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First EAGE Workshop on Fibre Optic Sensing

RESERVOIR AND PRODUCTION MONITORING

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TNO innovation for life

Abstract No. 9
Using Fibre-Optic DAS surveying to de-risk a shallow geothermal energy storage site in Brussels, Belgium

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Introduction

- Climate goals 2030 require a step-up in use of sustainable energy resources (solar, wind, geothermal, CCUS)
- High Temperature - Aquifer Thermal Energy Storage (HT-ATES) is a technique which offers a large potential when it comes to sustainable energy storage and production. Knowledge of the aquifer is key.
- TNO and GFZ demonstrated the cost-effective acquisition of high-res seismic data and VSP on ATES site in Berlin
- TNO has an inhouse developed DAS system + interrogator but wishes to evaluate other systems and methods as well
- Getting a healthy DAS signal in urban environments is challenging: high noise levels, small offsets, weak sources, coupling issues of fibre-optic to surface/well/casing/aquifer formation
- Which DAS strategies will work and which won't? Let's find out at an ATES site in Brussels, Belgium…
- At this ATES site and many others in Brussels, Horizontal-to-Vertical Spectral Ratio (HVSR) bedrock mapping was done

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Location

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https://commons.wikimedia.org/w/index.php?curid=31591059

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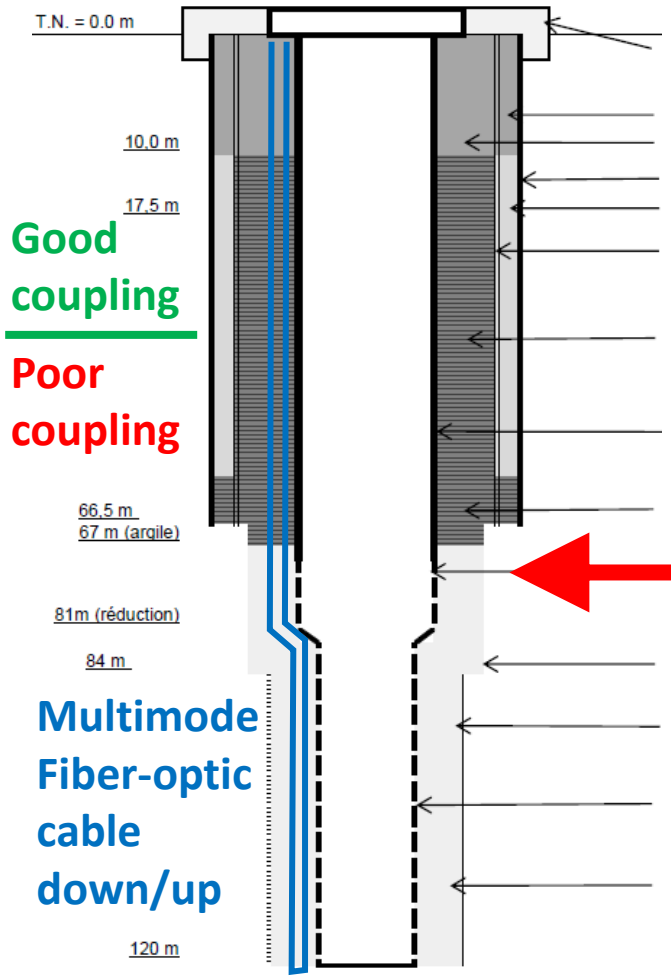
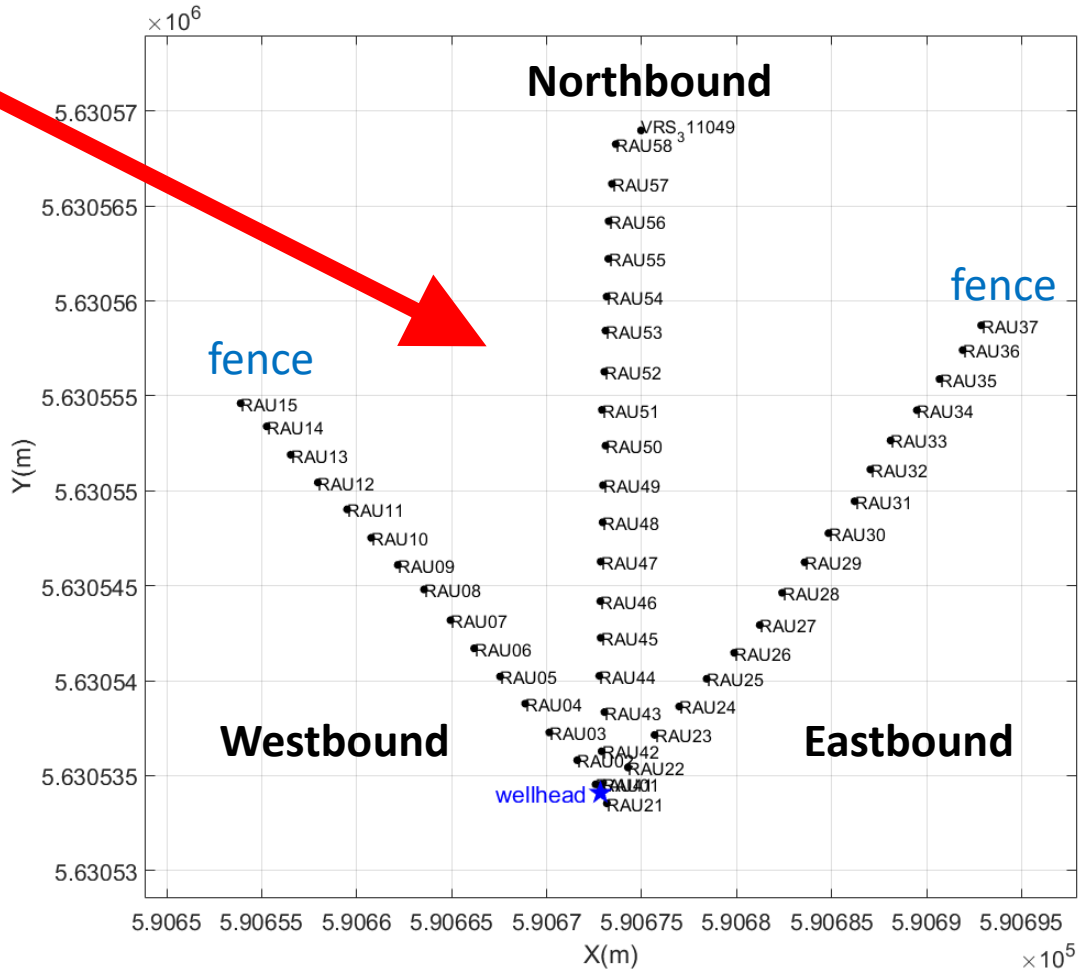


DAS VSP Field layout



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DAS VSP Field layout

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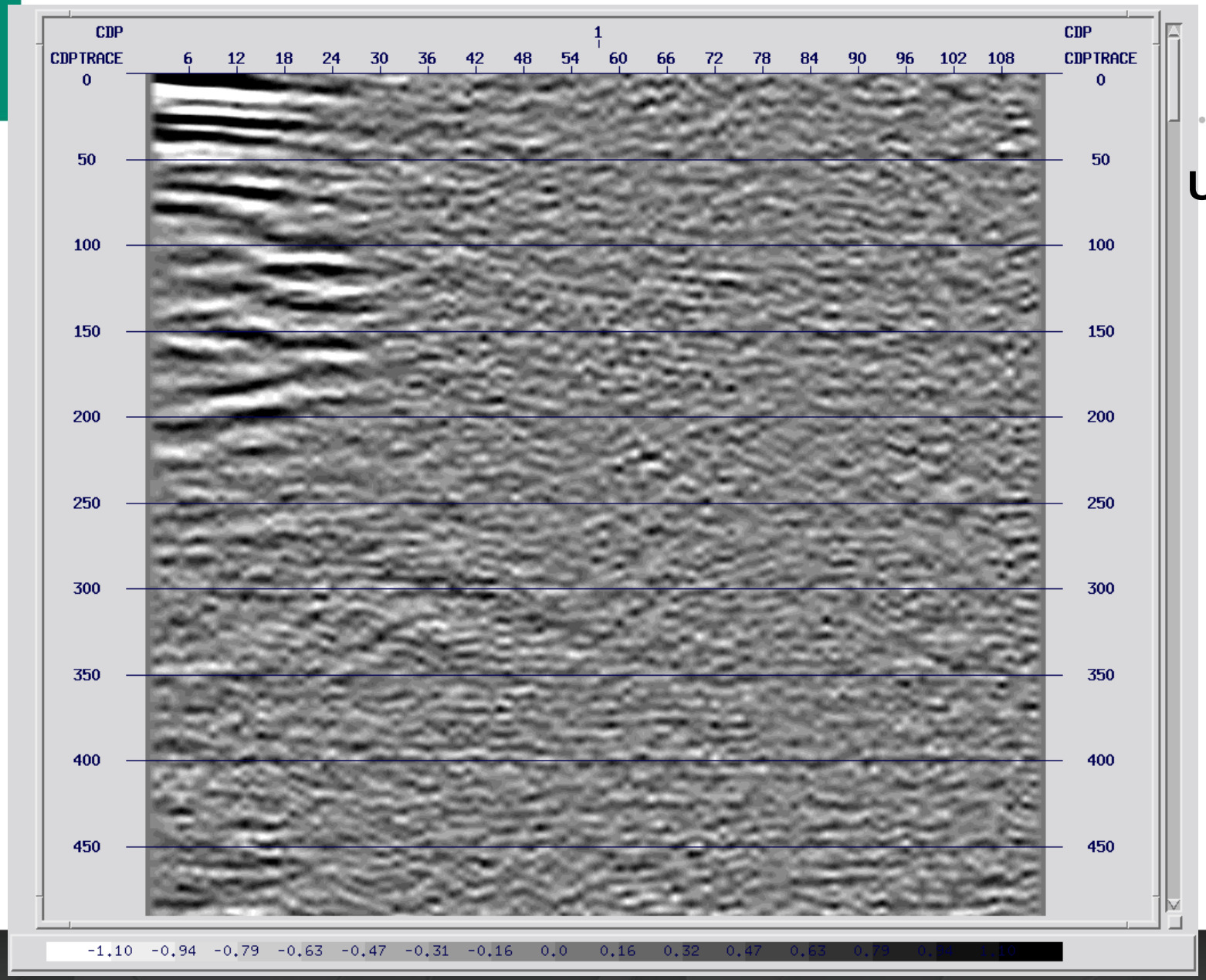

VSP processing:

Up- and down cable stacked per shot

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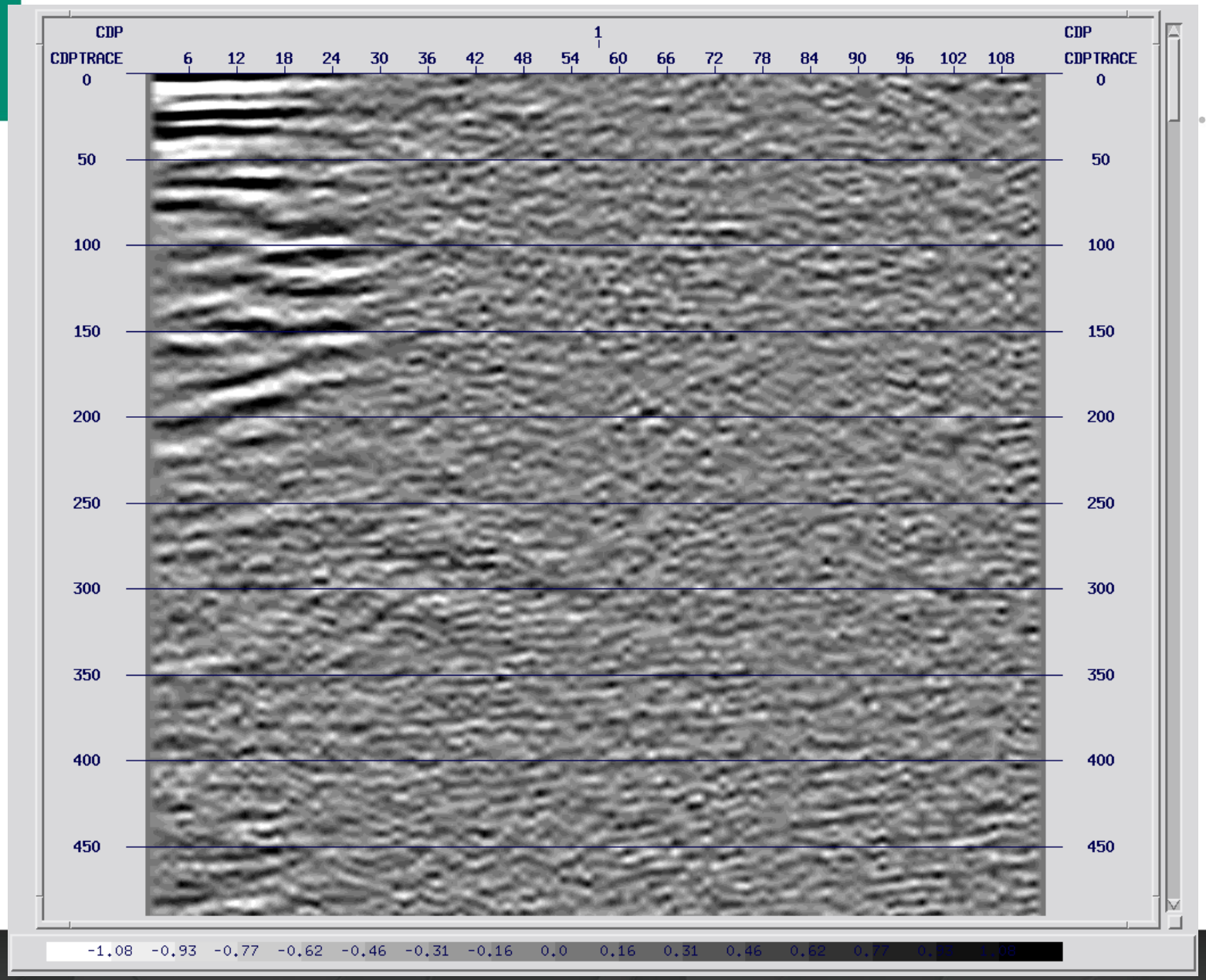

VSP processing:

Downgoing waves horizontal aligned

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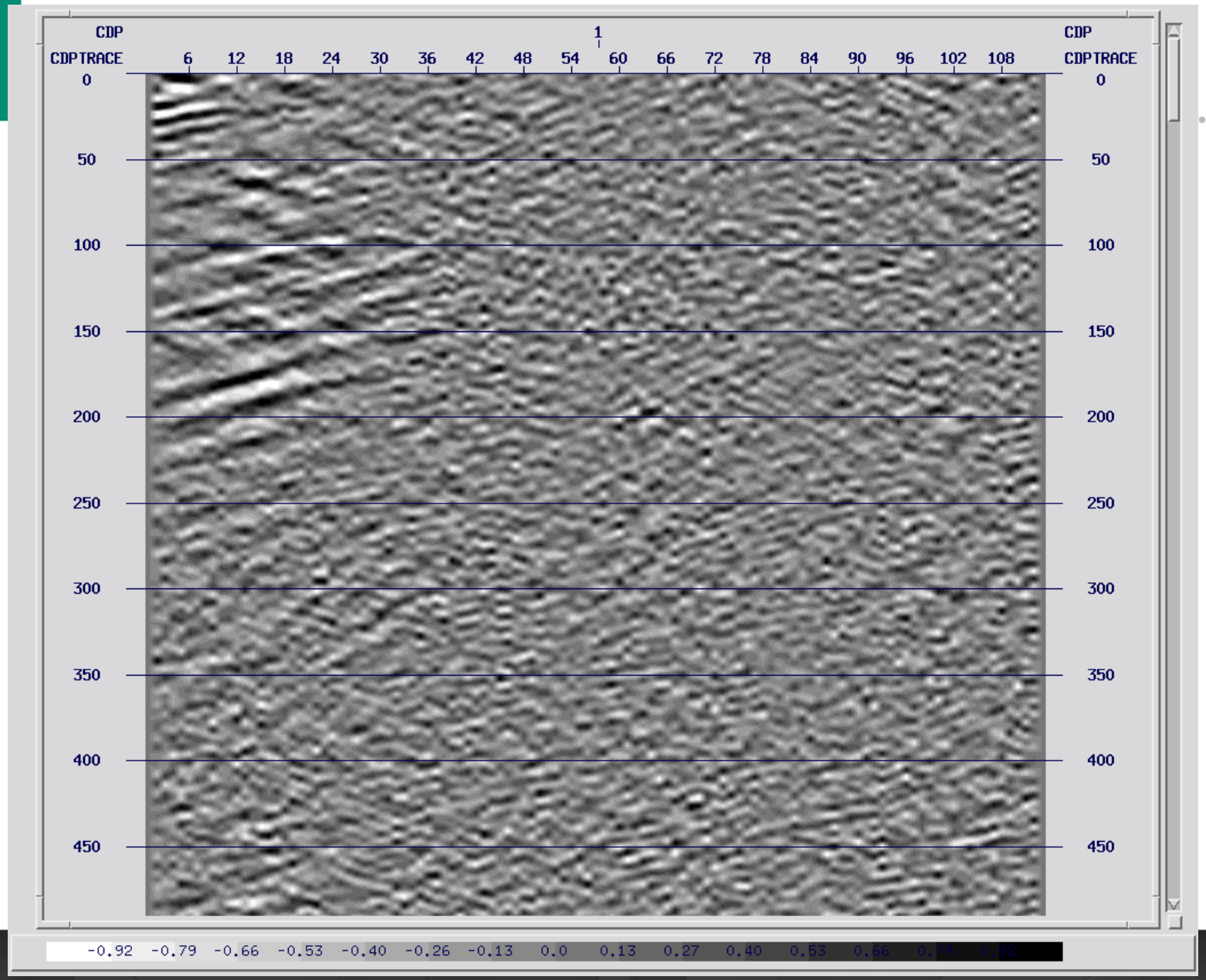

VSP processing:

Downgoing waves suppressed by Median filter

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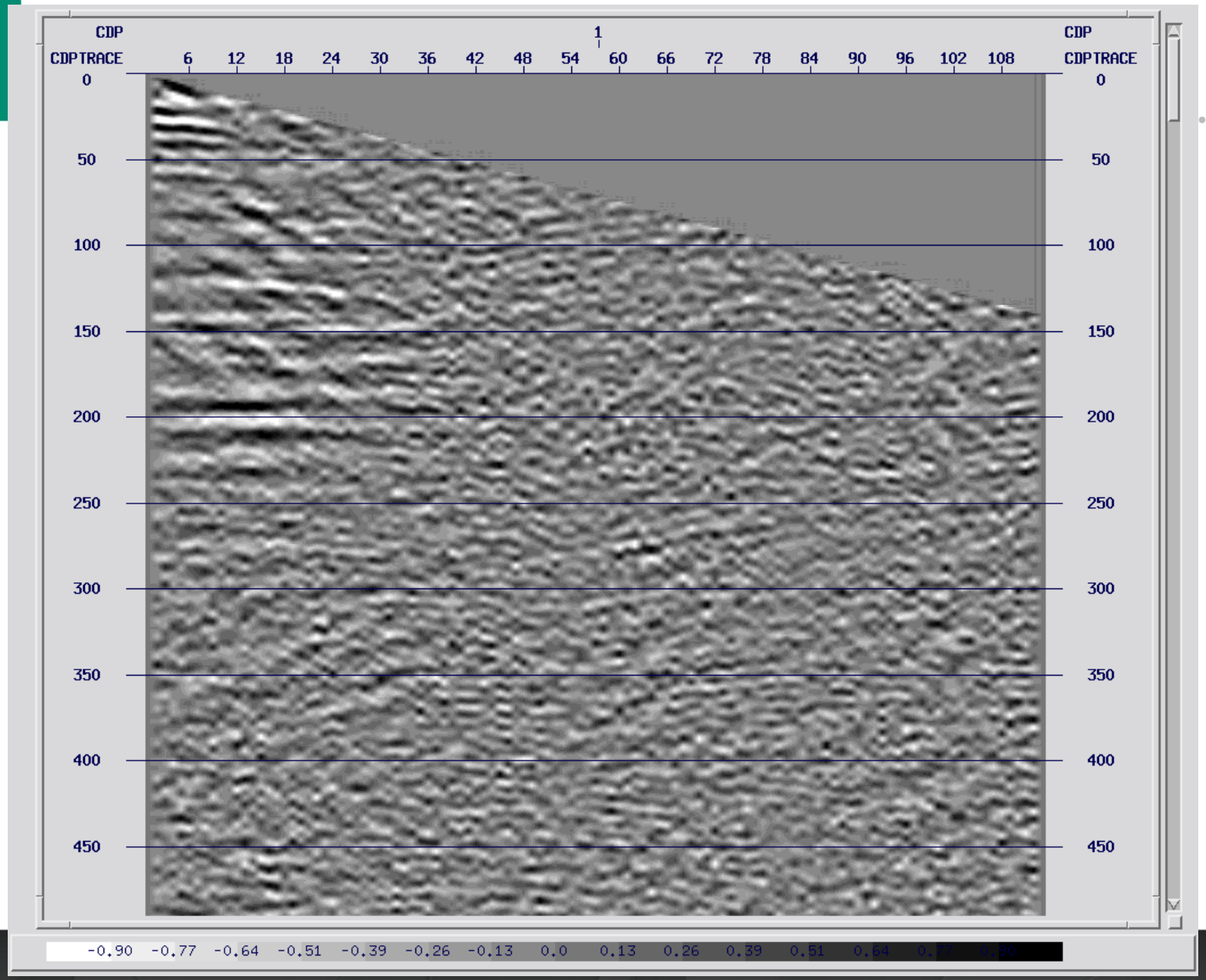

VSP processing:

Upgoing waves horizontal aligned per shot/CDP point

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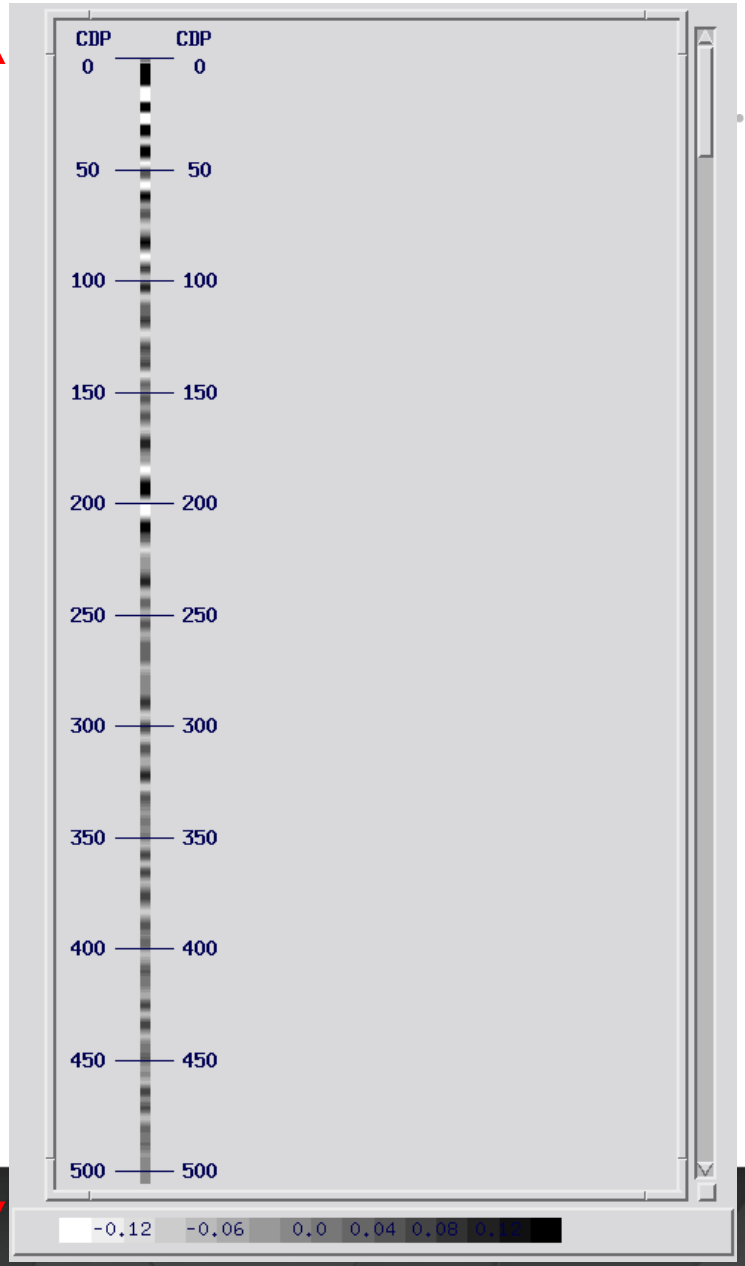
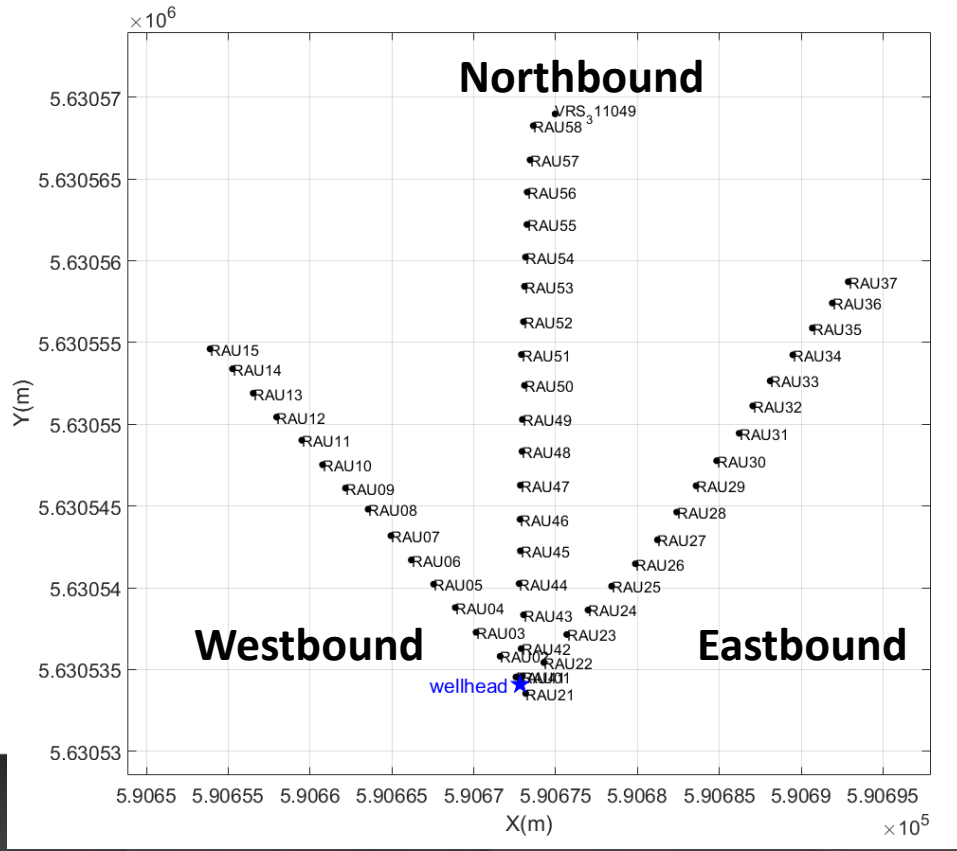
VSP processing:

Upgoing waves vertically stacked per shot/CDP point

500 ms ~ 400 m





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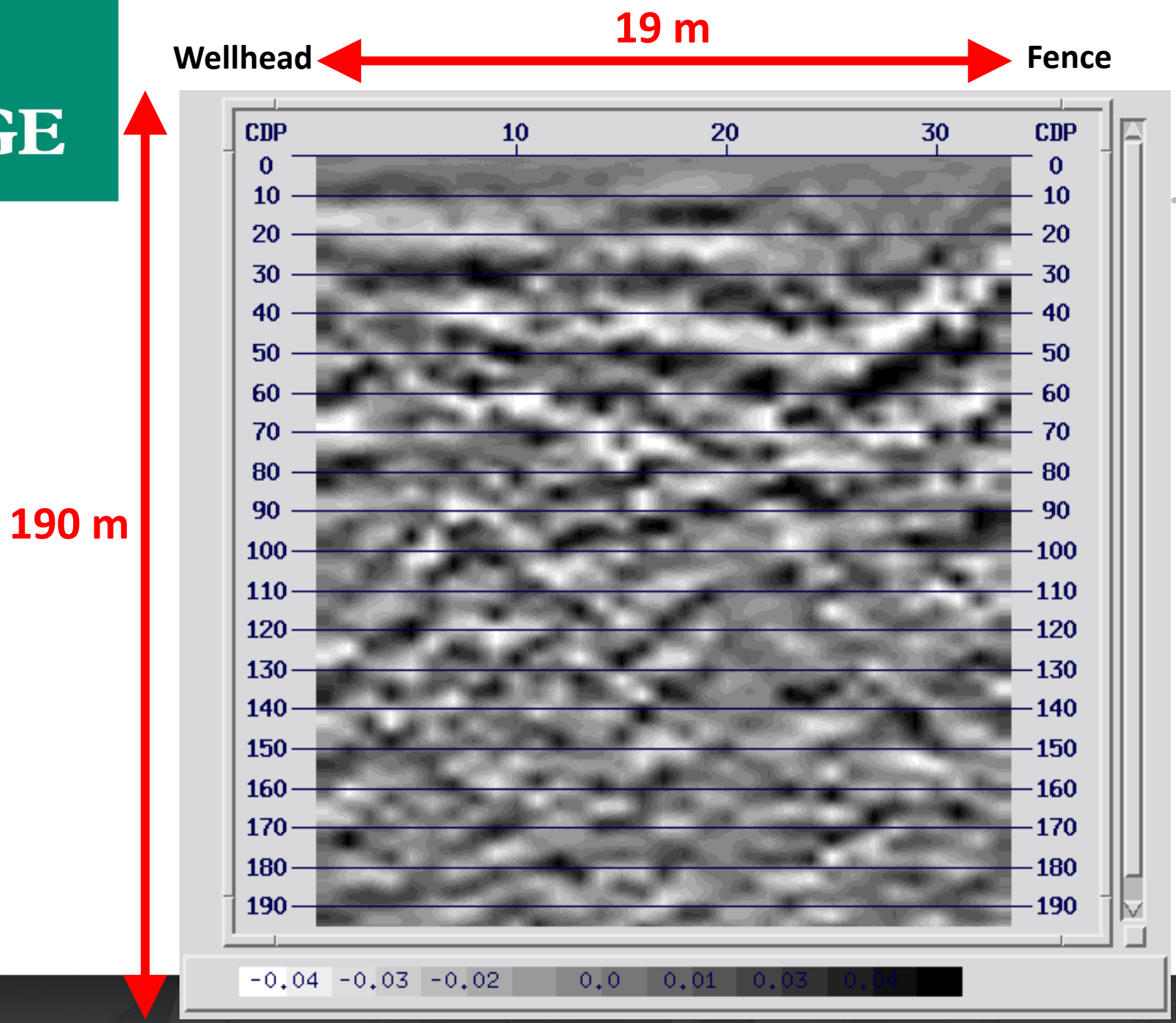

VSP processing:

Depth converted
Corridor stack of
all shot/CDP points
- Eastbound line

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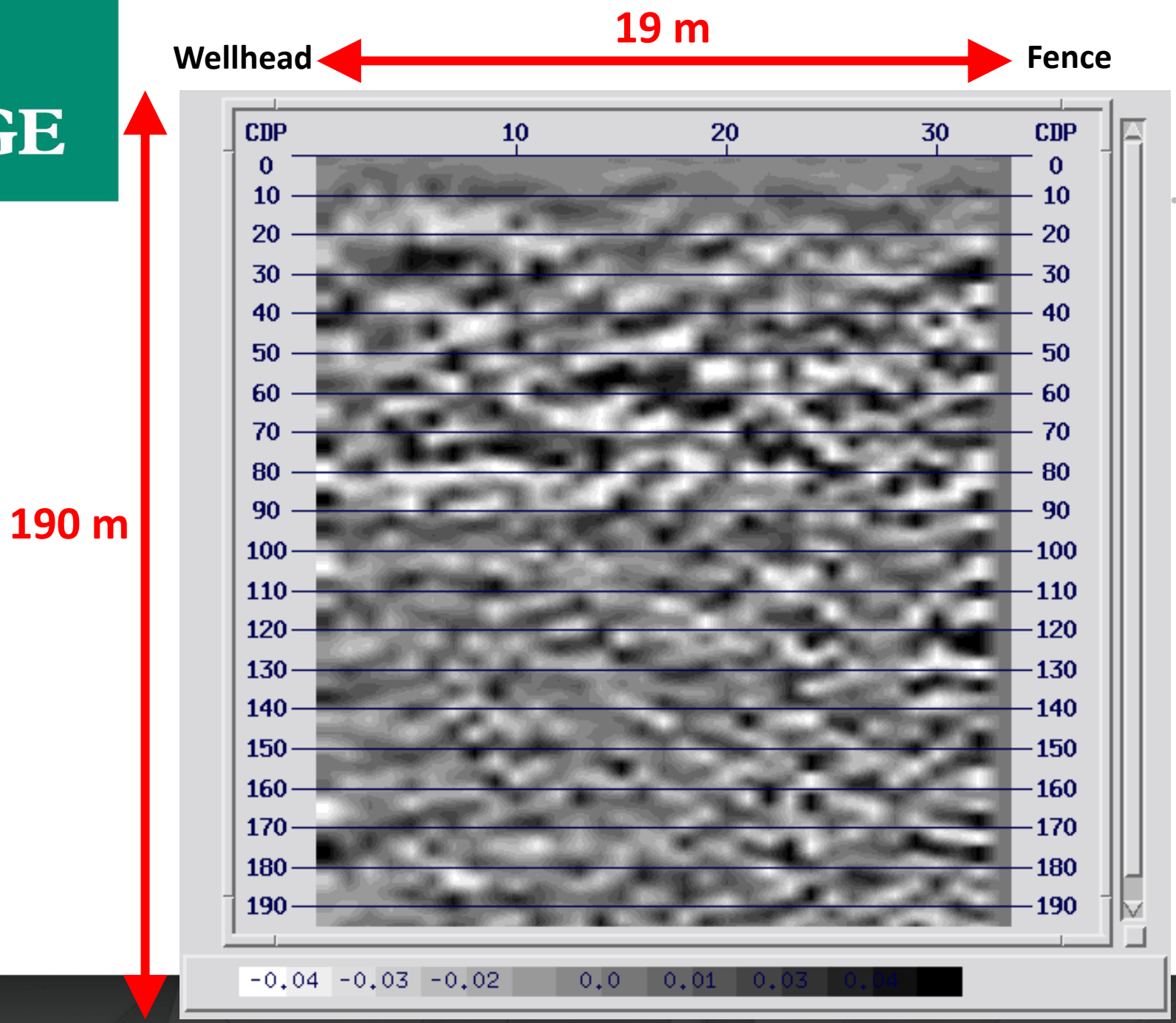

VSP processing:

Depth converted
Corridor stack of
all shot/CDP points
- Northbound line

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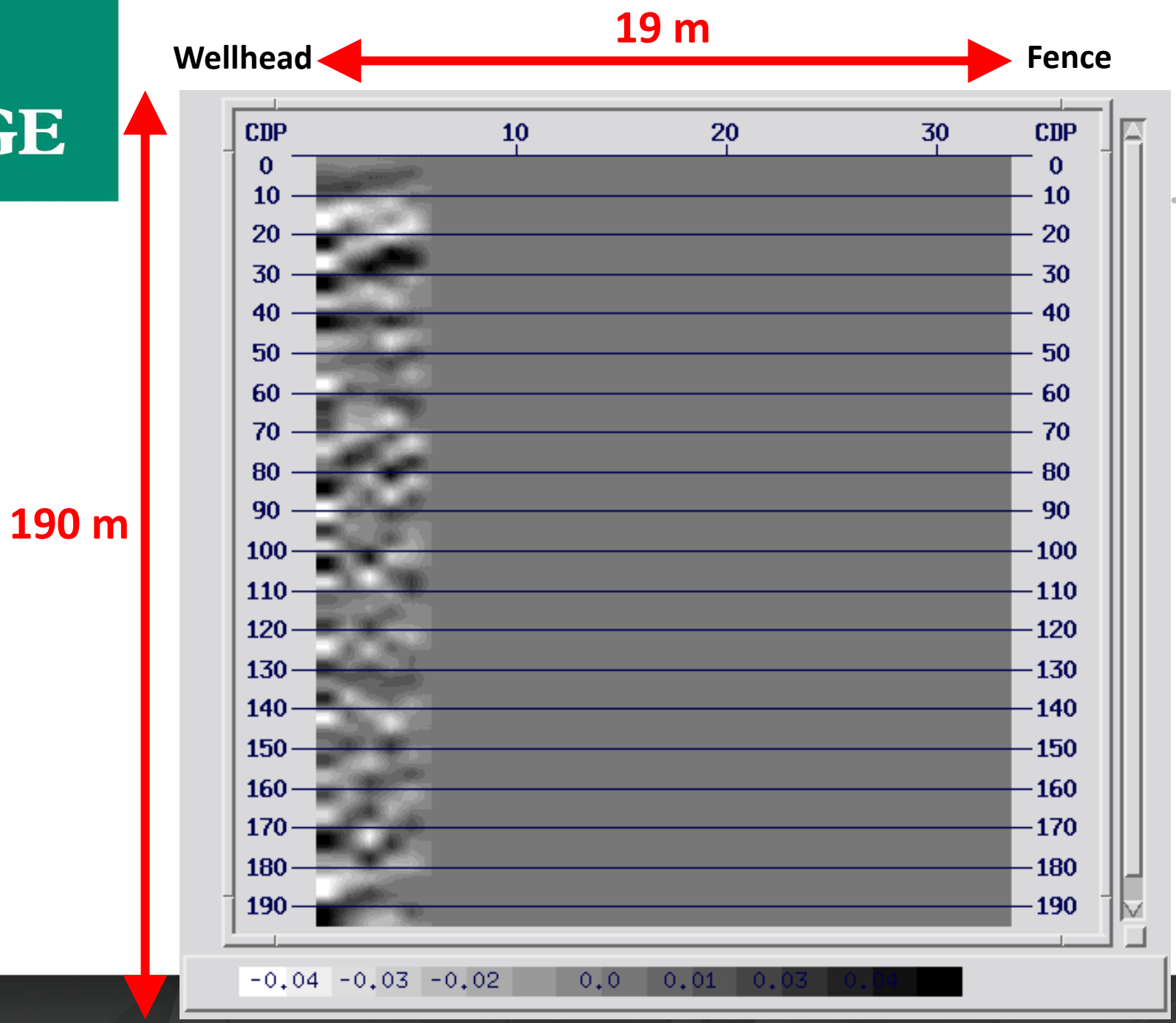
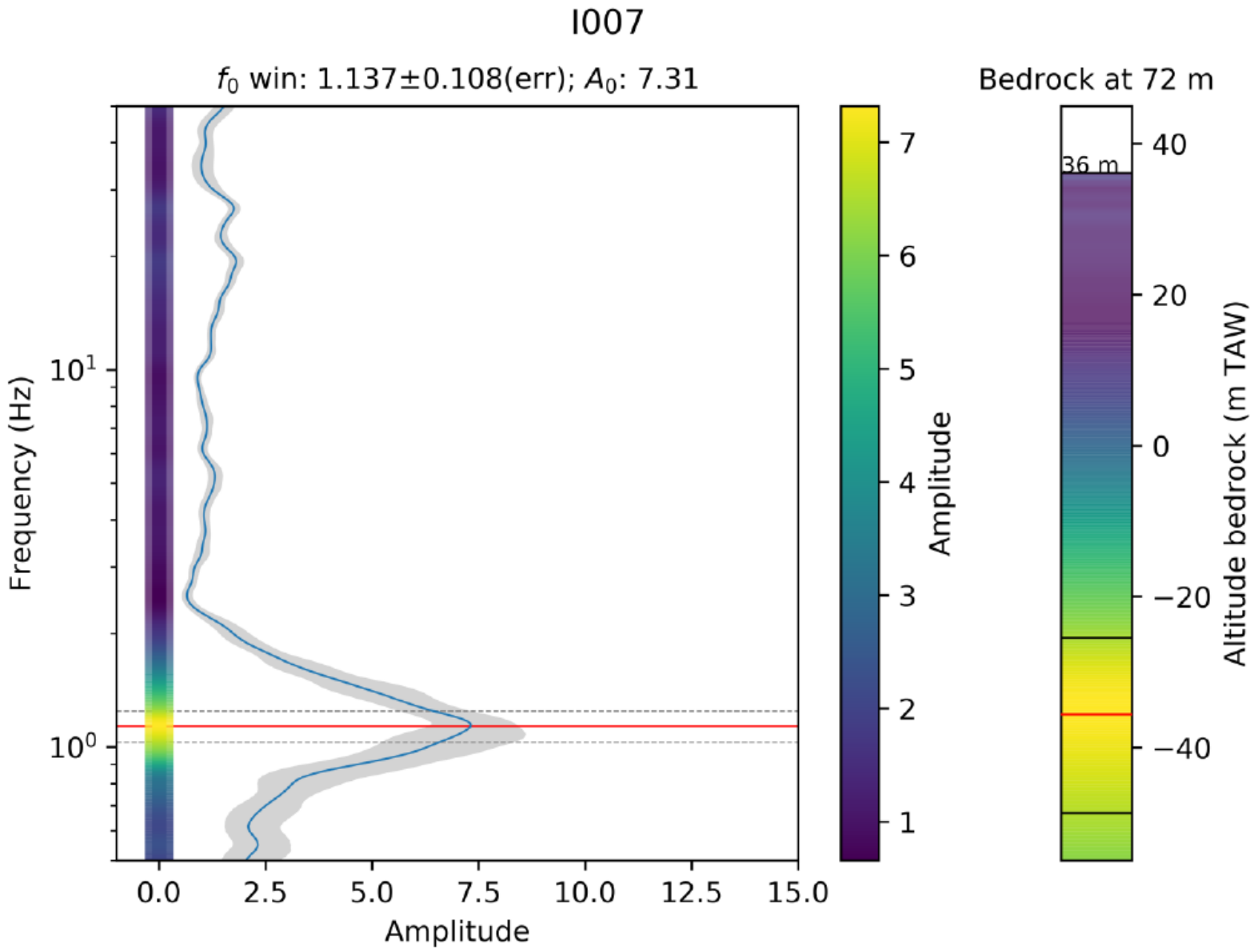


VSP processing:

Depth converted
Corridor stack of
all shot/CDP points
- Westbound line

Van Noten et al., 2018

2018 – HVSR ambient noise analysis - Anderlecht



Anderlecht PZ2 101E1437

HVSR analysis:

Figure = resonance spectrum below the Anderlecht borehole.

Resonance frequency of 1.137 Hz.

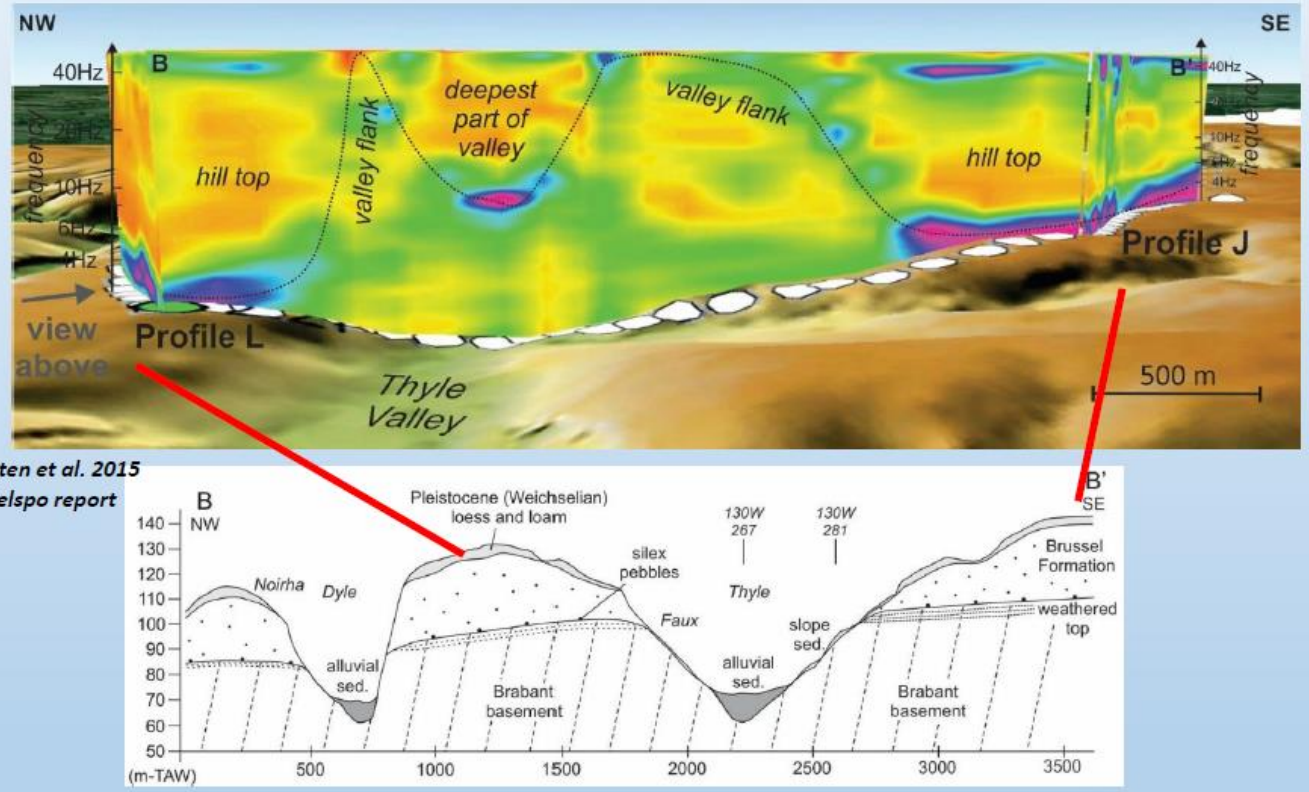
Converted to depth using a empirical equation between depth and resonance frequency. Depth equation is developed for Brussels by HVSR above boreholes with known bedrock depth (See Van Noten et al. EGU2018 Talk) .

HVSR analysis of measurement above the Anderlecht borehole indicates a depth of 72 m, which slightly overestimates the real depth to bedrock.

Van Noten et al., 2015

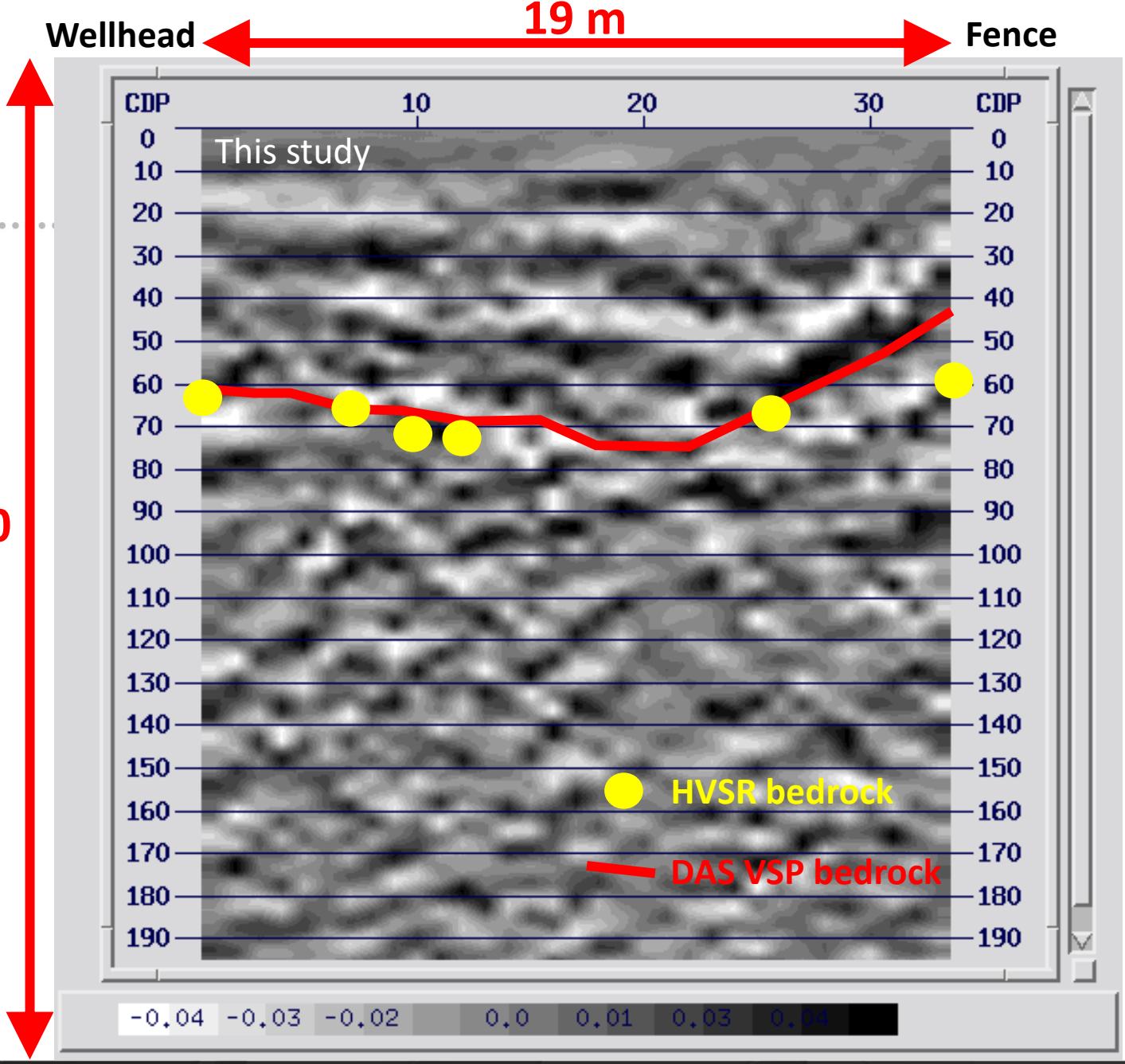
Calibration between depth and resonance frequency f_0

Interpolation between points allows "bedrock depth mapping"



Faux valley near Court-Saint-Etienne: bedrock depth 25 m at hill tops, 10 m in valley, 0-1 m at slopes


Van Noten et al., 2018
f0:1Hz depth: 60 mBM: -25m
f0:1Hz depth: 68 mBM: -33m
f0:1Hz depth: 69 mBM: -33m
f0:1Hz depth: 71 mBM: -36m
f0:1Hz depth: 69 mBM: -33m
f0:1Hz depth: 73 mBM: -37m
f0:1Hz depth: 66 mBM: -30m
f0:1Hz depth: 71 mBM: -35m
f0:1Hz depth: 72 mBM: -36m
f0:1Hz depth: 69 mBM: -32m
f0:1Hz depth: 71 mBM: -35m
f0:1Hz depth: 72 mBM: -36m
f0:1Hz depth: 65 mBM: -28m
f0:1Hz depth: 64 mBM: -27m
10 m


Wellhead
19 m
Fence
190 m
CDP
10
20
30
This study
HVSR bedrock
DAS VSP bedrock
-0.04
-0.03
-0.02
0.0
0.01
0.03
0.04


f0:1Hz
depth: 60
mBM: -25m
f0:1Hz
depth: 68
mBM: -33m
f0:1Hz
depth: 69
mBM: -33m
f0:1Hz
depth: 71
mBM: -36m
f0:1Hz
depth: 69
mBM: -33m
f0:1Hz
depth: 73
mBM: -37m
f0:1Hz
depth: 66
mBM: -30m
f0:1Hz
depth: 71
mBM: -35m
f0:1Hz
depth: 72
mBM: -36m
f0:1Hz
depth: 69
mBM: -32m
f0:1Hz
depth: 71
mBM: -35m
f0:1Hz
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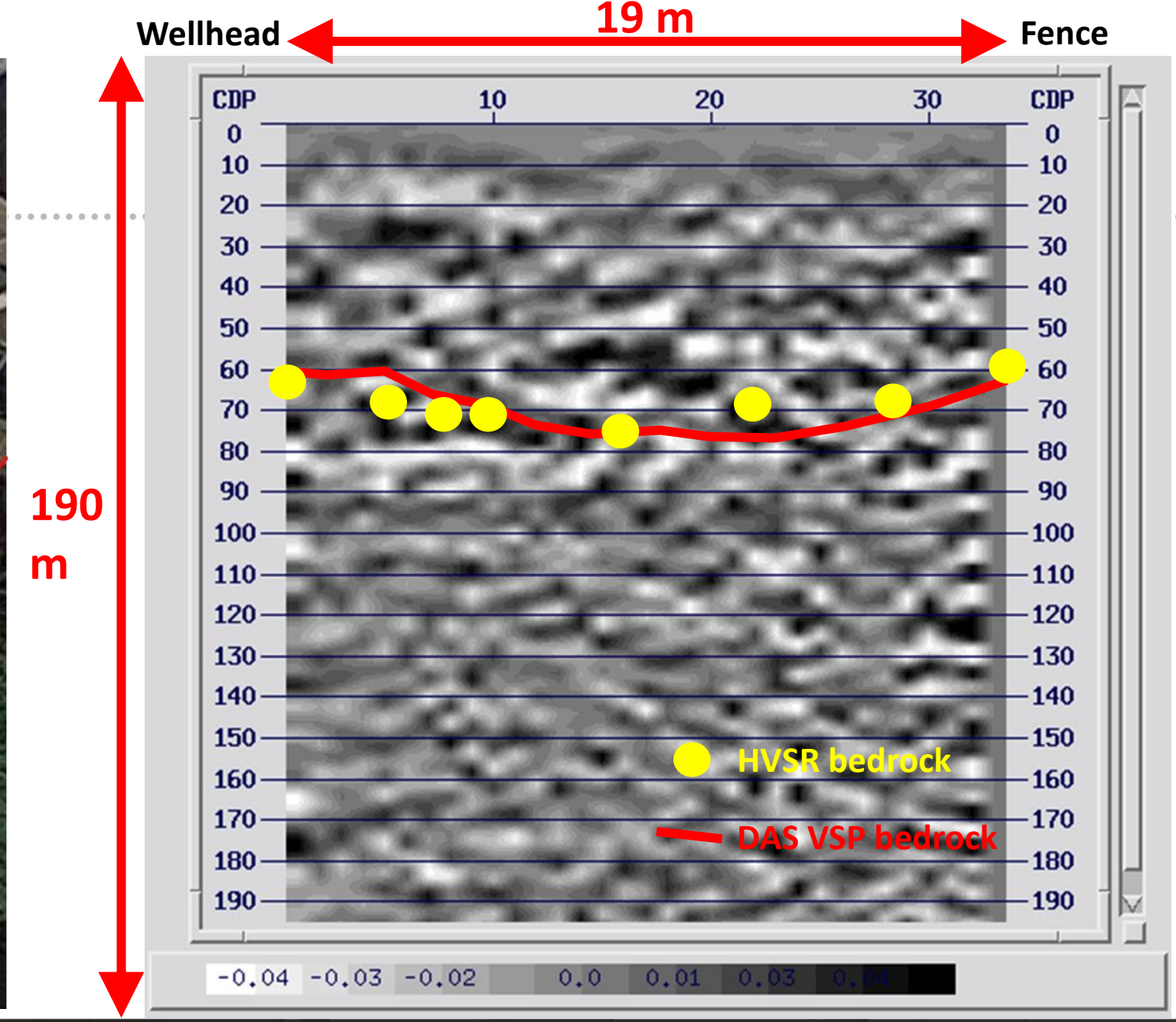
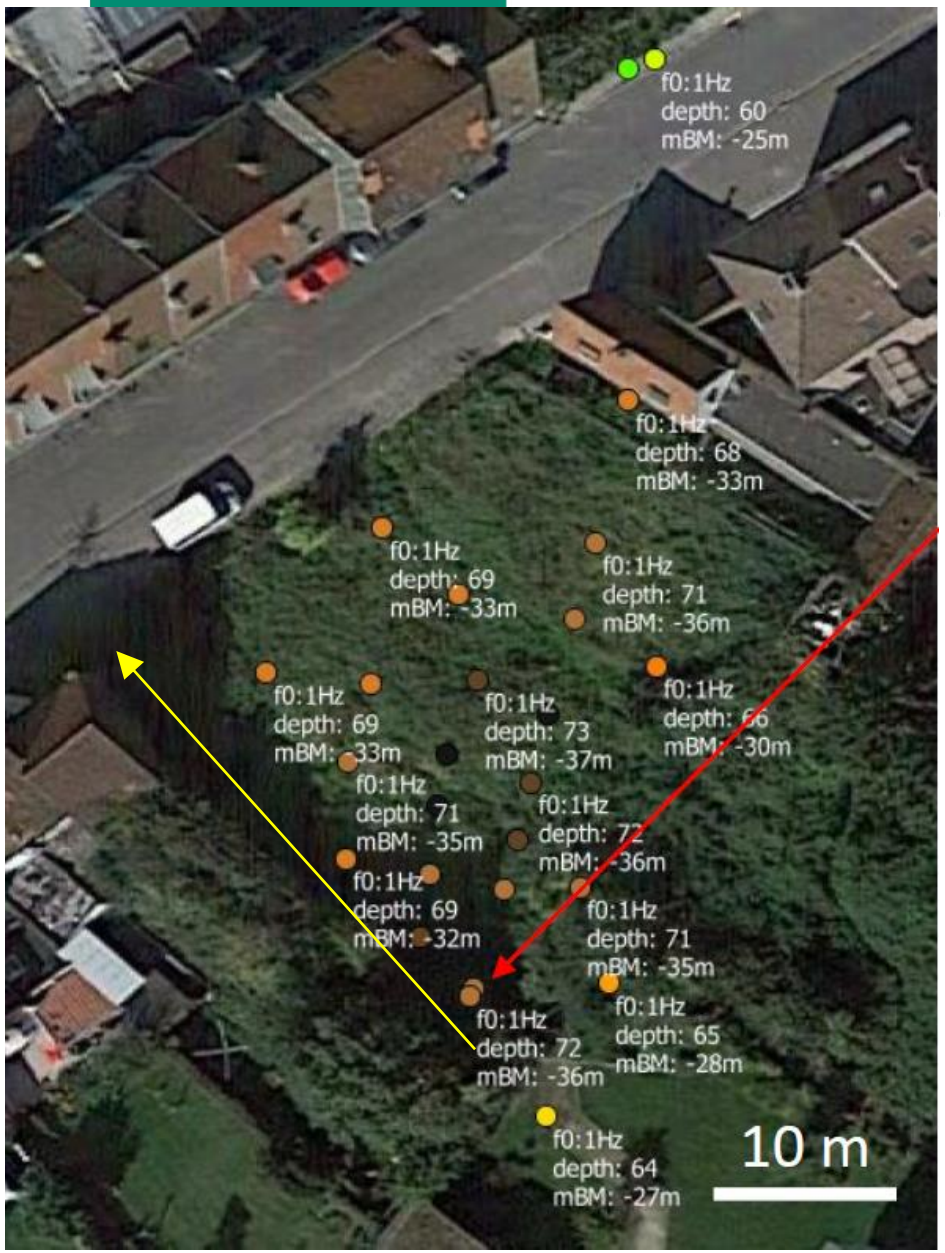
depth: 65
mBM: -28m
f0:1Hz
depth: 64
mBM: -27m
10 m


Wellhead
19 m
Fence
190 m
CDP
10
20
30
CDP
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
HVSR bedrock
DAS VSP bedrock
-0.04
-0.03
-0.02
0.0
0.01
0.03


f0:1Hz
depth: 60
mBM: -25m
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f0:1Hz
depth: 66
mBM: -30m
f0:1Hz
depth: 71
mBM: -35m
f0:1Hz
depth: 72
mBM: -36m
f0:1Hz
depth: 69
mBM: -32m
f0:1Hz
depth: 71
mBM: -35m
f0:1Hz
depth: 72
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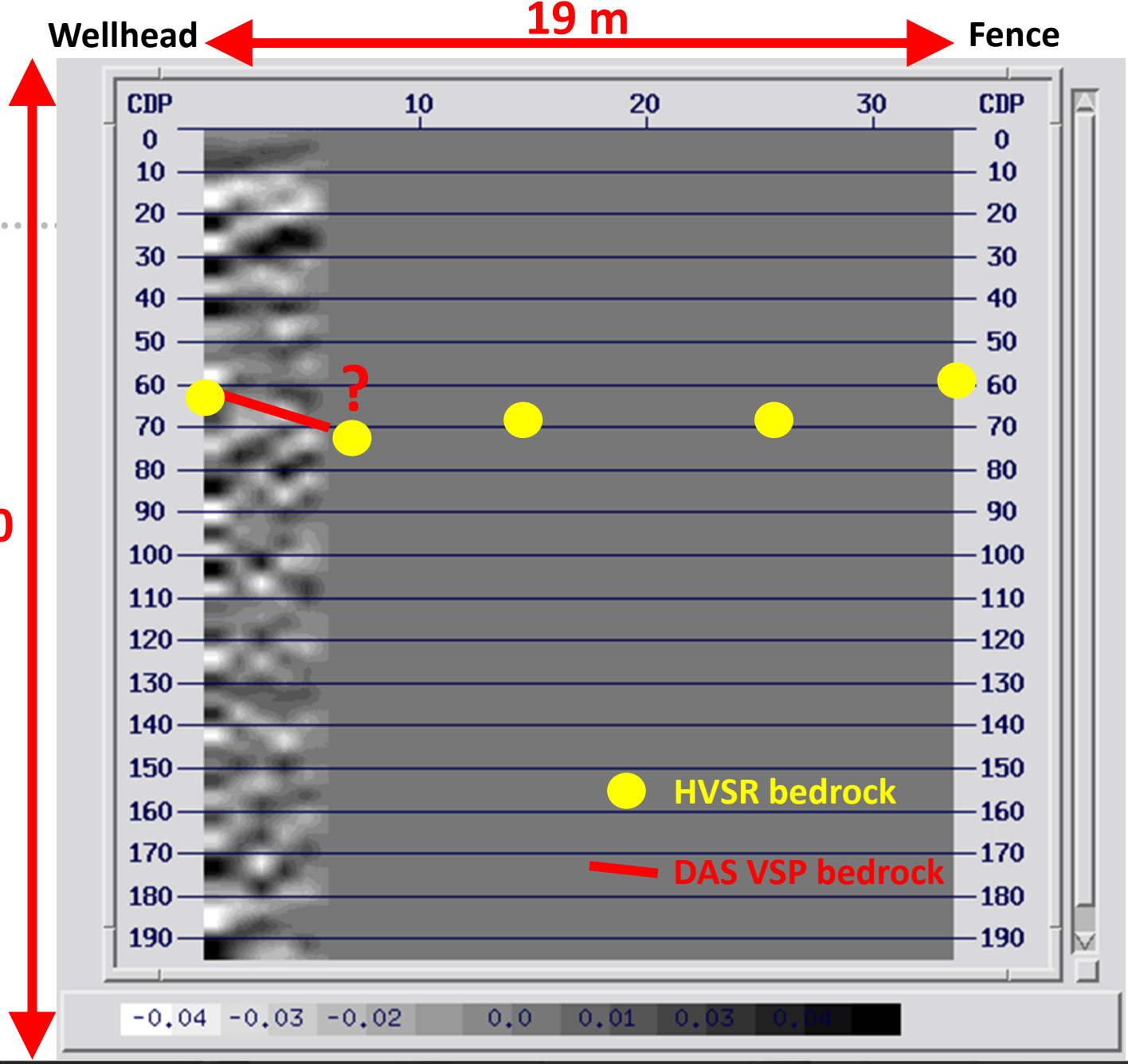
f0:1Hz
depth: 65
mBM: -28m
f0:1Hz
depth: 64
mBM: -27m
10 m


Wellhead
19 m
Fence
190 m
CDP
10
20
30
?
HVSR bedrock
DAS VSP bedrock
-0.04
-0.03
-0.02
0.0
0.01
0.03
0.04

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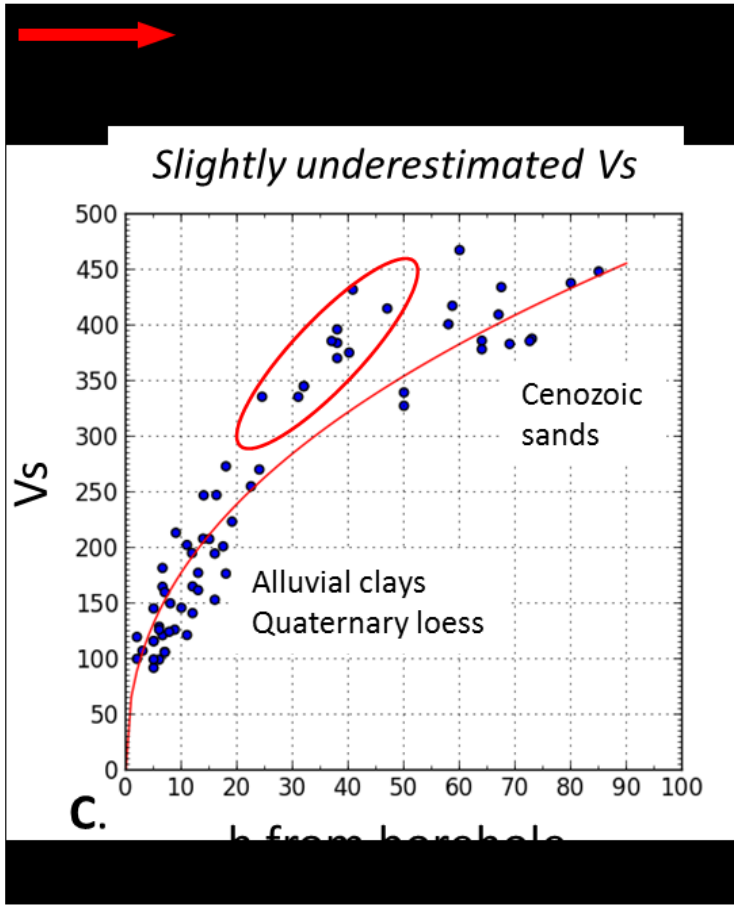
Discussion

- Problem: Velocities from DAS VSP indicate Vp velocities of > 1600 m/s whereas the HVSR indicates a Vs velocity of +- 320 m/s. This is possible, but the Vp/Vs ratio of +- 5 is rather high for unconsolidated sediments. This requires further investigation.

- Problem #2: Mismatch between HVSR and DAS VSP bedrock depth



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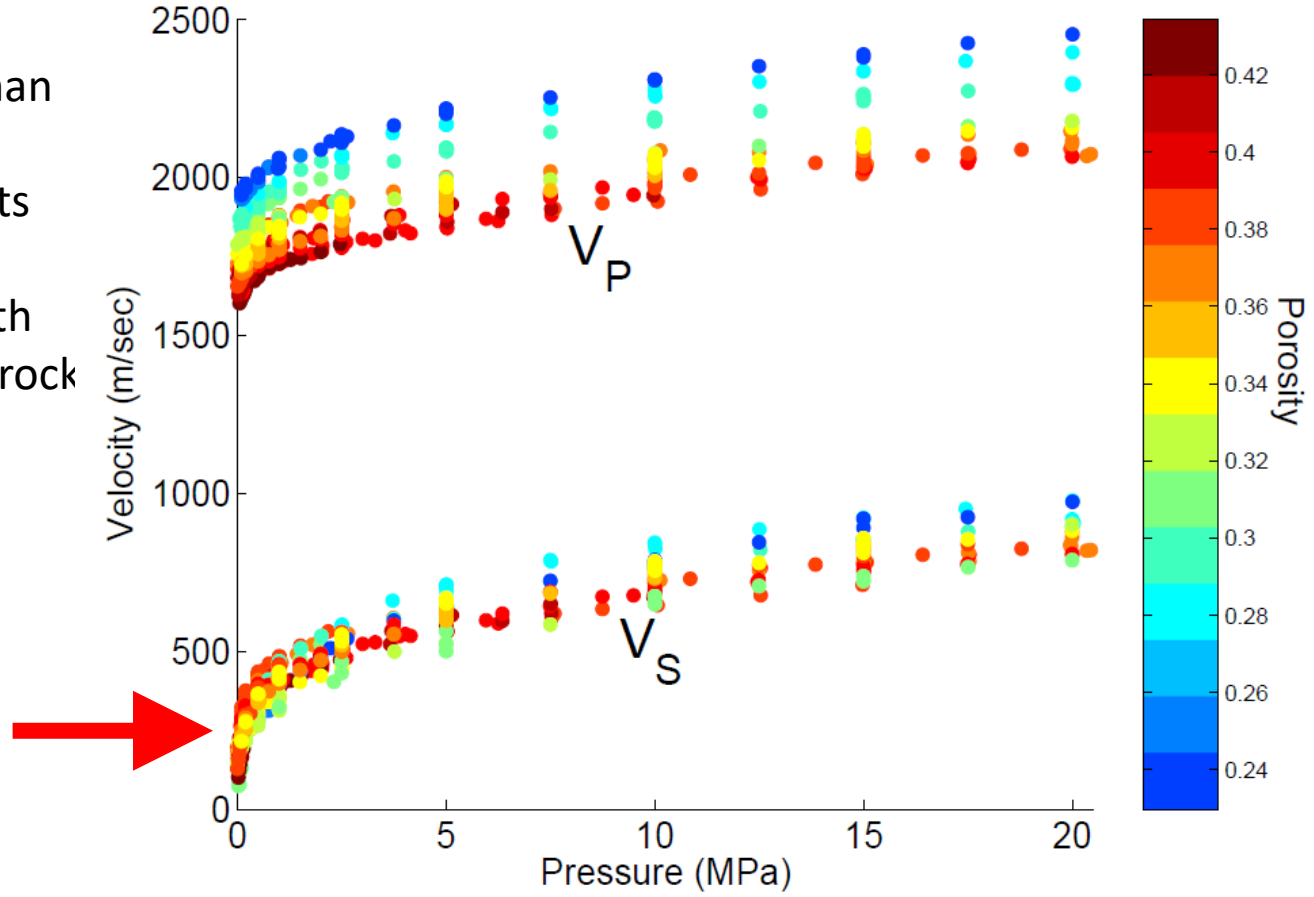
Discussion

- Possible solution: PhD work from Zimmer (2003) at Stanford University and Kruiver et al. (2017), Hofman et al. (2017) shows that at very shallow Vp and Vs such high Vp/Vs ratios of > 5 can occur in sediments

- Possible solution #2: Migration and better time-depth of corridor stack may align HVSR and DAS VSP bedrock



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Conclusions

- In spite of the difficult urban and operational conditions, the DAS VSP survey was a partial success
- High (urban) noise levels, small offsets, limited source strength proved challenges to good signal
- We conclude that the use of a small vibroseis source is not recommended as there is too much 1) overall attenuation, 2) uncoherent dissipation of especially high frequencies 3) other near surface effects. Impulsive source is better
- Poor coupling of the fibre-optic cable to the well casing/cement can sometimes be forgiving, but can also stop the show
- Need for better protocol in the field for obtaining geometry and layout of DAS array that goes beyond tap tests

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Acknowledgements / Thank You / Questions

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