Final Report: Seismic Analysis at Strategic Border Sites Trip 1: DTRA-OM4

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Final Report: Seismic Analysis at Strategic Border Sites
Trip 1: DTRA-OM4

Summary

The Kansas Geological Survey acquired 14 lines of active seismic data at 12 sites during two trips to the US-Mexico border. Data were processed using multi-channel analysis of surface waves (MASW), refraction tomography, and surface wave inversion to obtain 2-D profiles of shear-wave velocity (Vs), compressional-wave velocity (Vp), and seismic quality factor (Qs and Qp) for the near surface. This report contains final processing and results for the DTRA-OM4 site.

Data Acquisition

One line of seismic data (~345 m) was acquired on January 29, 2013, at DTRA-OM4 coincident with the USGS ERT profile (Figure 1). The system of sources and receivers, collectively, is the Active Seismic Imaging (ASI) system developed by and fabricated at the Kansas Geological Survey (Figure 2). Seismic sources were an accelerated weight drop for surface wave and long-offset compressional energy, sledge hammer and steel plate for near-offset compressional-wave energy, and sledge hammer and shear block for shear-wave energy. Seismic receivers were located in a towed 144-channel 3-component (3-C) land streamer with 48 stations separated by 1.2 m. Receivers were single 4.5 Hz and 40 Hz vertical geophones and two 14.5 Hz horizontal (SV orientation) geophones (Figure 3). Seismographs were a Geometrics Geode distributed system. The survey was fixed spread with variable 0-85.3 m source offset (Figure 4) to obtain sufficient seismic sampling within the depth of interest. Individual receiver spreads overlapped by one station.

Downhole data were acquired on August 12-13, 2013, essentially on top of the surface seismic line, with a 3-C downhole Geostuff geophone (Figure 5). The shallowest receiver station was located at a depth of 0.75 m, and receiver station spacing was 0.75 m (Figure 6). A repeatable shear and compressional 9 kg hammer source, developed and fabricated at the Kansas Geological Survey, was located at 3 m from the borehole (Figure 7). A 2.7 kg sledge hammer and steel plate were located at 22.9 m from the borehole.

For both the surface and downhole seismic surveys, multiple shots were acquired and recorded separately for each unique shot/receiver configuration and stacked during processing to minimize ambient noise (Figure 8) and increase the signal-to-noise ratio.

Figure 1: Aerial photo of DTRA-OM4 and the location of the active seismic line (red).

Figure 2: ASI towing a 144-channel 3-C land streamer.

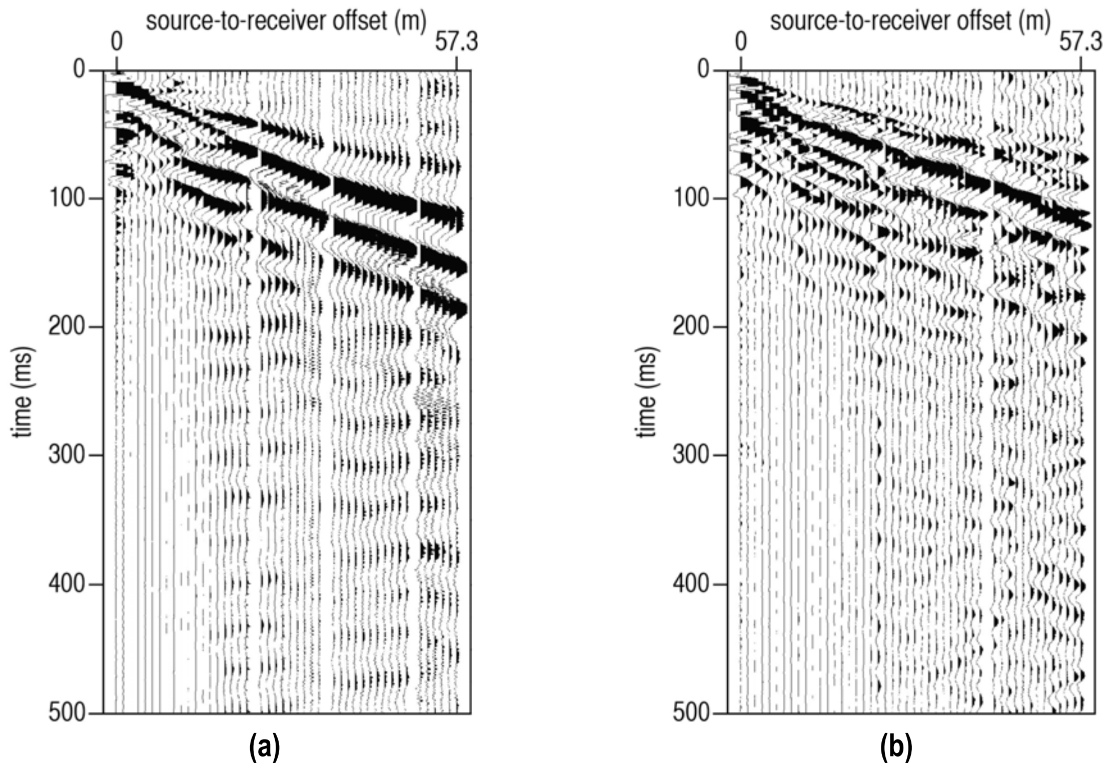

Figure 3: Representative off-end shot gathers at DTRA-OM4. (*a*) Sledge hammer and shear block source recorded with shear 14.5 Hz geophones, SV orientation. (*b*) Weight-drop source recorded with vertical 40 Hz geophones.

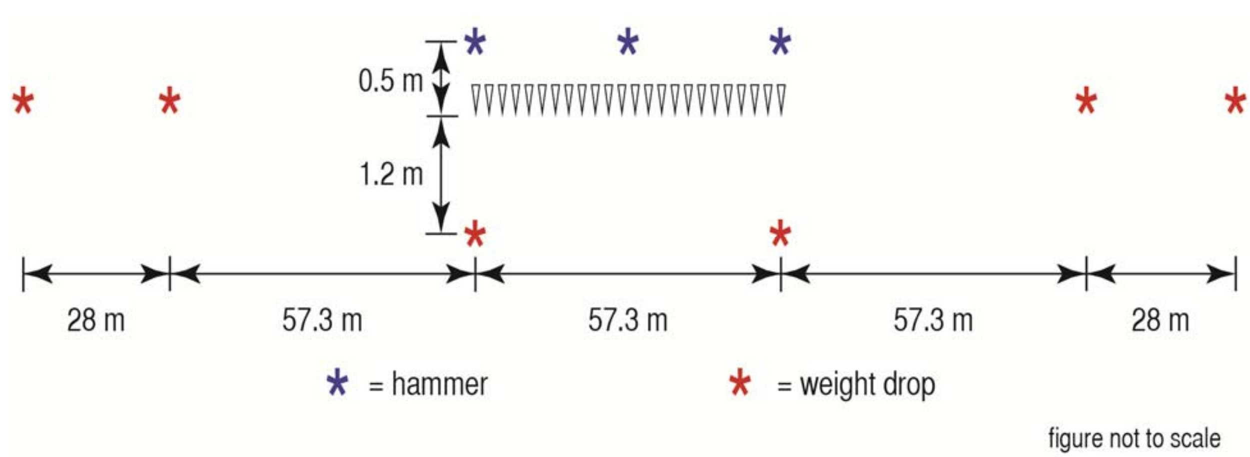

Figure 4: Diagram indicating all shot point locations relative to a single receiver spread. The receiver spread consisted of 48 stations separated by 1.2 m.

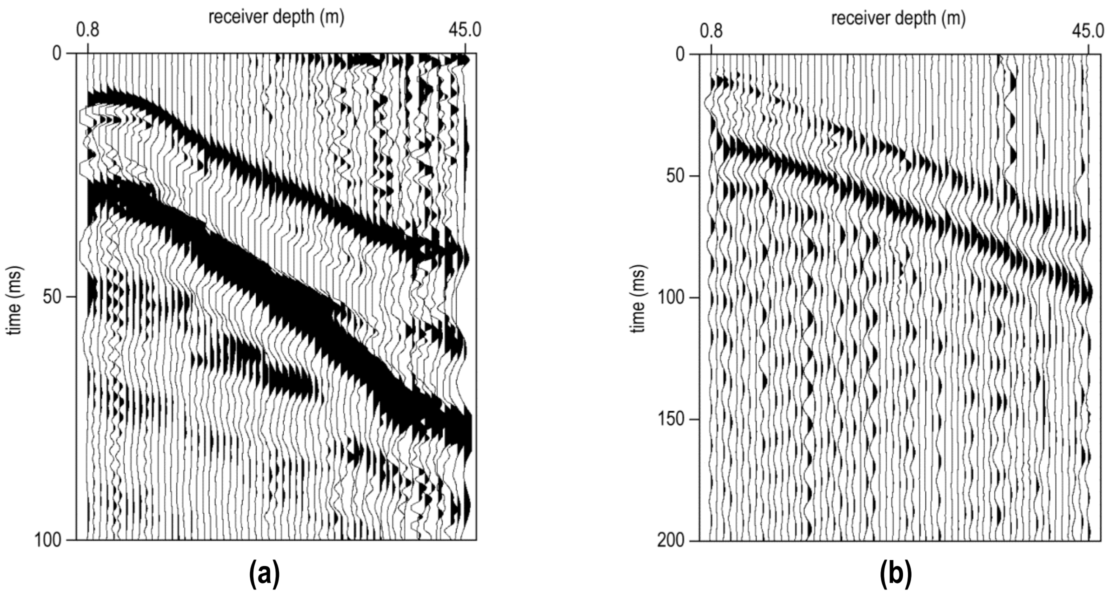

Figure 5: Representative downhole (*a*) vertical and (*b*) shear records at DTRA-OM4.

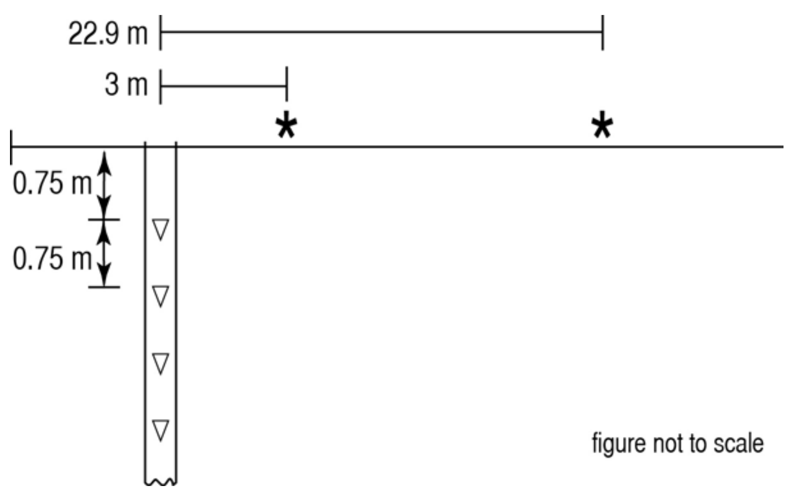

Figure 6: Downhole seismic field layout.

Figure 7: Downhole seismic acquisition utilized at DTRA-OM4.

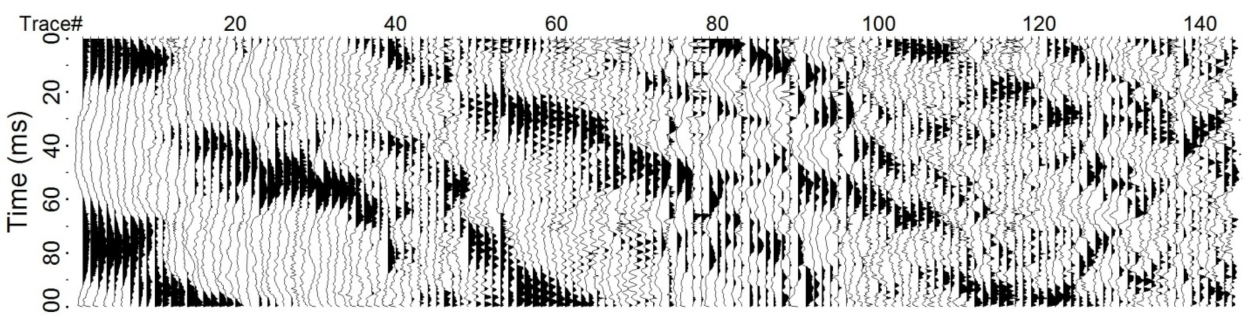

Figure 8: Representative ambient noise recorded at DTRA-OM4. Traces 1-48 represent the 4.5 Hz geophones, 49-96 represent the shear geophones, and 97-144 represent the 40 Hz geophones.

Data Processing

Multichannel-analysis of surface waves (MASW) was used to analyze dispersive Rayleigh-wave energy and estimate shear-wave velocity (Vs). Fundamental-mode energy was interpreted and inverted using a weighted, damped least-squares approach (Xia et al., 1999), resulting in a 2-D Vs profile. Average and interval downhole compressional-wave velocity (Vp) and Vs were calculated using the arrival time of the direct P-wave and S-wave, respectively, and pathlength from the seismic source to each receiver depth. Refraction tomography with 1.2 x 1.2 m cell size was used to generate Vs and Vp profiles. Shear- and compressional-wave seismic quality factors (Qs and Qp, respectively) were obtained using a surface wave inversion technique (Xia et al., 2010). Downhole shear records were numerically rotated to orient the recorded shear-wave traces in the vertical (SV) and horizontal (SH) polarization directions (Di Siena et al., 1984). The direct P-waves and S-waves were isolated on compressional and shear records, respectively, and the spectral ratio method was used to estimate Qp and Qs for each lithology identified in drilling notes (Tonn, 1991; Hasse and Stewart, 2004). The velocity and quality values calculated from downhole data were used to constrain inversion and improve accuracy of the results obtained using surface seismic methods.

Final Results

MASW

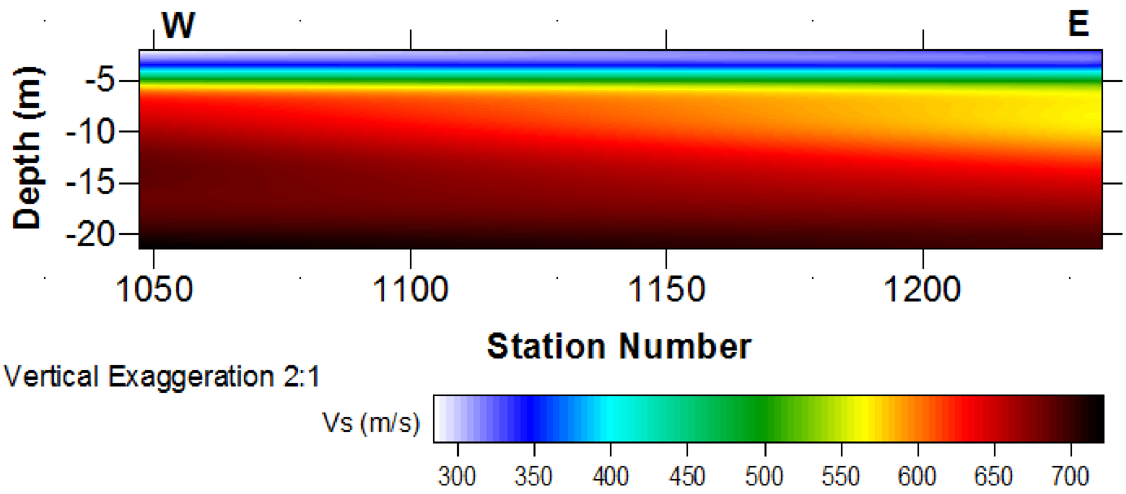

Figure 9: MASW Vs profile at DTRA-OM4.

Downhole Vs

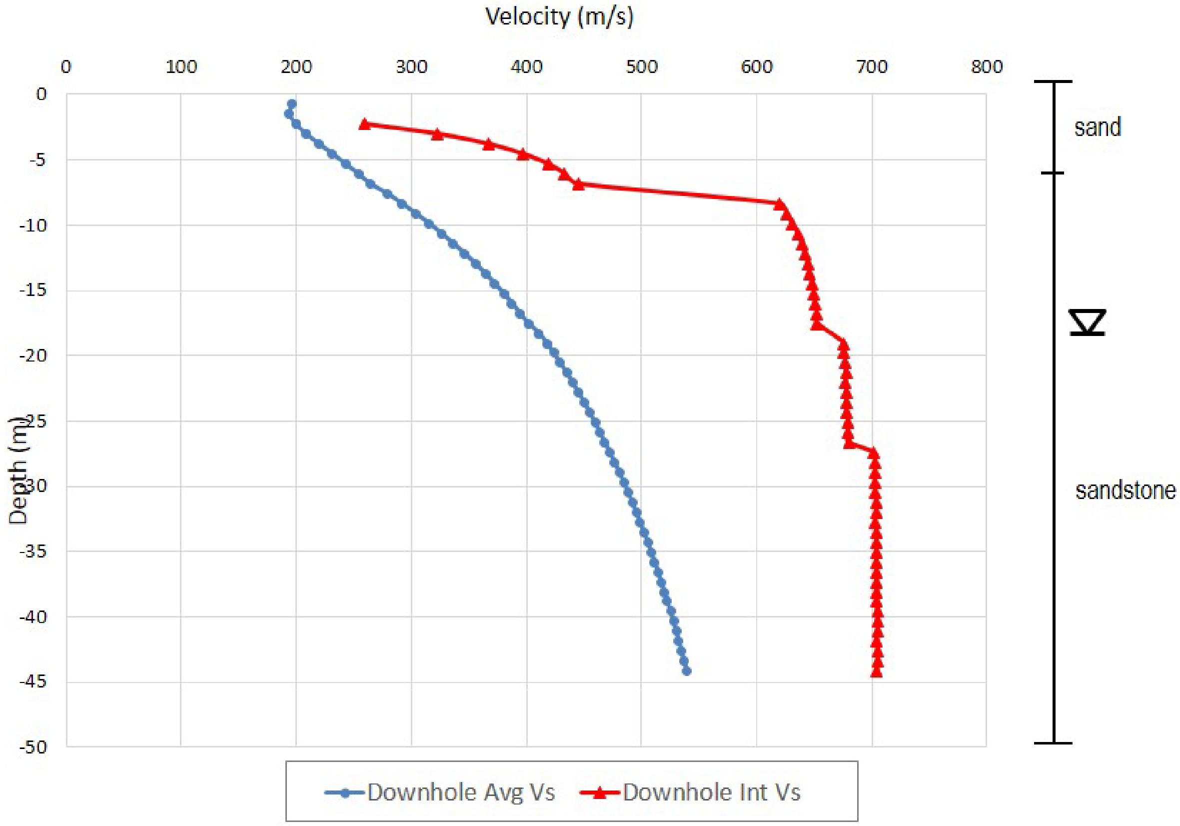

Figure 10: Downhole Vs profile at DTRA-OM4.

Downhole Vp

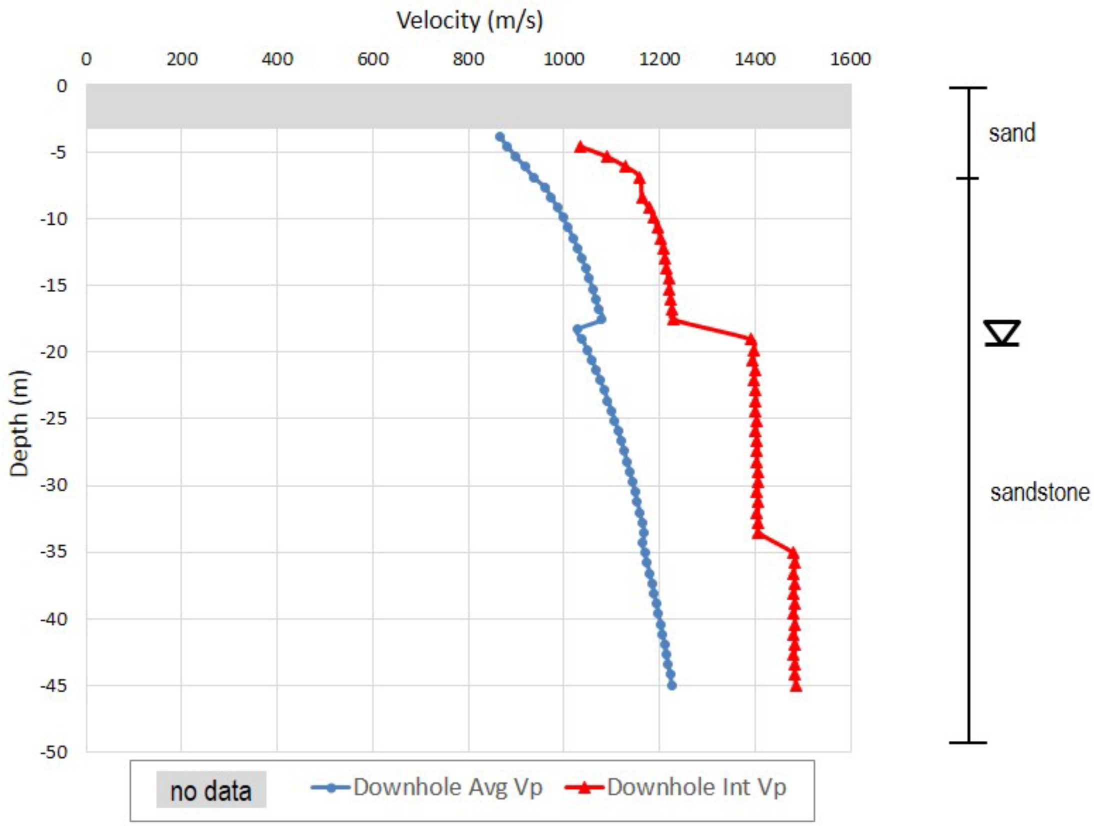

Figure 11: Downhole Vp profile at DTRA-OM4.

Vs Tomography

The initial model for final tomography results was generated based on downhole interval S-wave velocities. Information from downhole seismic data improved discrimination of shear waves from mode-converted seismic energy. Shot records were re-picked to ensure accurate arrival times of the direct and refracted shear waves. This is the only site with coincident borehole and surface seismic locations, to date. Not coincidentally, this is the only line where S-wave velocities obtained using both MASW and tomography are a near perfect match with downhole interval velocities, especially at shallow depths.

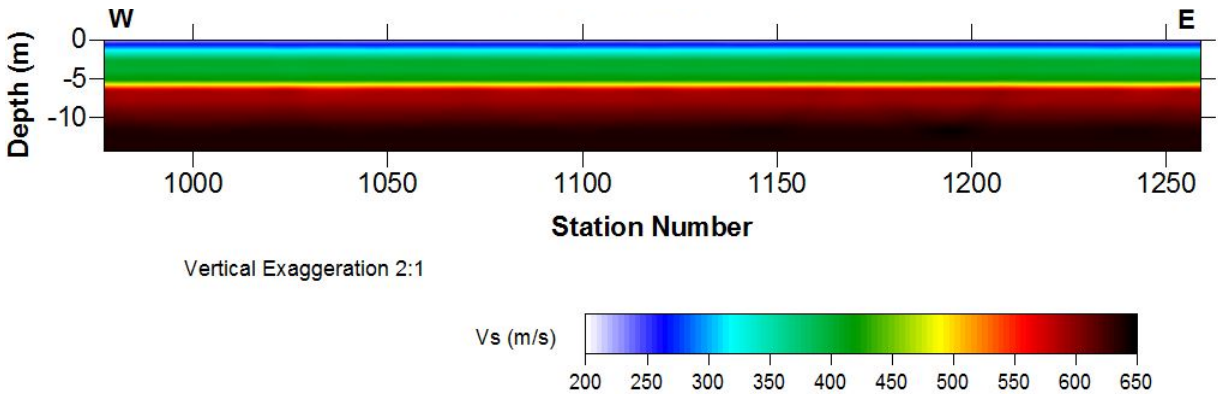

Figure 12: Vs tomography profile at DTRA-OM4.

Vp Tomography

The initial model for final tomography results was generated based on downhole interval P-wave velocities. Picked first arrival times used for preliminary processing were reviewed to confirm their accuracy and used for final processing. This is the only site with coincident borehole and surface seismic locations, to date. Not coincidentally, this is the only line where P-wave velocities obtained using tomography are a near perfect match with downhole interval velocities, especially at shallow depths.

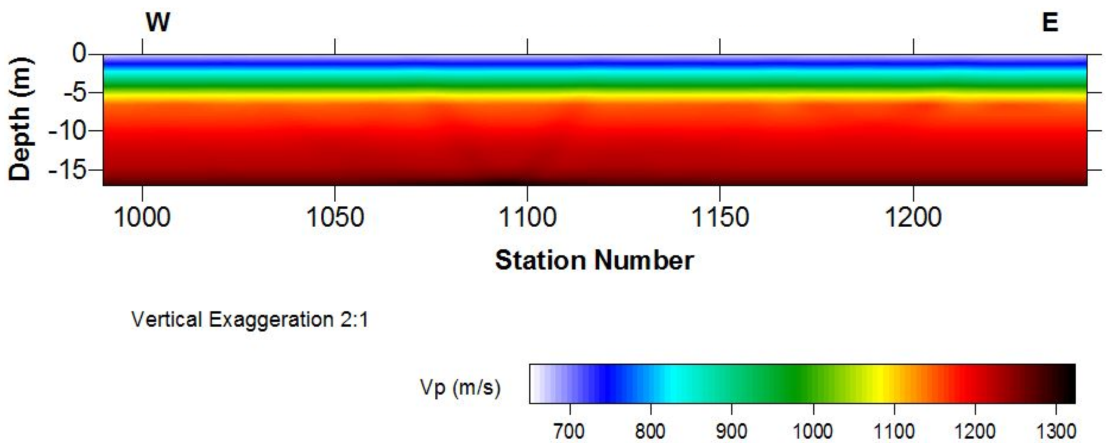

Figure 13: Vp tomography profile at DTRA-OM4.

Downhole Qs

Calculation of Q is highly sensitive to sources of noise (e.g., traffic) during acquisition.

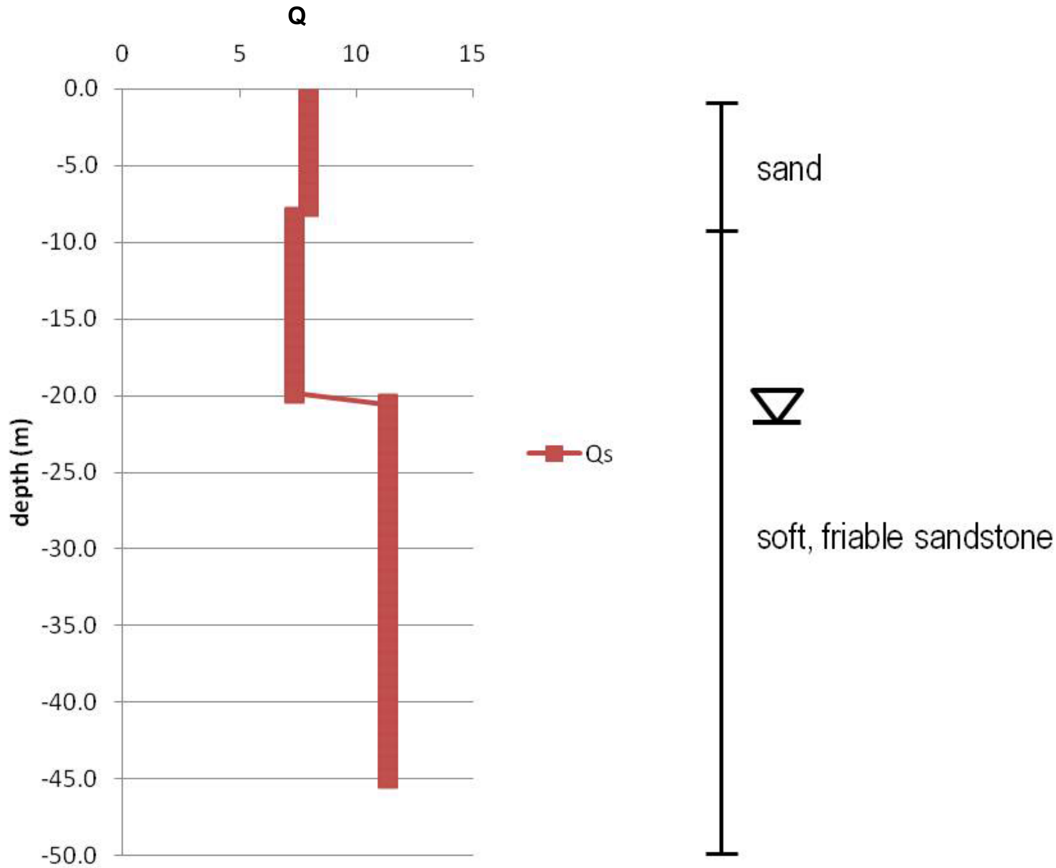

Figure 14: Downhole Qs profile at DTRA-OM4.

Downhole Qp

Calculation of Q is highly sensitive to sources of noise (e.g., traffic) during acquisition.

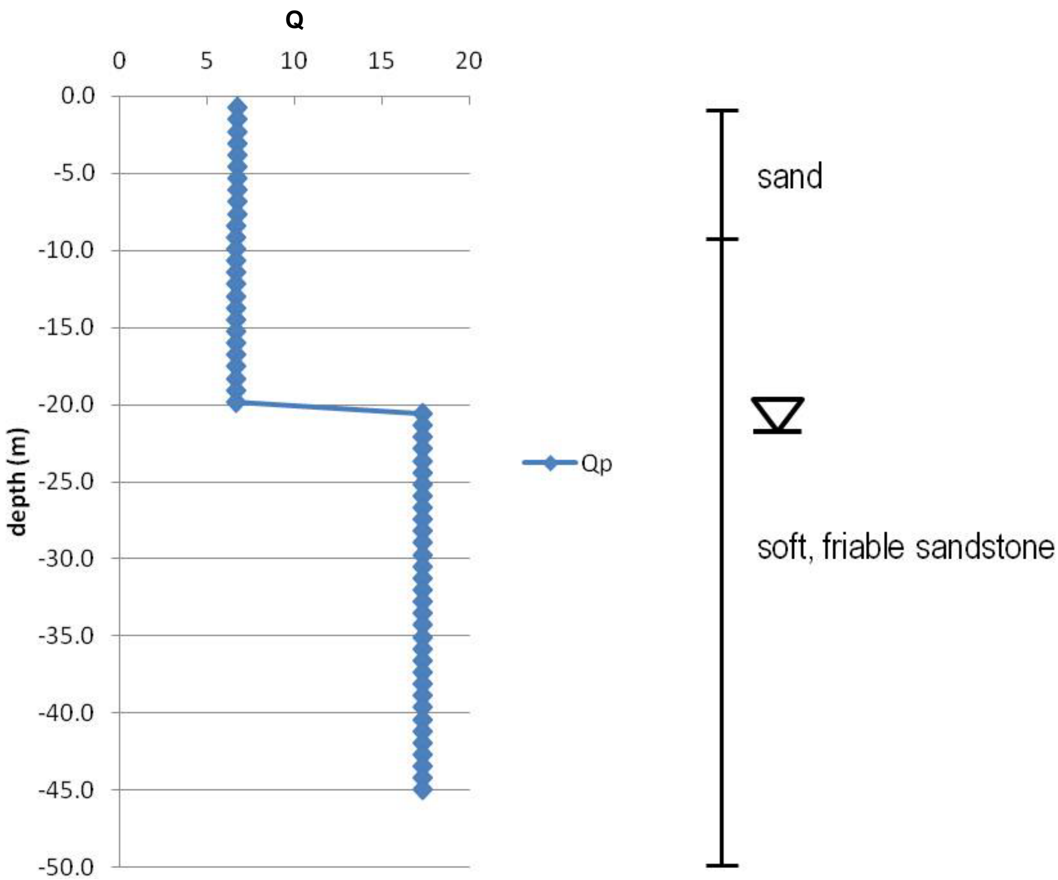

Figure 15: Downhole Qp profile at DTRA-OM4.

Surface Qs

Calculation of Q is highly sensitive to sources of noise (e.g., traffic) during acquisition. Due to lack of stability in the inversion, the upper 5-10 m is low confidence.

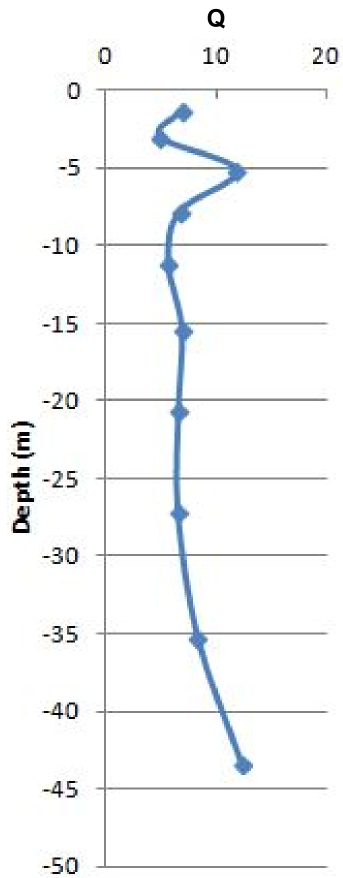

Figure 16: Surface Qs at DTRA-OM4.

Surface Qp

Calculation of Q is highly sensitive to sources of noise (e.g., traffic) during acquisition. Due to lack of stability in the inversion, the upper 5-10 m is low confidence.

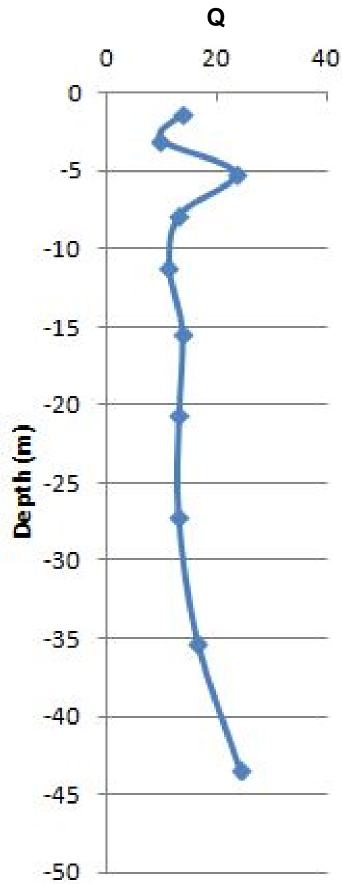

Figure 17: Surface Qp at DTRA-OM4.

Related Materials

Delivered materials include:

1. This report
2. PowerPoint presentation summarizing this report
3. Data files
4. Document explaining the data file format
5. Detailed list of deliverables

References

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