Geophysical Investigations of Subsurface Structure in the Avawatz Mountains

Geophysical tools such as reflection and refraction seismology can be used as a window into the subsurface. Such tools allow the user to acquire data by initiating seismic waves generated from a source and then recording the subsequent ground movement along a profile with sensors, or geophones. Acquired data can then be used to determine depth to bedrock, rock layers, subsurface deformation and can even result in high-resolution images of the subsurface.

In the Sheep Creek Wash study area, seismic reflection and refraction surveys are used with the aim of imaging the top of the blind reverse fault responsible for late Quaternary folding. The shallow seismic reflection profile was completed to image the subsurface fault geometry. The shallow seismic refraction line was acquired to better constrain the subsurface velocity structure. Together, they permit a more robust interpretation of the subsurface structure.

Data Acquisition

Project Setup

Both seismic lines were completed within the Sheep Creek Wash, an active wash composed of gravel and partially cemented sediments. The seismic profiles extended across the frontal anticline of the Avawatz with a total length of 982 meters for the longer (seismic reflection) survey. Elements of the surveys were placed along the line and locations are hereafter referenced by meter marker numbers.

For both the reflection and refraction surveys, 112 geophones were used to collect travel times. The 112 geophones consisted of three 24-Channel geophone lines borrowed from IRIS/PASSCAL and one 16-Channel geophone line plus two 12-Channel lines (considered as a set of 24 in the seismic line diagram) belonging to the University of Missouri.

A modified rolling spread survey was used for the seismic reflection profile, in order to maintain a consistent data density and provide sufficient data quality. This strategy uses all available geophones segments set up into an equally spaced line or spread. Shots are then produced up until just before the first geophone in the spread. The first segment in the spread is then moved or rolled, to end of the spread. With everything reattached, the shots would continue up until the spread and the process would repeat.

Seismic sources were placed every 8 meters along the line, while the 112-geophone spread was placed 2 meters apart (geophone spread totaling 224 meters in length) (Figure 0-1). The first shot was placed at meter zero, 56 meters in front of the first geophone. The last shot was placed at 760 meters, 224 meters before the last geophone. The first geophone was placed at 56 meters with the last geophone on the pre-rolled line placed at 278 meters and the final roll last geophone placed at 982 meters.

The seismic refraction survey used a fixed spread with the same 112-geophone spread used in the reflection line (Figure 0-2). Again, geophones were spaced every 2 meters, beginning at the 200-meter marker and ending at the 422-meter marker, for a total of 224 meters of length. Sources were placed every 8 meters, with the first source located at 168 meters, and the last source placed at 456 meters.

Data Collection

For both surveys, a seismic source was generated using a Betsy Gun and a 10-gauge, 400 grain charge (Triple-7 FFF powder), blank shotgun shell. Shot holes were dug to greater than 1ft depth and filled with water to promote coupling and mute the size of the airwave, therefore, improving the signal-to-noise ratio. Once the geophones were set up and all the equipment connected, the Betsy gun was loaded and place in the hole and secured with a blast plate and sandbags. A hammer was then used to initiate the blast and trigger the recording of the blast time and seismic travel times on the field computer.

For the reflection profile, shots were not fired into the rolling line (except for the last and final shot) as backwards reflectors were not pertinent to the reflection line. Shots were fired up to the beginning of the line, at which point the leading geophones were transported to the back of the line. The shots would continue up the next set of leading geophones, and the process was repeated until the seismic line was complete. Conversely, for the refraction profile, the geophones remained stationary as the shots continued through and past the end of the line.

Raw data seismic data were collected using a geode recording unit and collected on a field computer using Geometrics Seismodule Controller™ software. Data were collected using 40 hz receivers, a 14-fold stacking, and a sampling interval of 0.25 msec. Raw data were collected in the form of a seismic trace. Traces are created when geophone receivers detect the energy emitted from the source. Therefore, each seismic source should, and did, generate 112 traces. The collection of all traces is called a shot gather. In total, 37 shot gathers were collected for the fixed spread and 67 for the modified rolling spread. All files were saved as individual files for later processing.

Data Processing

Velocity Model and Tomography

A fixed-spread seismic profile provides accurate velocity measurements for depth conversion to assess structural geometry. Raw data can be analyzed and modeled by implementing various techniques using Geometrics SeisImager/2D software suite (2009). A time-term inversion technique was implemented to generate a velocity section. This model inverts the first-arrival picks by using a combination of delay time analysis and linear least squares (Geometrics Inc., 2009). This simple and rapid model is applied to determine gross velocities and depths (Geometrics Inc., 2009). Further, a tomographic inversion model was created by incorporating the time-term inversion velocity model. This model was run in order to better constrain the velocity structure of the near subsurface.

First breaks are defined as the earliest arrival of energy created from the seismic source. First breaks/arrivals are identified using SiesImager's Pickwin™ Module (2009). First arrival picks were selected from raw, unfiltered data. First pick data files were then transferred to SeisImager's Plotrefa™ Module (2009) for data modeling and interpretation (Figure 0-3). Before a time-term inversion can be generated, layers must be assigned. Data showed only a single change in slope, so a two-layer case was chosen (Figure 0-4). Once both layers were assigned, the time-term inversion was run, and a velocity model was created with an RMS error of 1.03 (Figure 0-5).

Next, this initial layered inversion model was applied to a preliminary 2D tomographic inversion model. The tomographic model was then reconstructed using smoothing parameters over numerous iterations to create the final tomographic model (Figure 0-6 and Figure 0-7).

Reflection Profile

The seismic reflection data were processed using W-GeoSoft visual_SUNT, a windows-based version of Seismic Unix (Jenny et al., 2012). Raw SEG-2 files were converted to SU format (Seismic Unix) for processing within visualSUNT. The working file was loaded, and geometry was input using the interactive station input. Data were filtered using a band pass filter to remove high-frequency and low-frequency noise to better improve the signal-to-noise ratio. Muting was applied to each shot gather to remove ground roll, and any signals before first arrivals. Shot gathers were then sorted into one frame, using a common depth point gather (CDP). The shot gather was then migrated, to reposition reflection to their actual subsurface location and to improve the seismic section resolution. Finally, a depth conversion was performed to convert the acoustic wave travel time to an actual depth and a final profile was produced (Figure 0-9).

Results and Summary

The first break pick composite indicated a two-layer model with a single change in slope along each profile line (Figure 0-4). Change in slope occurred between a travel time of 60 ms and 80 ms. The initial velocity model indicated 2 distinct velocities of approximately 1150 m/s in the upper 20-25 meters, and 2400 m/s just below (Figure 0-5). This model was used as the initial input for the tomography model, which enhances the vertical and horizontal resolution of the data set. The tomography displays a thin veneer (~ 2 m) of low velocity material between 550-1000 m/s likely attributed to the sedimentary fill of the Sheep Creek Wash. The profile shows an increasing velocity with depth, with a thicker (~ 25-40 m) velocity section between 1000-2200 m/s. Velocity continues to increase with depth. Conversely, the ray path model (Figure 0-8) indicates that velocities 40 meters beneath the surface are unreliable due to lack of crossover data. Increased vertical resolution of the model reveals an arcuate velocity increase in the center of the profile to depth. This arcuate change in velocity is attributed to a zone of folding and fracture above the fault tip of the blind reverse fault.

The modified seismic line resulted in a nearly 870-meter-long profile of the Sheep Creek Wash. The seismic reflection profile shows a relatively thick section of horizontal reflectors. Due to the relative thickness, it is unlikely to be related to sedimentary channel fill of the Sheep Creek wash. The seismic reflection profile indicates a clear subsurface expression of the fault tip belonging to the blind fault. The tip falls approximately meter marker 336 at a depth of 60 m (Figure 0-9). Additionally, there are multiple other discontinuities noted along the seismic line. The discontinuity noted in the upwash, southern direction is antithetic to the thrust system that is uplifting the Avawatz. The discontinuity noted in the downwash, northern direction is synthetic to the thrust system of the Avawatz, and according to the reflection profile, does not daylight at the surface.

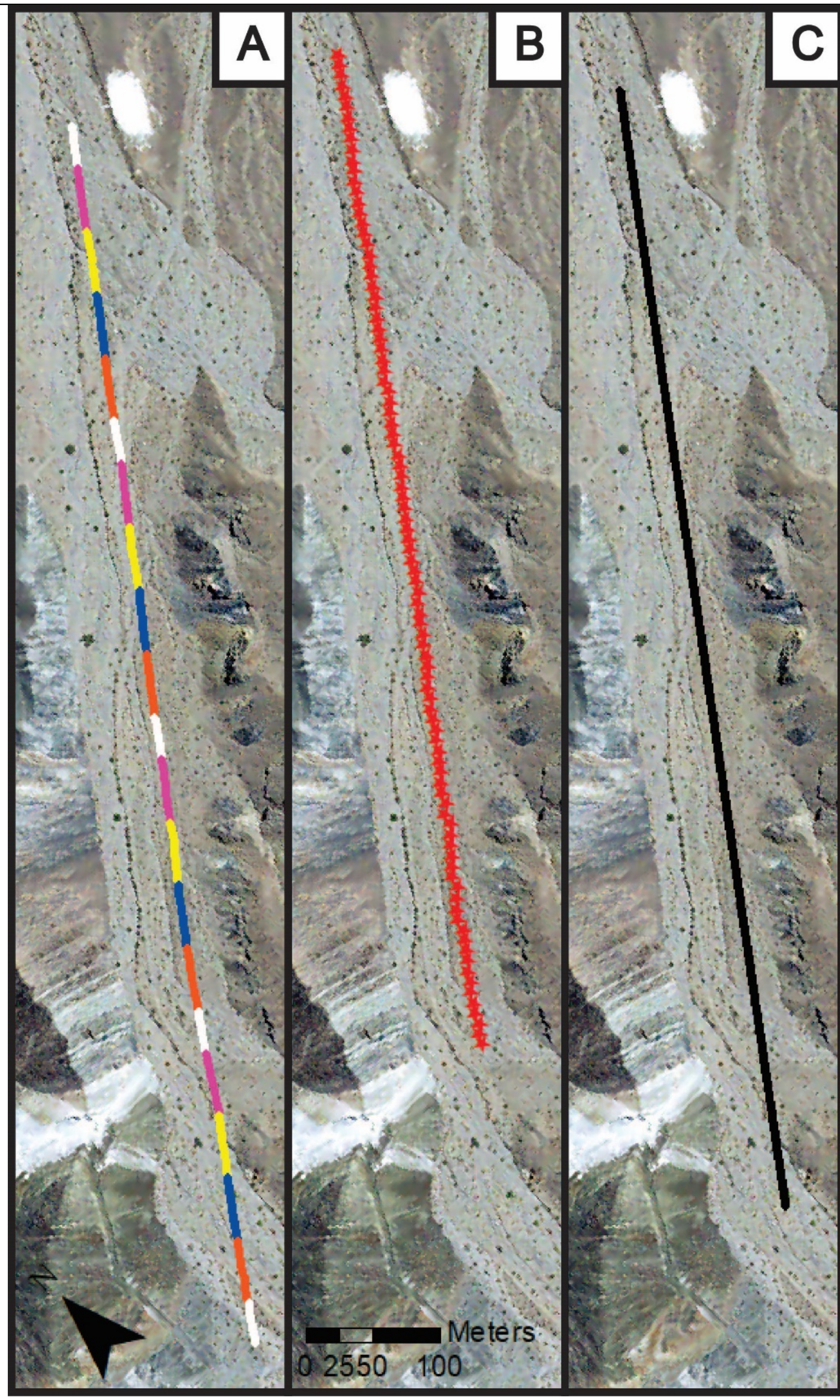

Figure 0-1 Rolling Spread Geophone Locations (A), Location of Shots/ seismic sources (B), Location of the seismic reflection surface projected CDP's within the Sheep Creek Wash (C)

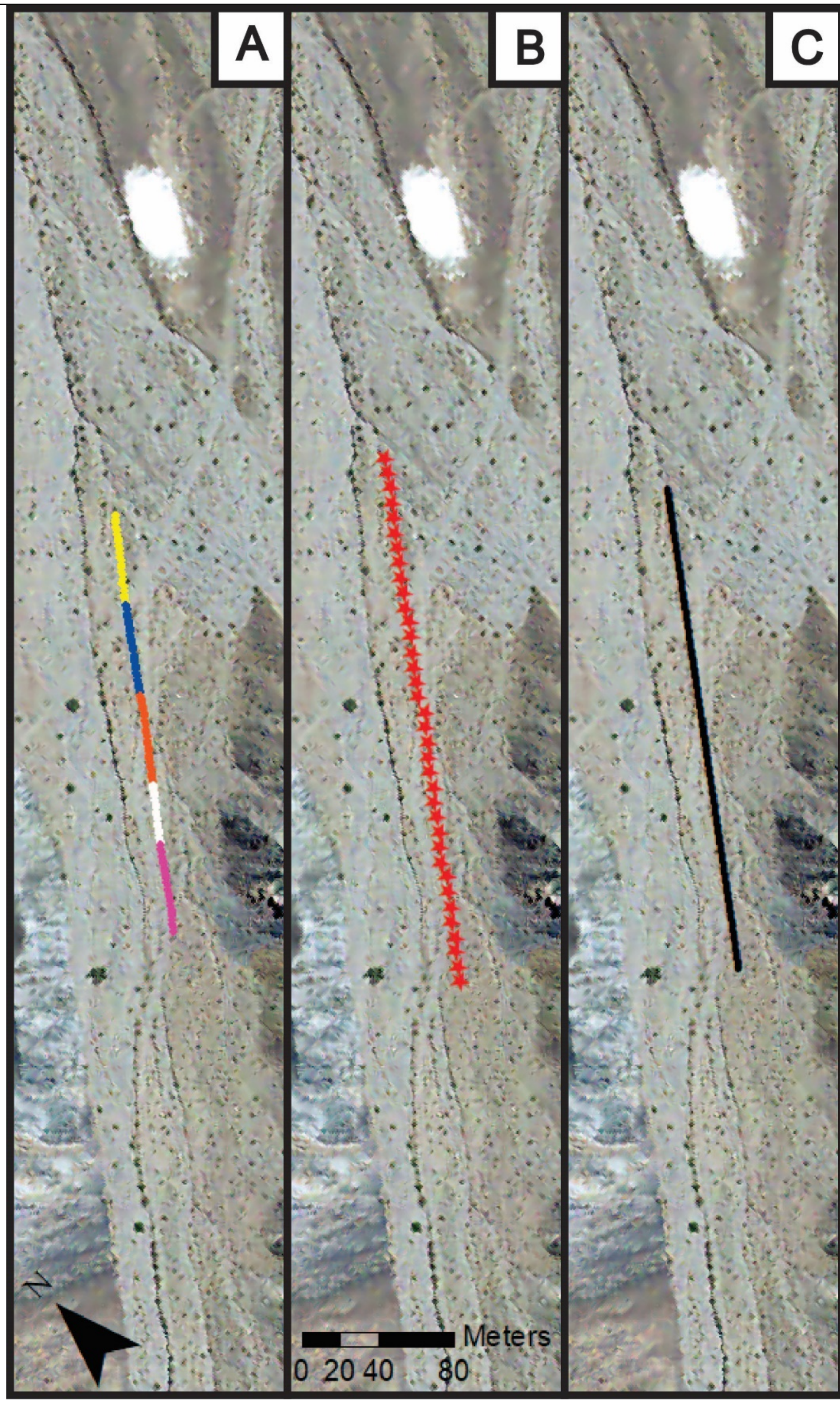

Figure 0-2 Fixed Spread Geophone Locations (A), Location of Shots/ seismic sources (B), Location of the seismic reflection surface projected CDP's within the Sheep Creek Wash (C)

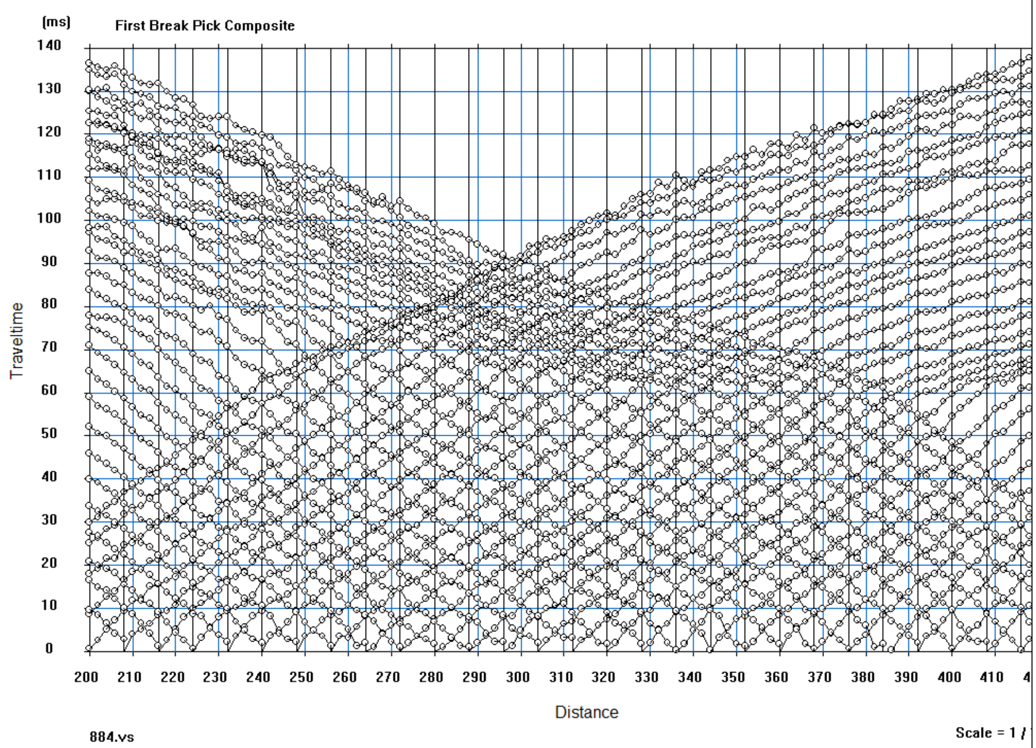

Figure 0-3 First Break Pick Composite

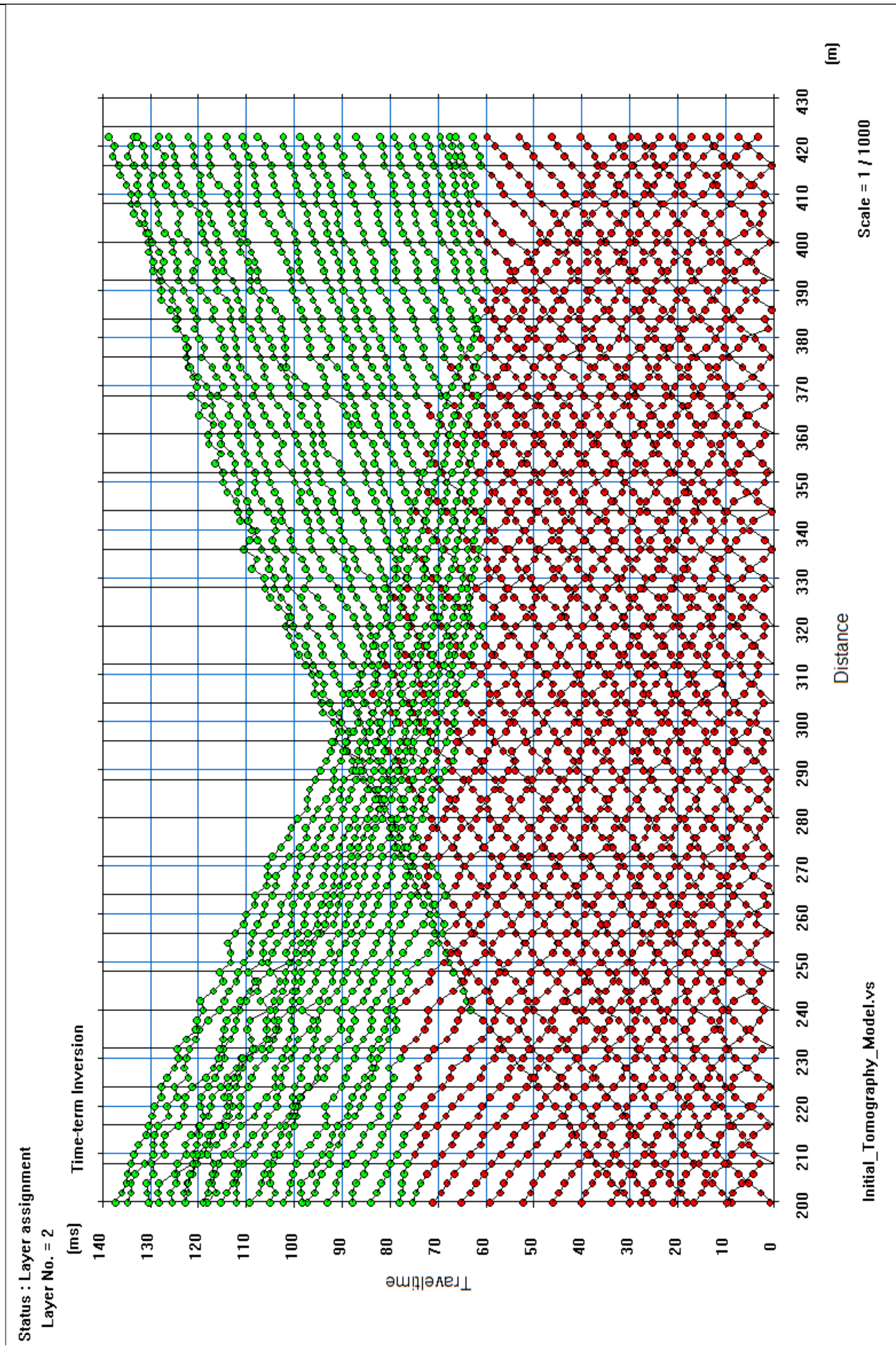

Figure 0-4 Layer Assignment- First pick data files in SeisImager's PlotrefaTM Module. First pick data show a single change in slope with 2 distinct velocities, indicating a 2-layer model. First layer assigned in red and second layer in green.

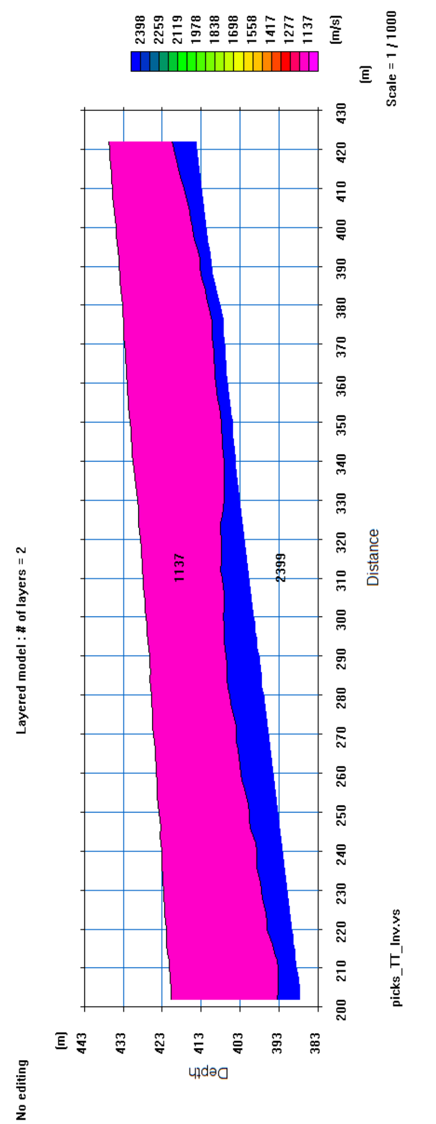

Figure 0-5 Two Layer Model

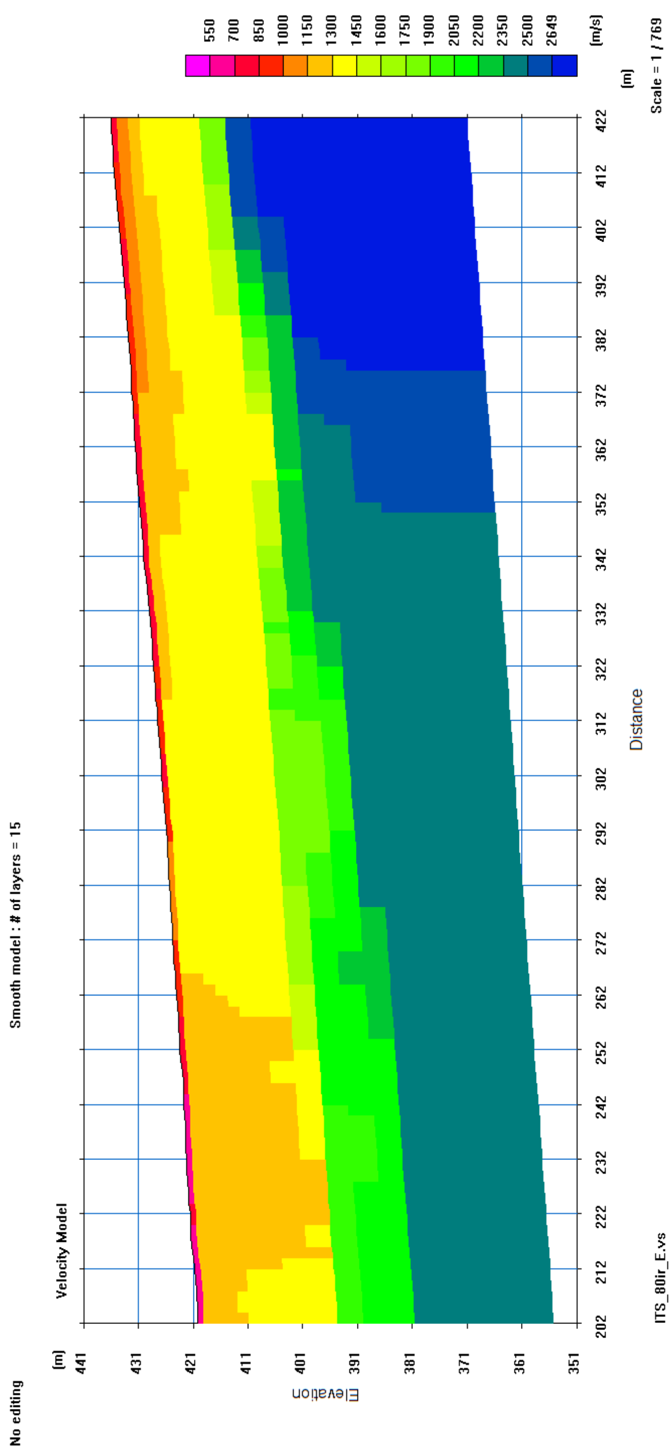

Figure 0-6 Tomography Model

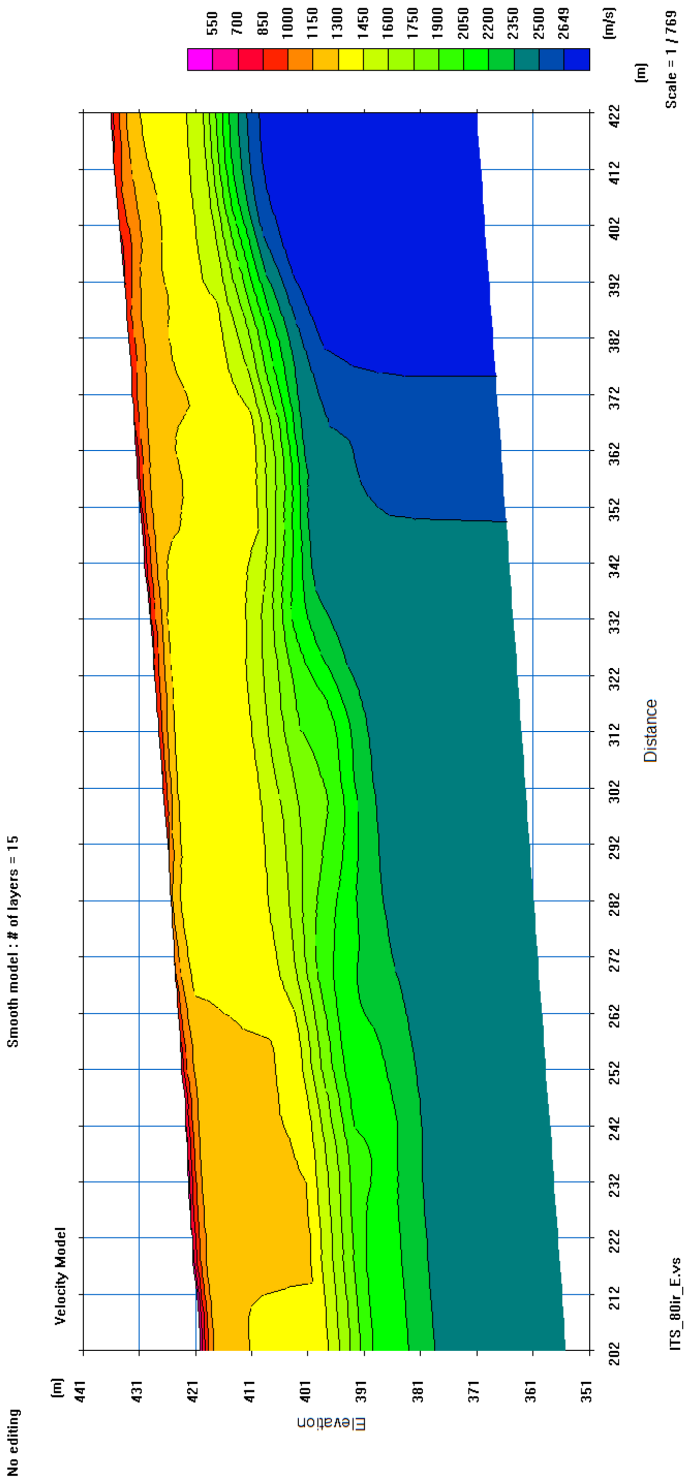

Figure 0-7 Tomography Model Contoured

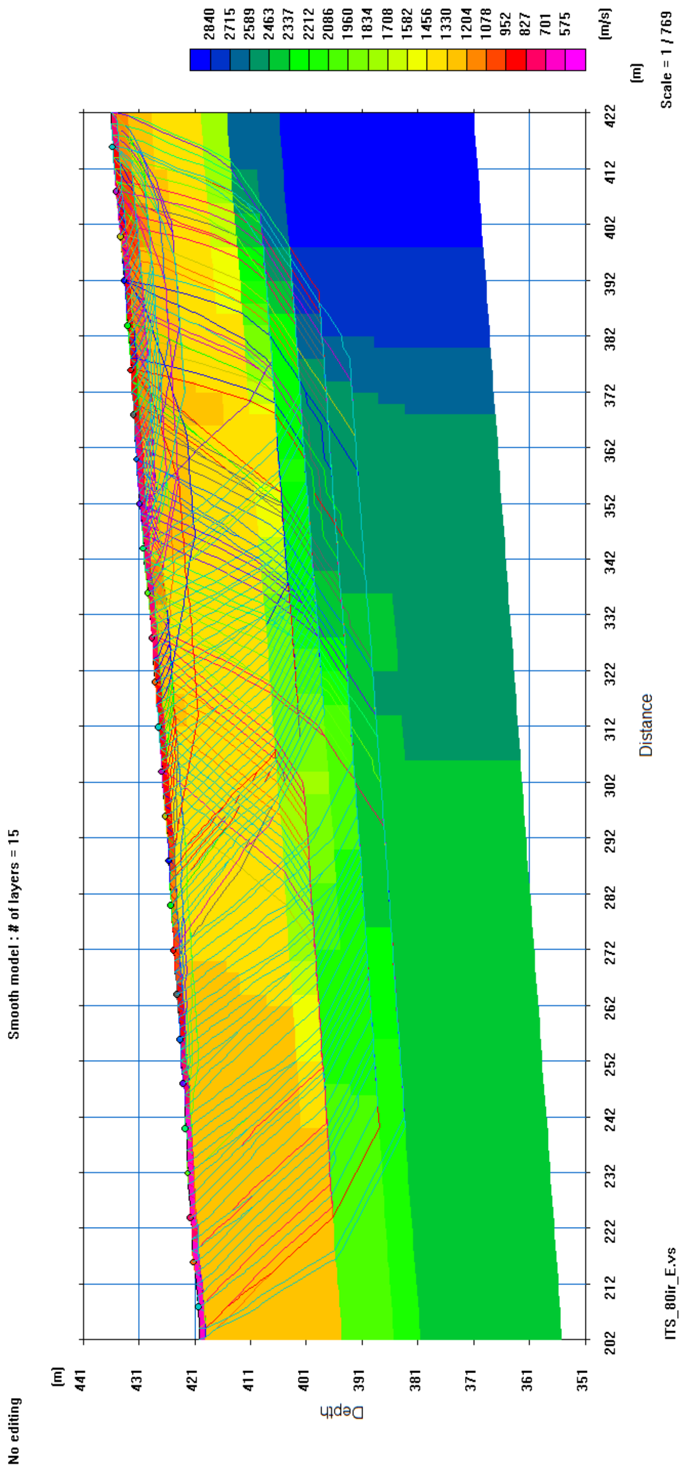

Figure 0-8 Raypath Diagram

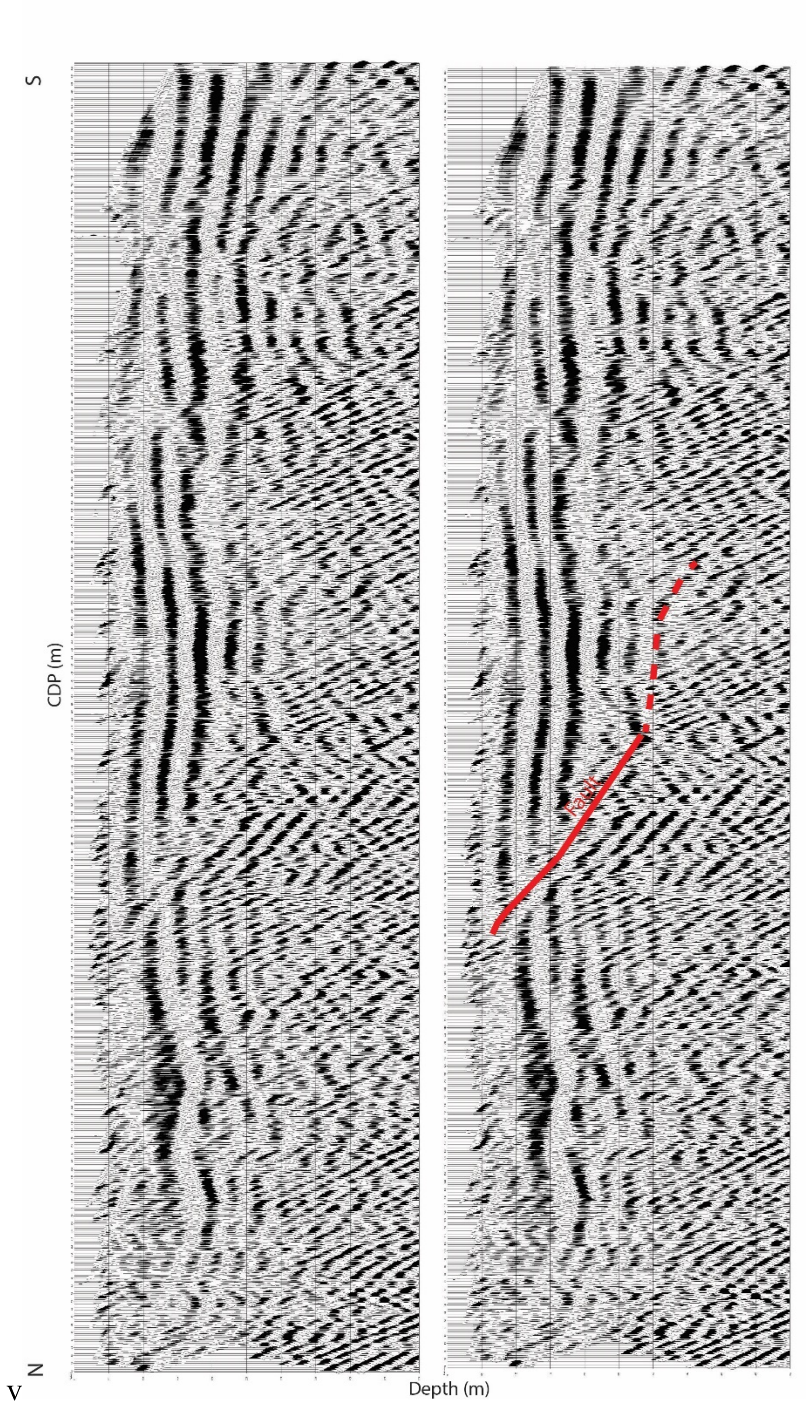

Figure 0-9 Processed Reflection Profile