SENSE

WEBINAR SESSION 3 - **18TH February 2022**

MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA Y EL RETO DEMOGRÁFICO

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Seismicity monitoring at onshore CO_2 geological storage sites

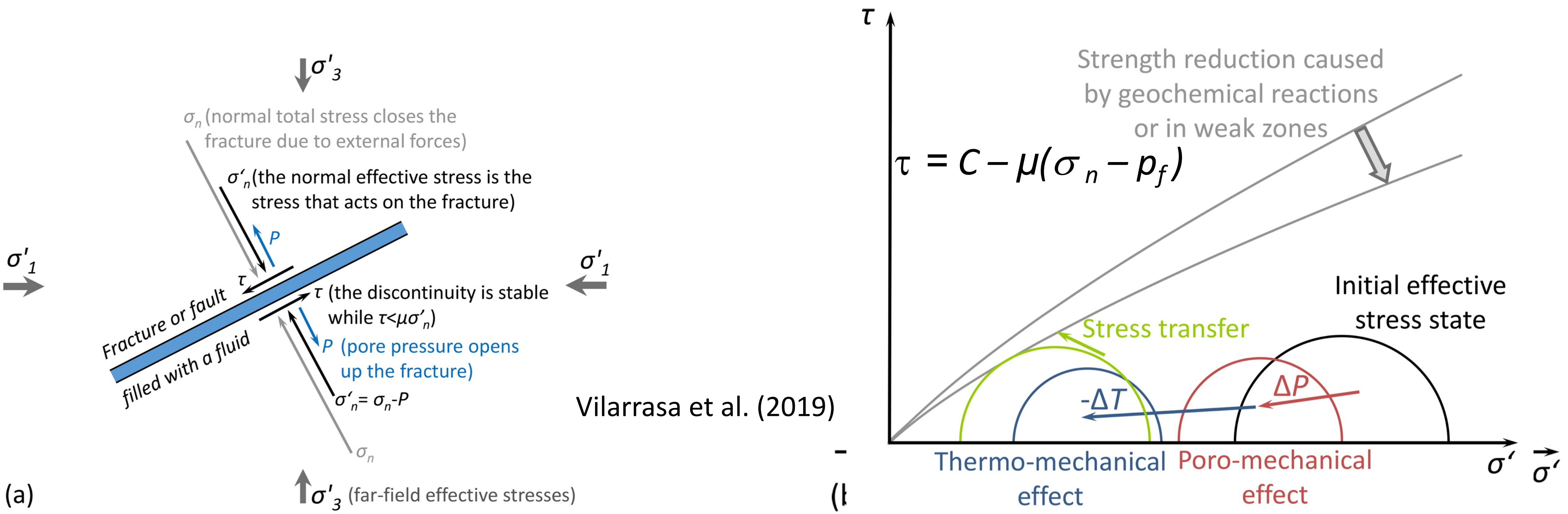
LESSONS LEARNT FROM HONTOMIN SITE

Dr. Almudena Sánchez de la Muela (CIUDEN)

How is seismicity induced?

Change in rock and fault stress state, **pore fluid pressure** rise favors failure

Poro-mechanical and thermo-mechanical effects, stress transfer, geochemical reactions and re-orientation of stress tensor also affect (modify Mohr circle diagram)



Vilarrasa et al. (2019)

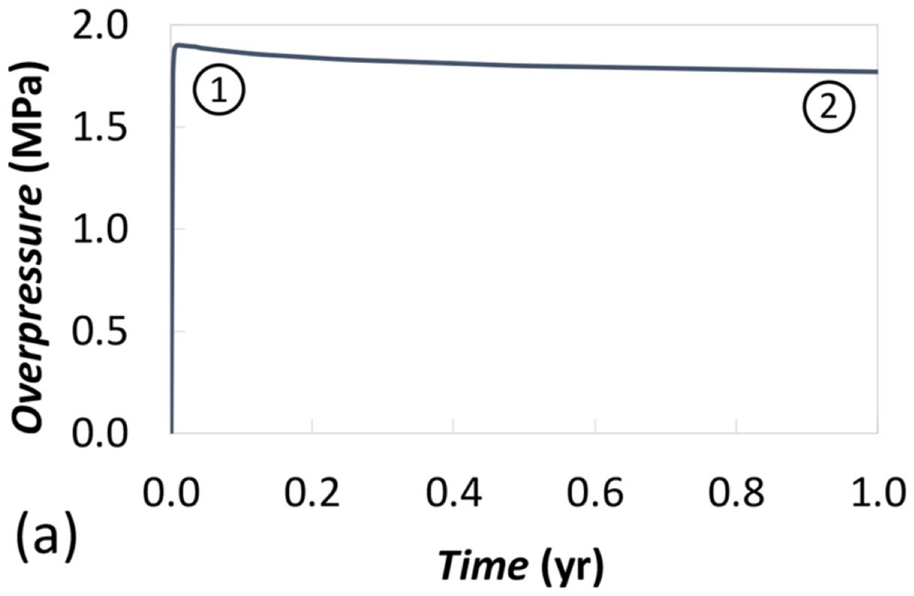
Seismicity induced by CO_2 injection

Might CO_2 injection cause less seismicity?

dCO_2 (room conditions) ~ 1.8 kg/m^3

dH_2O (room conditions) ~ 997.77 kg/m^3

Overpressure stays constant or lowers after initial injection (dissolution into brine, reservoir brine migration to fractures)



Vilarrasa et al. (2019)

Why do we care?

HAZARDS

Leakage into caprock

Triggering perceptible/larger earthquakes, specially outside the study area

BENEFITS

Permeability enhancement: if confined to reservoir

Seismicity provides useful information

Mitigation of induced seismicity

1. Assess the potential for induced seismicity
   Site characterization, 3D fault model, regional and/or local stress field
2. Seismicity monitoring:
   Pre- (baseline), co- and post-injection
3. Well control:
   hydromechanical characterization test and installation of pressure control valve
4. TRAFFIC LIGHT SYSTEM:
   set a maximum magnitude allowed (based on risk assessment, population and infrastructures that could be affected)

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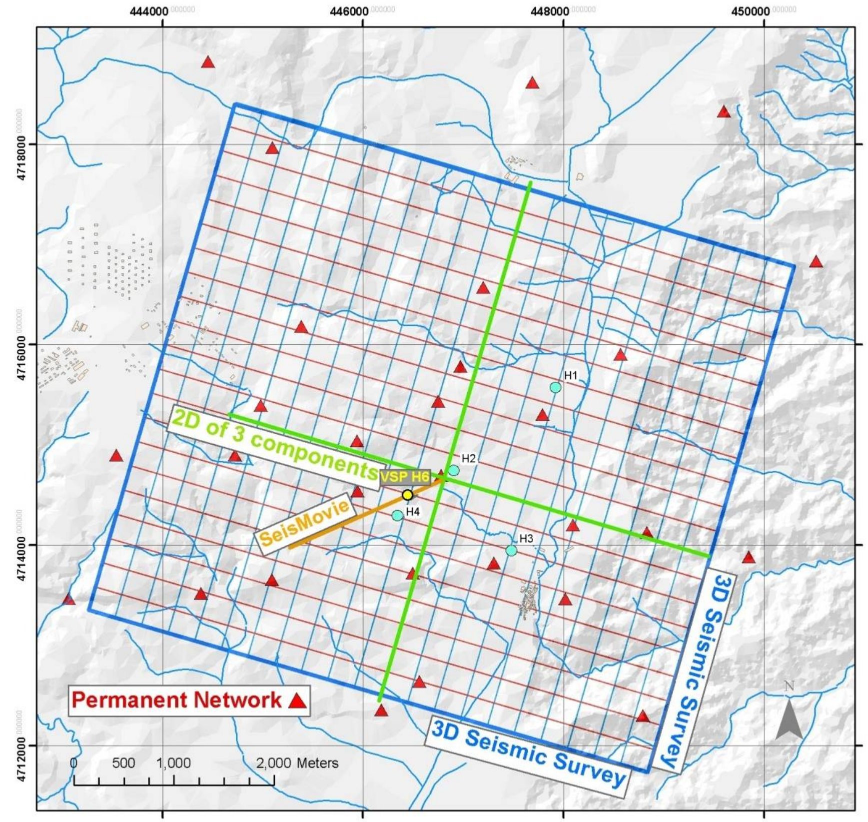
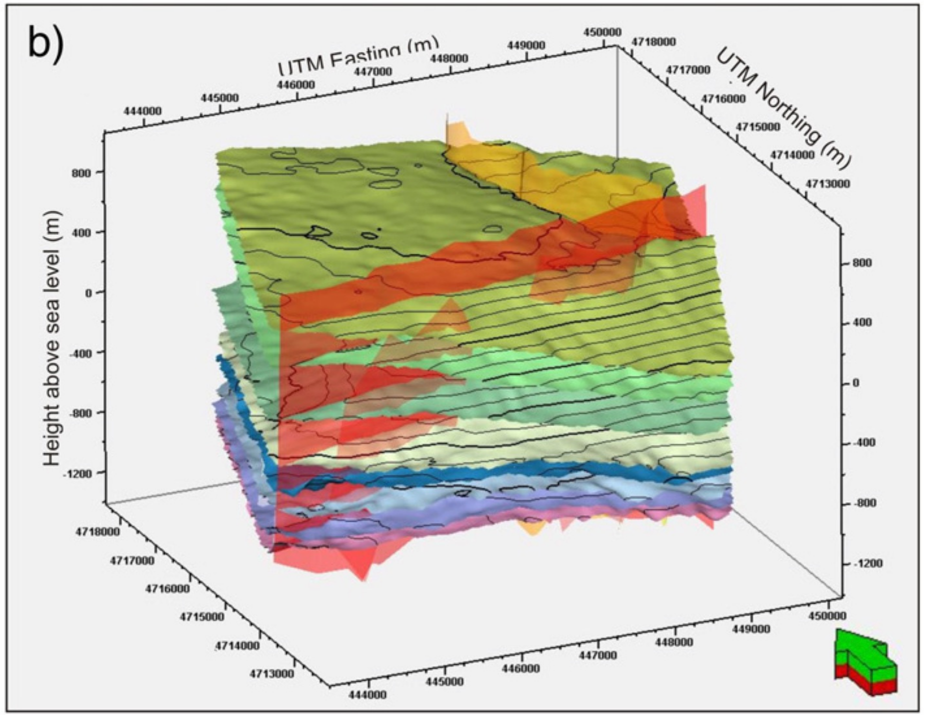
Mitigation of induced seismicity

1. Assess the potential for induced seismicity

   Site characterization, 3D fault model, regional and/or local stress field and seismicity modelling

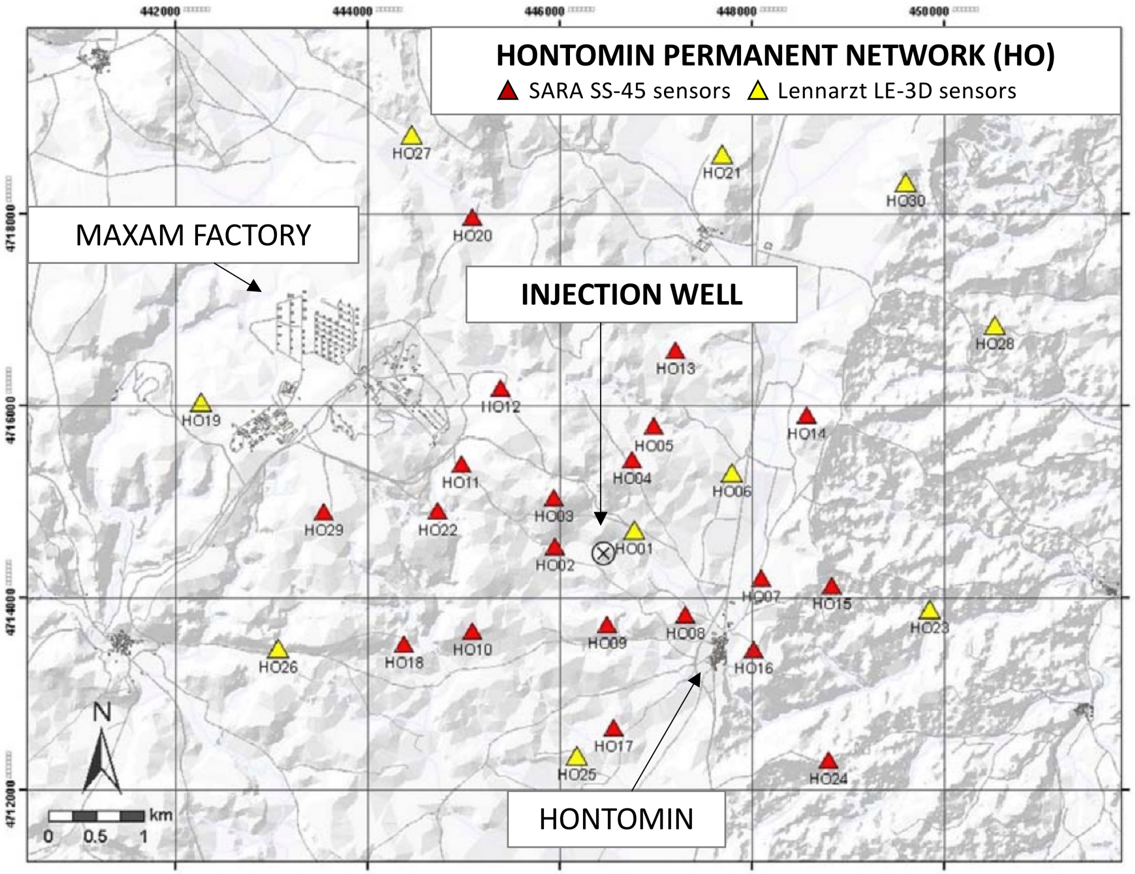




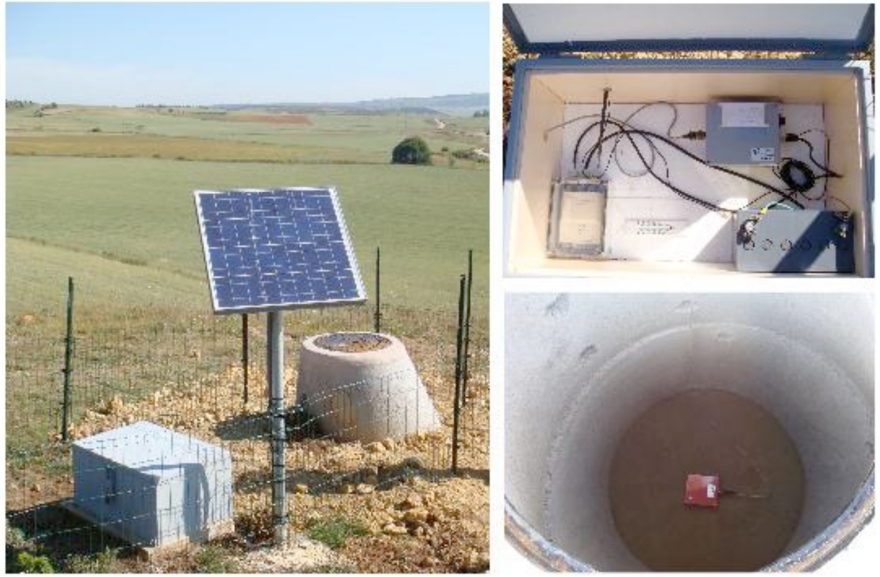
Alcalde et al. (2014)

Mitigation of induced seismicity

2. Seismicity monitoring: Pre- (baseline), co- and post-injection



Vertical array of geophones covering the caprock-reservoir interface was planned!



HO08 station: SARA SS-45 sensor and SARA SL-06 digitizers

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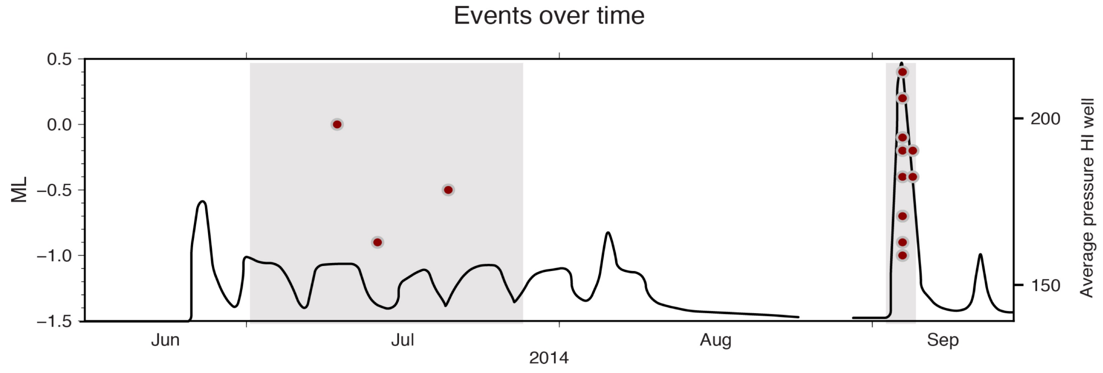
Mitigation of induced seismicity

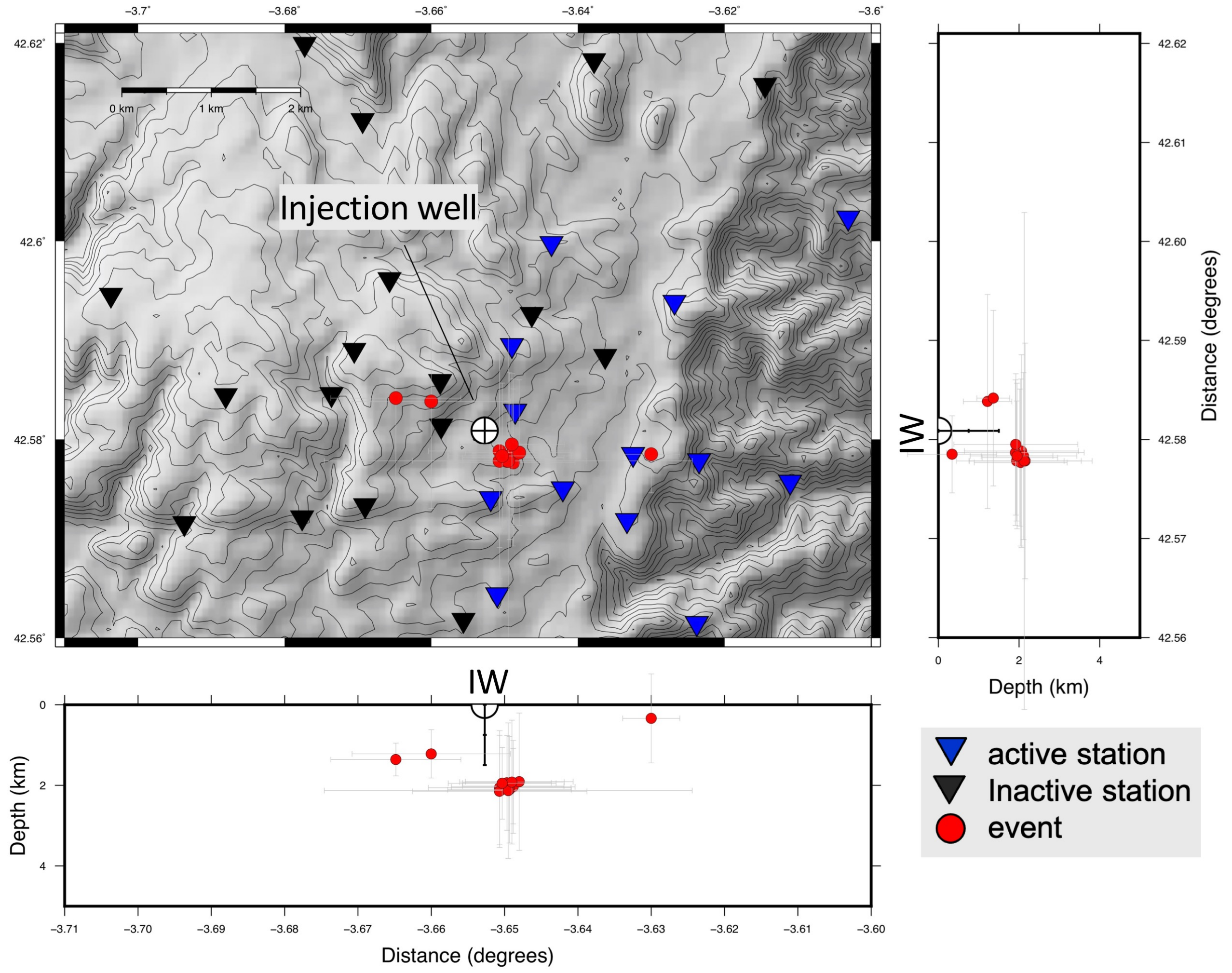
2. Seismicity monitoring: co-injection

Incomplete active network

Local magnitude (M_L) range= -1 to 0.4



average location accuracy = 0.9km (X,Y) and 1.13km (Z)



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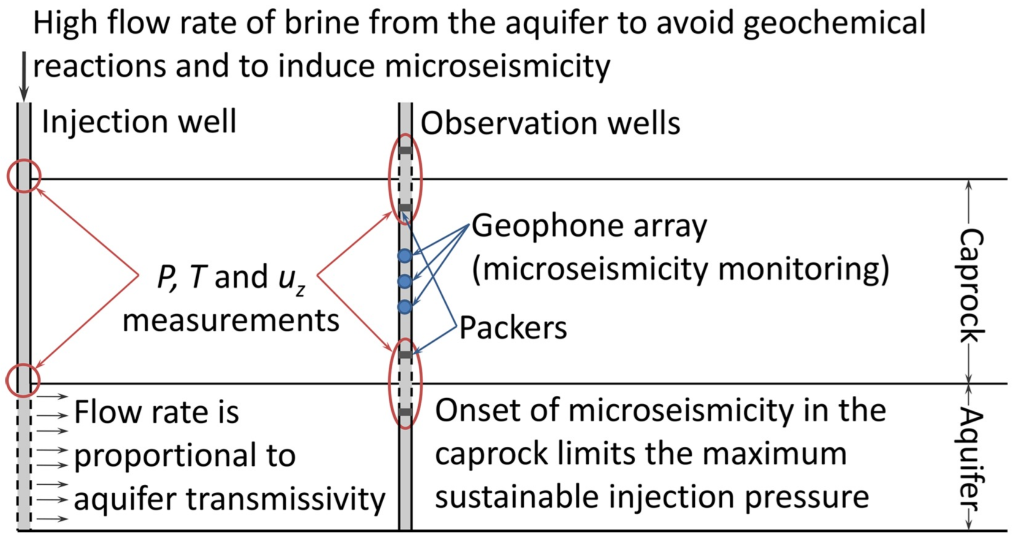
Mitigation of induced seismicity

3. Well control:

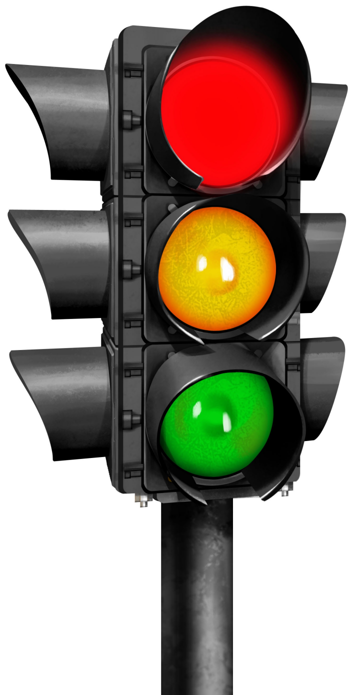
hydromechanical characterization test and installation of pressure control system



Vilarrasa et al. (2019)

4. Traffic Light System (TLS or ATLS):

- Real-time status
- Risk state levels: magnitude threshold
- **ATLS**: updated seismicity and geomechanical predictions



Unacceptable seismicity
Stop operations

Concerning seismicity
Modify operations

Acceptable seismicity
Continue operations as planned

Lessons learnt from Hontomín CCS

- A surface network is capable of monitoring micro-seismicity
  Resolution depends on network coverage
- Limitations for only-surface arrays: magnitude, surface noise and location accuracy
- Key steps:
  - Characterize baseline seismicity pre-injection
  - Fault network modelling and seismicity modelling pre-injection
  - Network performance monitoring: best scenario we had ~70% of stations active > reduced detection and location capability!!

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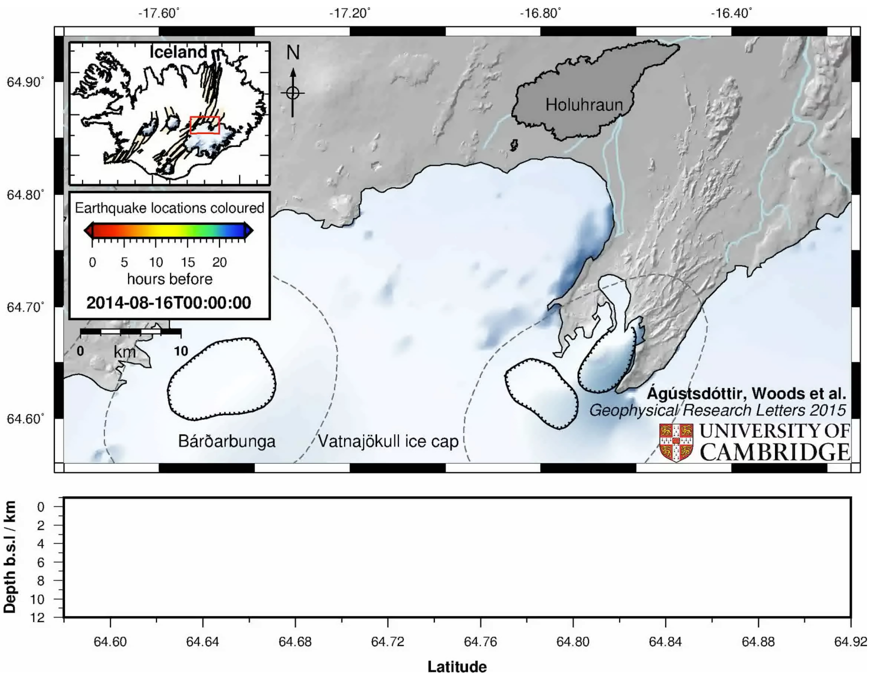
Constraints provided by seismicity

1. Spatial and temporal distribution of micro-earthquakes

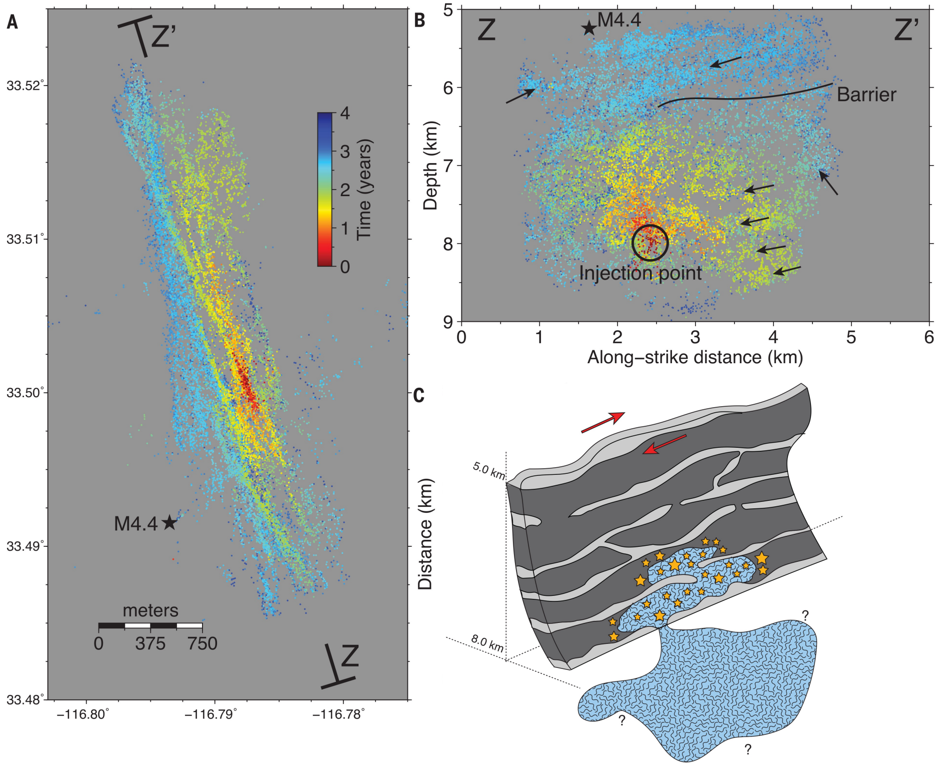
   Real data on pressure front migration!

Migration rate > fault hydraulic diffusivity > fault permeability!

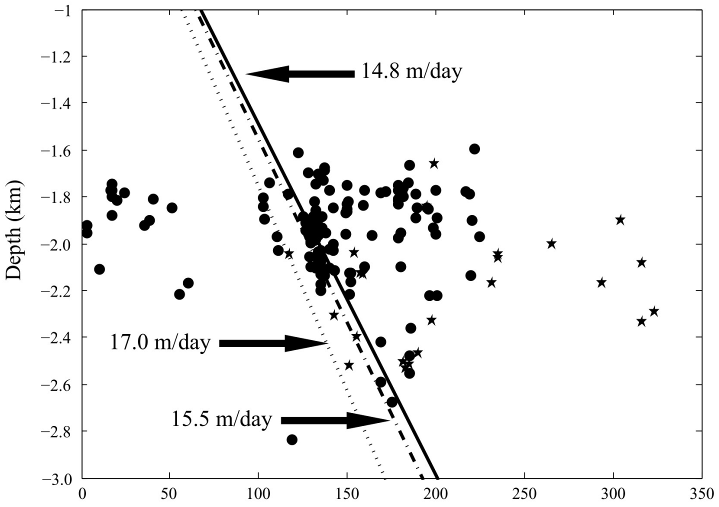
Bárðarbunga-Holuhraun dike intrusion



Ágústsdóttir et al. (2016)



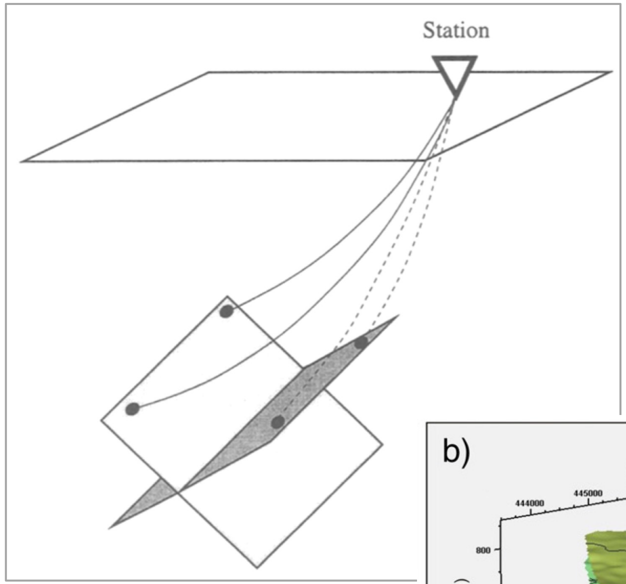
Ross et al. (2020)



El Hariri et al. (2010)

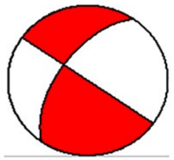
Constraints provided by seismicity

2. Fault geometry from nodal planes
   Improve fault model

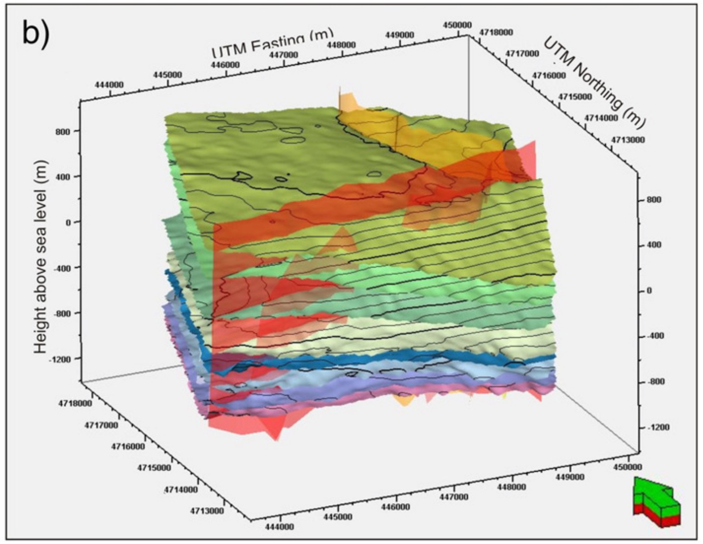


Delouis and Legrand (1999)

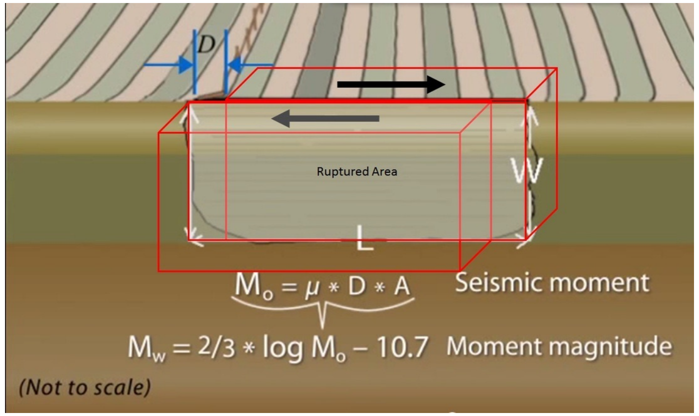
strike: 215°
dip: 60°
rake: 180°



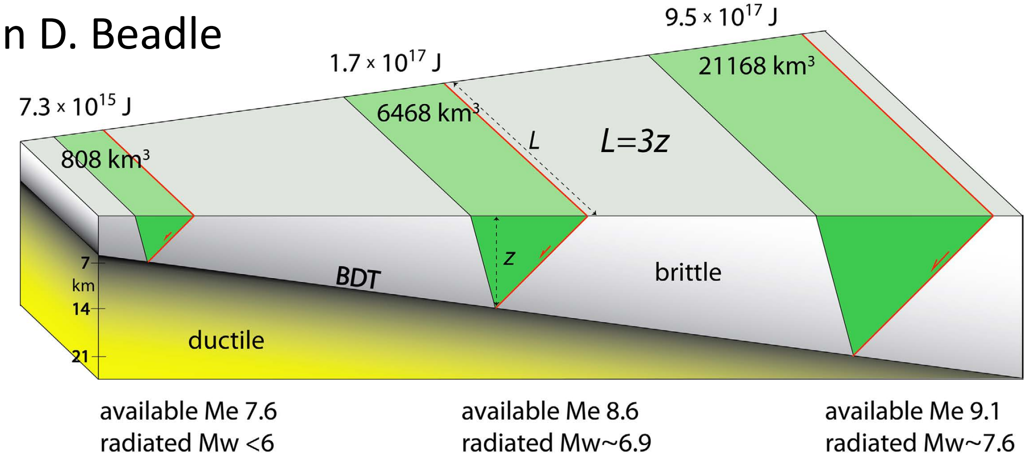
Champenois et al. (2017)



3. Magnitude > rupture extension > InSAR (compare displacement)



Brian D. Beadle

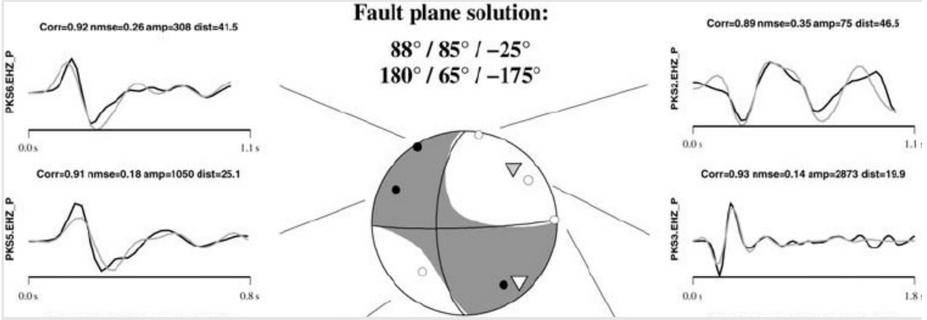


Doglioni et al. (2015)

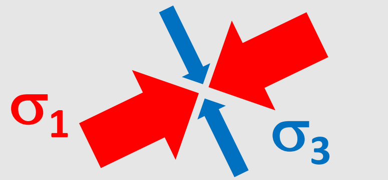
Constraints provided by seismicity

4. Local stress field: principal stress axes orientation and magnitude relation

Estimate moment tensors



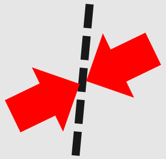
Invert for principal stress axes



Check for stress field rotations induced by injection tests

Regional SHmax

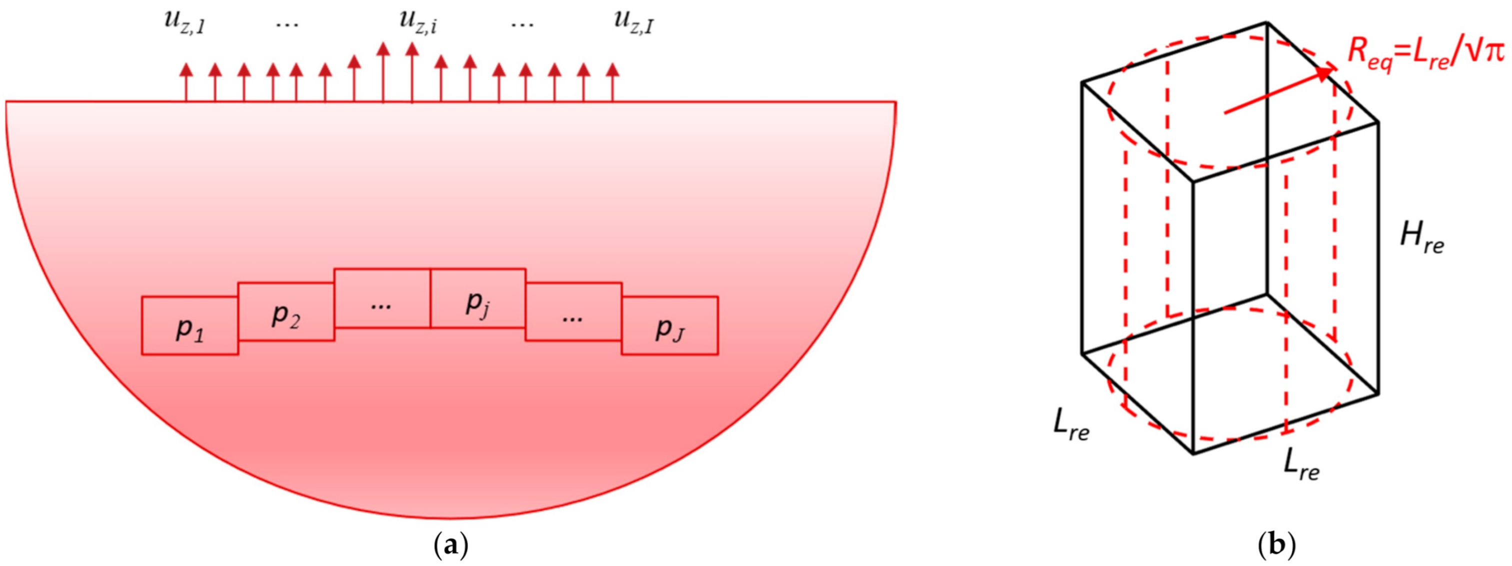
Local SHmax



Constraints provided by seismicity

Pressure front migration, updated fault network model, rupture extension and local stress field

Predictive geomechanical and surface deformation models



Generalized GEERTSMA solution - Park et al. (2021)

PROS and CONS of seismicity monitoring in onshore CCS

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- Cheap
- Easy management
- On-going and fast software advances
- Provides constraints on reservoir, caprock and CO_2 behaviour

  Leakage, pressure front migration, local reservoir stress fields etc

- Results depend on seismicity generation

  No or little seismicity = limited results

- Provides very localized data

  Limited for overall picture

- Depends on network characteristics and size

  The larger the network the better, more data

  the better is distribution, the better data quality will be

Take-home messages

- Seismicity monitoring is usually mandatory, and cheap. Take advantage and analyze data further to calibrate models and strengthen deformation characterization!

- The more resources and time invested, the more information obtained

- It is an exciting time for seismicity. Seismicity analysis is advancing quickly: keep an eye! new outputs to be obtained and cheaper tools (acquisition, processing and analysis) will be available