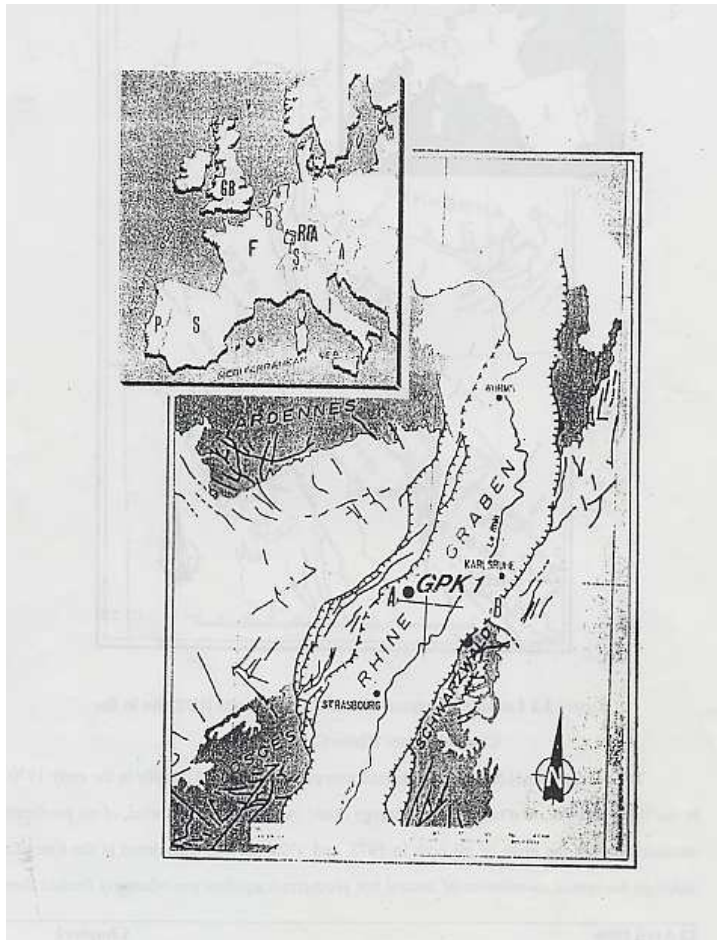
Au dessus du Keuper salin



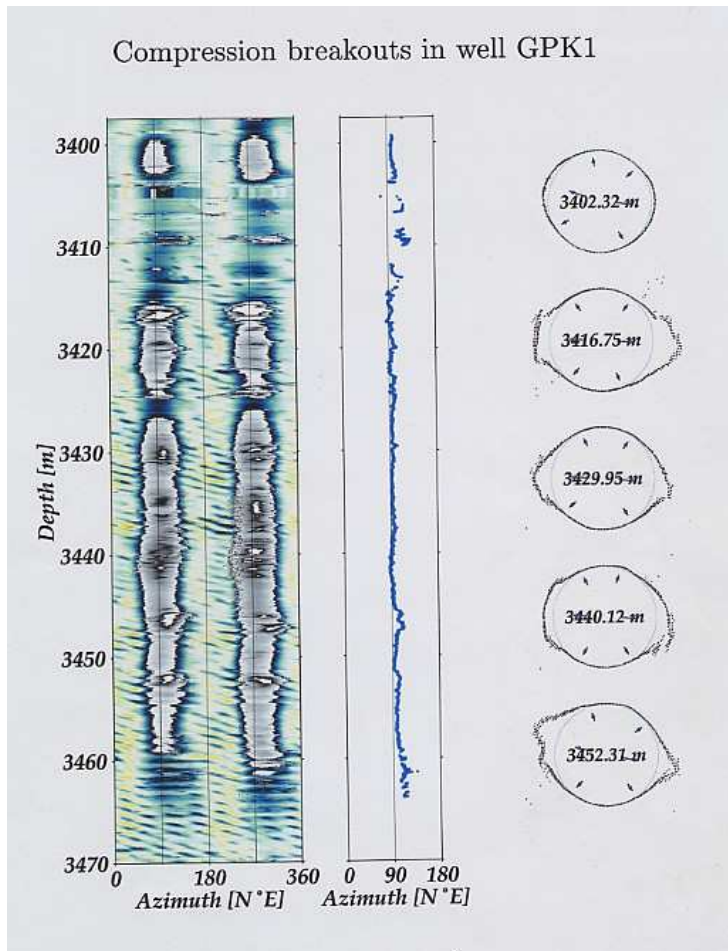
Au dessous du Keuper salin



# Le site expérimental de géothermie artificielle à Soultz

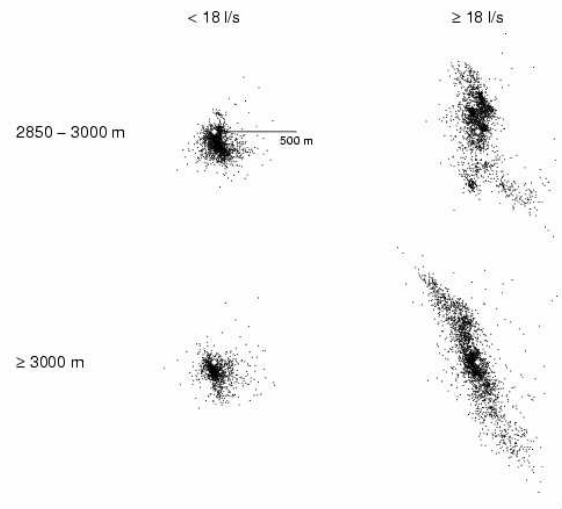
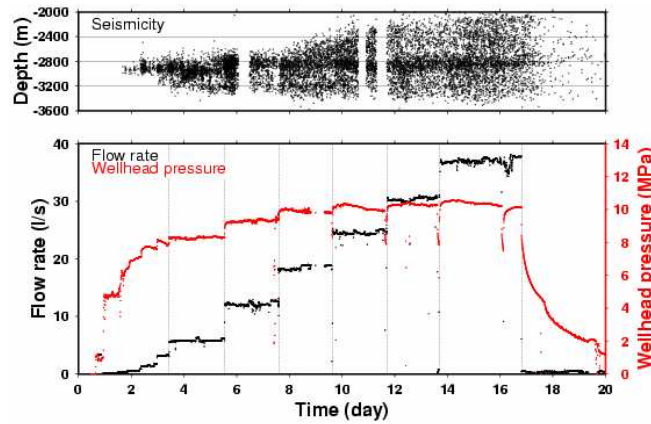


# “Breakouts” de compression observés dans le forage GPK1 vers 3440 m (Th. Bérard, 2003)



- Les “breakouts” de compression sont localisés dans les zones de contrainte tangentielle (orthoradiale) maximum :  
$$-\sigma_h + 3 \sigma_H - P_b - f(P_0) - \alpha E \Delta \theta / (1 - \nu) = \sigma^c$$
- Pas de “breakouts” vus initialement dans le forage GPK1 : **Problème de l’influence du temps sur le développement des « breakouts »**.
- Influence du temps sur la résistance en compression (e.g. Hudson & Brown, 1973)

# Écoulement , sismicité induite, et seuil de rupture

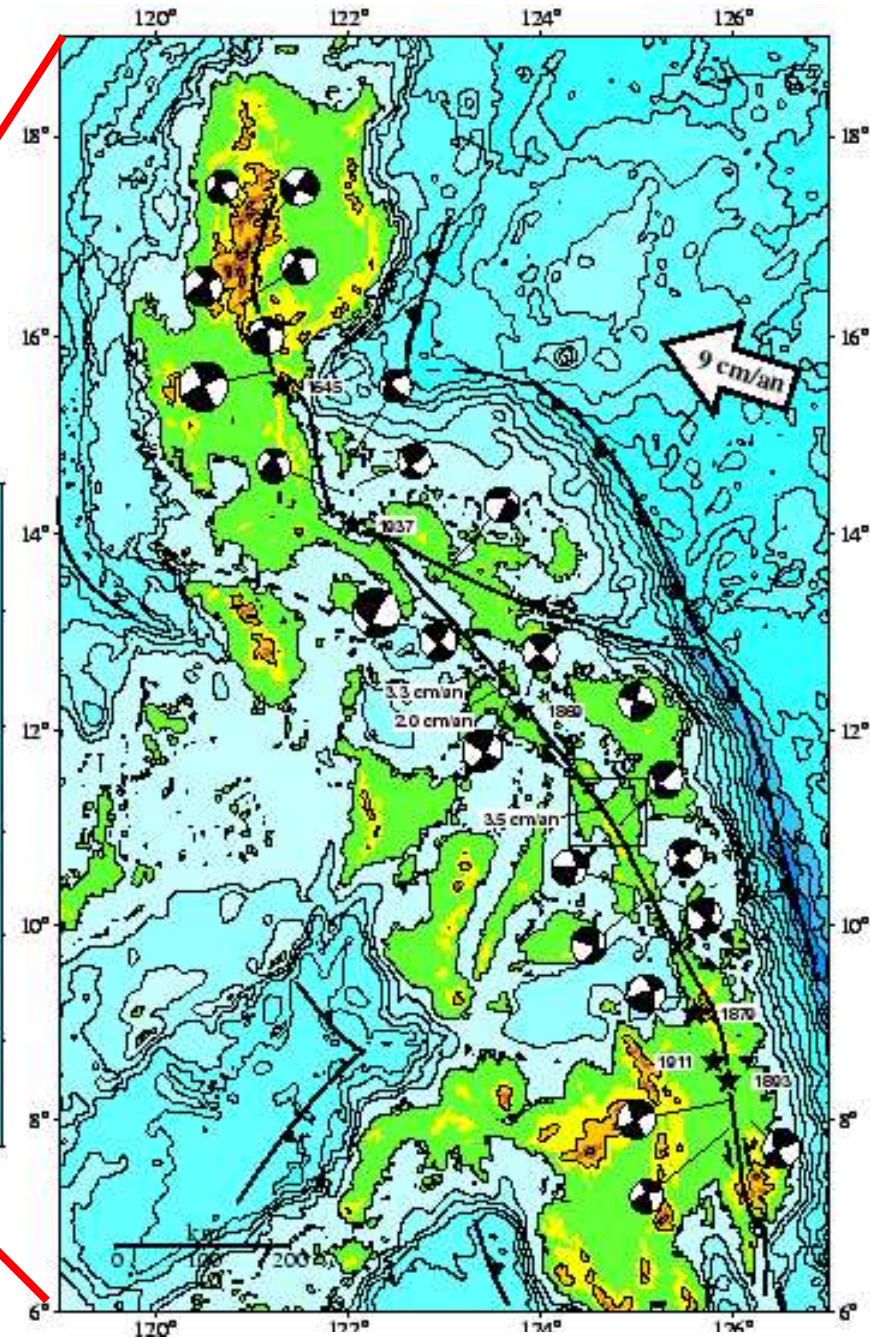
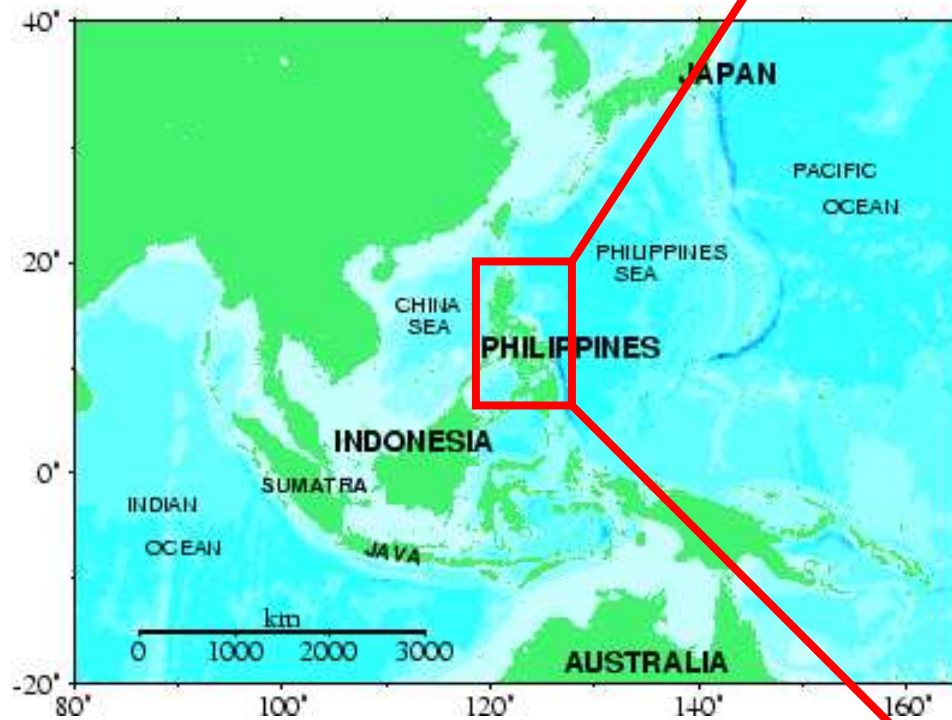


# Des questions posées par la sismicité induite

- L'apparition de sismicité est-elle significative d'une instabilité majeure ?
- Comment prévoir la taille maximum des séismes induits sur un site donné ?

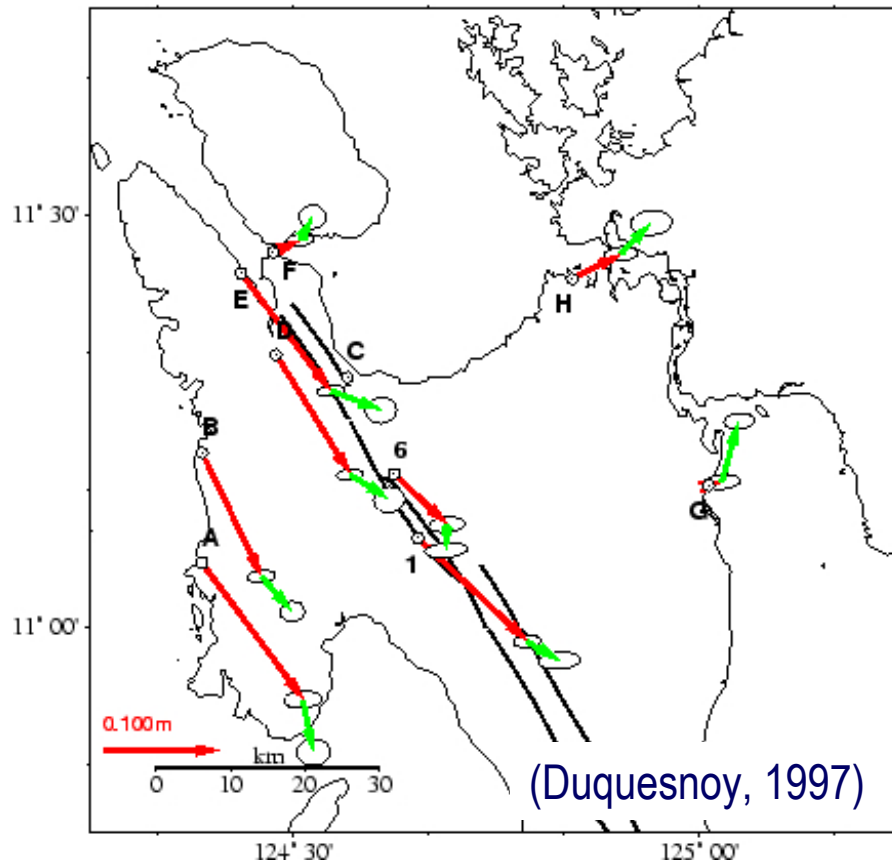
# Philippine Fault

Prioul, 2000



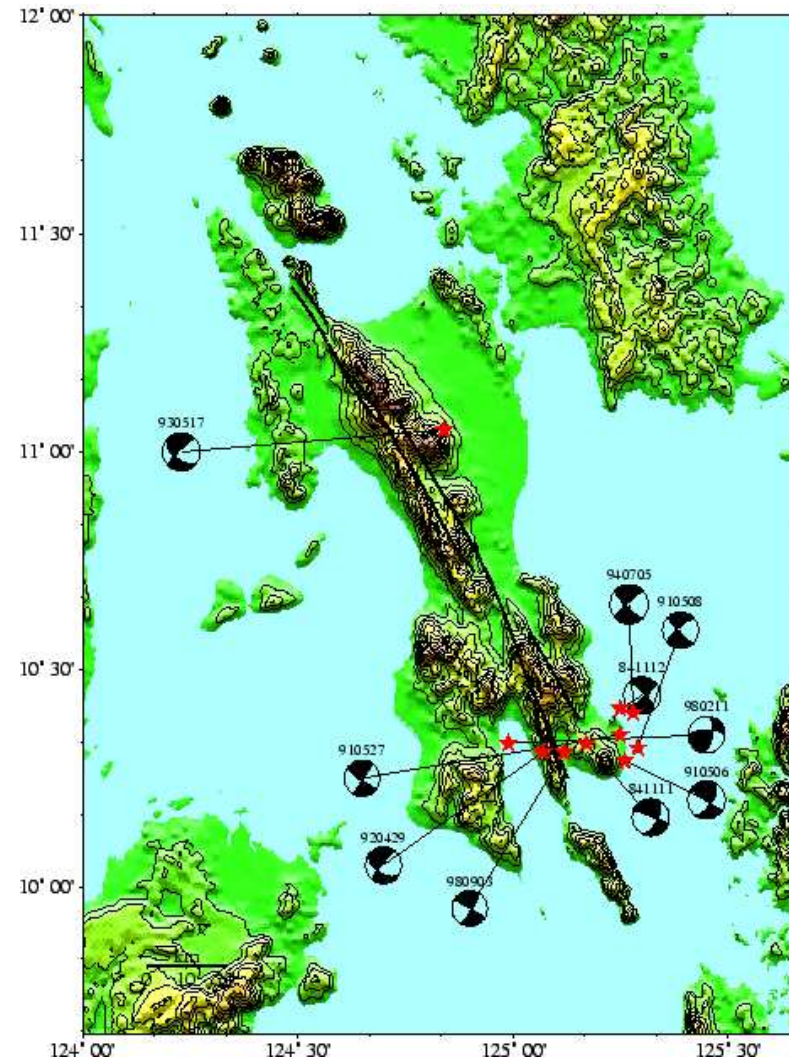


# Displacement field in the vicinity of the fault

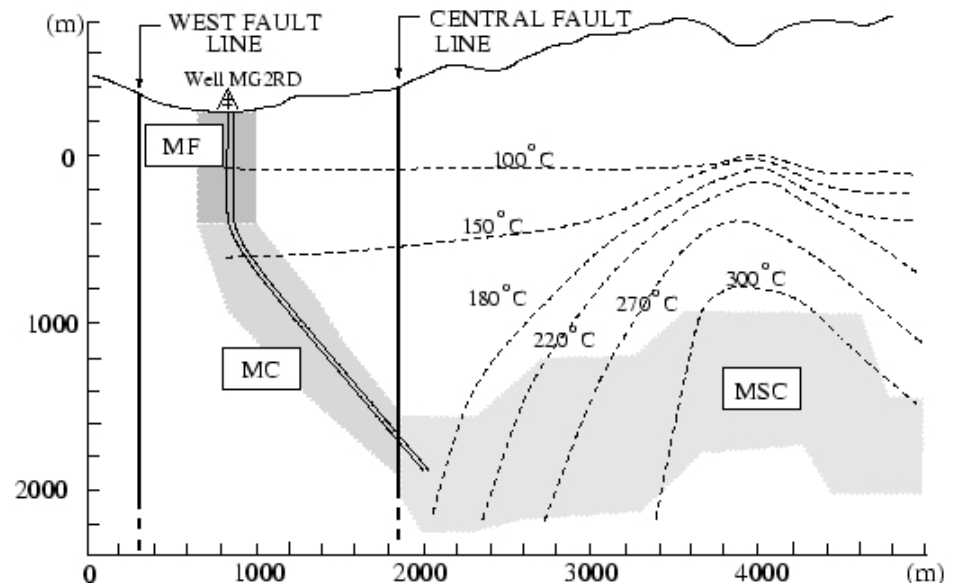
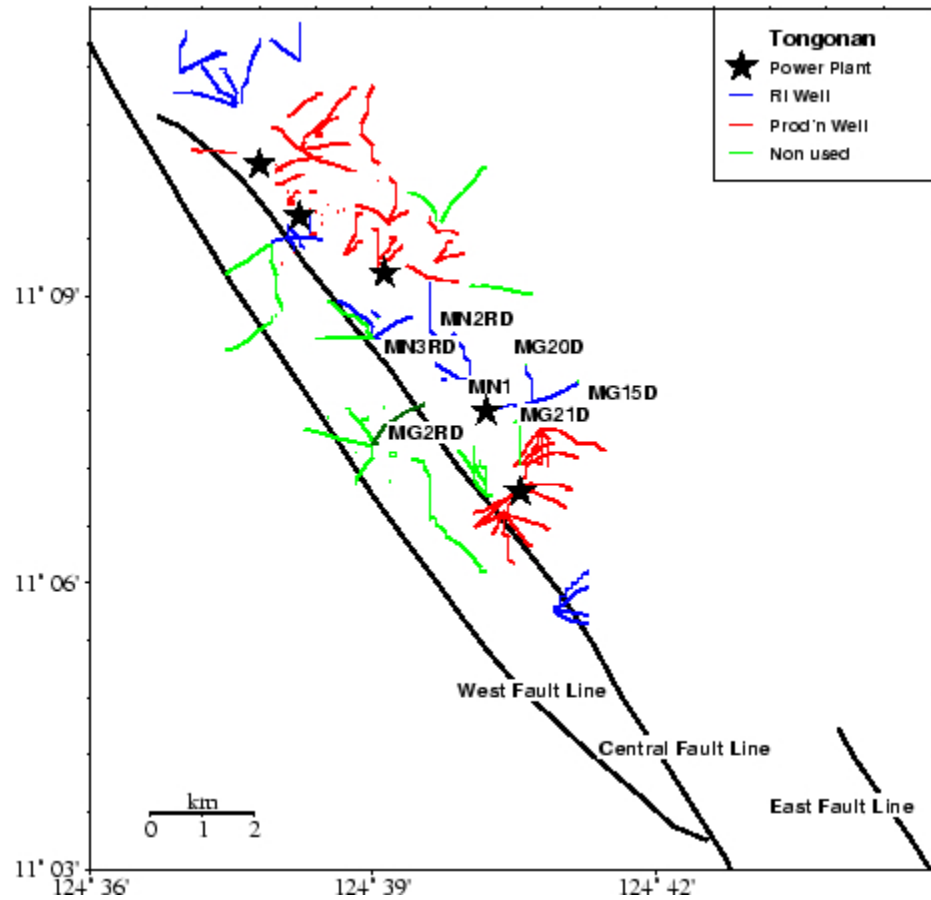


- GPS measurement 91-94-95
- 3.5 cm/y of creeping displacement
- (C is taken as reference point)

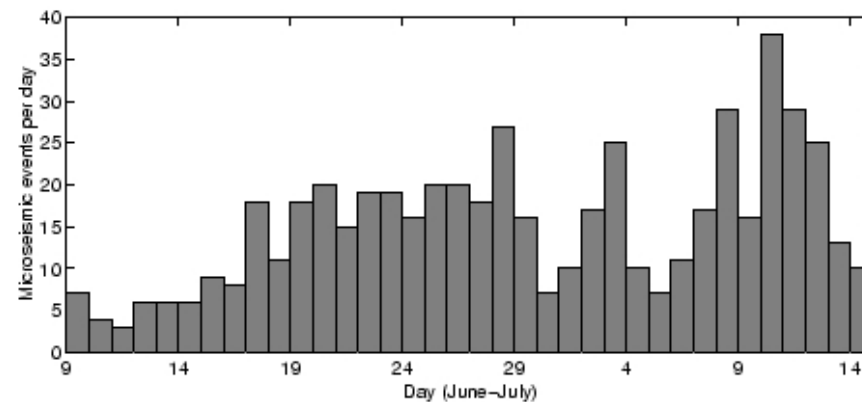
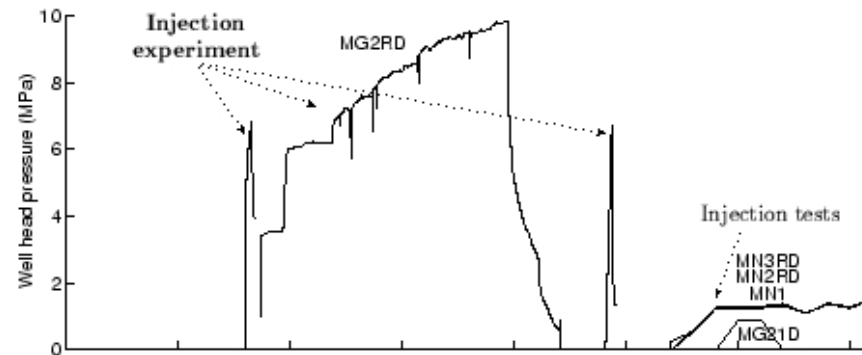
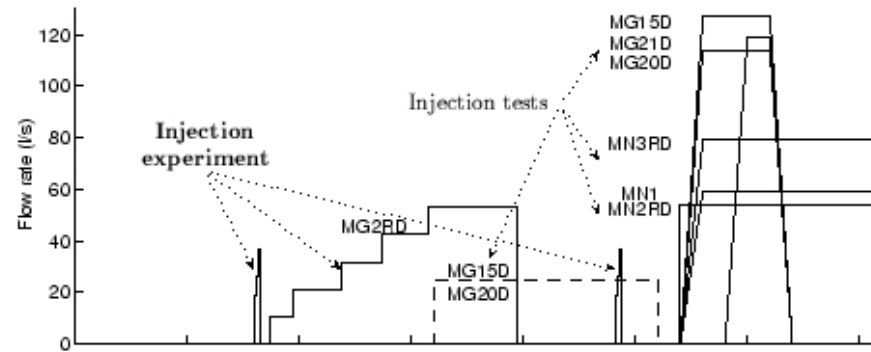
# Seismicity



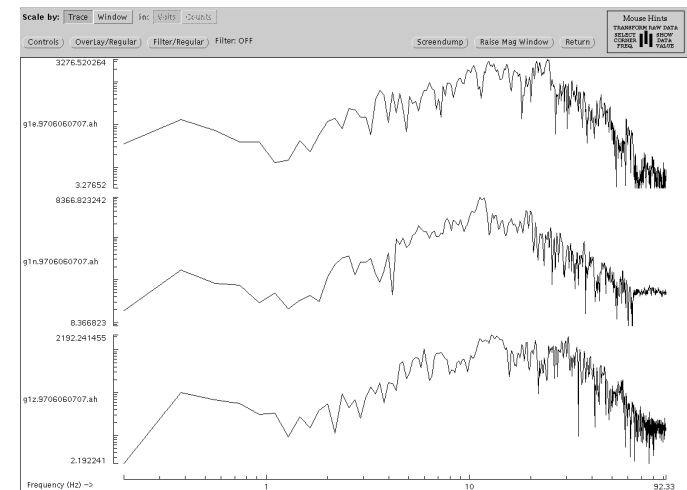
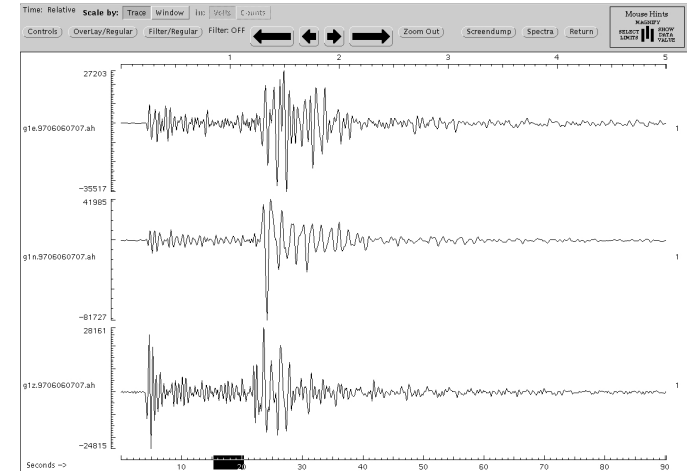
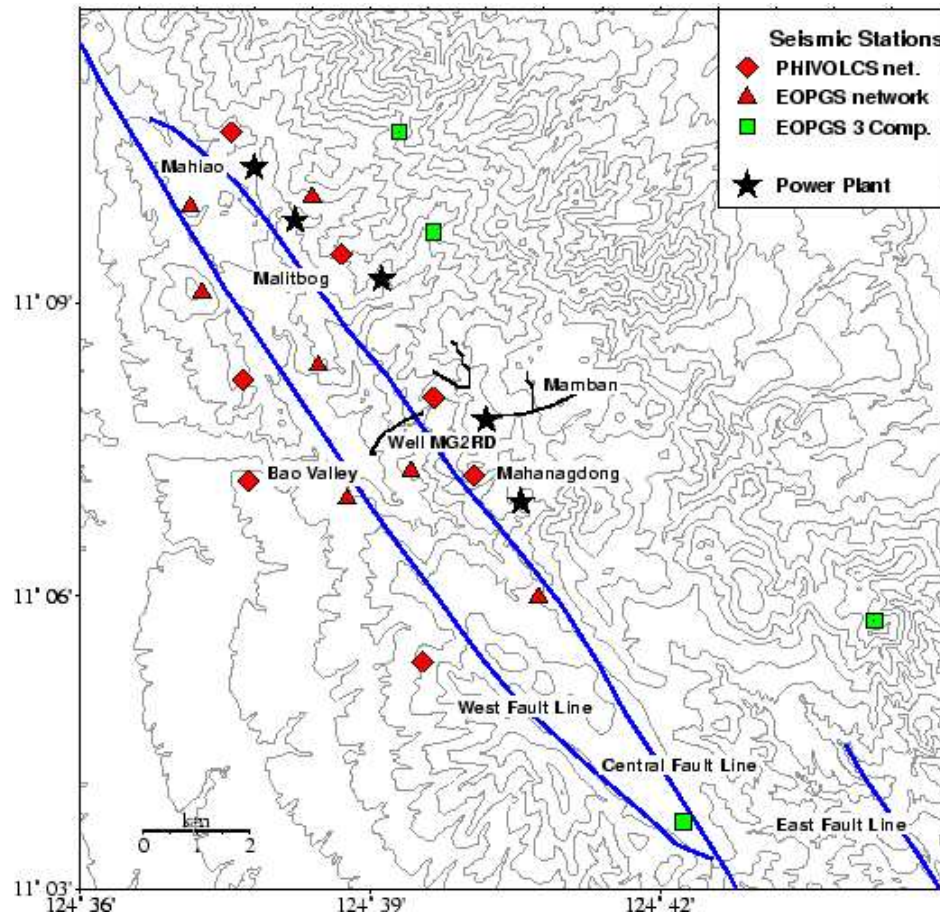
# Injection experiment



# Injection experiment

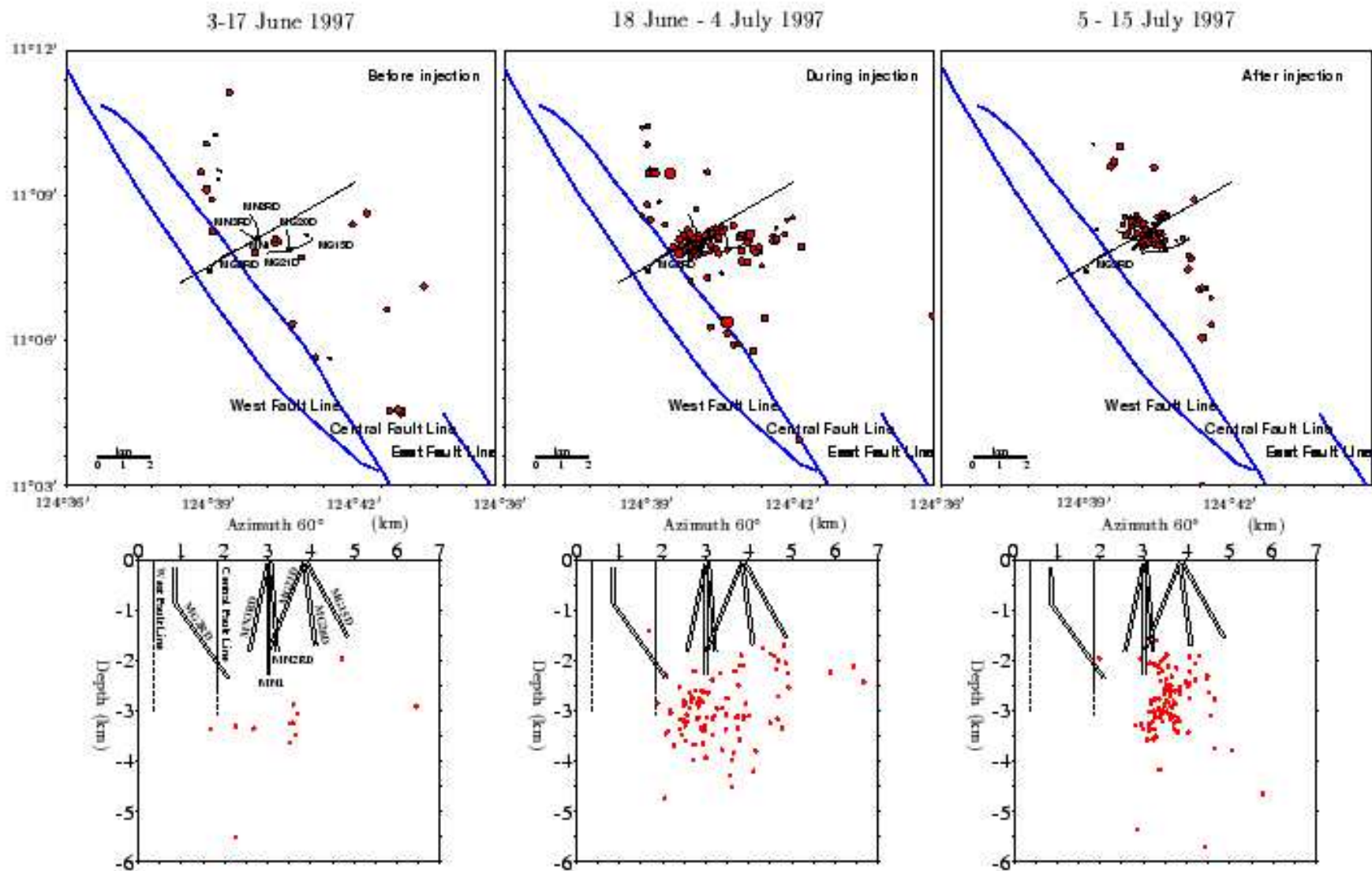


# Seismicity monitoring



- Surface network (1-30 Hz)
- Feb. – Aug. 96 (Period 1) and Nov. – May 97 (Period 3): 7 stations
- Oct. – Nov. 96 (Period 2) and Jun. – Jul. 97 (Period 4): 18 stations (Four 3-C)

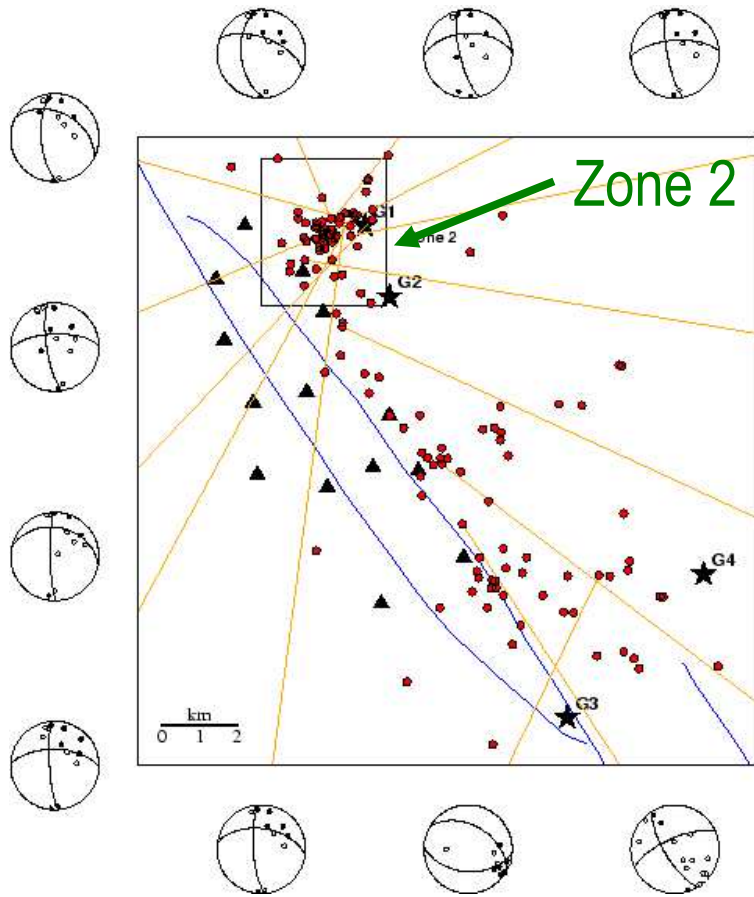
# Induced microseismicity locations



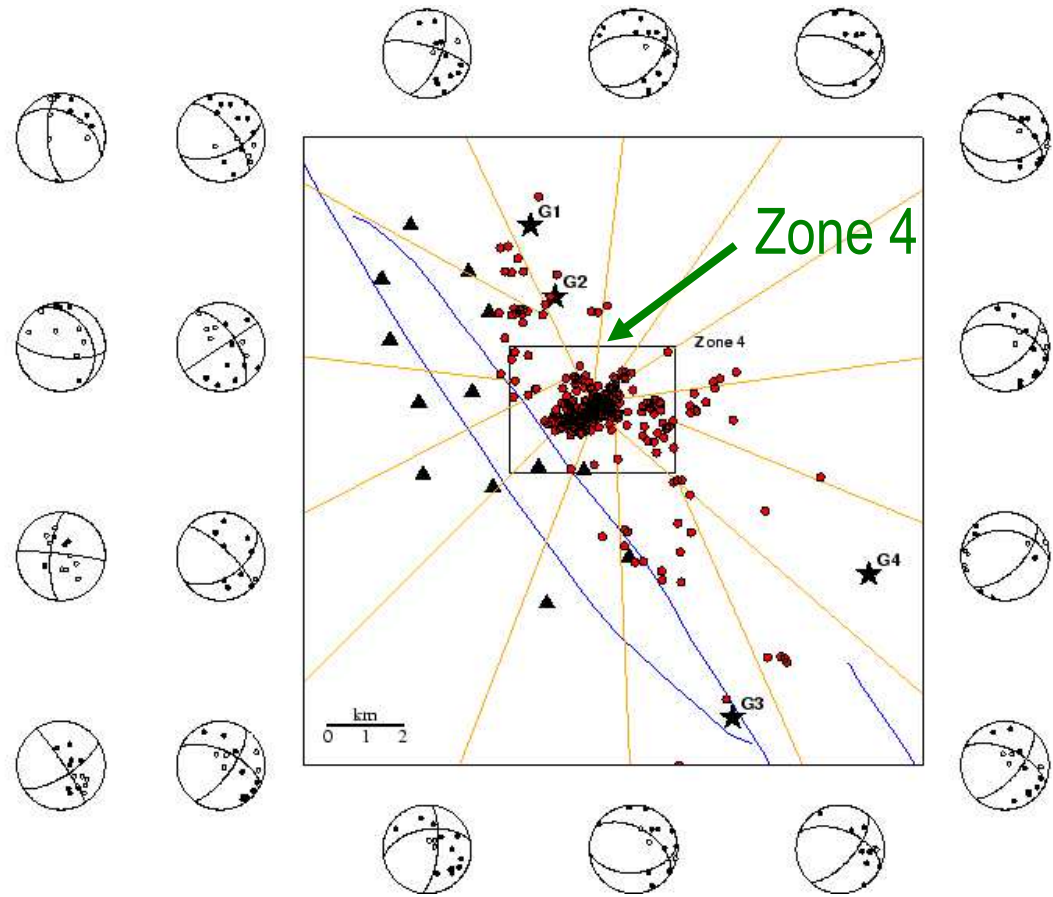
# Focal mechanisms

Period 2

Period 4



32 solutions

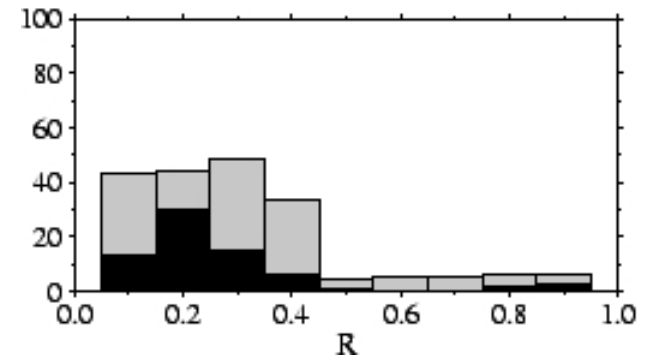
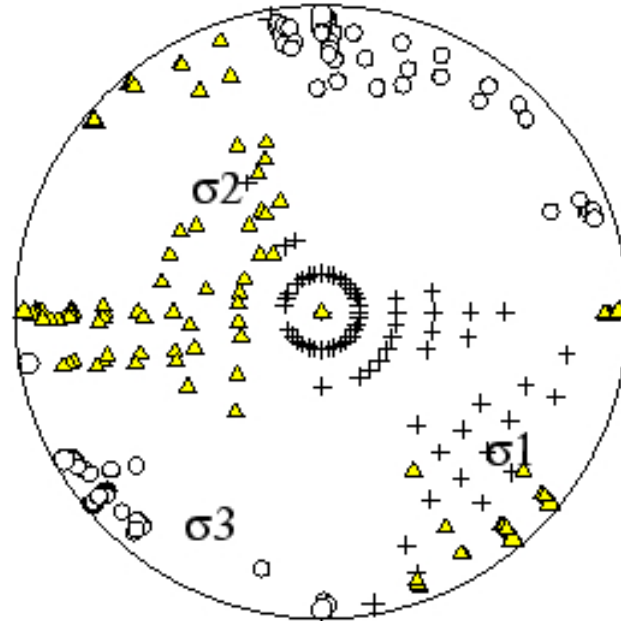


40 solutions

# Focal mechanisms inversion -first trial by zones-

Zone 2

23 focal mechanisms



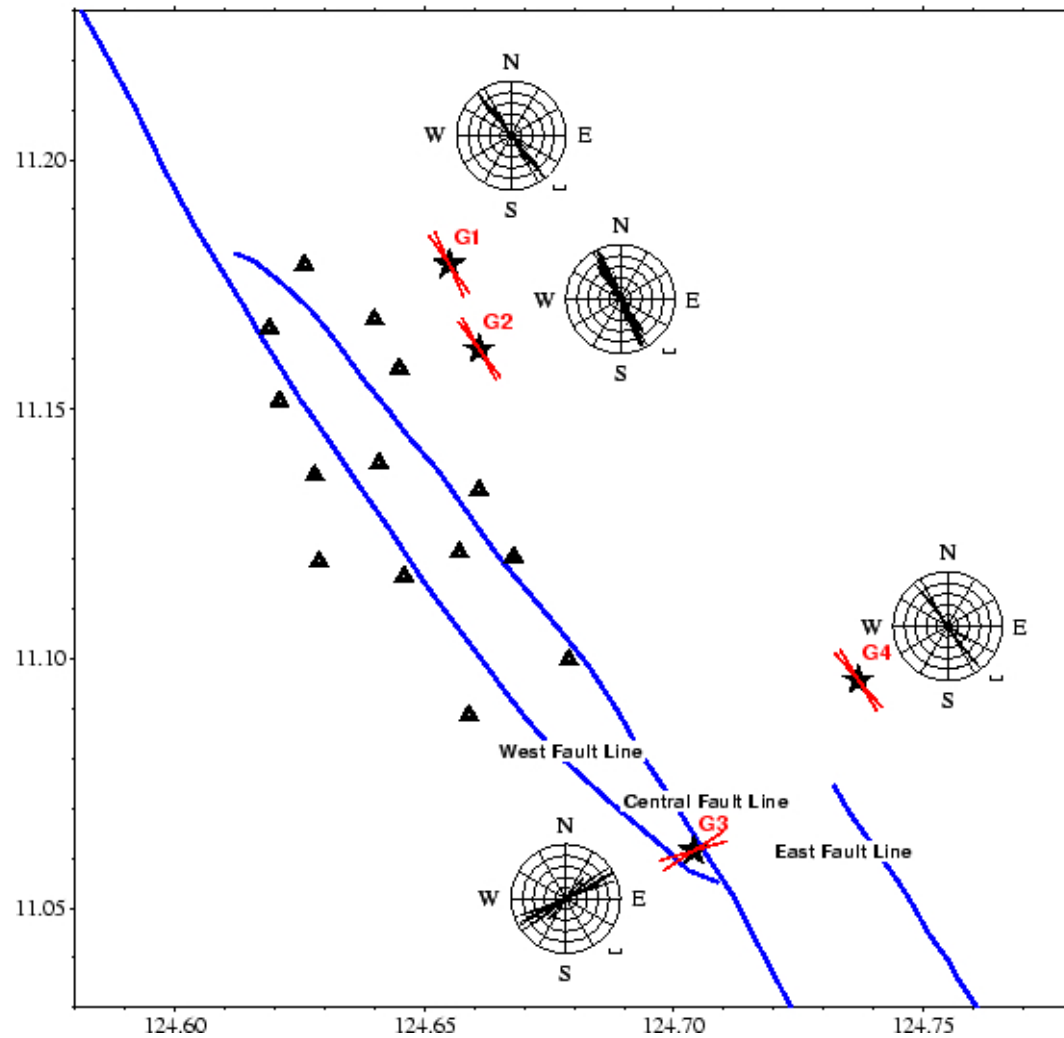
Solutions in 90 % confidence domain

Best solution compatible with 83 % of the data

Zone 4: no solution

# Fast S- wave polarisations

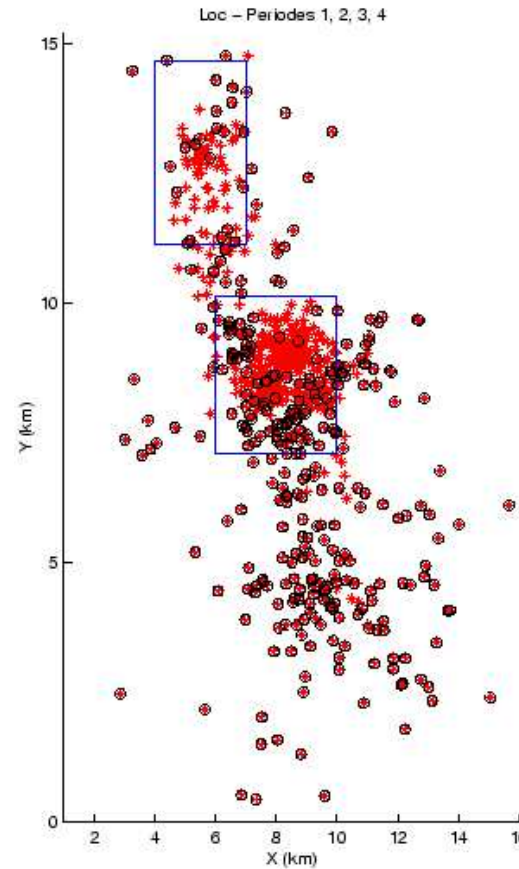
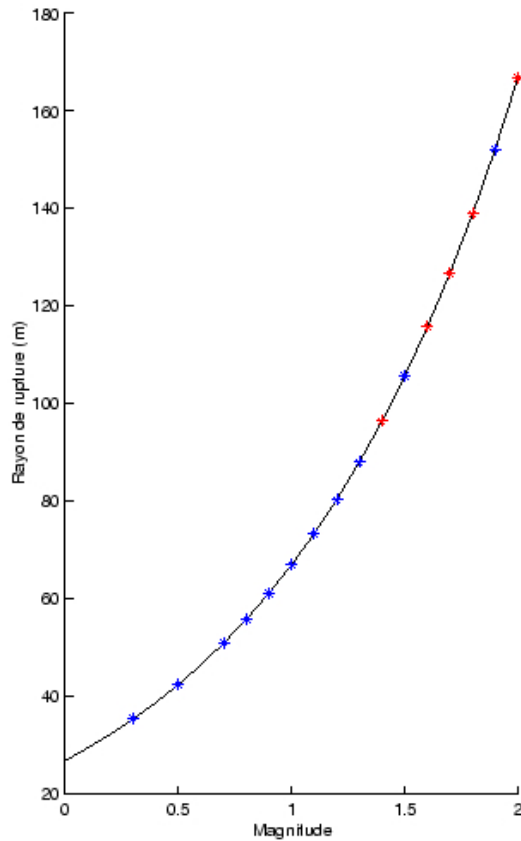
-Period 2 and 4 -



- Shear wave splitting
- G1, G2, G4: parallel to fault
- G3: orthogonal to fault



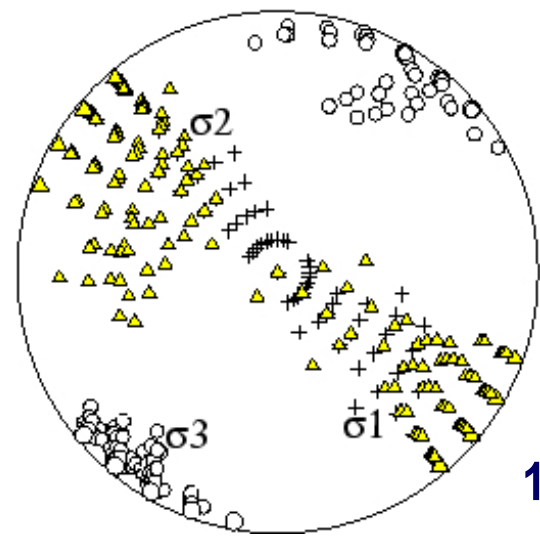
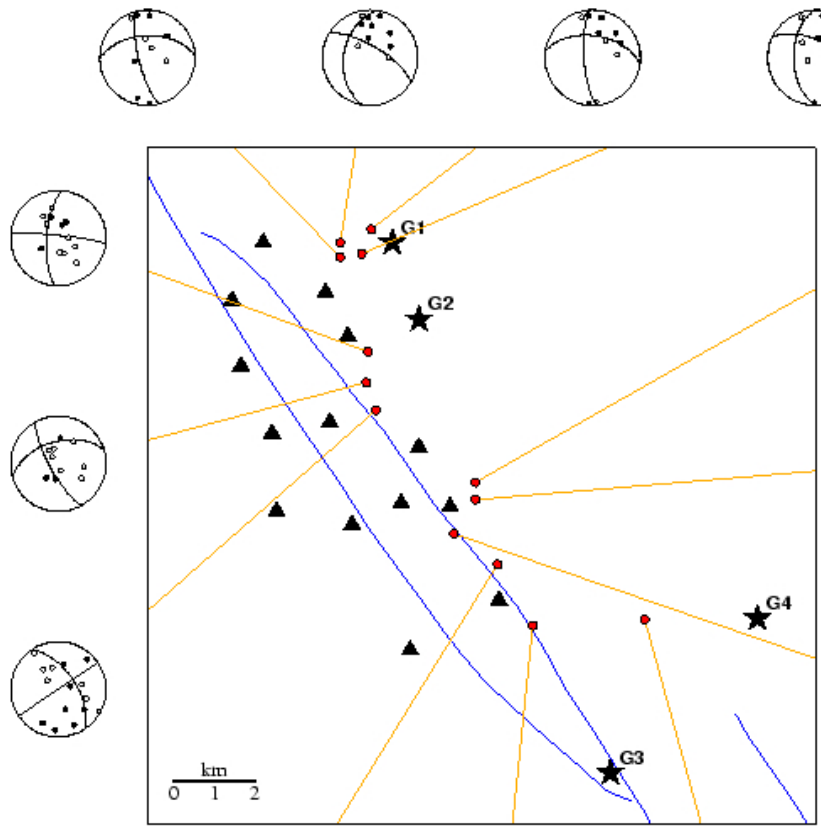
# Stress heterogeneity in the seismicity cloud?



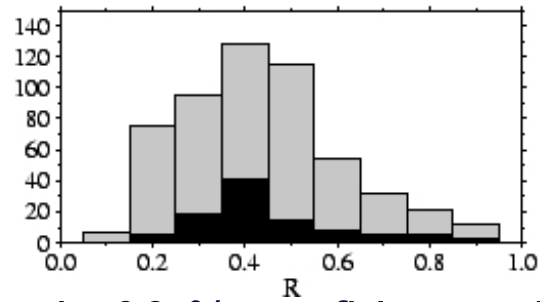
## New data selection:

- Definition of a sphere for each event with radius~rupture dimension
- Successive events with intersecting spheres are excluded

# Focal mechanisms inversion -new data selection-



13 foc. Mech.

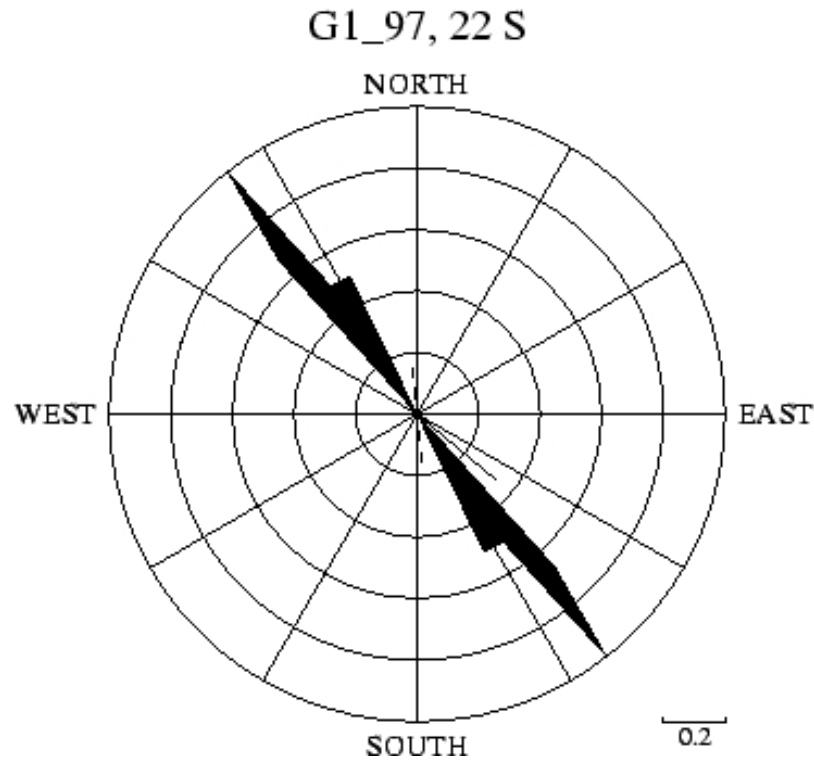


Solutions in 90 % confidence domain  
Best solution compatible with 91 % of the data

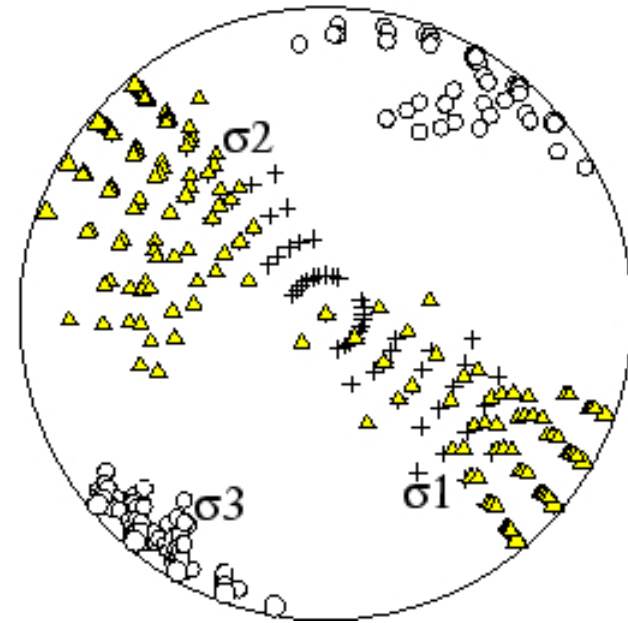
# Fast S- wave polarisations Inversion focal mechanisms

-east of the Central Fault (G1, G2, G4) -

-new selection-

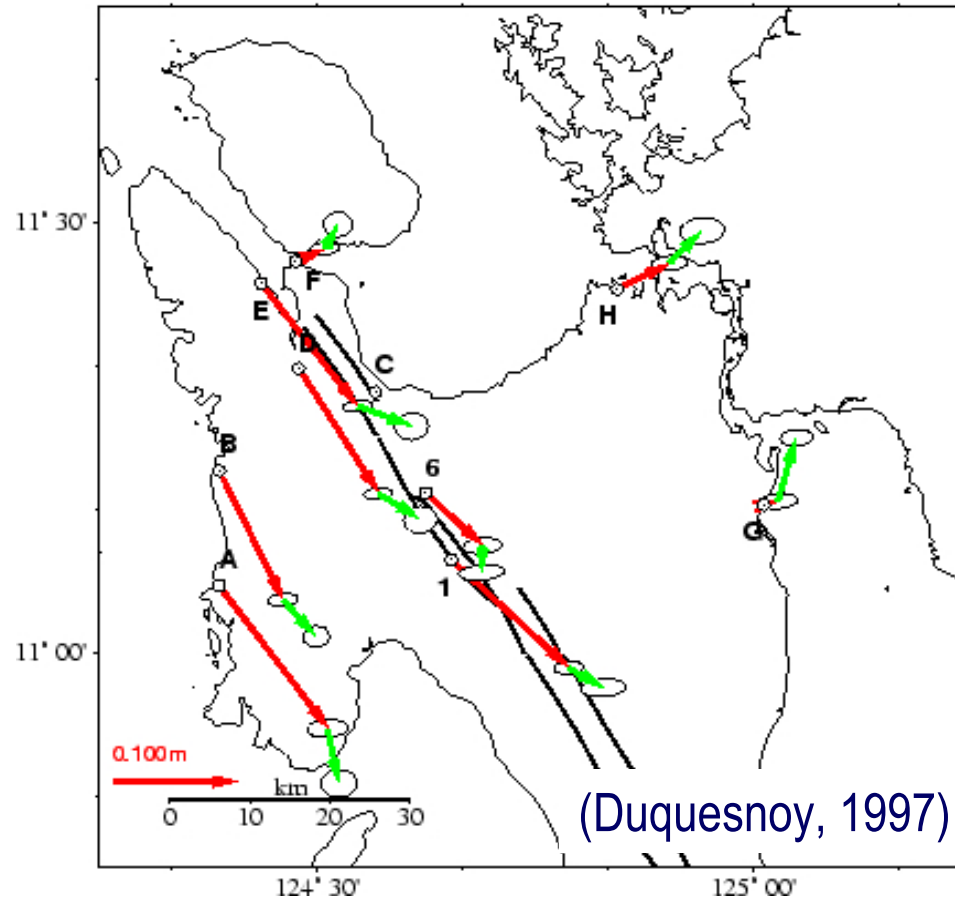


Fast polarisation ~ 145 deg.



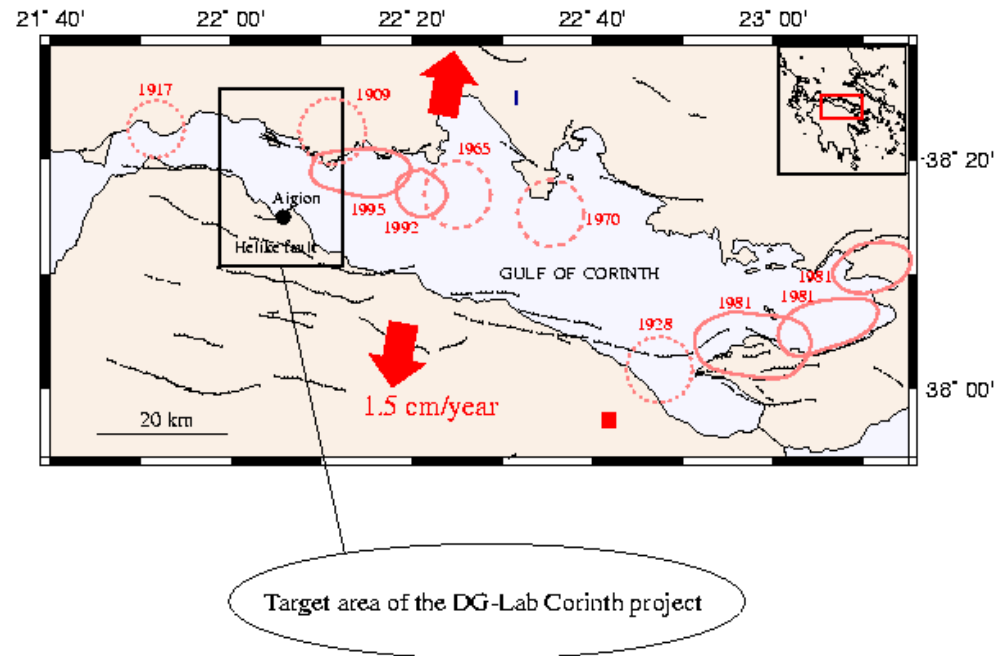
$\sigma_1$  and  $\sigma_2$  ~ 110-150 deg.

# compatibility with regional context



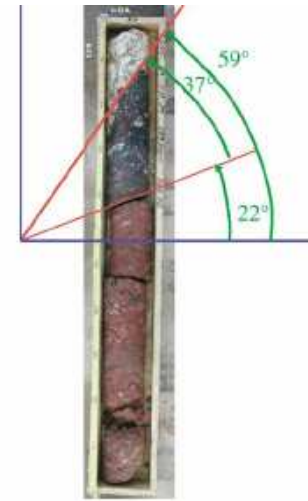
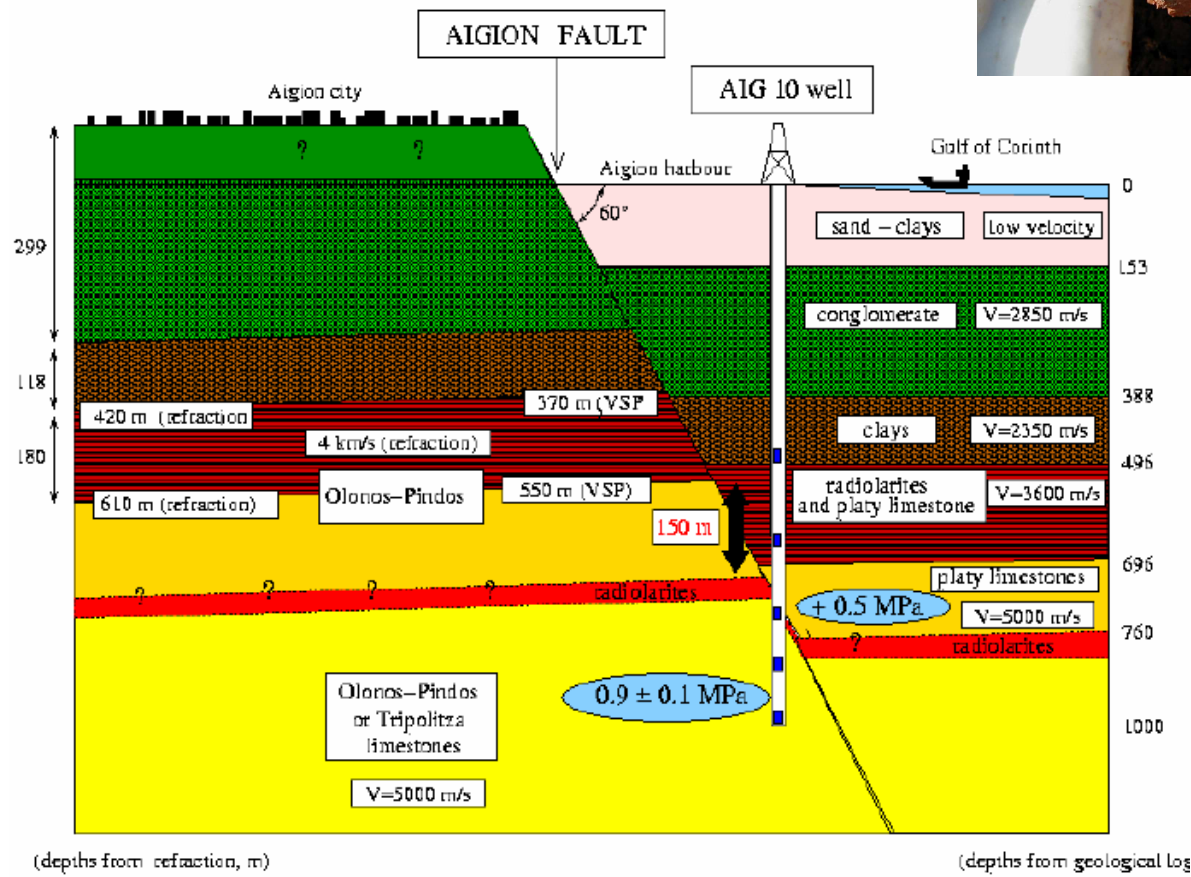
- Minimum principal stress orthogonal to fault
- GPS data show extension orthogonal to fault  $\sim 0.6-1.8$  cm/y

# The Corinth Rift Laboratory

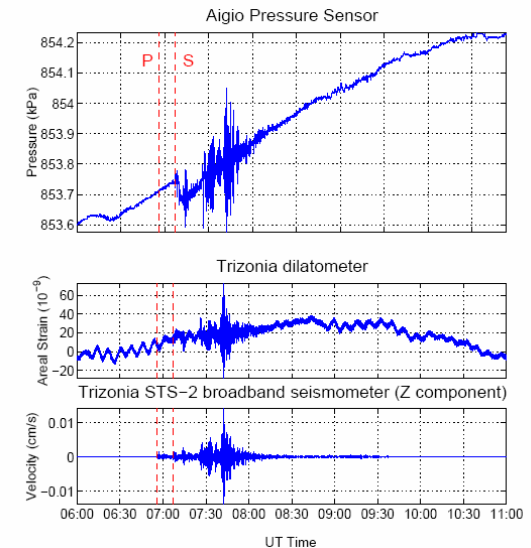


- **Surface and sub-surface networks :**
  - Seismological network ; deformation monitoring; hydrological monitoring; fluid geochemistry monitoring ; underwater geodetic surveys
- **Borehole investigations**
  - In Trizonia (150 et 350 m deep boreholes)
  - In Aigion (1000 m deep borehole)

# In situ observation with the 1000 m deep AIG10 well

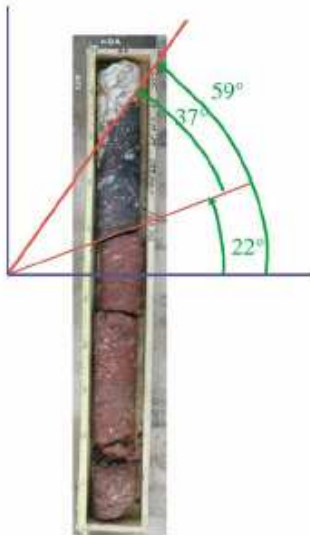


Local pore pressure drop triggered by a 10 000 Km Magnitude 8 Earthquake



# Stress field in the vicinity of the fault

(Sulem, 2006, Prioul, 2004)



- Given the mechanical properties of the clays of the fault, the analysis of the orientation of the slip plane and of the orientation of the slip lines in the plane yields a principal stress direction perpendicular to the mean fault plane.

