8. Application examples

- AVS30
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- 2D levee investigation at New Orleans
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Average S-wave velocity to 30 m depth (AVs30m) and site class (IBC)

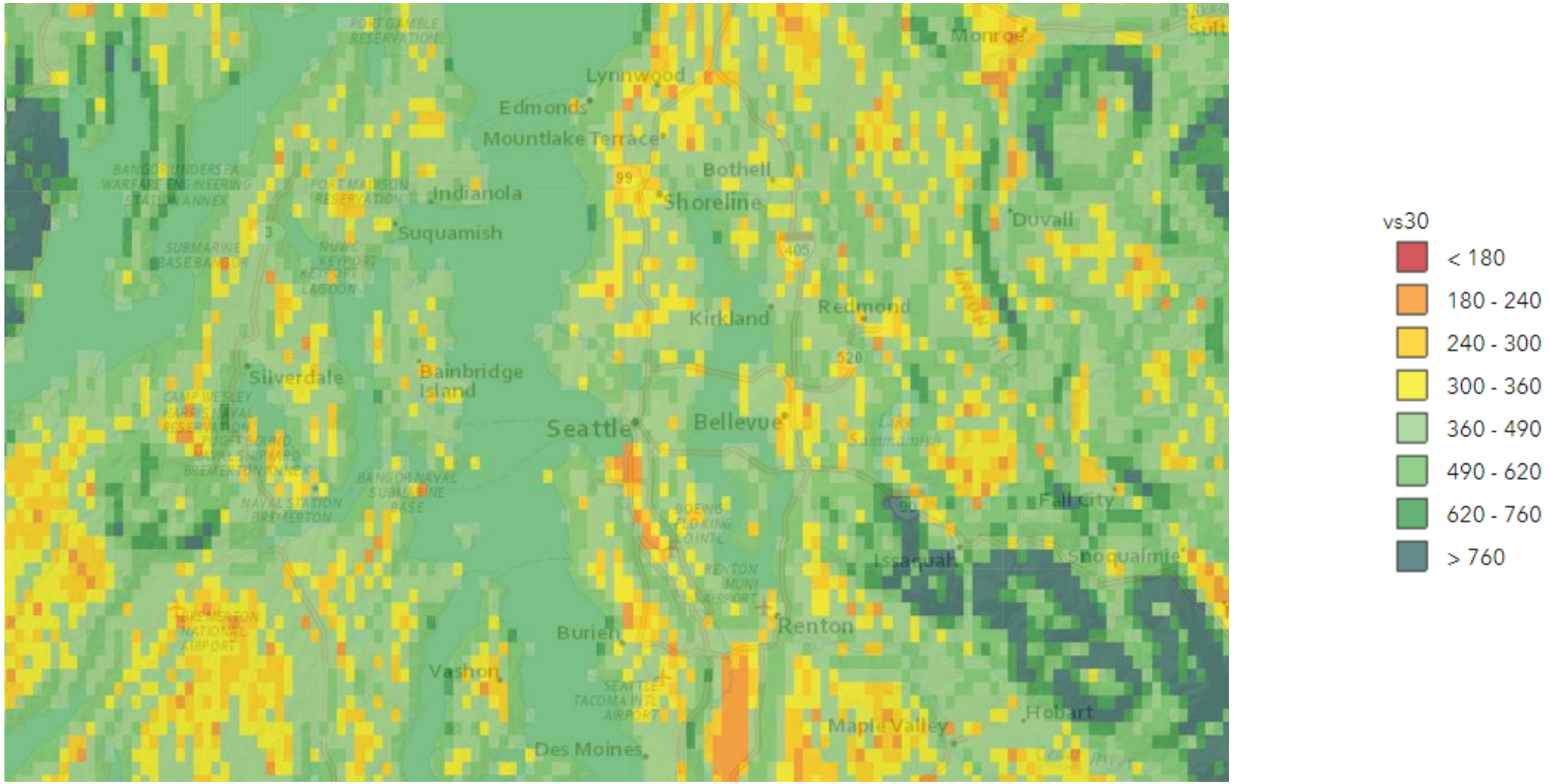
$$AVS30 = \frac{30}{\sum_{i-1}^{n} \frac{d_i}{Vs_i}}$$

AVS30m is time average

d : thickness
Vs : S-wave velocity
n : number of layers

Site class	Soil profile name	Soil shear wave velocity (Vs)	
		feet/sec	m/sec
A	Hard rock	5000 < Vs	1500 < Vs
B	Rock	2500 < Vs ≤ 5000	760 < Vs ≤ 1500
C	Very dense soil and soft rock	1200 < Vs ≤ 2500	360 < Vs ≤ 760
D	Stiff soil profile	600 < Vs ≤ 1200	180 < Vs ≤ 360
E	Soft soil profile	Vs < 600	Vs < 180

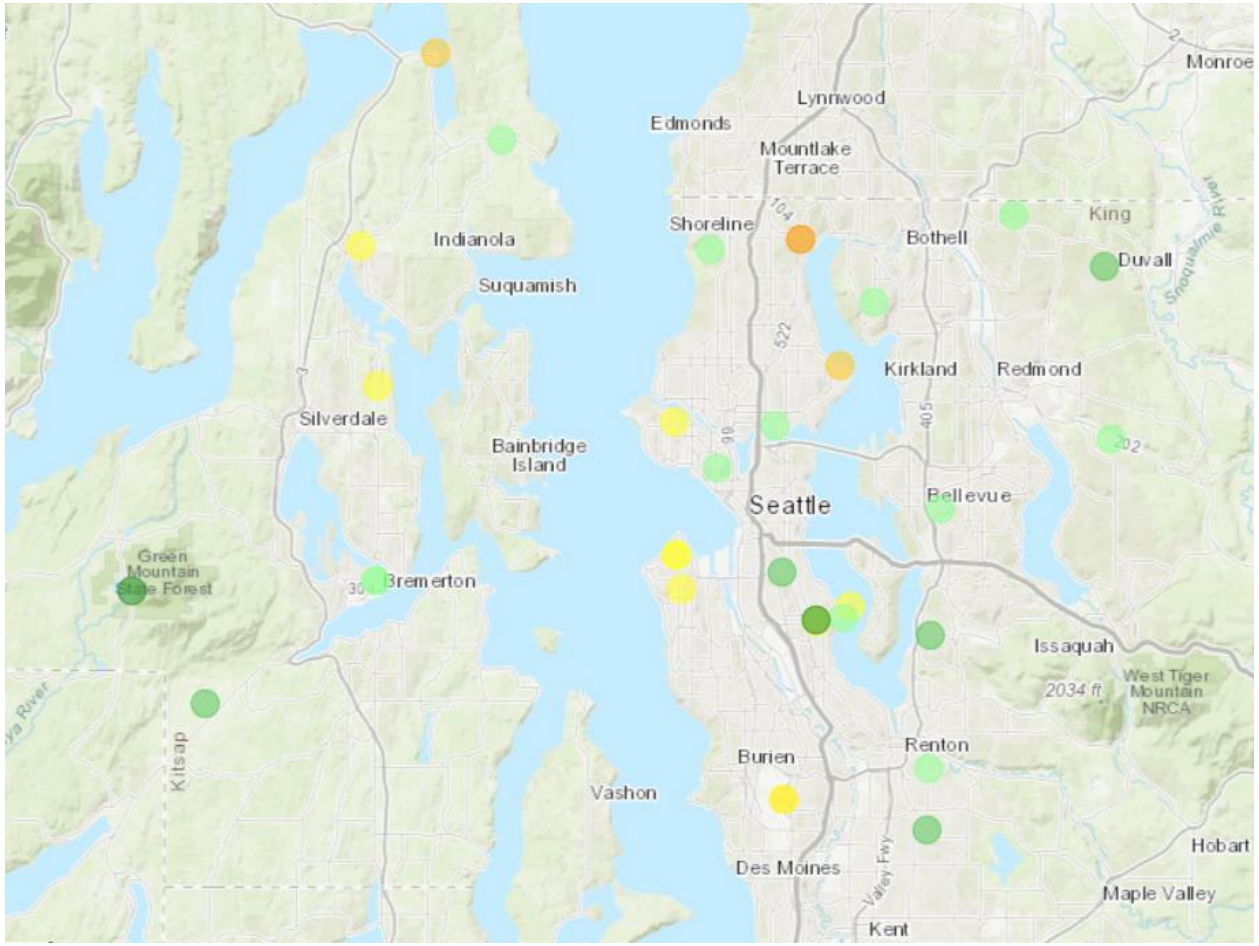
Slope based VS30 Map (USGS)



Database of measured Vs30

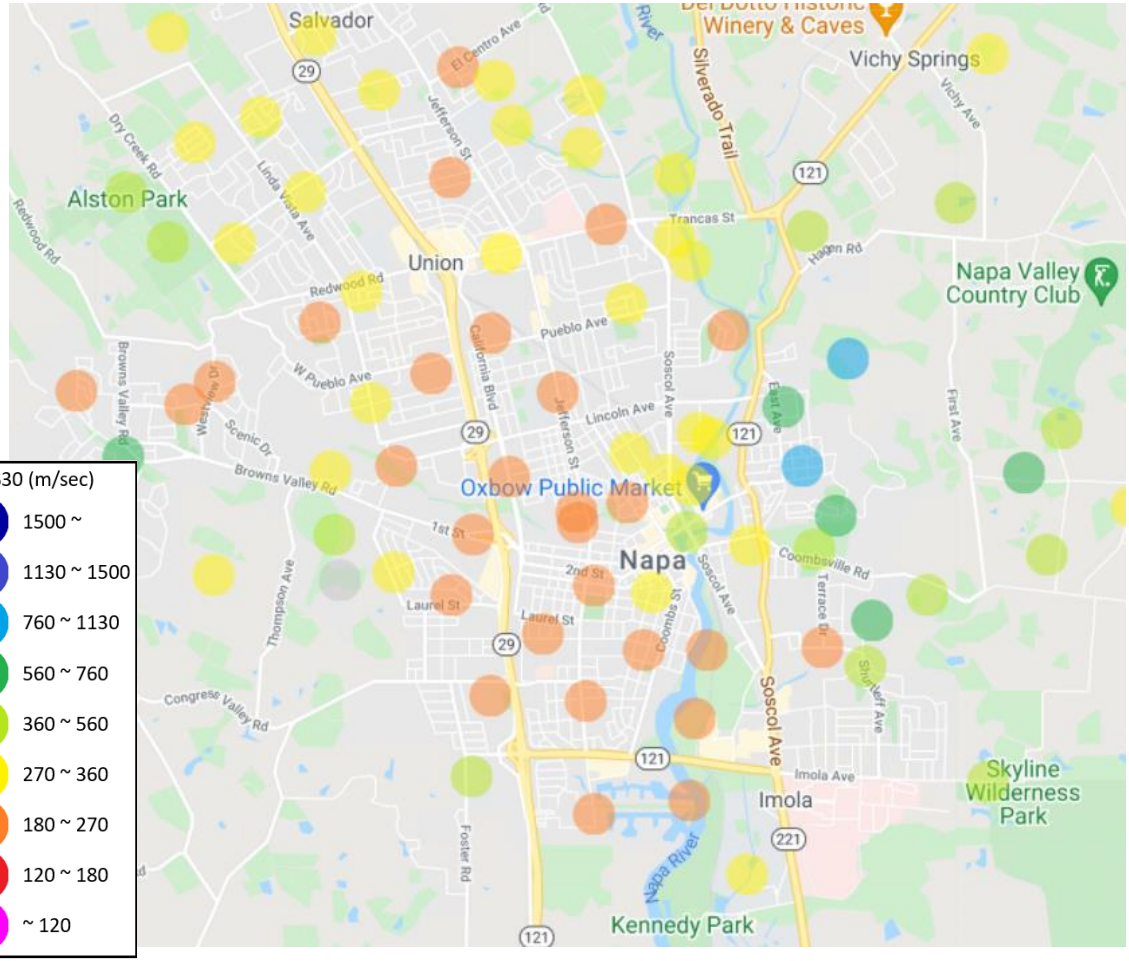
USGS

https://earthquake.usgs.gov/data/vs30/us/

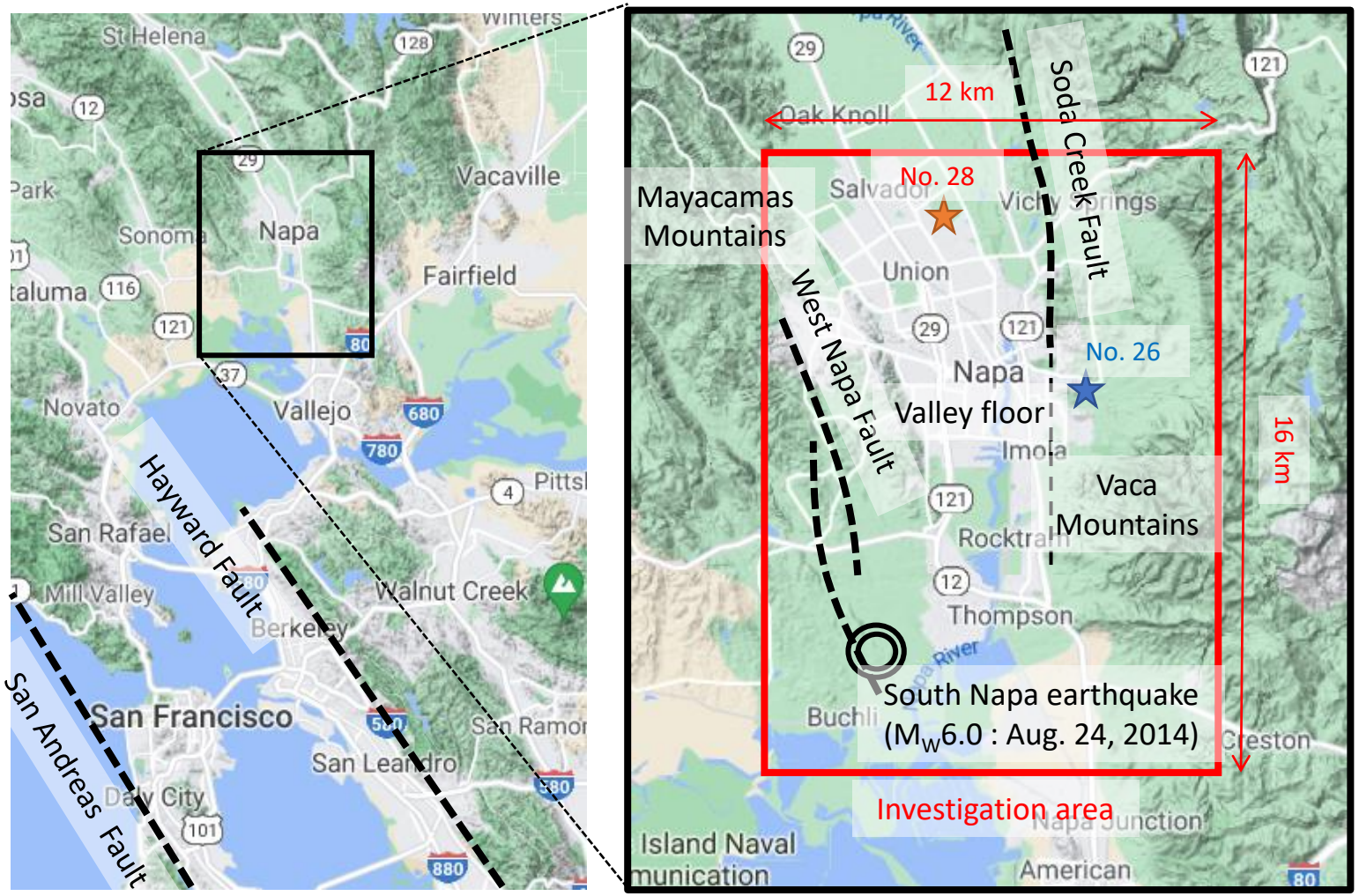


SeisImager

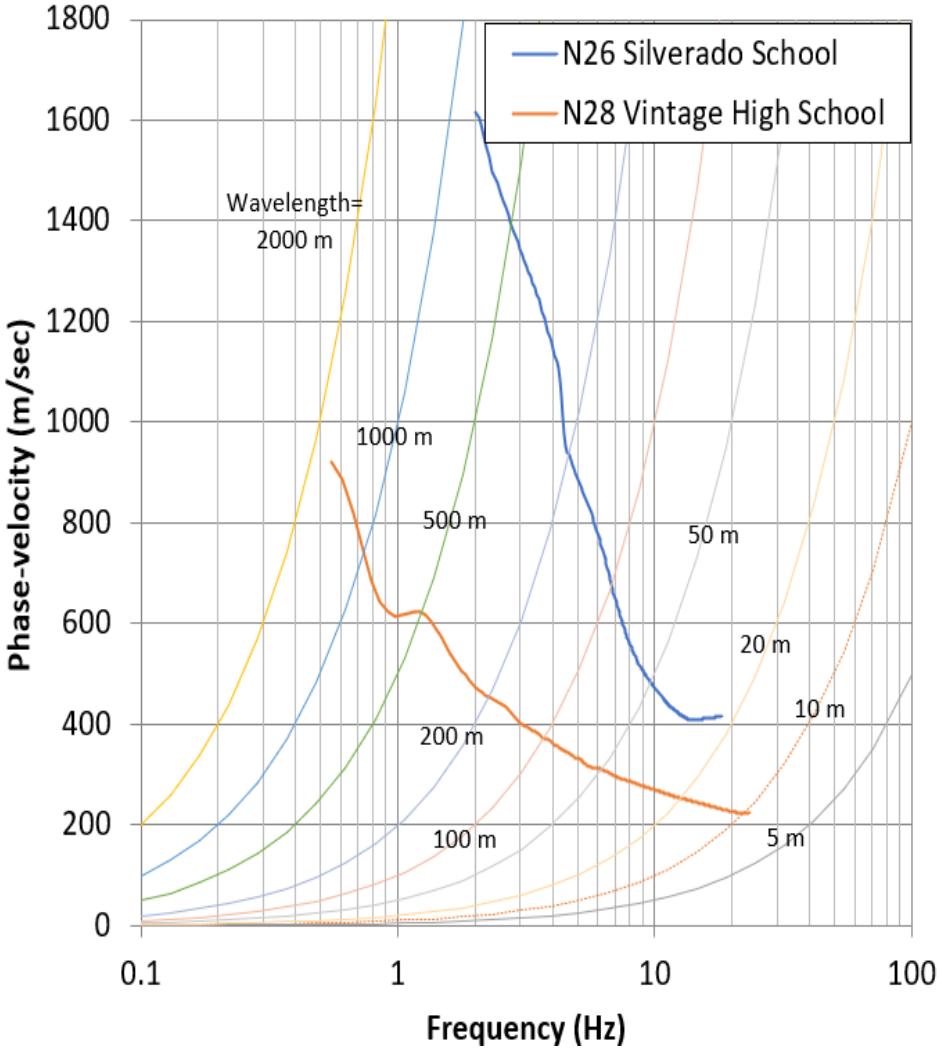
http://seisimager.com/

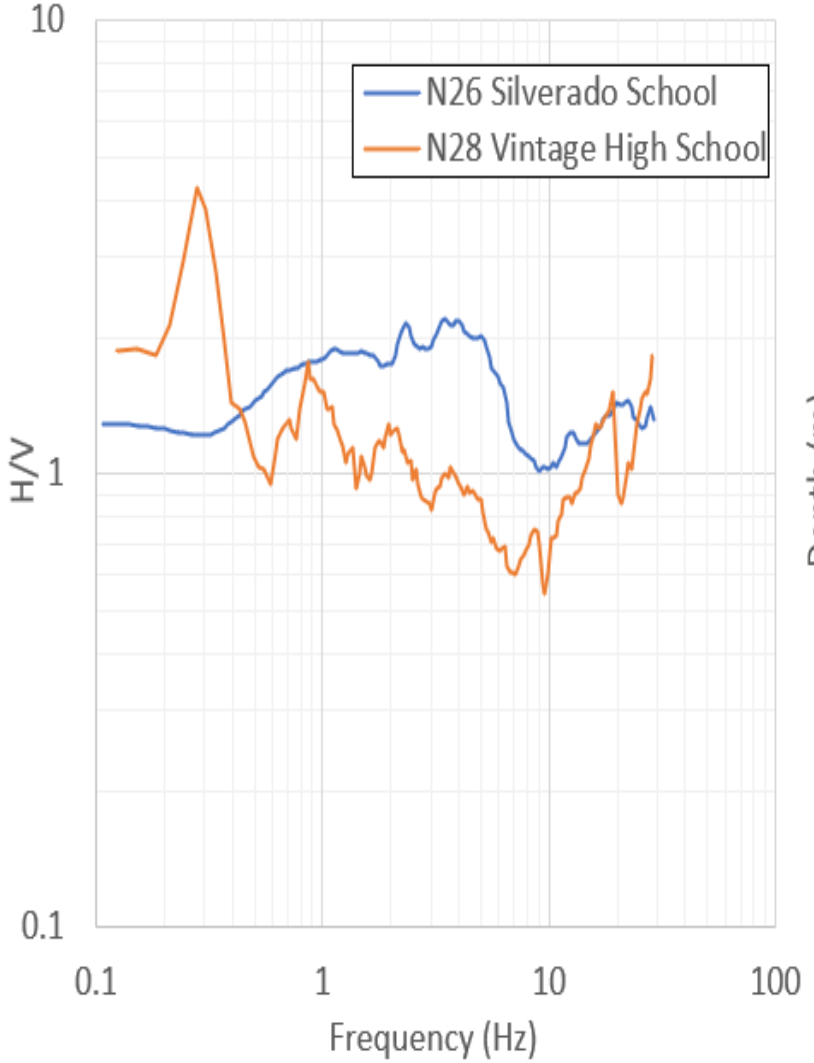


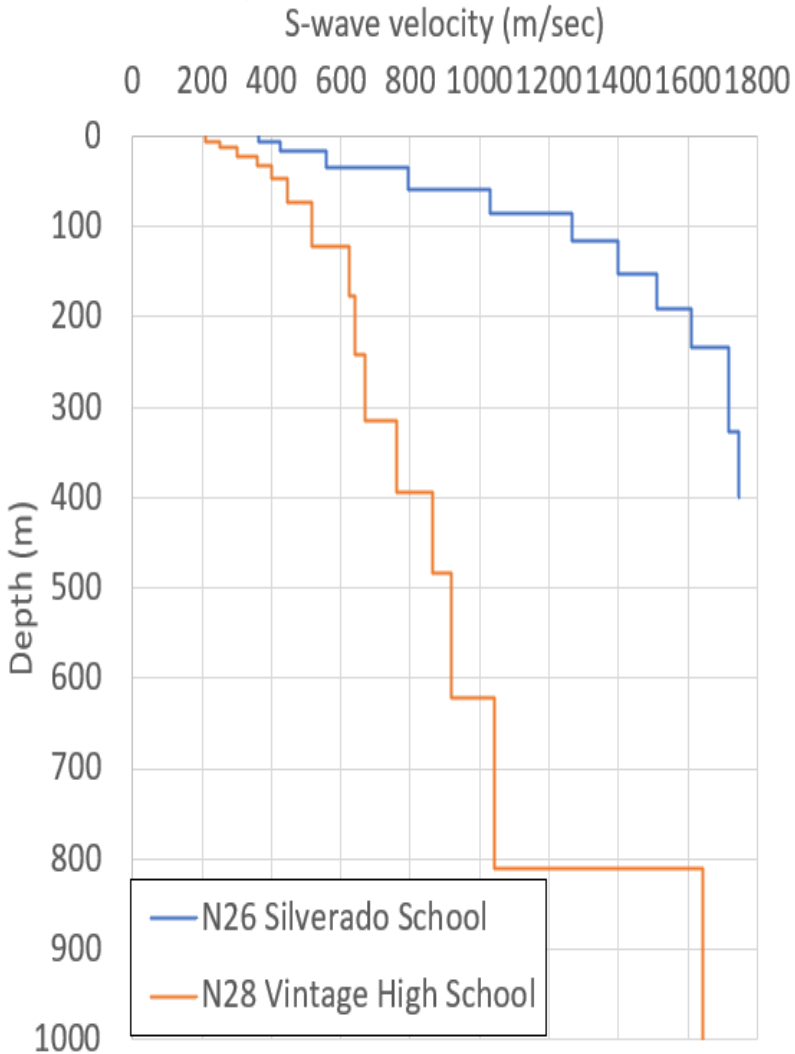
AVS30 mapping at Napa Valley, CA



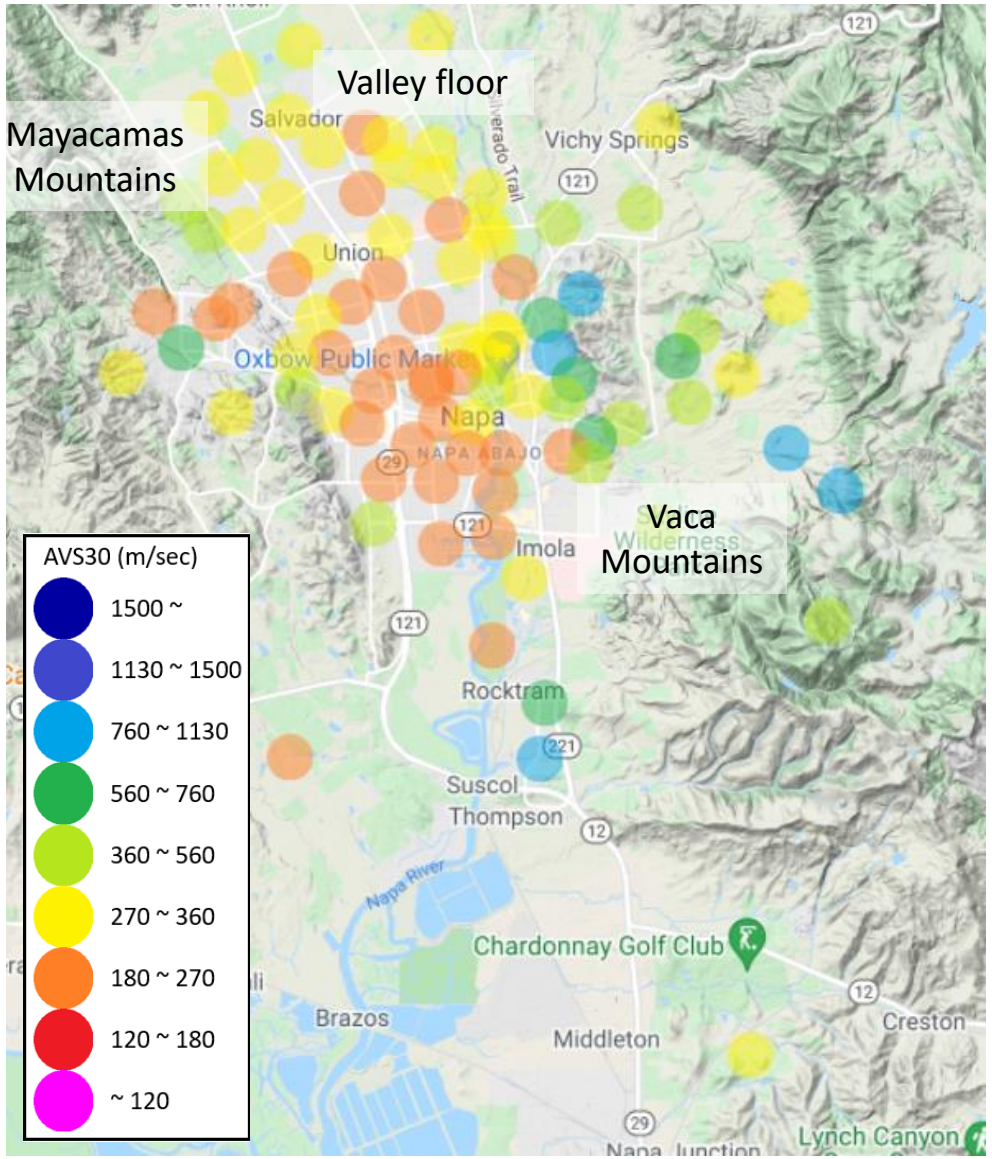
Typical dispersion curves, H/Vs and Vs profiles

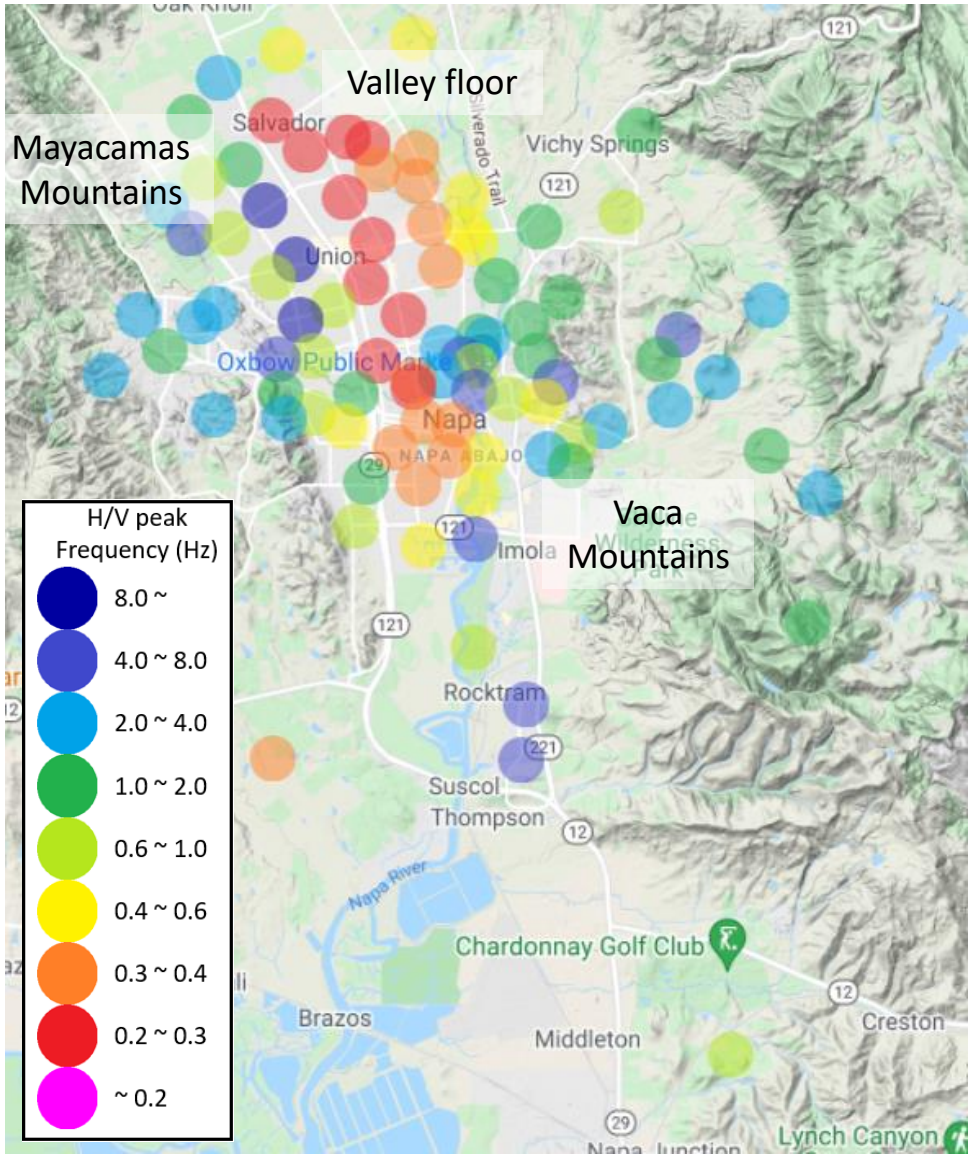




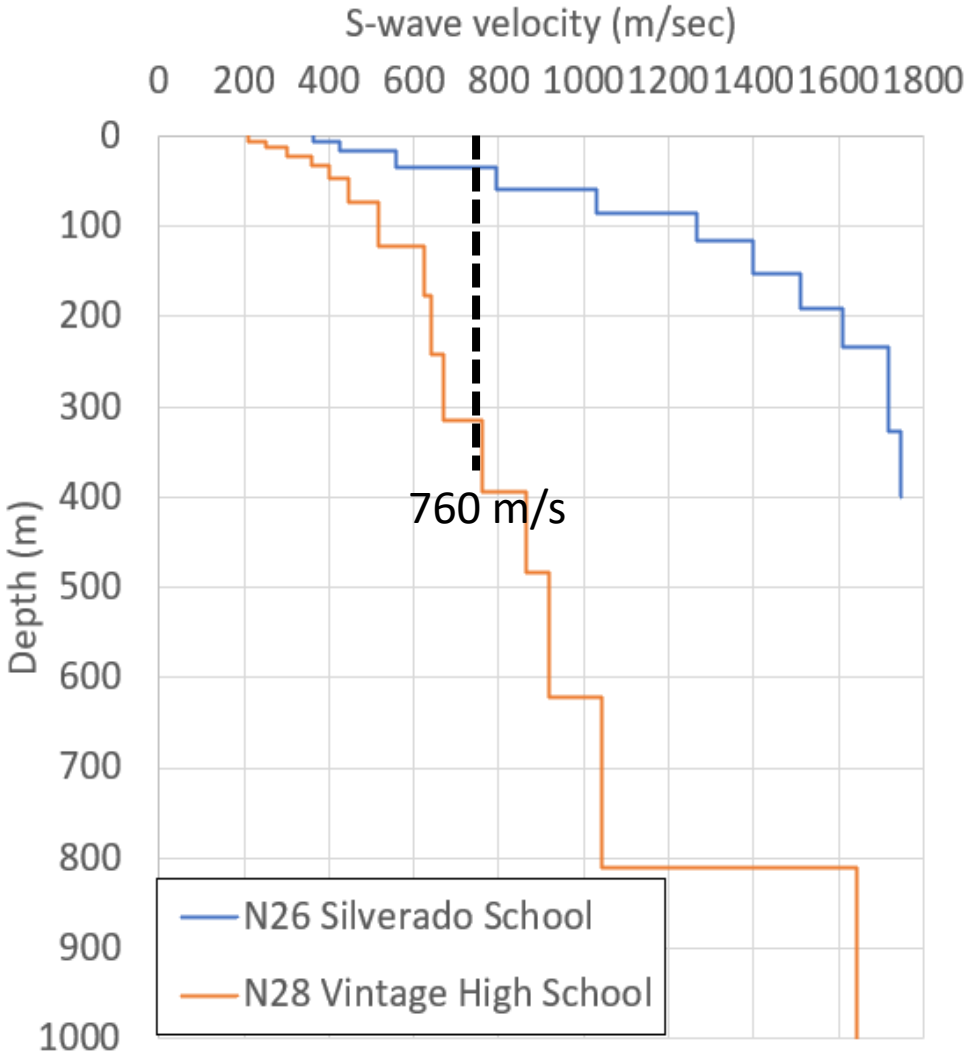


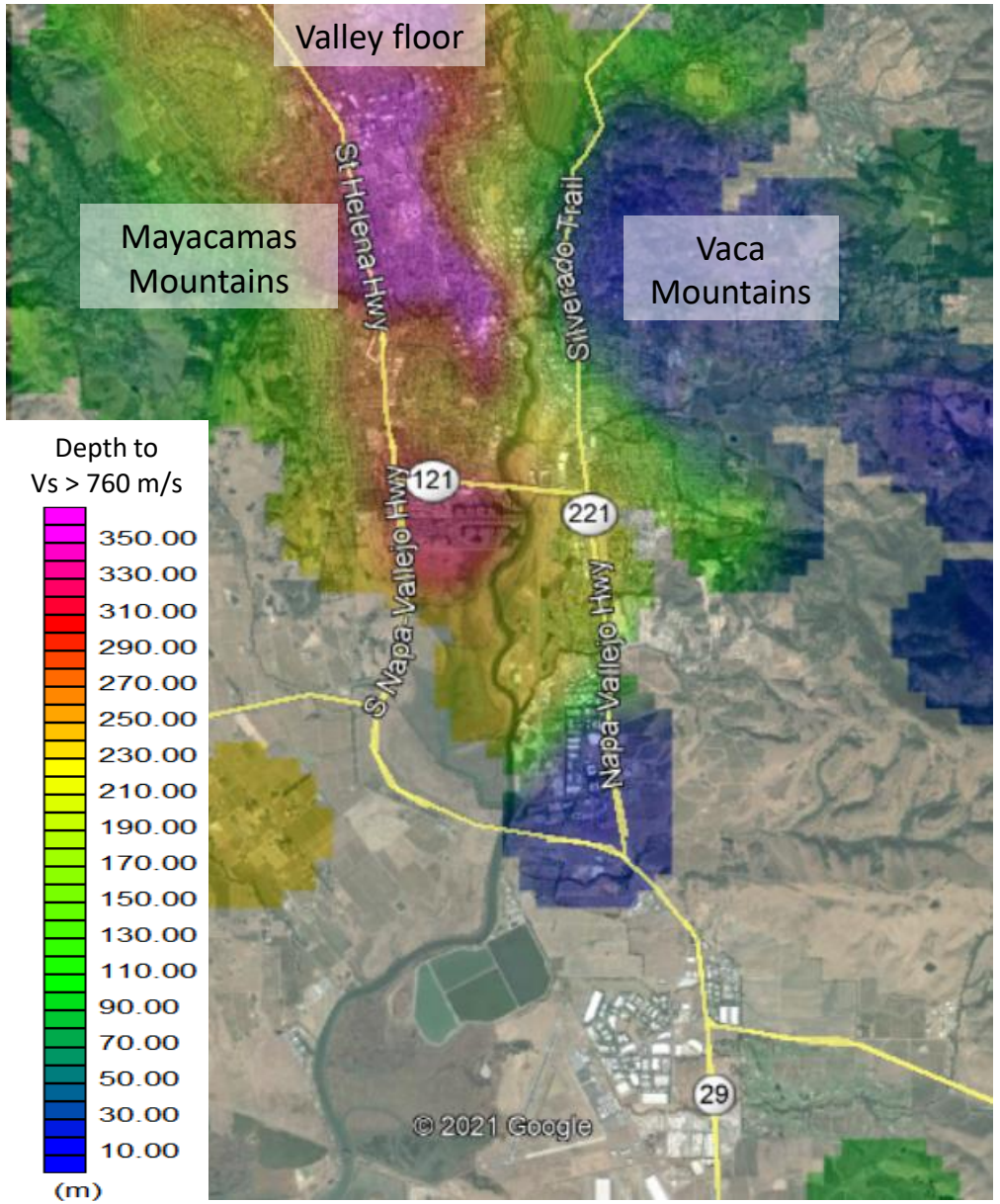
AVS30 and H/V peak frequencies



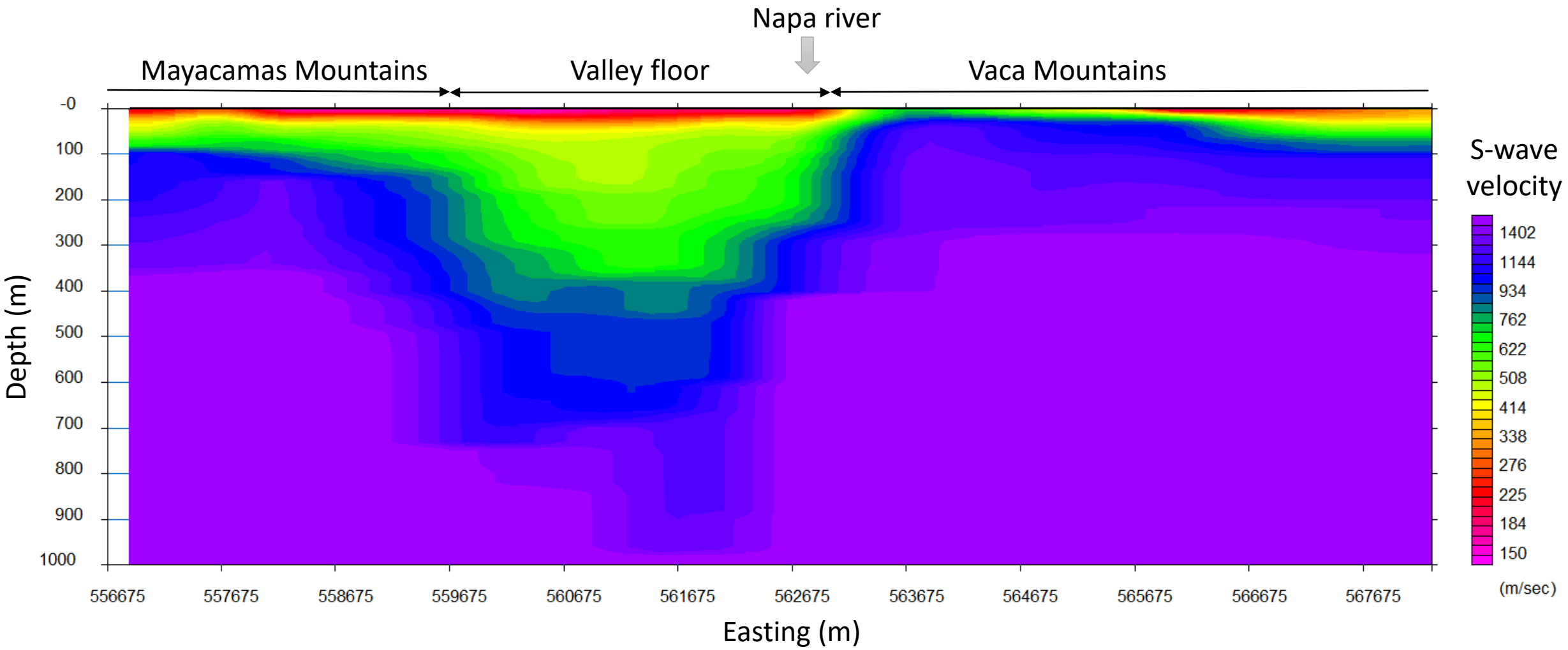


Depth to bedrock (Vs=760 m/s)

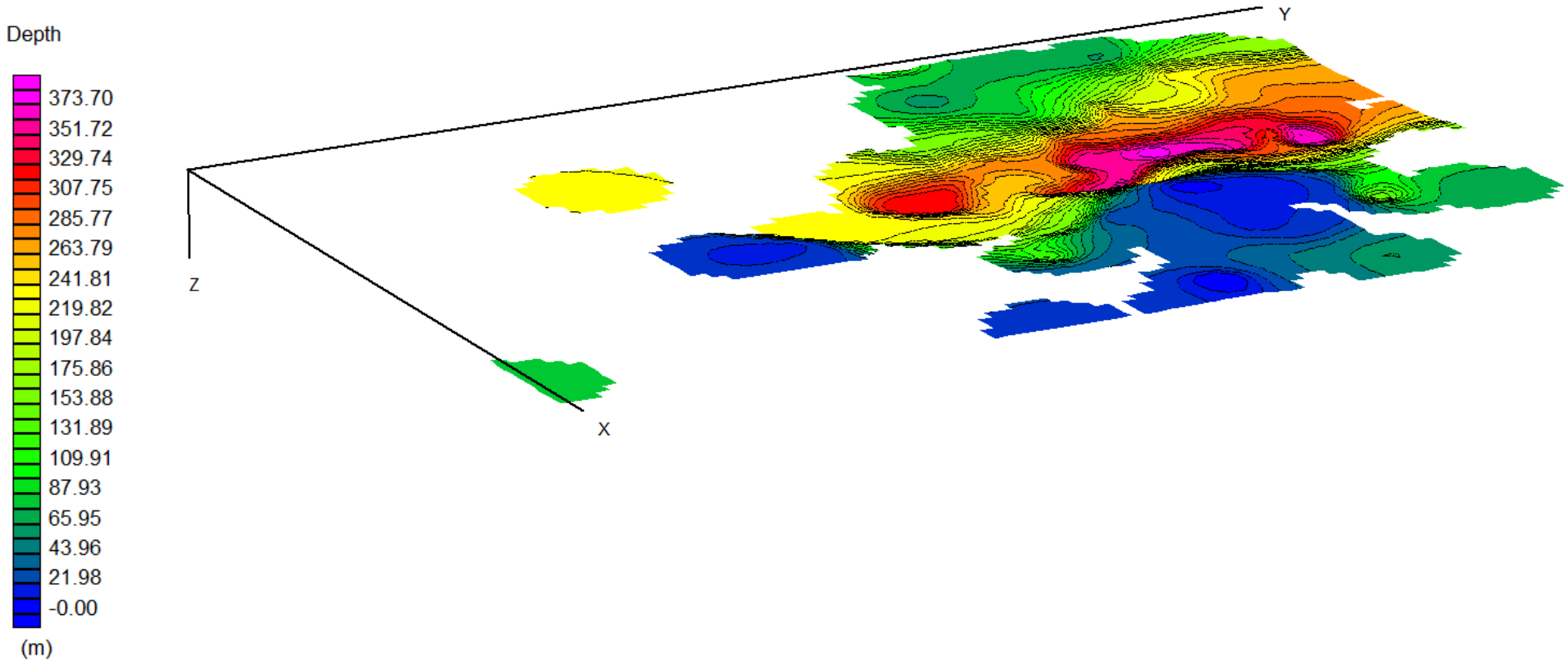




Vs cross section crossing the Valley



Depth to bedrock (Vs=760 m/s)



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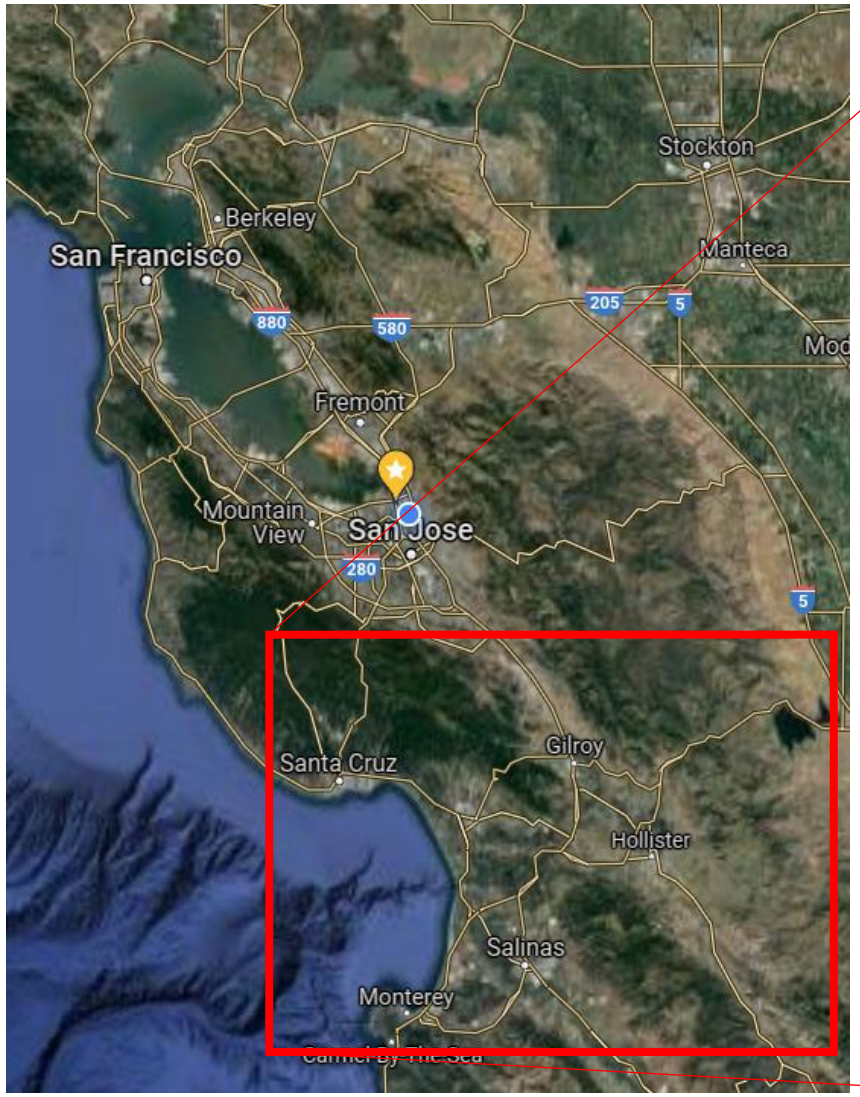
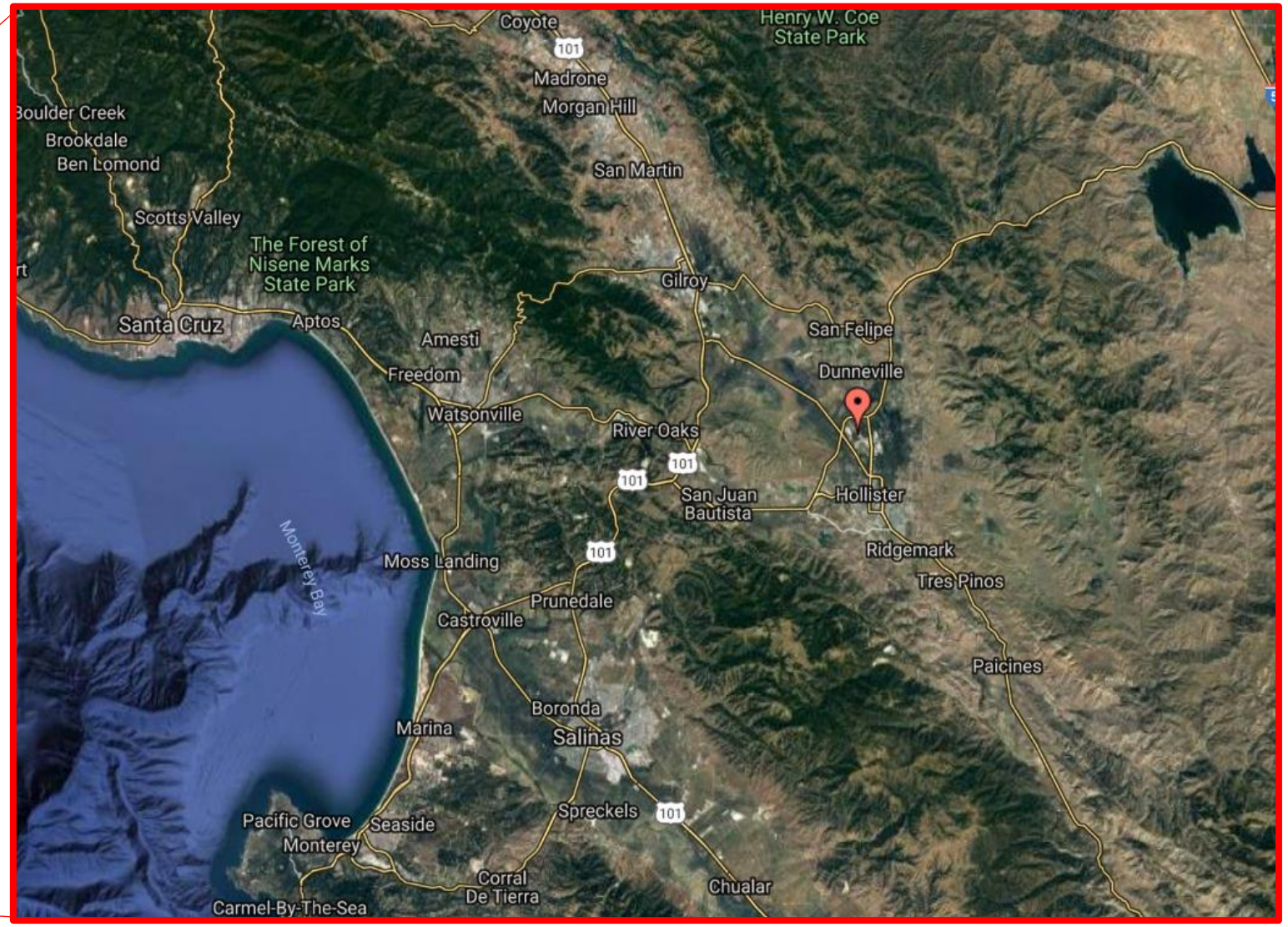
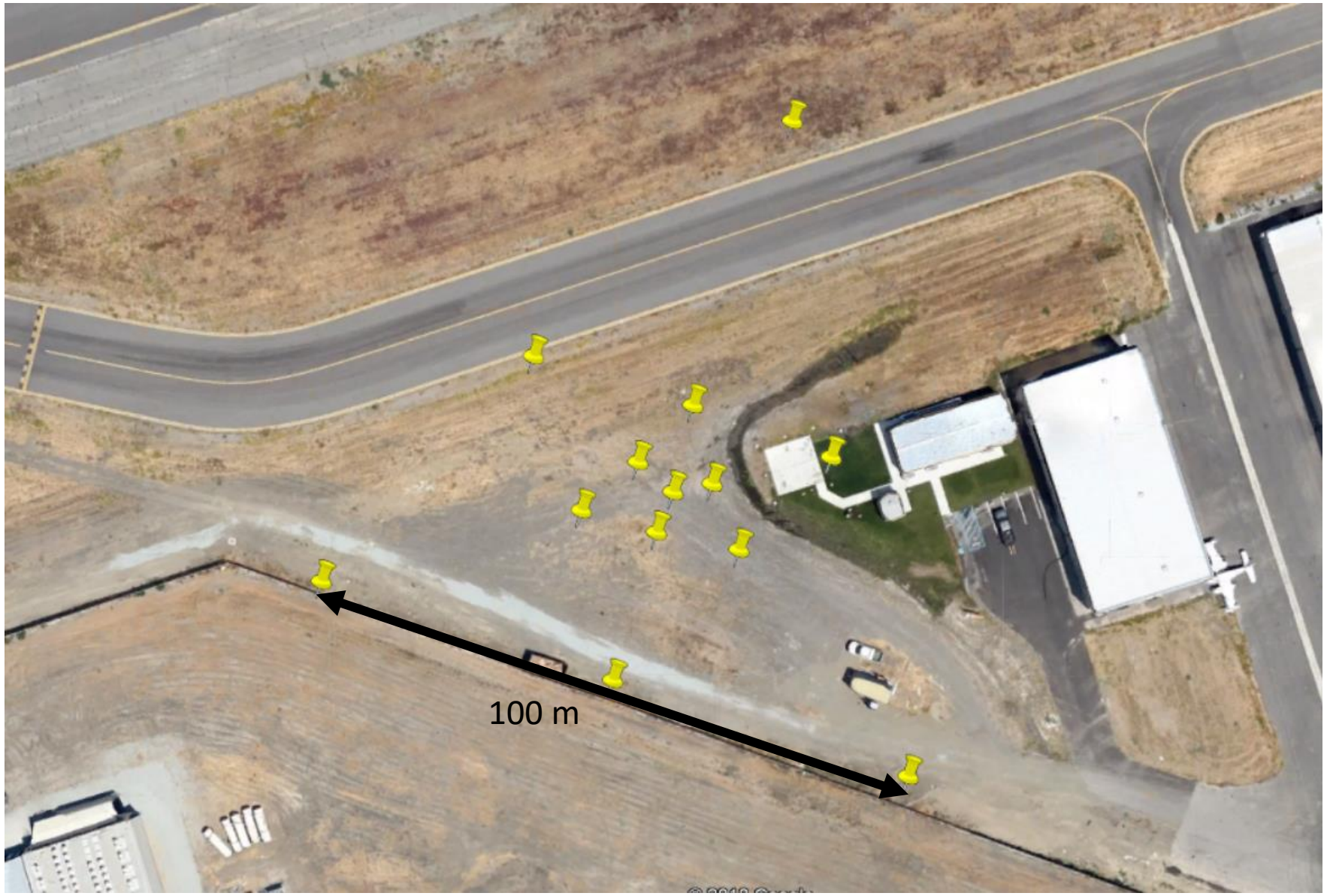
Investigation site

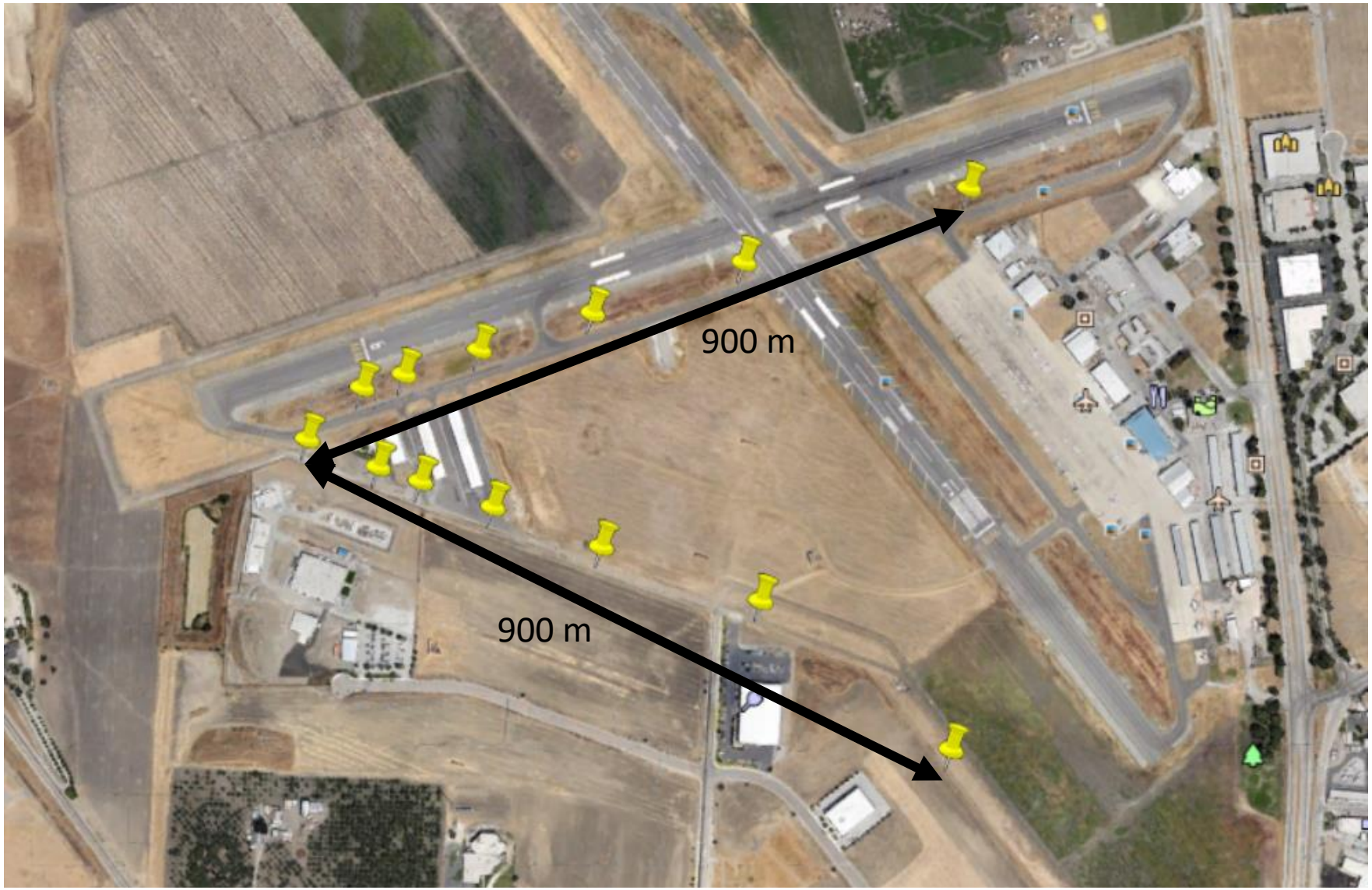




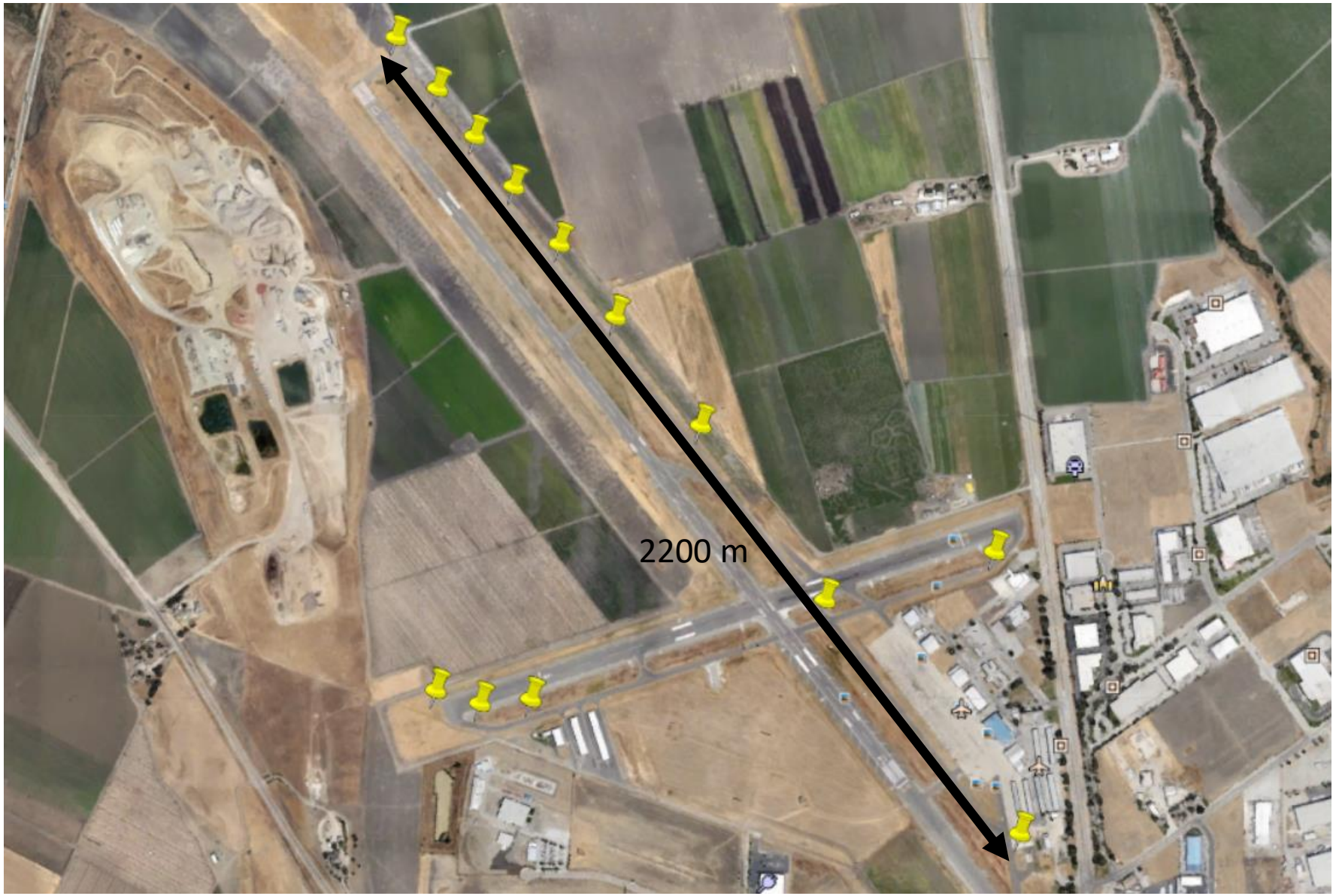
Small array : triangle 100 m



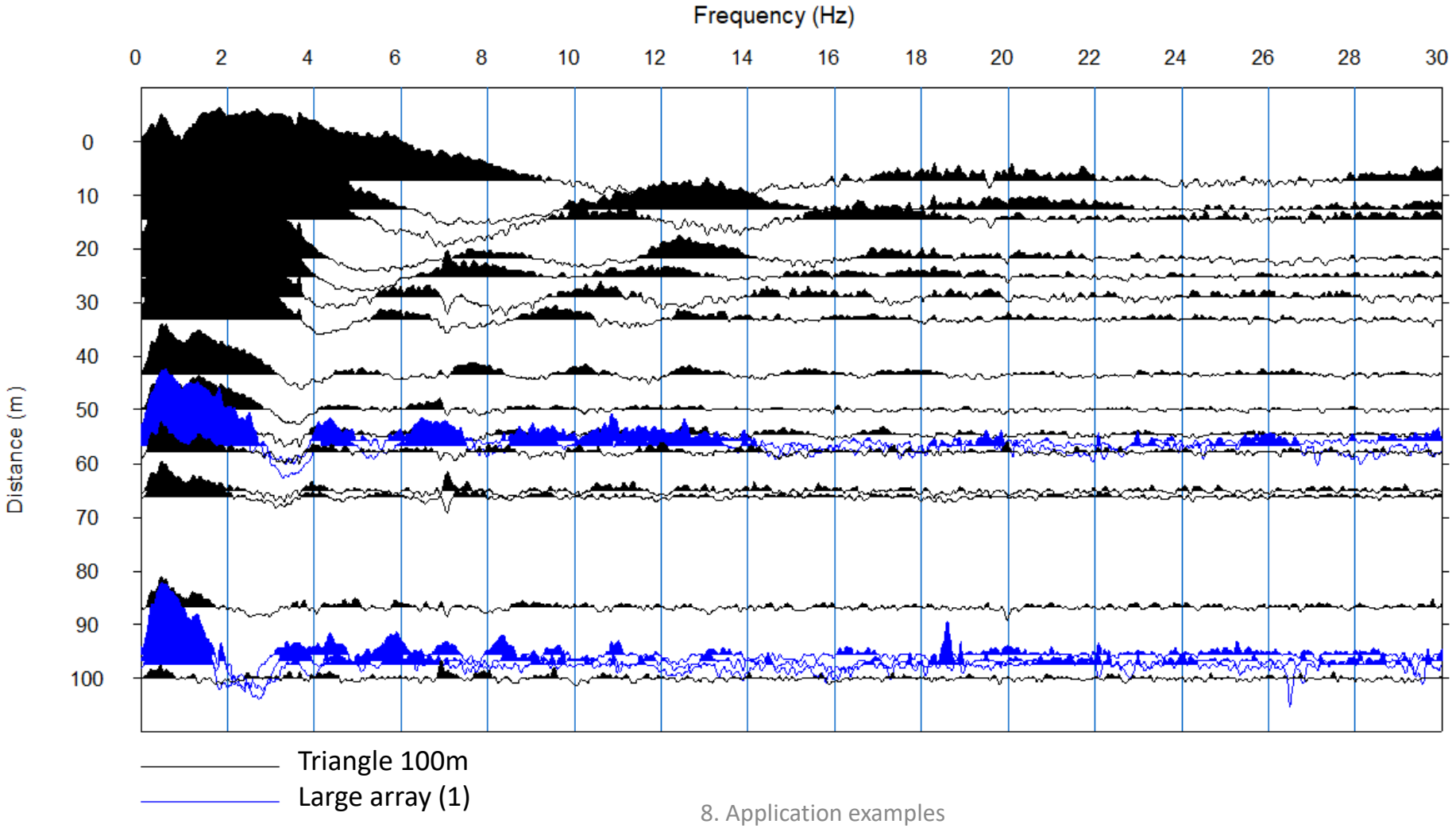
Large array (1)



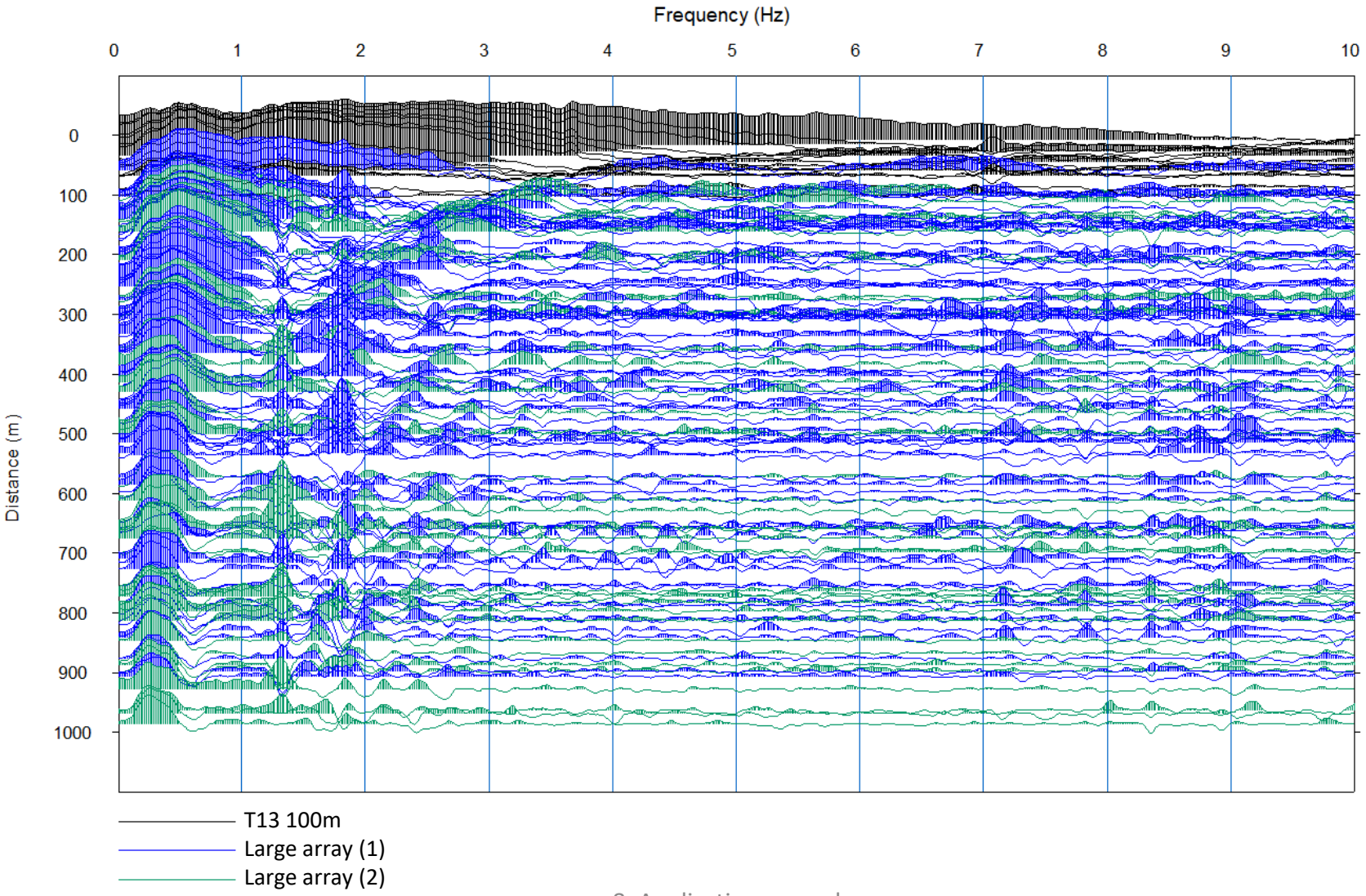
Large array (2)



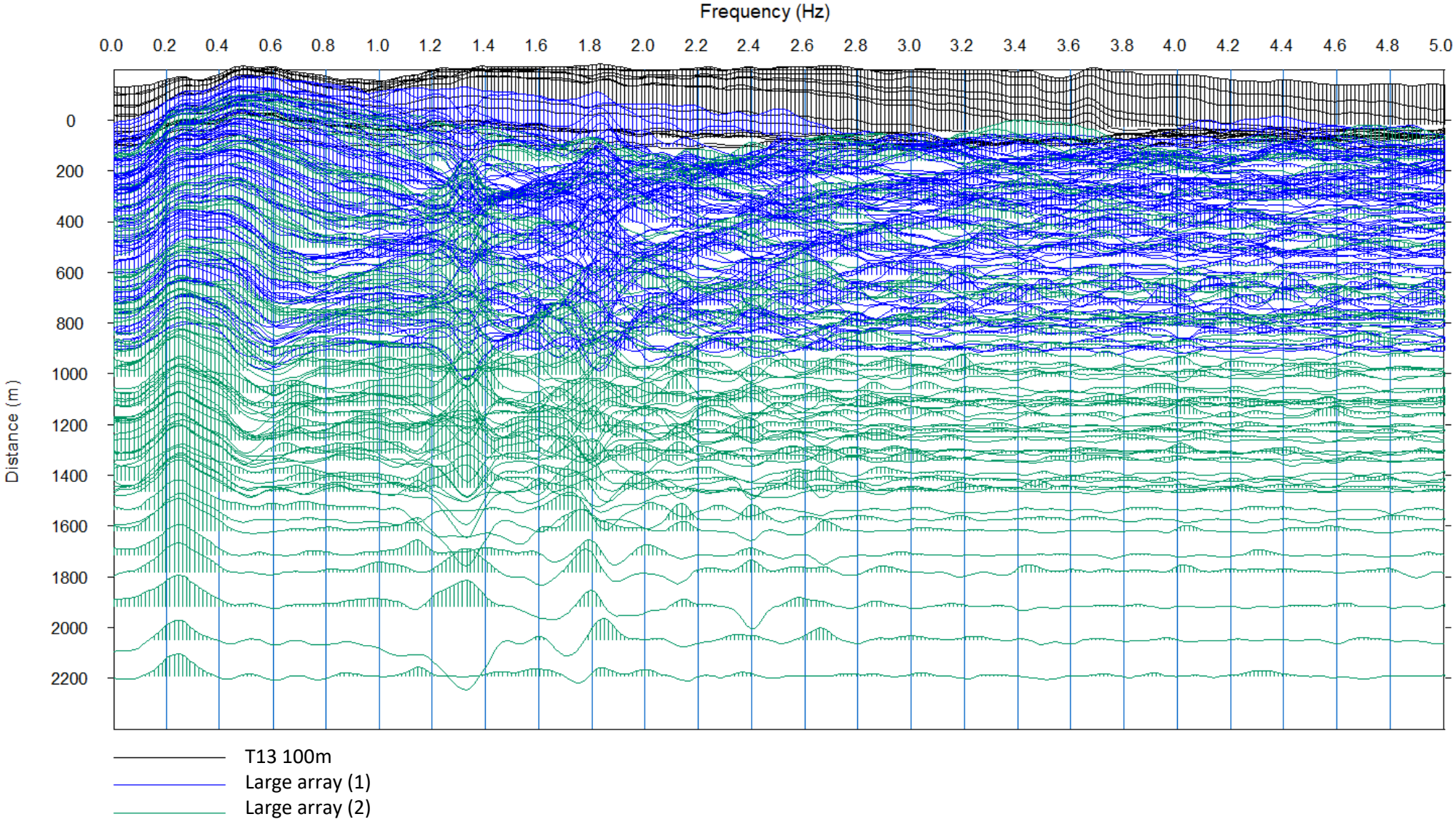
Coherencies (small array)



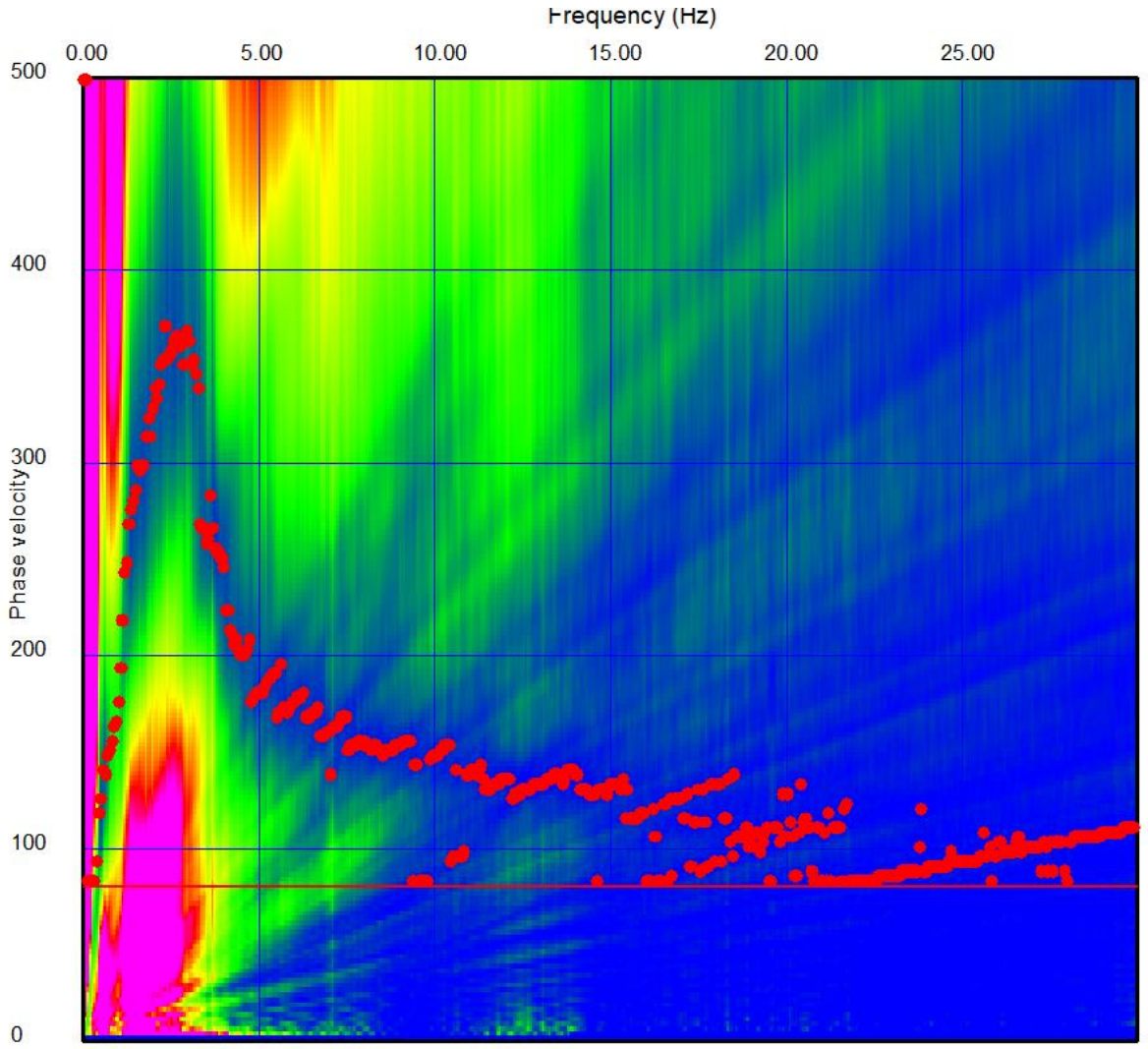
Coherencies (all arrays)



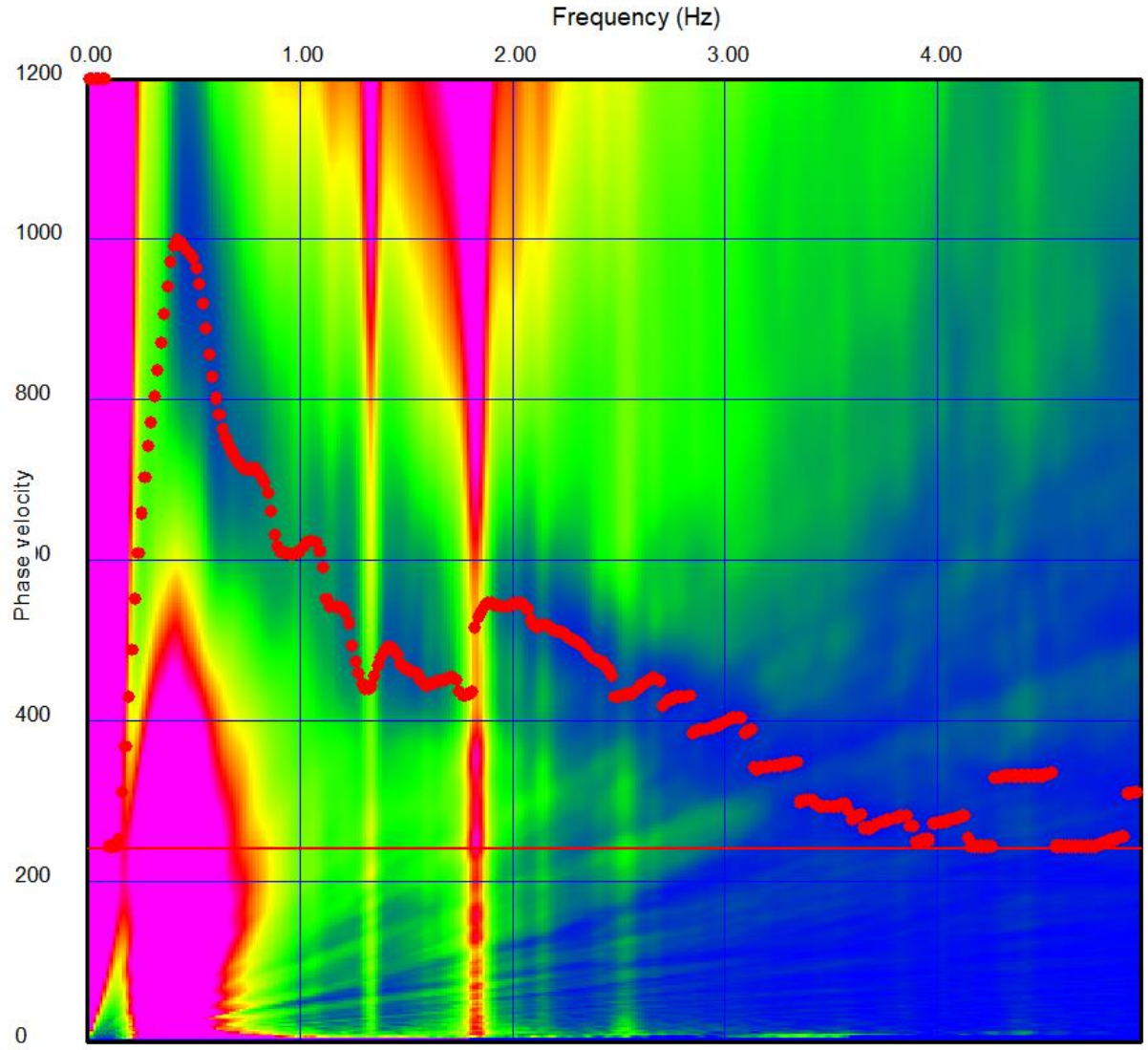
Coherencies (all arrays)



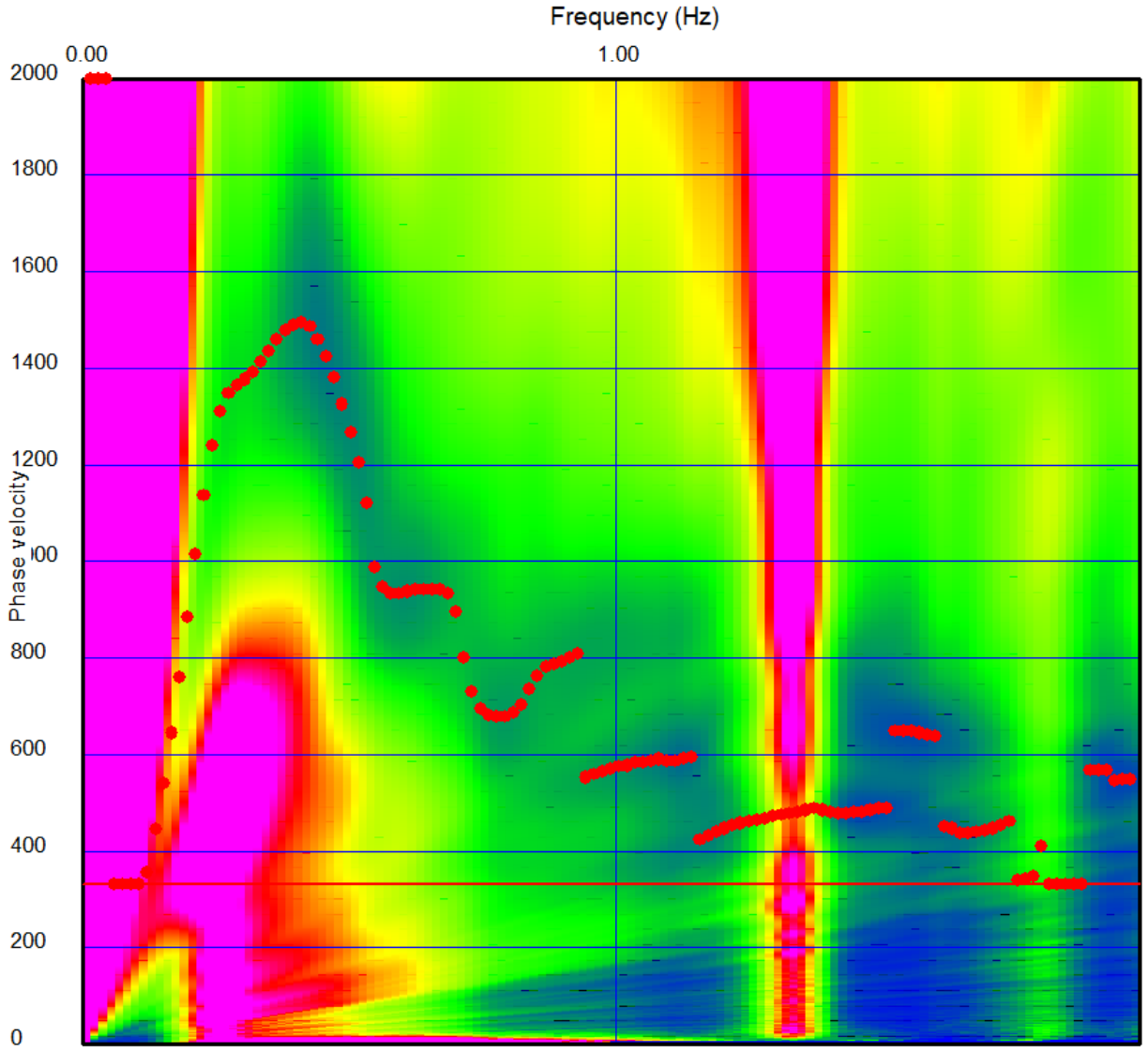
Phase velocity image in frequency domain (Triangle 100 m)



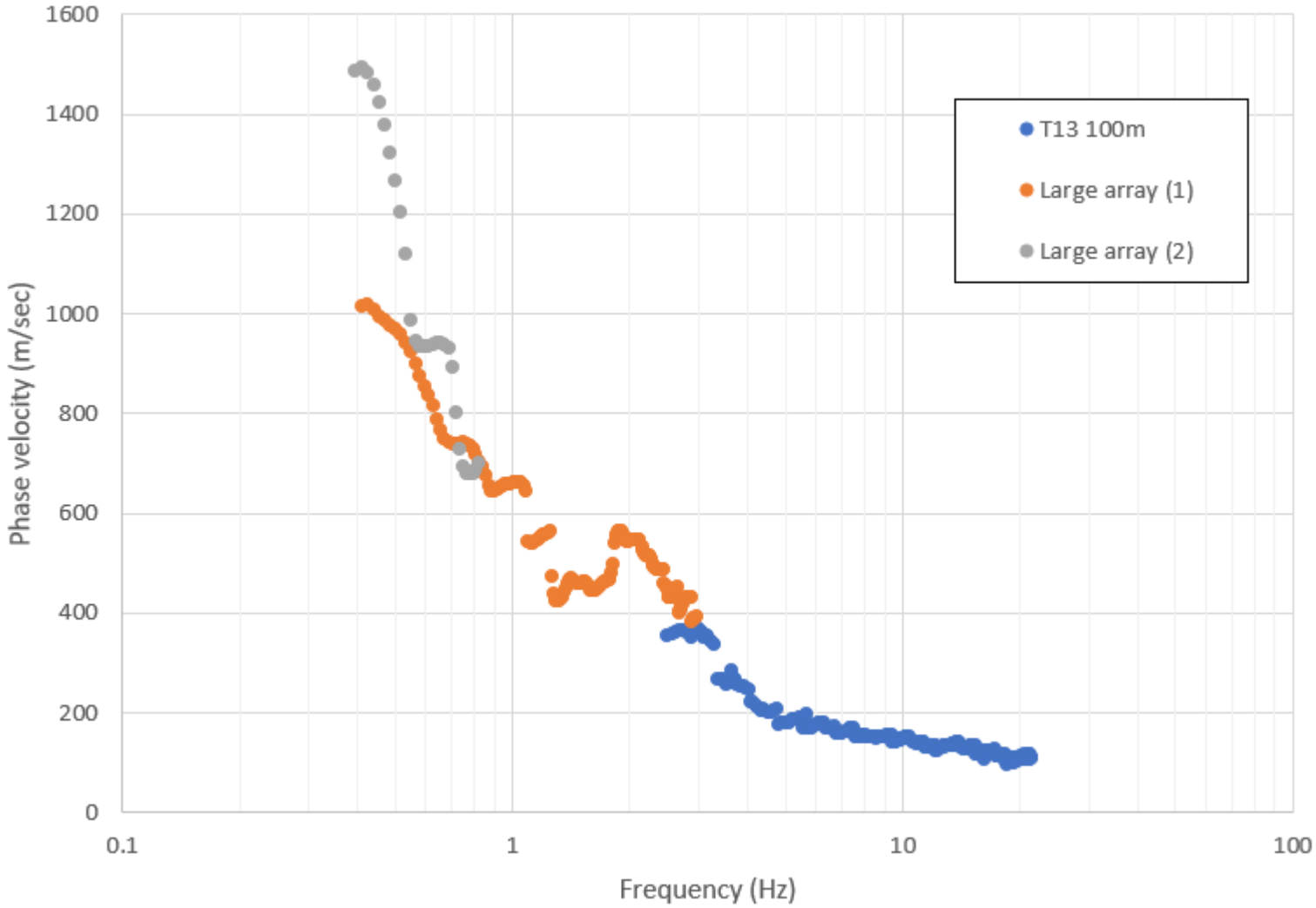
Phase velocity image in frequency domain (Large array (1))



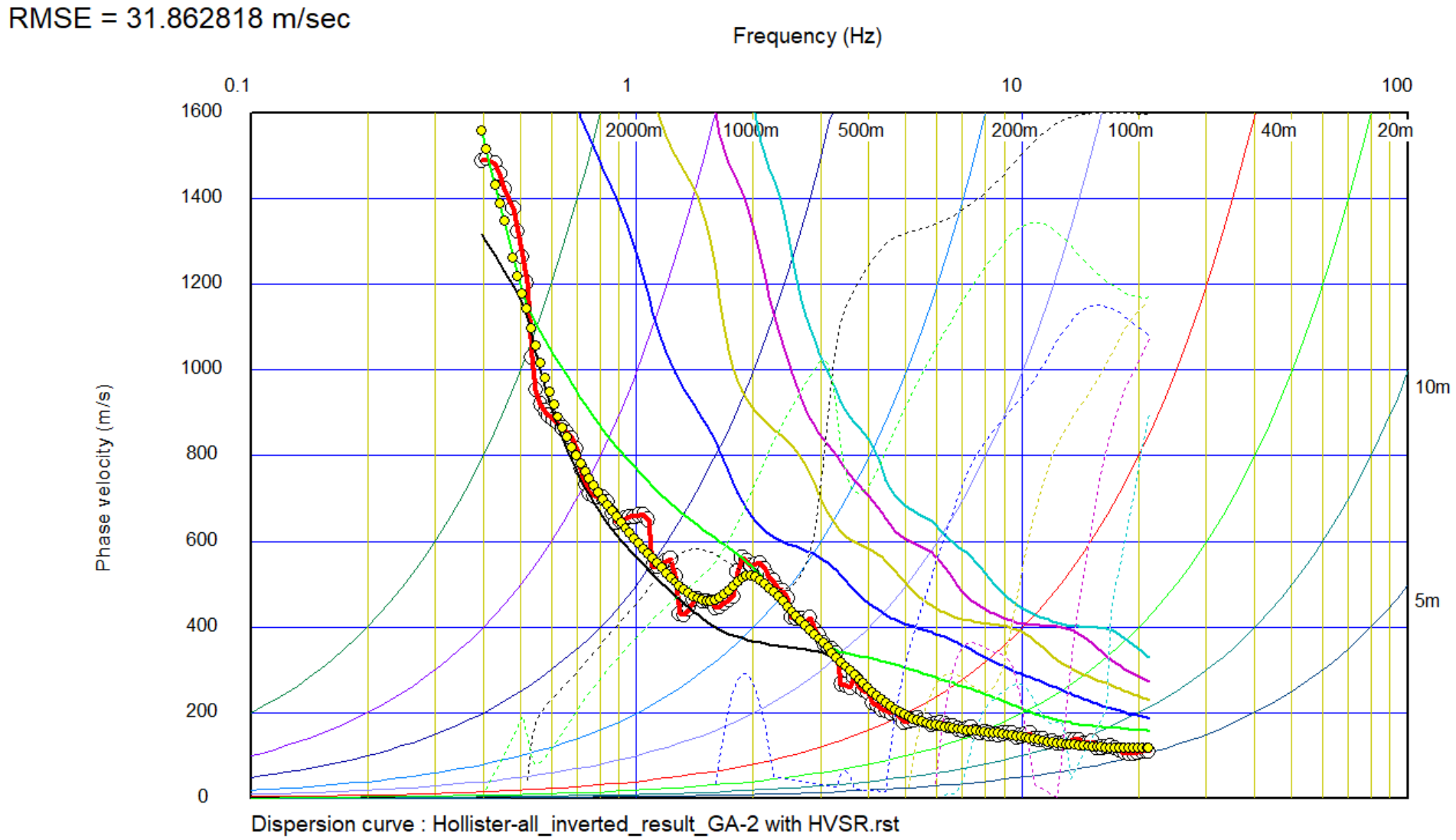
Phase velocity image in frequency domain (Large array (2))



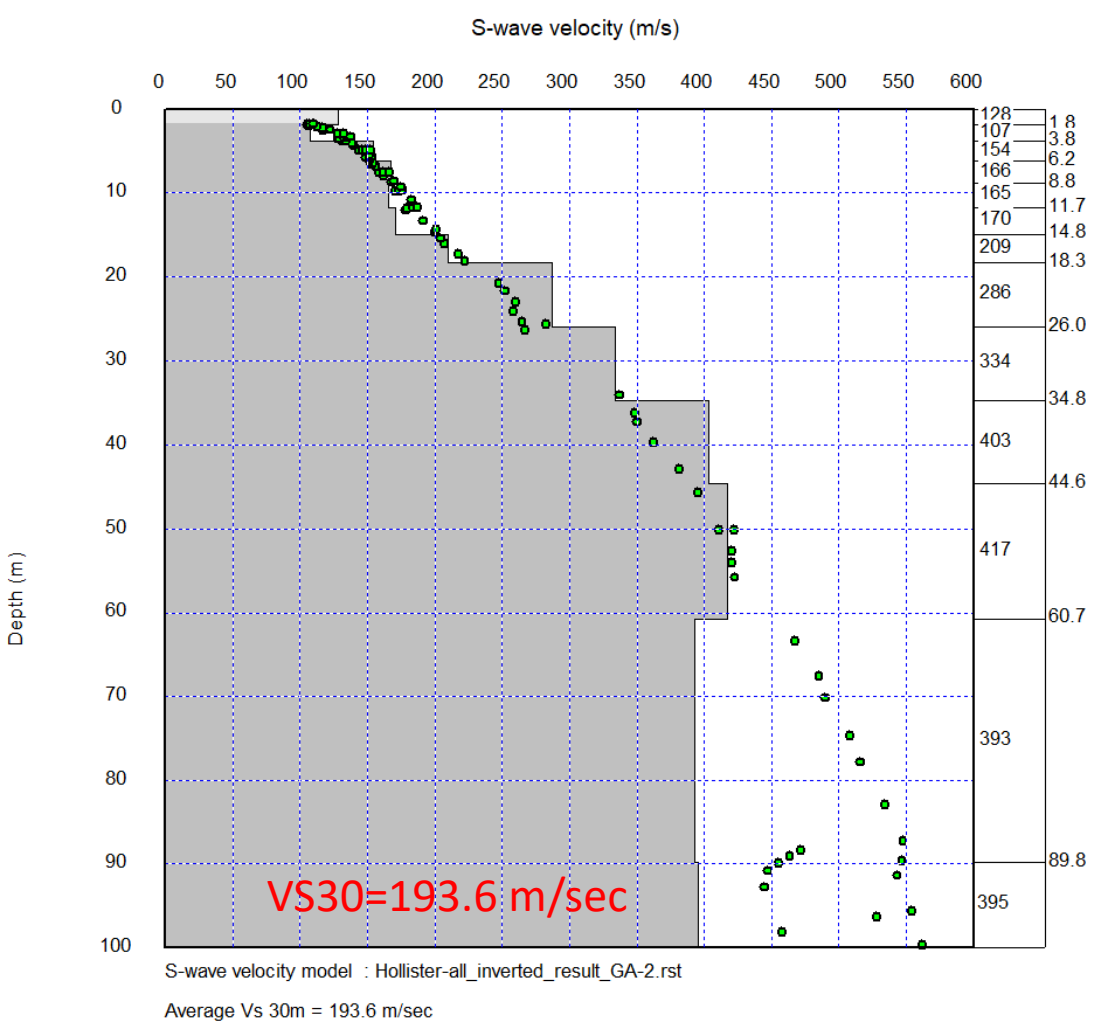
Comparison of observed dispersion curves

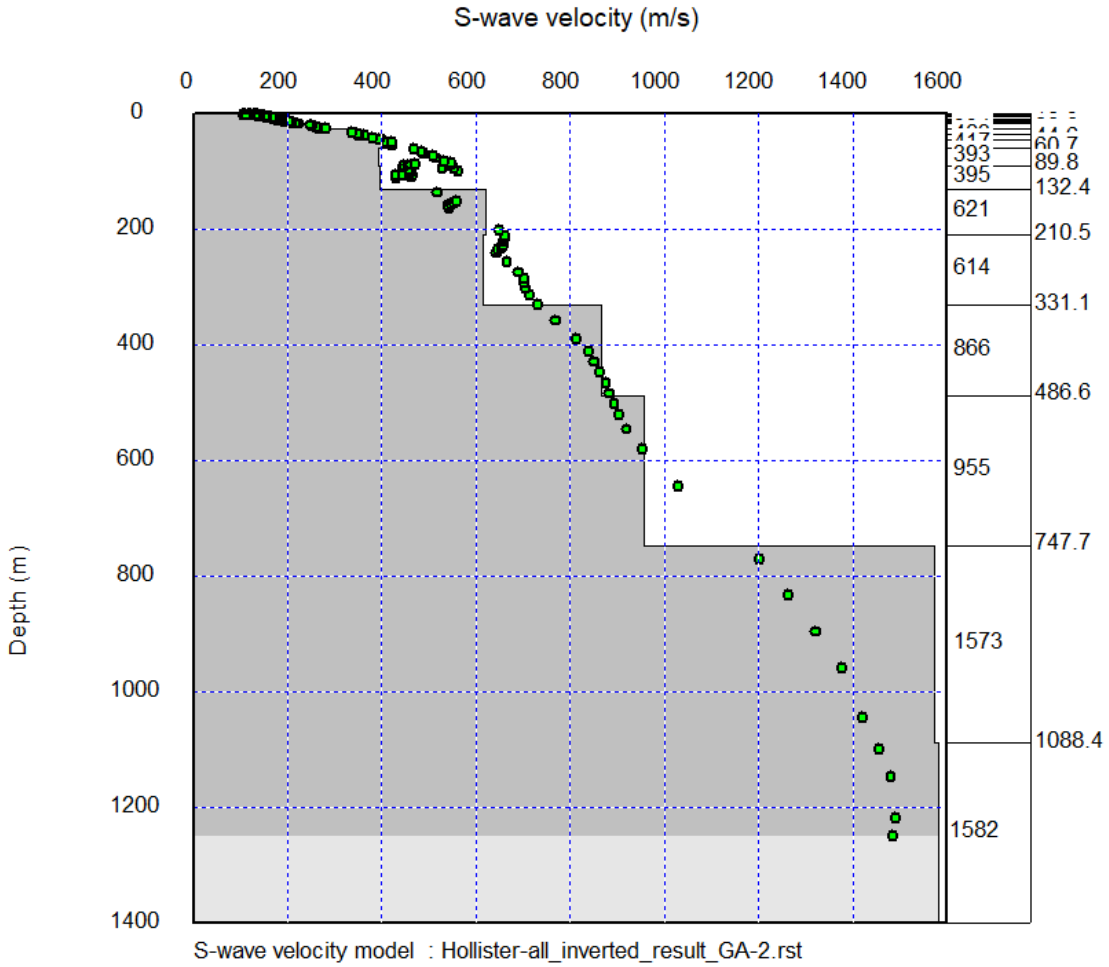


Comparison of observed and theoretical dispersion curves



Velocity model





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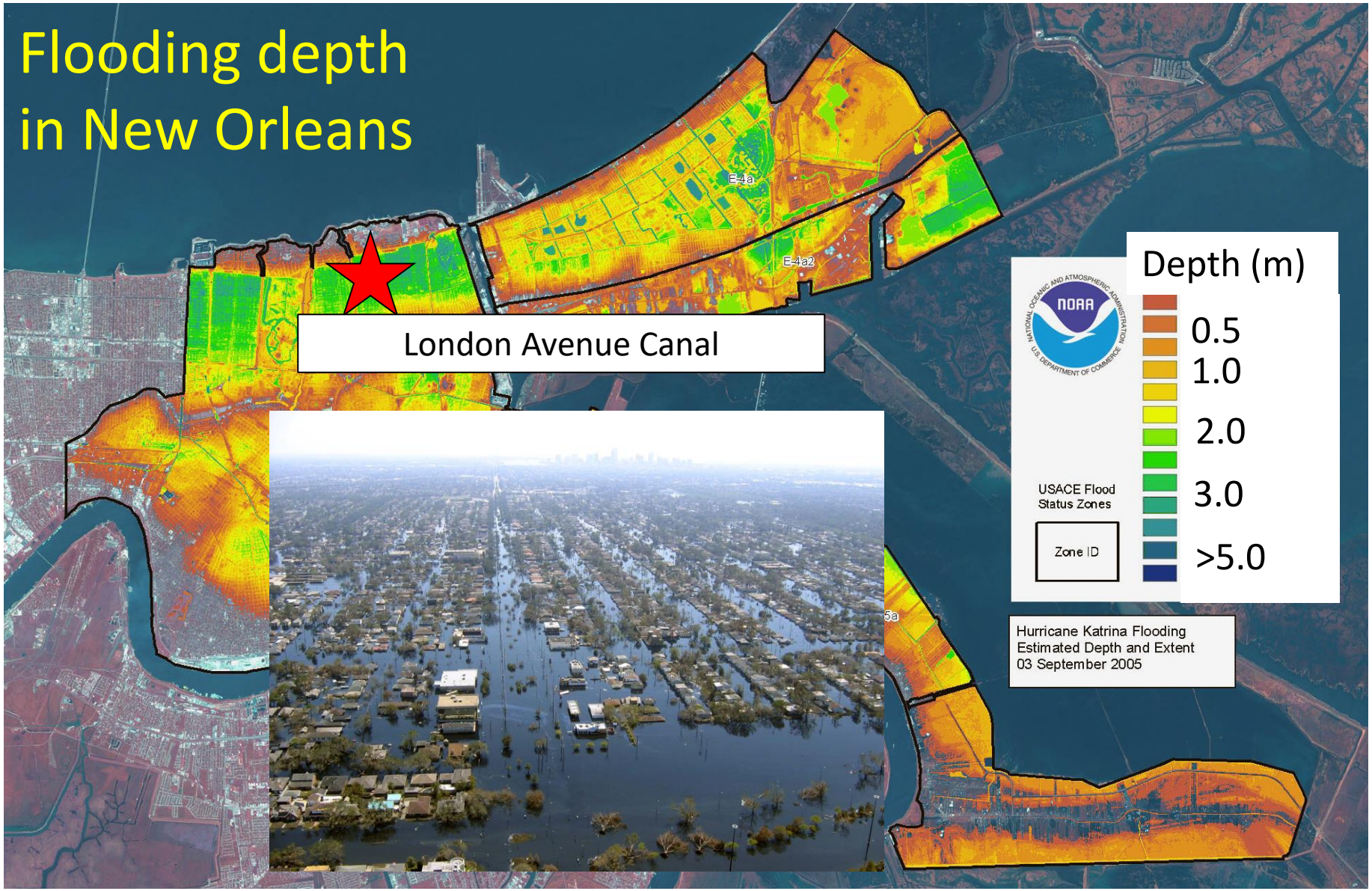
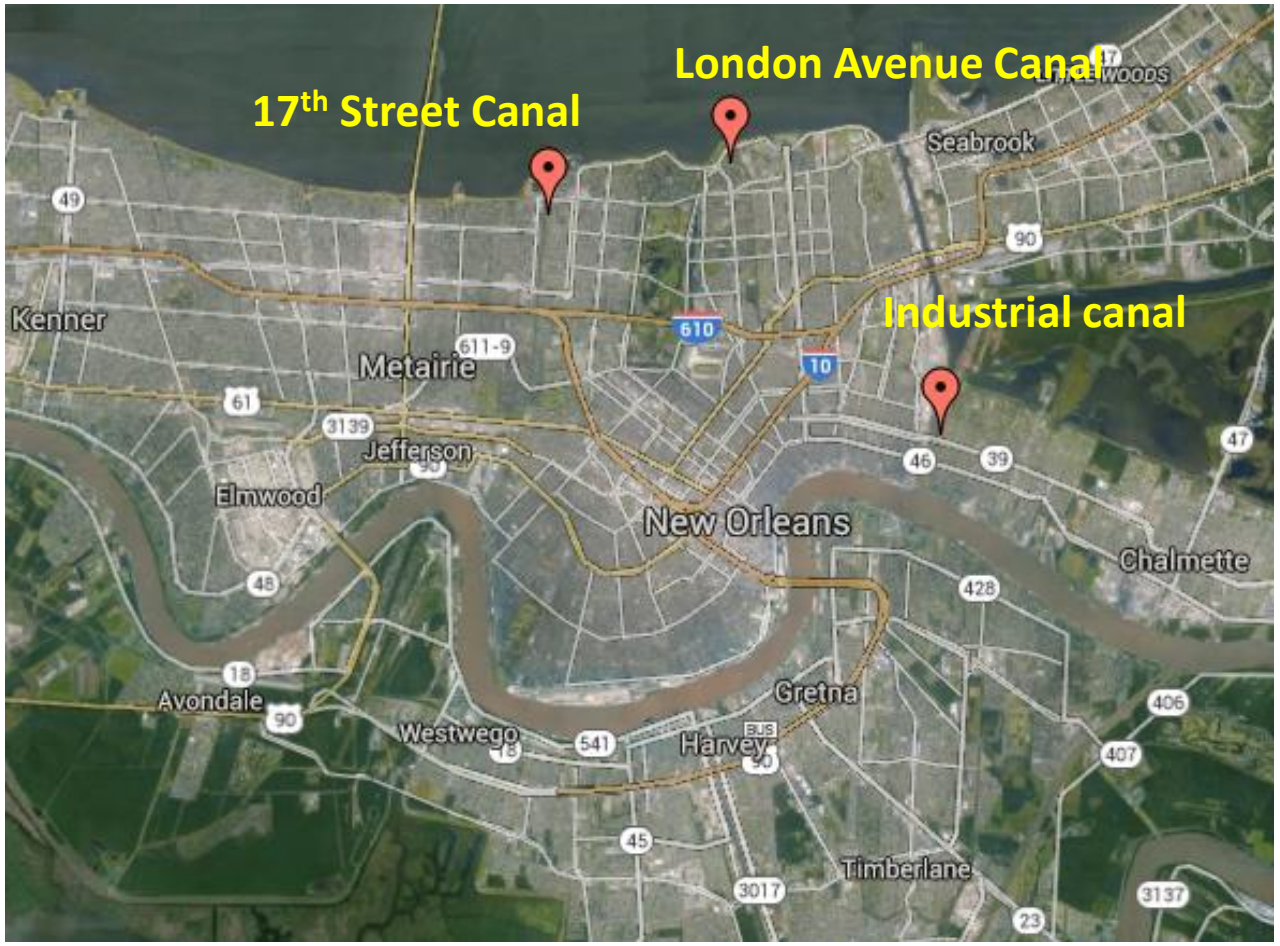
Hurricane Katrina (2005)

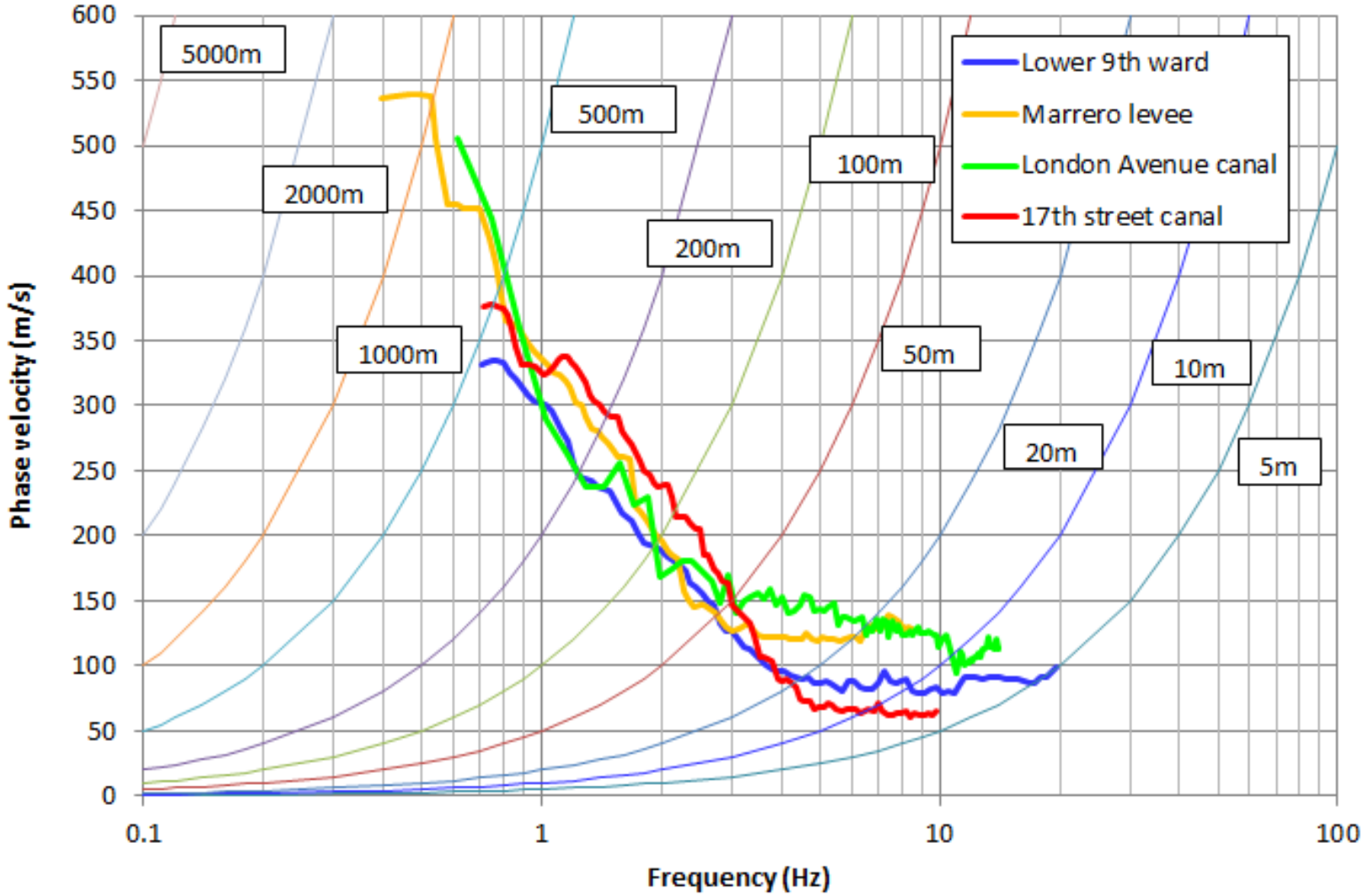


Sites of Investigation

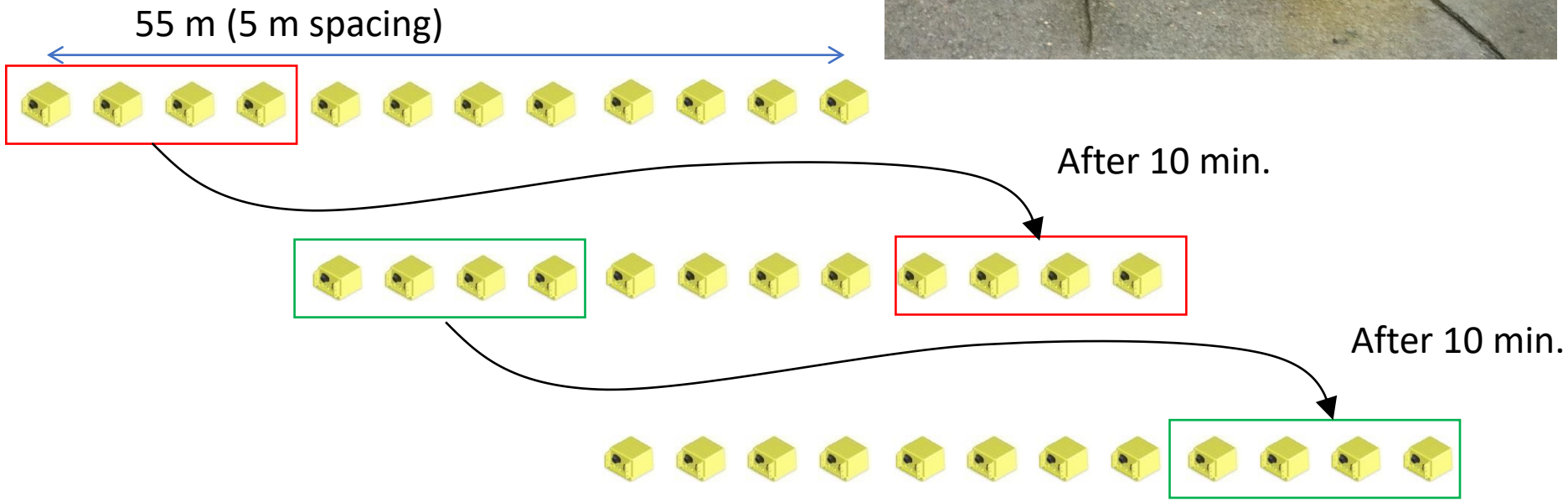


Deep investigation (2016)

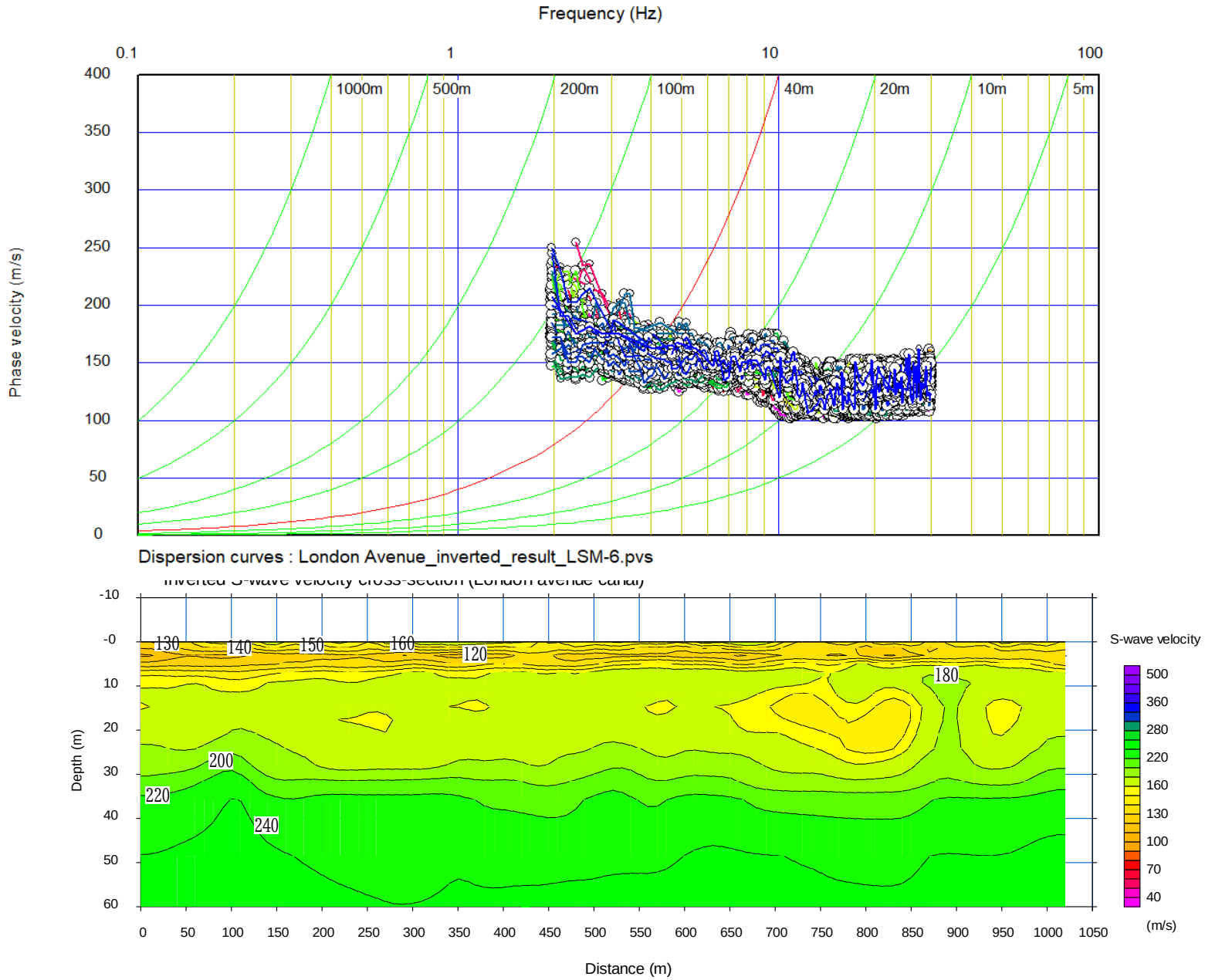
Deep investigation (2016)
Comparison of dispersion curves



2D Ambient Noise Tomography with Linear Array



London avenue canal



London Avenue Canal

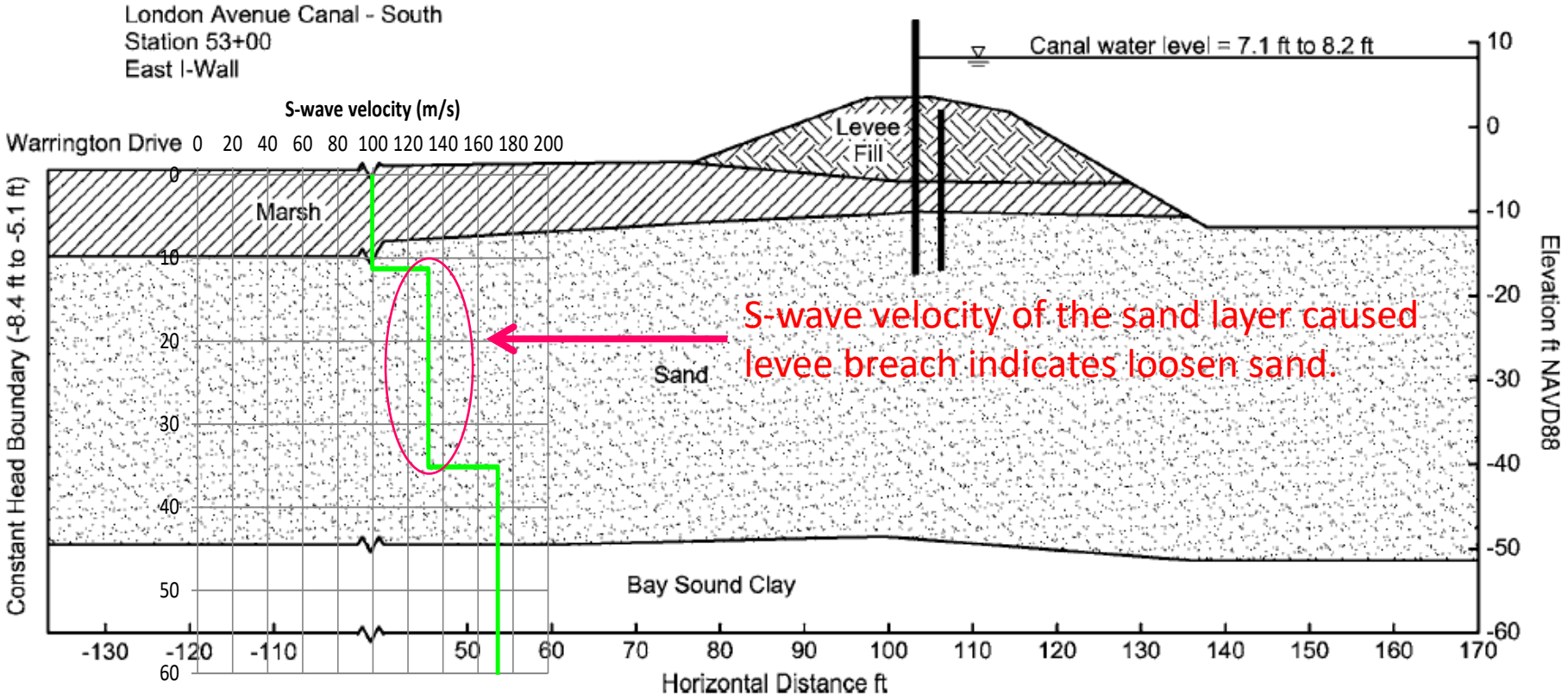
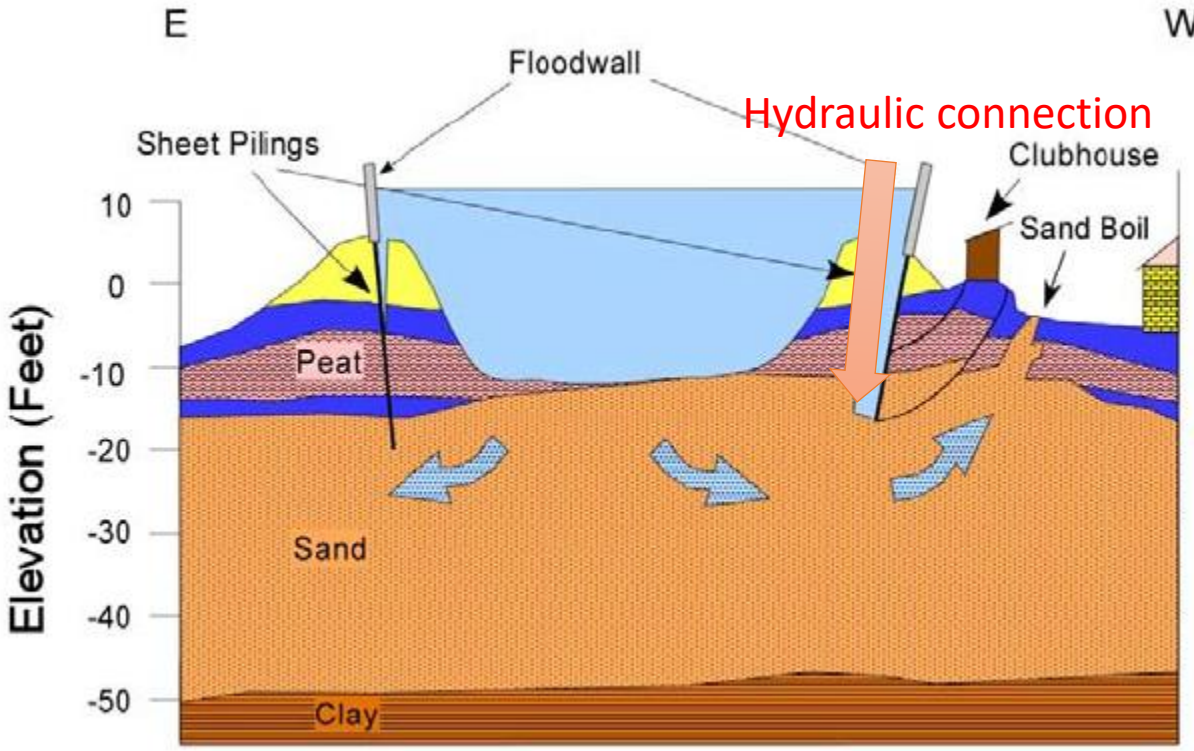


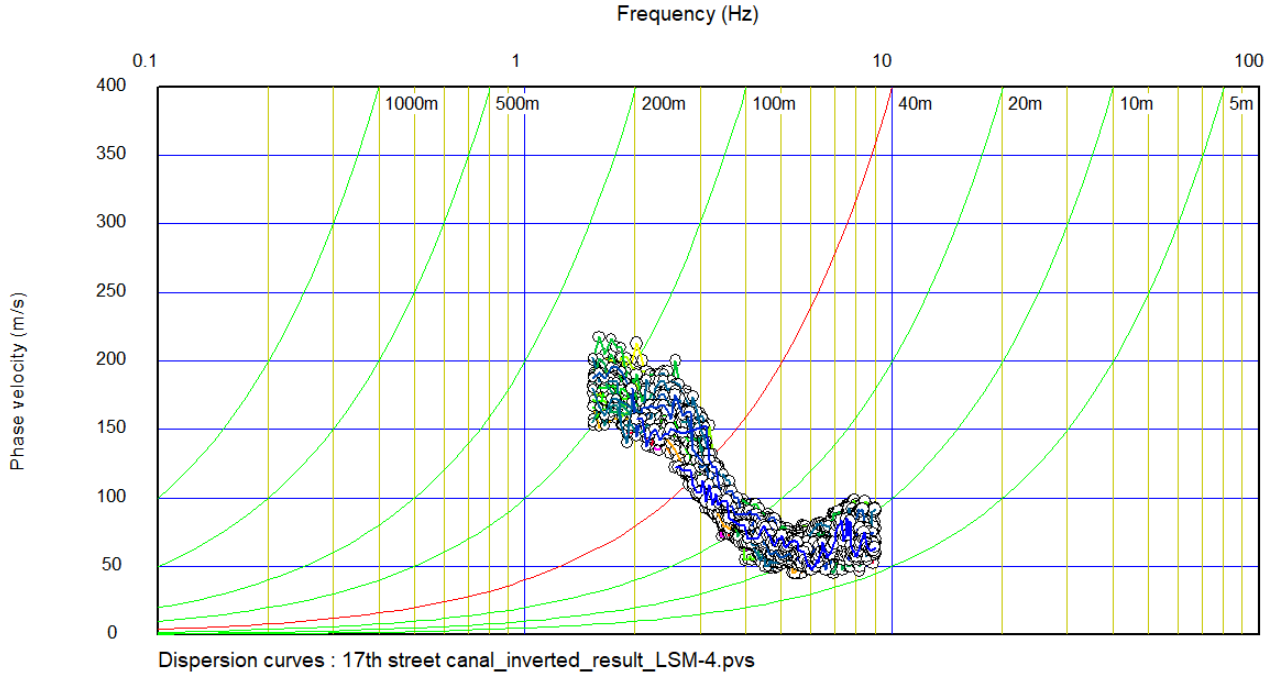
Fig. 10. Cross section of south breach area of London Avenue Canal

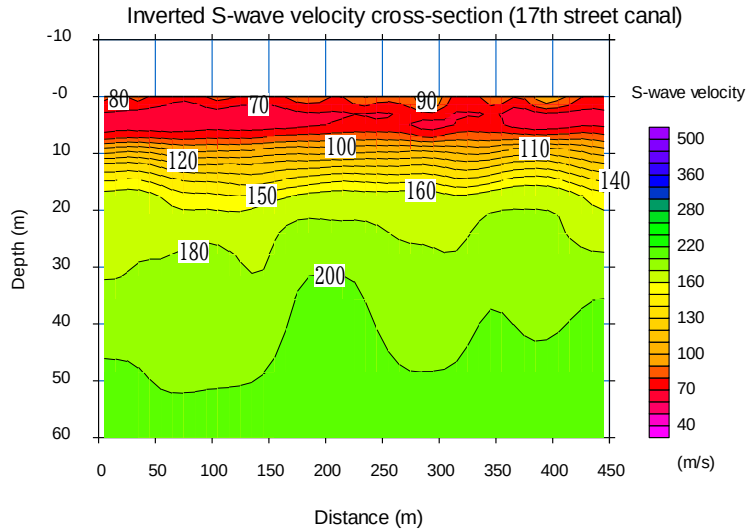
Sand boil at London Avenue Canal



17th Street Canal

2D MAM : 17th street canal





17th Street Canal

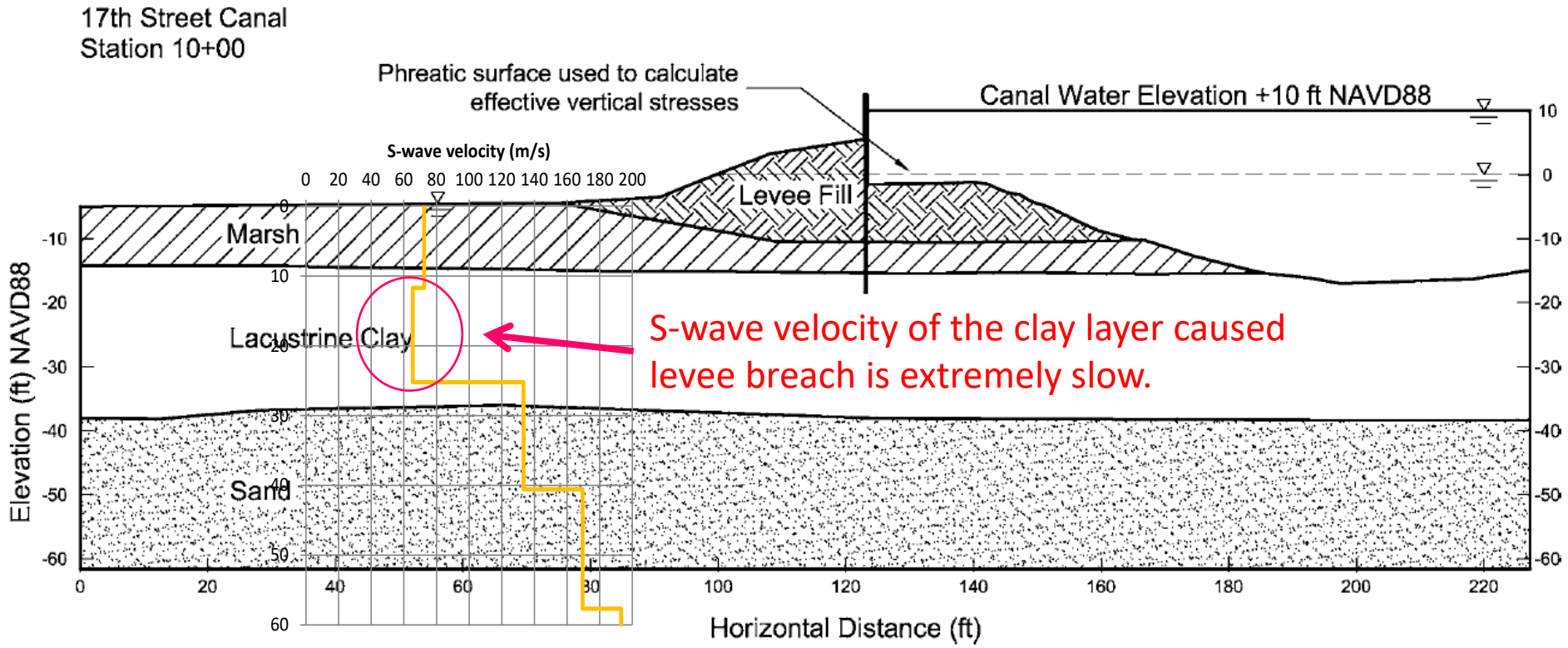
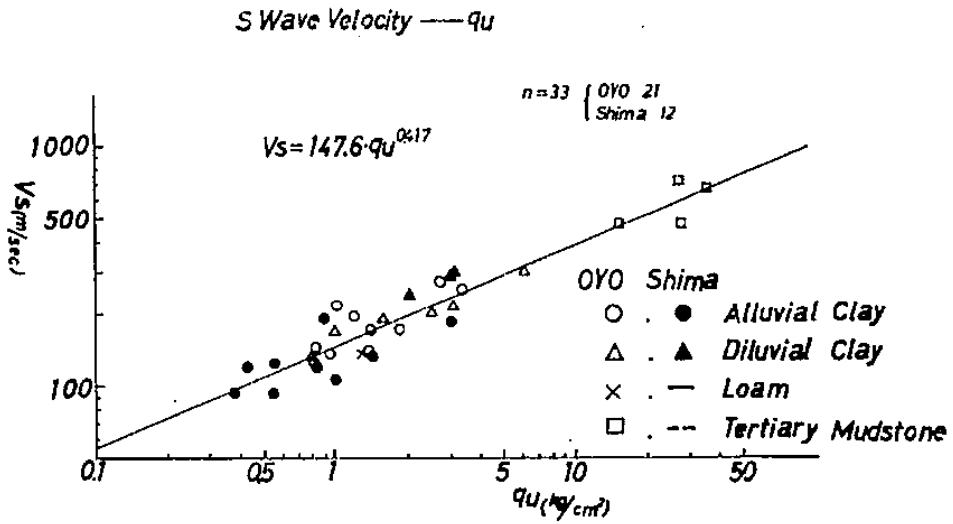


Fig. 4. Cross section of 17th Street Canal I-wall at Station 10+00

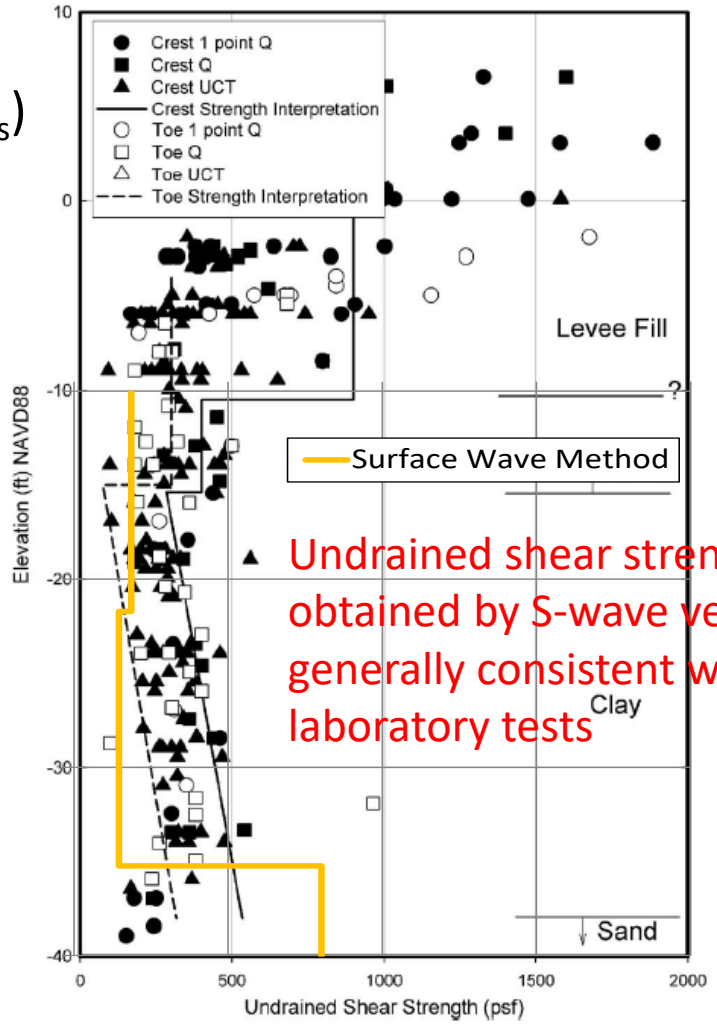
17th Street Canal

Comparison of undrained shear strength (S_u) empirically calculated from S-wave velocity (V_s)



S-wave velocity (m/s) and unconfined compression strength (q_u(kg/cm^2))

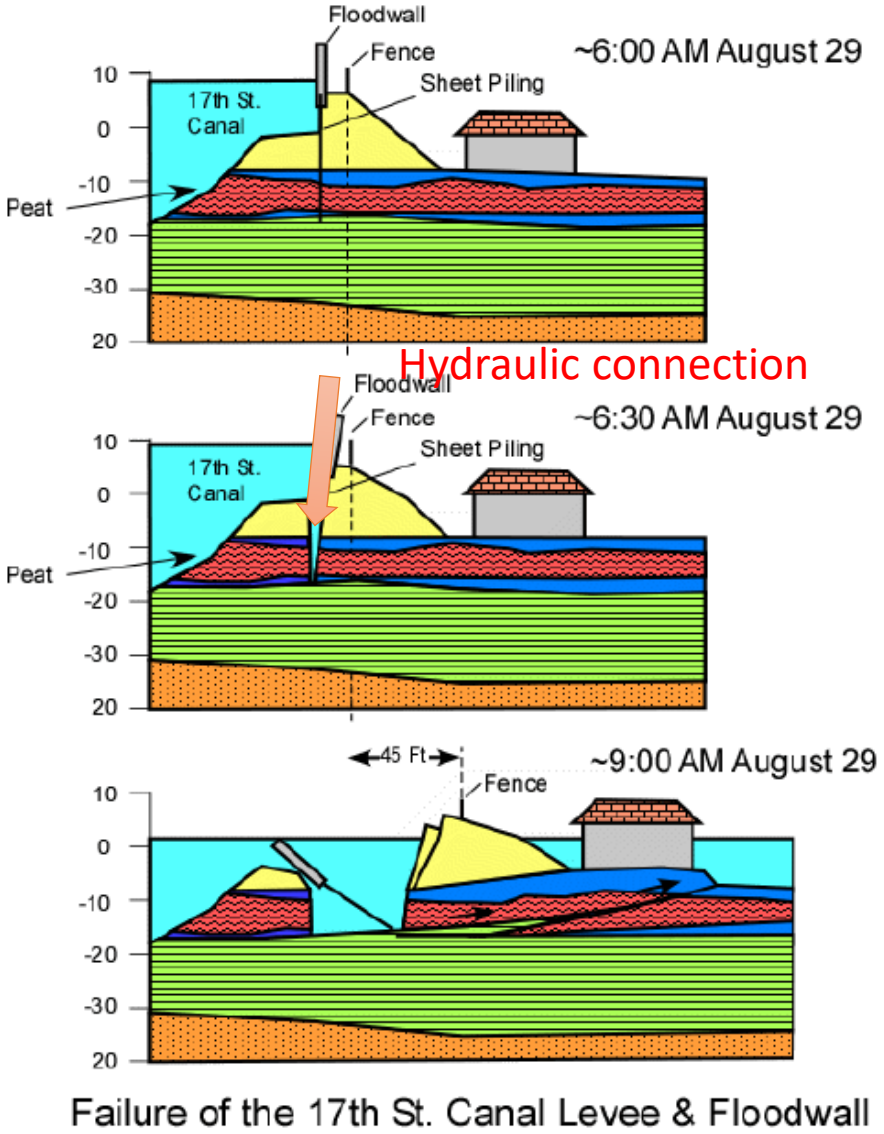
$$V_S = 147.6 q_u^{0.417} \qquad S_u = \frac{q_u}{2}$$



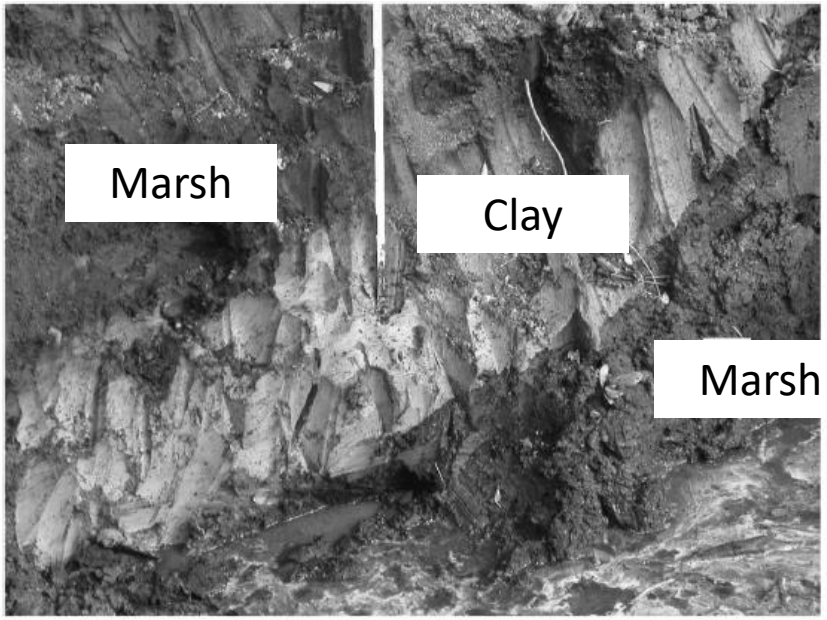
Undrained shear strength obtained by S-wave velocity is generally consistent with the laboratory tests

Fig. 5. Laboratory undrained shear strength test results from crest and toe borings and strength interpretation for 17th Street Canal I-wall at Station 10+00

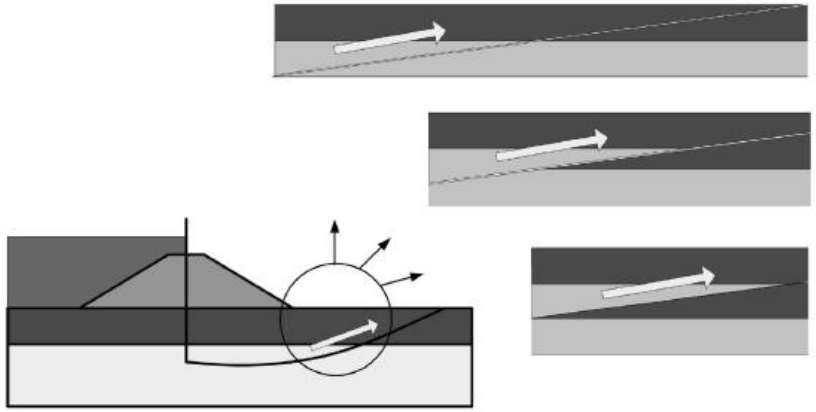
Shear failure at 17th Street Canal



Failure of the 17th St. Canal Levee & Floodwall



(a) Photograph of exploration trench showing clay layer above marsh layer.



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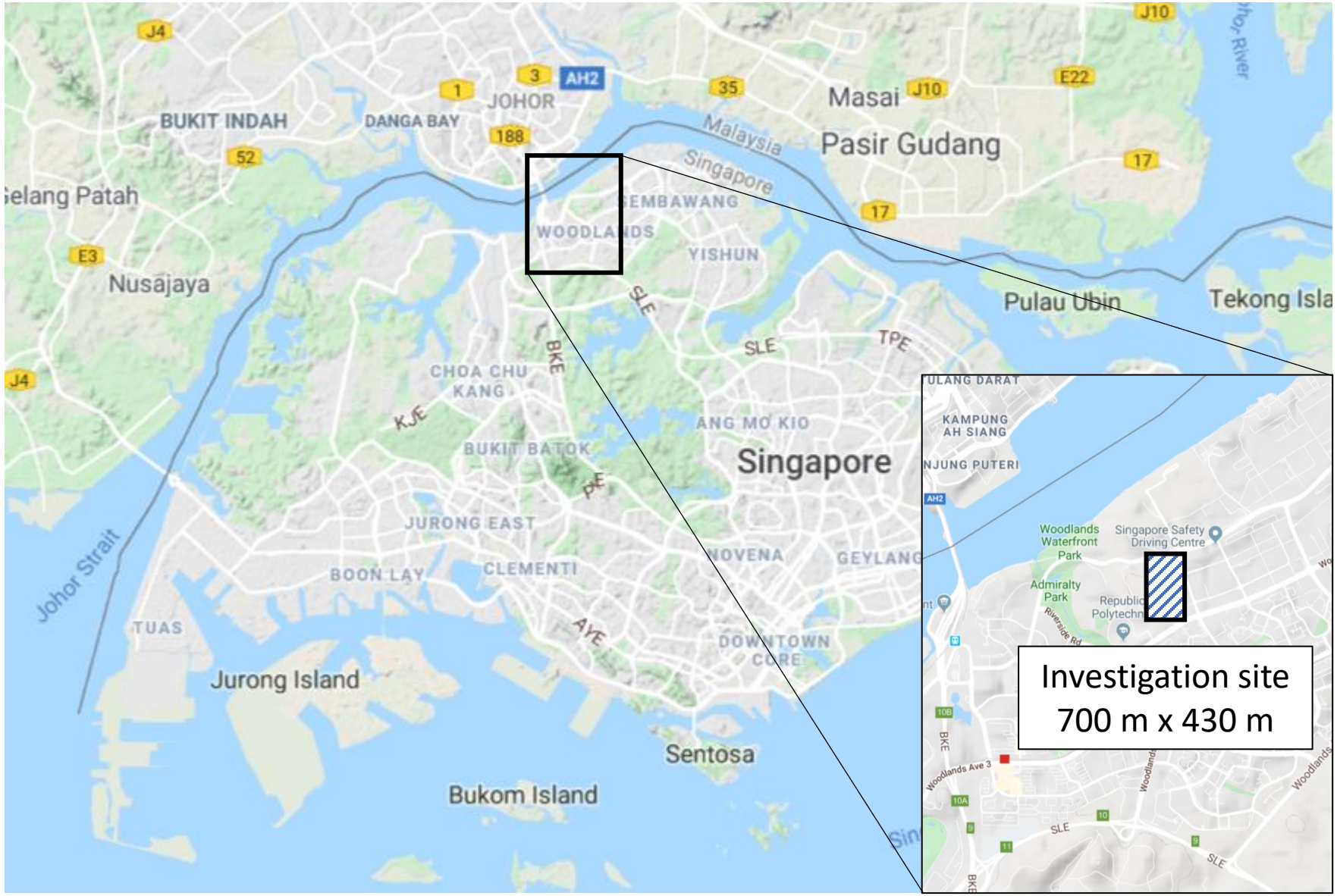
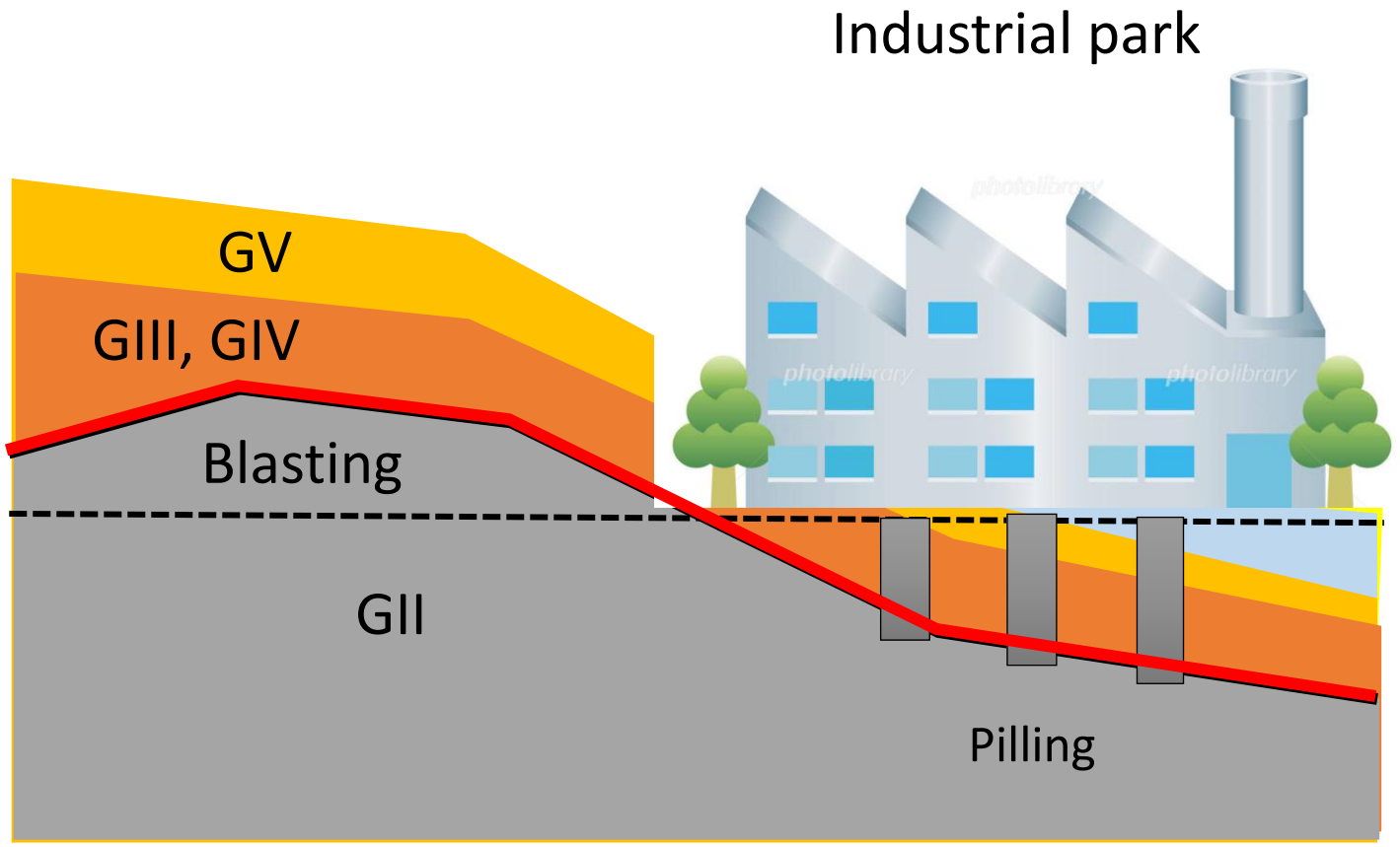
3D Bedrock Investigation at Singapore



Investigation purposes

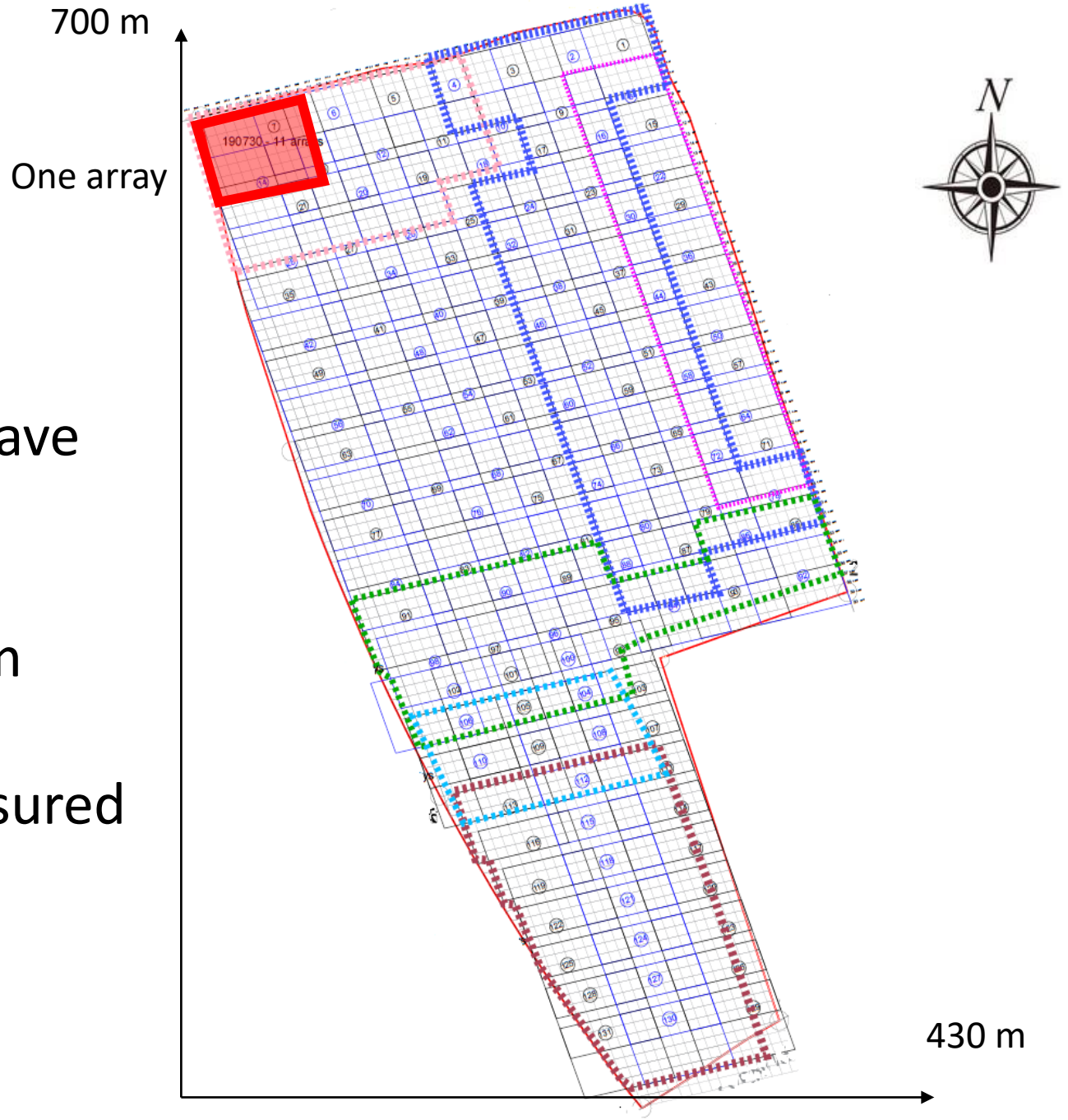
Granite Hills



Delineate the depth to GII to estimate volume to blast and length of piles

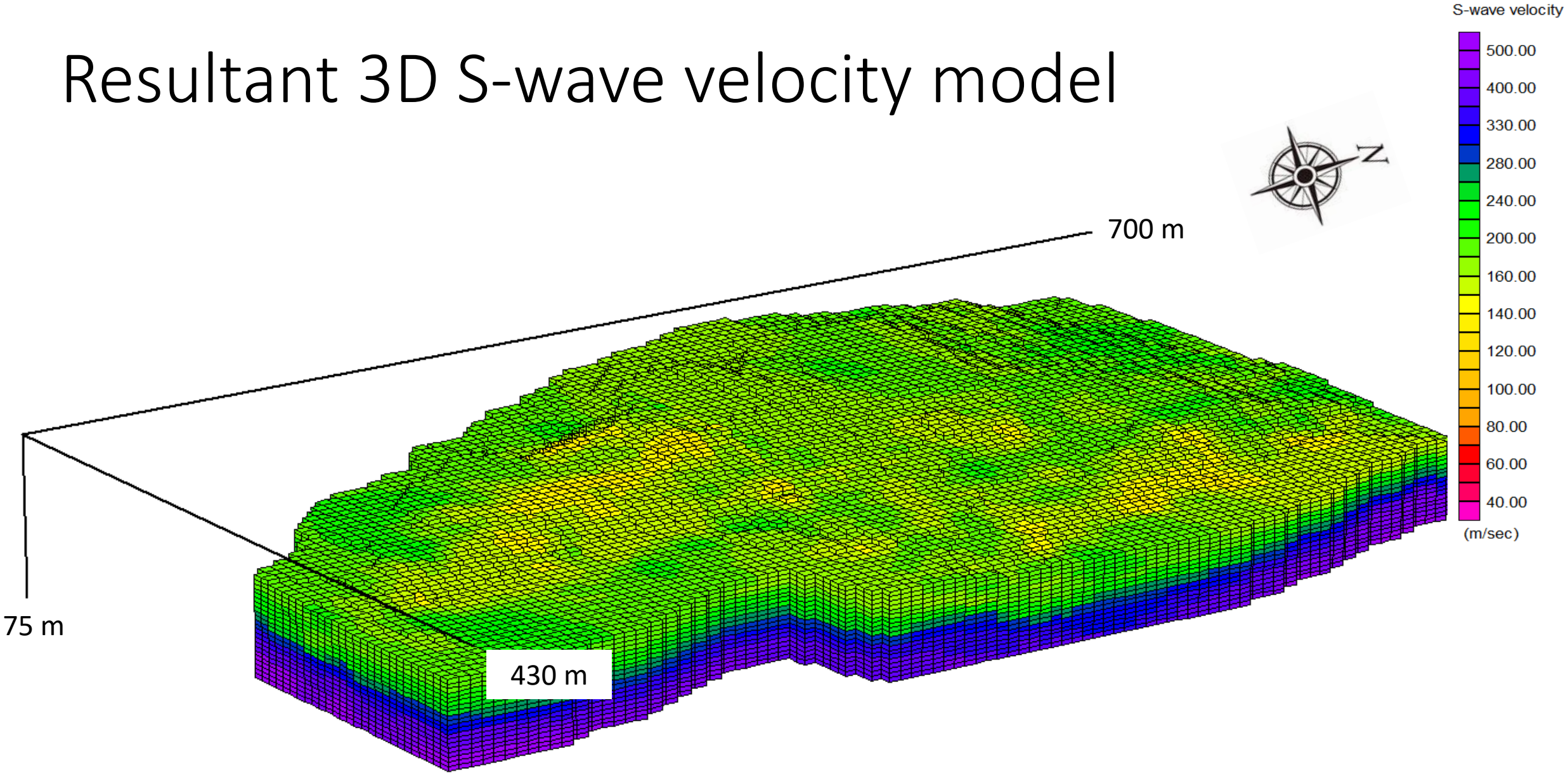
Acquisition geometry

- In order to delineate depth to a bedrock (GII), ambient noise tomography (3D passive surface wave method) was carried out.
- Investigation area is 700 X 430 m.
- 70 sensors were deployed with 7 m spacing.
- 133 arrays with overlap were measured and total sensor location is approximately 2300.

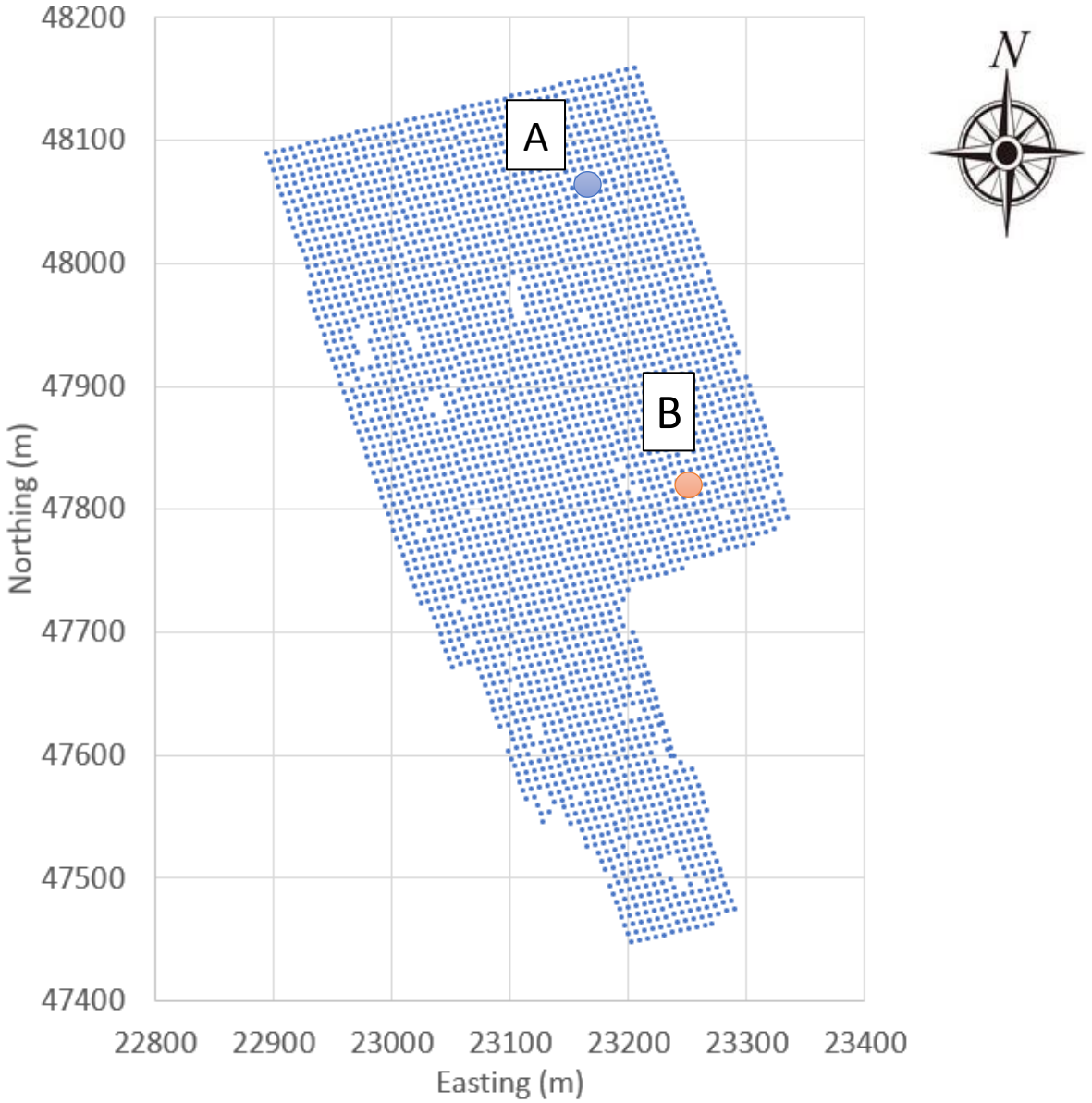


Fieldwork

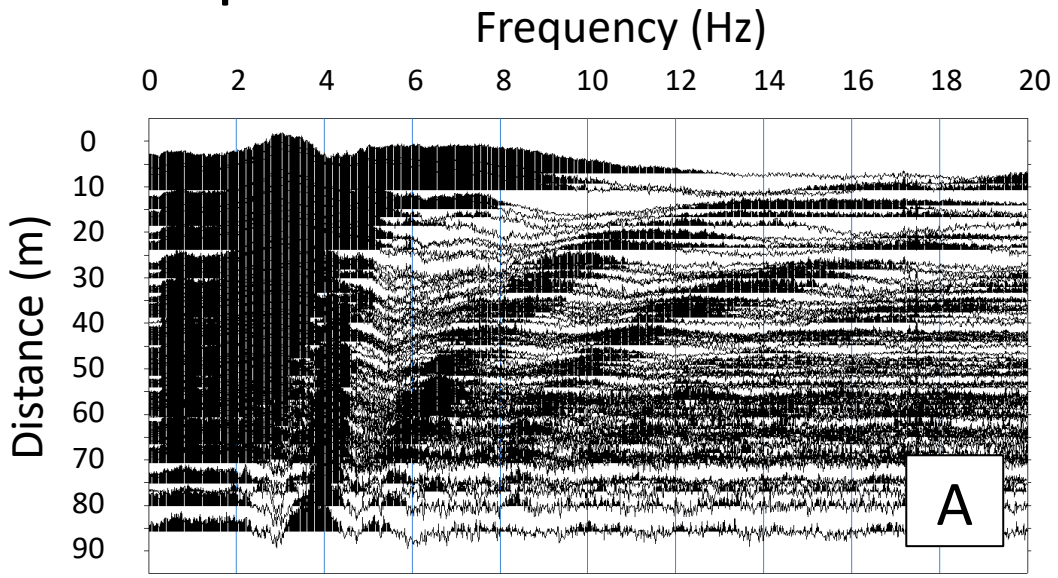
Resultant 3D S-wave velocity model

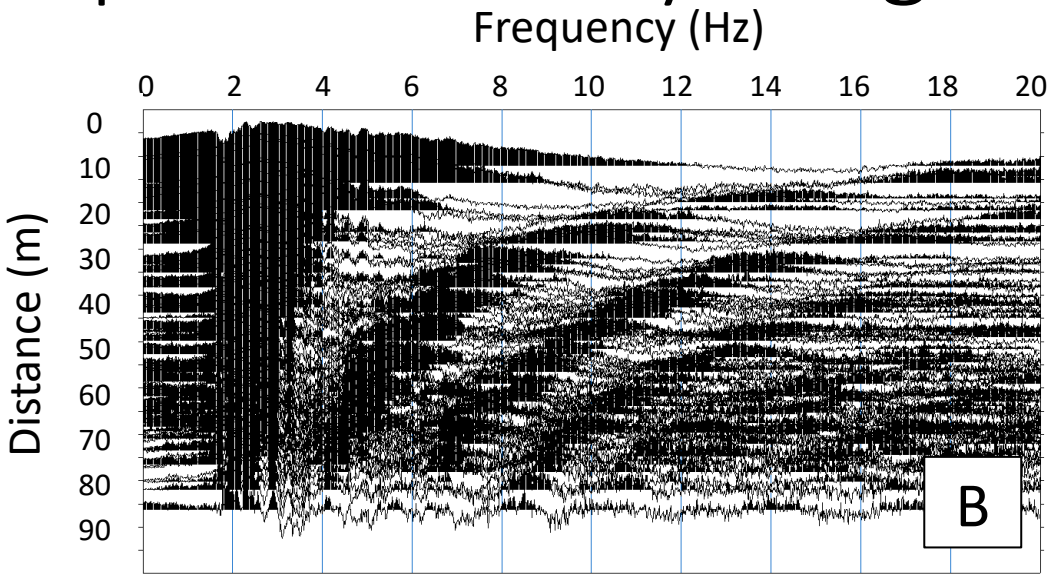


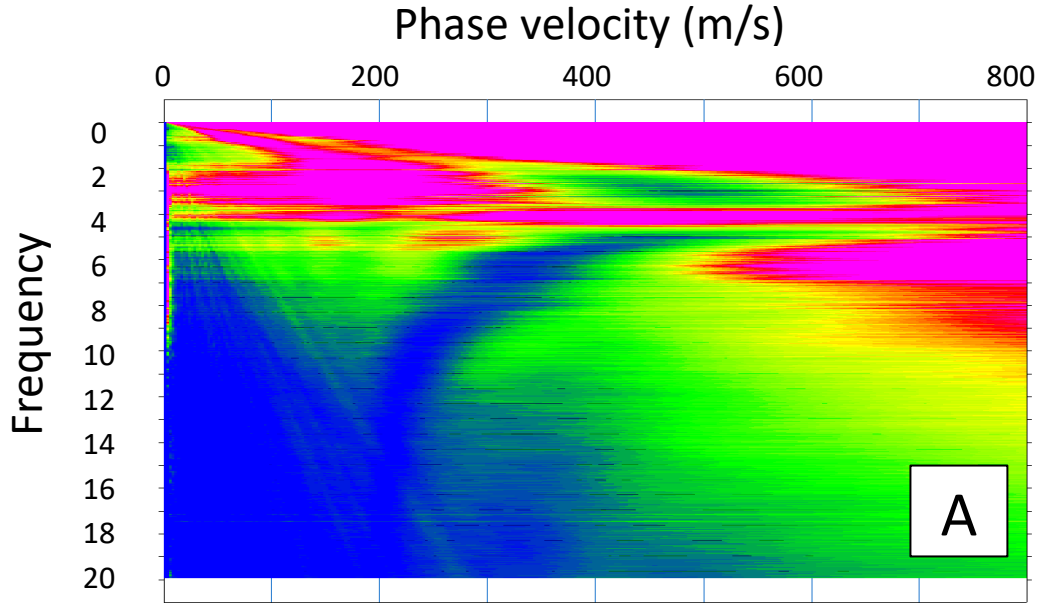
Examples of CMP-SPAC and phase velocity image

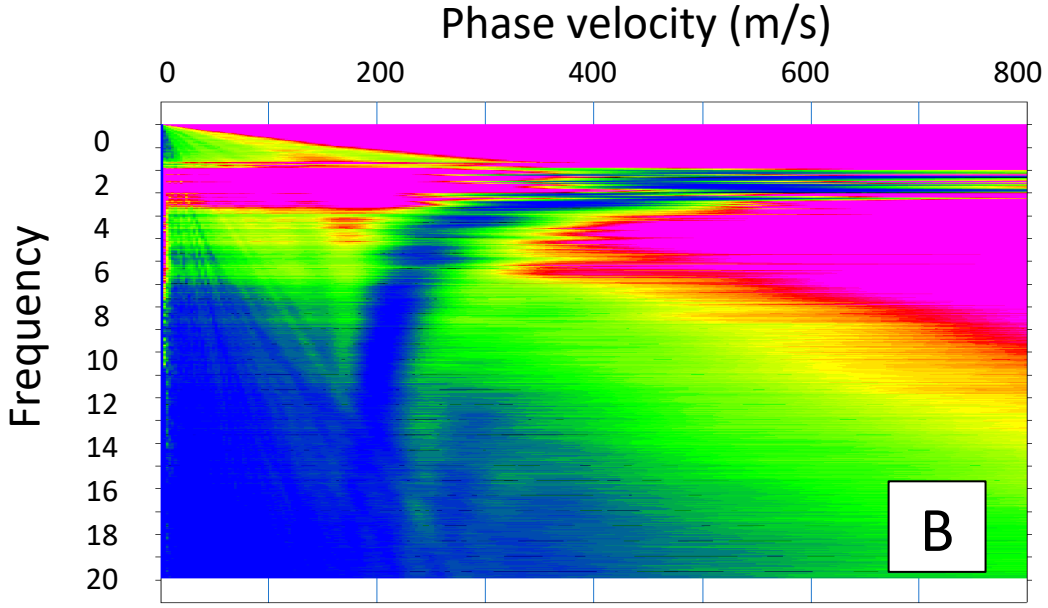


Examples of CMP-SPAC and phase velocity image

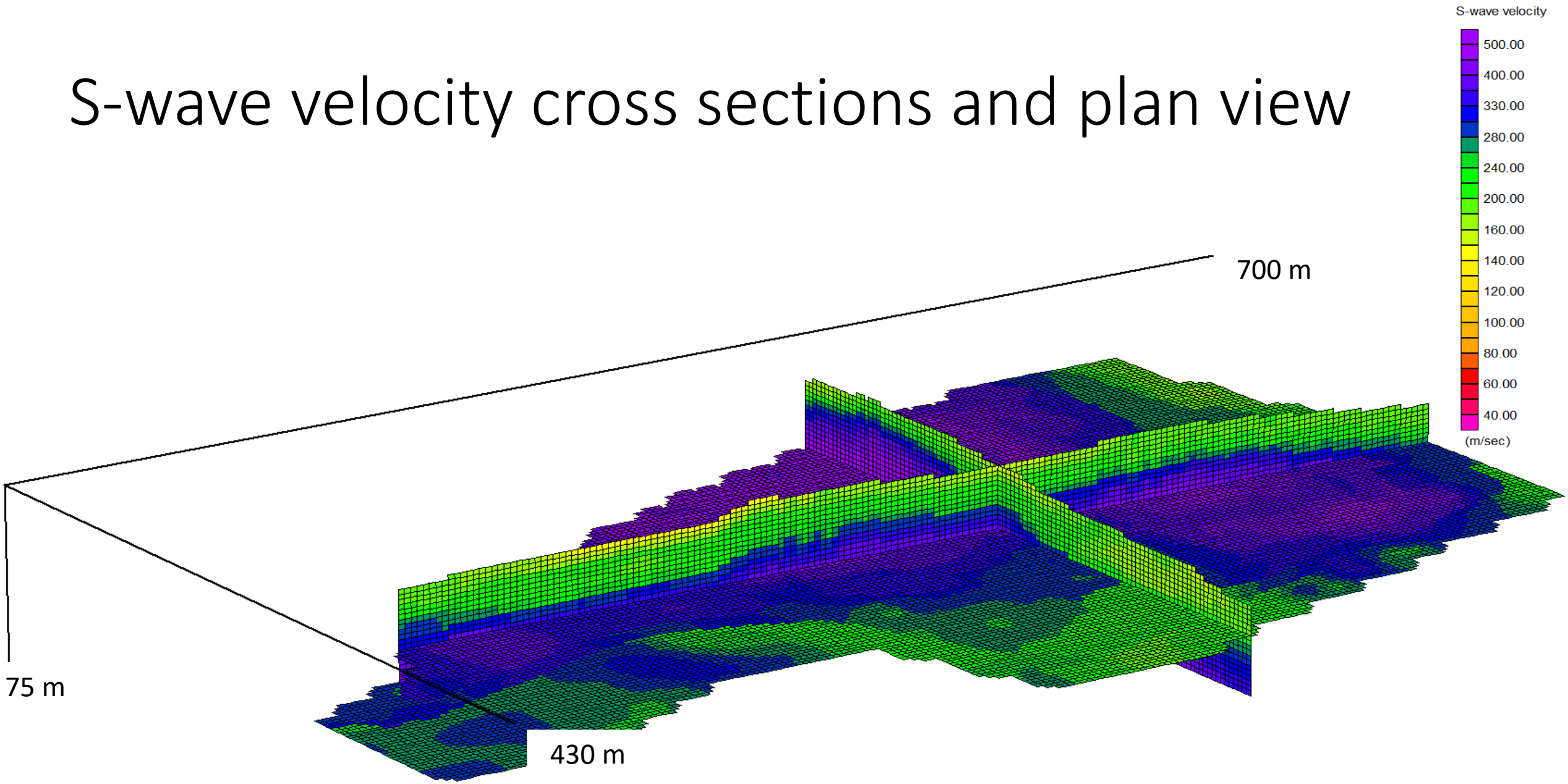




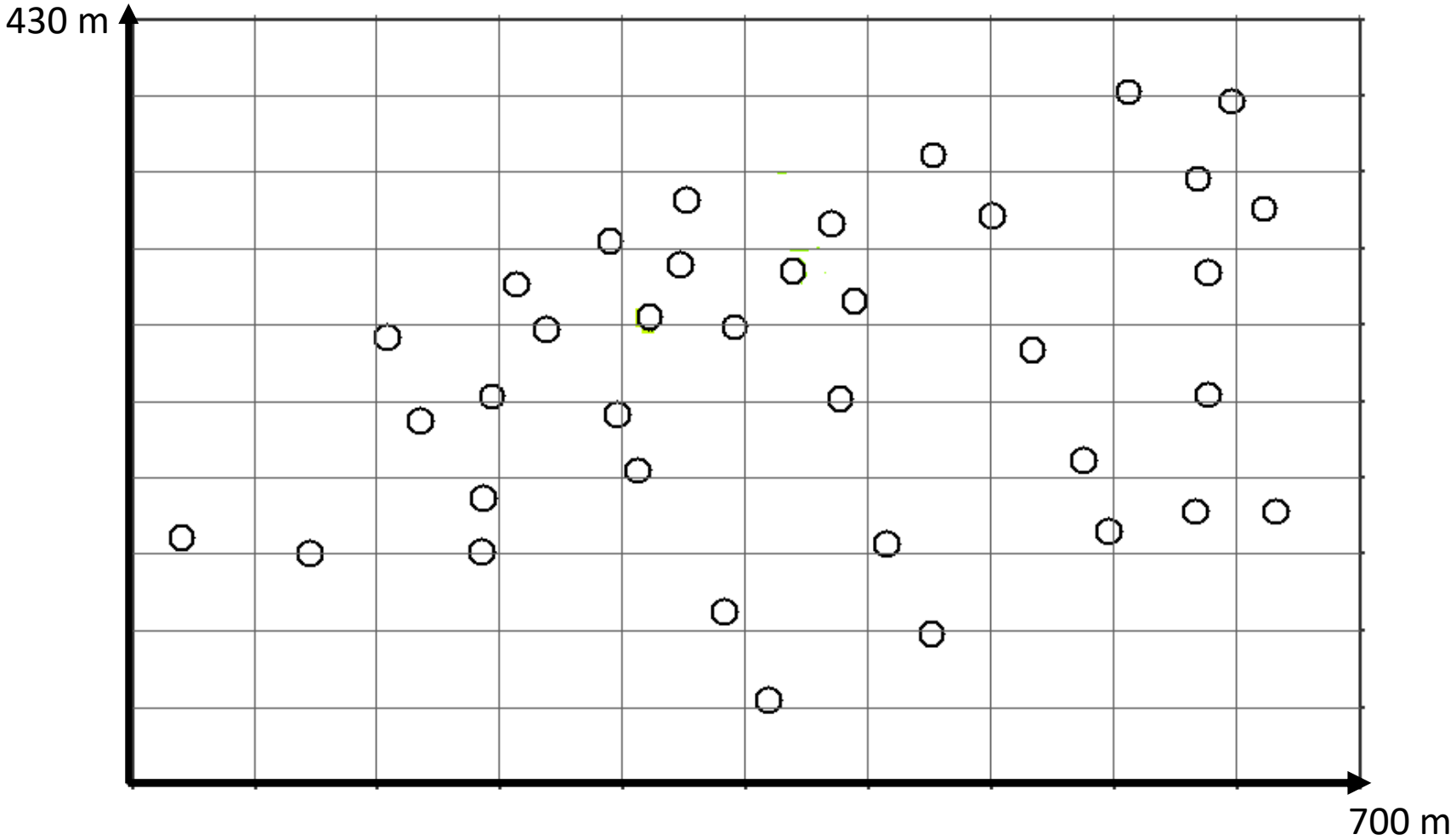




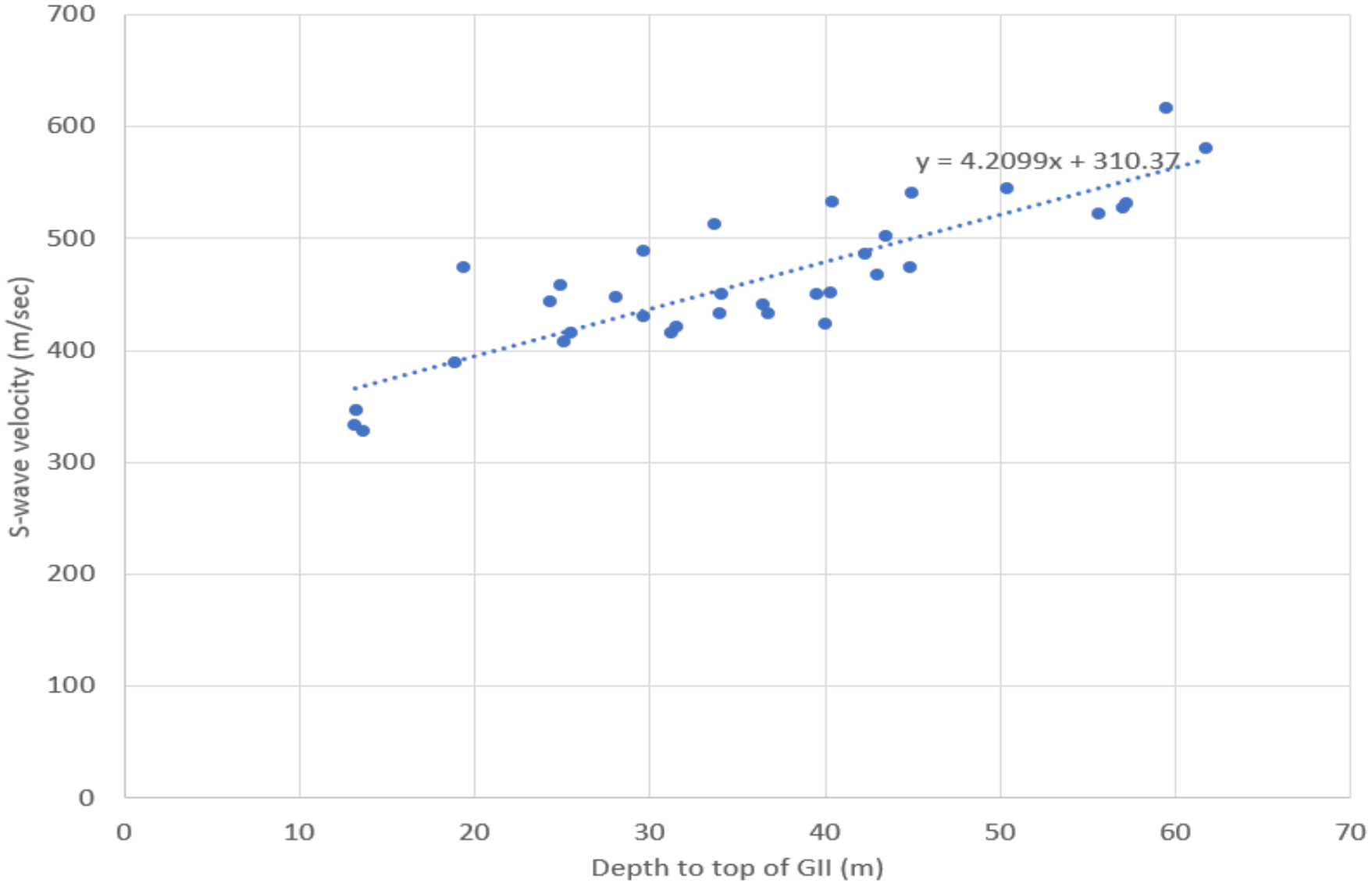
S-wave velocity cross sections and plan view



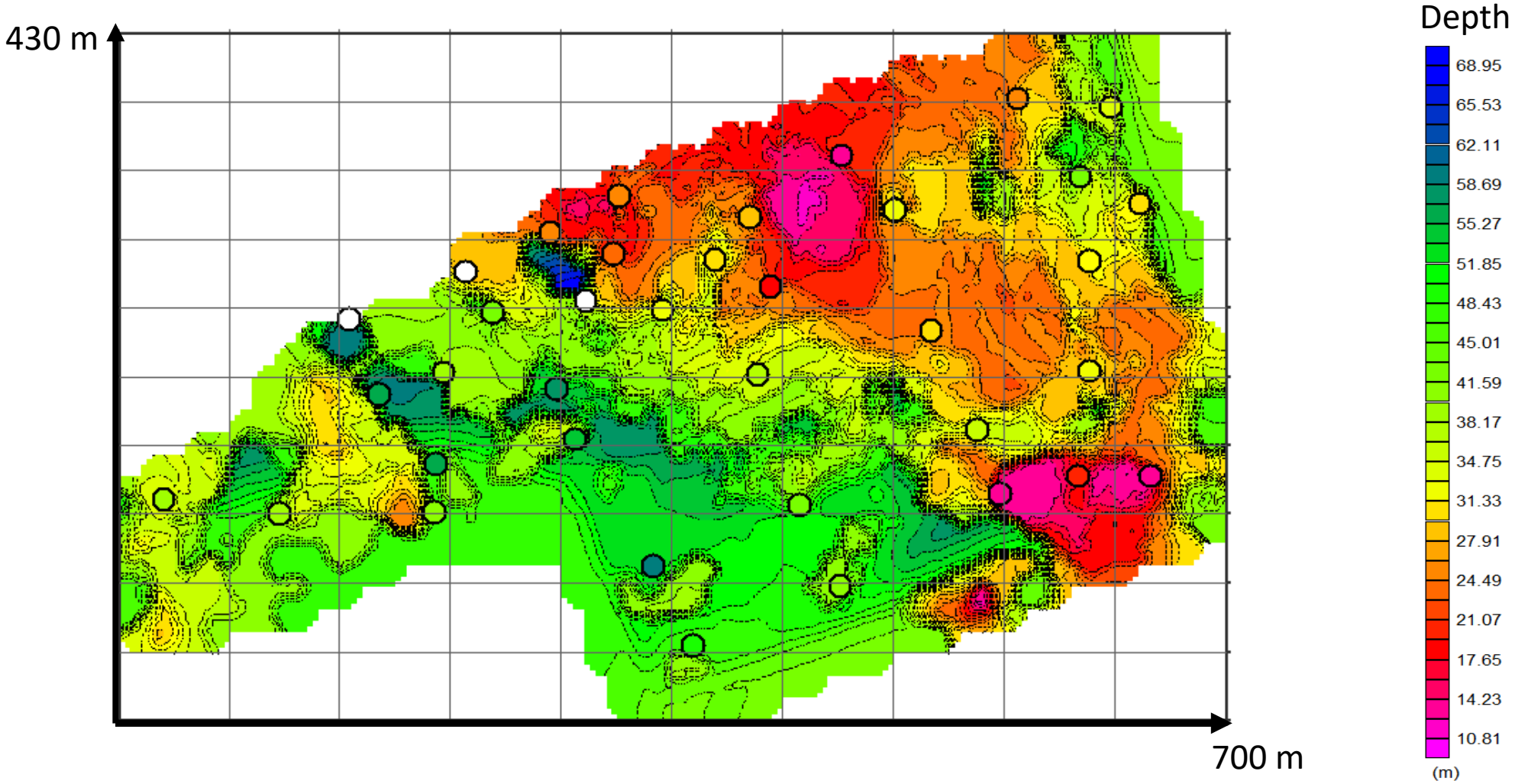
37 borehole at the site



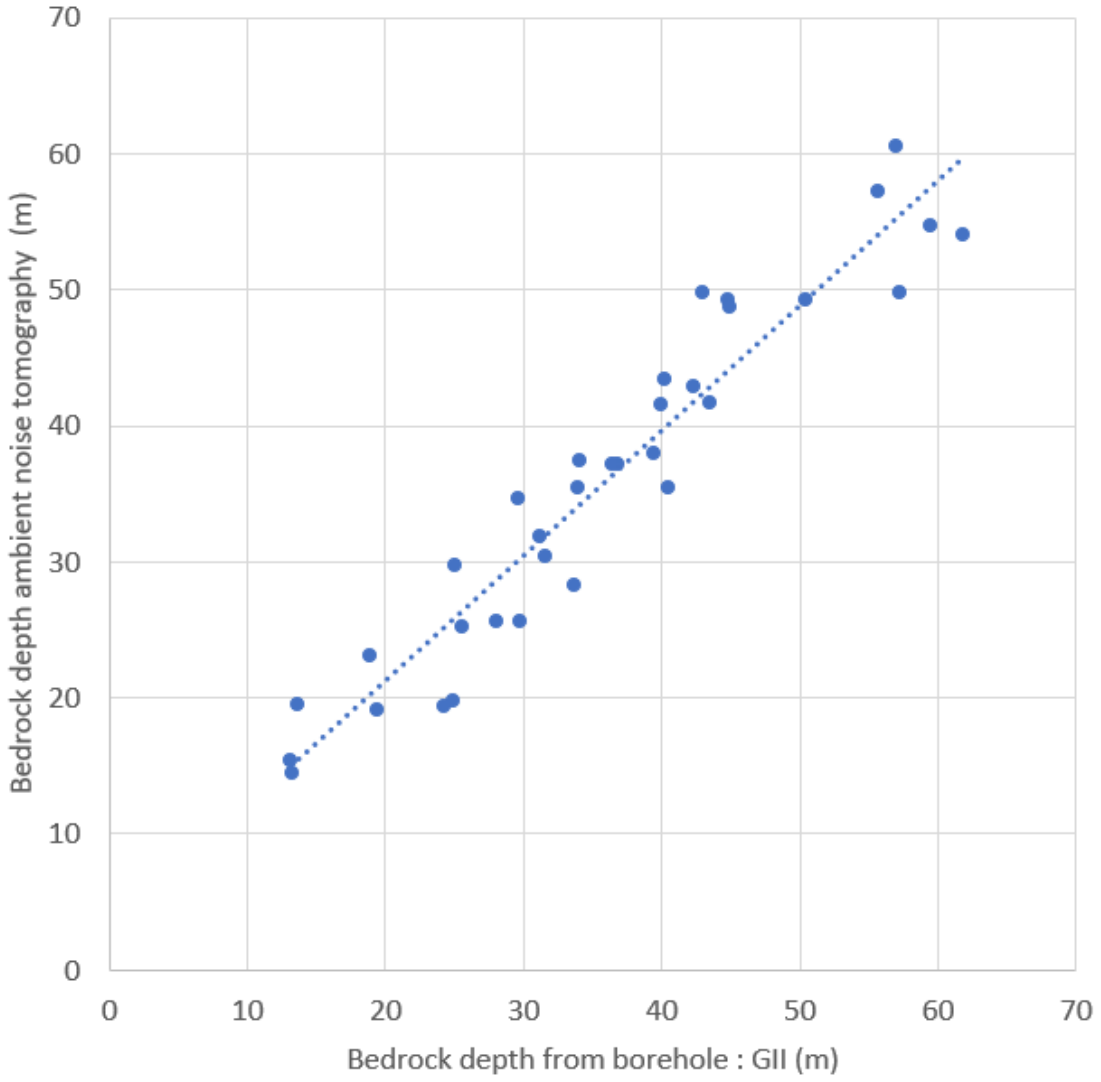
S-wave velocity at GII confirmed by boring



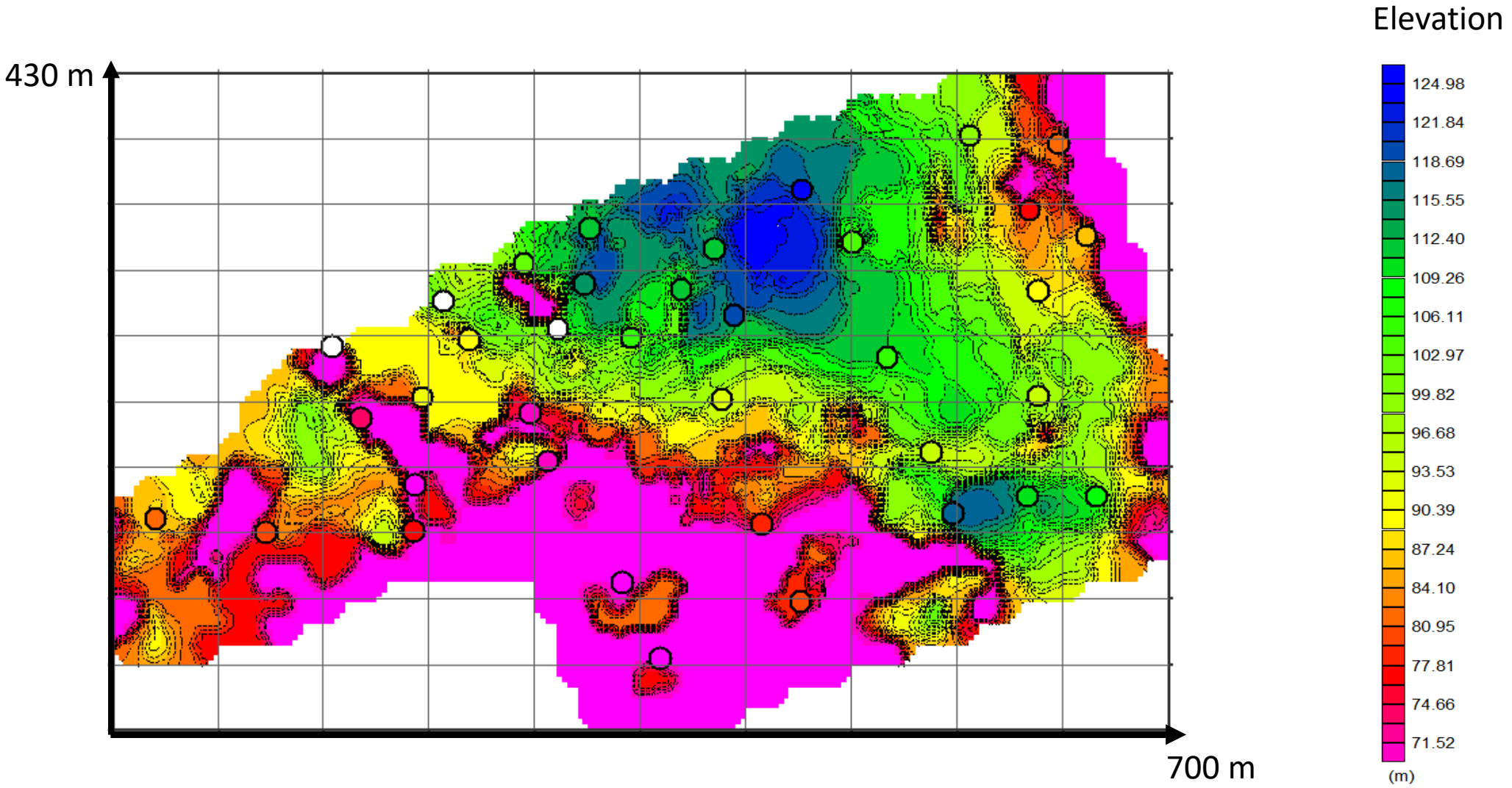
Depth to bedrock (GII)



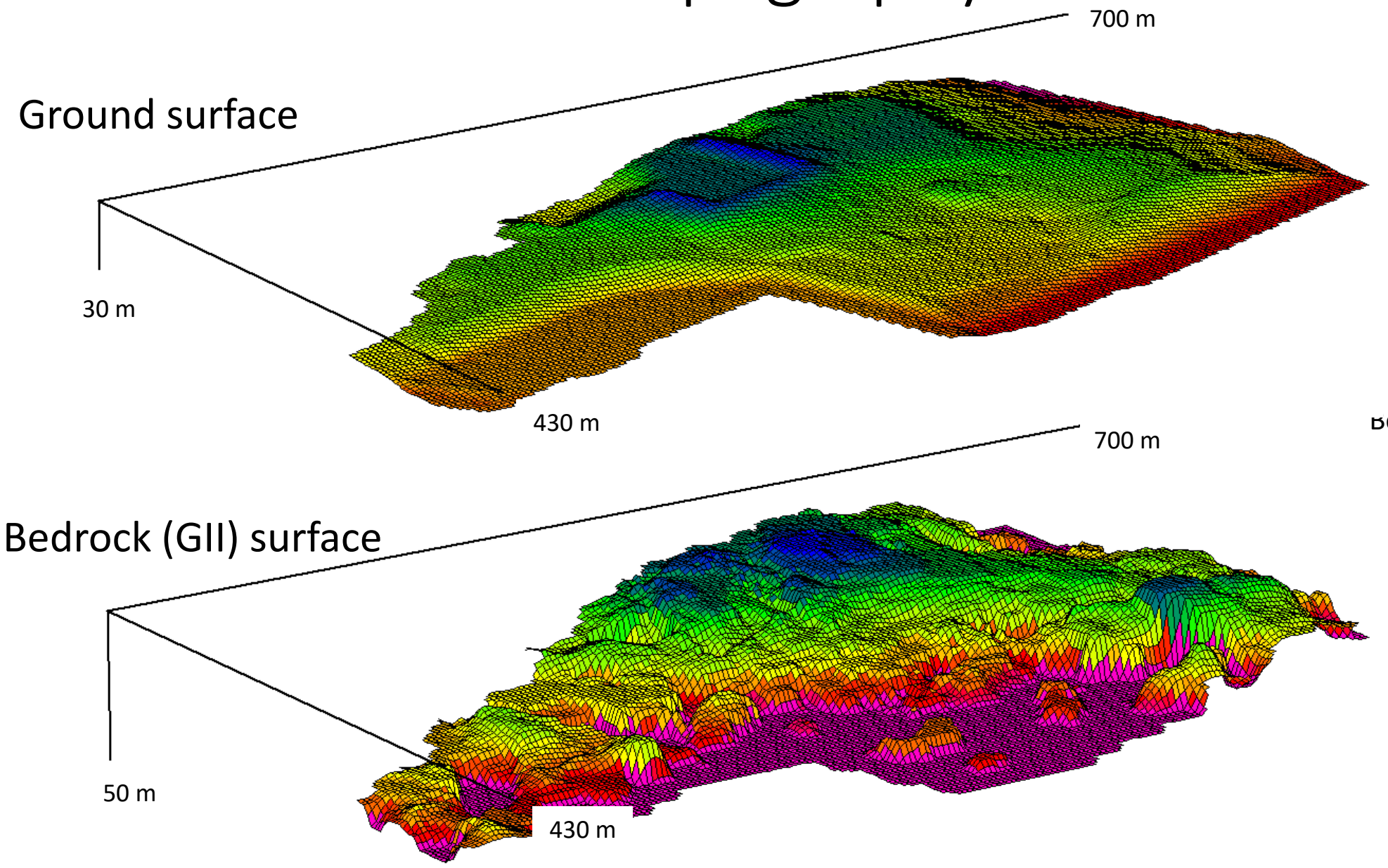
Comparison of bedrock (GII) depth estimated by ambient noise tomography and boring



Bedrock (GII) elevation



Surface and bedrock topography



8. Application examples

- AVS30
- 1D deep investigation
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- 3D active fault investigation at Beijing, China
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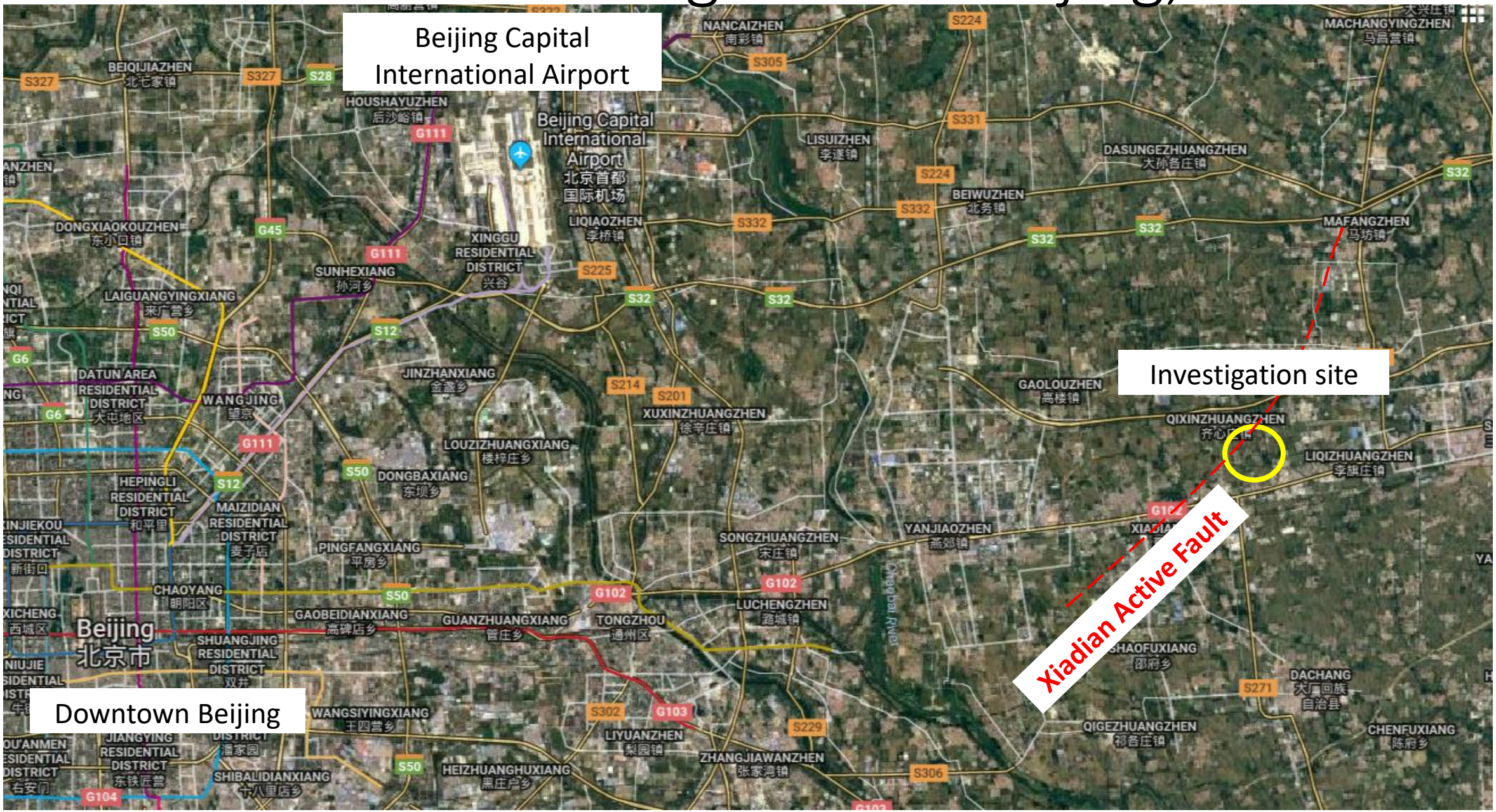
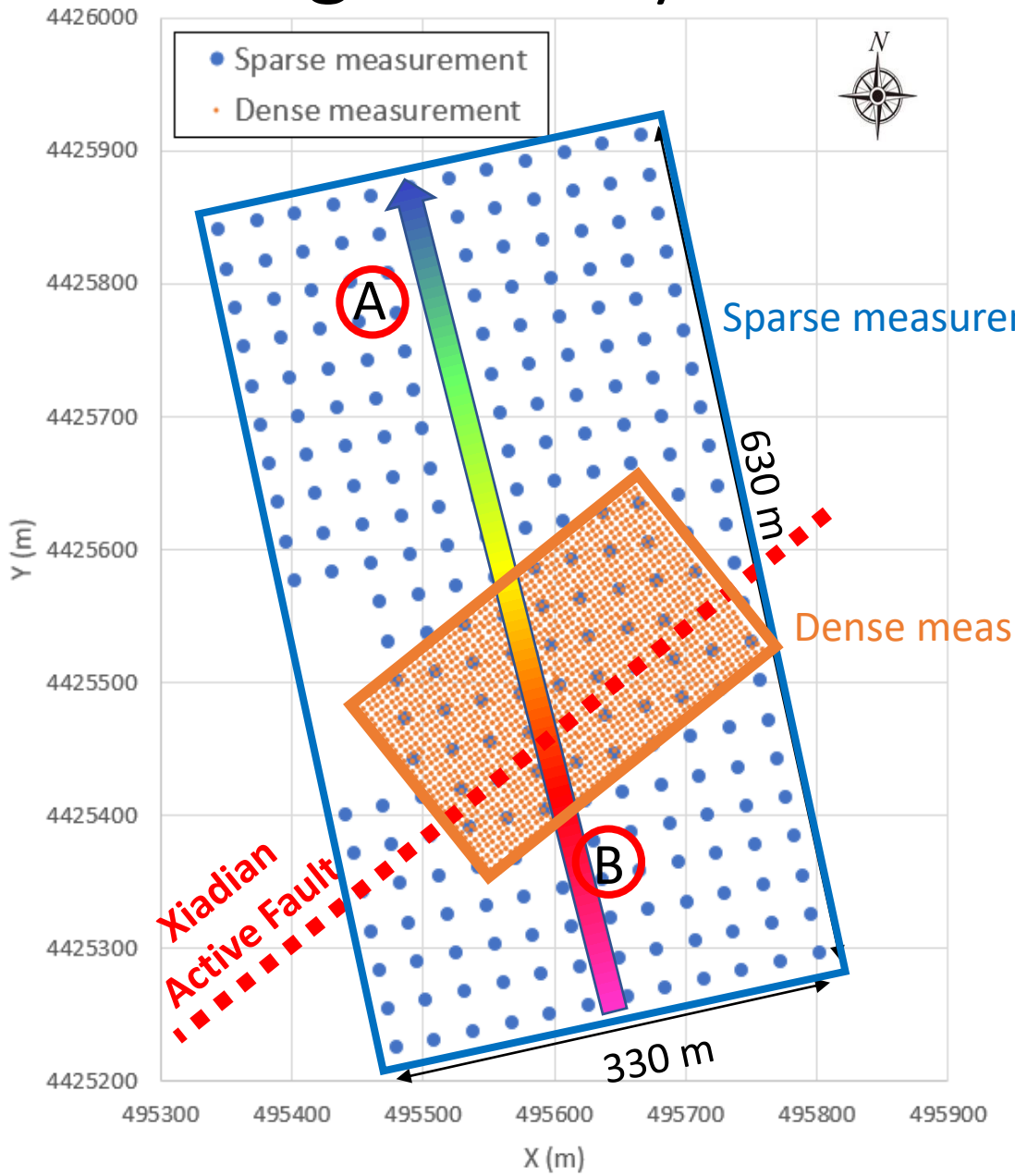
3D Active fault investigation at Beijing, China

3D Active fault investigation at Beijing, China



Acquisition geometry of ambient noise method

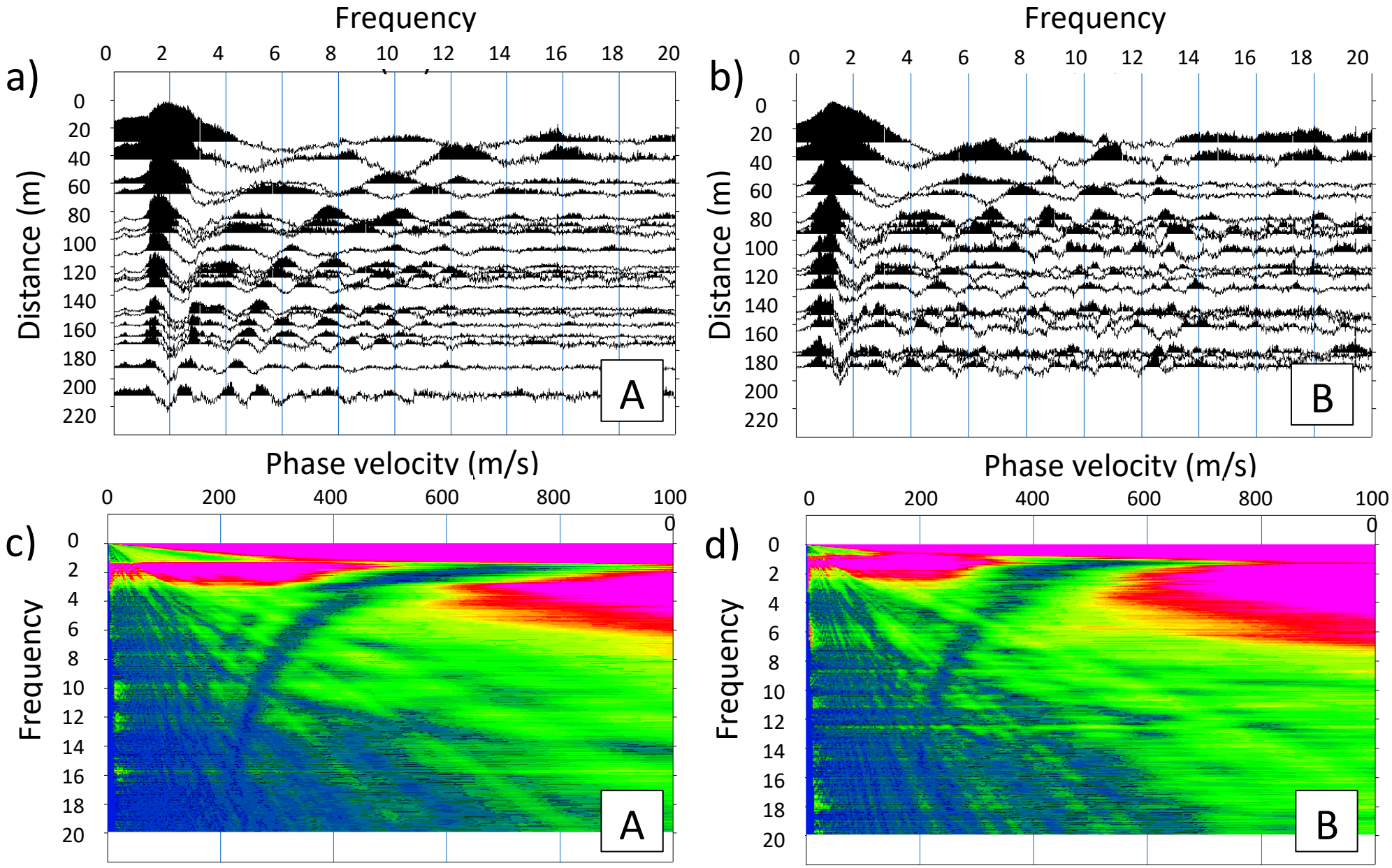


Sparse measurements (30 m spacing)

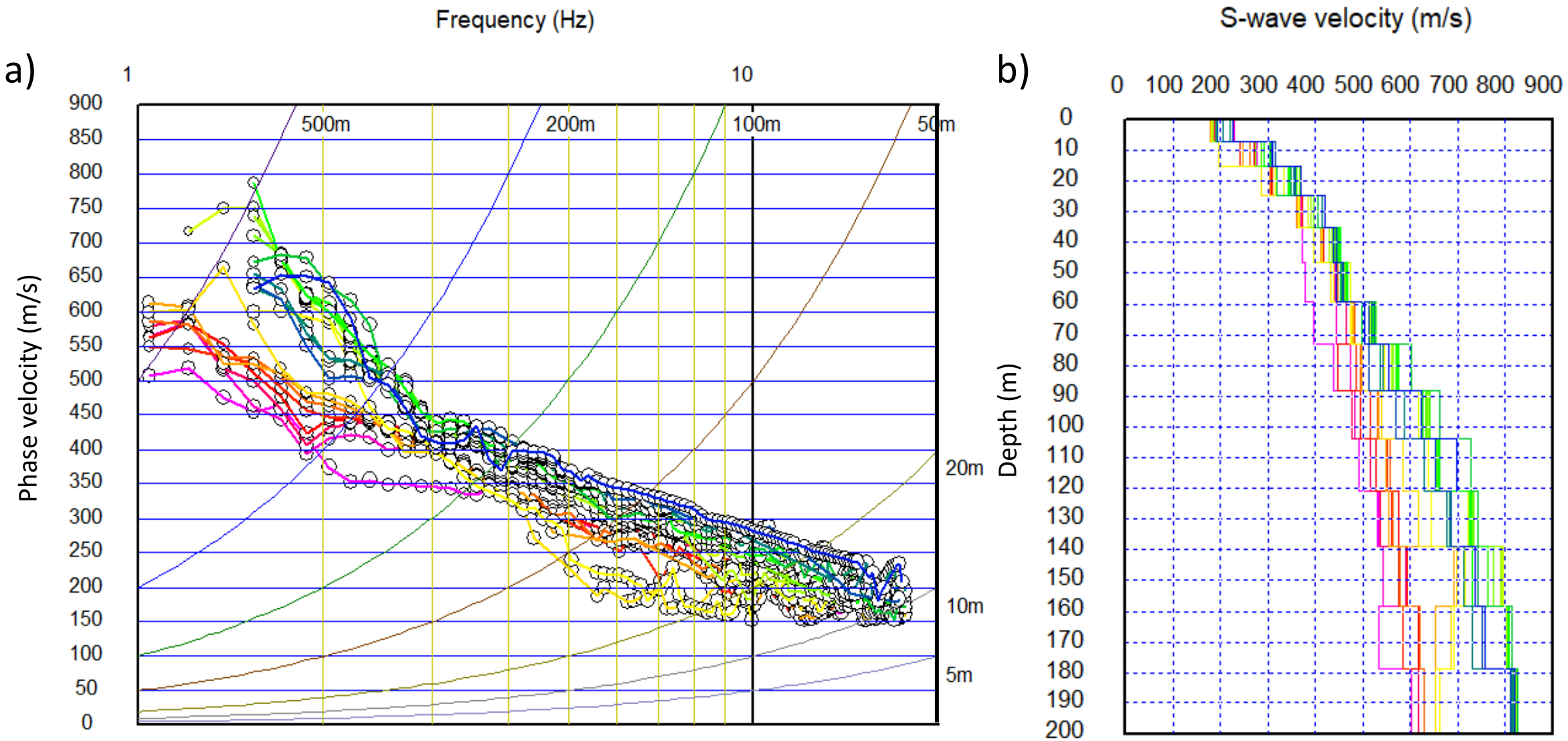
Dense measurements (5 m spacing)

Total number of receiver locations are 1835 in the dense measurements and 253 in the sparse measurements.

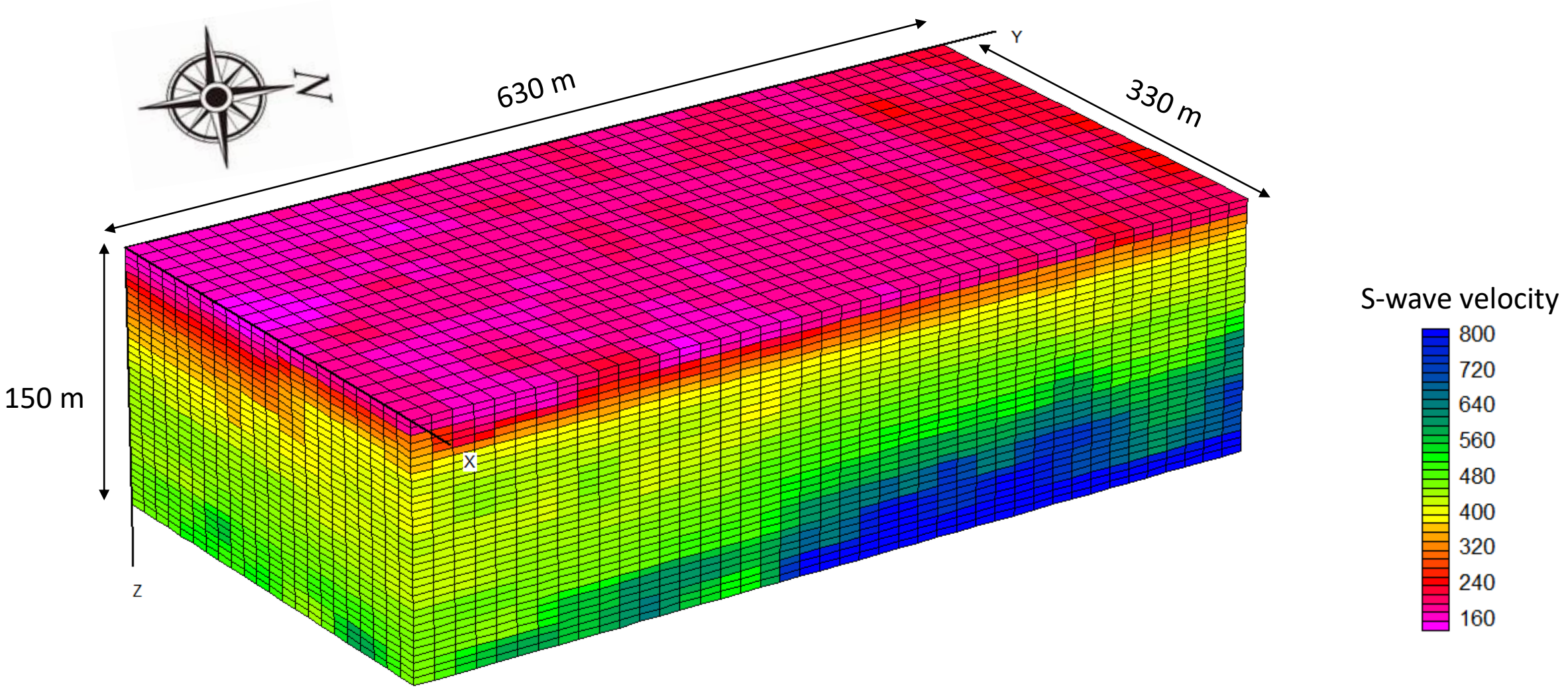
Coherencies and phase velocity images in frequency domain



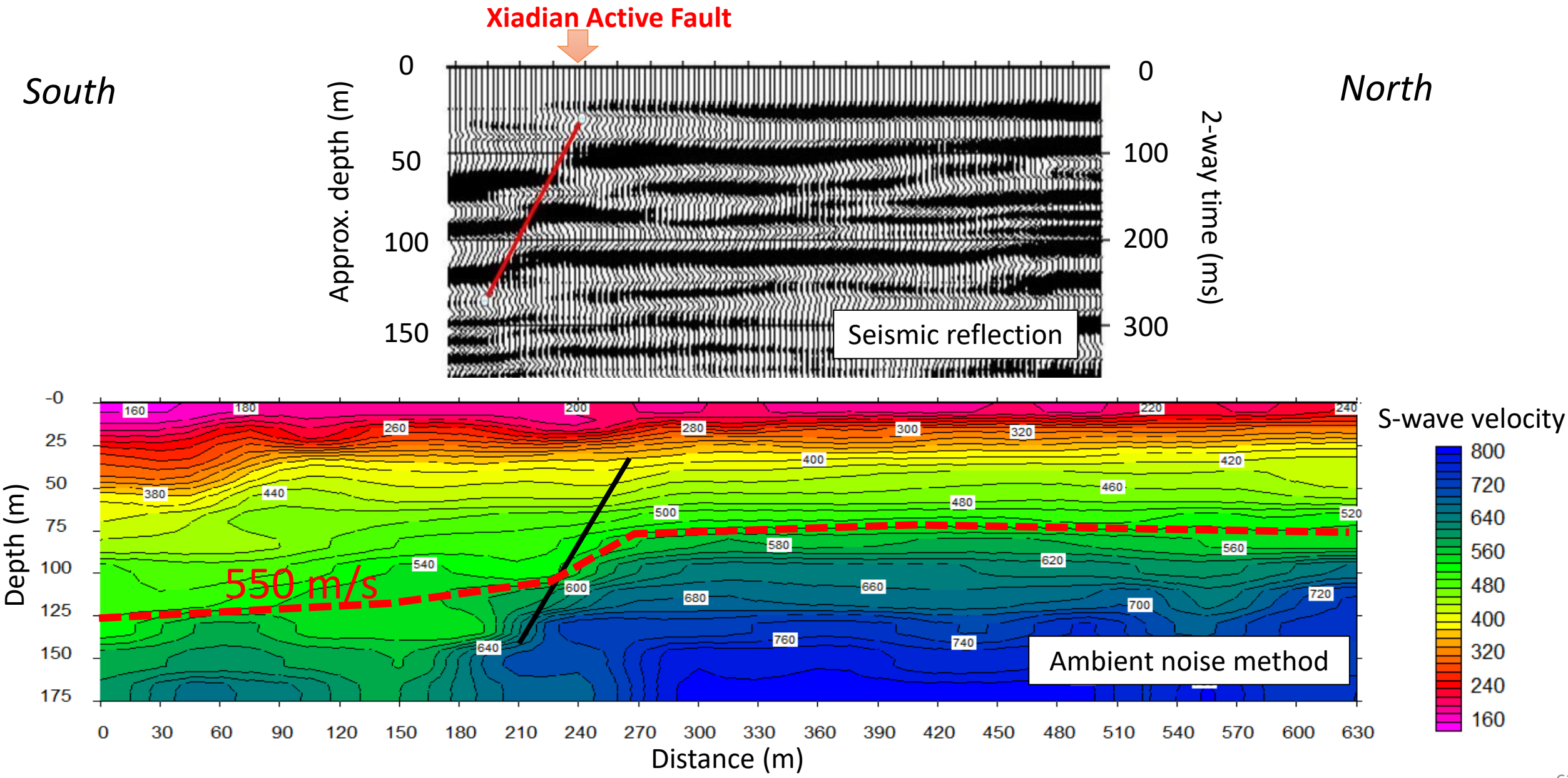
Dispersion curves and S-wave velocity models



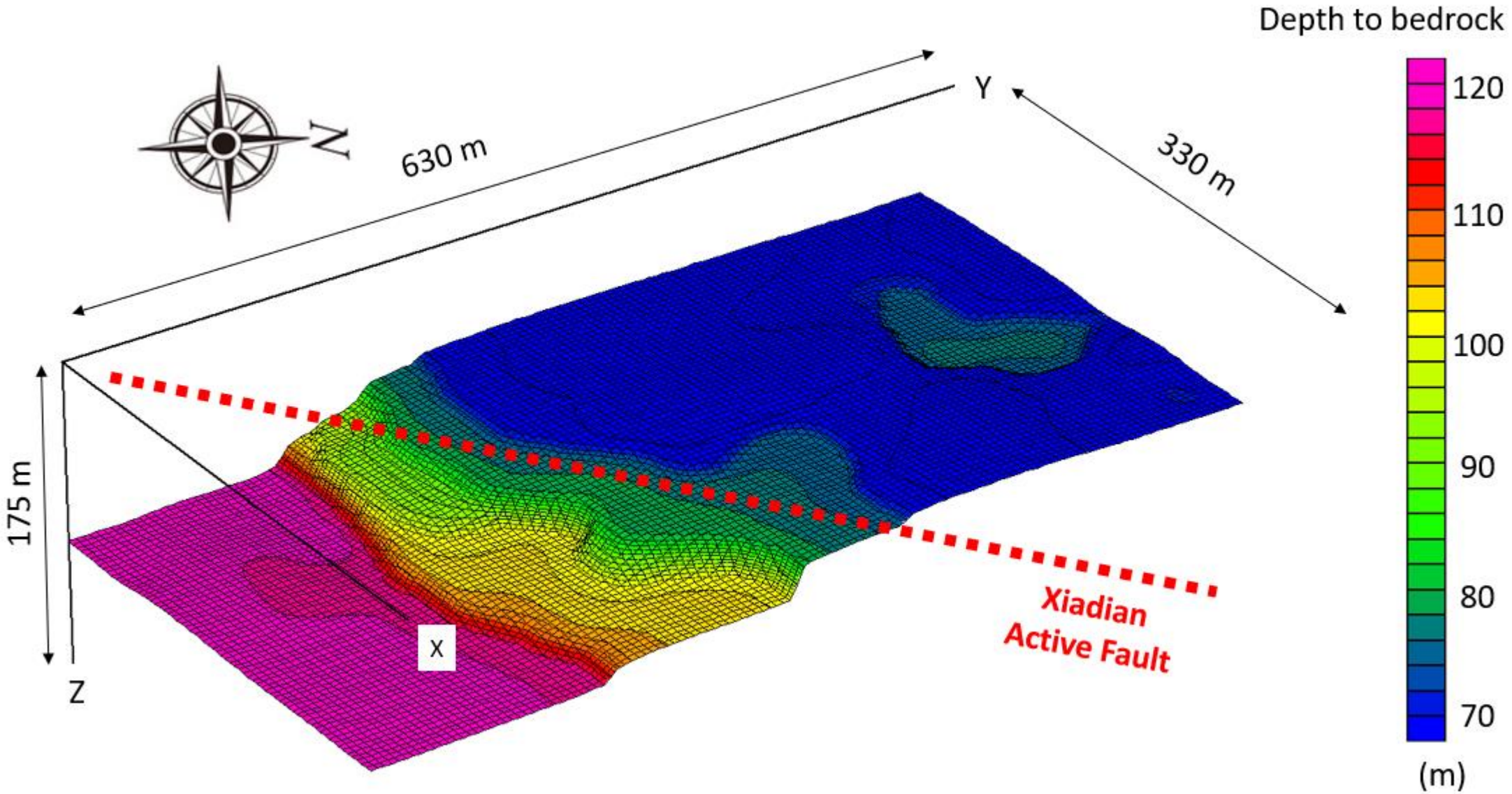
Active fault investigation at Beijing , China



Comparison with reflection method



Depth to bedrock (Vs = 550 m/s)



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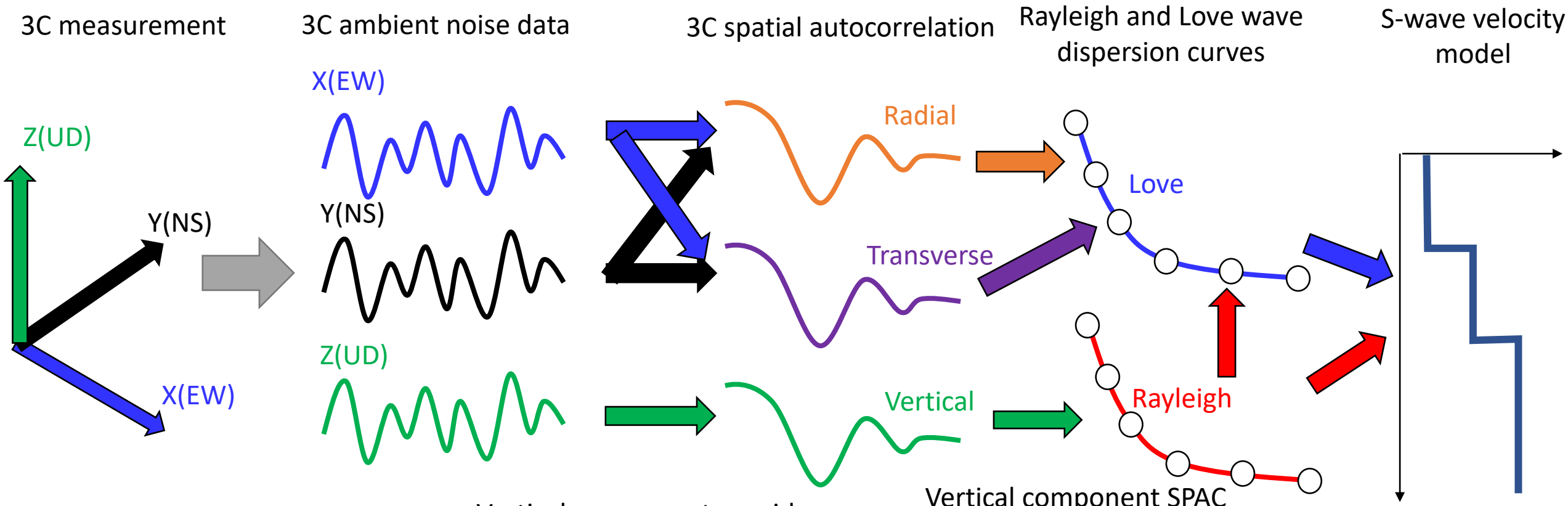
Outline of three-component (3C) measurement and processing



3C measurement provides 3C ambient noise data.

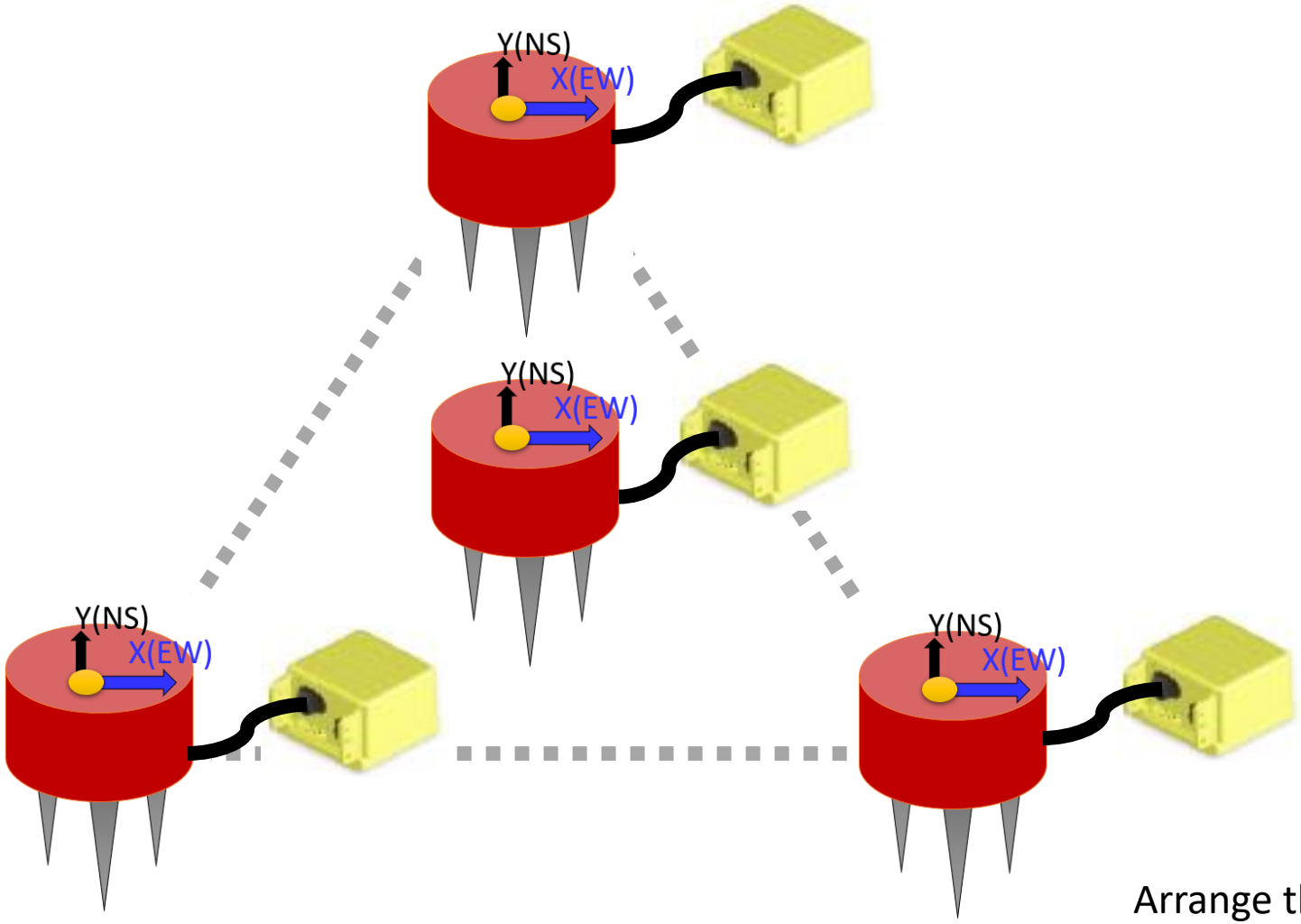
Vertical component provides vertical component SPAC. Horizontal components (X and Y) provide radial and transverse component SPACs.

Vertical component SPAC provides a Rayleigh dispersion curve. Horizontal components (radial and transverse) provide a Love dispersion curve using Rayleigh dispersion curve.

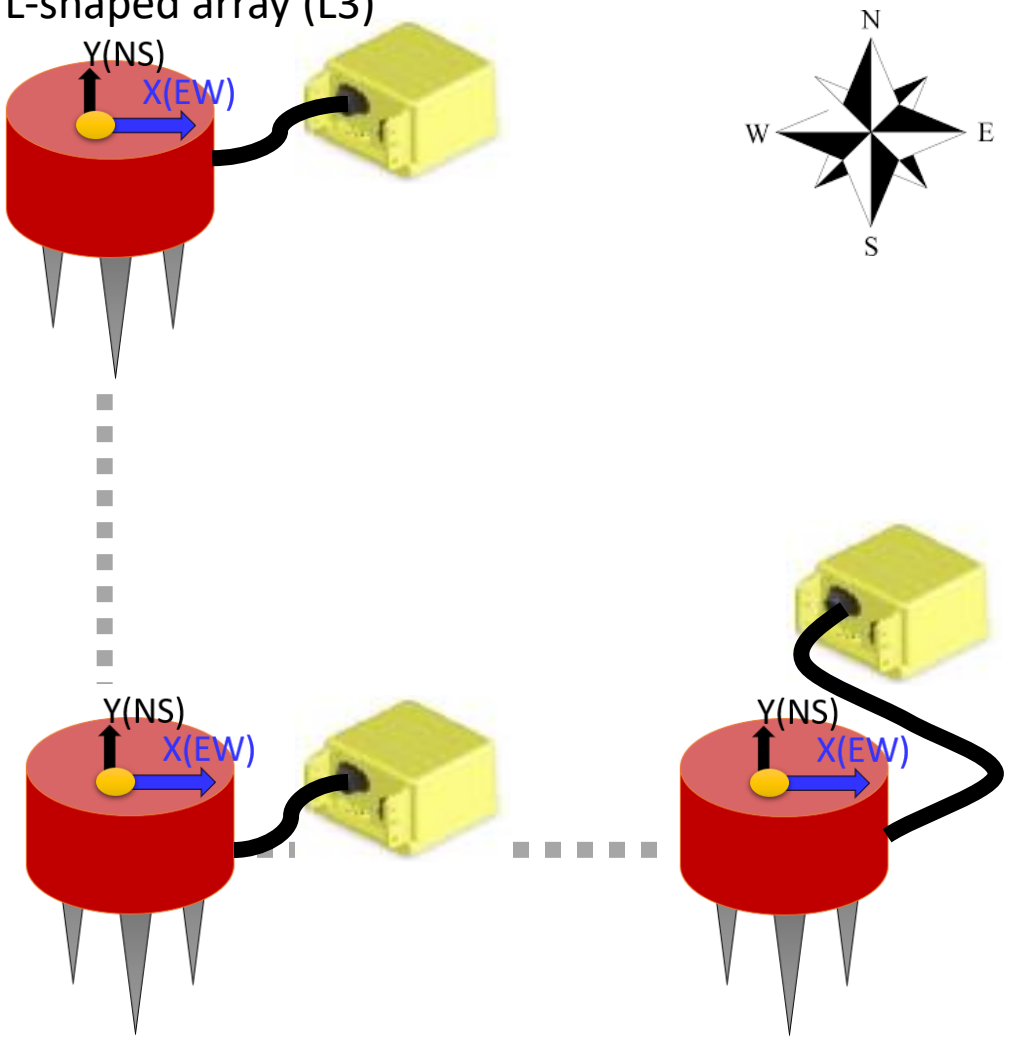
Joint inversion of Rayleigh and Love dispersion curves provide an S-wave velocity model.

3C ambient noise measurements for SPAC

Triangular array (T4)



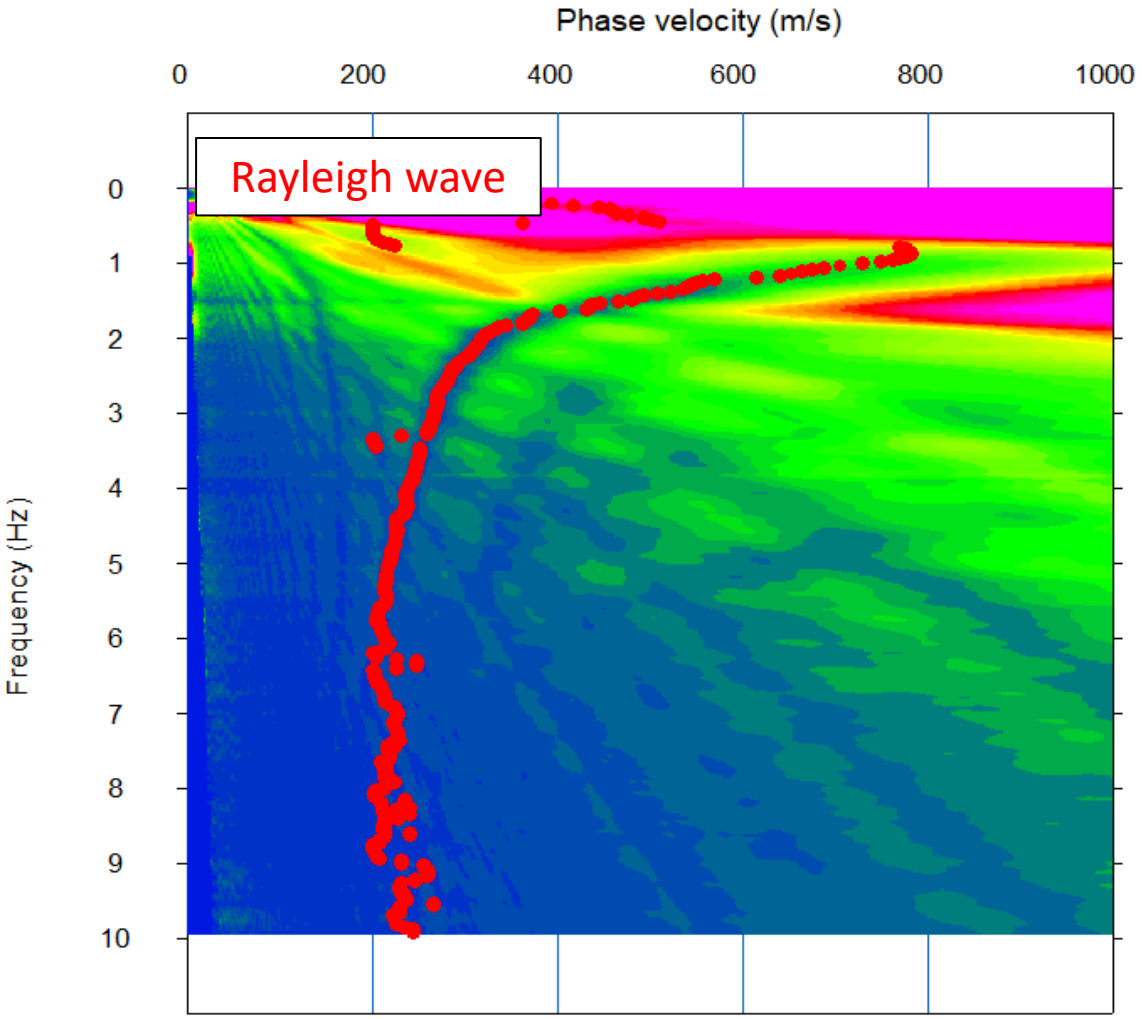
L-shaped array (L3)

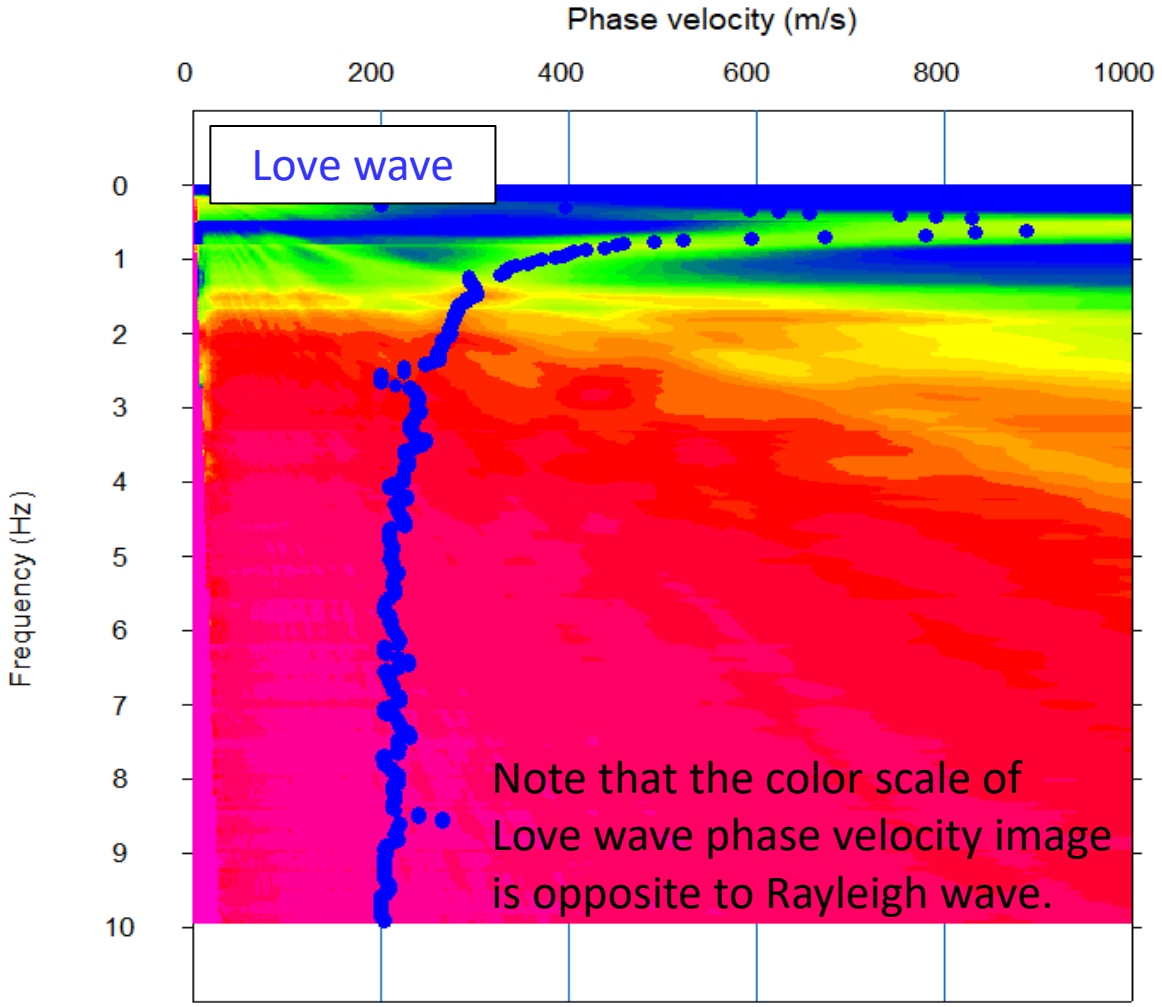


Arrange the orientation of all sensors to be the same direction

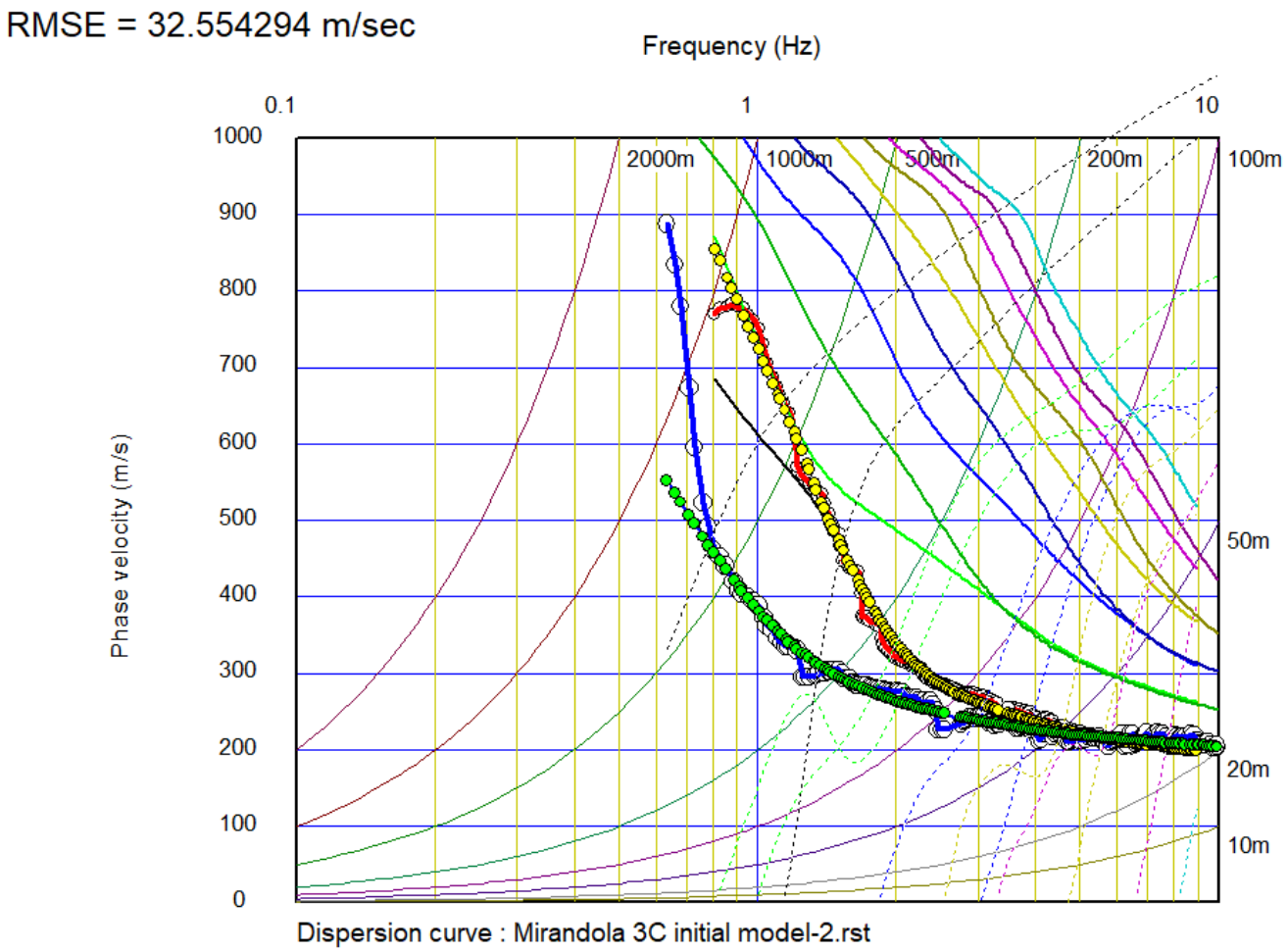
Calculate Rayleigh and Love phase velocity images

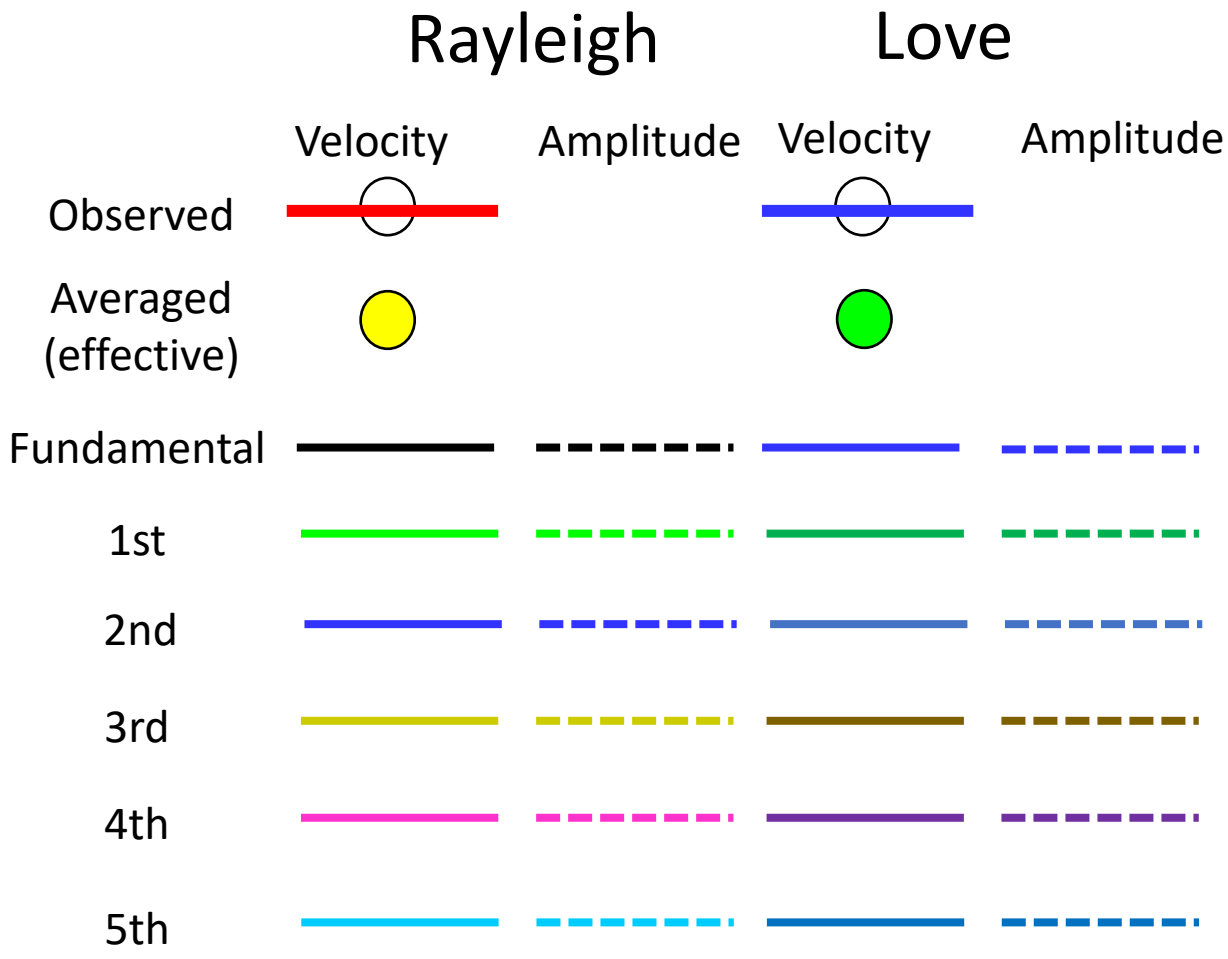
Ryleigh wave phase velocity images.





Comparison of observed and theoretical dispersion curves (Higher modes)





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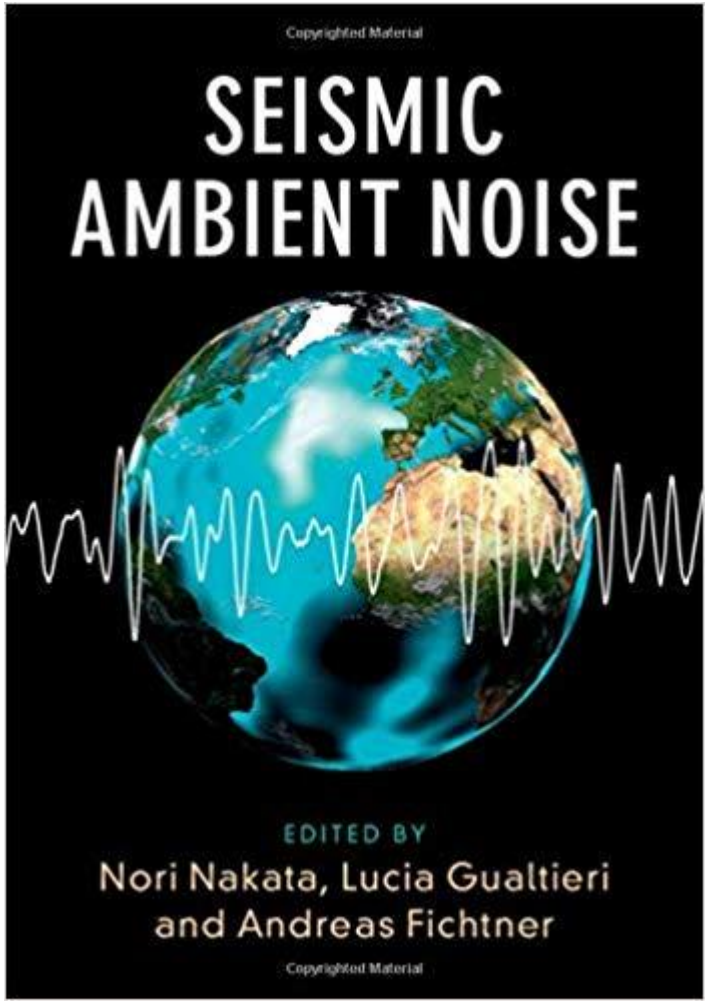
Conclusions

- We need to use S-wave velocity (Vs) at urban area from geo-technical point of view
- Conventional seismic refraction method does not work at lowland and we need to use surface wave methods
- Seismic ambient noise is quite efficient to delineate depth from several meters to several kilo-meters
- Ambient noise tomography was utilized to delineate 2D/3D near-surface Vs structures.
- CMP-SPAC method was used to calculate dispersion curves from spatially unaliased ambient noise data obtained from relatively dense receiver arrays.
- Numerical and field examples demonstrated that the methods can be used to simply and quickly estimate 2D/3D Vs structures to a depth greater than 100 m.

Acknowledgement

- I wish to thank all those people who contributed to the development of the active and passive surface-wave methods.
- A very special thanks to Dr. Wong Leong Toh, Seik Yean Yoong and Seik Yean Suang of Pacific Geo-Science for their effort on fieldwork, processing and cooperation with the course.
- A very special thanks to Dr. Shunjia Tan, Bin He and Daxiang Cheng of Laurel for their effort on fieldwork, processing and cooperation with the course.
- I would like to thank Prof. Sebastiano Foti of Politecnico di Torino for taking great pictures at the Leaning Tower of Pisa.
- I wish to thank Deborah Underwood of Geometrics for her assistant to prepare the course.
- Finally, I would like to thank all Geomatrix people, particularity Matt Guy, for their effort on the course preparation.



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Nori Nakata, Lucia Gualtieri, Andreas Fichtner
Cambridge University Press