Passive subsurface imaging around the KAUST shallow well site using a multi-scale seismic acquisition system

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1 - Introduction

Figure 1: Site location and acquisition set-up of the control well (green triangle), the autonomous STRYDE nodes (red solid line) and the broadband stations (blue squares).

Objective: Improve the imaging of the subsurface layers by accurately characterizing the shallow subsurface first.

Why ?
- The shallow subsurface contains strong velocity variations and high attenuation
- These factors prevent the propagation of energy at deeper layers

Where ?
- At a site located in KAUST, around a pilot well drilled for a project of geothermal energy

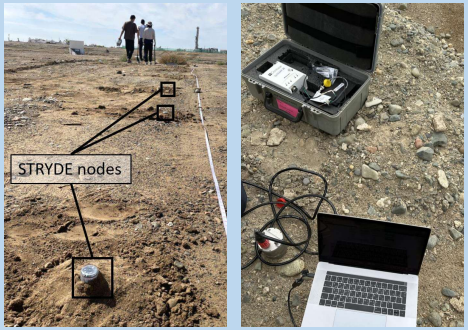


Figure 2: [left] Close-up on the STRYDE nodes, the well is at the upper-right corner. [right] Close-up on a broadband station before it is buried.

2- Methods

2a- Shallow subsurface: seismic interferometry

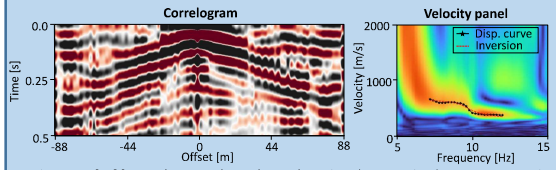
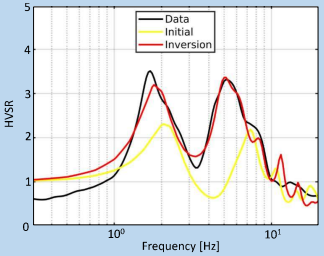


Figure 3: [Left] Correlogram along the nodes, virtual source in the center. Negative offsets towards the south, positive offsets towards the north. [Right] Velocity panel of the positive offsets of the correlogram in [left].

- Interferometry by cross-correlation on the nodes
- Data recorded in 9h segments on 7 different days
- No well activities taking place

2b- Deeper subsurface (S-waves): HVSR



HVSR: Horizontal-to-Vertical Spectral ratio

- 5 months of recording
- 4 Broadband stations

Figure 4: Original HVSR data from station B1, and HVSR from the initial velocity model and inversions.

2b- Deeper subsurface (P-waves): SWD

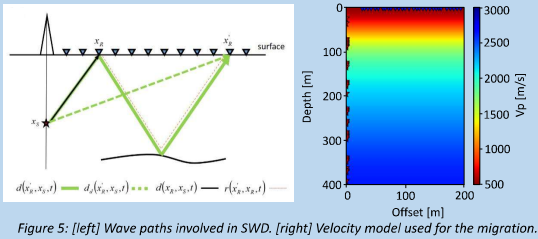


Figure 5: [left] Wave paths involved in SWD. [right] Velocity model used for the migration.

SWD: Seismic While Drilling

Developed method for P-waves imaging with nodes:
- Multi-dimensional deconvolution to remove the surface-related multiples and source signature effects
- Reflection response imaged using pre-stack Kirchhoff depth migration

3- Results

3a- Shallow subsurface

- Inversion of the dispersion curves with *evodcinv*.
- 2D S-wave velocity model built from mean 1D profiles at the receivers (100 inversions per receiver).

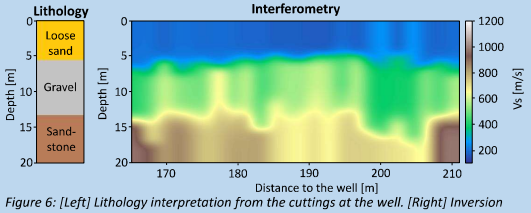


Figure 6: [Left] Lithology interpretation from the cuttings at the well. [Right] Inversion results for the shear waves via interferometry.

3b- Deeper subsurface

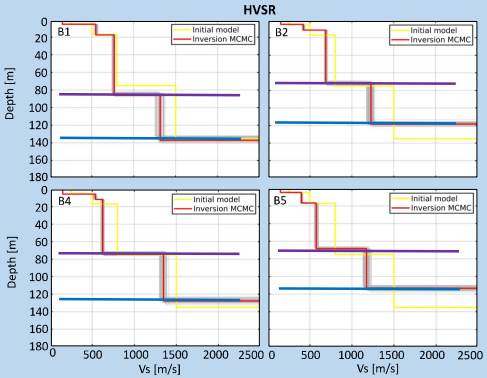


Figure 7: Initial velocity model for HVSR, and results from the Markov-Chain Monte Carlo (MCMC) inversion for the four broadband stations. The purple and blue line would represent the two first main reflectors in Figure 9.

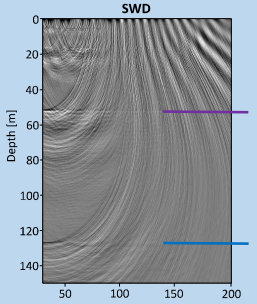


Figure 8: SWD P-wave imaging results. The purple and blue line would represent the two first main reflectors in Figure 9.

- The two main reflectors at ± 75m and ± 135 m are successfully recovered.
- Reflector at 20 m imaged but not seen in the cuttings interpretation from the well.

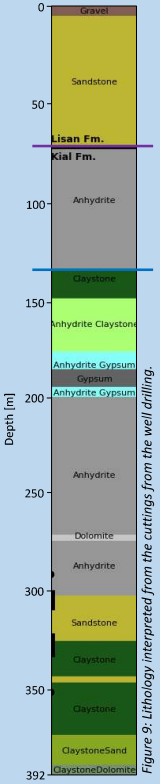


Figure 9: Lithology interpreted from the cuttings from the well drilling.

4- Discussion and conclusion

Discussion

Depth variation could be attributed to:
- Imaging errors
- Lateral heterogeneity due to:
  - Anhydrite layer (that can be ductile)
  - Transition between marine (Kial) and continental (Lisan) formations, that might induce erosion.

Key results for this multi-scale analysis:
- We used interferometry for shallow subsurface recovery, followed by HVSR and SWD for the deeper layers.
- Two main reflectors successfully imaged at ± 75m and ± 135 m.
- The SWD method detected the first reflector slightly shallower at around 55m, likely due to the P-to-S wave velocity ratio.
- An additional reflector at around 20m was observed with SWD and HVSR but was not identified in the lithology from the cuttings.