Machine learning in marine microseismicity analysis

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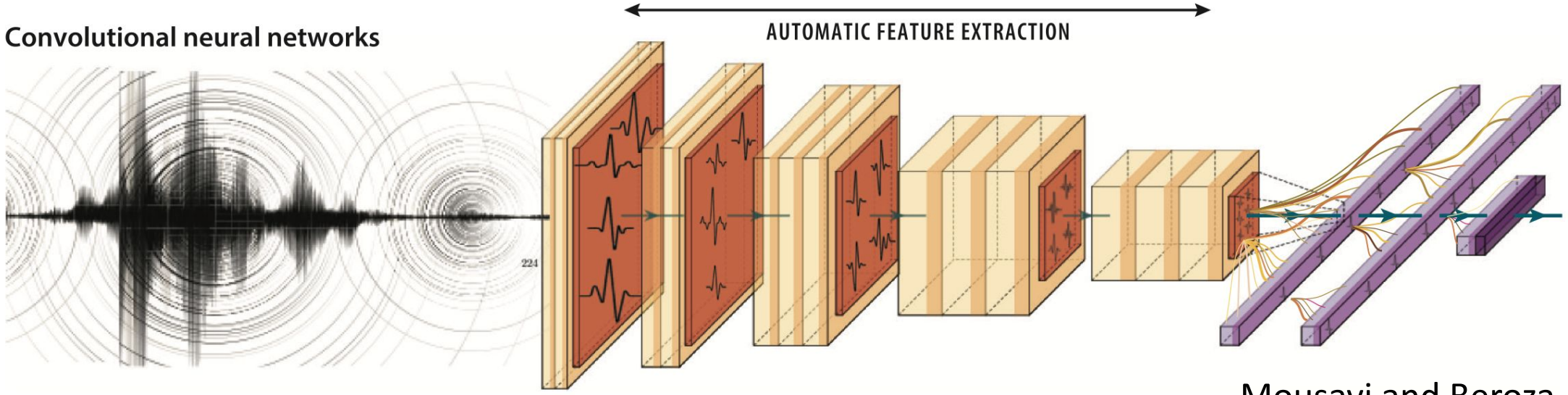
and 4castGofar science team

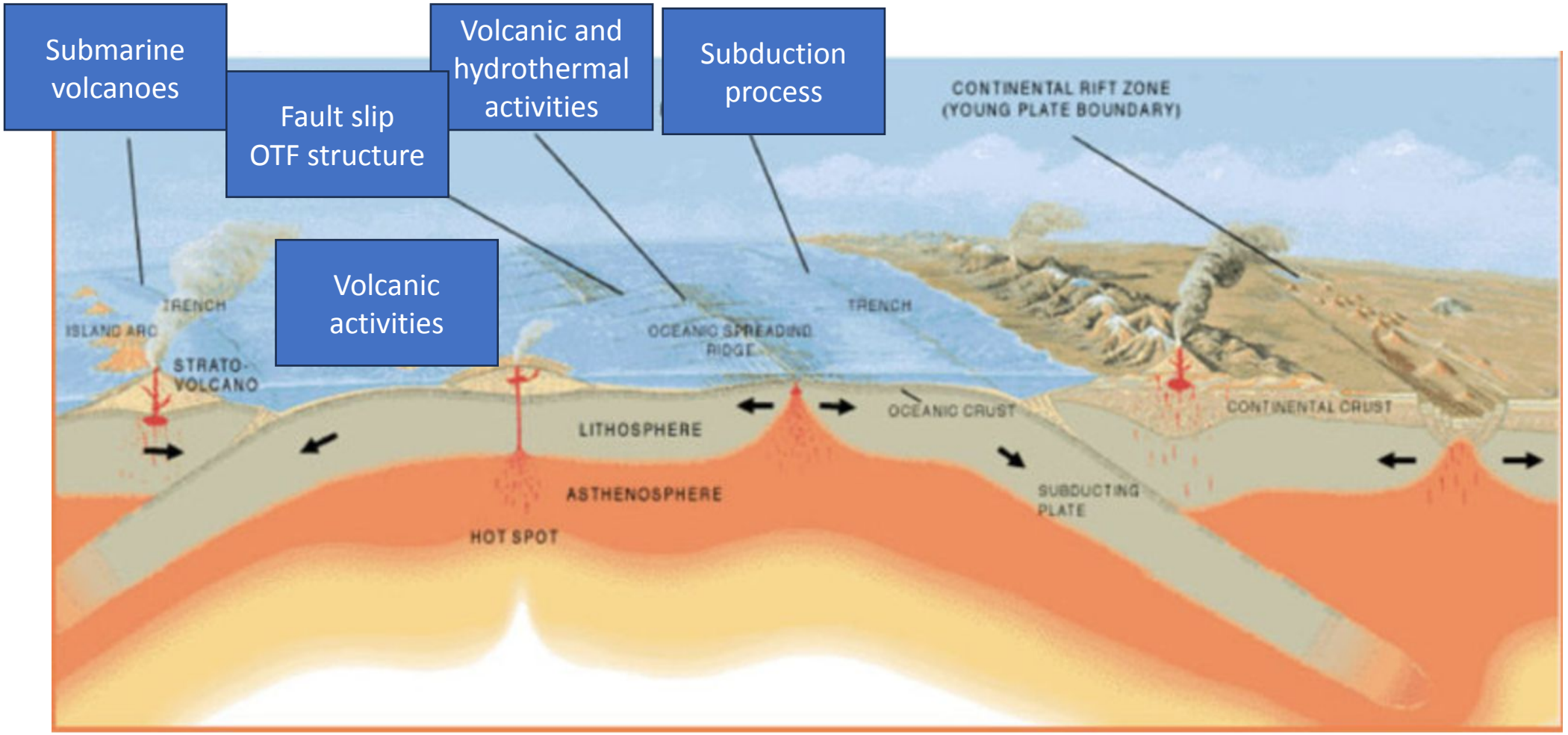
Machine learning

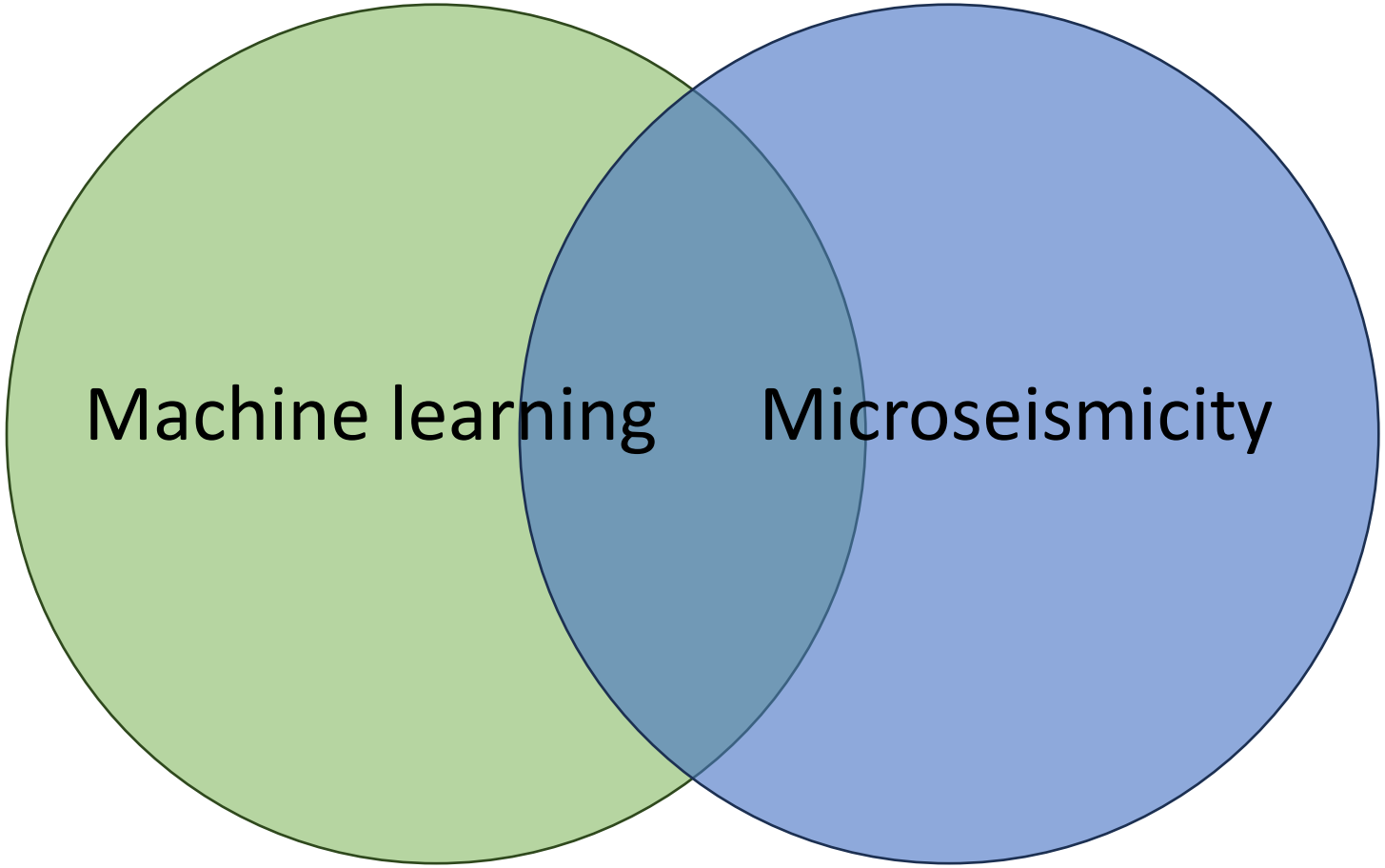


Mousavi and Beroza, 2023

- ML is a collection of methods used to develop understanding and predictive capability by learning relationships embedded in data.
- ML methods are becoming the dominant approaches for many tasks in seismology.

Microseismicity in marine environment





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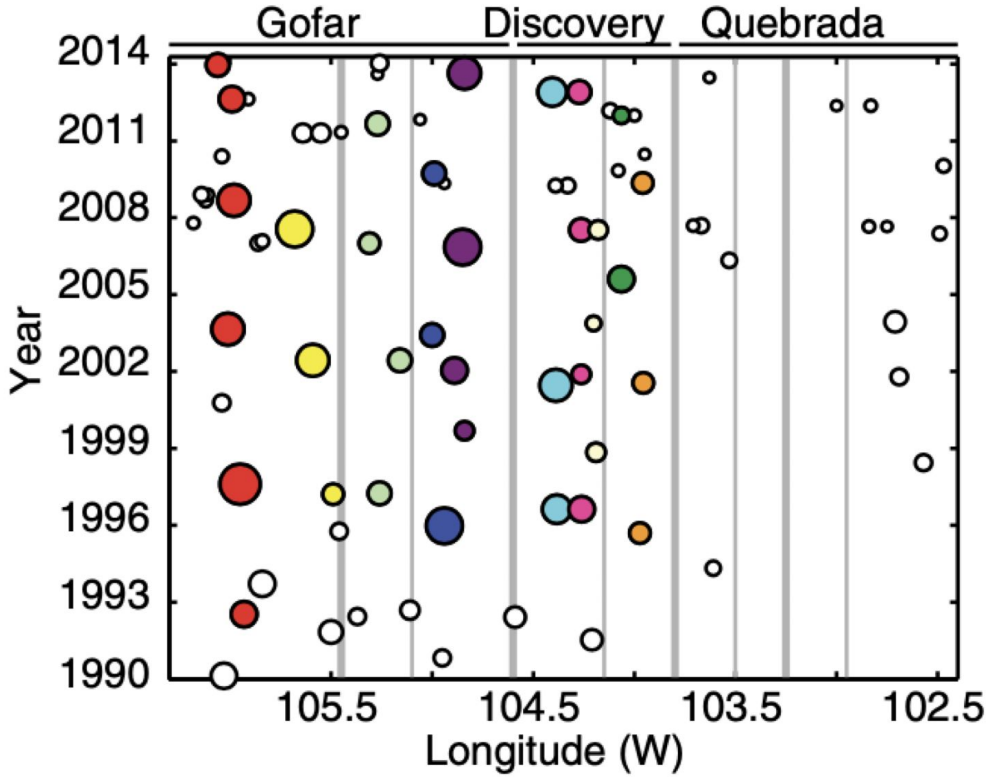
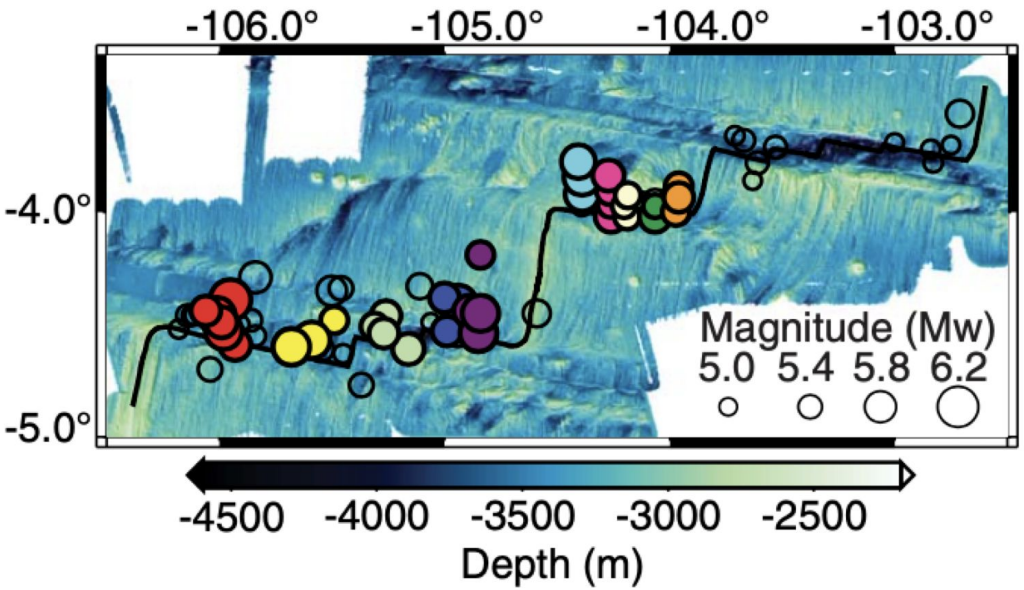
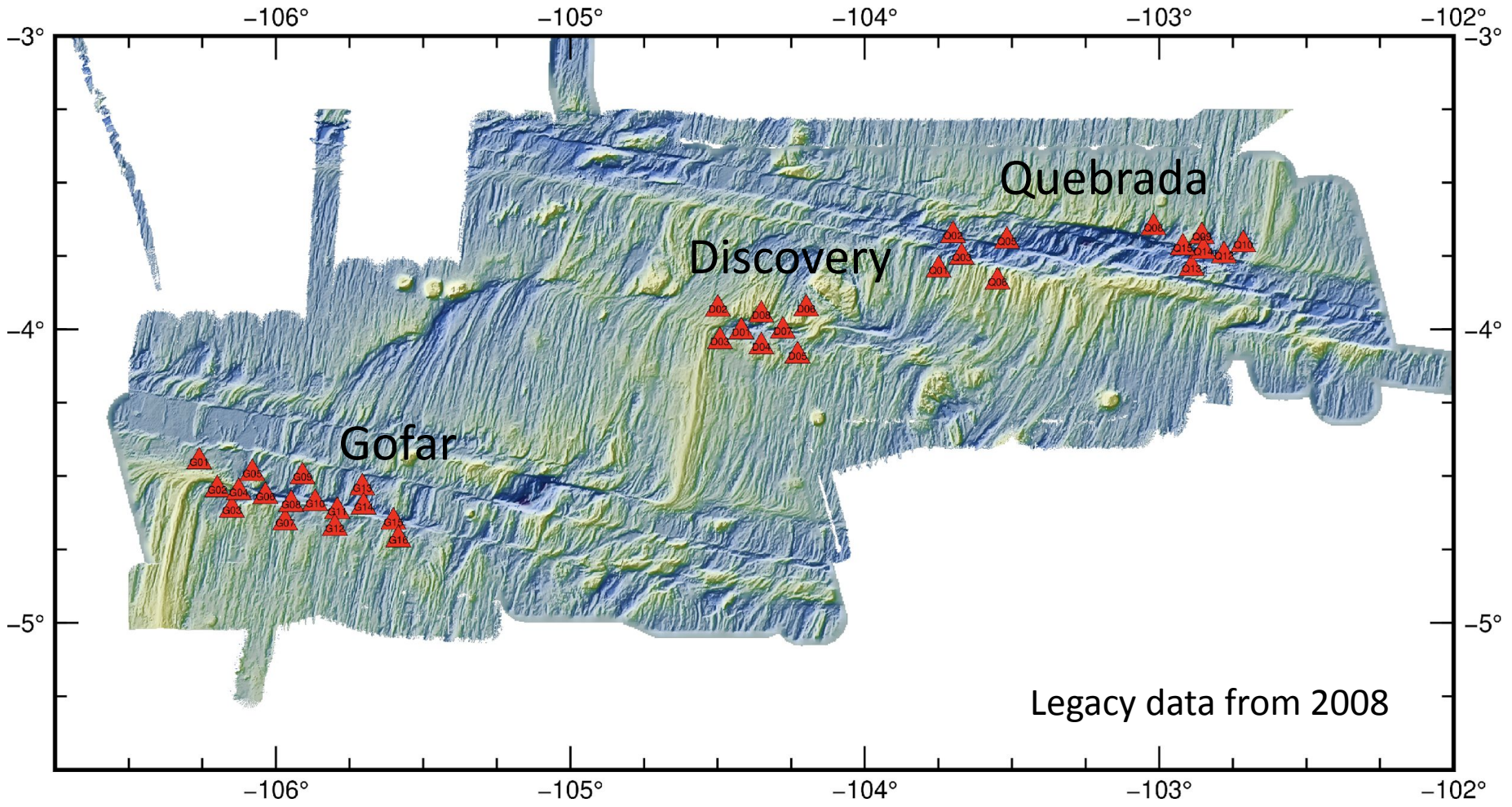


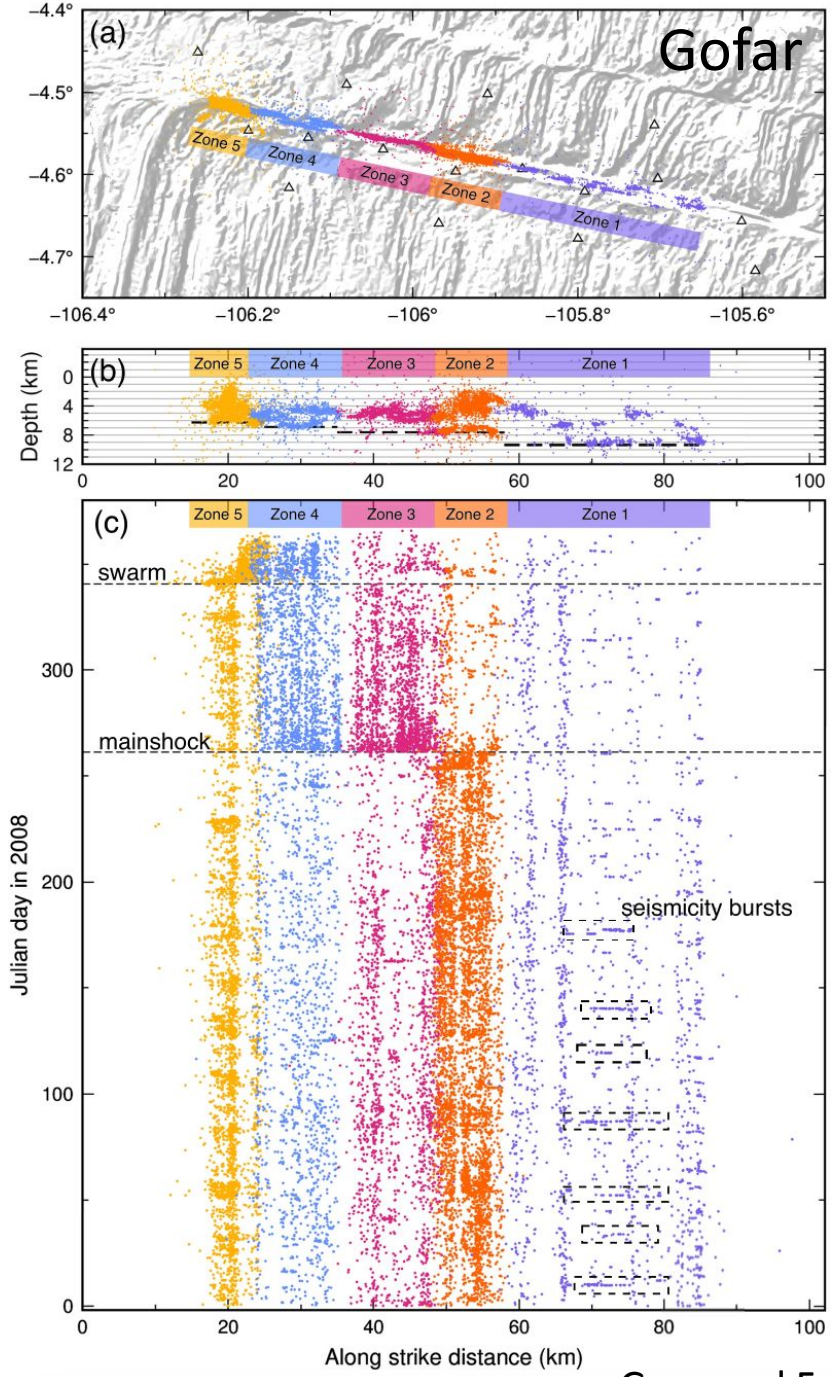
Quasi-periodic M6 events

M6 events occur every 5-6 years along Gofar and Discovery!

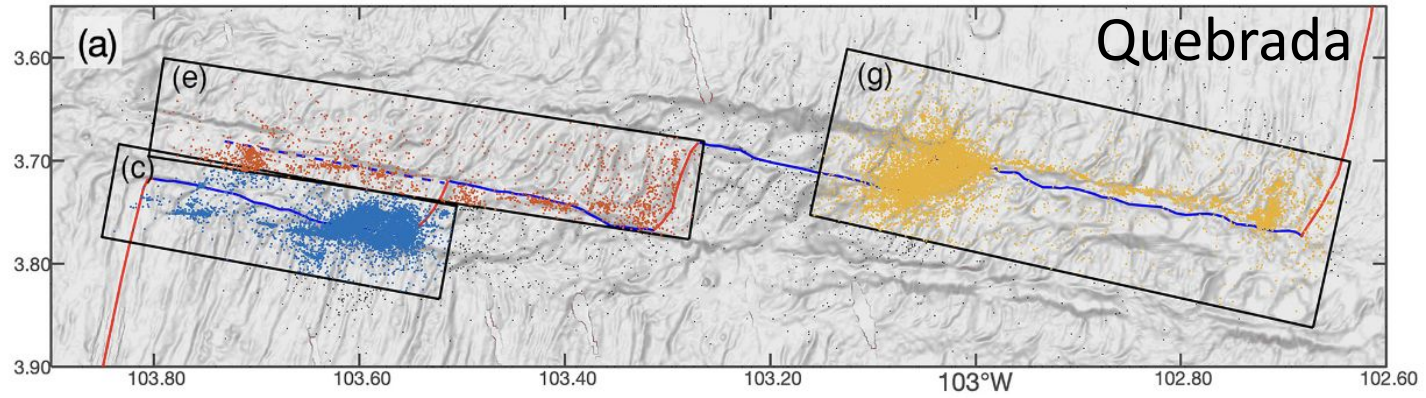


A machine learning workflow to study microseismicity at oceanic transform faults

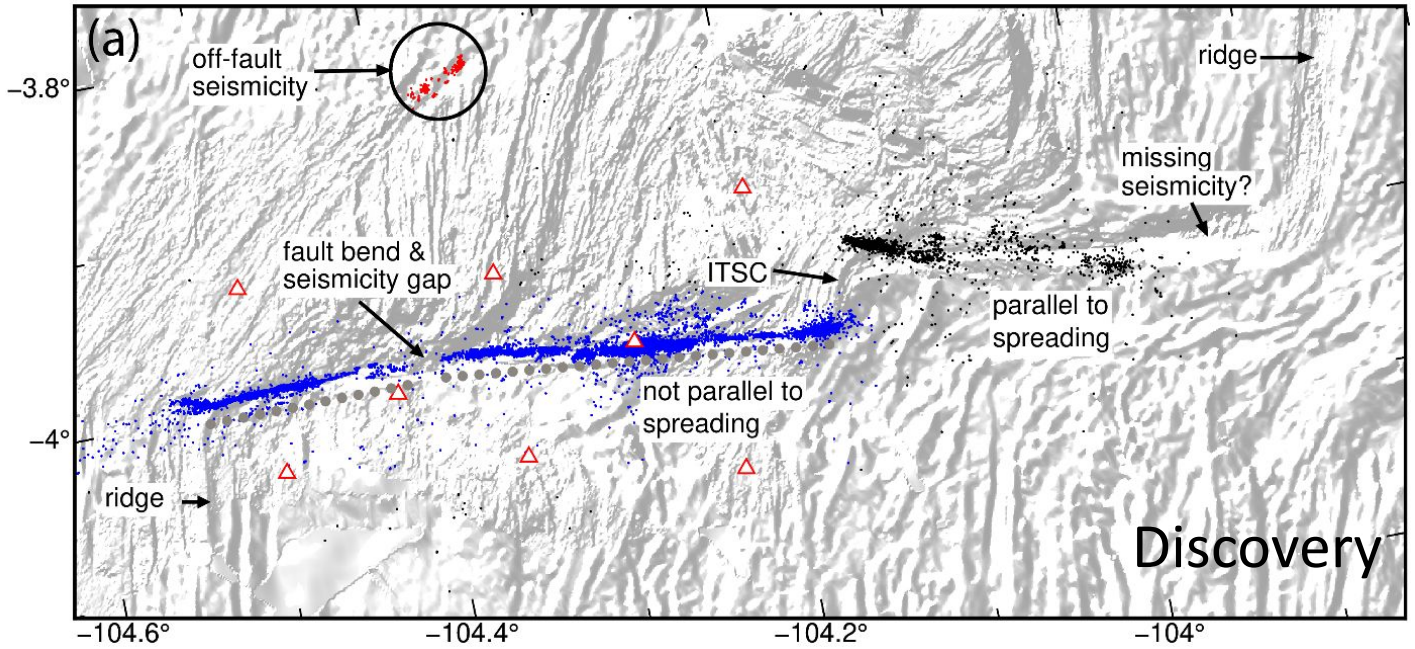




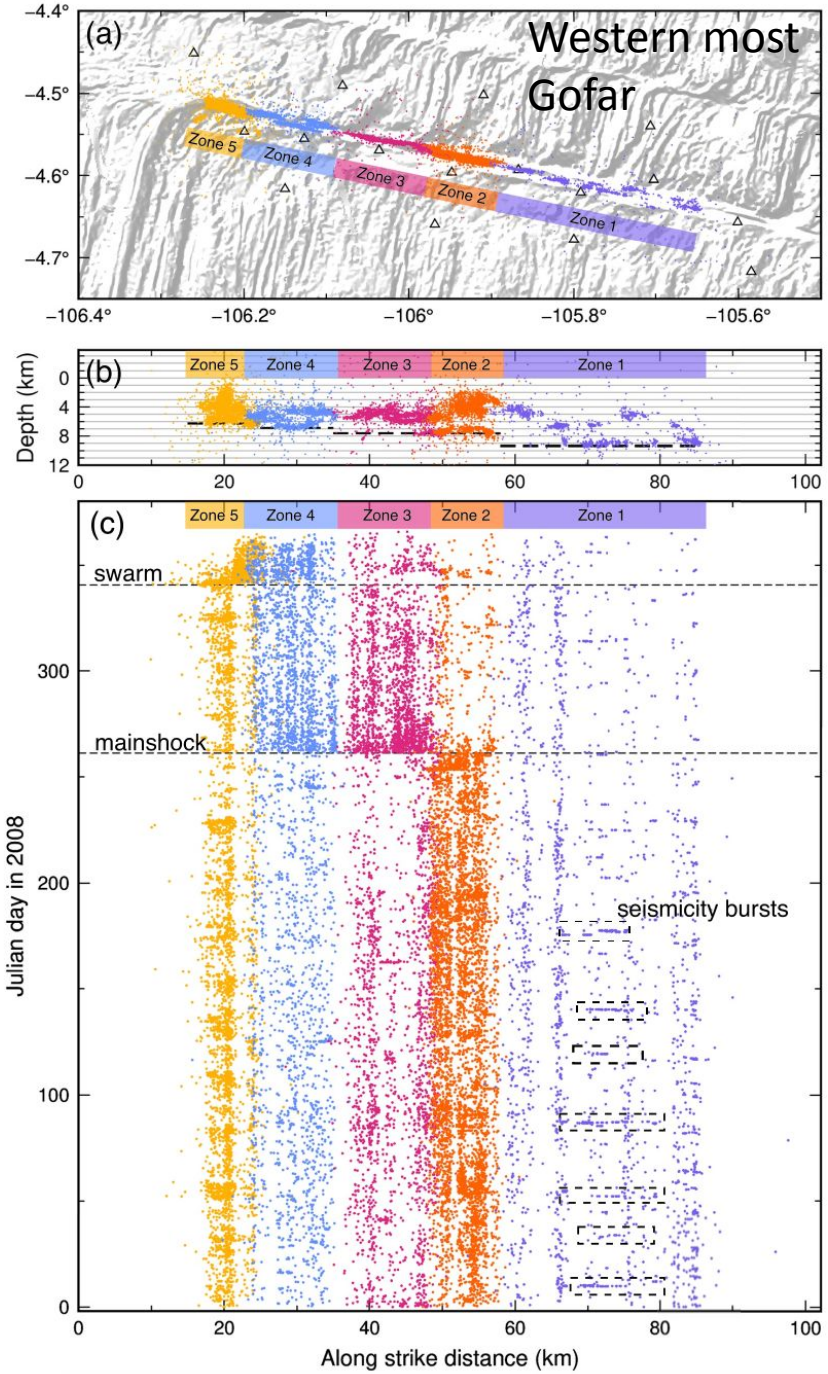
Gong and Fan, 2022

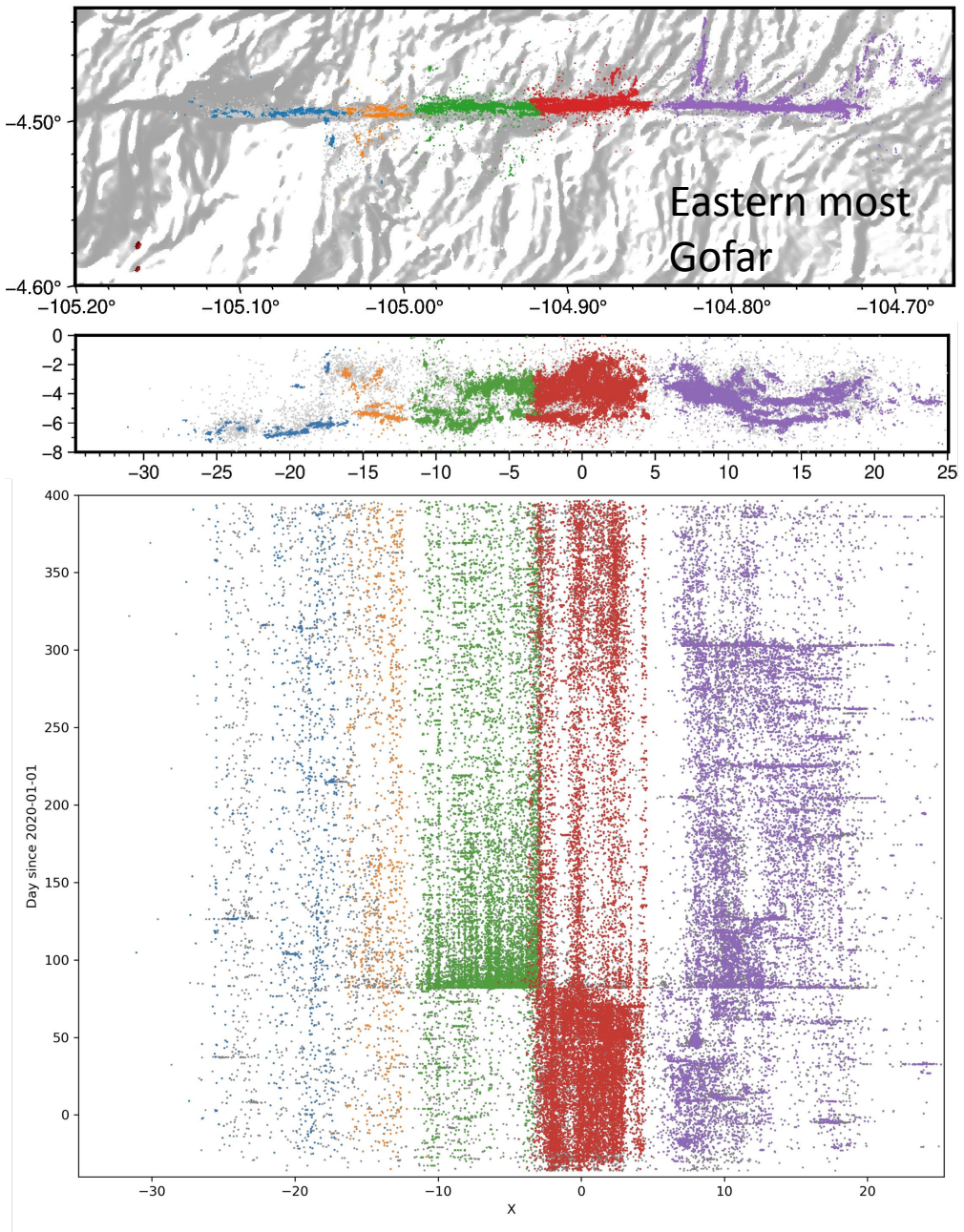


Gong et al., 2021

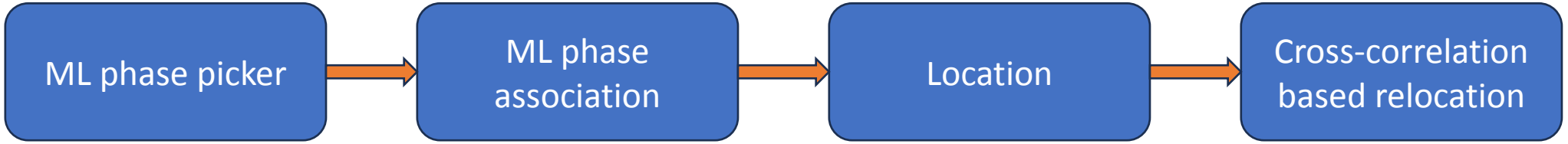


Gong et al., 2023


(a)
Western most Gofar
Zone 5
Zone 4
Zone 3
Zone 2
Zone 1
−4.4°
−4.5°
−4.6°
−4.7°
−106.4°
−106.2°
−106°
−105.8°
−105.6°
(b)
Depth (km)
0
4
8
12
0
20
40
60
80
100
(c)
swarm
mainshock
seismicity bursts
Julian day in 2008
0
100
200
300
Along strike distance (km)


−4.50°
−4.60°
Eastern most Gofar
−105.20°
−105.10°
−105.00°
−104.90°
−104.80°
−104.70°
0
−2
−4
−6
−8
−30
−25
−20
−15
−10
−5
0
5
10
15
20
25
Day since 2020-01-01
400
350
300
250
200
150
100
50
0
−30
−20
−10
0
10
20
X

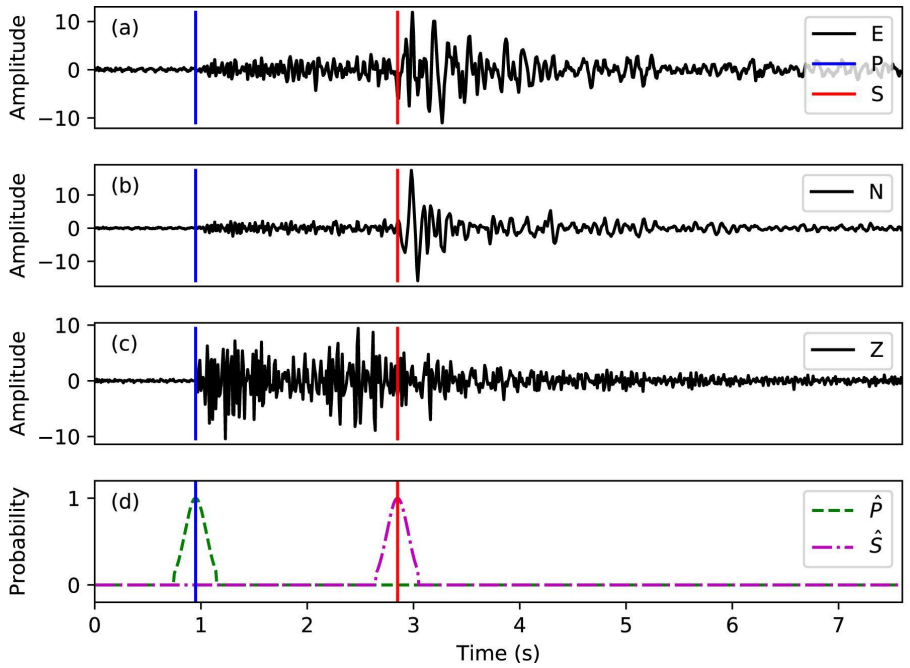
Workflow



Software	EQTransformer (Mousavi et al., 2020) PhaseNet (Zhu and Beroza, 2019)	GaMMA (Zhu et al., 2022)	COMPLOC (Lin and Shearer, 2006)	GrowClust (Trugman and Shearer, 2017)
Time	12 min one month's data a single station	Scale with the number of phase picks	10s of min Scale with the number of events	A few days Cross correlation is time consuming. But this can be parallelized.
Example	2 hr 20 min one year of detection at a single station	20-30 min for each month	30-45 min for 30 k events	4-5 days for 30 k events

ML for phase picking

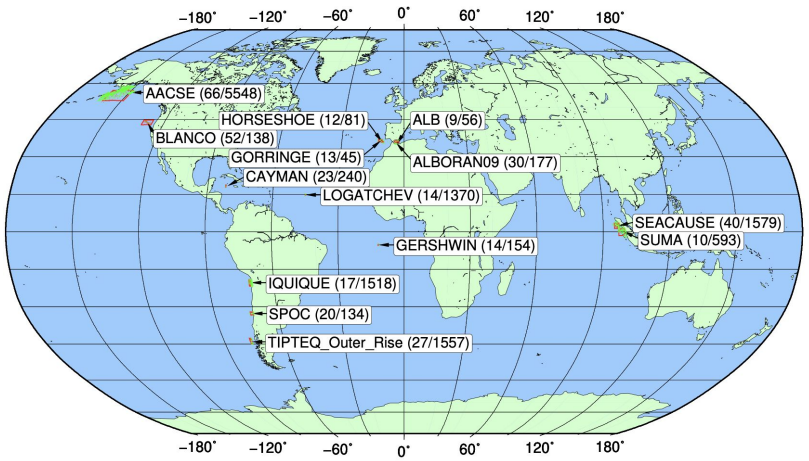
- A game changer!
- ML algorithms are able to pick more P and S arrivals with a higher precision.



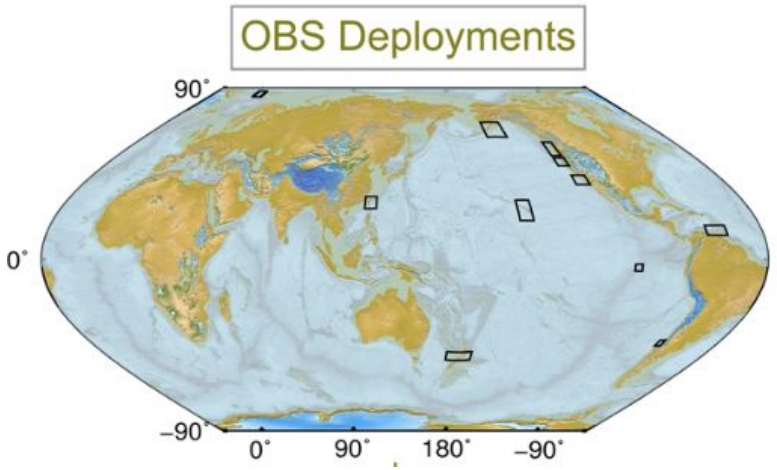
Zhu and Beroza, 2019

Recent progress of phase pick on OBS

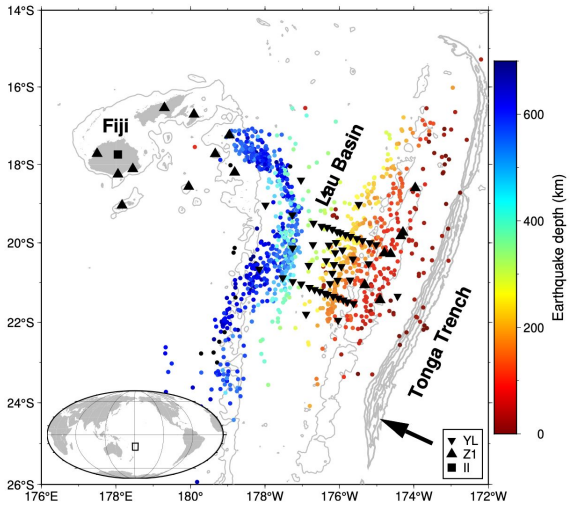
PICKBLUE, Bornstein et al., 2023



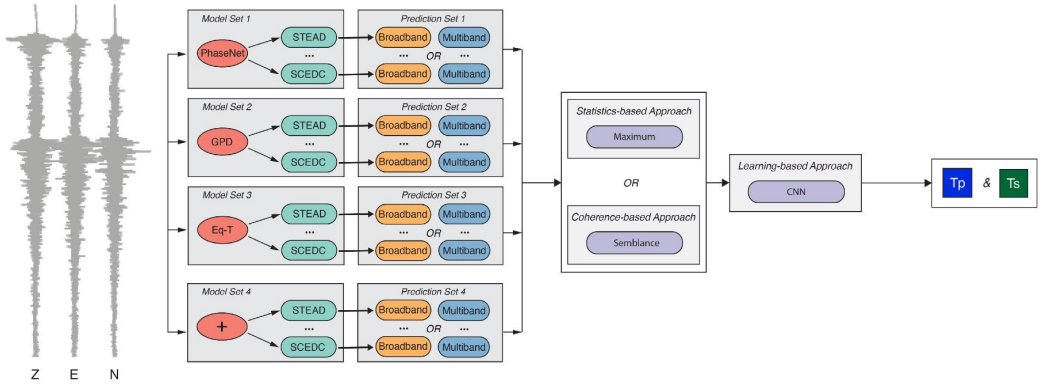
OBSTransformer,
Niksejel and Zhang, et al., 2023

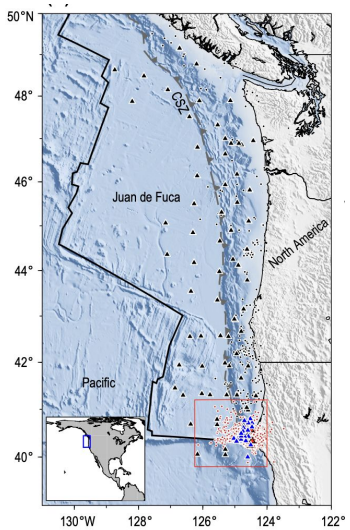


PhaseNet-TF, Xi et al., 2023



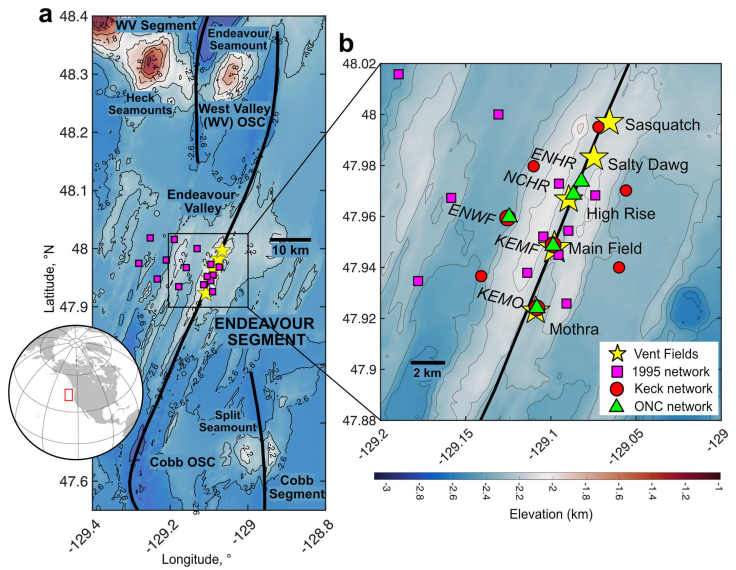
Yuan et al., 2023



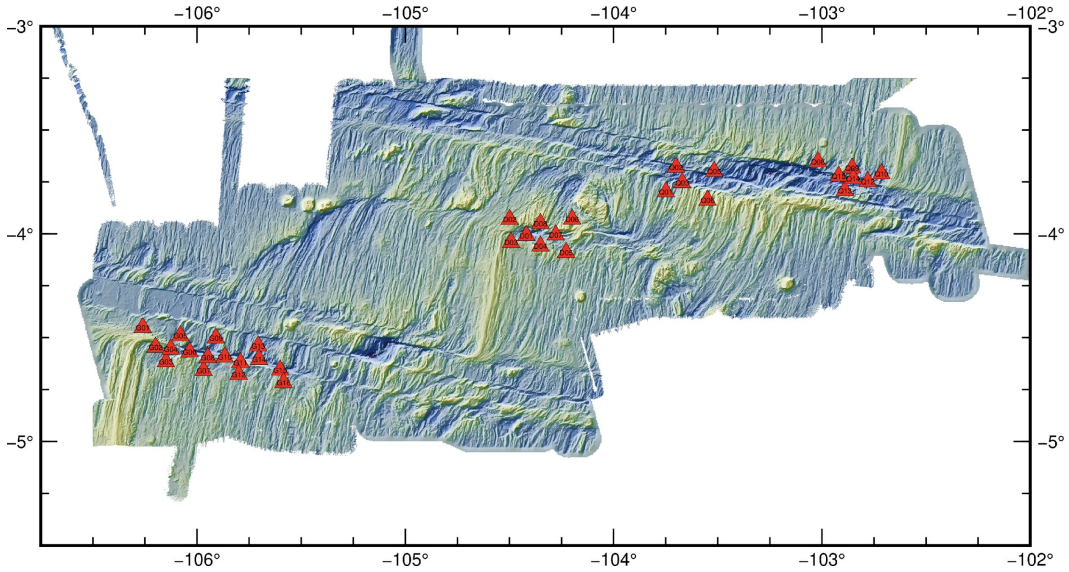


OBSPD,
Cheng et al., 2023

Reprocess the archived data



Krauss et al., 2023

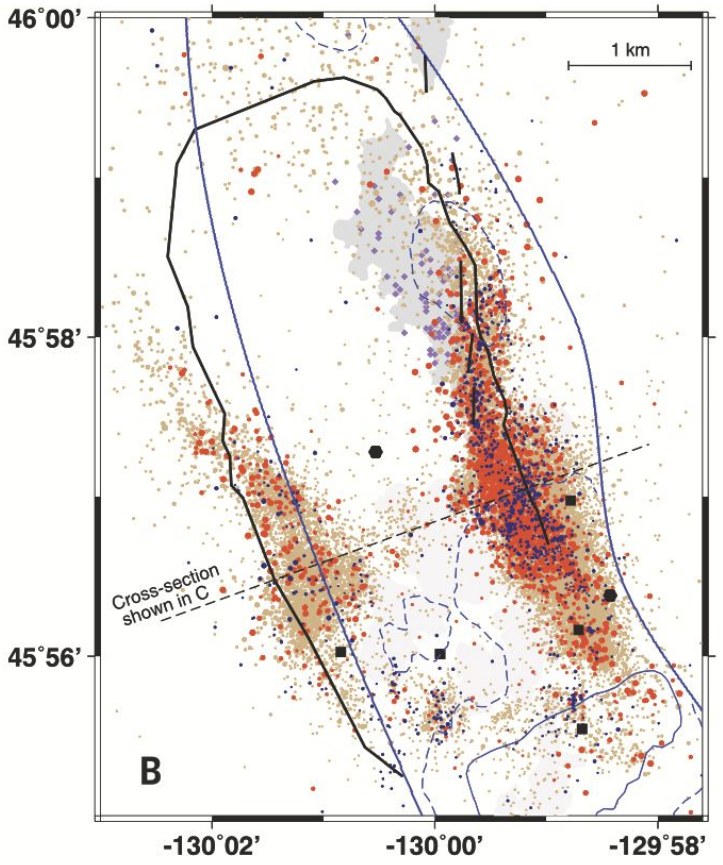


Several poster/oral presentations next week

S13E-0390: Ridge-transform fault interaction controls earthquake swarm activity at the Gofar transform fault
V14B-03: Characterizing seismic and acoustic signals at Axial Seamount with unsupervised machine learning
V43A-07: Source mechanism of impulsive events during the 2015 Axial Seamount eruption
S53B-08: Real-time Production and Analysis of High-Precision, Deep Magnitude Earthquake Catalogs
V43A-07: Source mechanism of impulsive events during the 2015 Axial Seamount eruption
S54C-01: Accurate Rayleigh Wave H/V Ratio Measurements using a Phase-Tracking Method for the Blanco Transform Ocean-Bottom Seismometer Experiment

Challenges:
How to handle the large amount of seismicity?

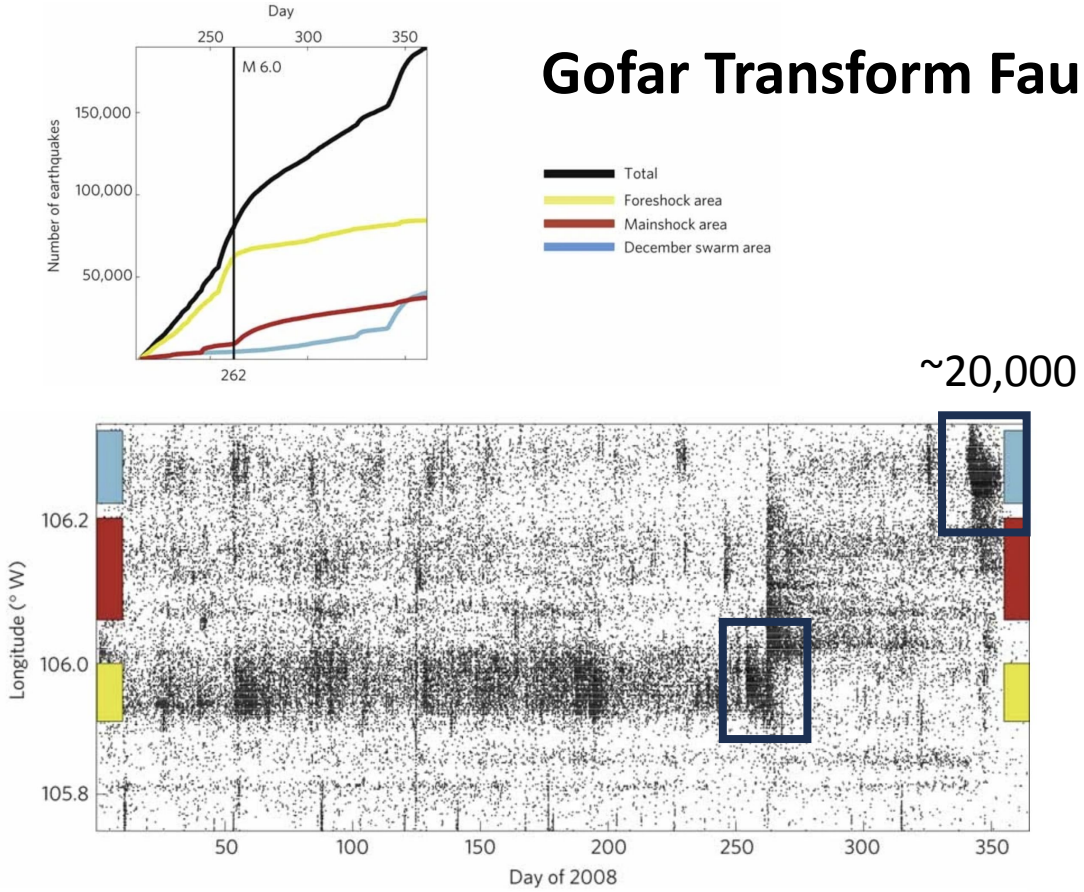
- The number detected seismicity: from 1k-10k to 100k-1M



Axial Seamount

~60,000 events in the 3 months prior to the eruption

Wilcock et al., 2016



Gofar Transform Fault

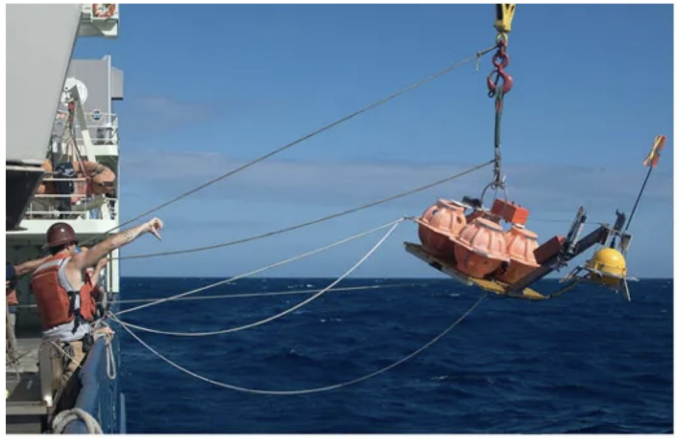
McGuire et al., 2012

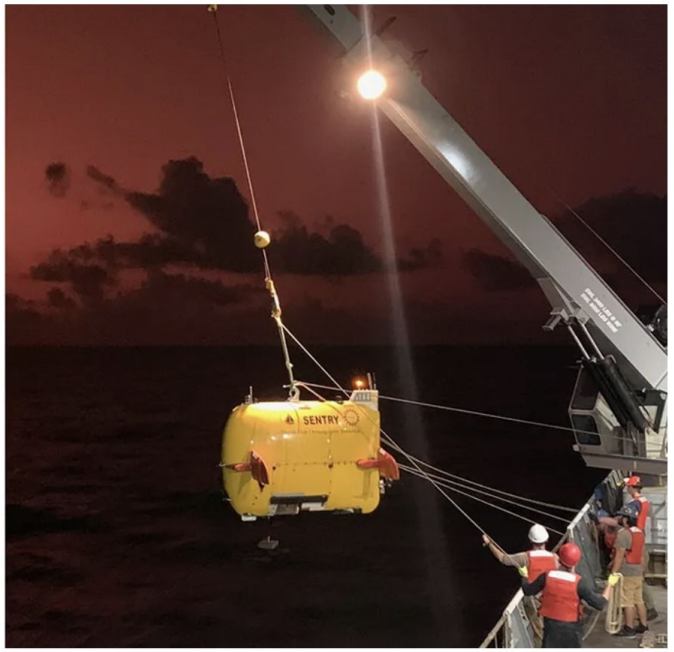
Challenges:
How to handle the large amount of seismicity?

- The number detected seismicity: from 1k-10k to 100k-1M
  - Data mining: classification, clustering, sequential patterns, etc
  - Visualization
  - Error estimates
  - Big Data Seismology, Arrowsmith et al., *Rev. of Geophys*, 2022

Multidisciplinary experiment

- 1st cruise: OBS deployment and bathymetry mapping
- 2nd cruise: OBS recovery and geological/geophysical survey, such as rock dredging, diving, and EM
- Process the seismic data during the 2nd cruise?
  - Extract OBS data after recover on the ship and send the data onshore
  - It takes about 2 weeks (not including OBS preprocessing or data transfer) to finish the location for an array of 15 OBS if a computer cluster is available.
  - Seismicity can potentially help to identify interesting areas for dredging and diving.





Boettcher et al., EOS, 2023

Conclusion

- Microseismicity analysis has a broad application in marine seismology.
- ML methods are becoming the dominant approaches for many tasks in seismology.
- ML algorithms trained using marine seismic data can achieve better performance.
- Reprocess archived data with ML methods can bring new insights of various tectonic processes in marine environment.
- New data mining methods are needed to make valuable inference from the large amount of microseismicity.

Thank you!