ANGLE-DEPENDENT TOMOSTATICS

Lindsay M. Mayer, Kansas Geological Survey, University of Kansas, Lawrence, KS
Richard D. Miller, Kansas Geological Survey, University of Kansas, Lawrence, KS
Julian Ivanov, Kansas Geological Survey, University of Kansas, Lawrence, KS
Tom Weis, Thomas V. Weis & Associates , Centennial, CO
Bob Anderson, Newmont Gold, Denver, CO

Abstract

Statics are a dynamic problem that affects most seismic surveys. The key to addressing the statics problem is an accurate estimation of near-surface velocity variability. Reflection velocity analysis is critical to meaningful CMP stacks, however a reliable velocity function depends on reflections with the trace-to-trace static variability associated with an irregular near-surface velocity. Using conventional correlation approaches the problem then becomes cyclic because the relationship between statics estimations and corrections are intertwined with reflection velocity analysis. In this study we explore a new method for correcting medium to short-wavelength statics defined by a reflection of interest, using turning-ray tomography to characterize the near-surface velocity field iteratively and using correlation statics as a constraint on our inversion. We do this by exploiting first-arrival information and potentially eliminating the need for post-NMO corrections by optimizing our initial tomographic model using correlation statics post-NMO as a guide. By applying a set of static corrections before normal-moveout, this method will also effectively eradicate the influence of reflection velocity analysis on the time corrections and tie time-shifts to properties in the near-surface geology. Data for this survey were collected along Highway 50 near Hutchinson, KS. These vibroseis data were recorded with a 10 s upsweep from 25-300 Hz. The processing flow using iterative tomography before normal-moveout corrections is superior to post-NMO correction techniques that use correlation as a guide.

Introduction

Near-surface reflection seismology is an increasingly important tool for both environmental and exploration applications. It is a deductive problem and most commonly approached with little to no well control or specific knowledge about the study area. The target for most near-surface exploration surveys is at or below bedrock and can only be imaged properly with an accurate velocity model in the weathered layer. Furthermore, accuracy within the velocity model is most often determined and verified by identifiable reflections in the shot gathers. Seismic energy will disperse in unconsolidated environments and create static (time shifts) problems that screen the target reflectors (Cox, 1999). Coherency of reflection events within seismic shot gathers is vital to seismic reflection processing.

Velocity analysis is one of the most important steps in near-surface reflection processing, however it is dependent on a good characterization of the weathered interval. As seismic energy passes through the weathered zone it is shifted in time, due to velocity variation and changes in thickness (Figure 1). As with most conventional processing steps, velocity analysis incorrectly assumes laterally homogenous layers with small velocity gradients with depth. In highly irregular weathered areas, the near-surface velocities change laterally and the reflecting layers are often discontinuous, creating a challenge in high-resolution velocity modeling. Adjustments for NMO on shallow reflection data are generally complicated by low S/N ratio, high static-shift-to-dominant-period ratio, and a minimal number of traces with identifiable reflections with the optimum window (Miller and Xia, 1998).

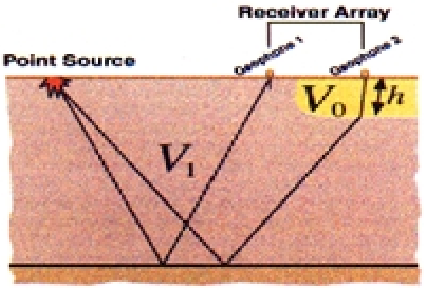

Figure 1: Flat layer model showing velocity variation that would reflect a time shift between geophones 1 and 2. (Steeples and Baker, 2002)

An effective way to estimate two-dimensional, near-surface velocity distribution from seismic data is tomographic imaging (Zhu and McMechan, 1988). Turning-ray tomography is a reliable source of both lateral and vertical velocity information. Since velocity analysis and static problems are coupled, tomography is used to estimate offset-based statics iteratively before NMO correction, to better serve velocity analysis. This will effectively increase reflection coherency in the shot domain and create an optimized velocity solution.

Geologic Setting

The Kansas Geological Survey with funding from the Kansas Department of Transportation collected this CMP data set along Highway 50, south of Hutchinson, KS in central Reno County. The geology of the area is characterized by a carbonate sequence of shales, limestones, and dolomites with the Hutchinson Salt member imbedded 270- 400 ft deep. The overburden is an approximated 50 m. deep and consists of Quaternary gravel and sand deposits (Bayne, 1956). The data possesses significant statics as a result of the near-surface velocity irregularities. The data were collected using an IVI Minivib generating a 10 s upsweep of 25-300 Hz with 240, 40 Hz geophones live per shot. The total length of the survey was 6.2 mi with a rolling-fixed spread, a 2.5 m station interval and 1 ms sampling rate.

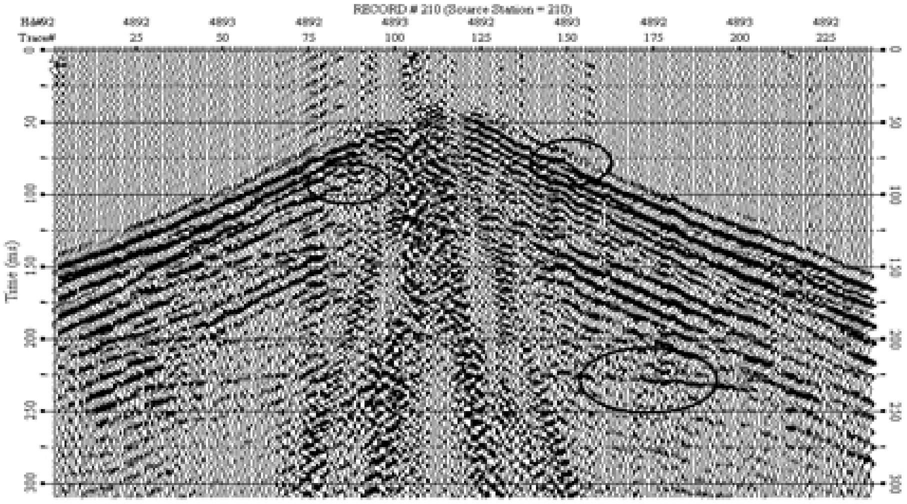

Figure 2: Raw shot gather with static areas circled. Two circled areas are statics within the refracted and guided wave between 50 and 100 ms, and 250 ms there is static in a reflection.

A section of the 6.2 mi seismic line was chosen which had significant static shifts (Figure 2) to test the method. The number of shot gathers needs to be large enough to avoid underdetermined sampling of the surface for the first-arrival inversion used in tomography. There are 359 shot gathers included the test data.

Processing and Modeling

A typical CMP processing sequence was followed to initially process the data set (Figure 3). Raw vibroseis data was first pre-whitened and cross-correlated with a synthetic sweep to produce a zerophase wavelet in the shot records, which is not shown in Figure 3. Conventional bandpass filtering, muting, and automatic gain control (AGC) were then applied to the shot gathers in order suppress noise and enhance reflections. First-arrivals were picked before any processing was carried out on the data to prevent phase or frequency shifting.

The tomography is run following the input of first-arrival information and source geometry. The stratigraphy of the area is mostly flat-lying carbonate sequences, so the tomographic parameters only include horizontal smoothing[1] and an RMS limit of 5 ms.. The cell size for the model is one station interval (2.5 m) to optimize the resolution of the static corrections (Figure 4).

Figure 3: CMP processing flow used for these data flow. Pre-stack is any process before CDP stacking.

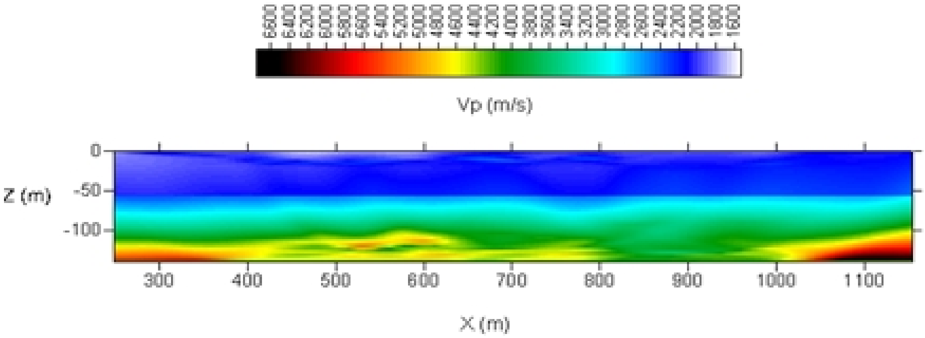

Figure 4: Tomographic model created using first arrival information from Hutchinson, KS data. RMS error = 5.1 ms.

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[1] Vertical smoothing was not used.

Methods

Static corrections are time corrections made to a trace to account for the weathering interval and topographic changes along the survey line. Most datum statics methods estimate overburden velocity using refraction techniques and simply subtract those velocities from the data assuming vertical incidence (Cox, 1999). Due to recent advancements in near-surface seismic data collection, some studies can target reflectors less than 3 meters deep (Baker et al., 2000). The vertical raypath assumption for datum statics corrections is incorrect for shallow reflectors because the reflection angle is greater than 10° for most offsets. Therefore, each source and receiver pair will have a different travelpath that is dependent on offset and reflection depth (Figure 5).

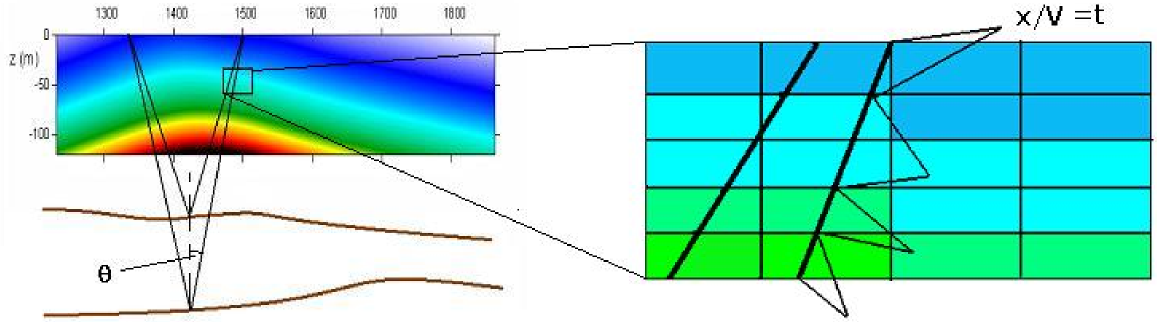

Figure 5: Raypath diagram for single trace with two reflecting points. Time corrections are calculated from raypath length and velocity through each cell in the tomographic image.

Using a detailed tomographic image, Figure 4, static corrections for each trace can be estimated for a target reflector before NMO corrections. Once these corrections are made to the shot gathers, surface-consistent statics will be applied to check that wavelet correlation is improving. The process is iterative so that the initial model for tomography will be prior tomographic image and the first-arrivals are repicked to create a new tomographic image. The tomographic image is optimized once the static corrections are small enough to be attributed to residual statics (< 2 ms). NMO velocities are affected by the statics corrections, so velocities are reanalyzed, residual statics applied, and a final stack produced.

Discussion

Tomostatics is a general term used to describe tomographic methods to determine statics corrections and is commonly used for near-surface velocity characterization (Sheriff, 2002). In near-surface seismic studies target reflectors are usually < 250 m, therefore vertically incident raypaths through the weathered zone cannot be assumed. Large offsets and strongly heterogeneous weathered layers generate the need for ray-path angle-dependent static corrections (Cox, 1999). Tomography estimates the both lateral and vertical heterogeneity that will better resolve the angle-dependent static problems.

Tomography determines a velocity distribution to a depth based ray penetration of the first-arrivals. When receiver spread lengths are much larger than the shallow reflections, the tomography will penetrate past the weathered zone into bedrock at ~50 m (Figure 4). Better ray penetration will result in deeper imaging, but the model cannot be trusted if there is no refraction energy at those depths. The problem of non-uniqueness becomes infinitely large and can be exacerbated by smoothing parameters, damping, and too many allowed iterations. Any tomostatic method is subject to error from mathematical anomalies, so the tomographic model chosen for static corrections must be geologically comparable to the area. Also, with each iteration of tomography, the parameters should stay fairly constant to avoid unnecessary variations.

The tomographic image generated in the second iteration of static corrections (after angle-dependent tomostatics had been applied once) is seen in Figure 6. The image is similar to the Figure 4 with small differences in the structure near the bottom of the model. The tomostatic is more evident in the shot gather domain where the reflection character is changed. The angle-dependent tomostatic was applied for a target reflector at ~220 ms[2] and a slight change in the coherency of the target reflection can be seen in Figure 7.

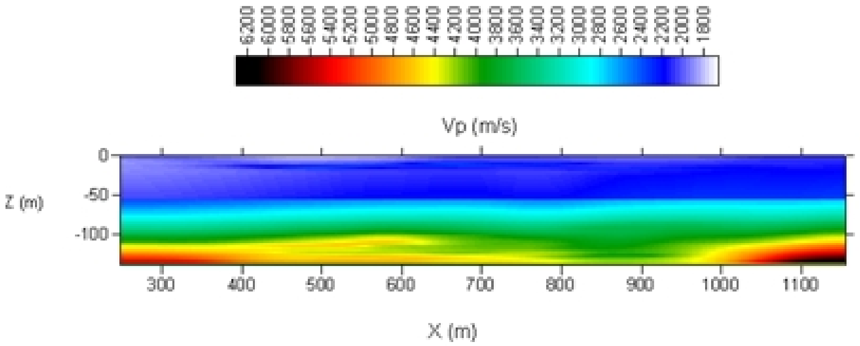

Figure 6: Tomgraphic image created after first application of tomostatic. Same parameters were used in both iterations and the initial model shown in Figure 4.

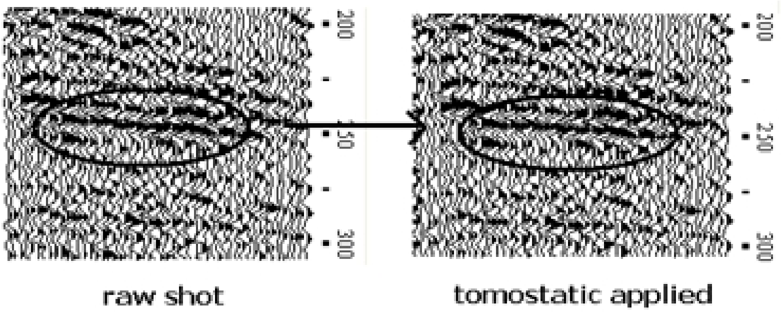

Figure 7: Target reflection in shot gather before and after angle-dependent tomostatic applied.

Although the improvement is very small in the shot gather domain, it can be quantitatively assessed by applying surface-consistent statics to the data. The absolute value of all source and receiver static corrections in the window of the target reflection show an overall decrease after tomostatic, which translates to an increase wavelet correlation. The total coherency of the reflector is also improved in the final stacked section as seen in Figure 8. In the stacked section, the reflection around 220 ms is more continuous after one iteration of angle-dependent tomostatics is applied.

The data from Hutchinson, KS is relatively smooth both structurally and stratigraphically. This method is successful on both stacked data and in the shot gather domain, but dramatic improvements are expected in extremely complex areas with a relatively thick weathered interval. The concept of angle-dependent tomostatics is based on extreme lateral heterogeneity in the near-surface where variations from trace-to-trace are otherwise unpredictable by conventional correlation static routines.

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[2] Figure 7 shows the far offset portion of reflection

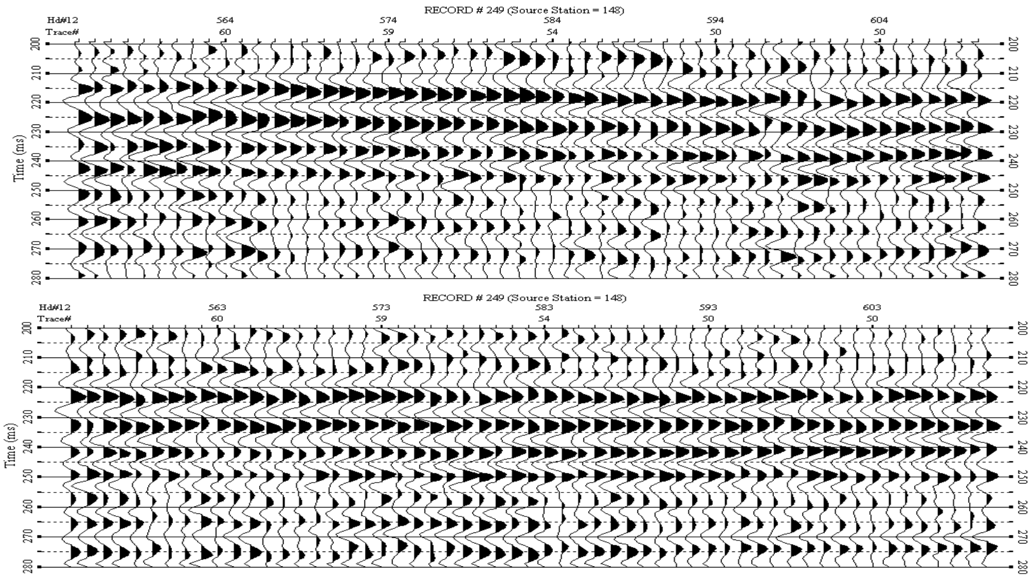

Figure 8: Stacked section of Hutchinson data before and after one iteration of angle-dependent tomostatic is applied. The top image is before and the bottom is after tomostatic is applied targeting the reflector at 232 ms.

Conclusions

Static shifts in the data are a result of a laterally inhomogeneous subsurface. Certain processing techniques can highlight and adjust for variability within a spread. A smooth and detailed velocity function increases the coherency of the stacked reflections and therefore the accuracy of interpretation. The specific properties of the velocity model will depend on the target and degree of change in the near-surface.

Static corrections are necessary in most environments and tomostatics is a convenient application of refraction data to improve reflection coherency. In shallow reflection surveys, angle-dependent tomostatics is necessary to account for the large offset with respect to target reflections. This approach will increase the coherency of target reflectors, however tomographic parameters must be carefully tested and monitored before applying tomostatics to near-surface reflection data.

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Acknowledgements

This research would not have been possible without funding from Newmont Mining Corporation and the SEG Foundation as a project of merit.