Data-driven multi-parameter model integration using Self-Organizing Maps (SOM)

Klaus Bauer (GFZ Potsdam)

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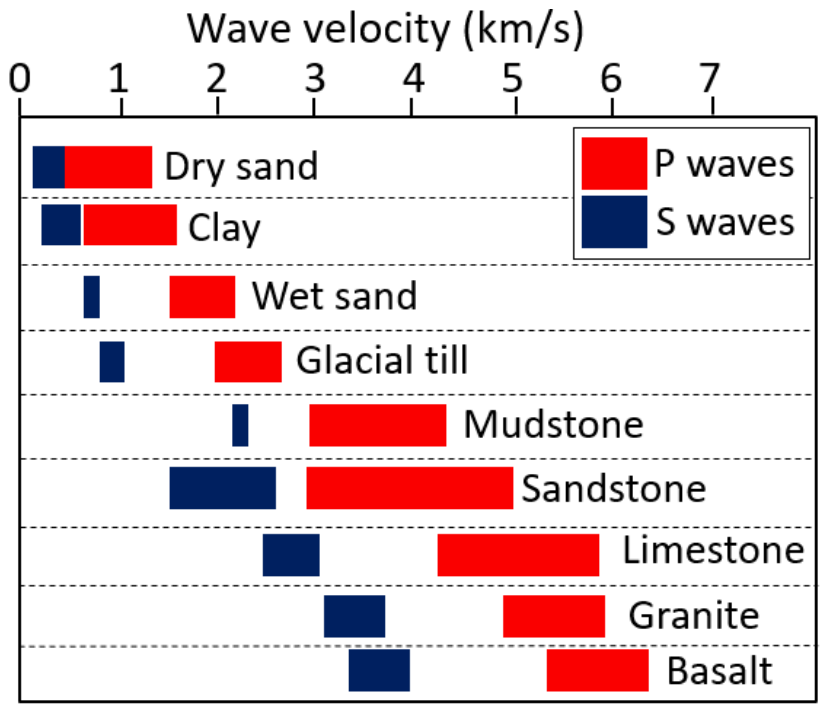
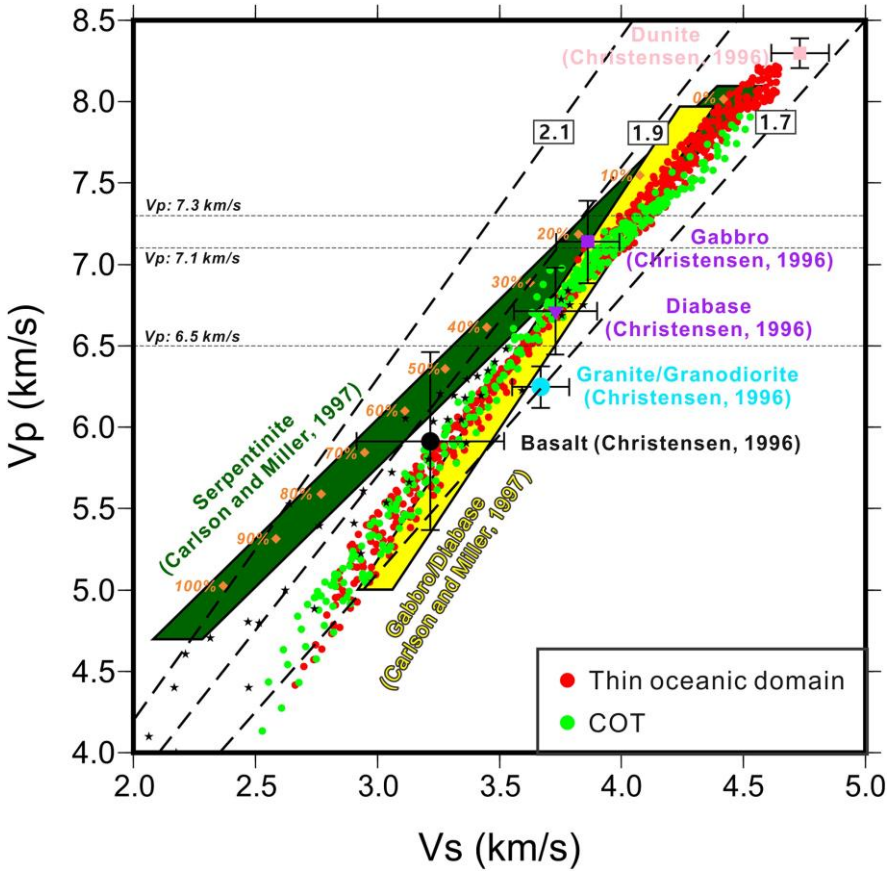
- Motivation: Integration of multi-parameter information
- Tool: Self-organizing map – How does it work
- Case studies

petrophysical properties



BC Open Textbooks

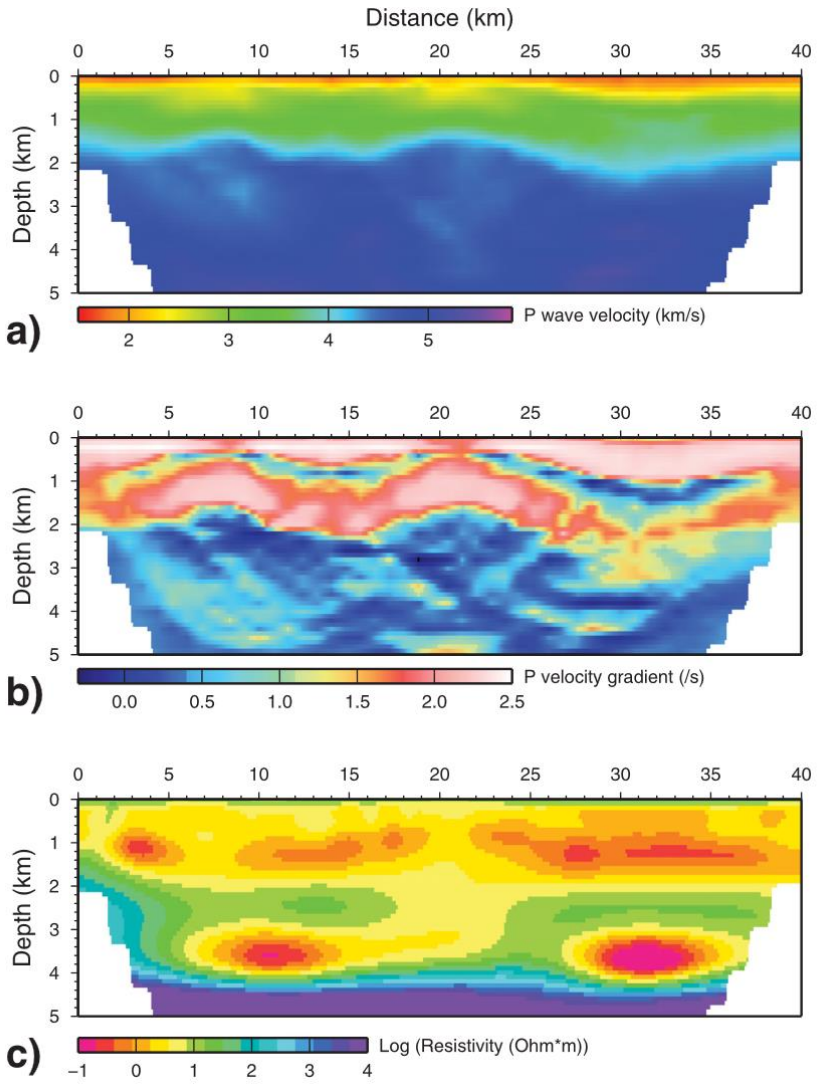
combined analysis improves rock type classification

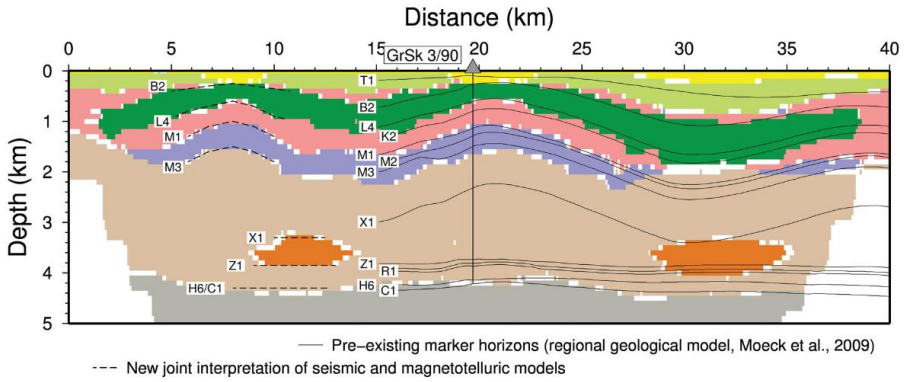


Li et al. (2021)

Multi-parameter models (seismic tomography, MT)

Geological interpretation (lithology, rock type)





	Lithology	Stratigraphy
1:	Sand, gravel	Quaternary
2:	Clay, marl	Tertiary, Cretaceous
3:	Silt, claystone	Cretaceous, Triassic (Keuper)
4:	Shale, clay	Jurassic
5:	Limestone	Triassic (Muschelkalk)
6:	Sandstone, evaporite, sandstone	Triassic (Buntsandstein), Upper Permian (Zechstein) Lower Permian (Rotliegend)
7:	Anhydrite, highly fractured	Upper Permian (Zechstein)
8:	Volcanics, quartzite	Lower Permian (Rotliegend), Carboniferous

Bauer, Muñoz, Moeck (2012)

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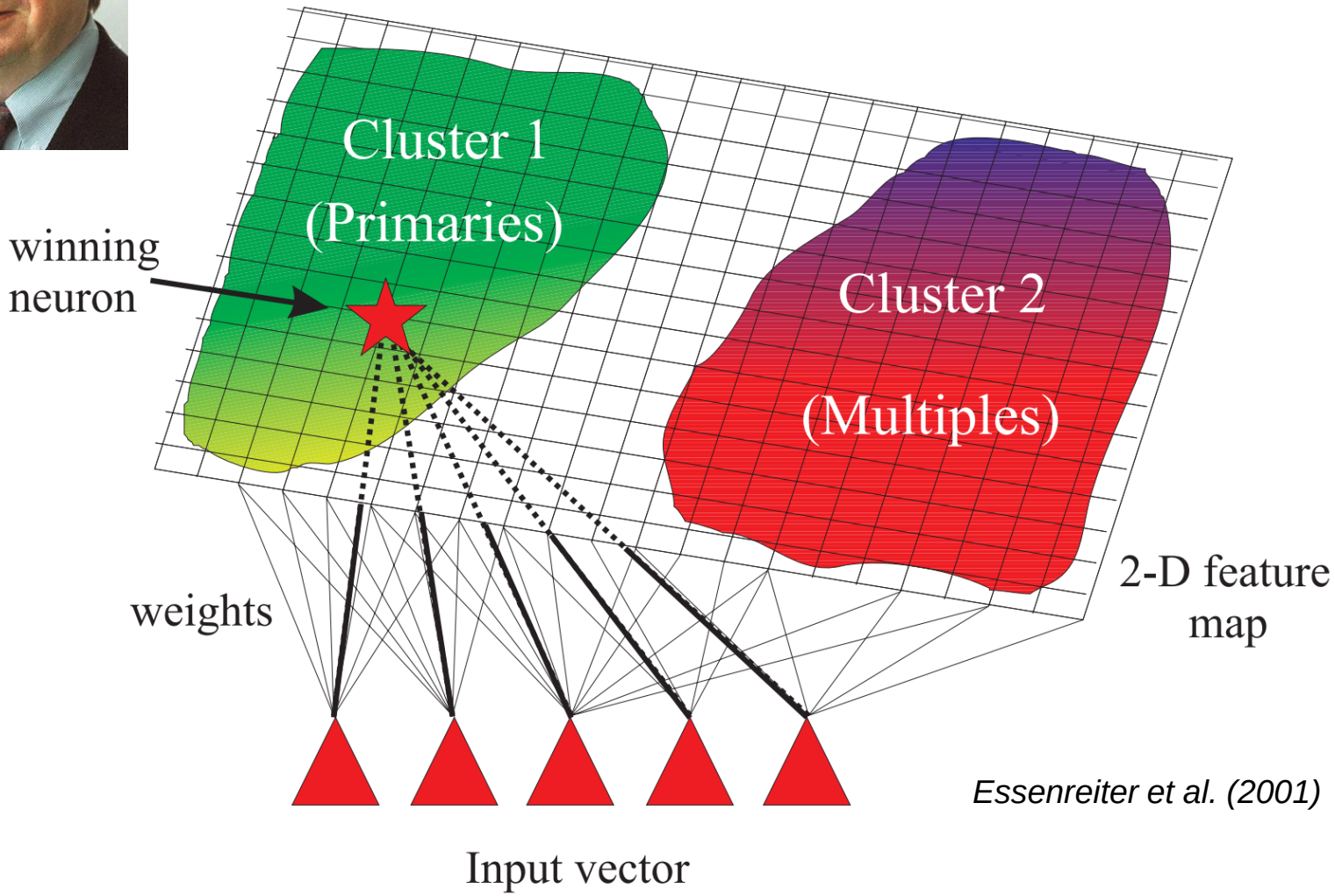
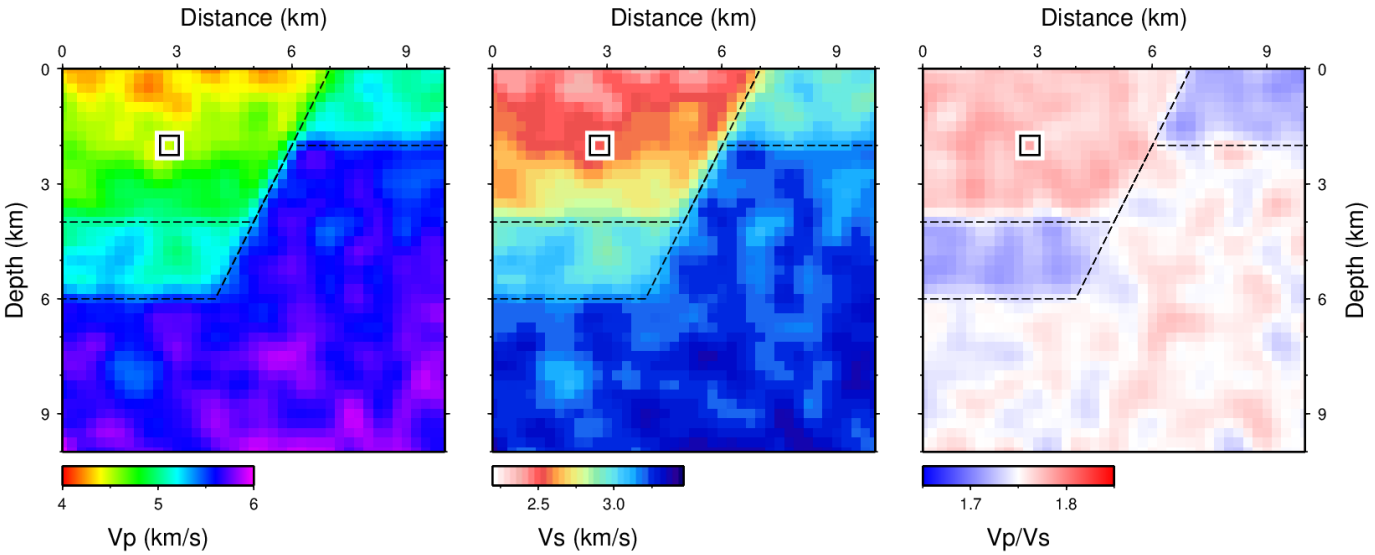
Teuvo Kohonen

Self-organizing map (SOM) (Kohonen network)

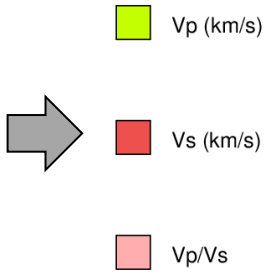


Essenreiter et al. (2001)

multi-parameter input models

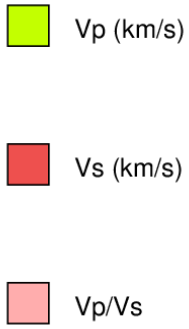


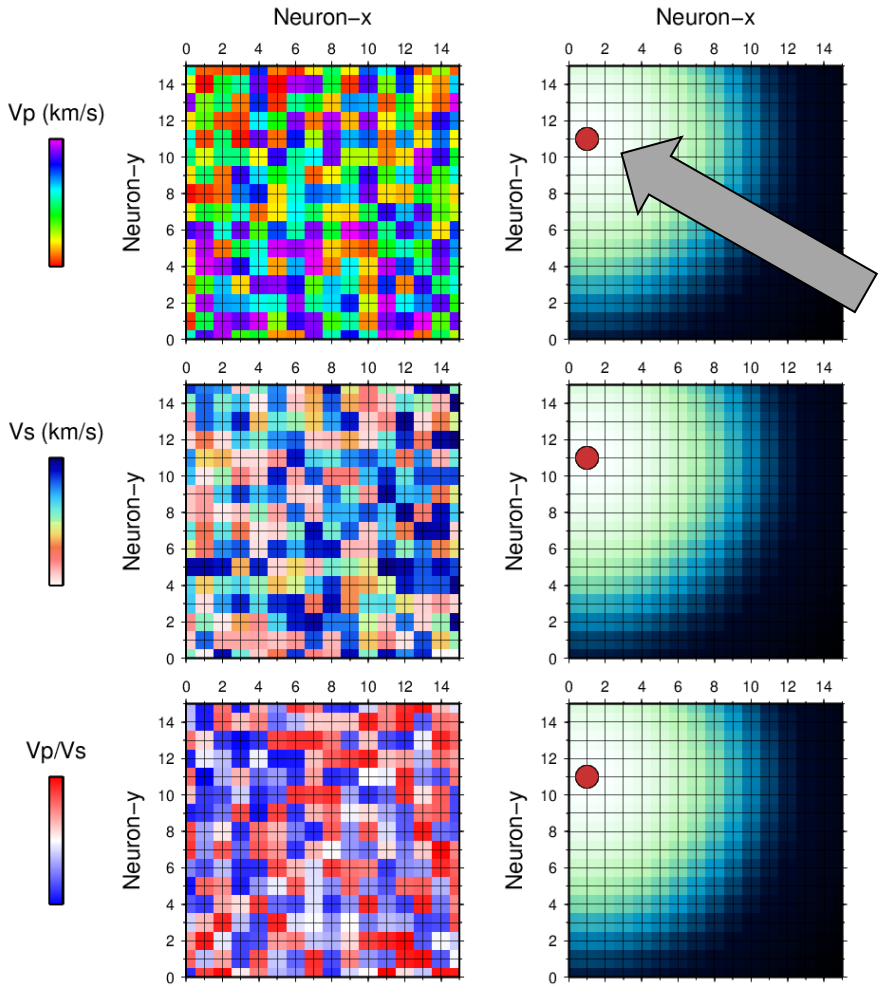
data pattern



data pattern (x)

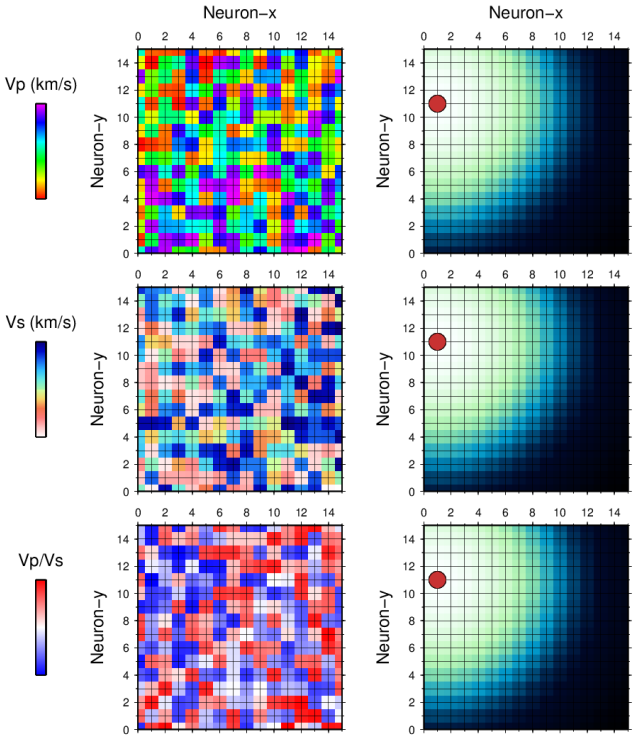
Kohonen layer with neuron patterns (m)

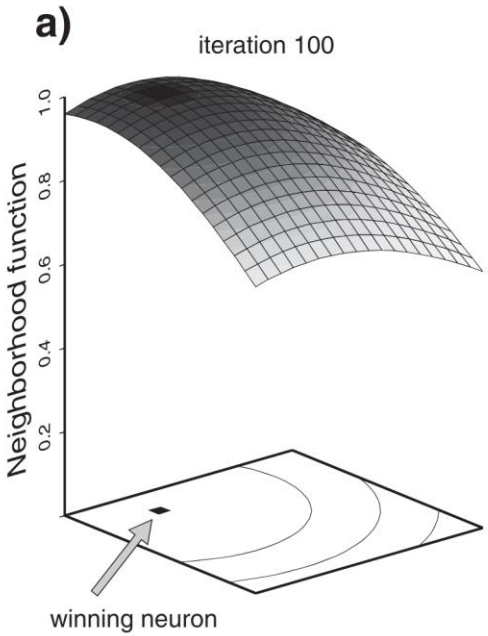


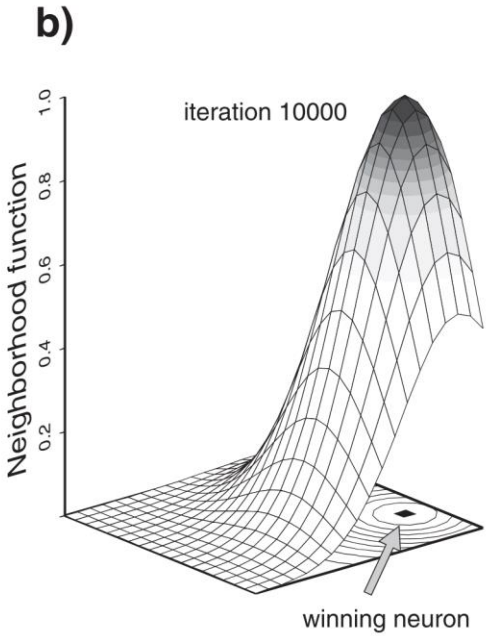


best-matching winning neuron

$$\vec{m}_i(t+1) = \vec{m}_i(t) + \lambda(t)\, n_{w,i}(t)\,(\vec{x}(t) - \vec{m}_i(t))$$

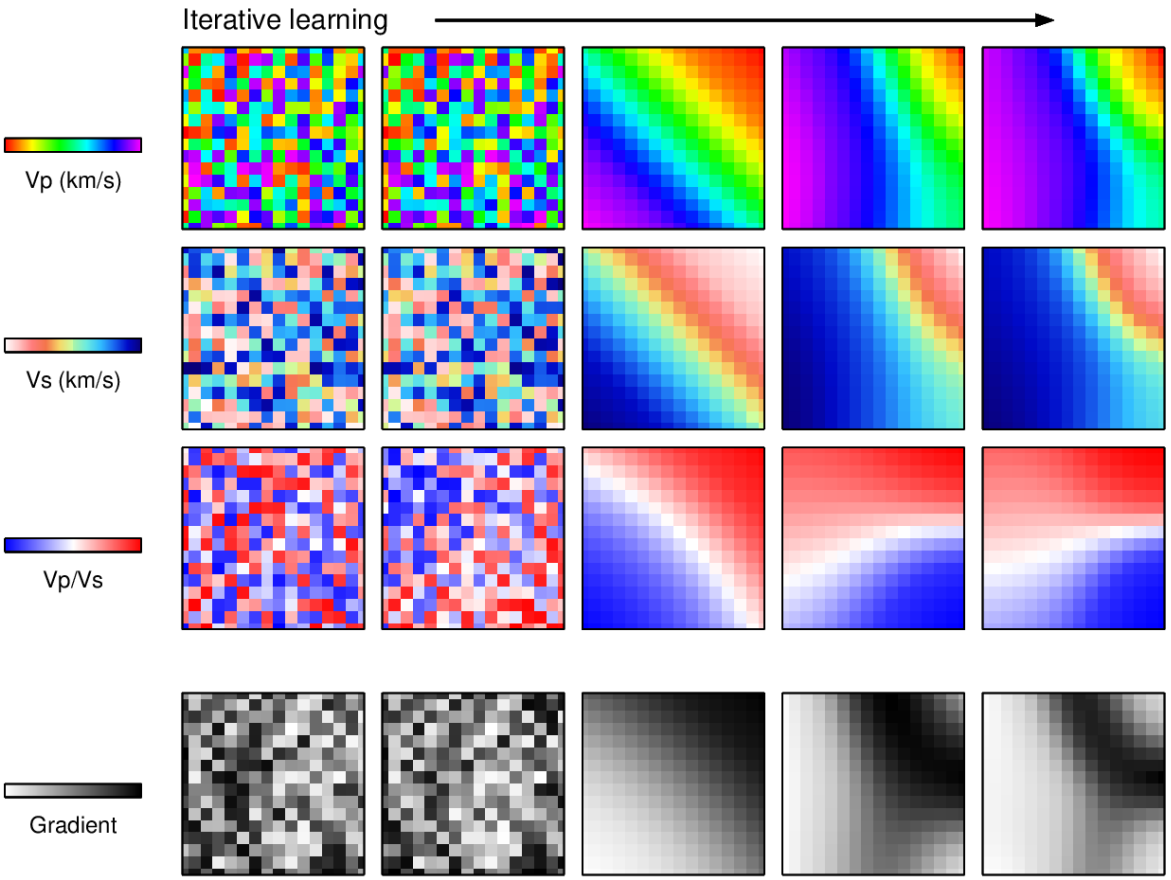




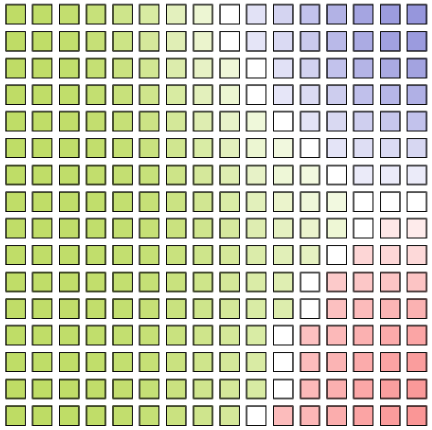


$$n_{w,i}(t) = \exp\left(-r_{w,i}^2 / 2\sigma^2(t)\right)$$

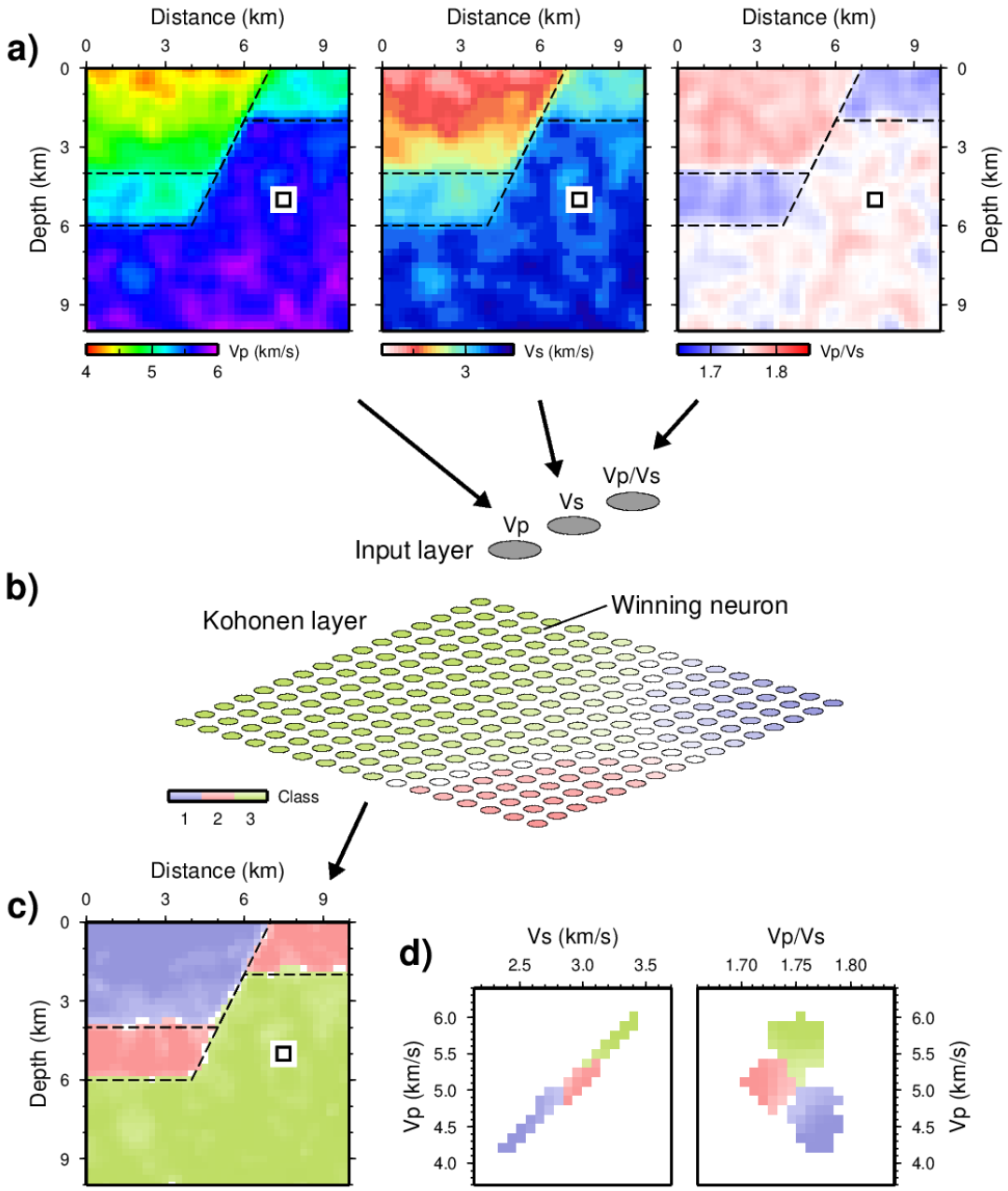
unsupervised learning



Kohonen layer
with classes



Bauer et al. (2012, 2015, 2020)



multi-parameter input models

Kohonen layer with classes

re-mapping in sub-surface domain petrophysical domain

Braeuer & Bauer (2015)

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- Tool: Self-organizing map – How does it work
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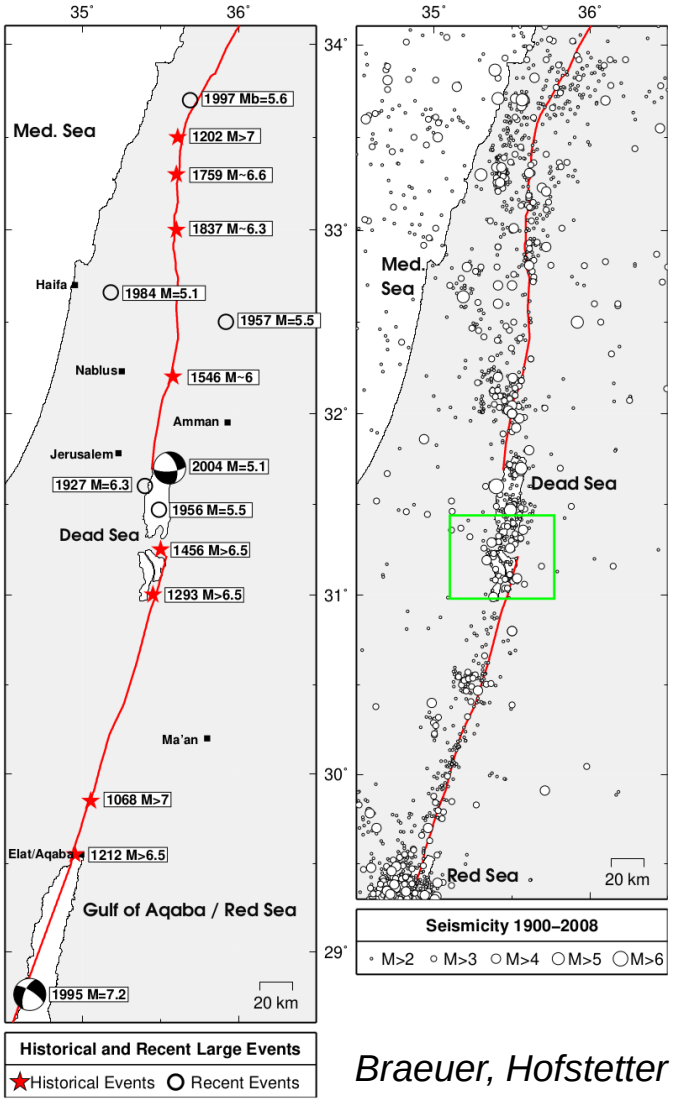
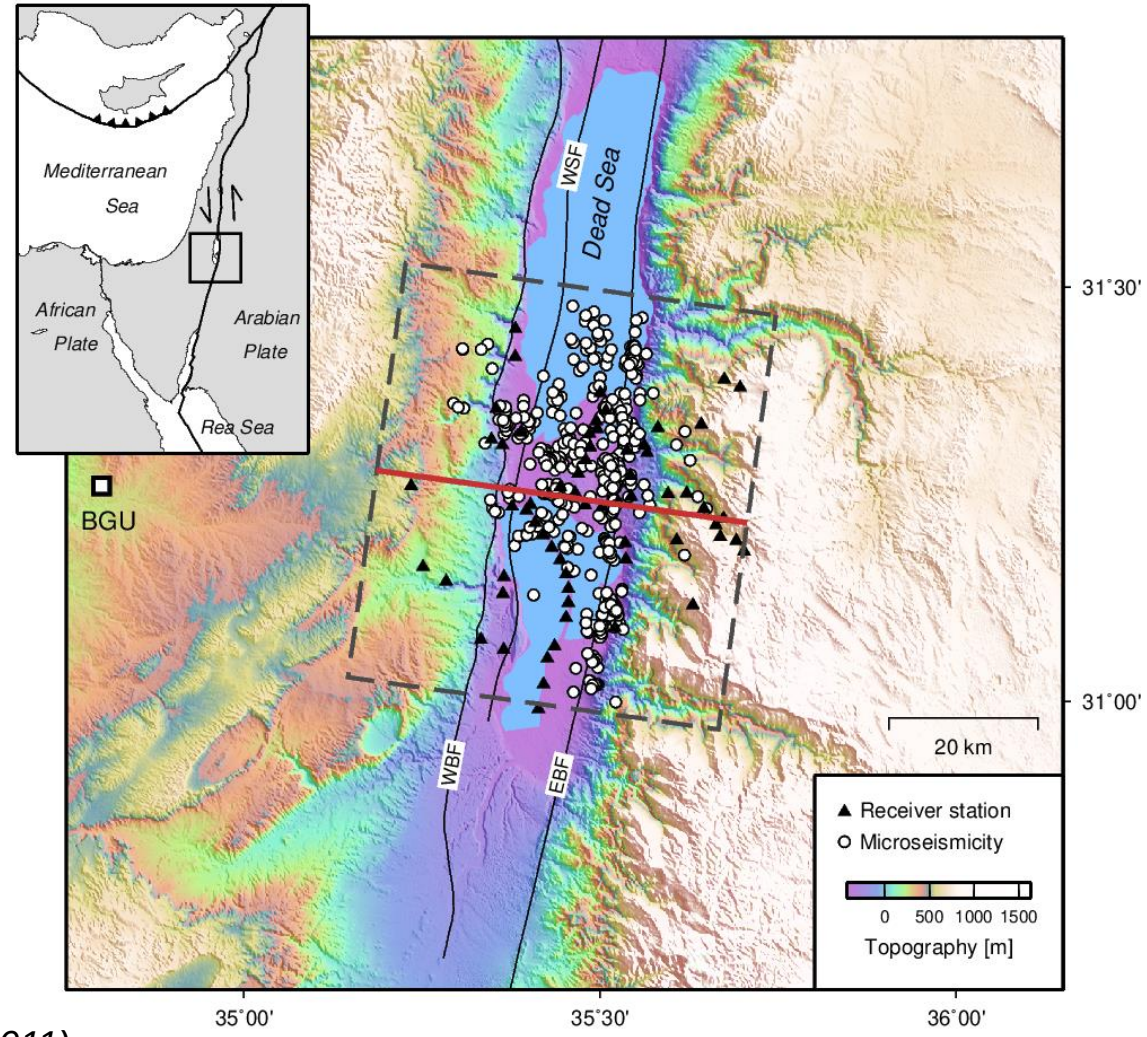
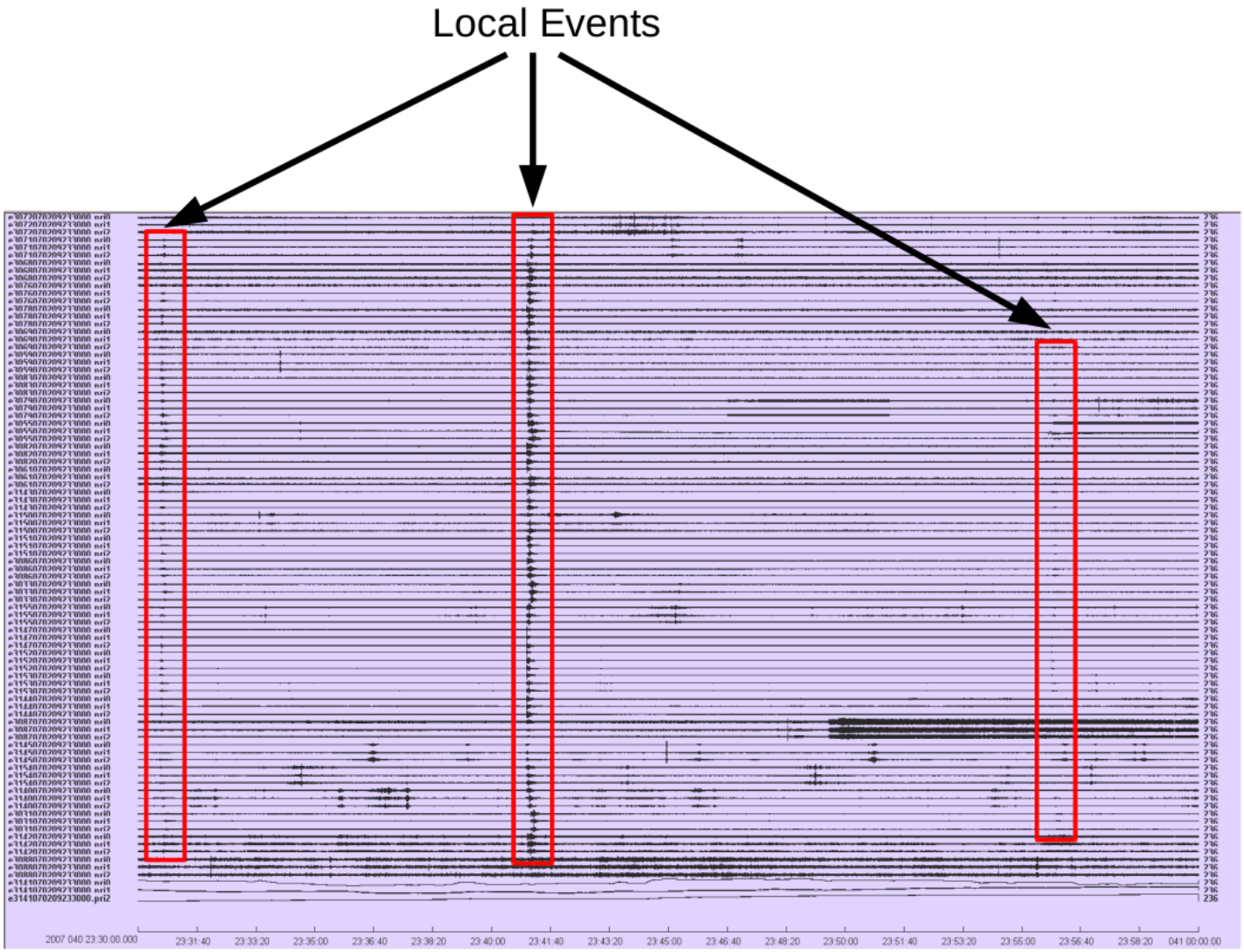
Application 1
Local earthquake tomography in Dead Sea region



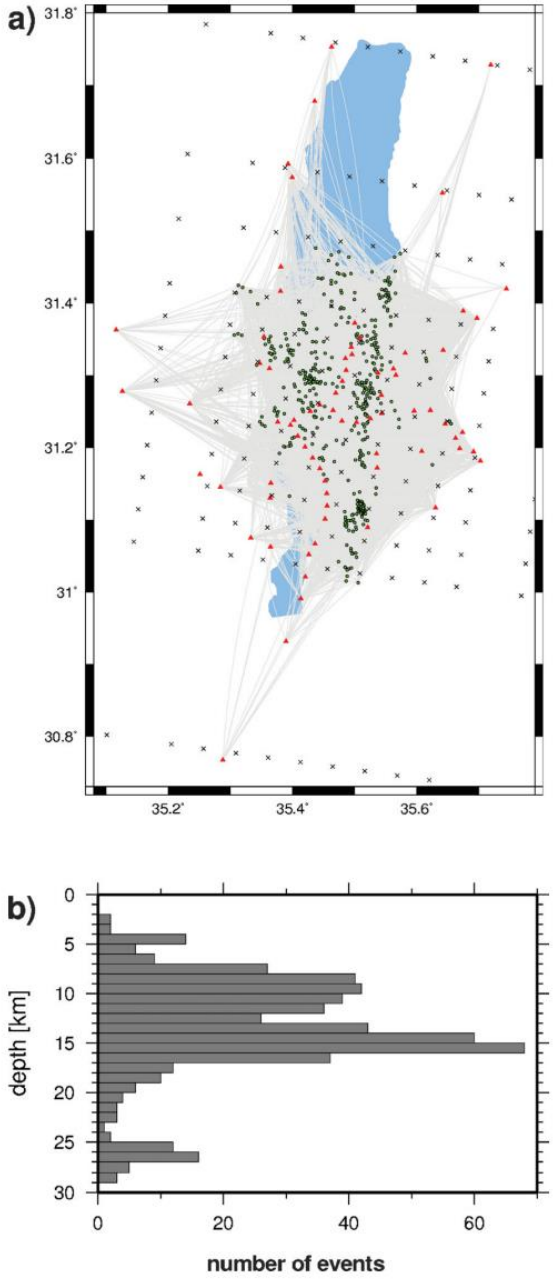


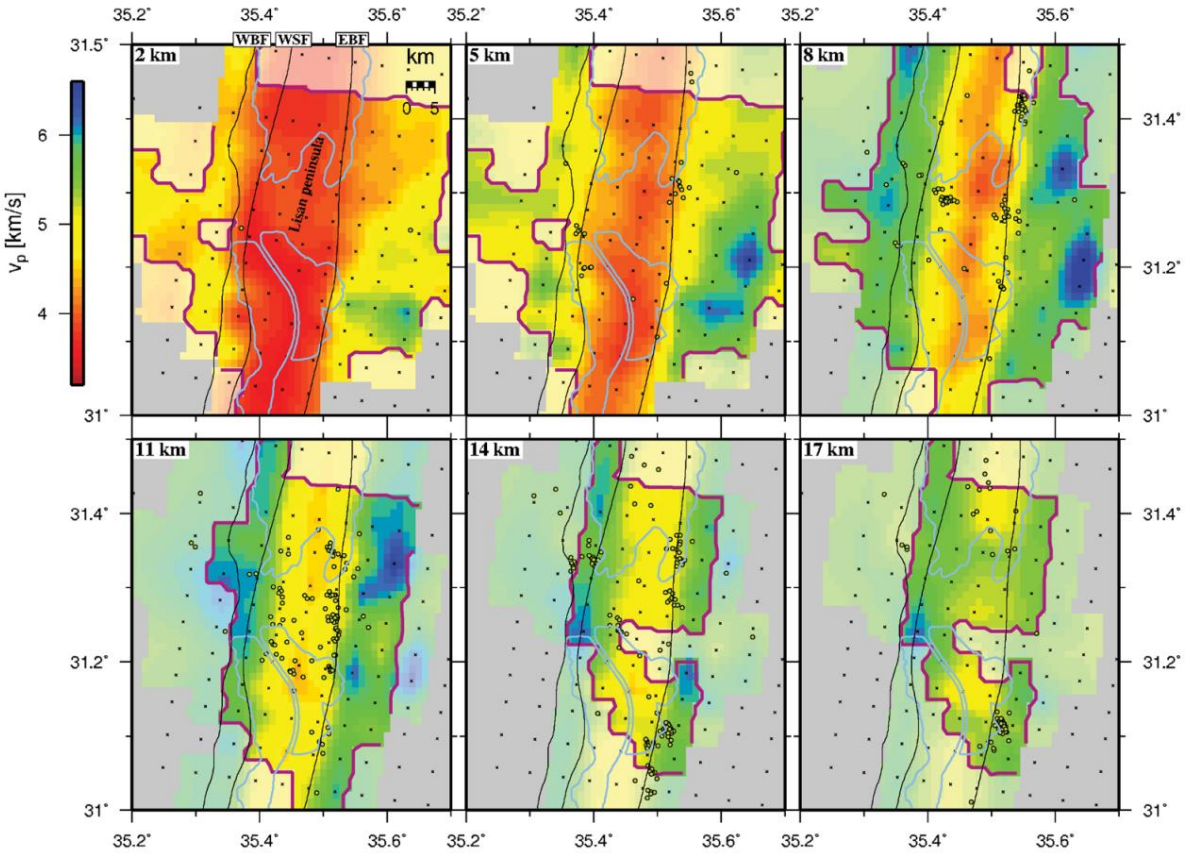
Braeuer, Hofstetter (2011)

Deployment of 65 stations in Israel and Jordan
October 2006 – March 2008

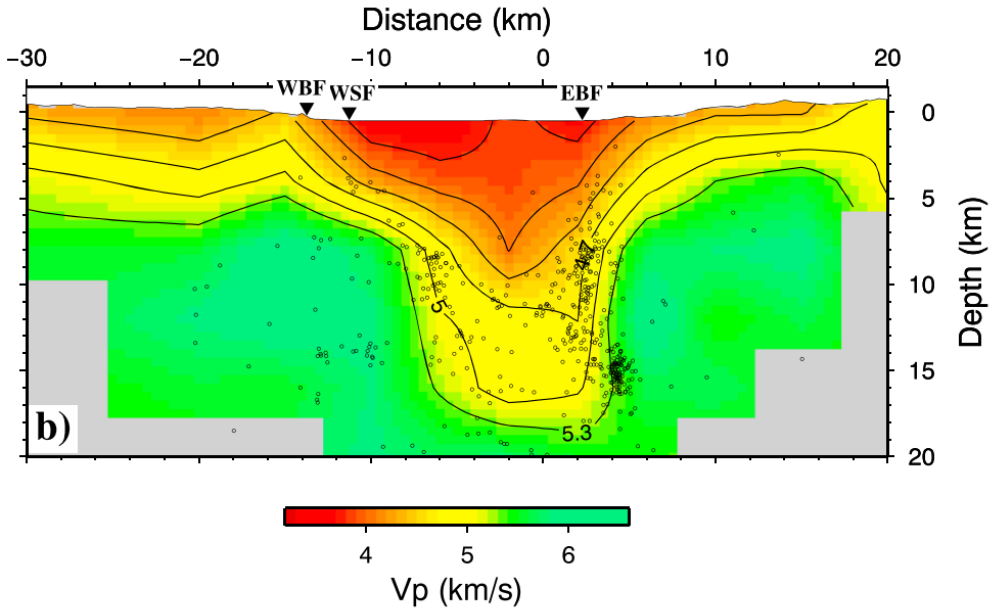

Local Events
2007 040 23:30:00.000
23:31:40
23:33:20
23:35:00
23:36:40
23:38:20
23:40:00
23:41:40
23:43:20
23:45:00
23:46:40
23:48:20
23:50:00
23:51:40
23:53:20
23:55:00
23:56:40
23:58:20
041 00:00:00

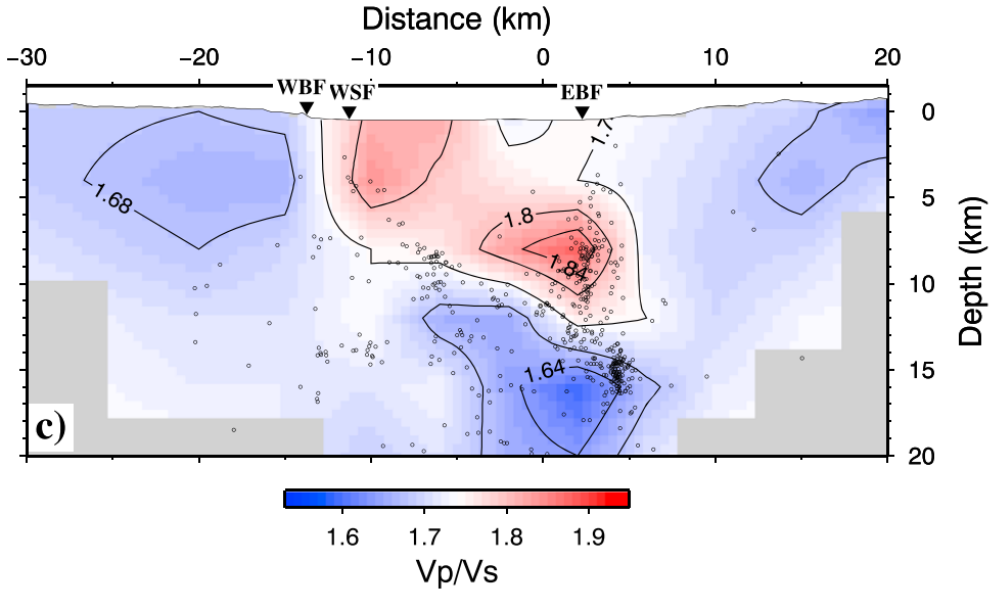
530 events within 18 months used for tomography

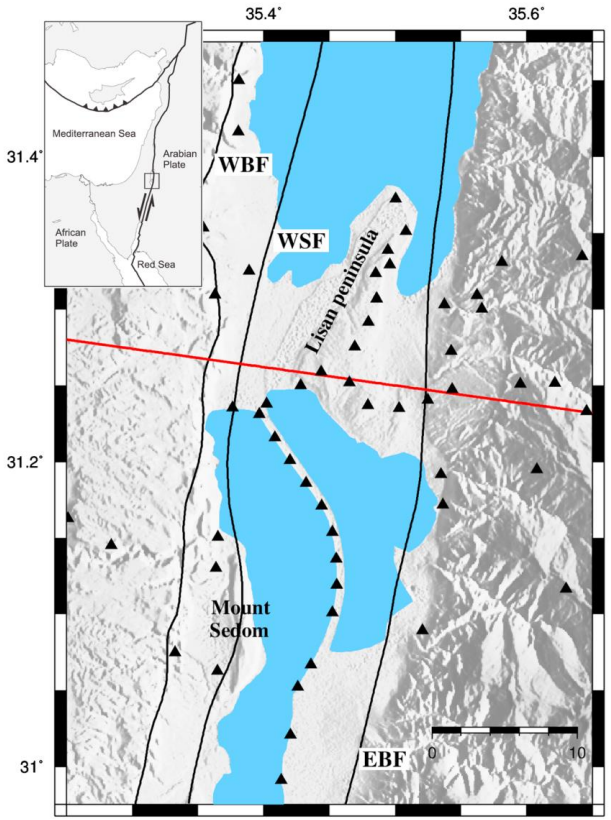


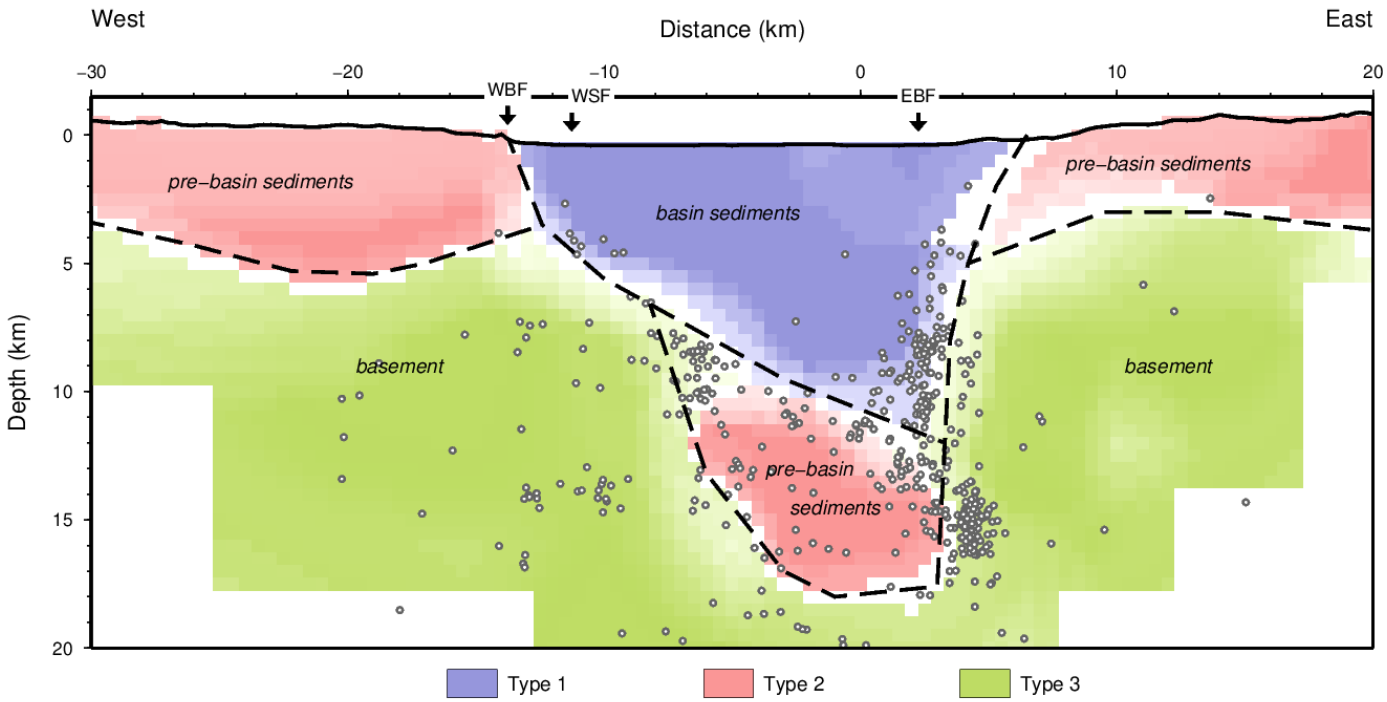


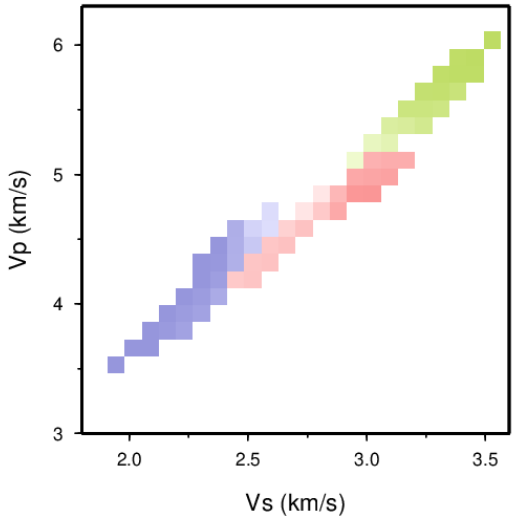
Braeuer et al. (2012)

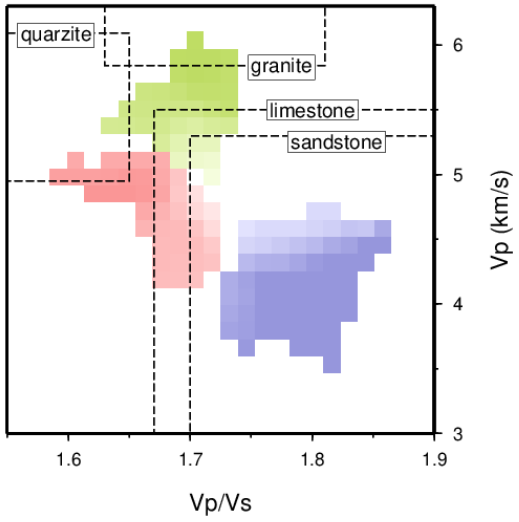

Distance (km)
−30
−20
−10
0
10
20
WBF
WSF
EBF
0
5
10
15
20
Depth (km)
5.3
b)
4
5
6
Vp (km/s)


Distance (km)
−30
−20
−10
0
10
20
WBF
WSF
EBF
1.68
1.7
1.8
1.84
1.64
c)
0
5
10
15
20
Depth (km)
1.6
1.7
1.8
1.9
Vp/Vs


35.4°
35.6°
31.4°
31.2°
31°
Mediterranean Sea
Arabian Plate
African Plate
Red Sea
WBF
WSF
Lisan peninsula
Mount Secom
EBF
0
10

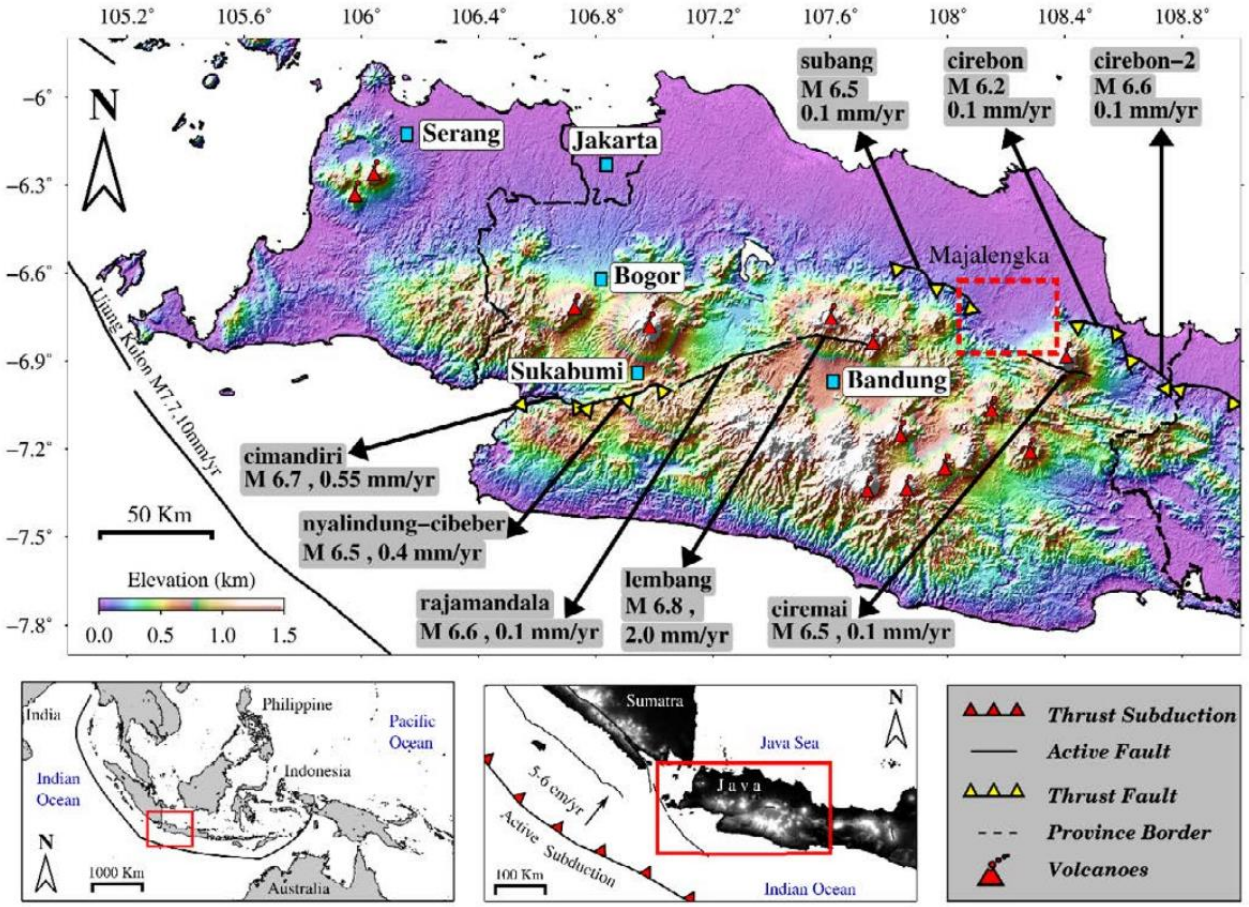


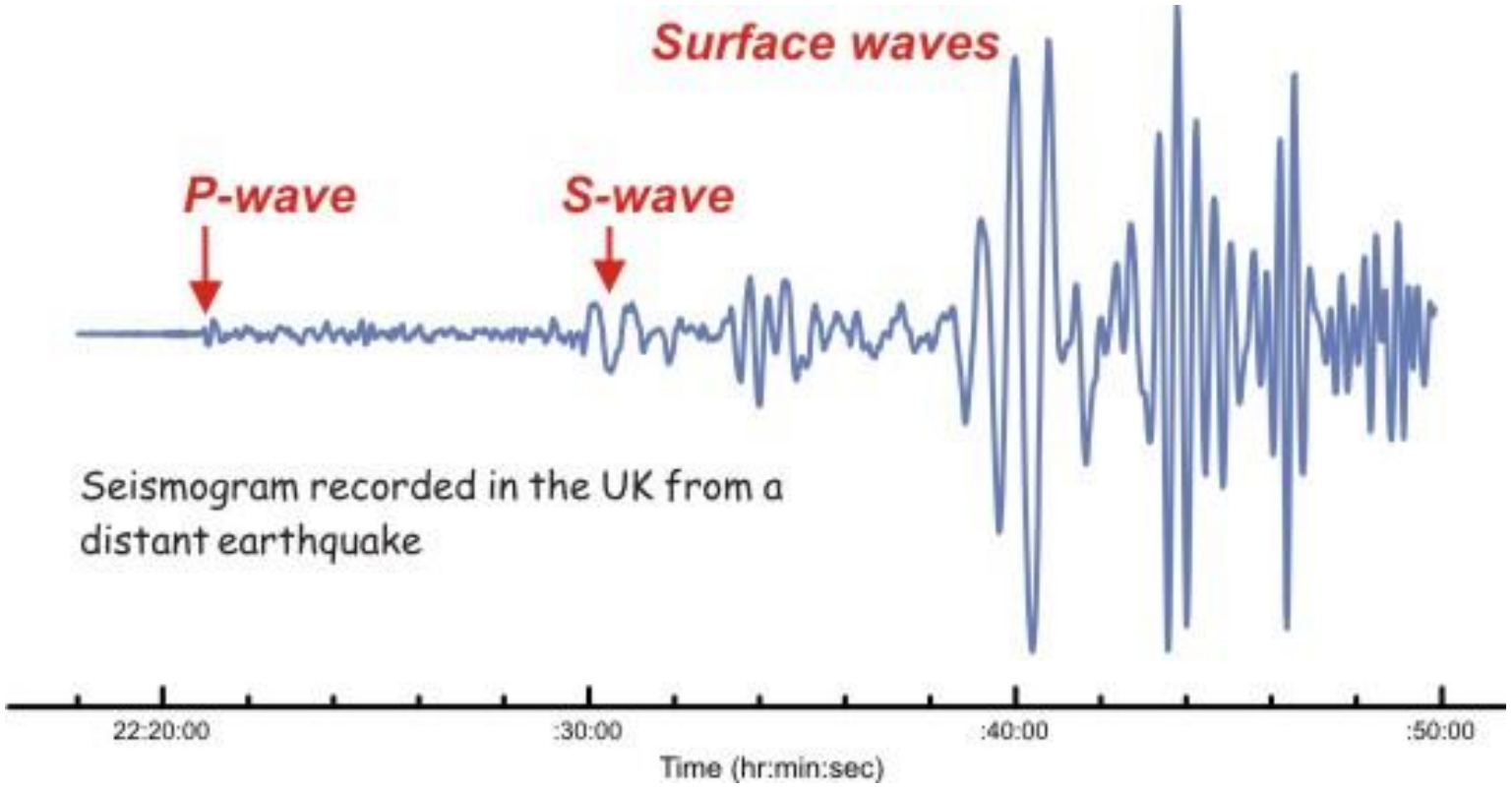




Braeuer & Bauer (2015)

Application 2
Seismic vulnerability evaluation in Indonesia





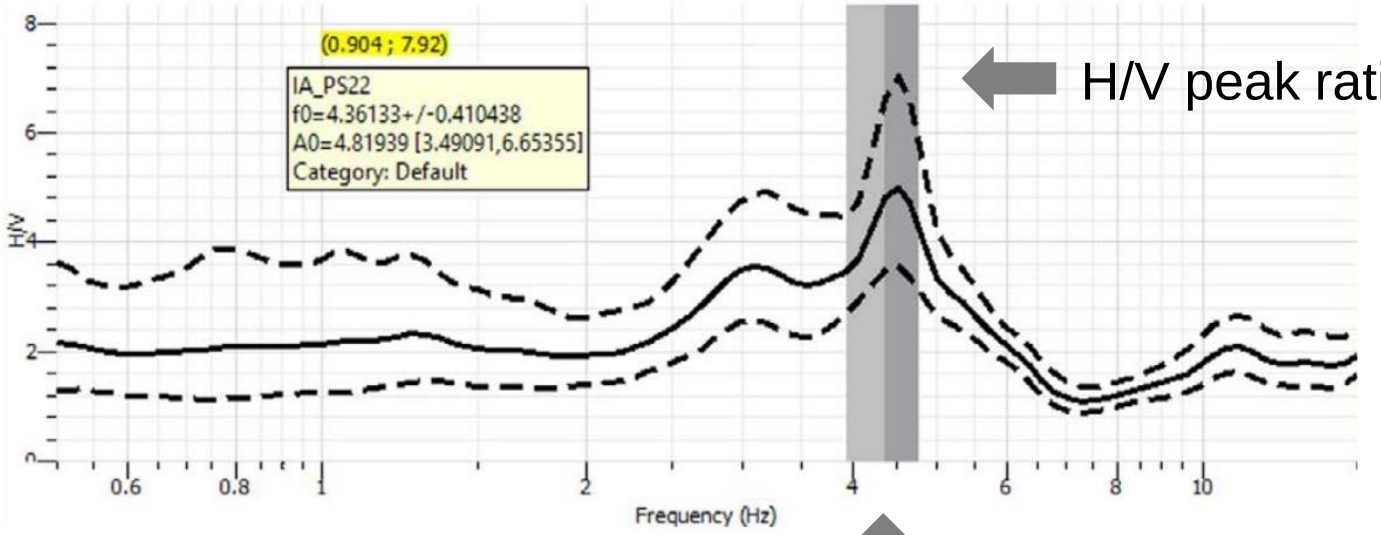
Source: British Geological Survey

Controlled-source multi-channel seismic measurements

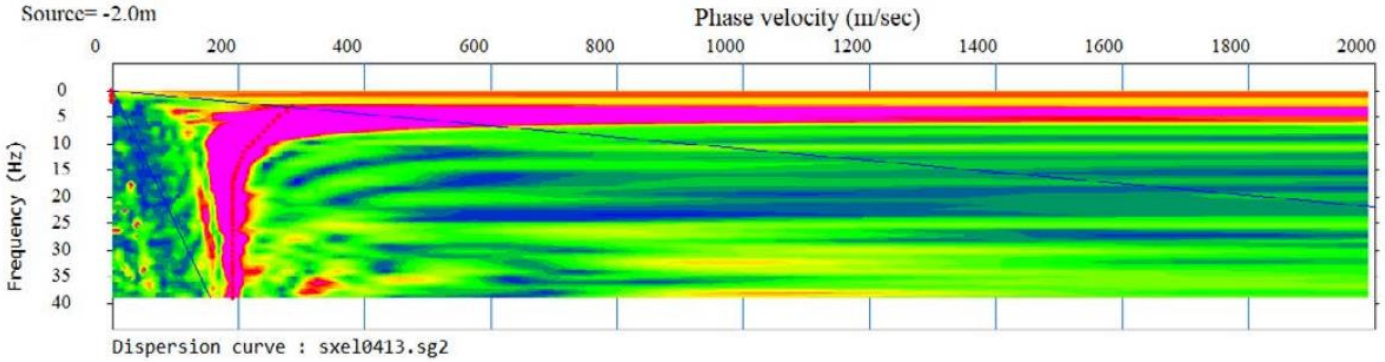
H/V
measurements

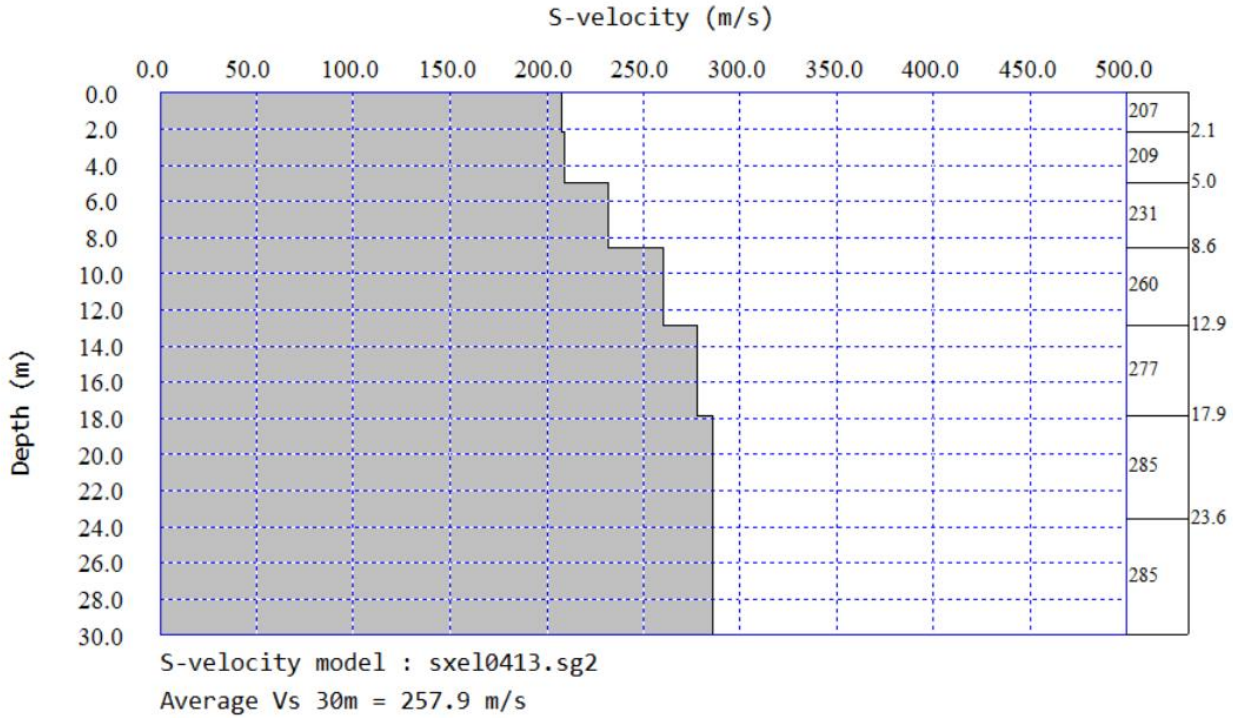
using
single-stations
with 3-component
geophones

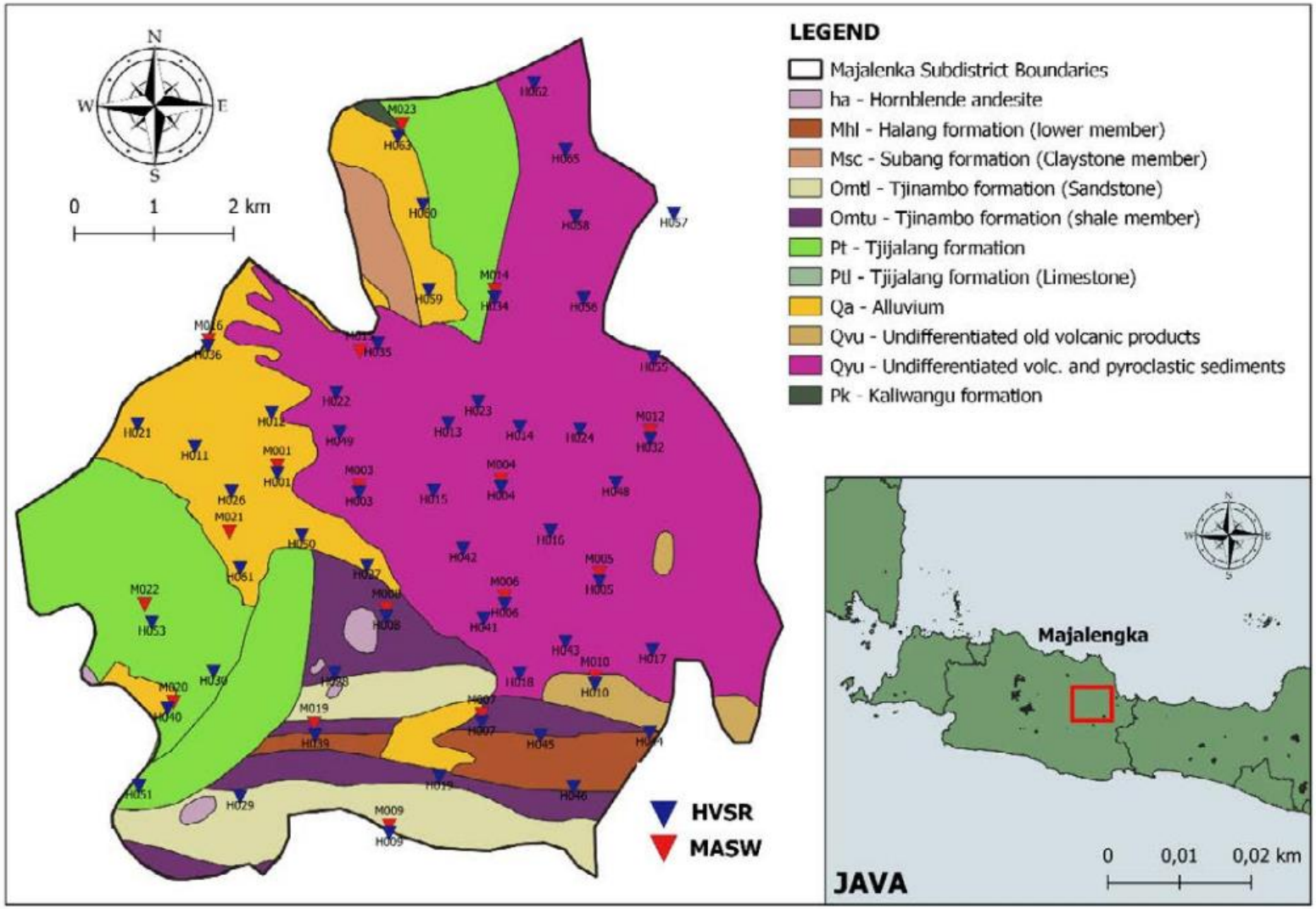
Horizontal-to-vertical (H/V) spectral ratio method



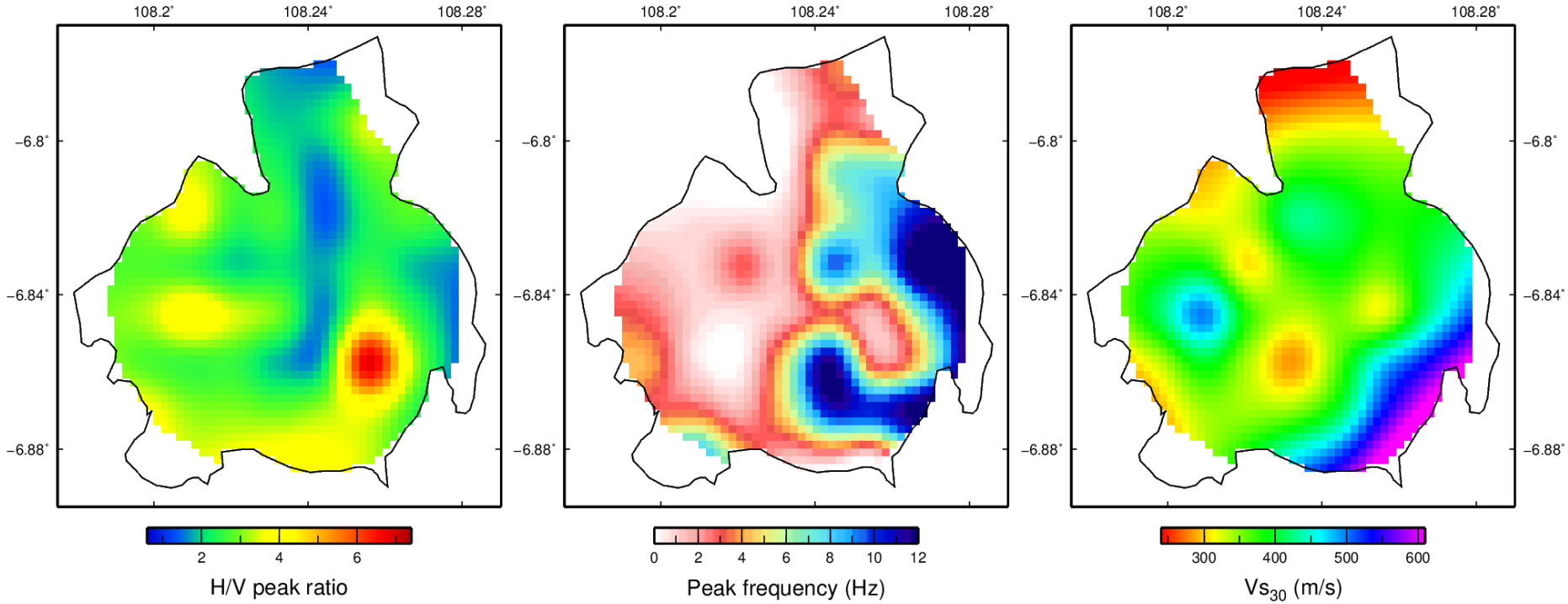
Multi-channel analysis of surface waves (MASW) method



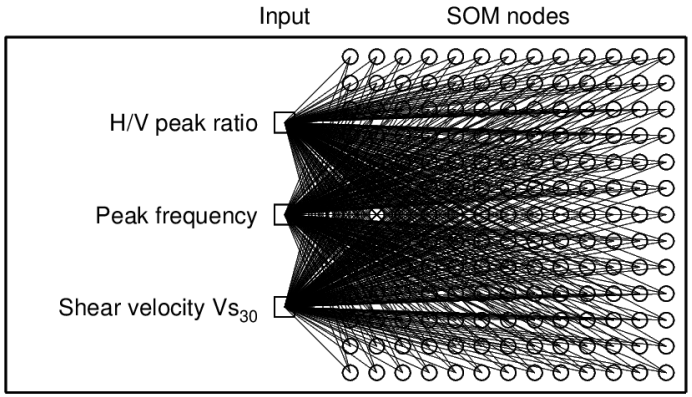


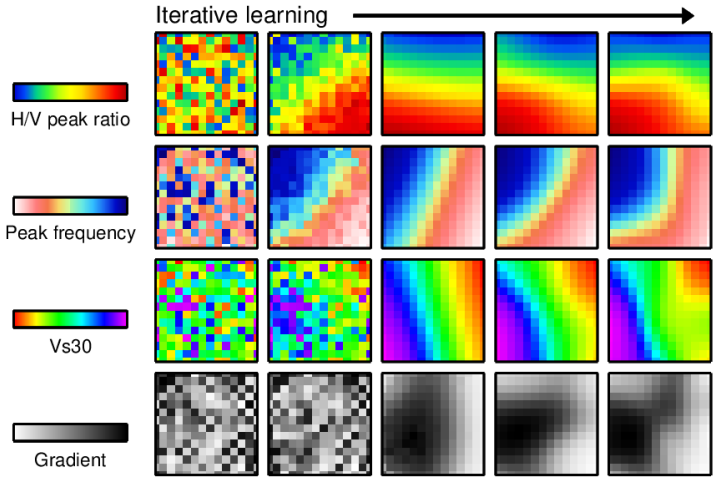

N
W
E
S
0 1 2 km
LEGEND
Majalenka Subdistrict Boundaries
ha - Hornblende andesite
Mhl - Halang formation (lower member)
Msc - Subang formation (Claystone member)
Omtl - Tjinambo formation (Sandstone)
Omtu - Tjinambo formation (shale member)
Pt - Tjijalang formation
Ptl - Tjijalang formation (Limestone)
Qa - Alluvium
Qvu - Undifferentiated old volcanic products
Qyu - Undifferentiated volc. and pyroclastic sediments
Pk - Kaliwangu formation
HVSR
MASW
Majalengka
JAVA
0 0,01 0,02 km

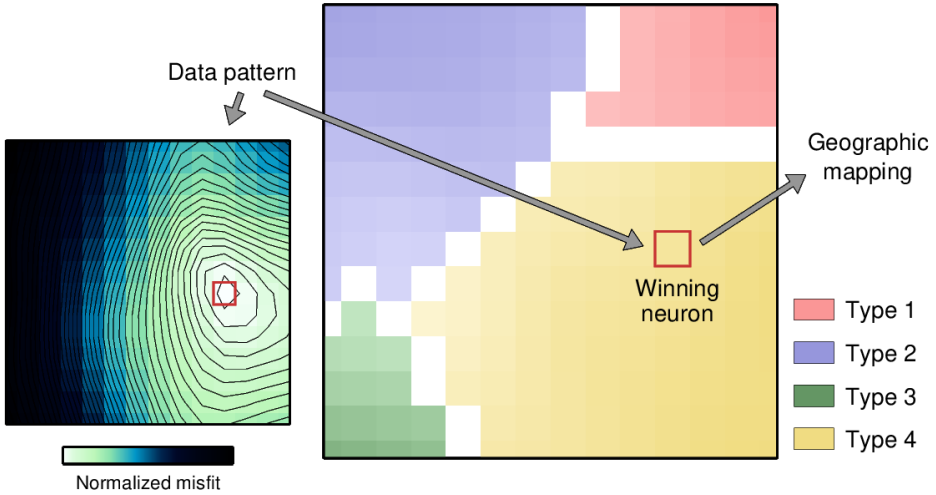
Geographic mapping of three measured and analysed variables



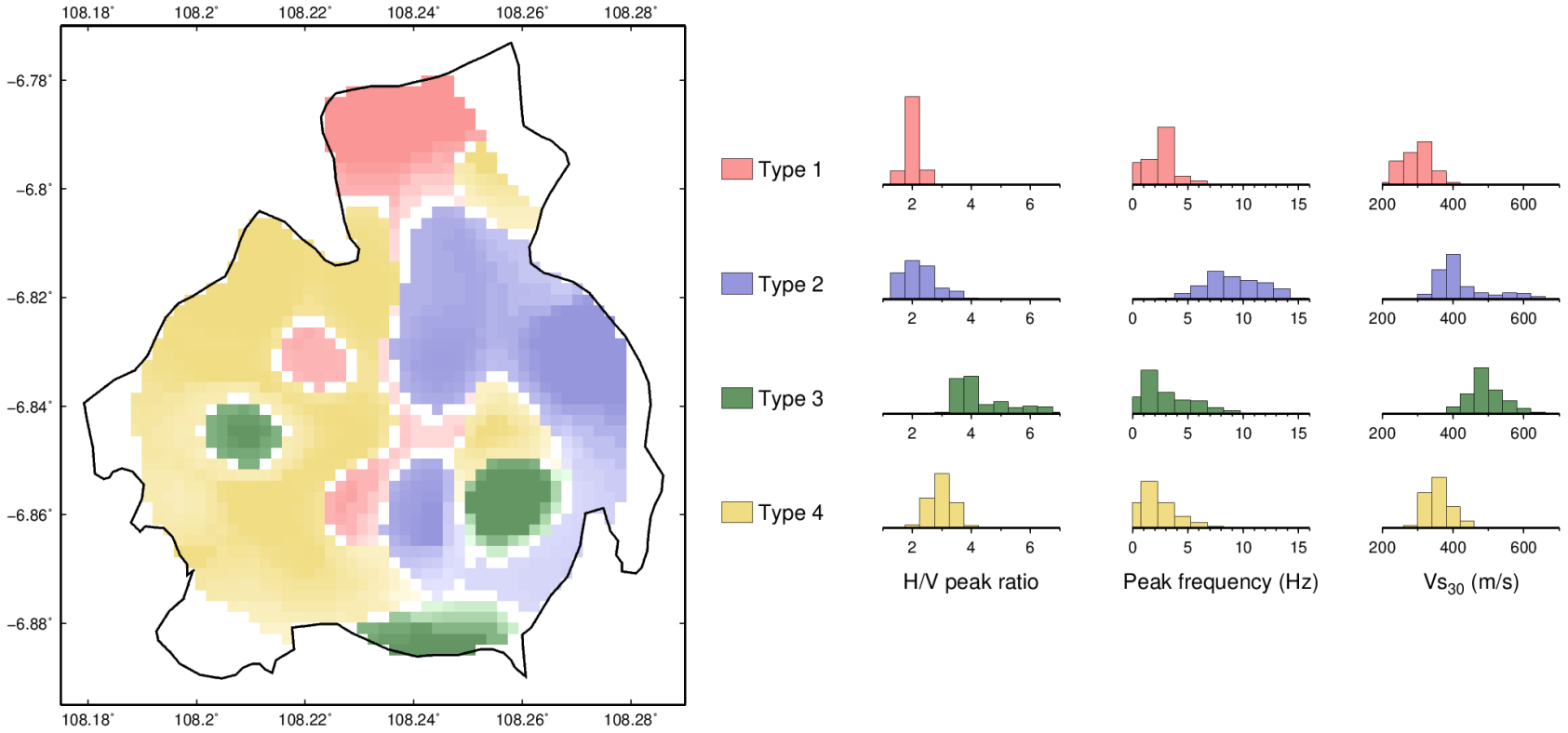
Design and training of SOM neural network







Geographic mapping and characterization of seismic vulnerability classes



Muksin et al. (2023)

Summary

Self-organizing maps can be used as a tool to support combined interpretation of different geophysical models

Application 1 (Tomography in southern Dead Sea area):
+ new interpretation with ultra-deep pre-basin sediments
+ seismicity distribution correlates with SOM-derived structures

Application 2 (Vulnerability evaluation in Java):
+ SOM clustering shows 4 different types in study area
+ histogram plots reveal seismic characteristics of each type
+ input for further steps (modelling)

More applications:
+ seismic reflection data interpretation (geothermal targets)
+ downhole logging data (characterization of gas hydrates)
+ classification of geochemical data (hydrochemistry, petrology)