הסכנה לעירור רעידות אדמה כתוצאה מהפקת אנרגיה גאוטרמית בסמוך לשבר הסורי-אפריקאי

פרופ עינת אהרונוב

המכון למדעי כדוה"א

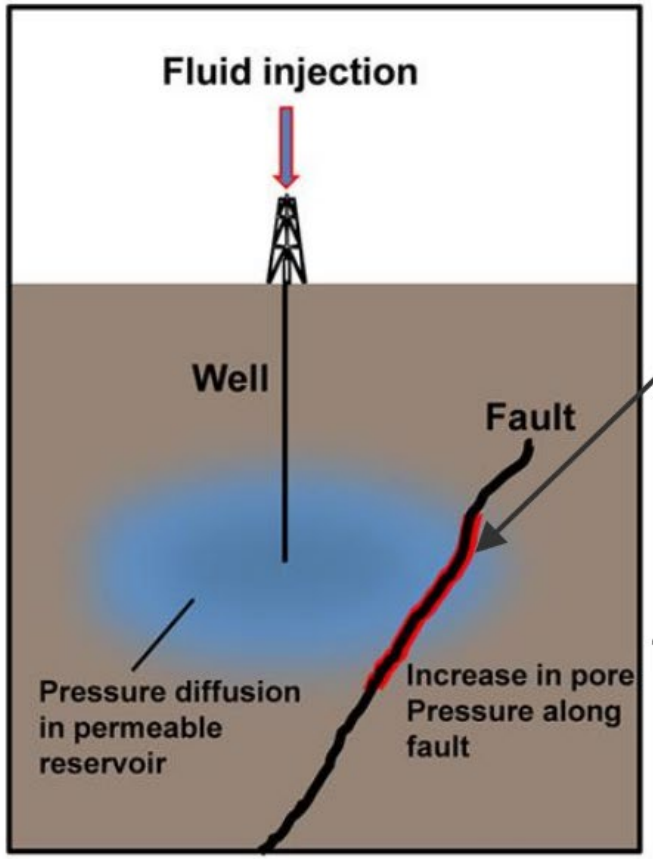
האוניברסיטה העברית בירושלים

What are fluid-injection/extraction induced earthquakes?

- Seismic events triggered by the injection or extraction of fluids into or out of the subsurface
- The phenomenon has gained attention over the last 20yrs, particularly in relation to oil and gas extraction, geothermal energy production, and carbon capture and storage.

The Key Mechanism of induced seismicity

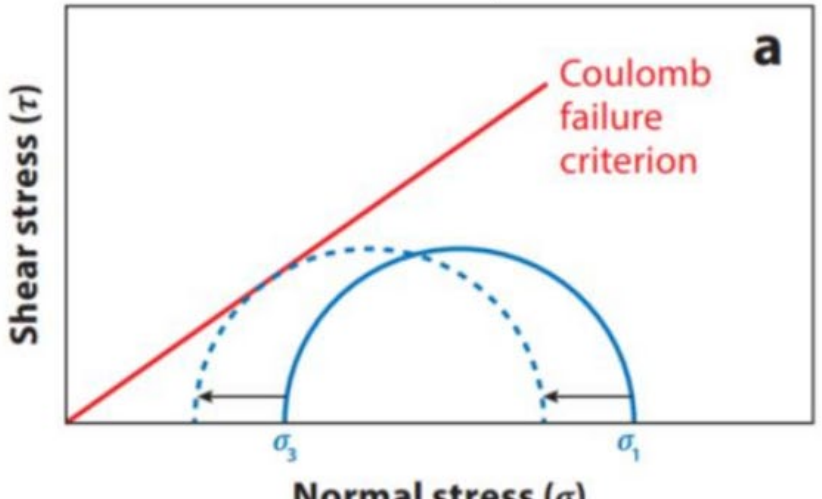
Fluid injection increases fluid pore pressure within fault zones, reducing the effective normal stress. This may trigger slip even on previously inactive faults.



Permeable Fault Zone

Resisting shear stress, σ_s , for sliding on a fault, drops with increasing fluid pressure P

$$\sigma_s = C + \mu(\sigma_n - P)$$



Keranen & Weingarten. "Induced seismicity." *Annual Review of Earth & Planetary Sciences* (2018)

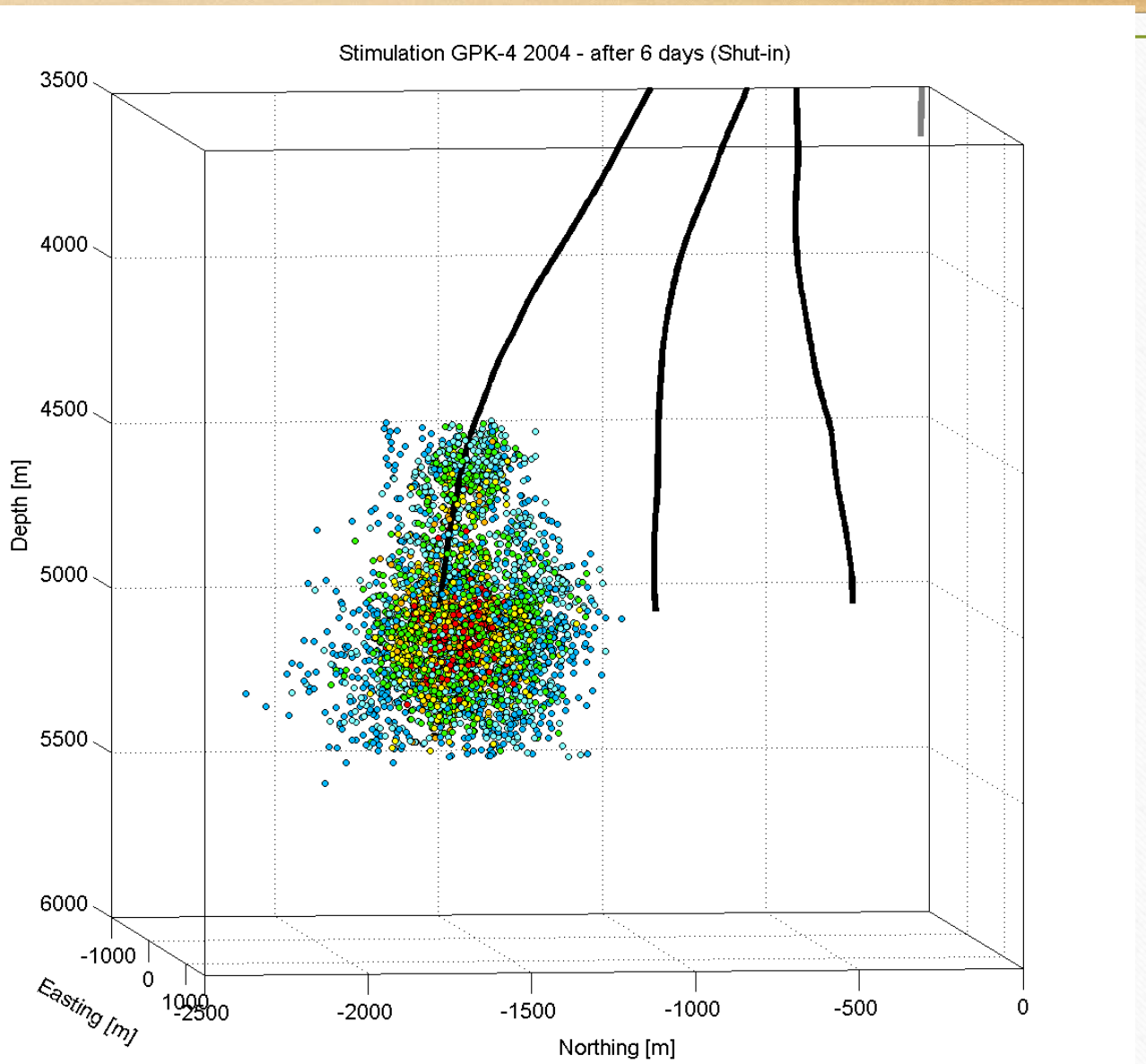
An Example of Expanding Zone of Seismicity around a Geothermal Energy Production Site

The **GPK4 well** at the **Soultz-sous-Forêts Enhanced Geothermal System (EGS) site**, the Upper Rhine Graben, NE France, was drilled to a depth of **5,200 meters in 2003.** GPK4 is part of the triplet of deep wells (GPK2-4) utilized for heat extraction from granitic basement rocks.

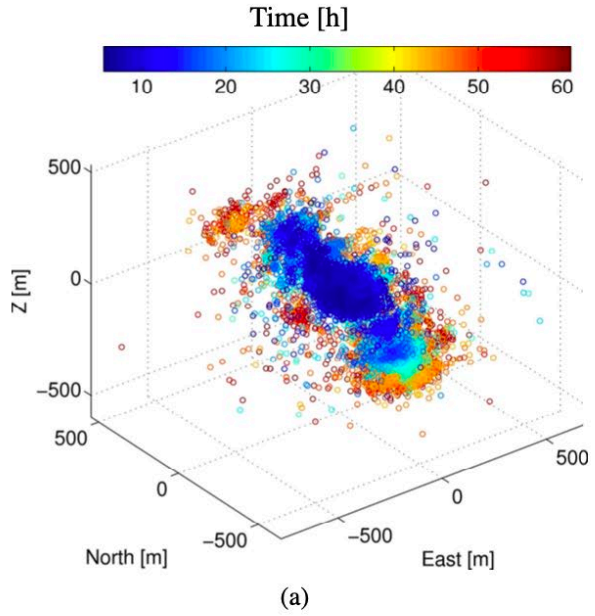
- This site is a **flagship European EGS pilot project**, aiming to demonstrate geothermal energy production from deep, fractured granite with low permeability through stimulation and circulation of water.

GPK4 (Sep04): Microseismic Development

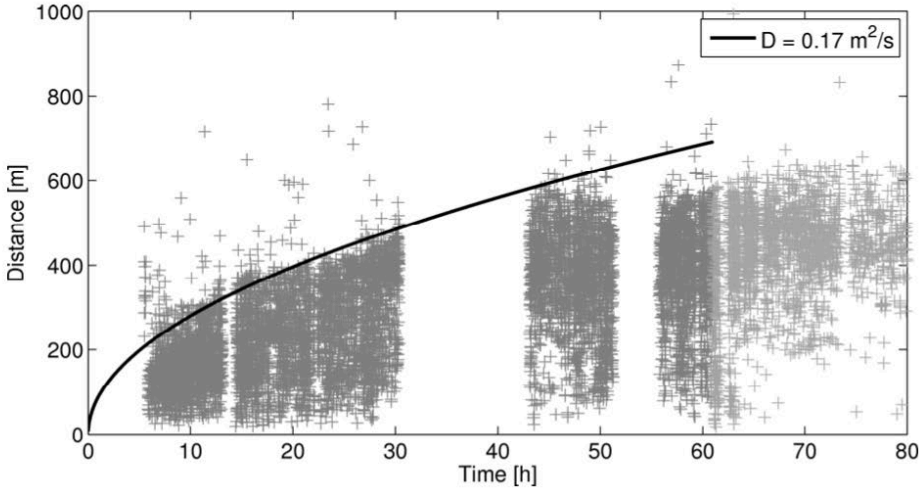
Kohl and Thorhallsson, 2009



Dinske, C. (2011). *Interpretation of fluid-induced seismicity at geothermal and hydrocarbon reservoirs of Basel and Cotton Valley* (Doctoral dissertation).



(a)



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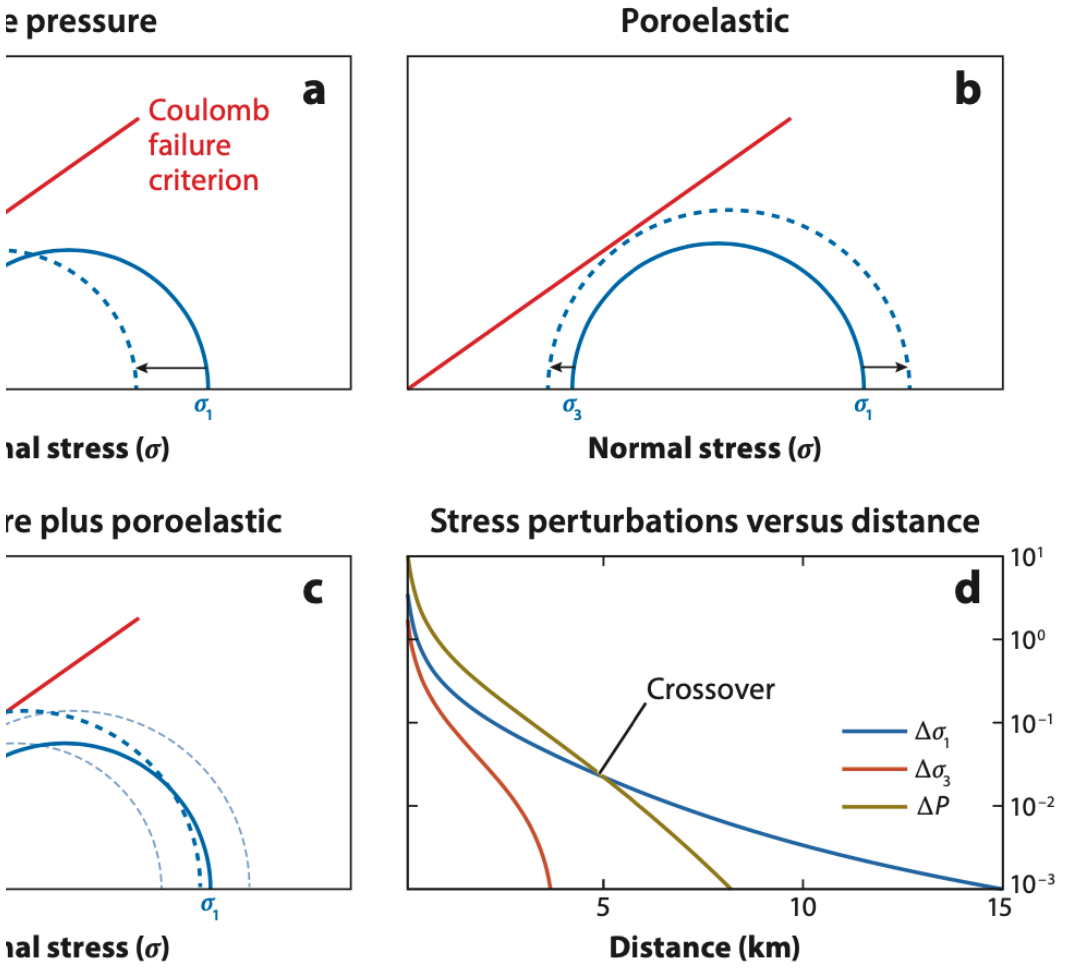

Key Scientific & Engineering Issues Related to fluid-injection induced triggering

- **Mechanism of Triggering**: pore pressure and poroelastic stress changes.
- **Spatial & Temporal Patterns**: Induced seismicity can occur far from injection sites due to pressure diffusion.
- **Fault Reactivation**: minor pressure perturbations at depth can reactivate critically stressed faults.
- **Modeling Approaches**: Coupled hydro-mechanical models may simulate pore pressure changes & fault stability.
- **Seismic Hazard Assessment**: Integrating induced seismicity into probabilistic seismic hazard assessments (PSHA).
- **How Large are the Induced Eqs? And How Far From Injection?**

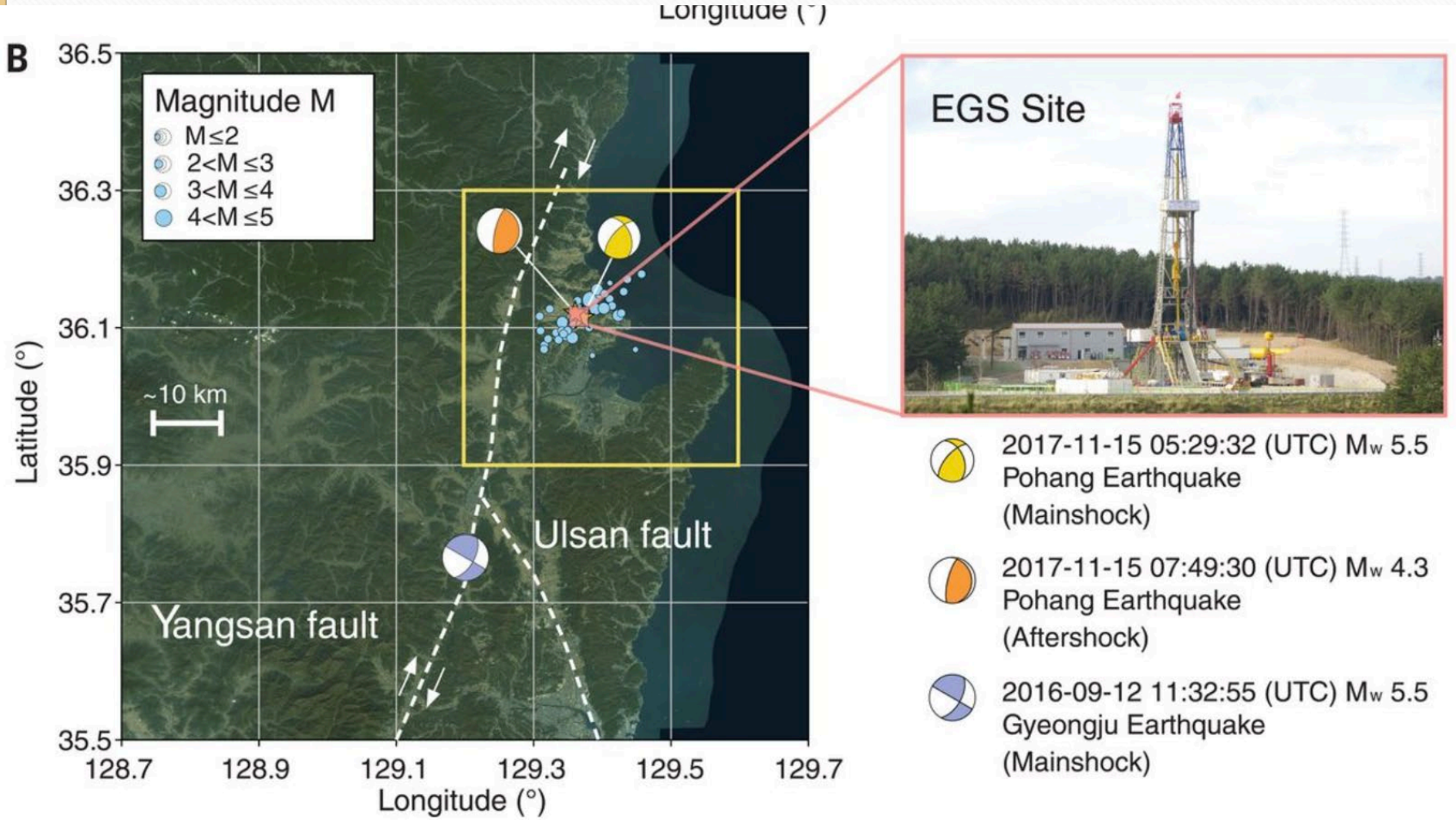

Fig. 1 The 2016 and 2017 M_w 5.5 earthquakes in South Korea.
(**A**) Regional map showing locations of the Gyeongju and Pohang earthquakes, the Yangsan fault, and the available open seismic stations. (**B**) Map of the study area showing the main faults of the area, the distribution of seismicity with respect to the EGS site, and the mechanisms of the largest events. A more detailed map of the area of study (outlined by the yellow square) is shown in Fig. 2A. UTC, universal time coordinated. EGS SITE PHOTO: COURTESY OF THE DESTRESS PROJECT TEAM

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How far may Eqs be induced?

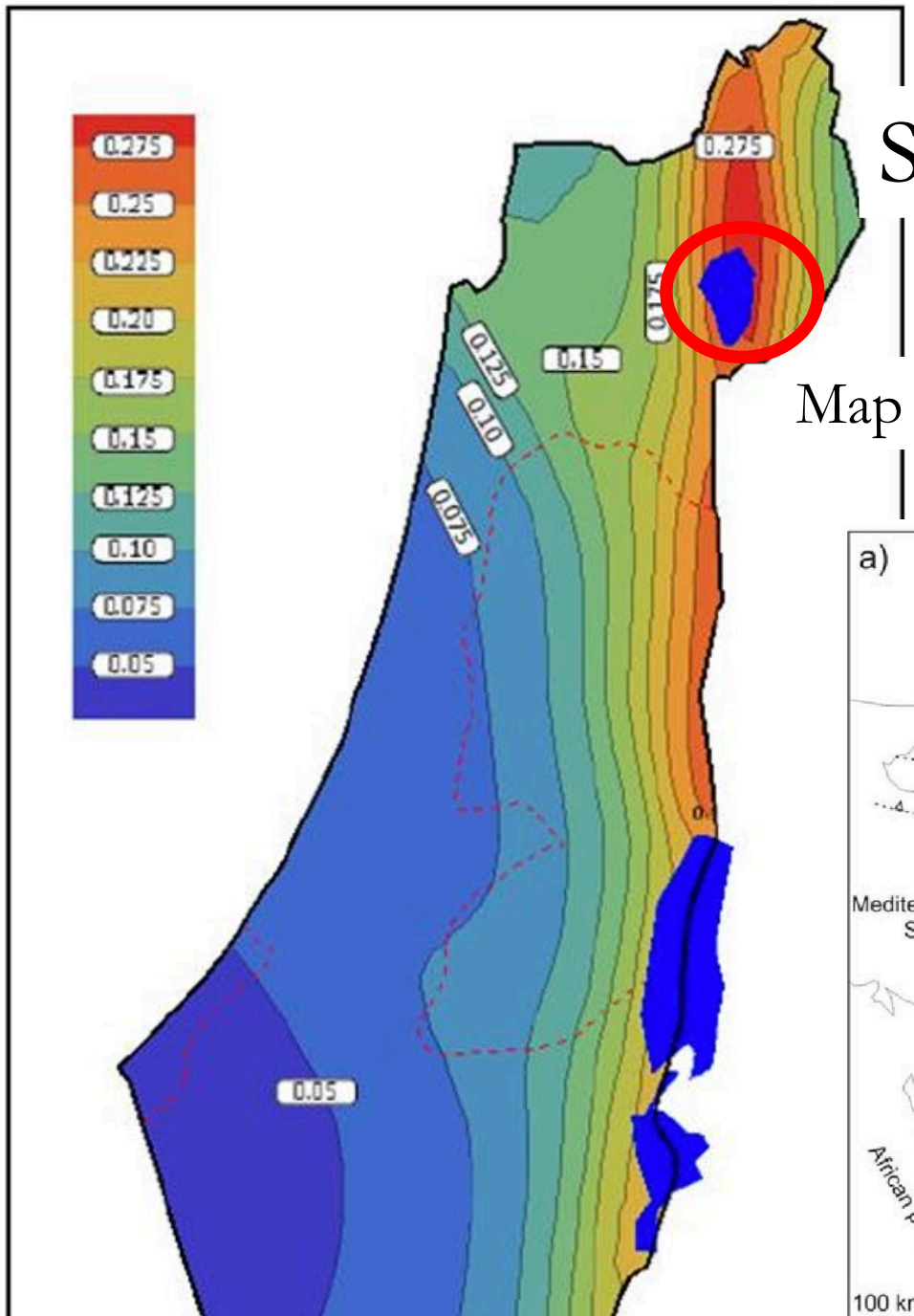
•**~10–20 km**: Common in several U.S. wastewater injection cases (e.g., Oklahoma, Texas).

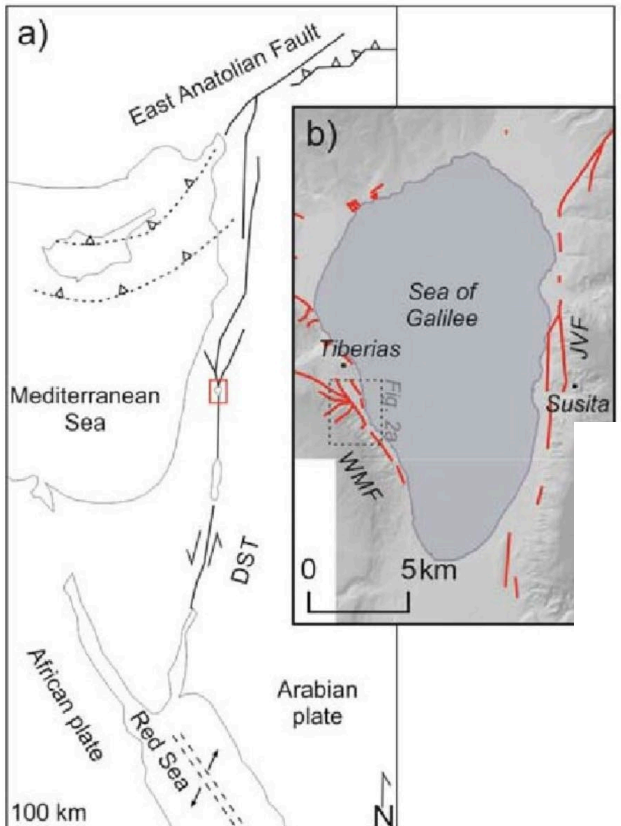
•**~30 km or more**: Rare, but documented. For example:

- **Raton Basin, Colorado/New Mexico**: Seismicity linked to injection extended **~30 km** from wells.
- **Paradox Valley, Colorado**: Modeling shows stress perturbations could extend **up to 20–30 km** depending on fault orientation and pressure diffusion.

S Golan is situated near active faults.

Map of PGA for 475 years return time, Klar et al 2011.





Figure

Caption

Fig. 1: a) General tectonic setting of the Dead Sea Transform (DST), modified after Garfunkel (1981); the Sea of Galilee is marked in red. b) Digital elevation model and main active faults around the Sea of Galilee.

6th International INQUA Meeting on Paleoseismology, Active Tectonics and Archaeoseismology, 19-24 April 2015, Pescina, Fucino Basin, Italy

INQUA Focus Group on Paleoseismology and Active Tectonics

paleoseismicity.org

Evaluation of earthquake hazard for the city of Tiberias (Israel): archaeoseismology and paleoseismology

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Abstract: *The city of Tiberias (Israel) is sited on the shores of the Sea of Galilee, a pull-apart basin located along*

Artesian geothermal wells are less likely to produce EQs, but any subsurface pressure/stress change can produce EQs.

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Earthquake Swarms Triggered by Groundwater Extraction Near the Dead Sea Fault

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In 2013 and 2018, earthquake swarms with a maximum Mw 4.5 occurred ~5 km from the northern section of the Dead Sea Transform Fault. …aquifer pressure data, interferometric synthetic aperture radar surface deformation time series, and seismic monitoring suggest that groundwater withdrawal triggered these earthquakes.

Conclusions

- Unclear if geothermal energy extraction in S Golan may induce a long overdue large EQ near the Sea of Galilee.
- Less likely due to the Artesian nature of the wells, but requires careful modeling and scientific study.