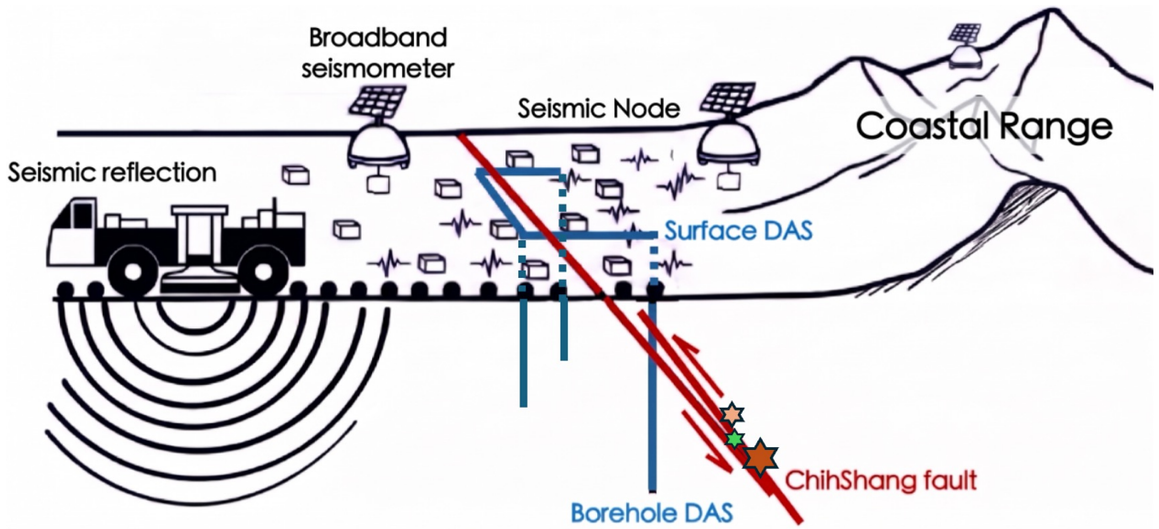
2026.11.11 新興地質調查技術經驗分享會@犇亞商務會議中心

池上斷層多維度觀測計畫（MAGIC）之微震觀測應用

郭陳澔[1,2]、孫維芳[2]、管卓康[1]、潘勝彥[1]、劉耀宏[1]、傅慶州[3]、古進上[3]

Since 2022

1. 台大地質系
2. 台大新碳勘中心
3. 中研院地球所



深層地熱發電避免不了的問題：誘發地震

規模多大？ 位置？應力？裂隙發育？
誘發地震時空演化？舊斷層活化？

REPORT

The November 2017 M_W 5.5 Pohang earthquake: A possible case of induced seismicity in South Korea

F. GRIGOLI, S. CESCA, A. P. RINALDI, A. MANCONI, J. A. LÓPEZ-COMINO, J. F. CLINTON, R. WESTAWAY, C. CAUZZI, T. DAHM, AND S. WIEMER

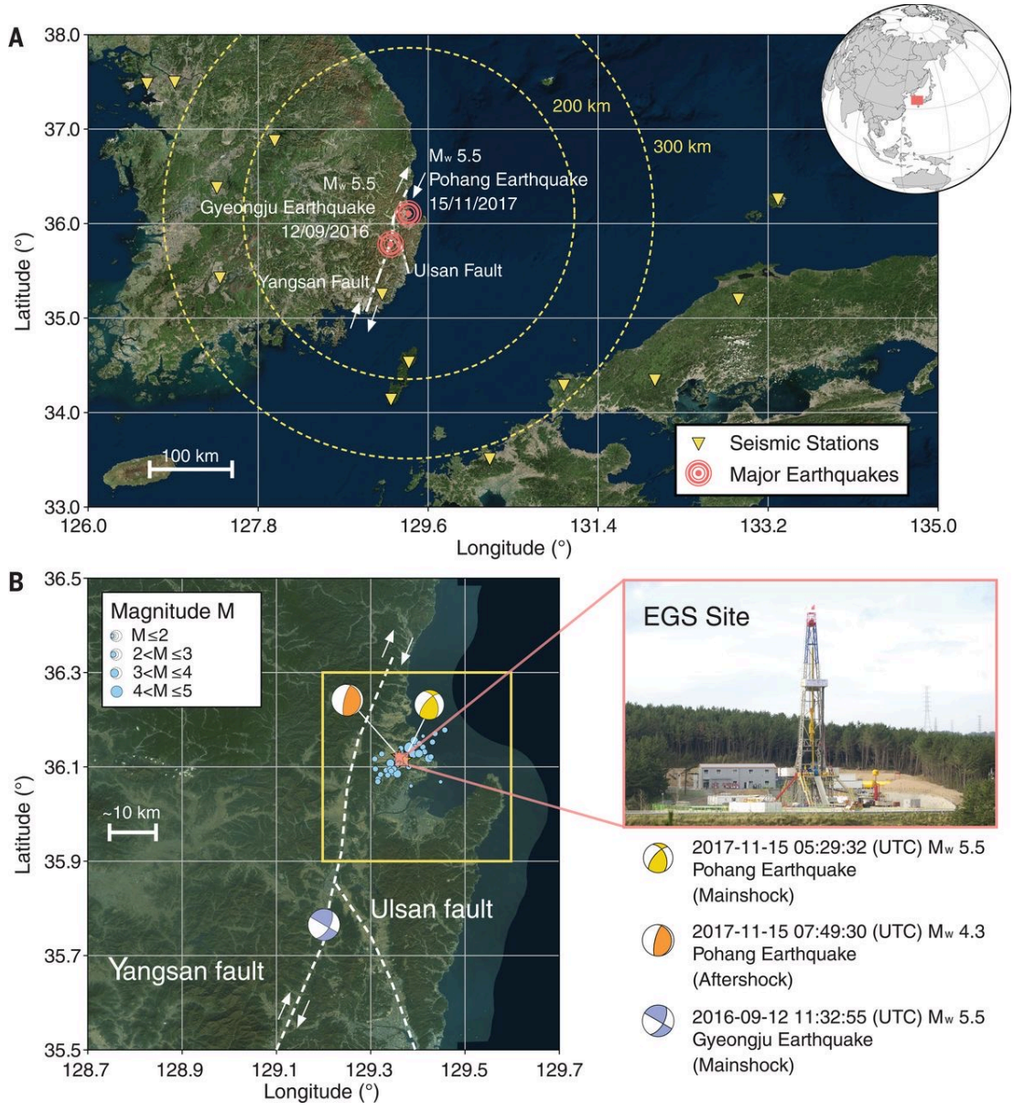
Authors Info & Affiliations

SCIENCE · 26 Apr 2018 · Vol 360, Issue 6392 · pp. 1003-1006 · DOI: 10.1126/science.aat2010

2,386 266

Triggering quakes in a geothermal space

Enhanced geothermal systems (EGSs) provide a potentially clean and abundant energy source. However, two magnitude-5 earthquakes recently occurred in South Korea during EGS site development. Grigoli *et al.* and Kim *et al.* present seismic and geophysical evidence that may implicate the second of these earthquakes, which occurred in Pohang, as an induced event. The combination of data from a local seismometer network, well logs, satellite observations, teleseismic waveform analysis, and stress modeling leads to the assessment that the earthquake was probably or almost certainly anthropogenically induced. The possibility remains



深層地熱發電避免不了的問題：誘發地震

規模多大？ 位置？應力？裂隙發育？
誘發地震時空演化？舊斷層活化？

震驚！韓國史上第二強震是人為誘發的(圖)

發表：2019-03-21 07:11

手機版 简体 打賞 1個留言 列印 特大 大 中 小

标签：
韓國
地震
浦項
地熱發電廠
朝鮮半島



2017年11月15日，韓國發生了規模5.4的浦項地震，圖為震後的浦項市。(圖片來源：公有領域 維基百科)

【看中國2019年3月20日訊】2017年，在韓國浦項發生了芮氏規模5.4強震，這次地震是朝鮮半島自1978年有記錄以來的第二強震，導致多棟建築物倒塌、傾斜及出現裂縫等，也釀91人受傷。日前專家公布調查結果，赫然發現該起地震並非自然地震，而是由於地熱發電廠向地底注水所誘發的。

根據《韓聯社》報導指出，2017年11月15日，韓國發生了規模5.4的浦項地震，並造成91人受傷，此起地震亦暴露出韓國抗震性差的問題，因為致使2000多棟建築物與大量汽車受損，也使大學聯考被迫延後舉行。

去年4月，韓國、瑞士及英國的研究小組於《科學》刊文稱，該小組質疑此次地震可能是非自然地震，地震的引起是鄰近震央的地熱發電廠所誘發的。為此，韓國政府立即進行調查。

浦項強震經過專家團隊長達一年的調查，20日已經公布調查結果，確認浦項強震並非自然地震，而是由於地熱發電廠的開採活動所誘發的。調查也發現，地熱發電廠曾經向數千公尺深的地底高壓注水，而導致水滲入此前未知的斷層之中，以造成斷層相對滑動，才誘發主震。

報導中說，在這調查結果公布之後，地熱發電廠與韓國政府恐將面臨巨額的賠償訴訟。

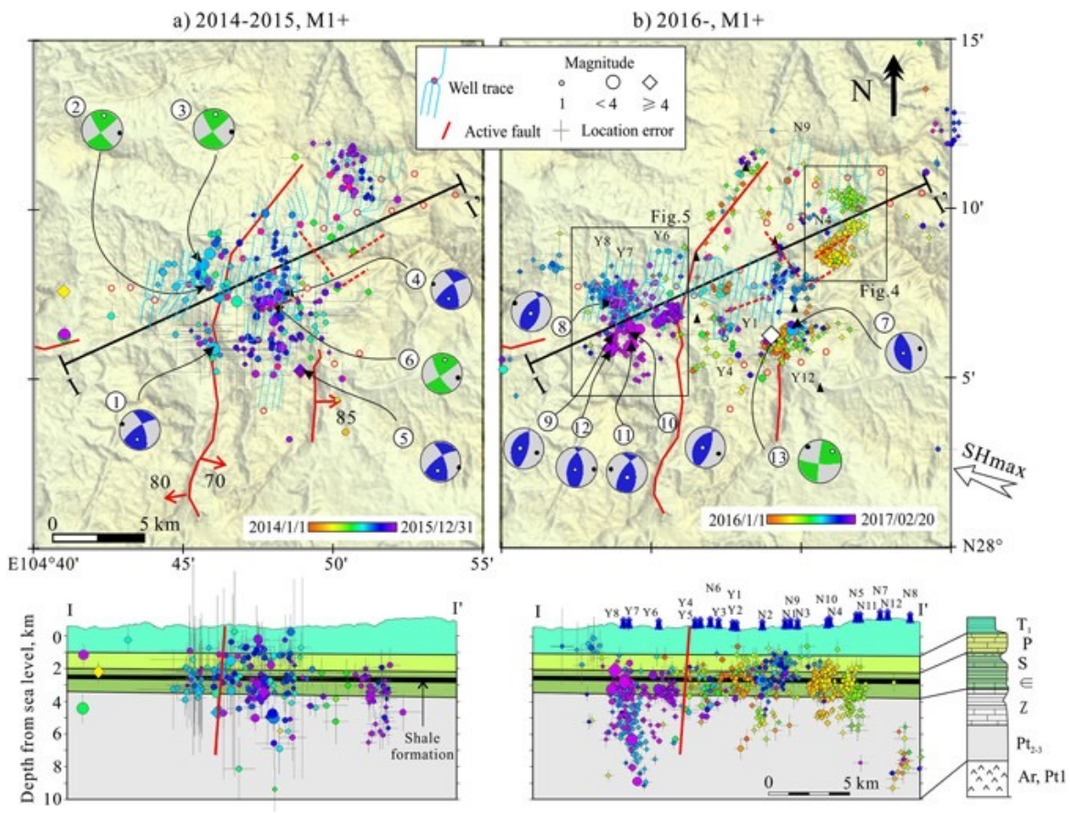
首爾不到30%建築物能防震

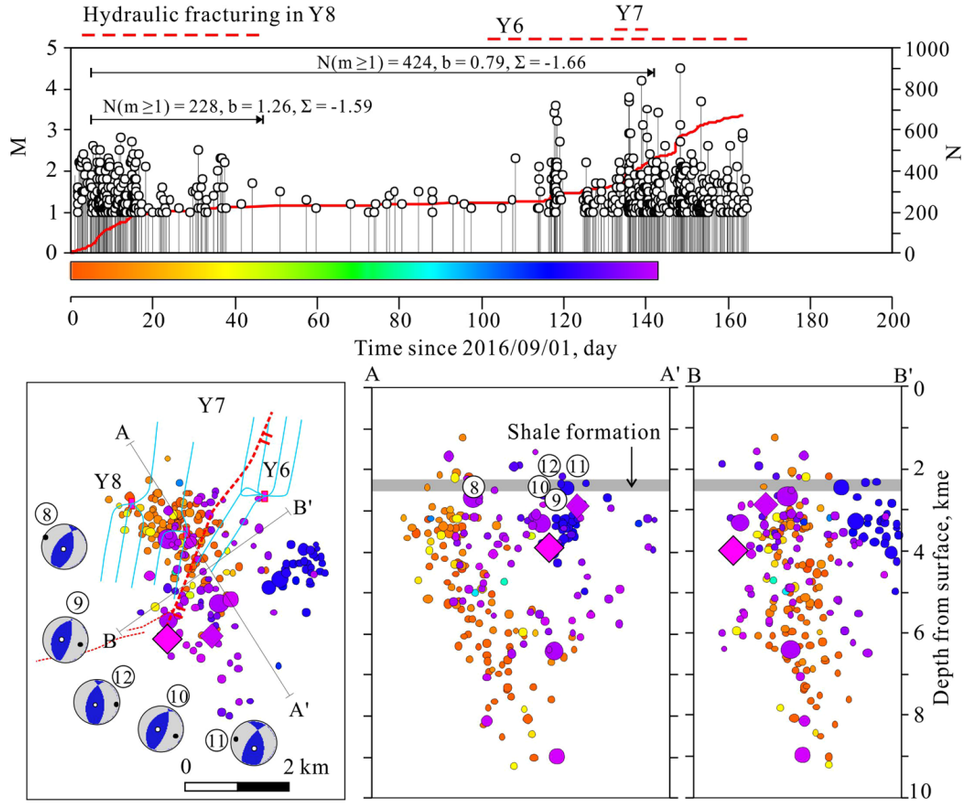
2017年11月15日，韓國發生規模5.4地震，也是該國有監測數據以來的第二大強震，並導致不少建築物受損。從當局的調查資料顯示，首爾能夠防震的房屋不到30%。

根據《韓國時報》報導，在首爾全部30萬1104棟建築物之中，僅有8萬8473棟足以防震，只佔了總數的29.4%而已；而首爾的非住宅建築，其擁有的抗震設計比率最高，其中商業建築物有63%達標；但是學校只有33.5%的能夠防震。

水裂(Hydraulic fracturing) 的誘發地震監測

規模多大？ 位置？應力？裂隙發育？
誘發地震時空演化？舊斷層活化？





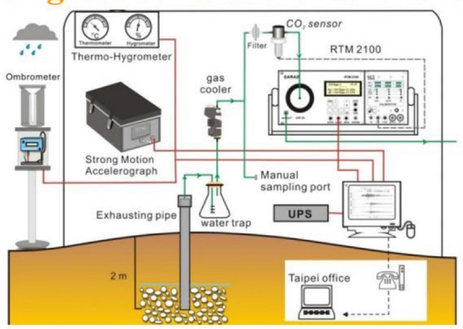
Lei et al., 2017

池上斷層多維尺度監測計畫：解析地震孕育與深部流體循環的鍵連

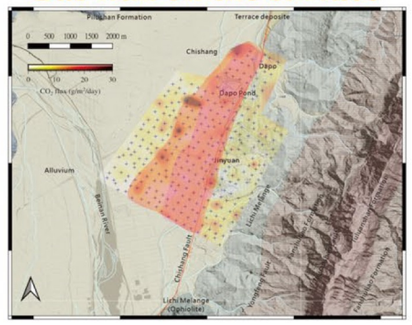
地化 + 地質 + 地物

計畫主持人：傅慶州

Soil gases conc. at the fault zone



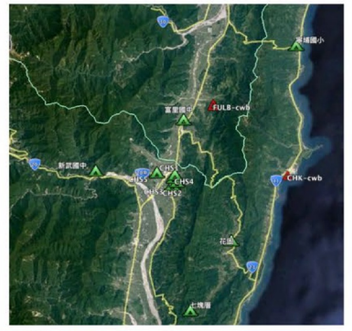
Gas flux on the surface



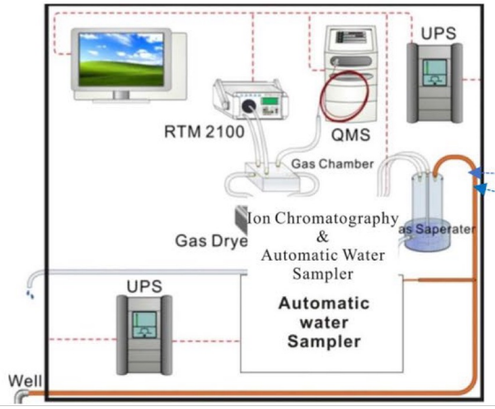
Geophone seismic array

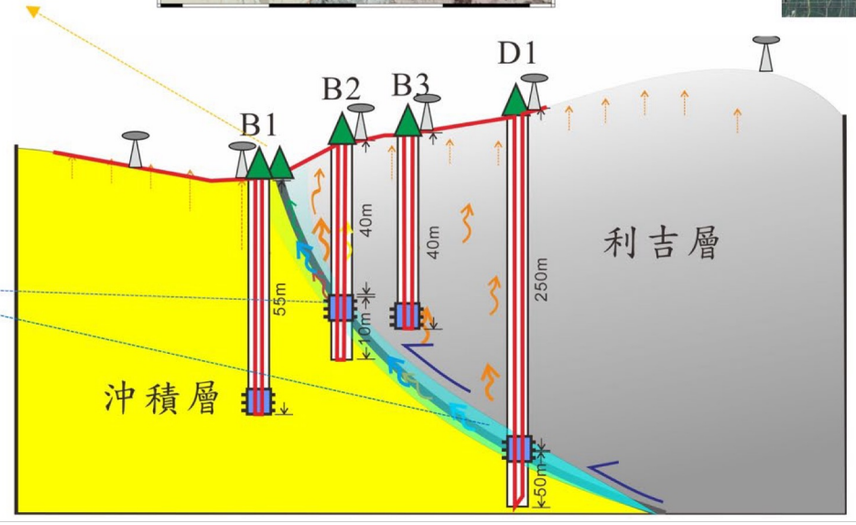


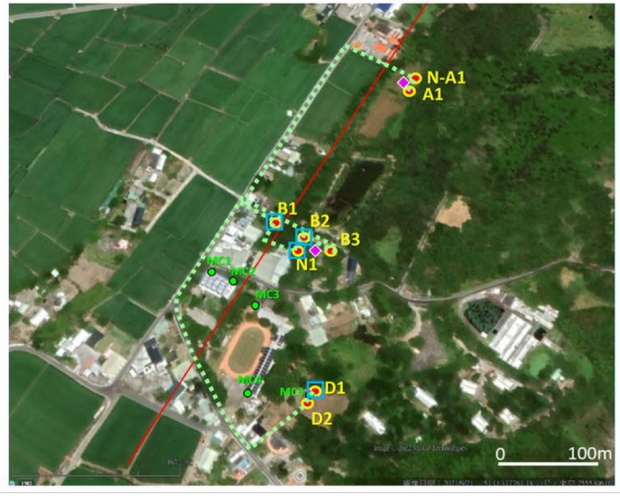
Micro-seismic array



Gas & fluid from the fault zone



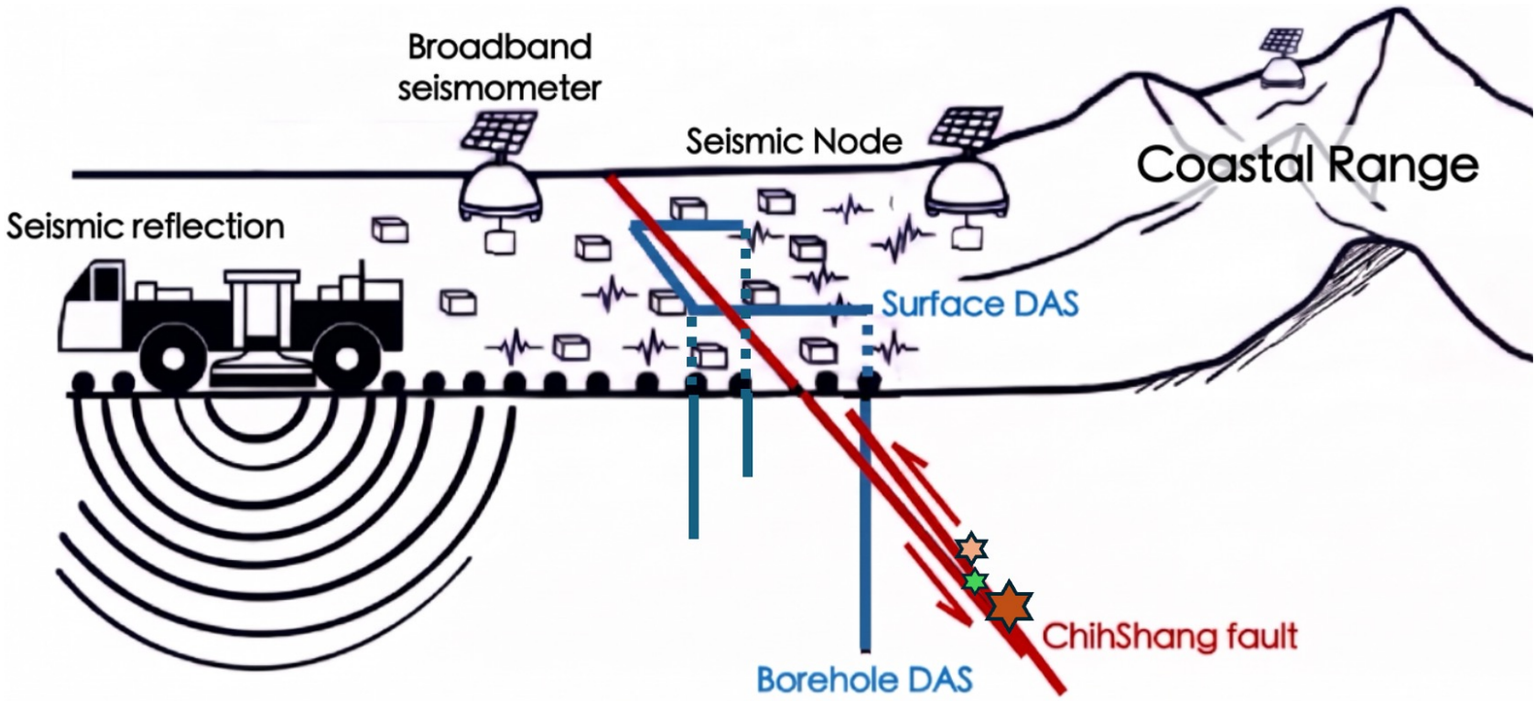




池上斷層多維尺度微震監測

規模多大？ 位置？應力？裂隙發育？
誘發地震時空演化？舊斷層活化？

主動震源		寬頻地震網
	PLUS	密集地震網 (node)
被動震源		地表井下 光纖 (DAS)



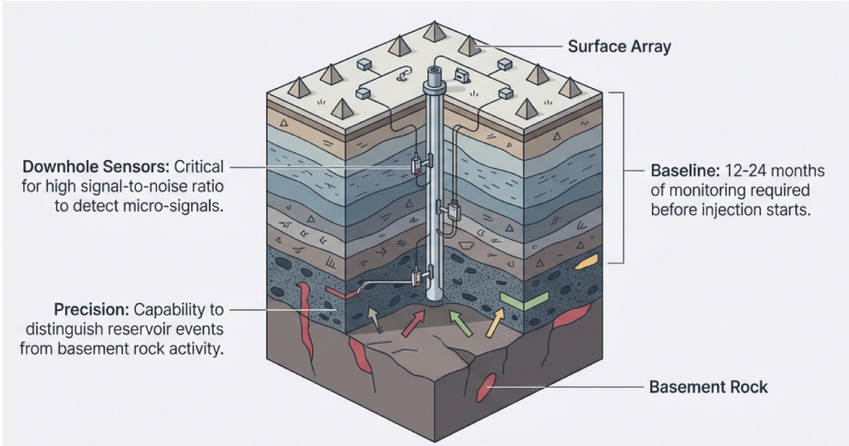
微震監測

GEOSEIS-AI · GEOthermal SEISmic AI Platform

Dense Seismic arrays + AI data processing

背景地質調查
+
誘發地震監測





Field
Dense seismic arrays

→ **Lab**
Download Continuous waveforms

→ **Phase picking**
Local-AI trained pickers

→ **Inversion**
EQ Catalogues + tomography

(Sun et al. X1.131, EGU26-16026)

Earthquake location
Fractures · seismicity
Pinpoints active fracture networks.

(Pan et al. X1.134, EGU26-18228)

Focal mechanism
Stress field
Maps regional stress orientation.

(Chang et al. X1.132, EGU26-15833)

Shear Wave Splitting
Structure · fractures
Detects oriented cracks at depth.

(Guan et al. X1.133, EGU26-17354)

Vp and Vp/Vs Tomography
Lithology · steam · fluid
Resolves lithology and fluid pathways.

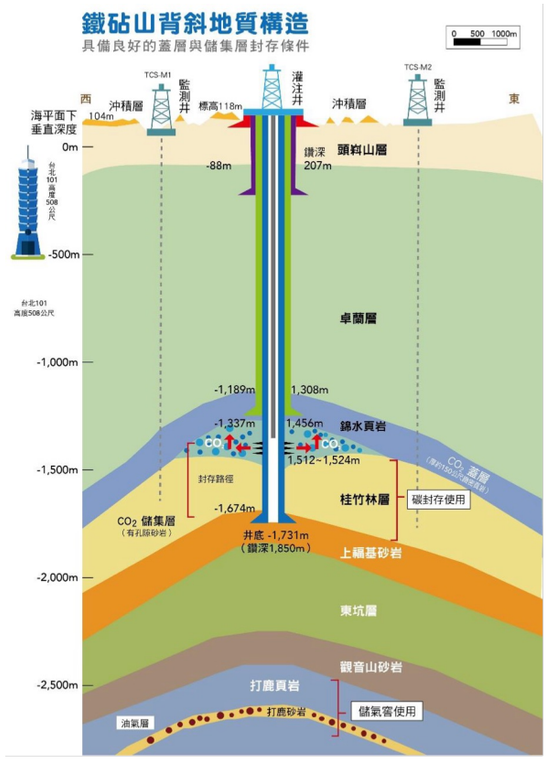
Local AI training database · Modular pipeline · Verifiable & rapid ·

Hao Kuo-Chen · Dept. of Geosciences, NTU · STRIDE-C

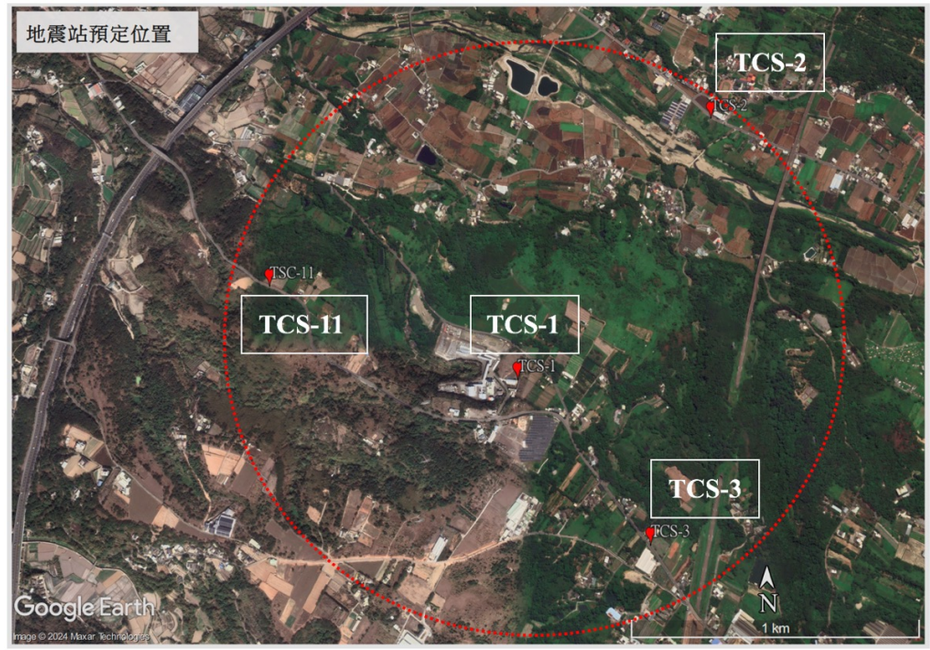
(Many codes can be obtained online, but verification of the results is needed)

Seismology for geothermal exploration

Both geothermal exploration and CCS&EGS induced EQ monitoring

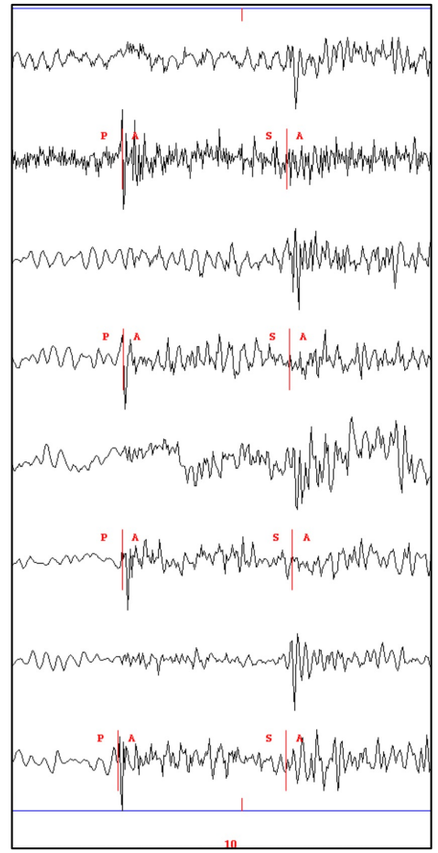


First demostration CCS onland site in Taiwan in 2026



2024-08-29_1.8M_L_Depth26.2km

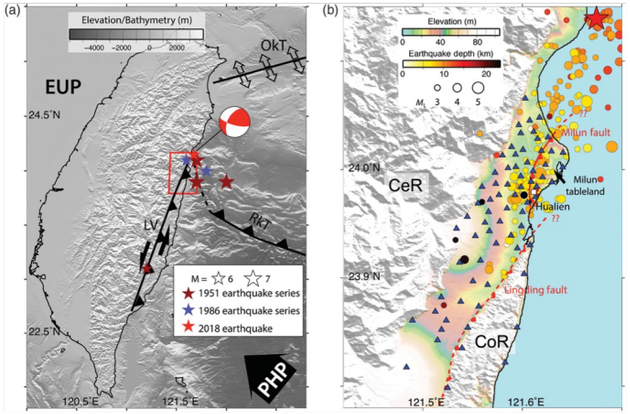


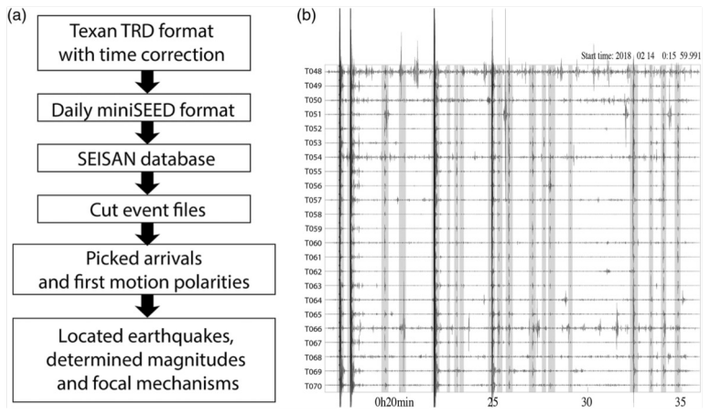


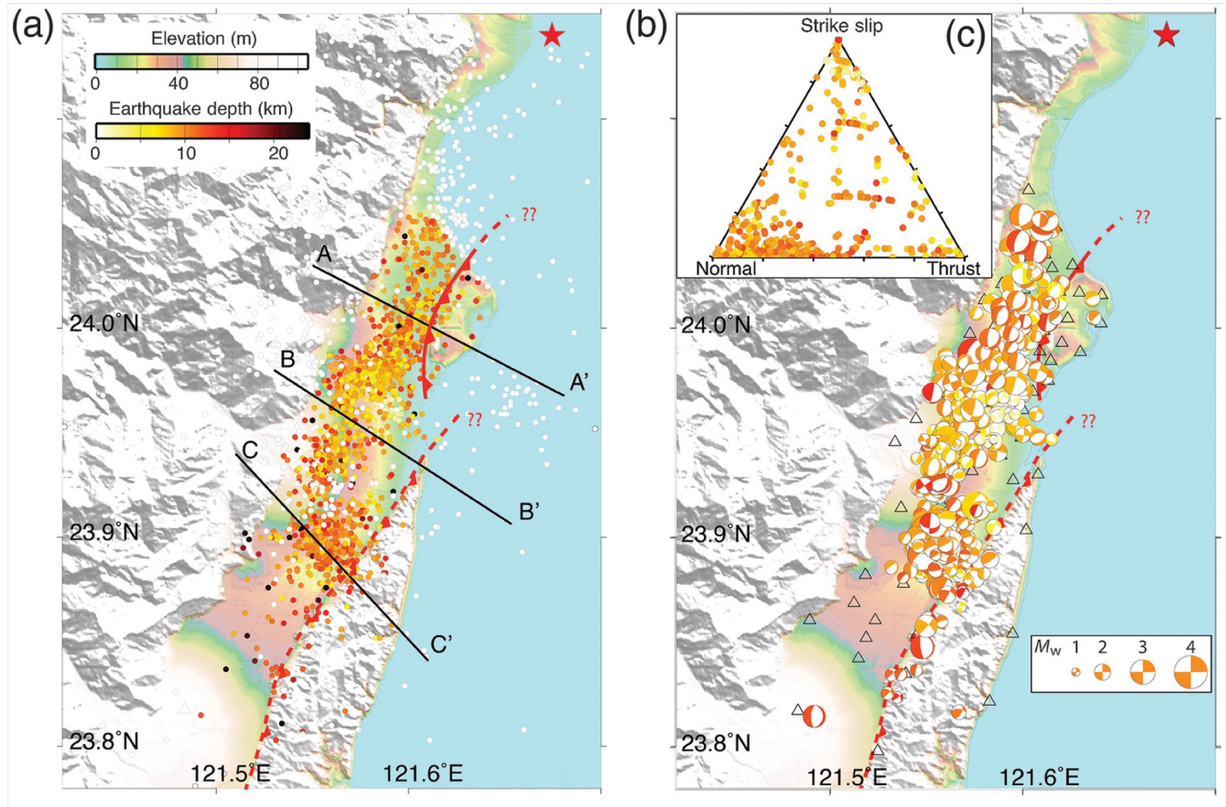
Seismology for geothermal exploration

Offline hand picking with dense seismic array before 2020

Over 2,000 events
~58,000 P-arrivals
~27,000 S-arrivals
6 months processing data





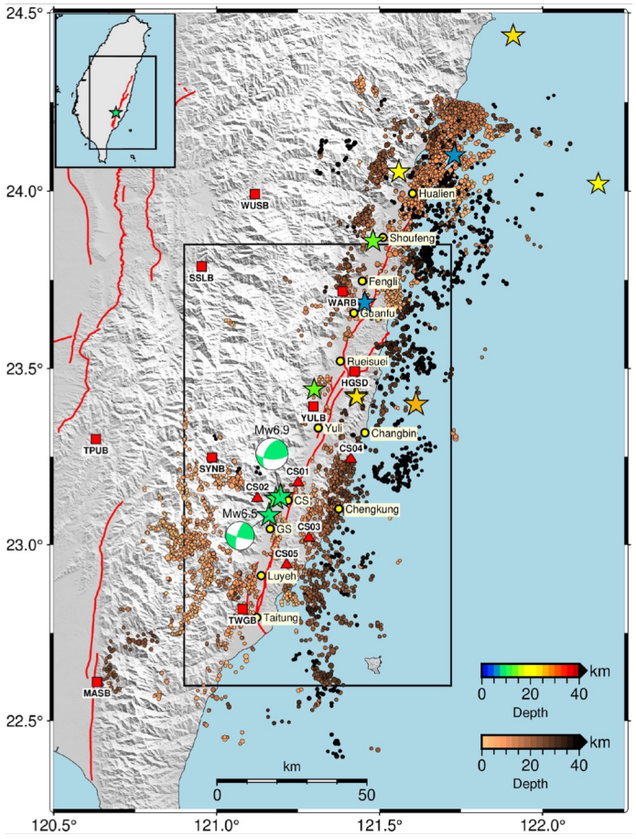


Kuo-Chen et al. (2019), TAO

Seismology for geothermal exploration

Over 14,000 events
~64,000 P-arrivals
~61,000 S-arrivals
3 days processing data

Offline AI picking with dense seismic array



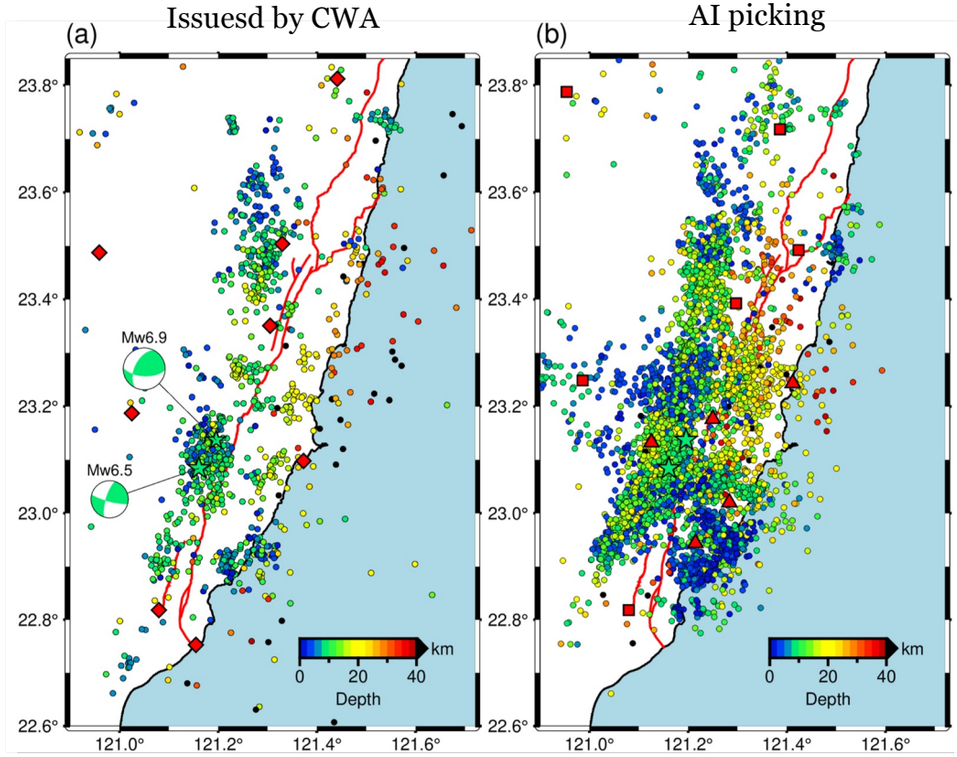
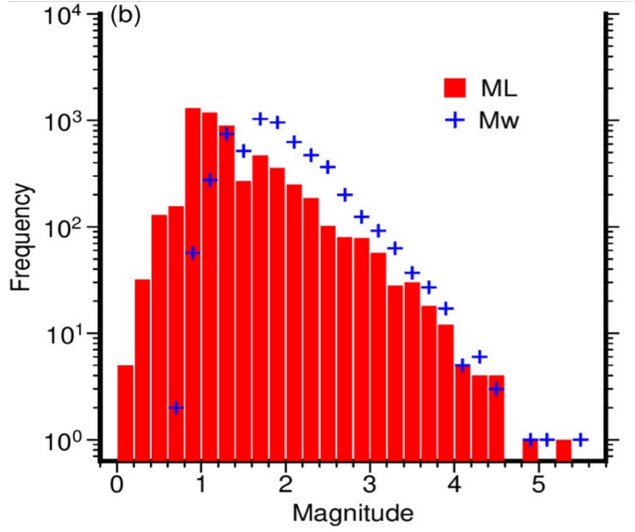


Fig. 6 Two-month seismicity of the 2022 M_W 6.9 Chihshang earthquake sequence of **a** CWA and **b** SeisBlue (this study). The rainbow color-coded circles and starts are seismicity and the Guanshan foreshock and Chihshang mainshock, respectively. Red diamonds, triangles and squares are permanent short period or broadband seismic stations of the CWA, CSN and BATS networks, respectively. Red traces are active faults mapped by CGS (Lin et al. 2021)

Low Magnitue detection

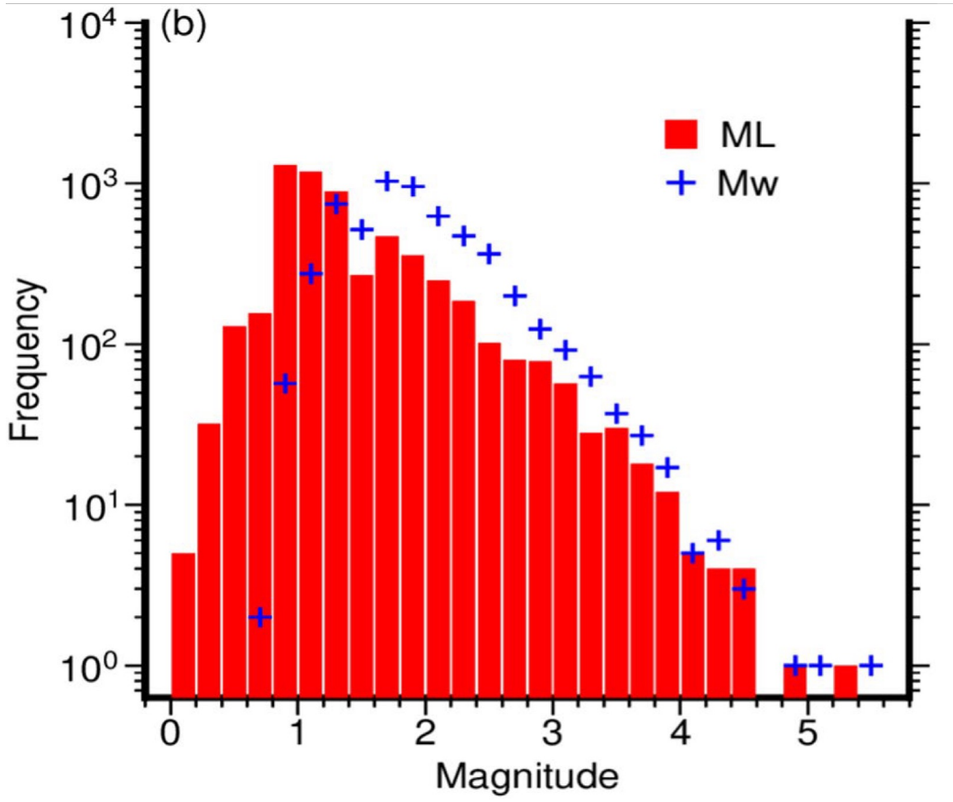


Sun et al. (2024), TAO

水裂(Hydraulic fracturing) 的誘發地震監測

規模多大？ 位置？應力？裂隙發育？
誘發地震時空演化？舊斷層活化？

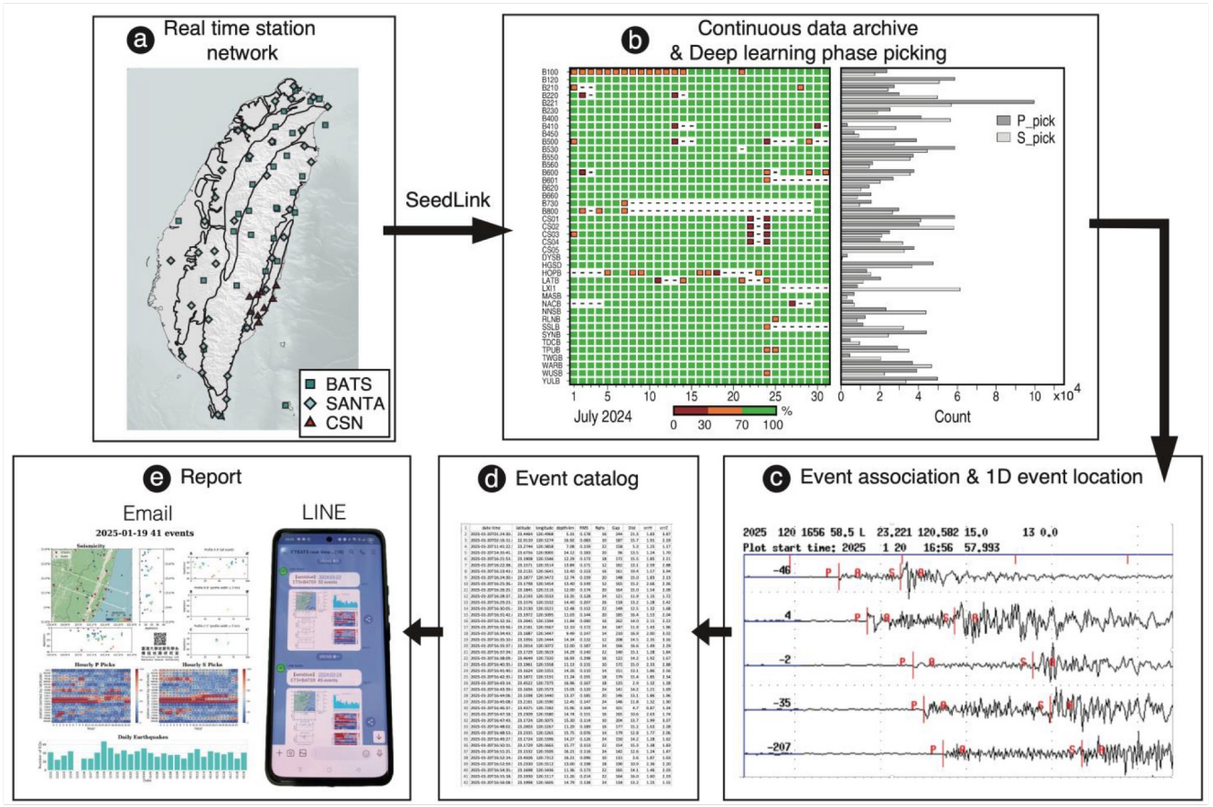
Low Magnitue detection

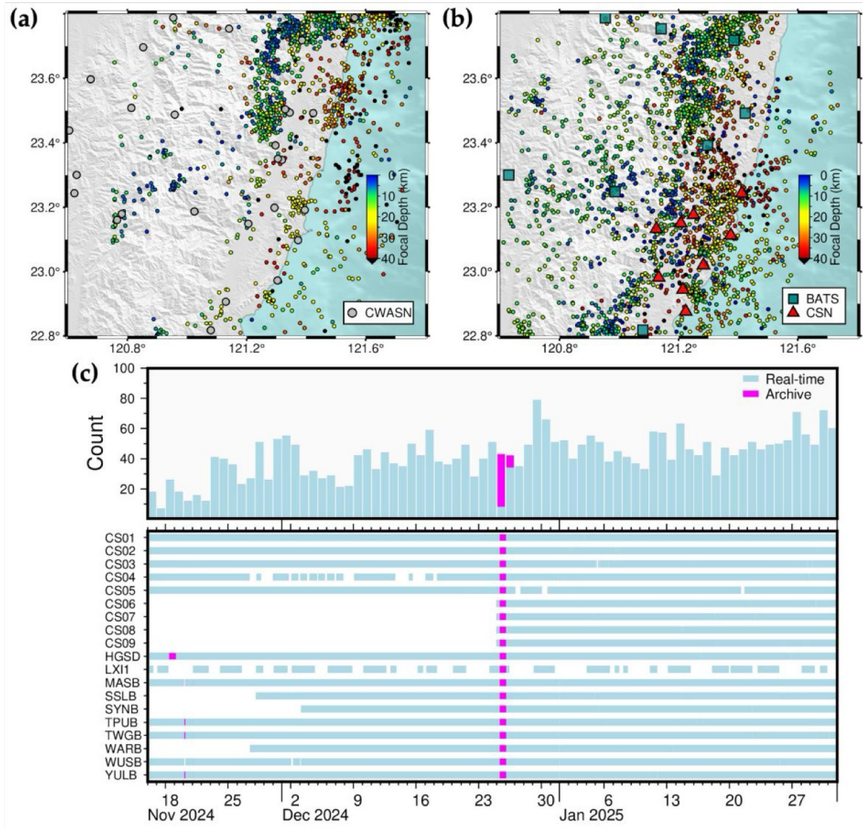


Sun et al. (2024), TAO

Seismology for geothermal exploration

RealTime monitroing for Mirco-Eq Monitoring System (RT-MEMS)

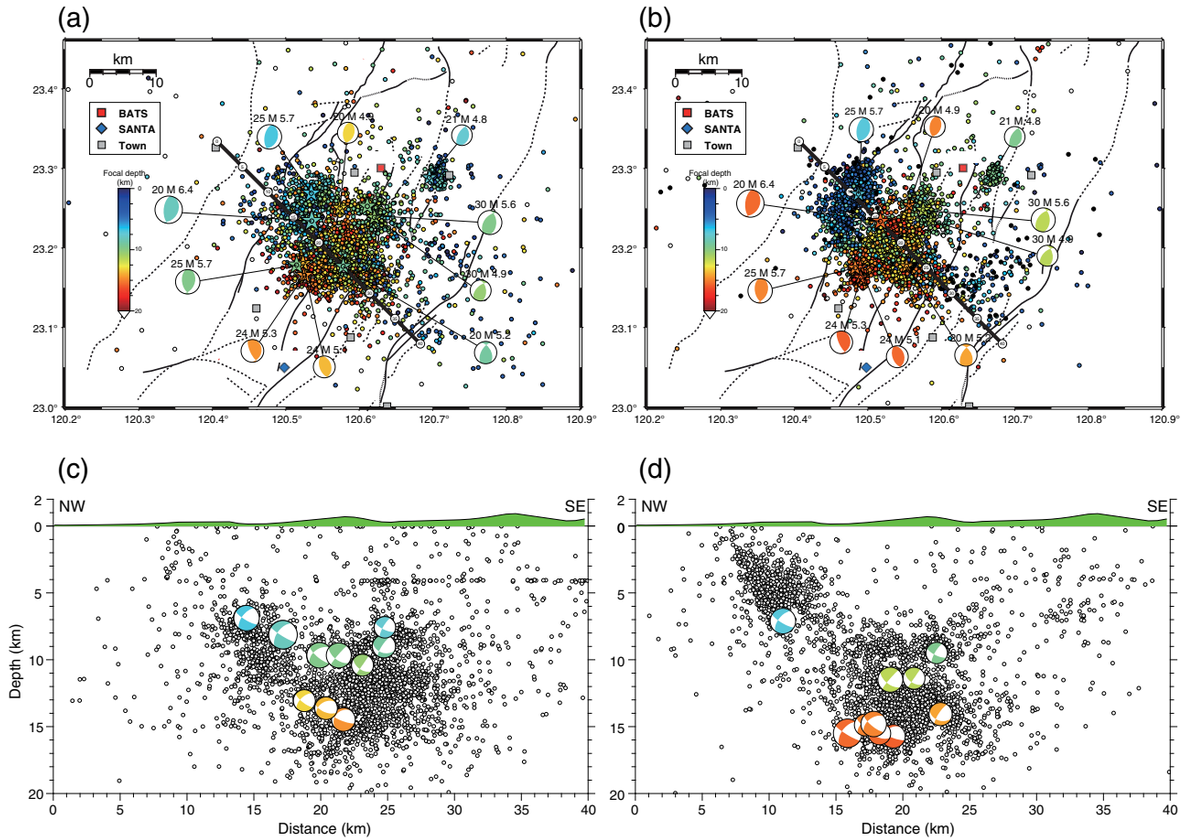




Sun et al. (2025), Sensors

水裂(Hydraulic fracturing) 的誘發地震監測

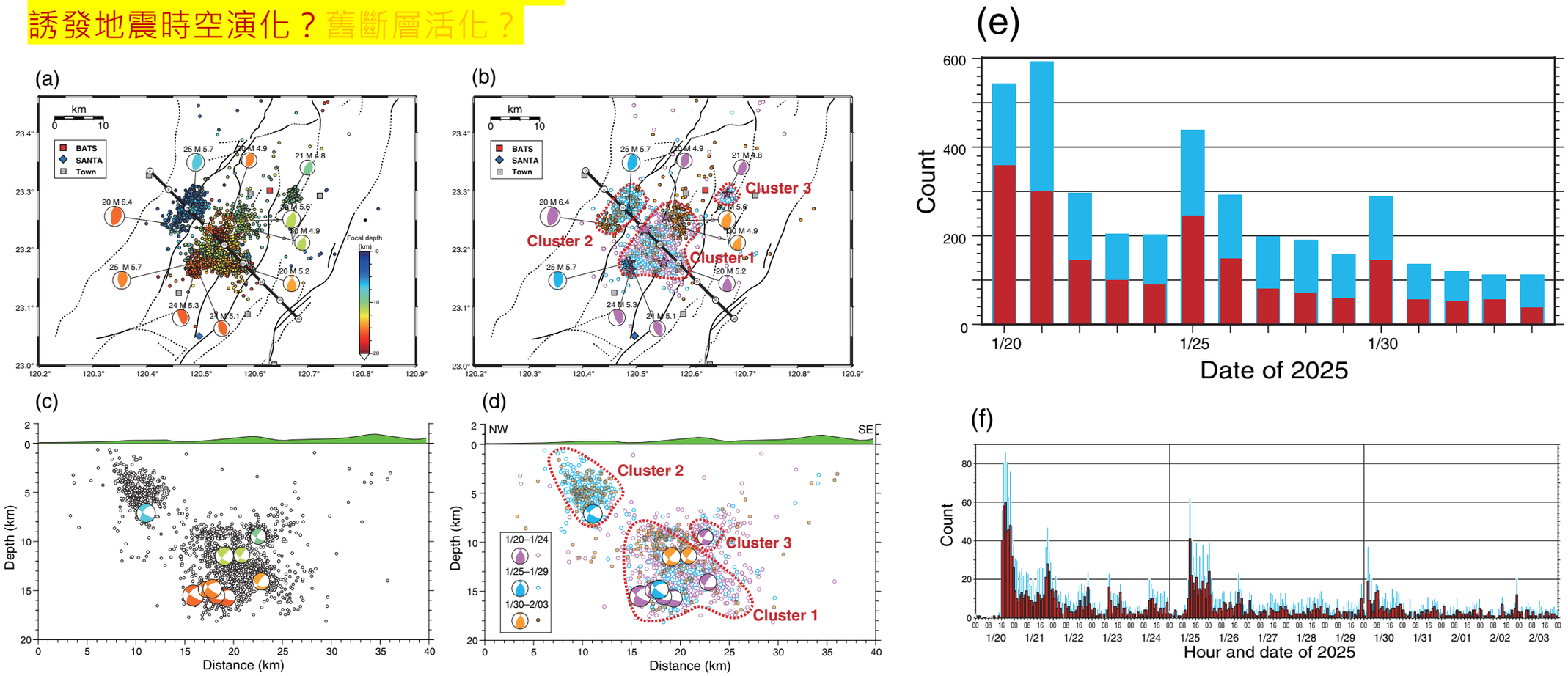
規模多大？ 位置？應力？裂隙發育？
誘發地震時空演化？舊斷層活化？



Kuo-Chen et al. (2025), The Seismic Record

水裂(Hydraulic fracturing) 的誘發地震監測

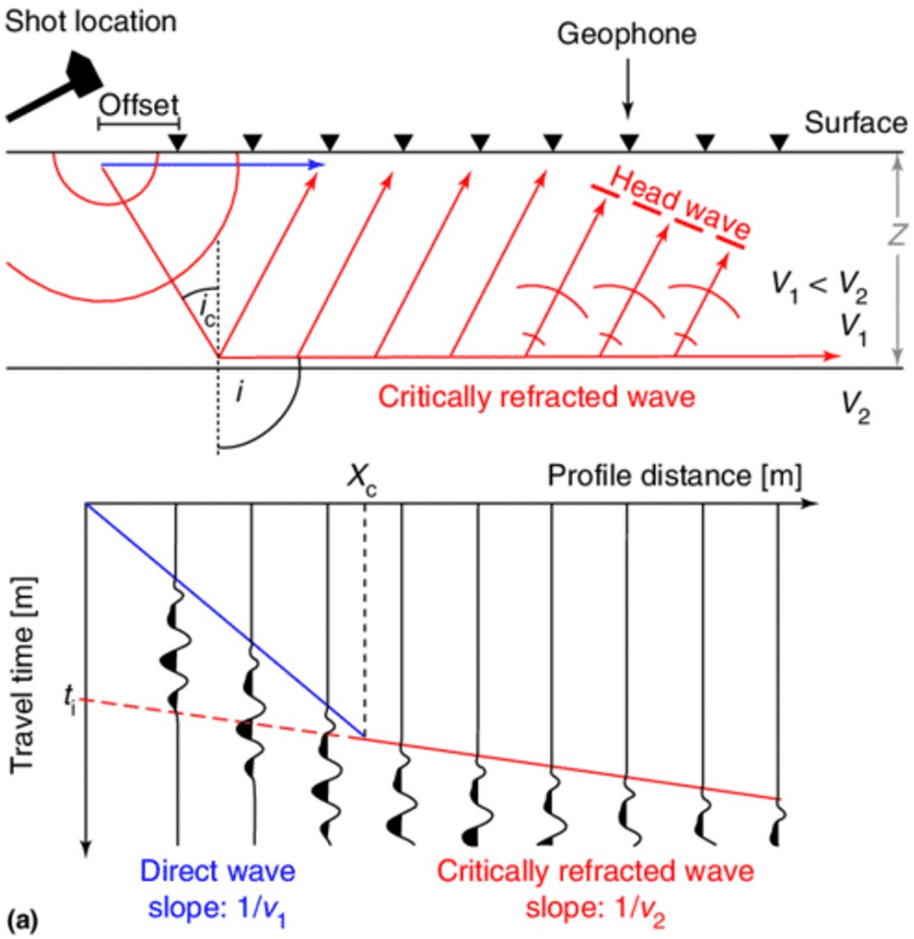
規模多大？ 位置？應力？裂隙發育？
誘發地震時空演化？ 舊斷層活化？

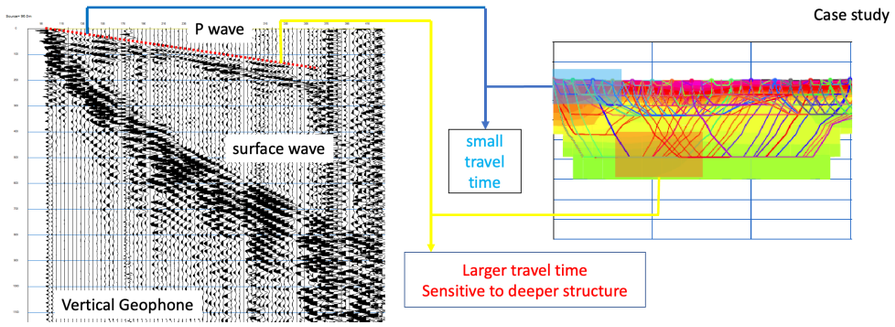


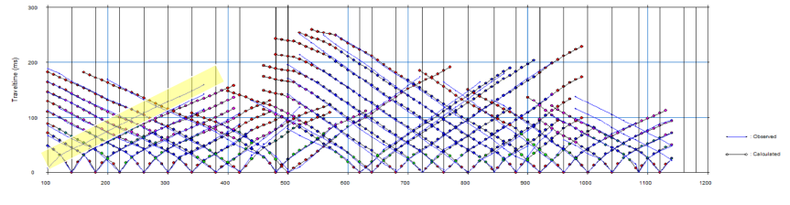
Kuo-Chen et al. (2025), The Seismic Record

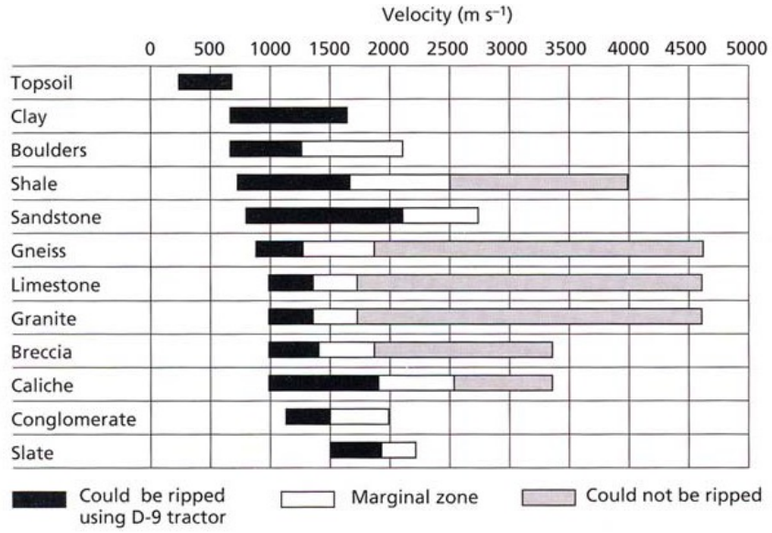
折射震測原理

看岩層速度









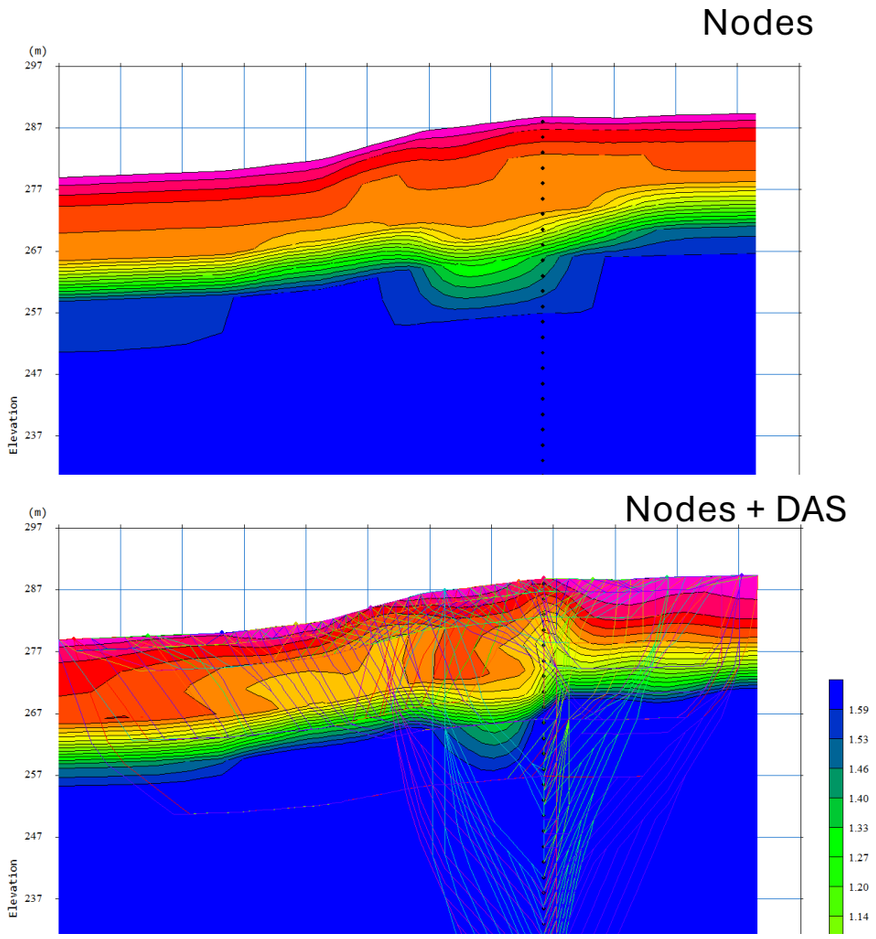
水裂(Hydraulic fracturing) 的誘發地震監測

規模多大？位置？應力？裂隙發育？
誘發地震時空演化？舊斷層活化？







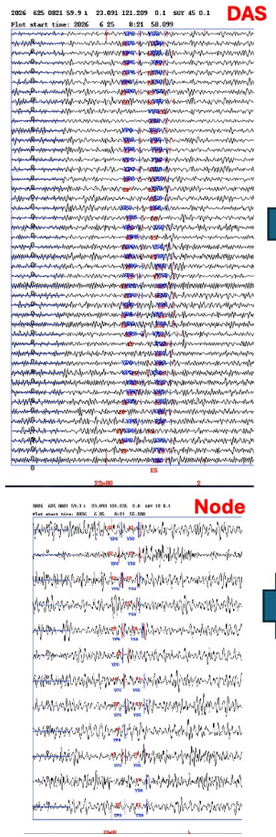


管卓康等(2026) 115年中華民國地質與地物年會

水裂(Hydraulic fracturing) 的誘發地震監測

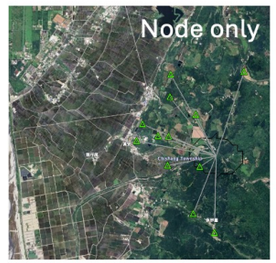
規模多大？ 位置？應力？裂隙發育？
誘發地震時空演化？舊斷層活化？

Seismic waveform & arrivals



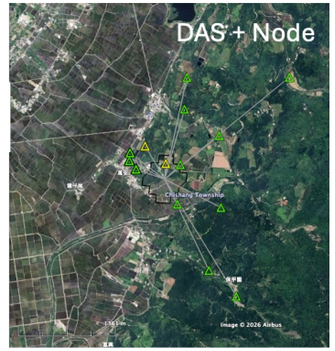


2026-06-25 08:21:59.9
23.091 121.209 0.1 km; RMS: 0.060
GAP=350 ERH=0.19 ERZ=0.50 ERX=0.60

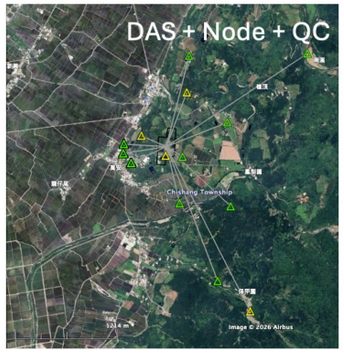


2026-06-25 08:21:59.3 M_W 0.2
23.093 121.135 2.0 km; RMS: 0.132
GAP=163 ERH=0.39 ERZ=0.40 ERX=0.60

- DAS can effectively improve the identification of seismic events due to its large number of nodes, but it is limited by station coverage, resulting in large location errors.
- Nodes can effectively improve the identification and location of seismic events, but long-term monitoring is quite challenging



2026-06-25 08:21:59.7 M_W 0.2
23.094 121.224 1.2 km; RMS: 0.175
GAP=134 ERH=0.49 ERZ=0.30 ERX=0.30



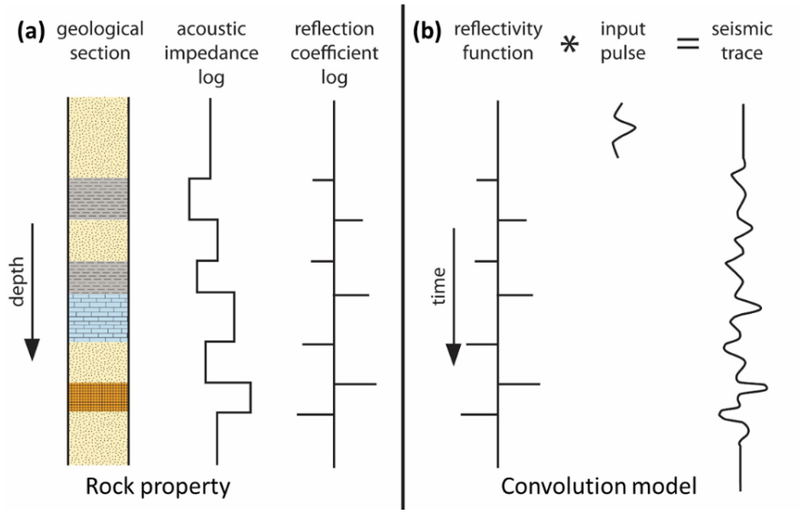
2026-06-25 08:21:59.8 M_W 0.2
23.097 121.224 0.9 km; RMS: 0.083
GAP=80 ERH=0.24 ERZ=0.20 ERX=0.10

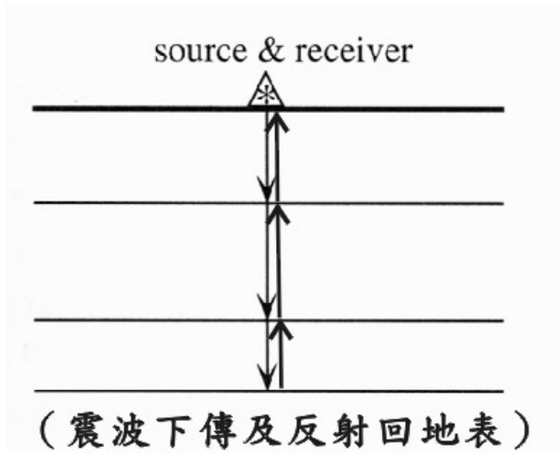
- **Combining DAS and node data can effectively improve the identification and location of seismic events along creeping fault zone**

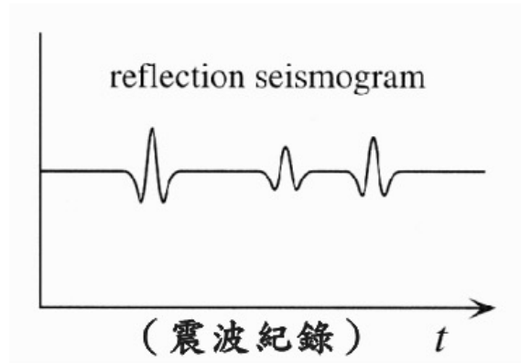
Sun et al. (2026), Optic Seismology and the Next Era in Seismic Sensing, SSA, Kona

反射震測原理

看地層界面

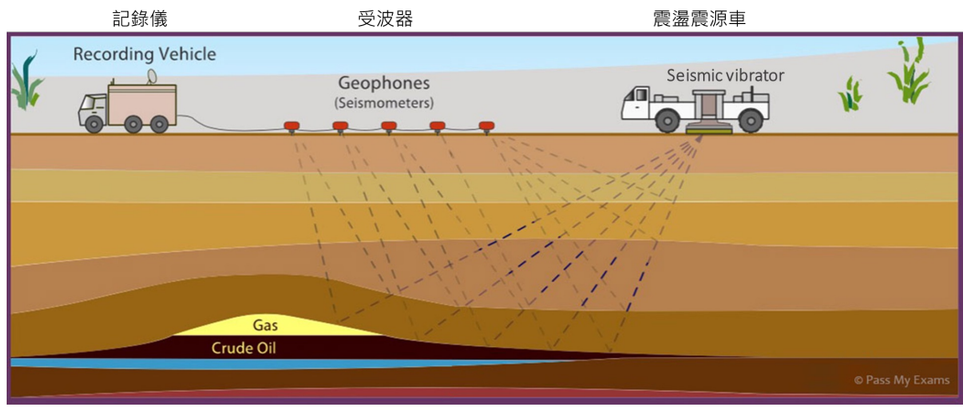


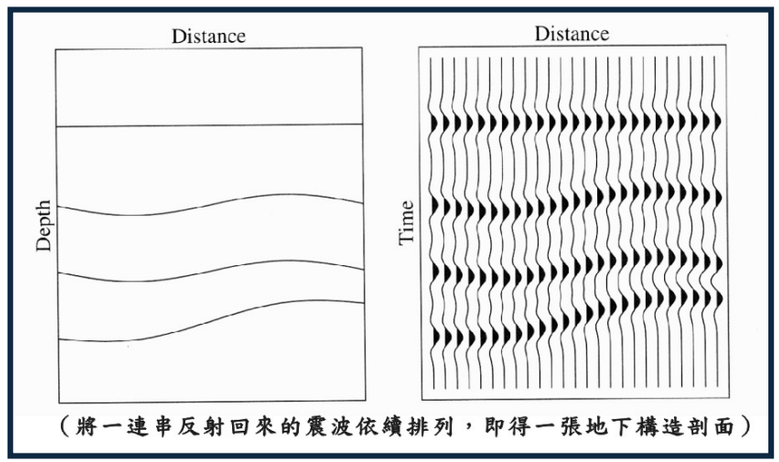




Source * Earth reflectivity = Seismogram

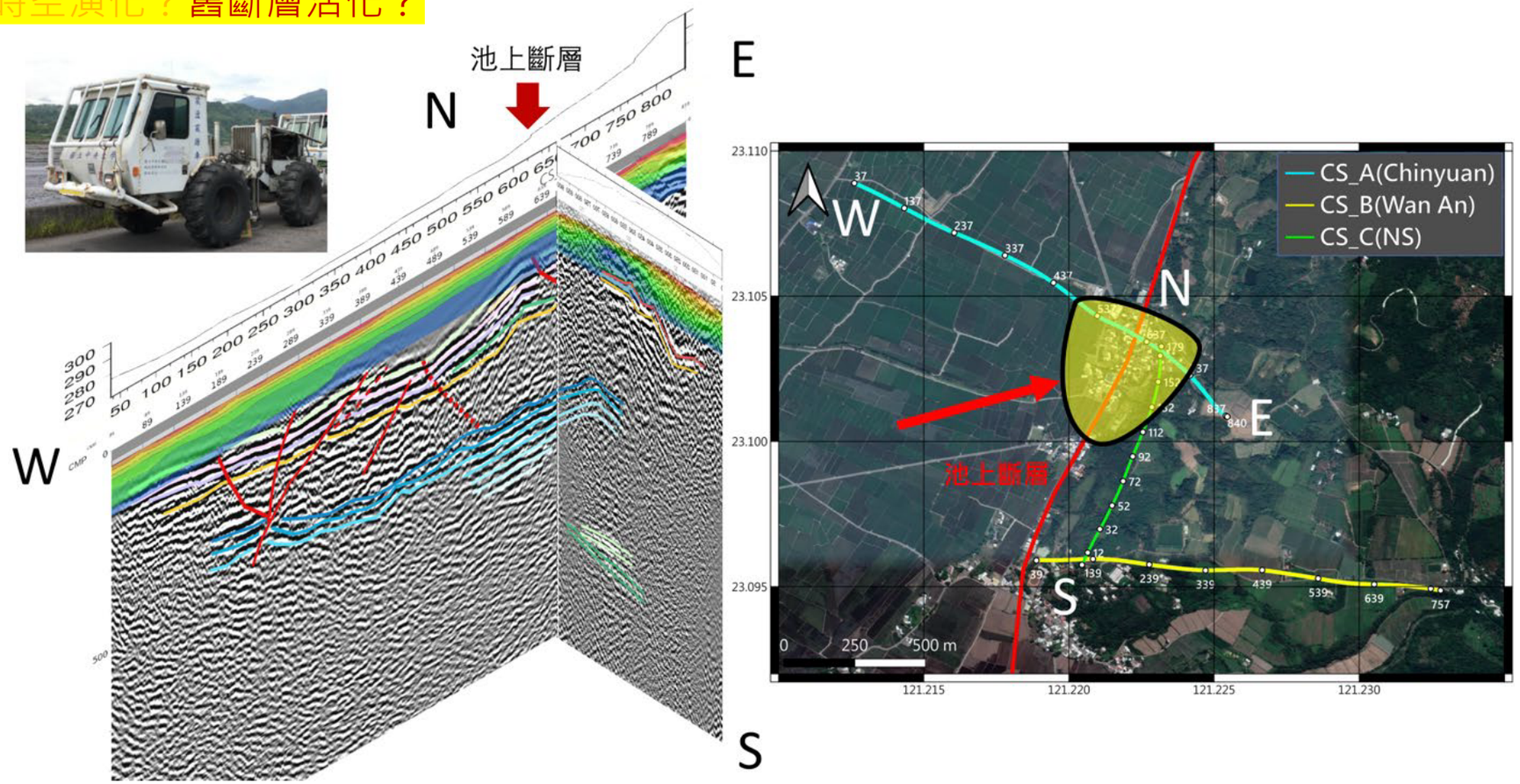
convolve





水裂(Hydraulic fracturing) 的誘發地震監測

規模多大？位置？應力？裂隙發育？
誘發地震時空演化？舊斷層活化？

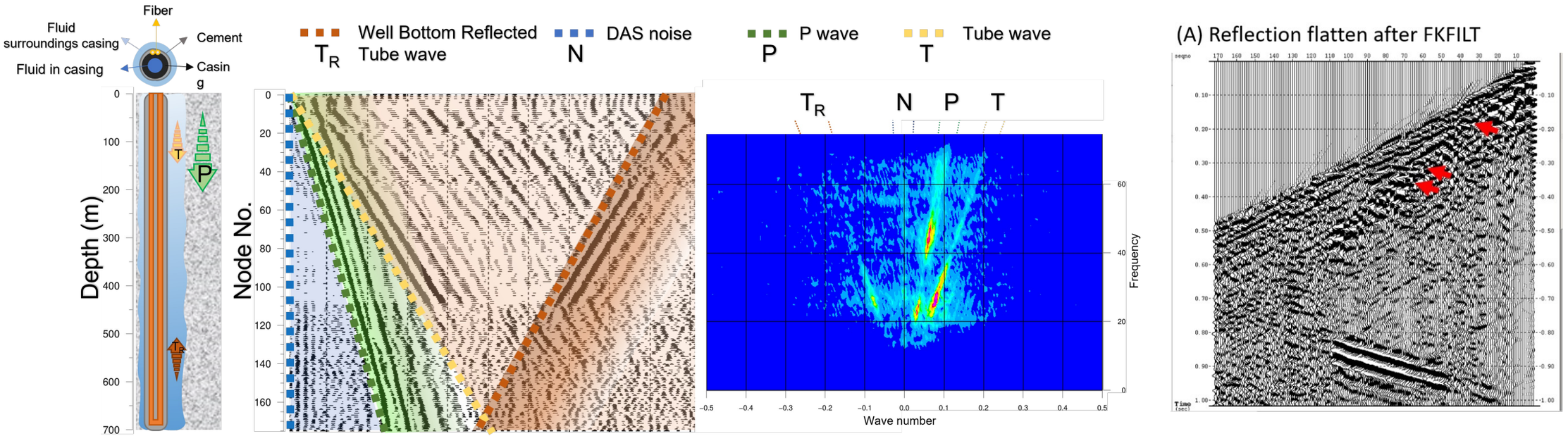


Chen, 2022, matser thesis

水裂(Hydraulic fracturing) 的誘發地震監測

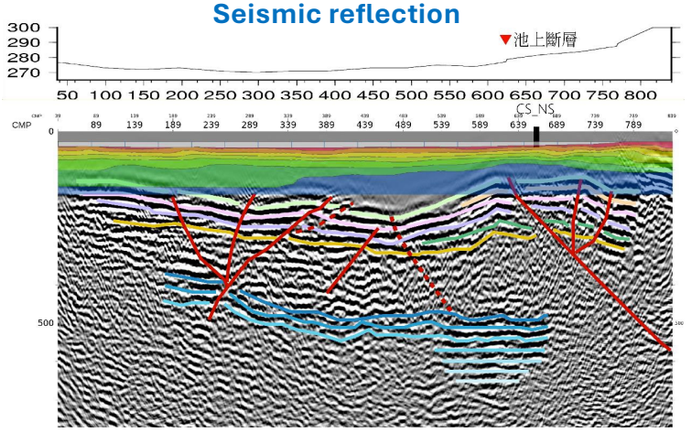
規模多大？位置？應力？裂隙發育？
誘發地震時空演化？舊斷層活化？

DAS-VSP



管卓康等(2024) DAS在震測上的應用-以米崙斷層VSP震測為例，DAS技術交流工作坊

Seismic reflection

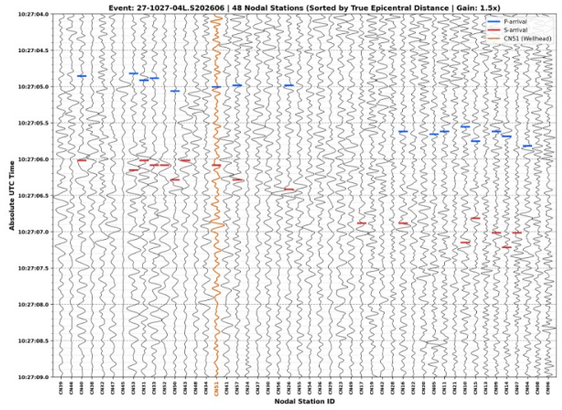


Chen, 2022

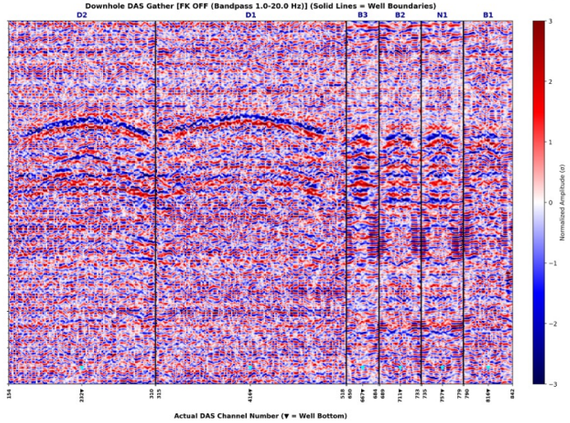


2026-06-27 10:27:03.5 M_W 0.4
23.097 121.233 2.0 ; RMS=0.154
GAP=234 ERH=0.44 ERZ= 0.40 ERX= 0.50

Node

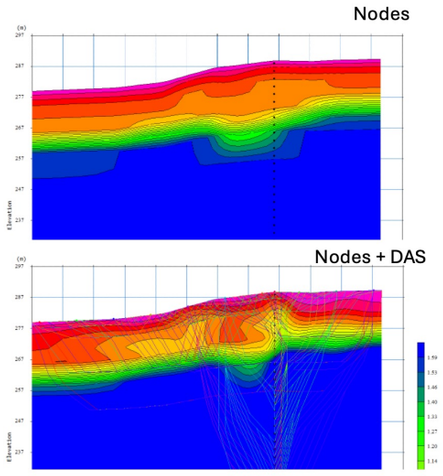


DAS (6 Boreholes)

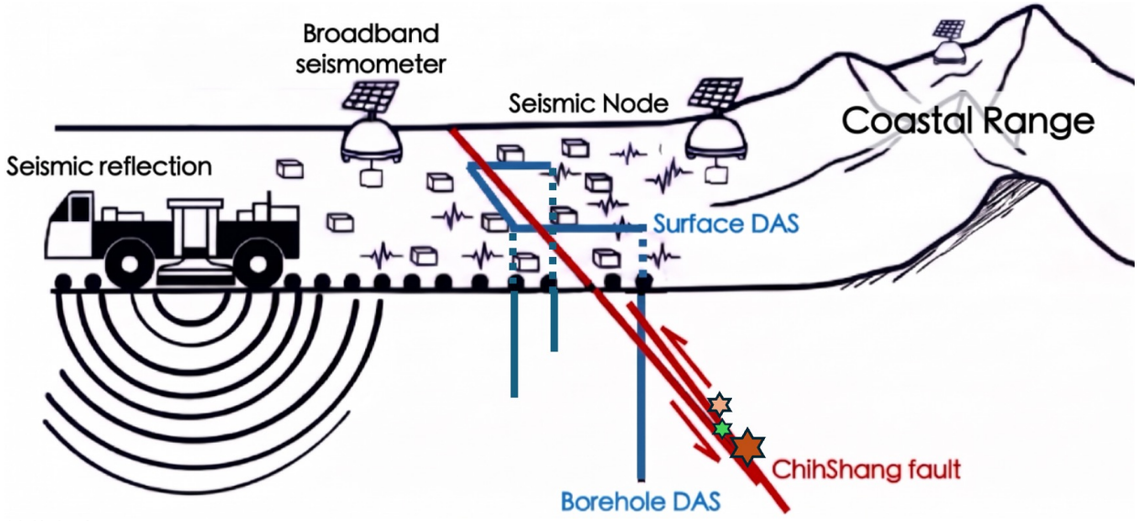


Sun et al. (2026), Optic Seismology and the Next Era in Seismic Sensing, SSA, Kona

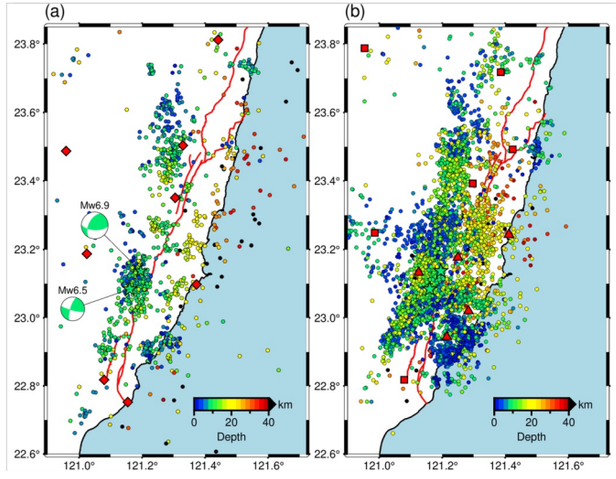
Seismic refraction



管卓康等(2026) 115年中華民國地質與地物年會



Broadband seismic network + AI



Sun et al. (2024), TAO

謝謝聆聽，敬請指教