Final Report: Seismic Analysis at Strategic Border Sites DTRA-T3

Richard D. Miller, Julian Ivanov, Shelby L. Peterie,
J. Tyler Schwenk, Yao Wang, J. Jordan Nolan,
Brett Wedel, Ryan Nelson, Brett Bennett, and Joe Anderson

Kansas Geological Survey
1930 Constant Avenue
Lawrence, KS 66047

Final Report to:

David Masters
U.S. Department of Homeland Security
Science & Technology Directorate
245 Murray Lane SW—MS0115
Washington, DC 20528-0115

John Lane, PhD
Branch of Geophysics
Office of Groundwater
U.S. Geological Survey
11 Sherman Place
Storrs-Mansfield, CT 06269

Open-File Report #2017-46

March 1, 2014

 This study was conducted in complete compliance with ASTM Guide D7128-05. All data, interpretations, and opinions expressed or implied in this report and associated study are reasonably accurate and in accordance with generally accepted scientific standards.

Final Report: Seismic Analysis at Strategic Border Sites
DTRA-T3

Summary

The Kansas Geological Survey acquired borehole and surface seismic data at 15 DHS sites near the US-Mexico border. Surface seismic 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. Downhole data were processed to obtain downhole Vs, Vp, Qs, and Qp. This report contains final processing and results for DTRA-T3.

Data Acquisition

One line of seismic data (~375 m) was acquired on February 19, 2013, at DTRA-T3 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 January 26, 2014, near the center of the surface seismic line, with a 3-C downhole Geostuff geophone (Figure 5). Receivers were located between depths of approximately 1.5 m and 42.7 m at approximately 0.75 m intervals (Figure 6). A repeatable shear and compressional 9 kg hammer source (Figure 7), developed and fabricated at the Kansas Geological Survey, was located at 3 m from the borehole. 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.

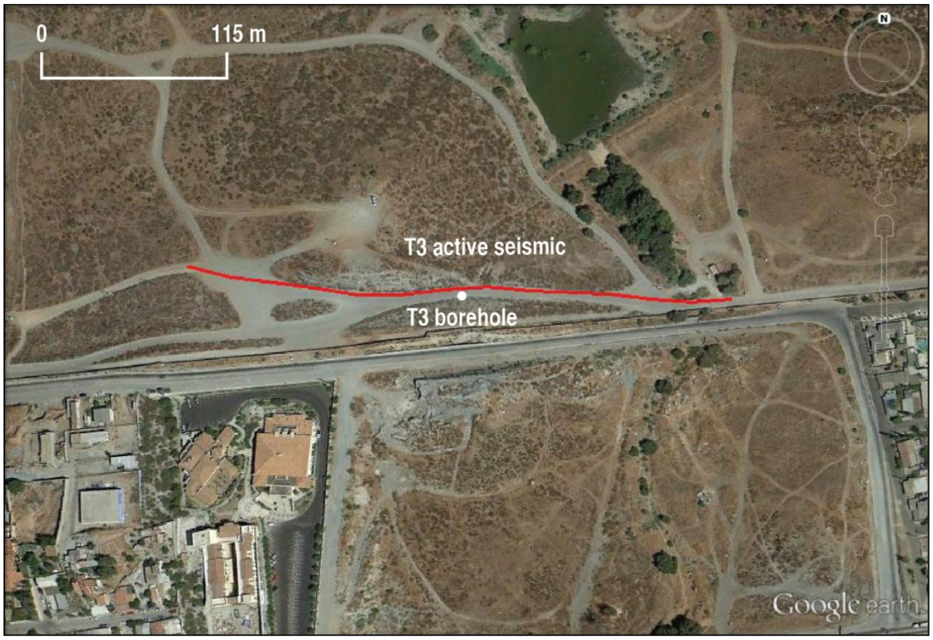

Figure 1: Aerial photo of DTRA-T3 and location of the active seismic line.

Figure 2: ASI towing a 144-channel 3-C land streamer with weight drop in use.

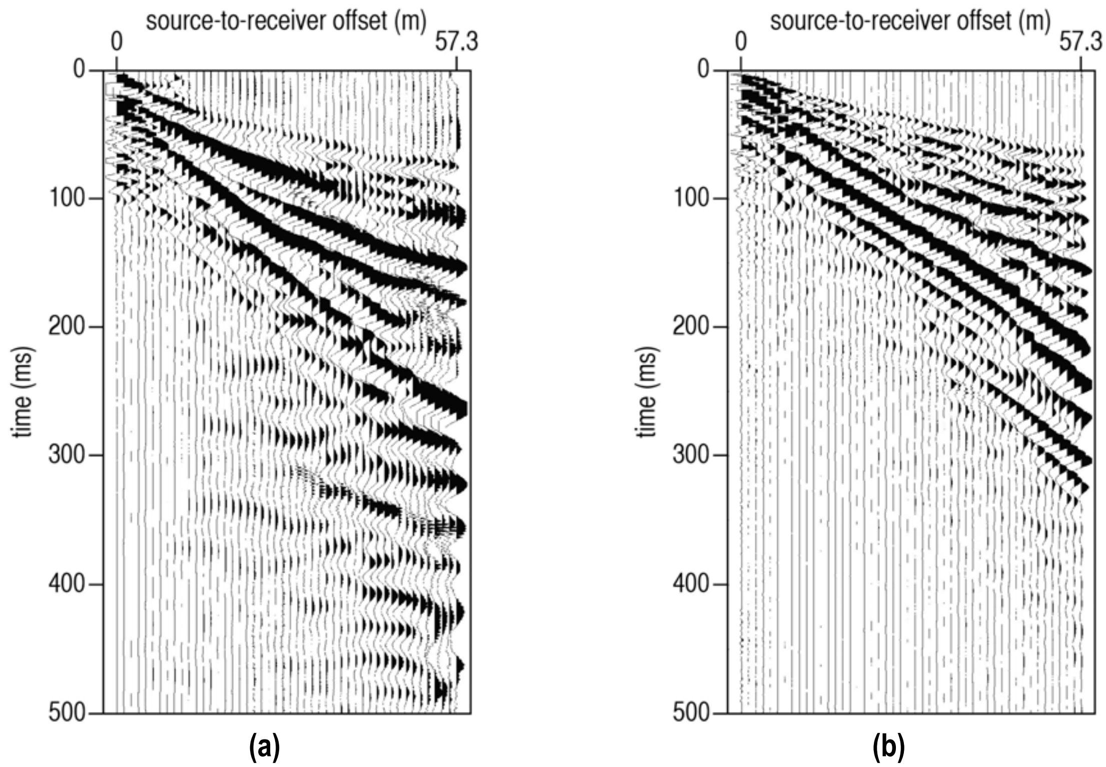

Figure 3: Representative off-end shot gathers at DTRA-T3. (*a*) Sledge hammer and shear block source recorded with shear 14.5 Hz geophones, SV orientation. (*b*) Weight-drop source recorded with vertical 40 Hz geophones.

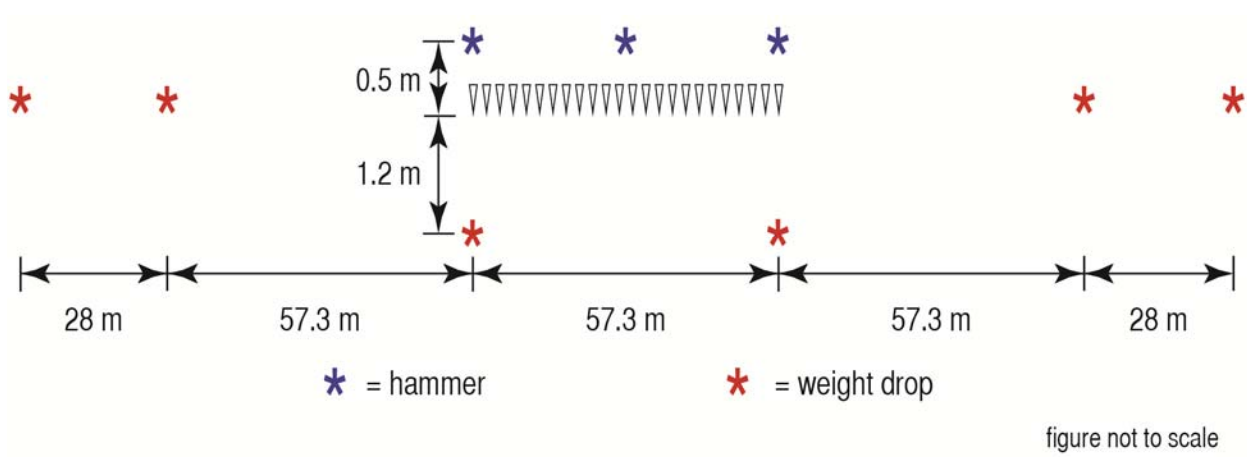

Figure 4: Diagram indicating all shot point locations relative to a single receiver spread. The receiver spread consisted of 48 stations separated by 1.2 m.

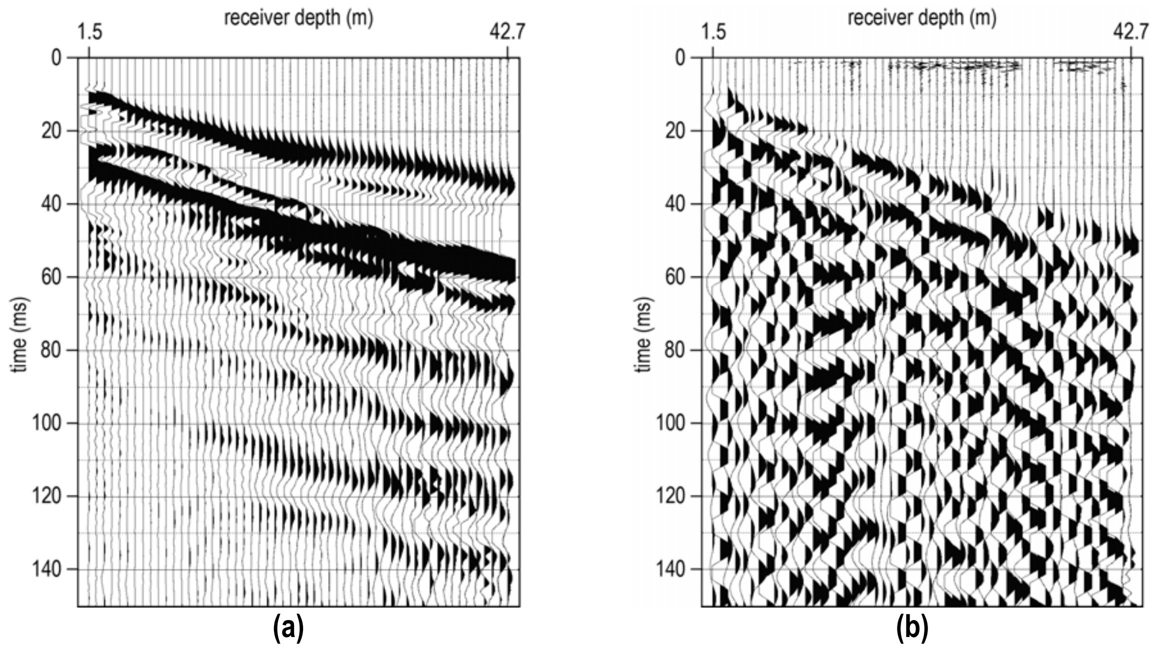

Figure 5: Representative unprocessed downhole (*a*) vertical and (*b*) shear records at DTRA-T3.

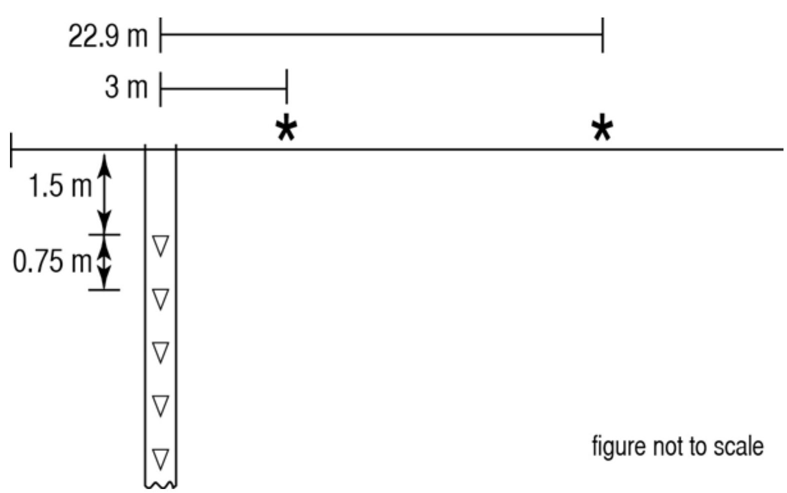

Figure 6: Downhole seismic field layout.

Figure 7: Downhole seismic acquisition at DTRA-T3.

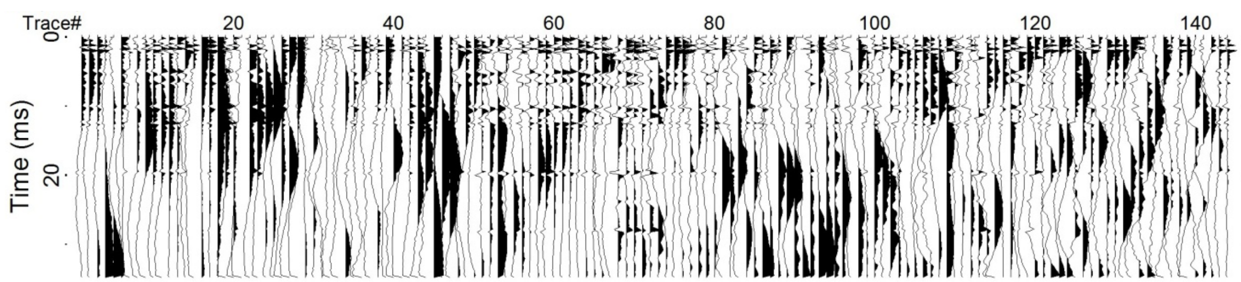

Figure 8: Representative ambient noise recorded at DTRA-T3. Traces 1-48 represent the 4.5 Hz geophones, 49-96 represent the shear geophones, and 97-144 represent the 40 Hz geophones.

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 estimate Vs and Vp. 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 physically realistic 2-D 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

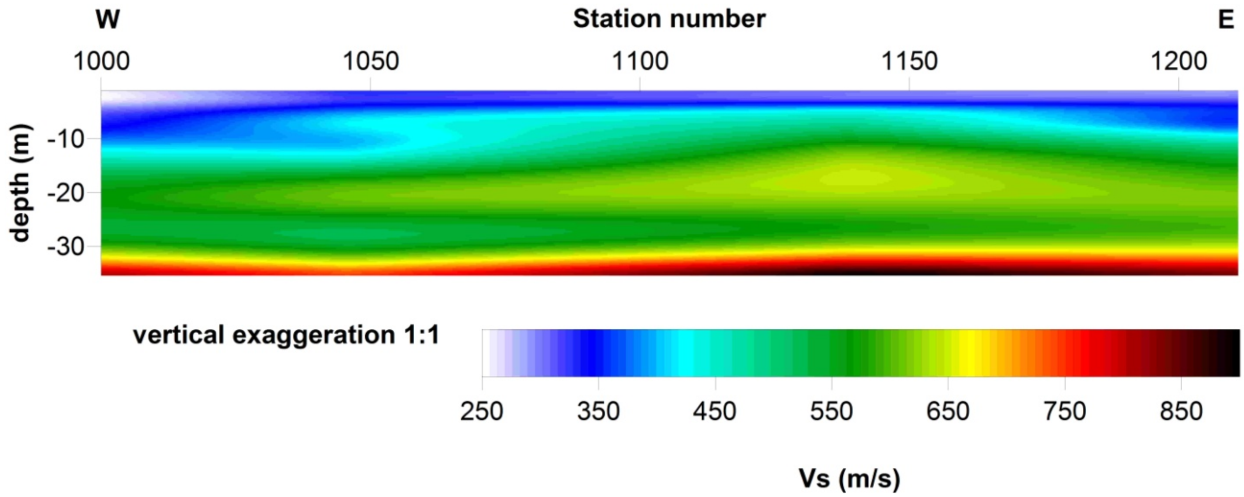

Figure 9: MASW Vs at DTRA-T3.

Downhole Vs

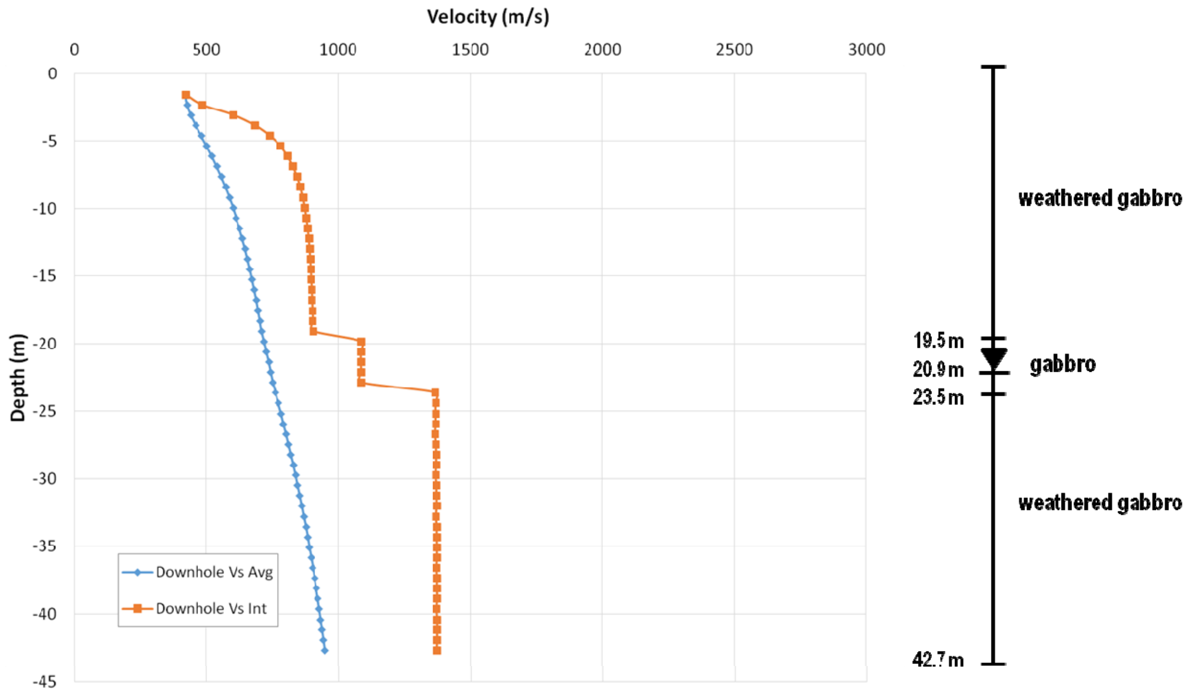

Figure 10: Downhole Vs profile at DTRA-T3.

Downhole Vp

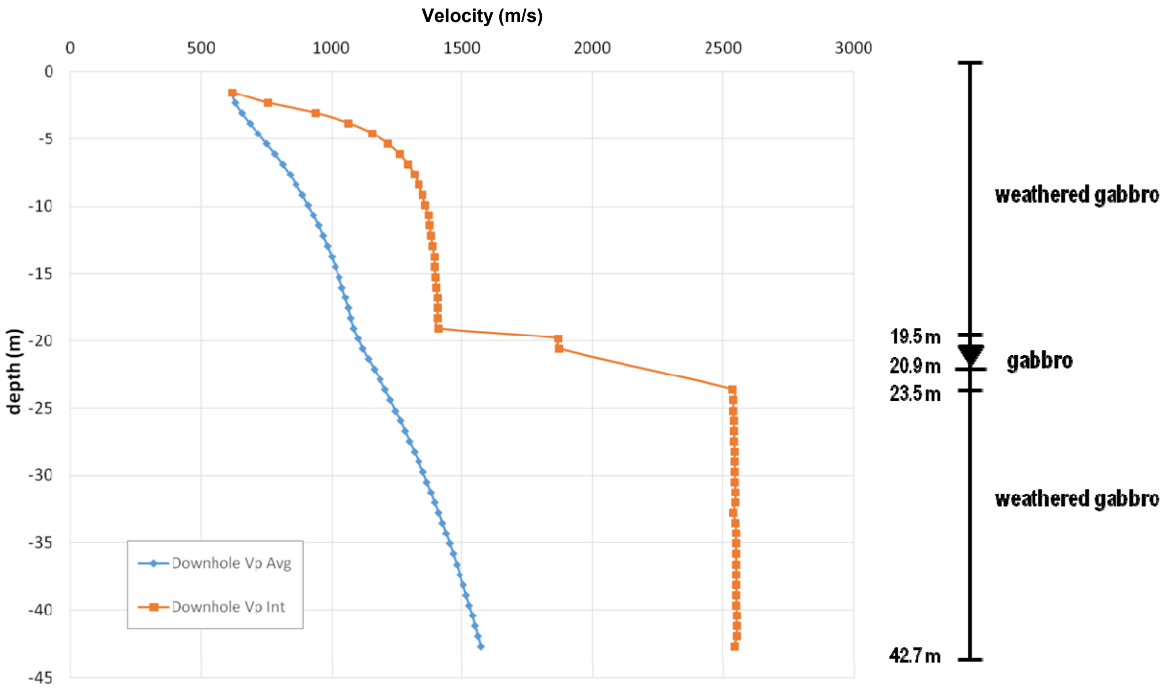

Figure 11: Downhole Vp profile at DTRA-T3.

Vs Tomography

Downhole interval shear-wave velocities are approximately 50% greater than the preliminary Vs tomography results and the final MASW Vs. The velocities obtained from downhole records are most likely the apparent velocities of a mode-converted shear wave and are therefore not reliable. This interpretation is consistent with the lithologic description of the samples obtained during drilling (i.e., intensely to very intensely fractured). Velocities obtained from MASW are reliable because Rayleigh waves are not subject to mode conversion. A smoothed version of the final MASW Vs profile was used as the initial model. Picked first arrival times used for preliminary processing were reviewed to confirm their accuracy and used for final processing.

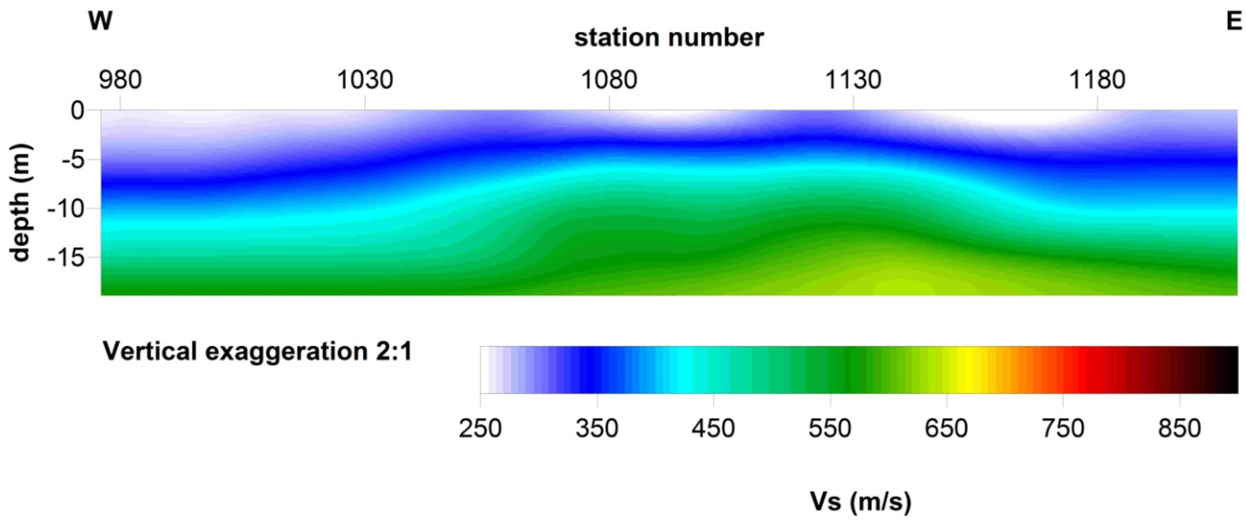

Figure 12: Vs tomography at DTRA-T3.

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.

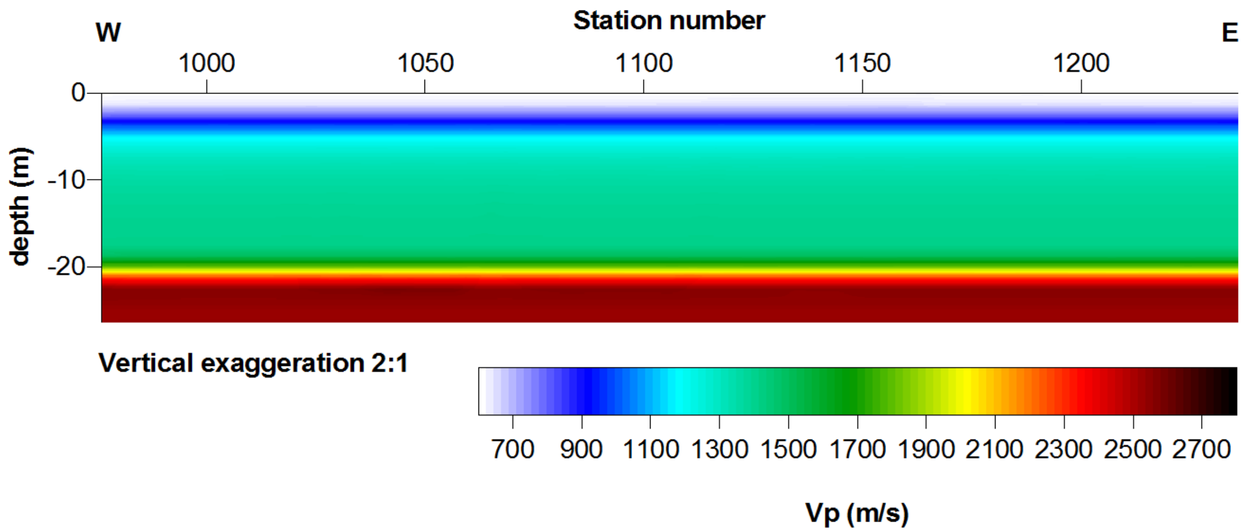

Figure 13: Vp tomography at DTRA-T3.

Downhole Qs

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

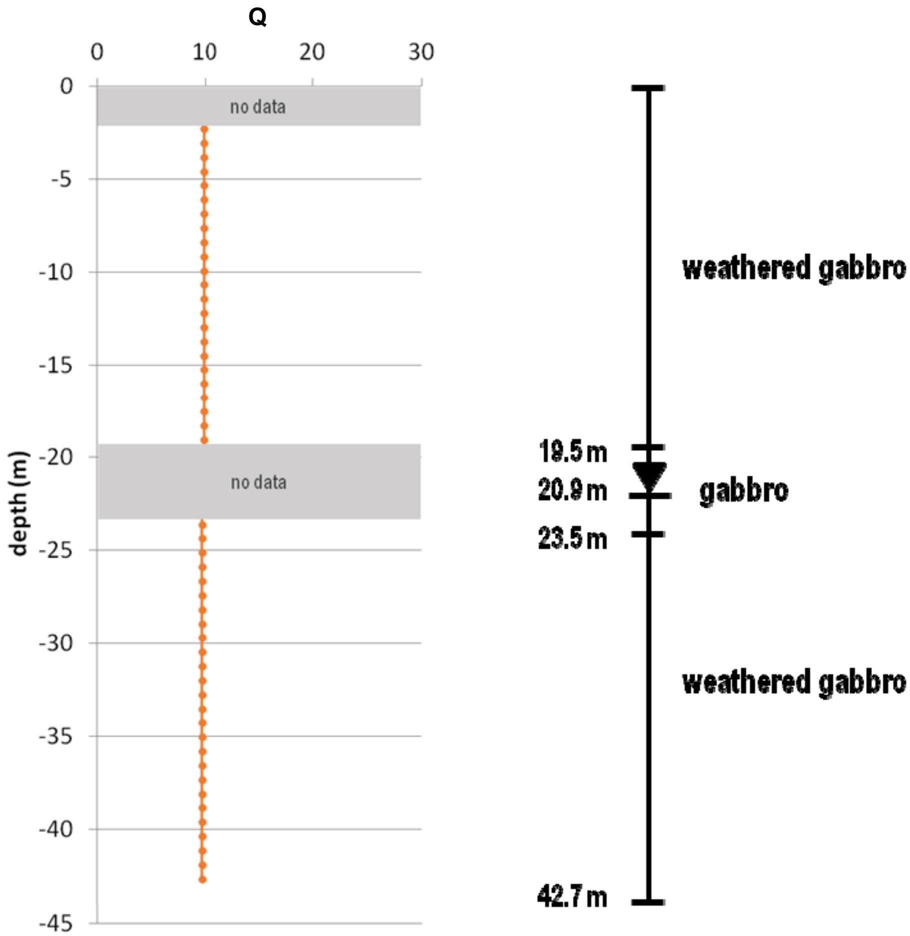

Figure 14: Downhole Qs profile at DTRA-T3.

Downhole Qp

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

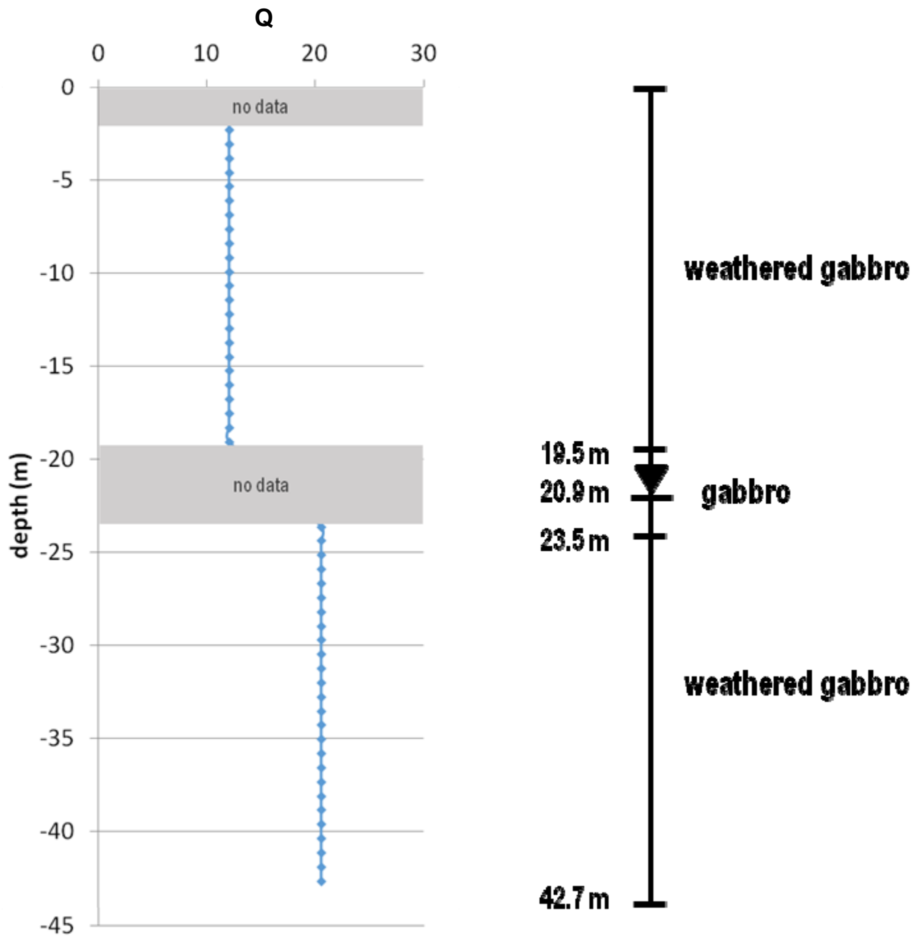

Figure 15: Downhole Qp profile at DTRA-T3.

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 10 m is low confidence.

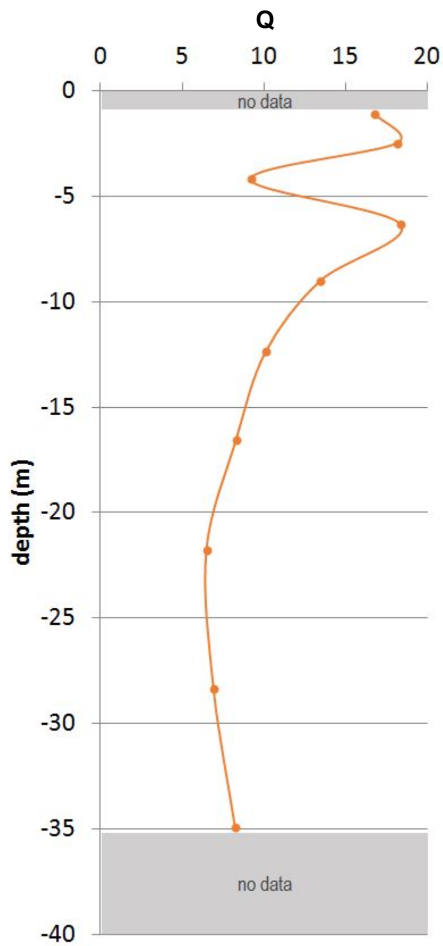

Figure 16: Surface Qs at DTRA-T3.

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 10 m is low confidence.

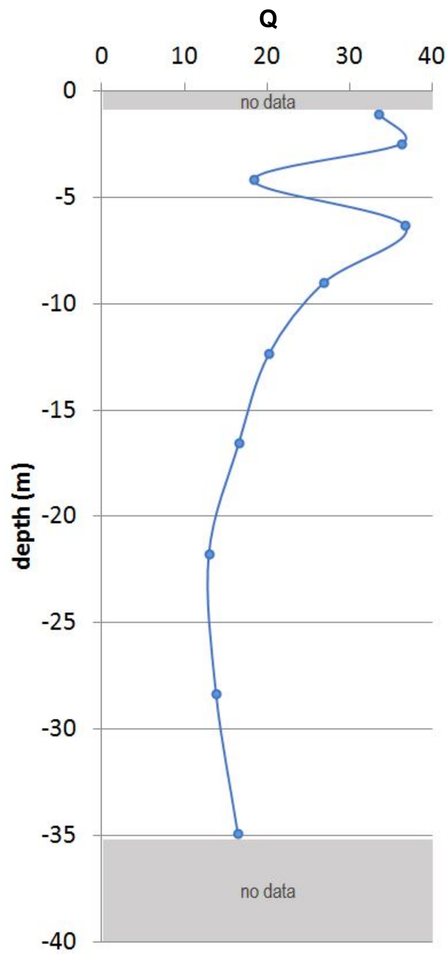

Figure 17: Surface Qp profiles at DTRA-T3.

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

Di Siena, J.P., J.E. Gaiser, and D. Corrigan, 1984, Horizontal components and shear wave analysis of three component VSP data, in *Vertical Seismic Profiling, Part B: Advanced Concepts*, pp. 175-235, eds. M.N. Toksöz and R.R. Stewart, Geophysical Press, London.

Hasse, A.B. and R.R. Stewart, 2004, Attenuation estimates from VSP and log data: SEG expanded abstracts, 2497-2500.

Ivanov, J., R.D. Miller, J. Xia, J.B. Dunbar, and S. Peterie, 2010, Chapter 20: Refraction non-uniqueness studies at levee sites using the refraction-tomography and JARS methods: in Advances in Near-Surface Seismology and Ground-Penetrating Radar, SEG Geophysical Developments Series No. 15, R. D. Miller, J. D. Bradford, and K. Holliger, eds., Society of Exploration Geophysicists, 327-338.

Tonn, R., 1991, The determination of the seismic quality factor Q from VSP data: A comparison of different computational methods: *Geophysical Prospecting*, **39**, 1-27.

Xia, J., and R.D. Miller, 2010, Chapter 2: Estimation of near-surface shear-wave velocity and quality factor by inversion of high-frequency Rayleigh waves: in Advances in Near-Surface Seismology and Ground-Penetrating Radar, SEG Geophysical Developments Series No. 15, R. D. Miller, J. D. Bradford, and K. Holliger, eds., Society of Exploration Geophysicists, 17-36.

Xia, J., R.D. Miller, and C. B. Park, 1999, Estimation of near-surface velocity by inversion of Rayleigh waves: Geophysics, **64**, 691-700.