Constraints on Fracture Distribution in Geothermal Fields Using Seismic Noise Beamforming

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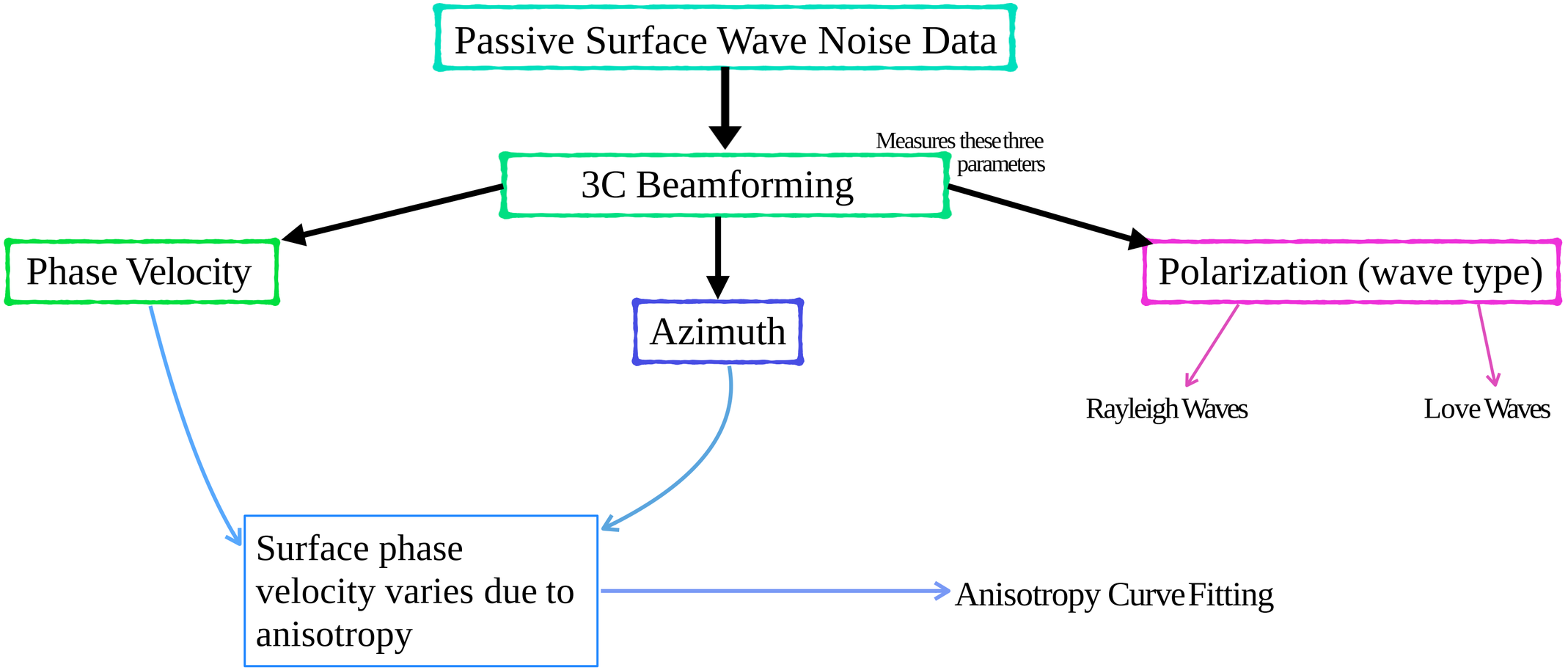
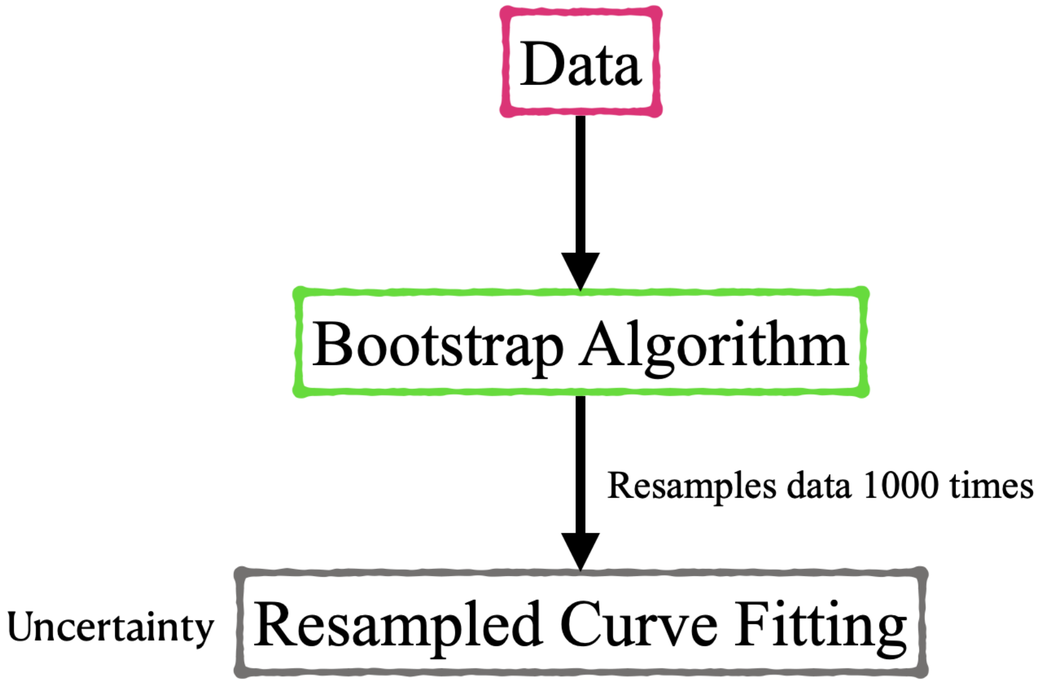
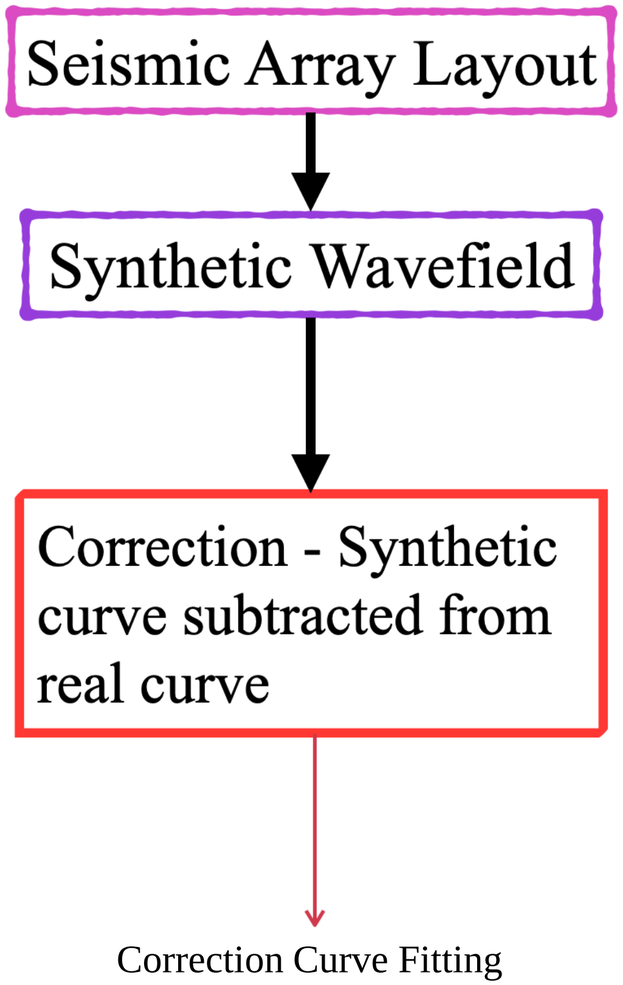
3C Beamforming



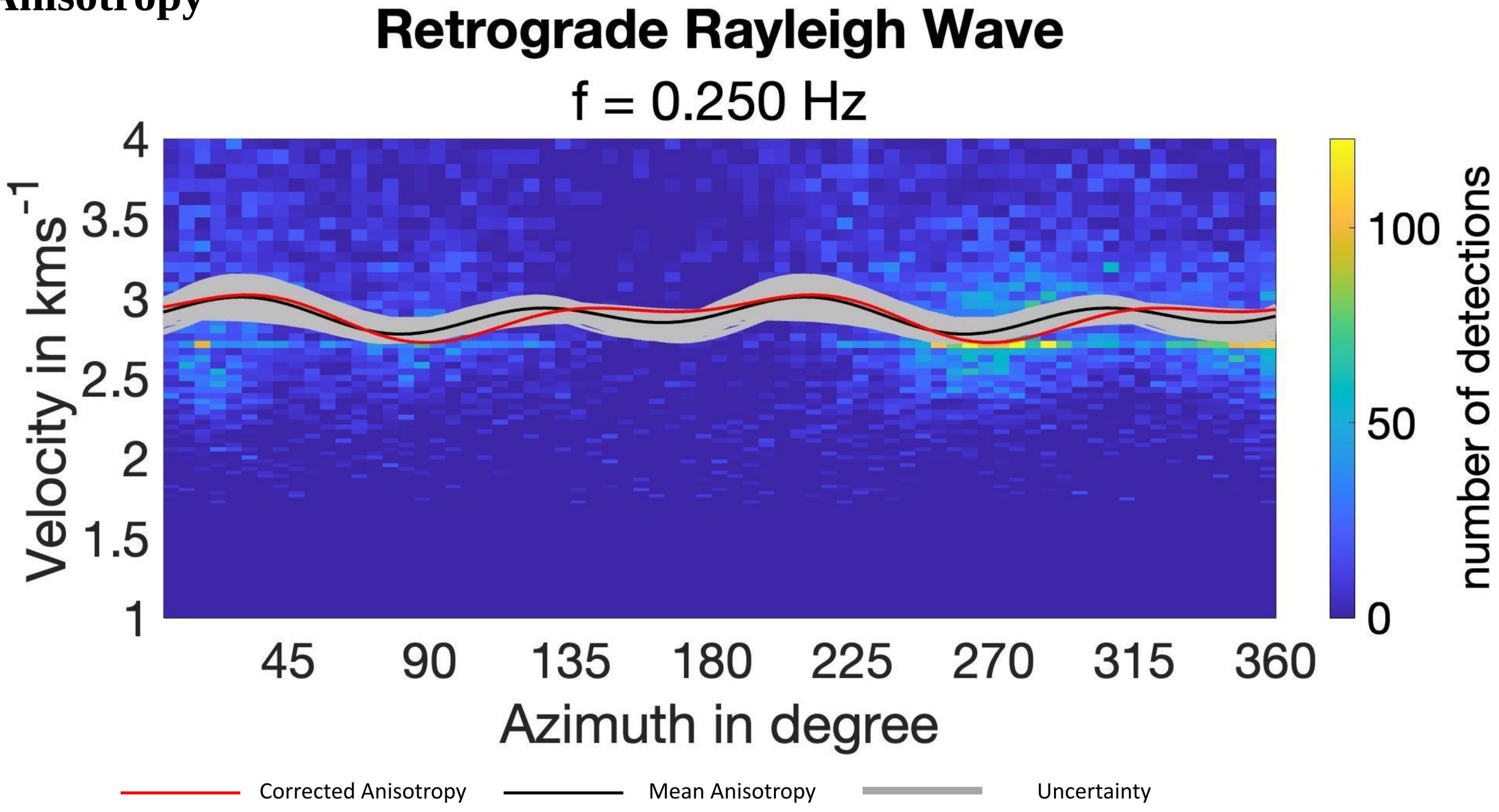
Uncertainty Assessment



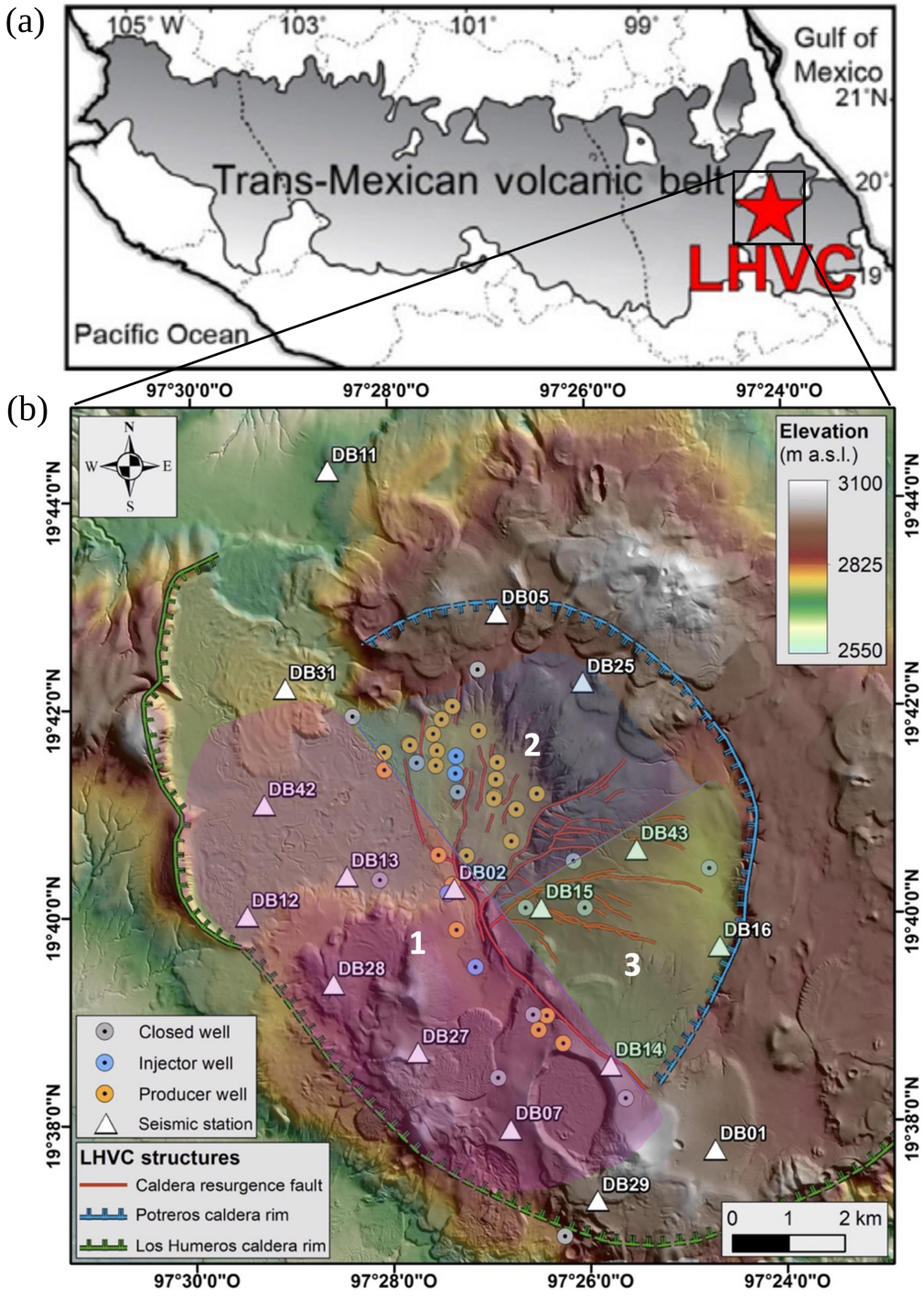
Correcting for ArrayEffect



Anisotropy


Retrograde Rayleigh Wave
f = 0.250 Hz
Velocity in kms-1
4
3.5
3
2.5
2
1.5
1
45
90
135
180
225
270
315
360
Azimuth in degree
100
50
0
number of detections
Corrected Anisotropy
Mean Anisotropy
Uncertainty

Los Humeros Geothermal Field



Closed well

Injector well

Producer well

Seismic station

LHVC structures

Caldera resurgence fault

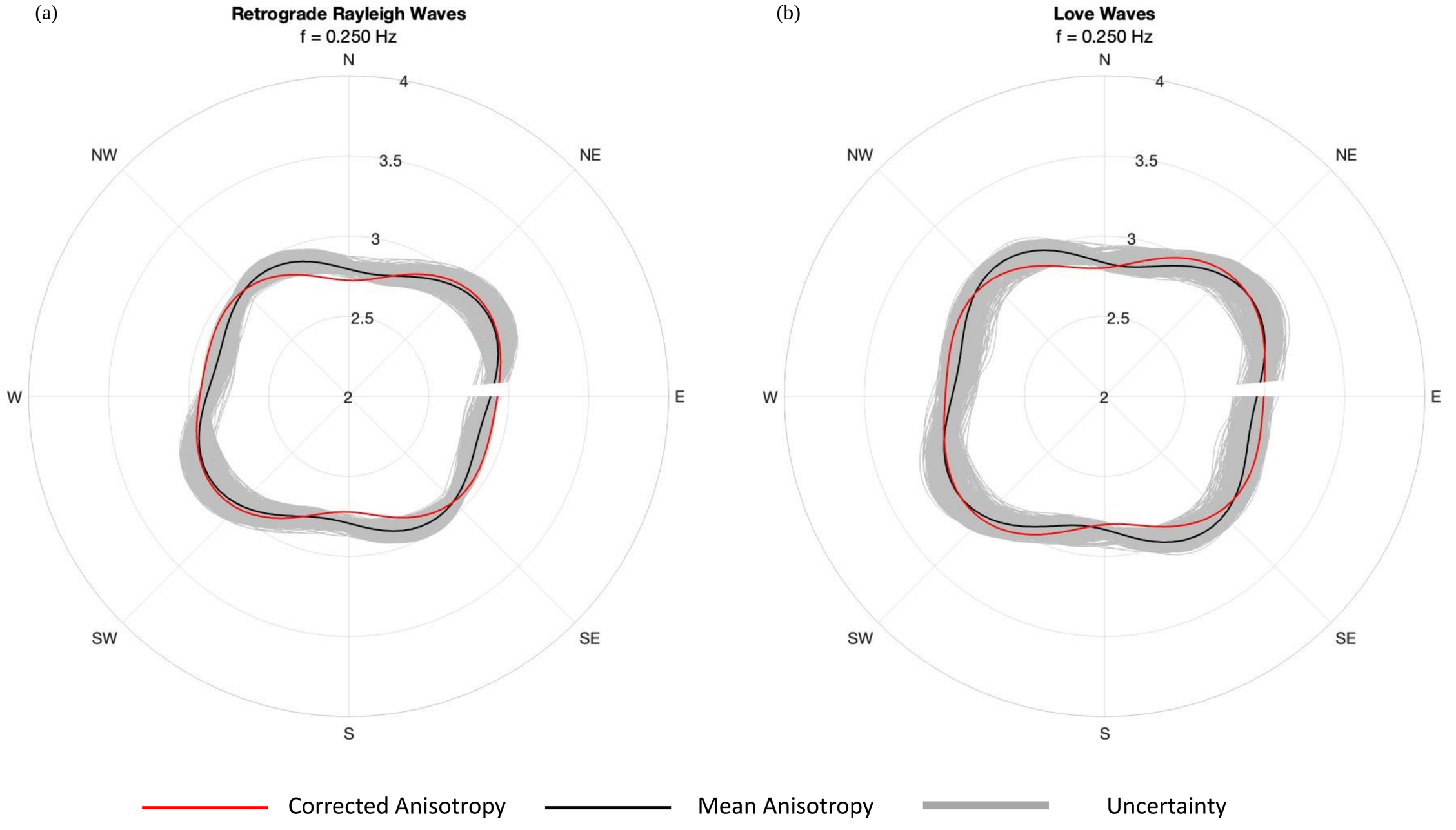
Potreros caldera rim

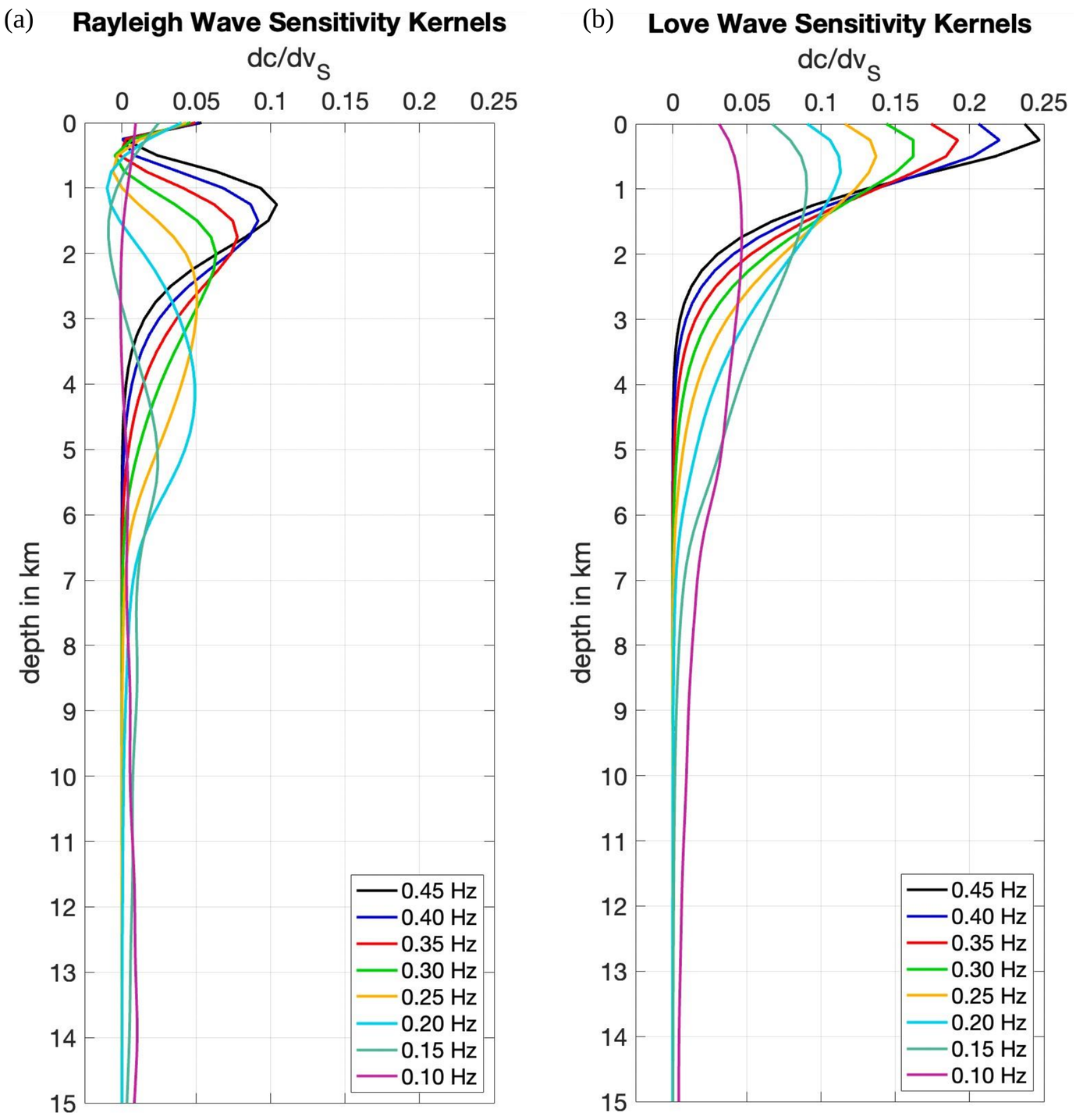
Los Humeros caldera rim

Zone 1

Zone 2

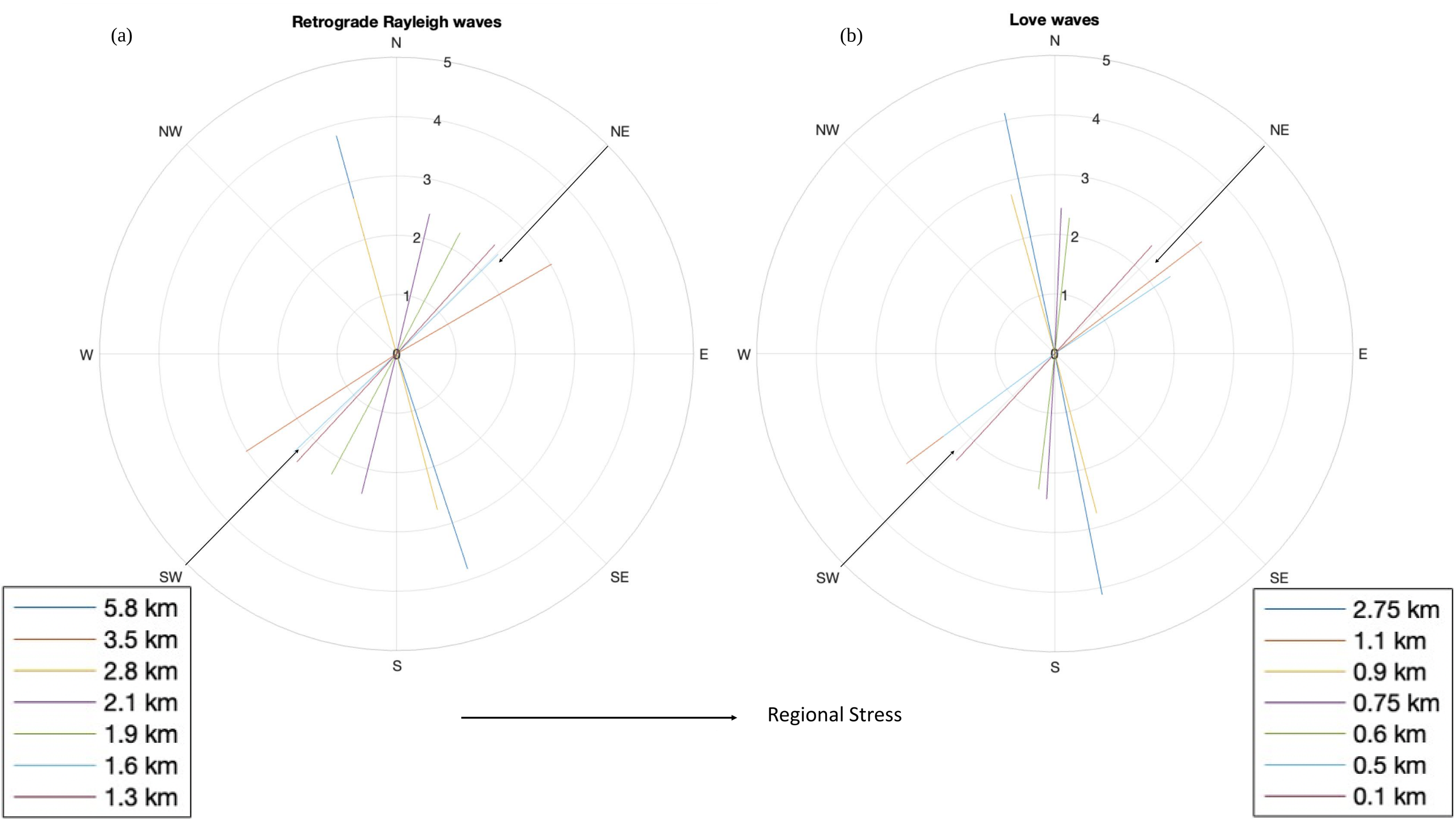
Zone 3


(a)
Retrograde Rayleigh Waves
f = 0.250 Hz
N
NE
E
SE
S
SW
W
NW
4
3.5
3
2.5
2
(b)
Love Waves
f = 0.250 Hz
N
NE
E
SE
S
SW
W
NW
4
3.5
3
2.5
2
Corrected Anisotropy
Mean Anisotropy
Uncertainty

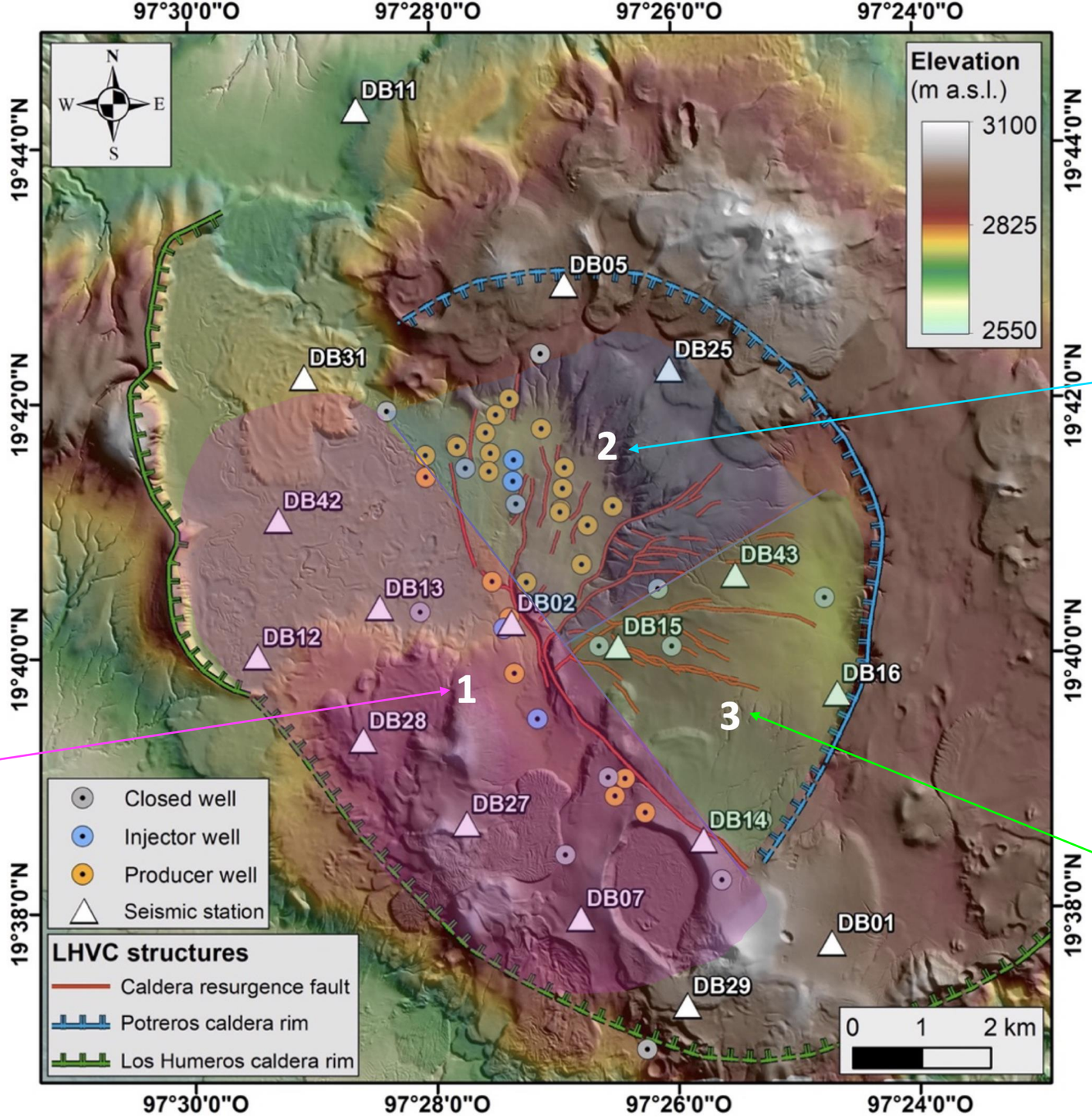


Depth Sensitivity

0.45 Hz
0.40 Hz
0.35 Hz
0.30 Hz
0.25 Hz
0.20 Hz
0.15 Hz
0.10 Hz


(a)
Retrograde Rayleigh waves
N
NE
E
SE
S
SW
W
NW
0
1
2
3
4
5
5.8 km
3.5 km
2.8 km
2.1 km
1.9 km
1.6 km
1.3 km
(b)
Love waves
N
NE
E
SE
S
SW
W
NW
0
1
2
3
4
5
2.75 km
1.1 km
0.9 km
0.75 km
0.6 km
0.5 km
0.1 km
Regional Stress

Resurgence Faults and Fractures



Maxtaloya-Los Humeros Fault Swarm

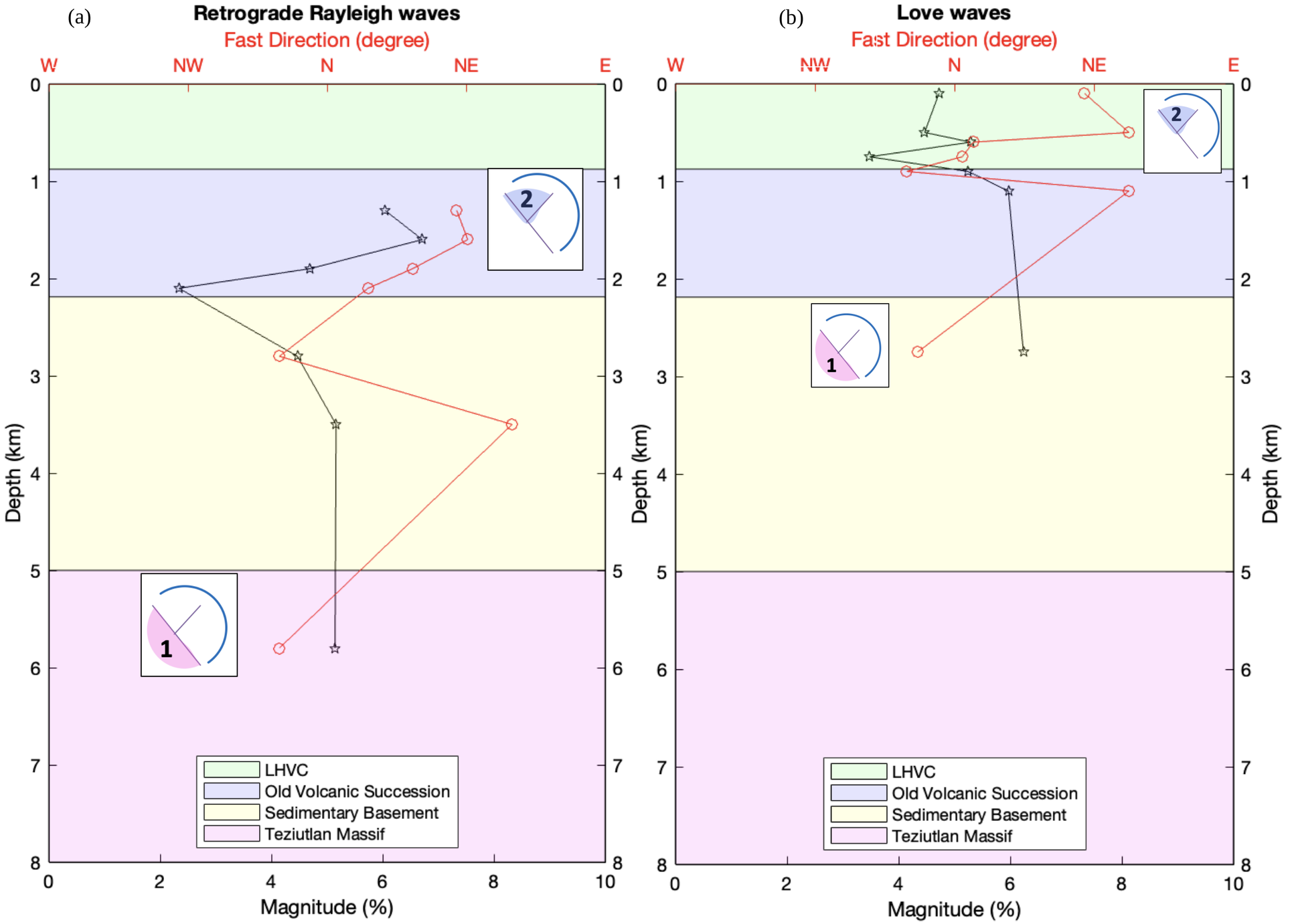
Arroyo-Grande Fault and Parallel Faults

Las Papas Fault Swarm

Fast Direction varying with Depth

Fast Direction

Magnitude of Apparent Anisotropy

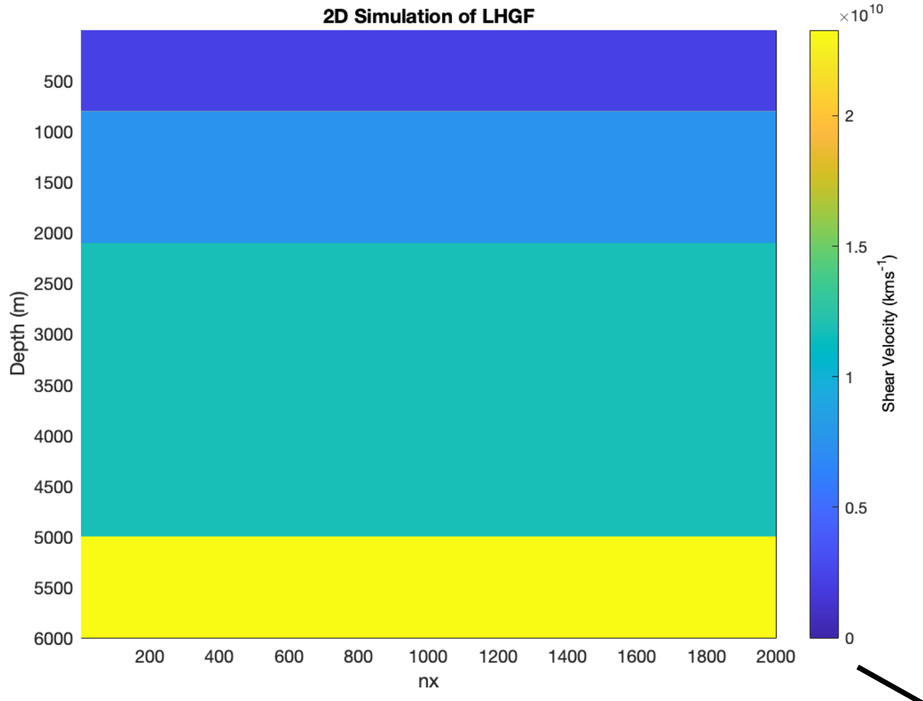


To Summarise

- 3C beamforming can estimate seismic anisotropy.
- Clear fast directions from seismic anisotropy indicate subsurface structures.
- Zone 1 and 2 dominant anisotropy match fast directions.
- Maxtaloya-Los Humeros fault swarm (zone 1) and Arroyo Grande fault/parallel faults (zone) are, therefore, seen at depths > 2 km.
- NE-SW trending Mafic dykes may also have caused an anisotropy response (such as 3.5 km in Fig.6a).

Implications for the Geothermal Field:

- Continuation of faults at depth
- Anisotropy might be sensitive to hydrothermal productivity
- No evidence for brittle-ductile transition zone at depths < 6 km.



Future work - Simulation

Apply observed anisotropy

Wave Response

3C beamforming of simulated wave response

Compare to current results