

# Final Report: Seismic Analysis at Strategic Border Sites Trip 1: DTRA-OM1

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# **Final Report: Seismic Analysis at Strategic Border Sites**

## **Trip 1: DTRA-OM1**

### **Summary**

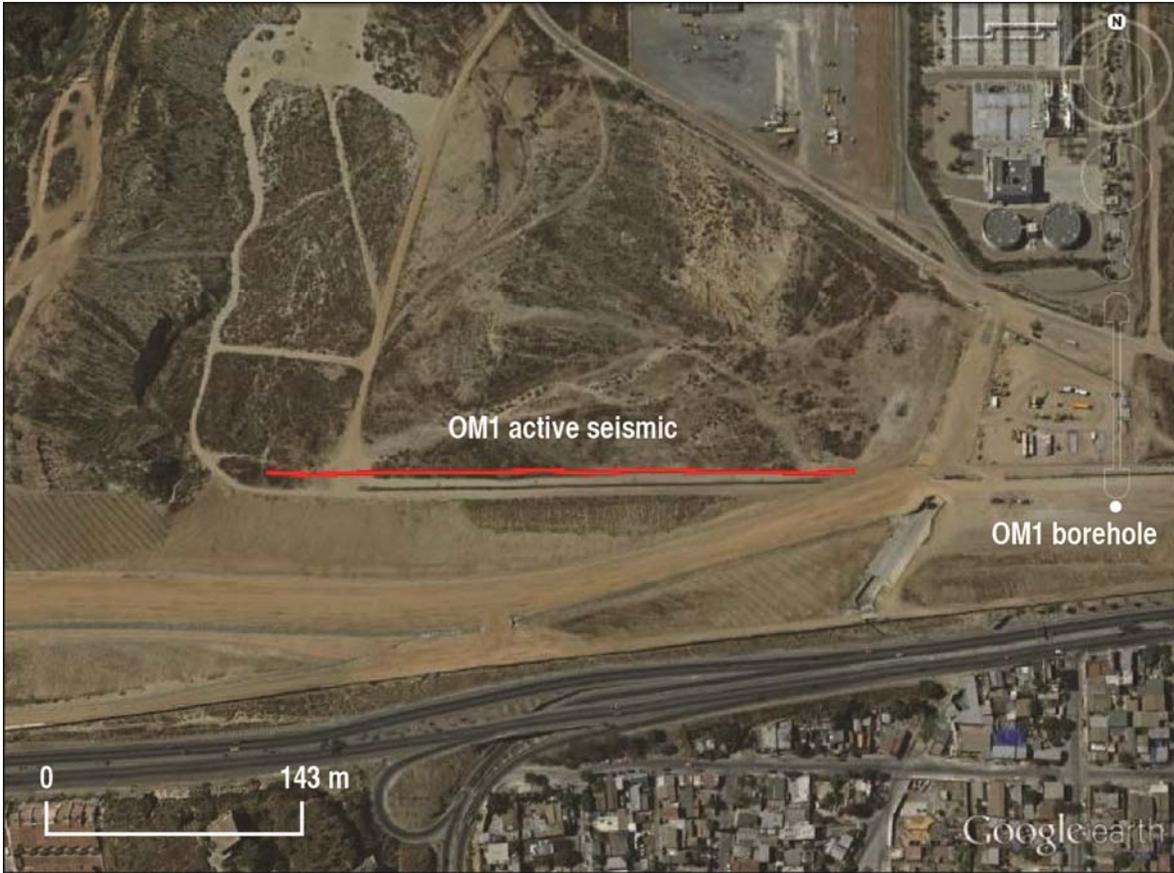
The Kansas Geological Survey acquired 14 lines of active seismic data at 12 sites during two trips to the US-Mexico border. Data were processed using multi-channel analysis of surface waves (MASW), refraction tomography, and surface wave inversion to obtain 2-D profiles of shear-wave velocity ( $V_s$ ), compressional-wave velocity ( $V_p$ ), and seismic quality factor ( $Q_s$  and  $Q_p$ ) for the near surface. This report contains final processing and results for the DTRA-OM1 site.

### **Data Acquisition**

One line of seismic data (~375 m) was acquired on January 30, 2013, at DTRA-OM1 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 14, 2013, approximately 350 m from the center of the surface seismic line, with a 3-C downhole Geostuff geophone (Figure 5). The shallowest receiver station was located at a depth of 1.5 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.

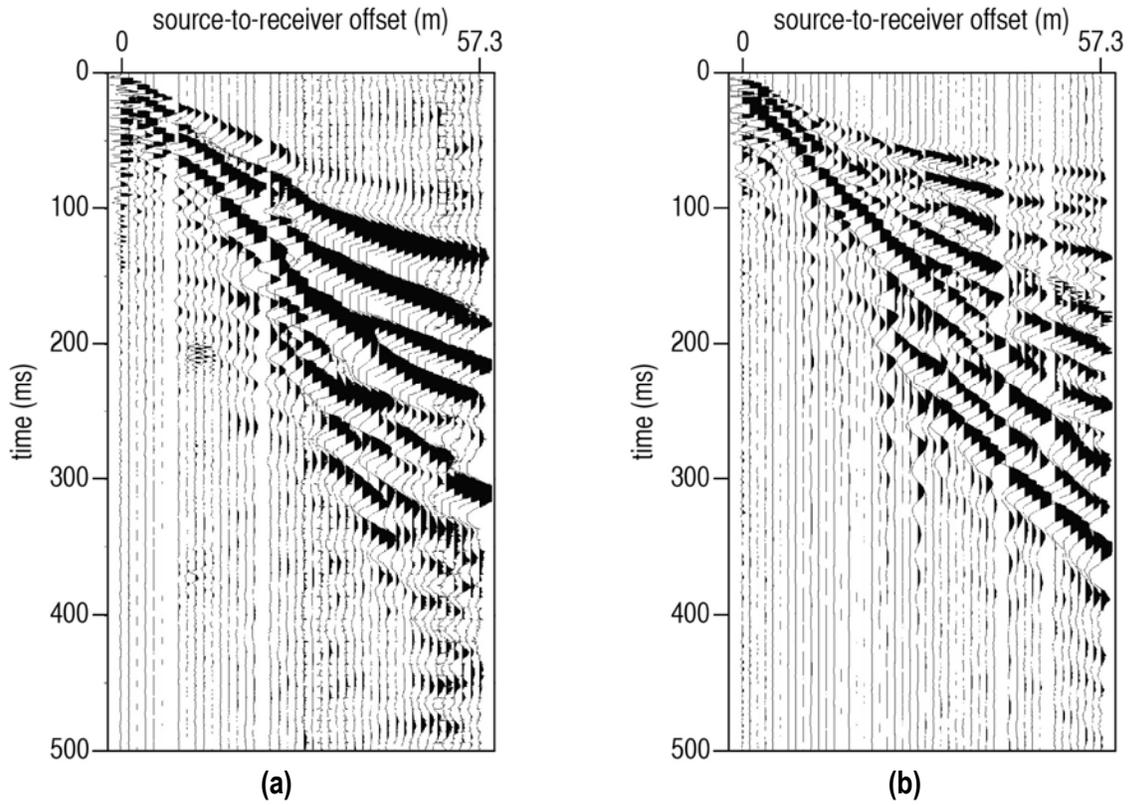
For both the surface and downhole seismic surveys, multiple shots were acquired and recorded separately for each unique shot/receiver configuration and stacked during processing to minimize ambient noise (Figure 8) and increase the signal-to-noise ratio.



**Figure 1:** Aerial photo of DTRA-OM1 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-OM1. (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.

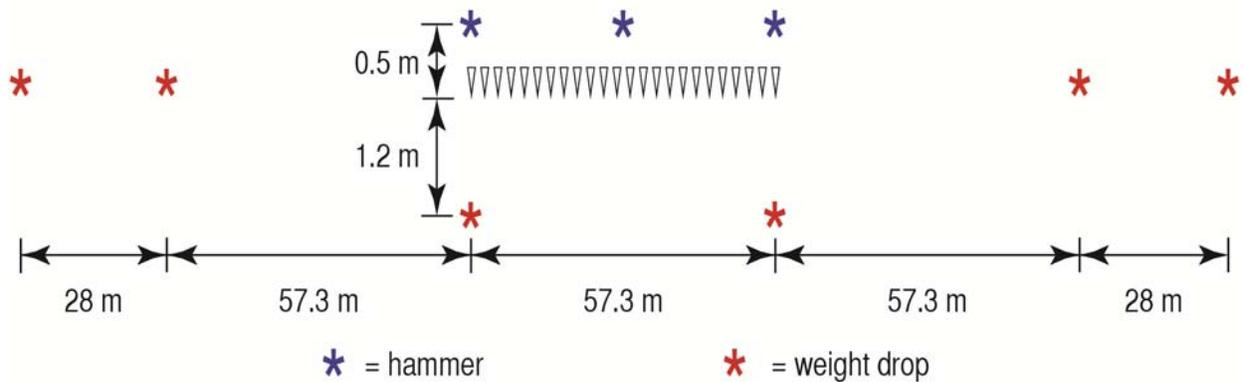
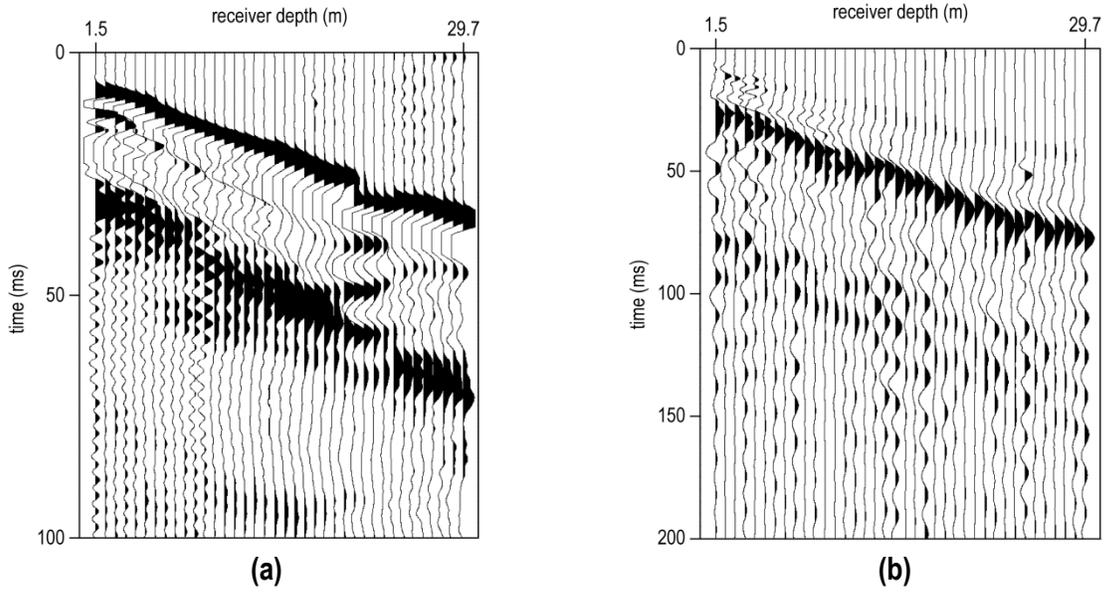
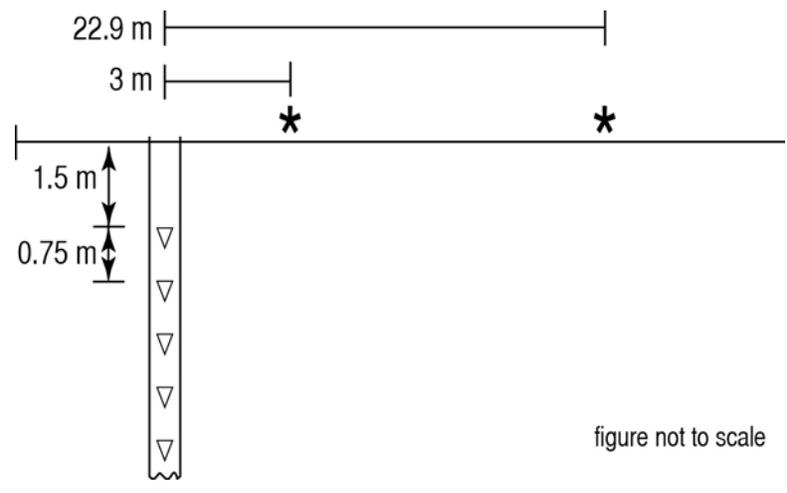


figure not to scale

**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.



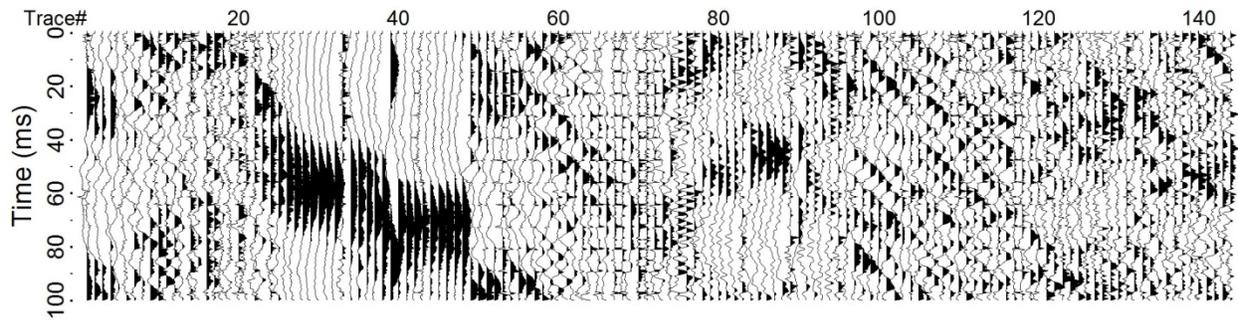
**Figure 5:** Representative downhole (a) vertical and (b) shear records at DTRA-OM1.



**Figure 6:** Downhole seismic field layout.



**Figure 7:** Downhole seismic acquisition utilized at DTRA-OM1.



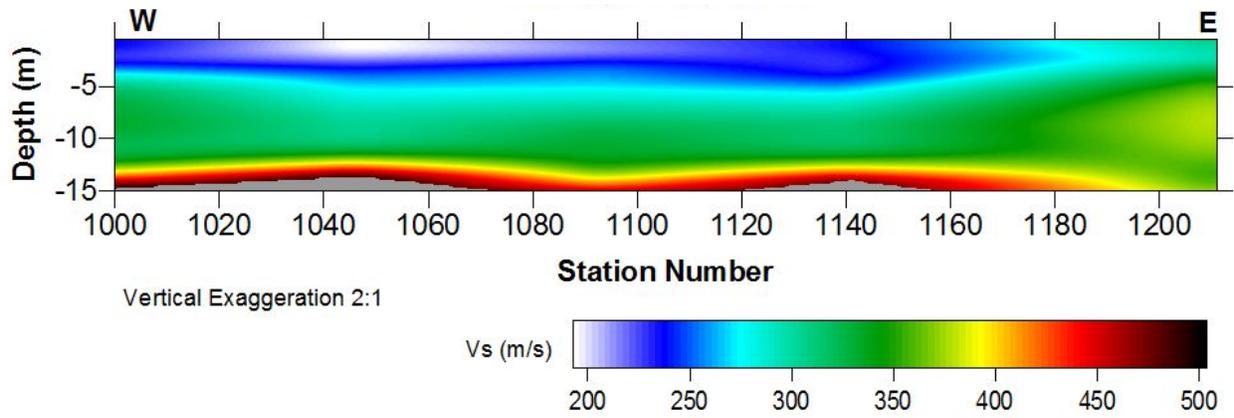
**Figure 8:** Representative ambient noise recorded at DTRA-OM1. Traces 1-48 represent the 4.5 Hz geophones, 49-96 represent the shear geophones, and 97-144 represent the 40 Hz geophones.

## Data Processing

Multichannel-analysis of surface waves (MASW) was used to analyze dispersive Rayleigh-wave energy and estimate shear-wave velocity ( $V_s$ ). Fundamental-mode energy was interpreted and inverted using a weighted, damped least-squares approach (Xia et al., 1999), resulting in a 2-D  $V_s$  profile. Average and interval downhole compressional-wave velocity ( $V_p$ ) and  $V_s$  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 estimate  $V_s$  and  $V_p$ . Joint-analysis of refractions and surface waves (JARS, Ivanov et al., 2010) was used to constrain the non-uniqueness inherently involved in refraction inversion, resulting in a physically realistic 2-D  $V_s$  profile. Shear- and compressional-wave seismic quality factors ( $Q_s$  and  $Q_p$ , respectively) were obtained using a surface wave inversion technique (Xia et al., 2010). The downhole geophone had a preferential orientation with very little rotation in the borehole, therefore numerical rotation of recorded shear traces was not required. The direct P-waves and S-waves were isolated on compressional and shear records, respectively, and the spectral ratio method was used to estimate  $Q_p$  and  $Q_s$  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.

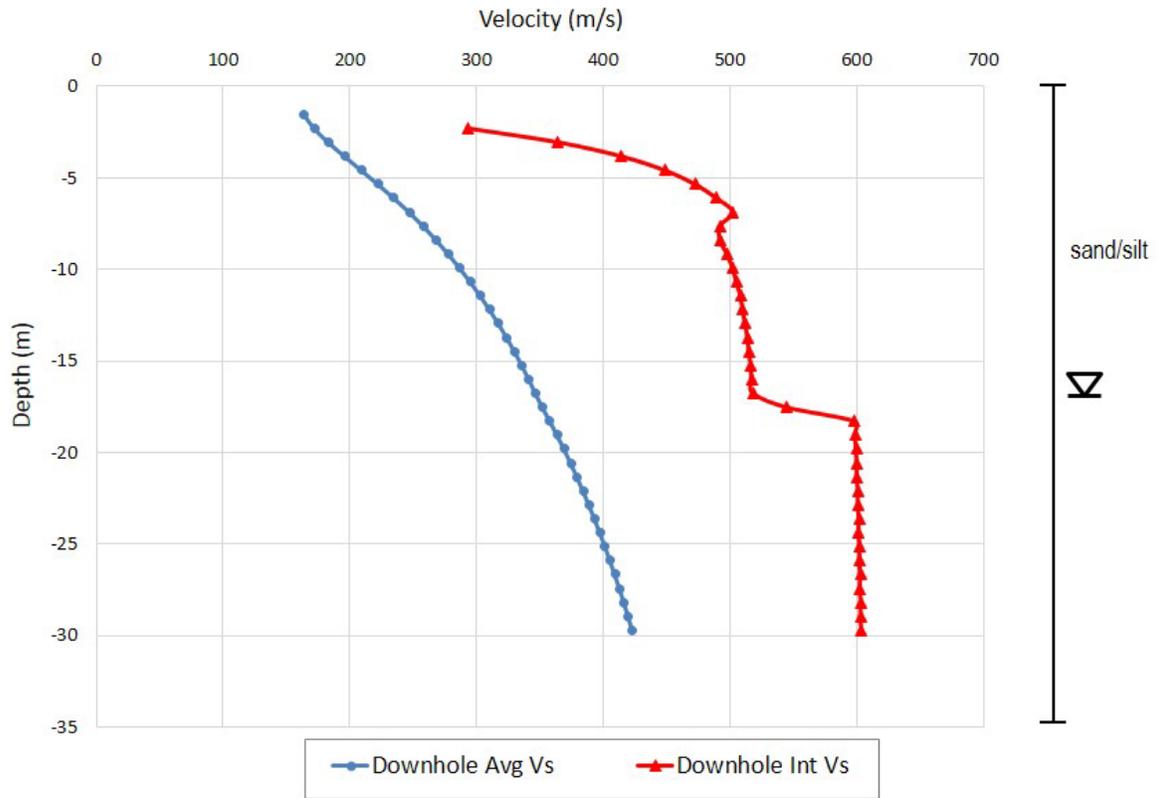
## Final Results

### *MASW*



**Figure 9:** MASW  $V_s$  profile at DTRA-OM1. Gray represents areas with no data.

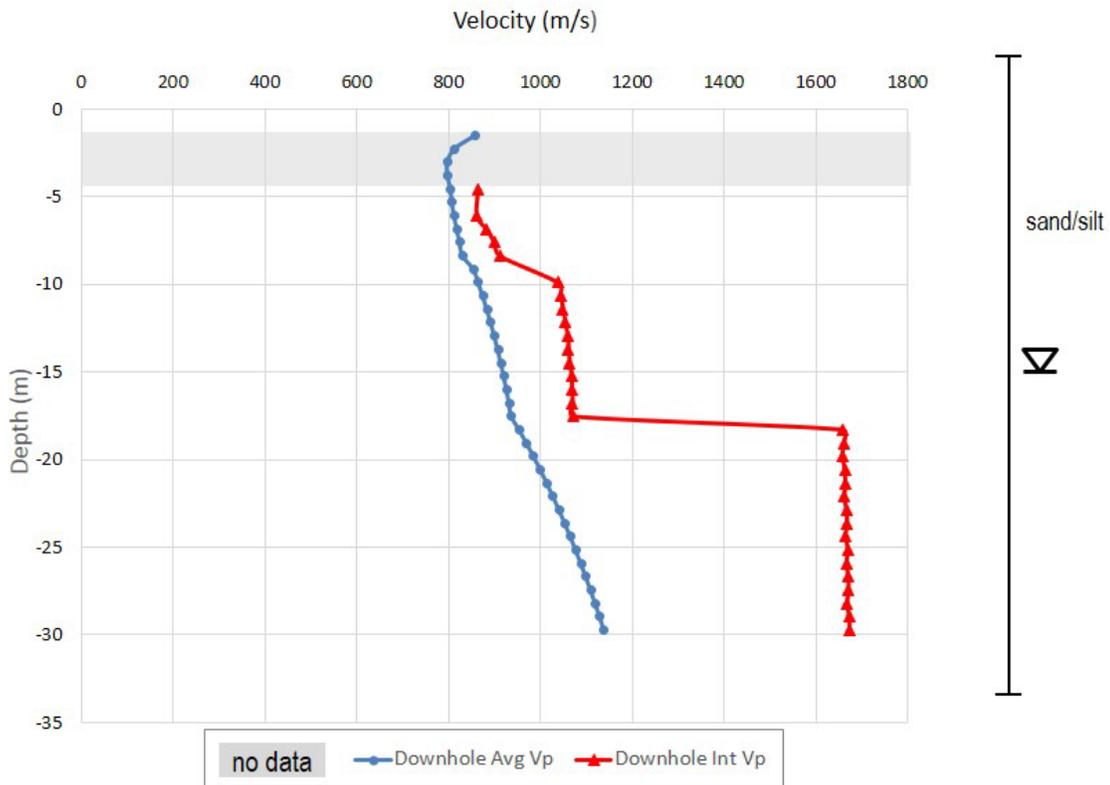
***Downhole Vs***



**Figure 10:** Downhole Vs profile at DTRA-OM1.

### Downhole Vp

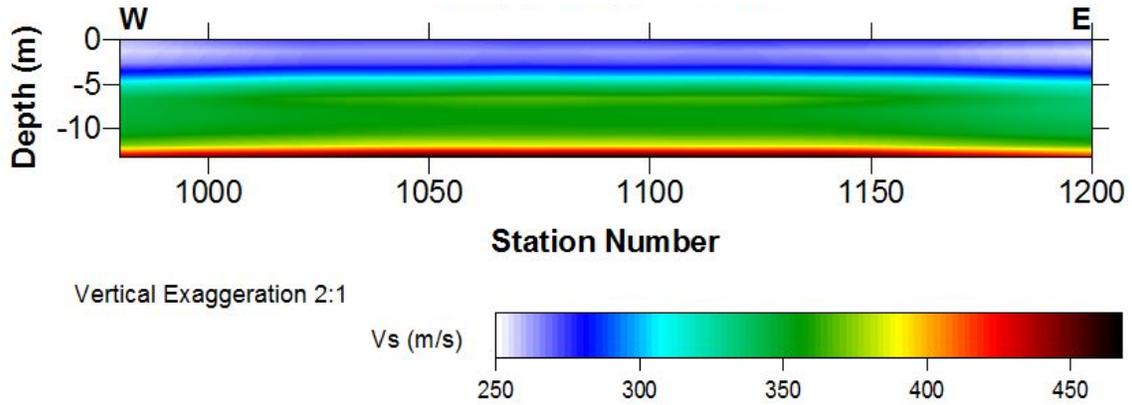
The waveform of direct P-wave recorded within receiver depths of 21.3 to 23.6 m is inconsistent with adjacent receiver depths (Figure 5a). In addition, the seismic energy that arrives after the direct wave has a high amplitude ring. This is suggestive of an anomaly outside the borehole casing. The location in the borehole is coincident with the water table, but there are multiple possible sources of these phenomena; without additional information, the exact cause is unclear. Arrival times, and thus velocity, on the four traces within this interval have greater uncertainty.



**Figure 11:** Downhole Vp profile at DTRA-OM1.

### *Vs Tomography*

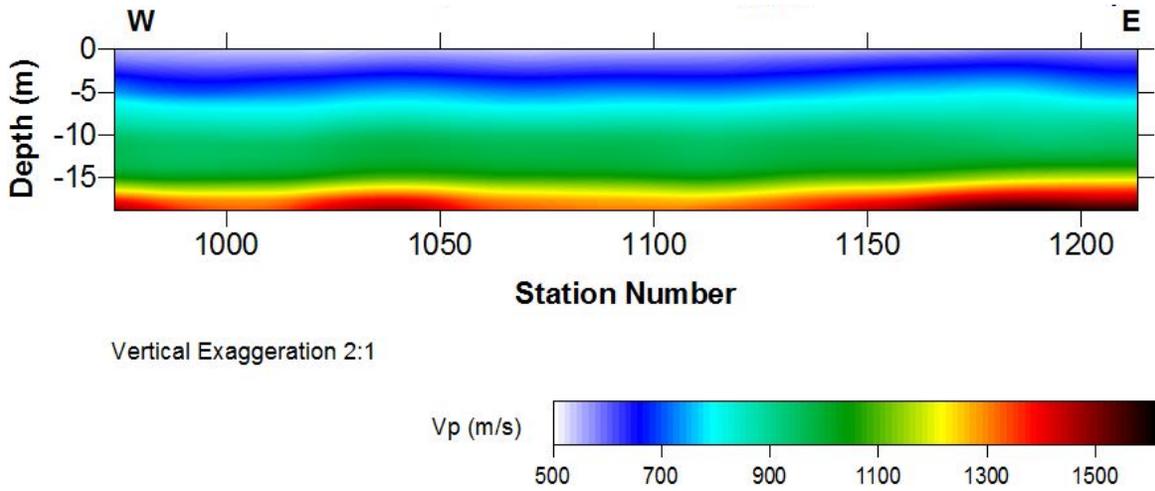
A smoothed version of the final MASW Vs profile was used as the initial model. Information from downhole seismic data improved discrimination of shear waves from mode-converted seismic energy. Shot records were re-picked to ensure accurate arrival times of the direct and refracted shear waves.



**Figure 12:** Vs tomography profile at DTRA-OM1.

### *V<sub>p</sub> Tomography*

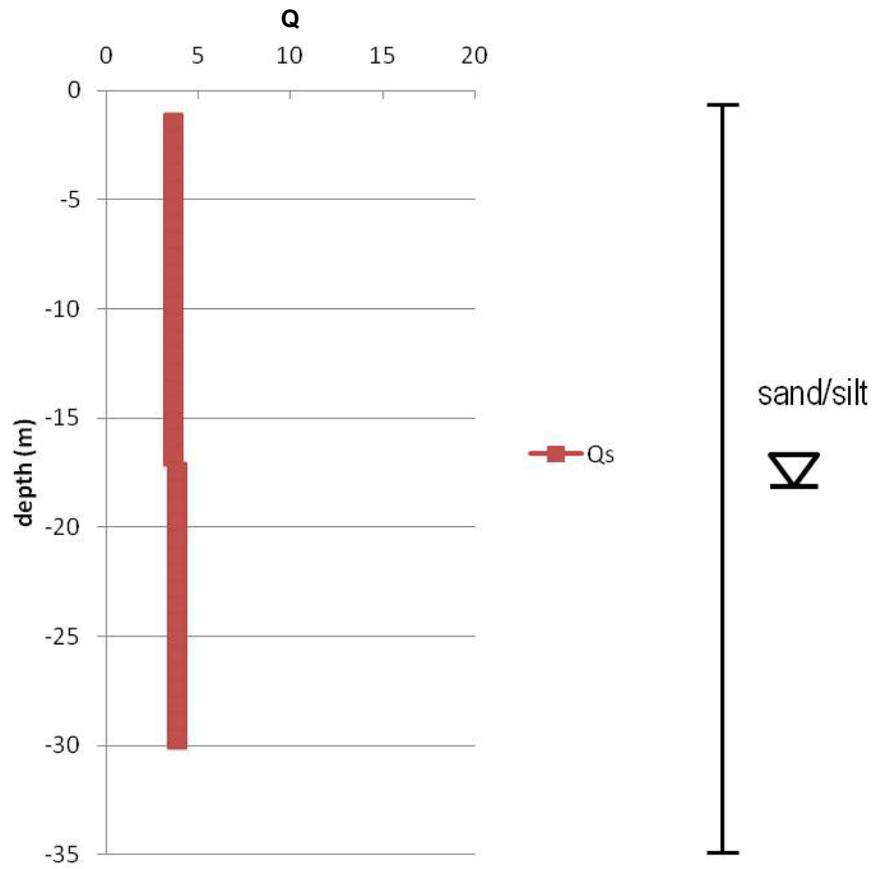
The initial model for final tomography results were generated based on downhole interval P-wave velocities. Picked first arrival times used for preliminary processing were reviewed to confirm their accuracy and used for final processing.



**Figure 13:** V<sub>p</sub> tomography profile at DTRA-OM1.

## Downhole $Q_s$

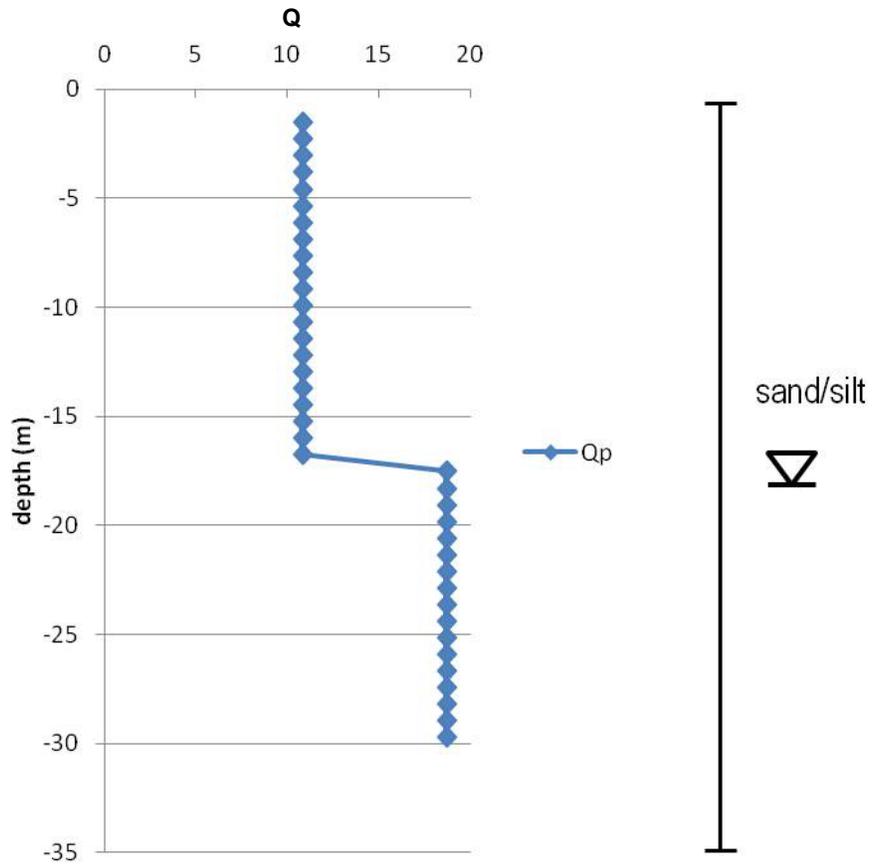
Calculation of  $Q$  is highly sensitive to sources of noise (e.g., traffic) during acquisition.



**Figure 14:** Downhole  $Q_s$  profile at DTRA-OM1.

## Downhole $Q_p$

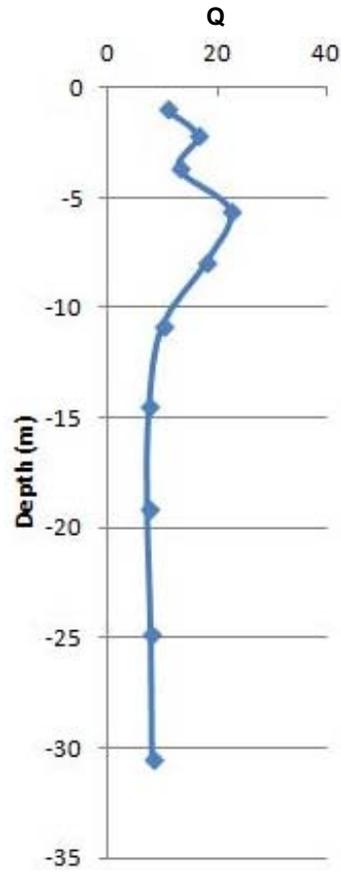
Calculation of  $Q$  is highly sensitive to sources of noise (e.g., traffic) during acquisition.



**Figure 15:** Downhole  $Q_p$  profile at DTRA-OM1.

### *Surface Qs*

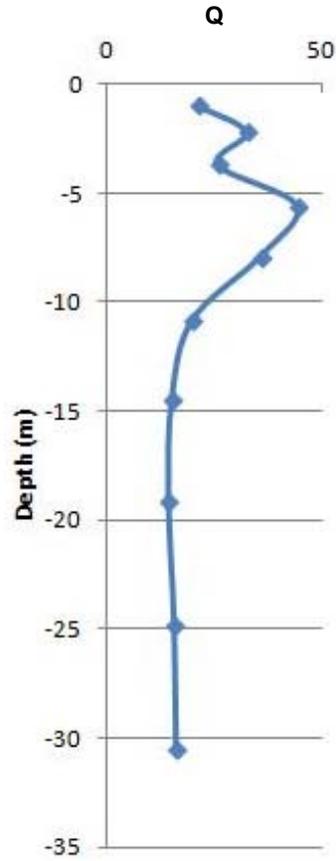
Calculation of Q is highly sensitive to sources of noise (e.g., traffic) during acquisition. Due to lack of stability in the inversion, the upper 5-10 m is low confidence.



**Figure 16:** Surface Qs at DTRA-OM1.

### *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-OM1.

## 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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