# ThrustLine Seismic Data Analysis System

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## Summary

GeoTomo's ThrustLine seismic data analysis system has the following distinctively unique features: (1) The system provides the analyst with powerful interactive tools to perform quality control of geometry and for appropriate specification of signal processing parameters; (2) the system is based on a workflow architecture that manages the project for the analyst and allows the analyst to focus on the geological and geophysical aspects of the project; and (3) the system does not burden the user with unnecessary and excessive parameter specification for each processing step.

ThrustLine has been designed to obtain an accurate earth model and earth image in areas with irregular topography, complex near-surface, and complex subsurface. (1) The near-surface model is estimated by nonlinear traveltime tomography that accounts for topography, and resolves lateral and vertical velocity variations. (2) The subsurface model is estimated by prestack time migration combined with powerful interactive tools to pick rms velocities that are structurally consistent and laterally consistent. (3) The subsurface image is obtained by prestack depth migration of shot gathers from topography.

Thrustline seismic data analysis system is unique in two respects: (1) The system is based on analysis in shot-geophone coordinates, not in midpoint-offset coordinates; and (2) the system performs modeling and imaging from topography, not from a flat datum.

## The ThrustLine Workflow

Conventional data analysis in midpoint-offset coordinates often fails to image complex imbricate structures associated with overthrust tectonics. Irregular topography associated with a rugged terrain and complexity of the near-surface that includes high-velocity layers and outcrops with significant lateral velocity variations prohibits analytic or linear inversion methods to delineate the near-surface model. Additionally, the nonhyperbolic moveout behavior associated with complex imbricate structures and the breakdown of the hyperbolic moveout assumption valid only for small spread lengths prohibit the application of conventional processing in midpoint-offset coordinates to image the subsurface. The ThrustLine analysis workflow, on the other hand, is designed to perform earth modeling and imaging in depth of seismic data in shot-receiver domain from topography.

We shall describe each step in the workflow using case studies from around the world.

(1) Starting with the SEGY file of the field records with geometry in trace headers, pick first-arrival times, and edit traces for high noise level or for lack of signal, and for polarity reversal.

(2) Combine all the picked first-arrival times, edit for bad picks. Check the reciprocal errors and make sure that they are sufficiently small. In general, the maximum reciprocal error should be less than 15 ms, and the average of the reciprocal errors for all shots should be less than 10 ms. In theory, reciprocity principle states that interchanging of the shot and receiver locations does not alter the traveltime. However, in practice, errors in geometry, charge depth, mispicks, and heterogeneities in the vicinity of the shot and receiver locations can cause a difference between the reciprocal times. Large reciprocal errors are often caused by geometry and/or picking errors. Therefore, the reciprocal error display is used to quality control the geometry and traveltime picks. Next, bundle the traveltime trajectories to form a general trend that can be associated with laterally invariant but vertically varying velocities within the near surface. Pick a traveltime trajectory while honoring the change in gradient. Determine the near-surface layer velocities and thicknesses inferred by the picked traveltime trajectory. Then, build an initial model for the near-surface based on these layer velocities and thicknesses.

(3) Compute the traveltimes associated with all shot and receiver locations by ray tracing using the initial velocity-depth model. Then, perturb the initial model parameters until the difference between the modeled and the observed (actual) traveltimes is minimum in the least-squares sense using nonlinear traveltime tomography (Zhang and Toksoz, 1998) that accounts for the change in traveltime gradient. Iterate until the difference between the modeled and the actual traveltimes, measured as the rms error in inversion, has been reduced to a sufficiently small value comparable to the reciprocal errors.

(4) View the near-surface model derived by the nonlinear traveltime tomography and pick the floating datum and the intermediate datum that defines the interface between the near-surface and the subsurface. Also, compute the replacement velocity taken as the lateral average of the velocities along the intermediate datum. Examine the raypaths associated with the nearsurface model and make sure that they do not hit the bottom of the model. This is an indispensable quality control to judge as to the acceptance of the near-surface model. Also, examine the differences between the modeled traveltimes associated with the tomography solution for the near-surface and the observed (picked) traveltimes, and make sure that the match between the modeled and the observed traveltimes is satisfactory.

(5) Using the near-surface model estimated in step 3, the floating datum and intermediate datum picked in step 4, and the replacement velocity determined in step 4, compute the shot and receiver statics. The computation is in two steps: first, shots and receivers are moved down from topography to the intermediate datum using the velocity field associated with the nearsurface; second, they are moved up to the floating datum using the replacement velocity. The shot and receiver statics are to be applied in the next step. We also calculate refractionbased shot and receiver residual statics.

(6) Perform signal processing of the edited shot records from step 1. After each process, examine the average amplitude spectrum, timevariant spectrum, and the autocorrelogram for assessment and quality control of the processing parameters. The signal processing includes resampling, inside and outside trace muting, *t*squared scaling for spherical spreading compensation, predictive deconvolution to compress the source wavelet to a desired length and attenuate short-period multiples and reverberations, time-variant spectral whitening to account for signal nonstationarity and thus flatten the spectrum within the signal passband, bandpass filtering, and AGC. Using the data attributes — average amplitude spectrum, timevariant spectrum, and autocorrelogram, we can decide on an optimum signal processing sequence with appropriate parameters.

(7) Perform prestack time migration of shot gathers from the floating datum using a constant velocity and sum the individual images from all the shot gathers to obtain a composite image of the subsurface. Repeat this process for a range of constant velocities and thus obtain a set of multiple images of the subsurface. By placing these constant-velocity image panels together, you create a velocity cube (Shurtleff, 1984), which is then interpreted in the next step to derive an rms velocity field associated with events in their migrated positions (Yilmaz, 2001). This rms velocity field is better suited for Dix conversion to derive an interval velocity field (step 11) compared to Dix conversion of stacking or DMO velocities, which are associated with events in their unmigrated positions.

(8) Display the three cross-sections of the velocity cube for picking the rms velocities. These are the distance along the line traverse versus event time after migration for a given rms velocity — the X-T plane, the rms velocity versus event time after migration for a specific location along the line traverse— the V-T plane, and the rms velocity versus the distance along the line traverse for a specific time — the V-X plane that represents a time slice from the velocity cube. Scan the X-T planes and pick velocity strands associated with the best image with the highest amplitude. Use the other two planes — the V-T and the V-X planes for quality control of the picked velocity strands. While the X-T plane provides structural consistency, the V-X plane provides the lateral consistency in picking the velocity strands. Combine all the velocity strands and create an rms velocity field associated with events in their migrated positions.

(9) Migrate the shot gathers of step 6 from floating datum, individually, and sort the shot images to common-receiver gathers (one type of image gathers). Each trace in a common-receiver gather represents the subsurface image beneath the receiver location contributed by a particular shot. If the rms velocity field is defined correctly (step 8), then the traces in a commonreceiver gather can be treated as the replicas of the same subsurface image. Thus, events on a common-receiver gather should be flat with no residual moveout. To obtain the image from prestack time migration, simply stack the traces in each common-receiver gather. Prestack time migration based on migration of shot gathers is performed using the phase-shift-plusinterpolation (PSPI) algorithm (Gazdag and Squazzerro, 1984), adapted to start the imaging from a floating datum (Reshef, 1991). The PSPI algorithm images steep dips accurately up to 90 degrees and accommodates lateral velocity variations not just within the bounds of time migration but also the cases that require depth migration.

(10) Unmigrate (demigrate) the resulting image from prestack time migration using the same rms velocity field as for prestack time migration. The demigrated section is a representation of a zero-offset wavefield; as such, it is the appropriate input to poststack depth migration (step 11) compared to the conventional stack, which is only an approximate representation of a zero-offset section.

(11) Begin with the rms velocity field for earth modeling in depth. Perform Dix conversion of the rms velocities from step 8 to derive an interval velocity field. Perform poststack depth migration of the demigrated section from step 10 using the interval velocity field. Overlay the image from poststack depth migration and the interval velocity field to check for consistency of the earth image with the earth model. Then, interpret a set of depth horizons associated with layer boundaries with significant velocity contrast. Divide each layer into a set of thin layers by creating phantom horizons so as to preserve the vertical and lateral velocity variations within each layer inferred by the interval velocity field. The resulting velocitydepth model can be considered as a representation of the structural geology, and, in principle, may be used as an initial model to perform layer-based model updating via residual moveout analysis of the image gathers from prestack depth migration (step 12).

(12) Perform depth migration of the shot gathers of step 6 from floating datum, individually, and sort the shot images to common-receiver gathers in depth (one type of image gathers). Each trace in a common-receiver gather represents the subsurface image beneath the receiver location contributed by a particular shot. If the interval velocity field is defined correctly (step 11), then the traces in a common-receiver gather can be treated as the replicas of the same subsurface image in depth. Thus, events on a commonreceiver gather should be flat with no residual moveout. To obtain the image from prestack depth

migration, simply stack the traces in each common-receiver gather. Prestack depth migration based on migration of shot gathers (Schultz and Sherwood, 1980; Reshef and Kosloff, 1986) is performed using the phaseshift- plus-interpolation (PSPI) algorithm (Gazdag and Squazzerro, 1984), adapted to start the imaging from a floating datum (Reshef, 1991). The PSPI algorithm images steep dips accurately up to 90 degrees and accommodates lateral velocity variations not just within the bounds of time migration but also the cases that require depth migration.

(13) Apply appropriate signal processing to the outputs from prestack time migration (step 9), demigration (step 10), poststack depth migration (step 11), and prestack depth migration (step 12). The signal processing includes predictive deconvolution to restore the flatness of the spectrum within the signal passband, timevariant spectral whitening to account for signal nonstationarity, bandpass filtering, *f-x* deconvolution for attenuation of random noise uncorrelated from trace to trace, and AGC. Using the data attributes — average amplitude spectrum, time-variant spectrum, and autocorrelogram, we can decide on an optimum signal processing sequence with appropriate parameters. In case of post- and prestack depth migrations, the sections are first converted from depth to time using the interval velocity field before the application of the signal processing sequence. They are then converted back to depth, again, using the interval velocity field.

(14) In this final step, all deliverables from ThrustLine workflow are collected for presentation and reporting. The deliverables include: (1) the rms velocity field (step 8); (2) the image from prestack time migration (step 9) with postmigration signal processing (step 13); (3) the unmigrated section from demigration (step 10) with postmigration signal processing; (4) the interval velocity field (step 11); (5) the image from poststack depth migration (step 11) with postmigration signal processing; and (6)the image from prestack depth migration (step 12) with postmigration signal processing. A complete processing history also is provided with the six deliverables listed above. The history includes all the parameters and file names for each step in the analysis.

## References


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