U027

A New Approach to Water Velocity Estimation and Correction

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SUMMARY

A layer replacement method for estimating and correcting seismic data for the variation in the velocity of sound in water not only overcomes some of the difficulties of a conventional method, it produces estimates of absolute rather than relative water velocity. The method involves iterative layer-replacement of water bottom reflection times and accounts for both dip of the water bottom and source-detector azimuth. Although the new and conventional methods share some elements, they differ in concept and result. The layer replacement method has been found efficient and effective in processing 3D marine seismic data.

Introduction

The sonic velocity of seawater is constantly changing. Currents and eddies flow through an area on many time and spatial scales, carrying water of varying temperature and salinity. Velocity is mostly dependent on temperature and salinity. As surveys in deep water became common place, geophysicists realized that the velocity changes were enough to misalign target reflections when sail lines were gathered and combined for stacking and other processes.

Chambers (1990) was one of the first exploration geophysicists to recognize that the seawater velocity could be measured directly with conventional velocity analysis applied to the reflections in the water column. Several papers have been presented concerning water velocity determination and correction, among them Lacombe, et al. (2006) and Wombell (1996).

My focus in this paper is in explaining a new layer replacement method for estimating and correcting water velocity variation and comparing it with a more conventional traveltime approach derived from the Fried and MacKay (2001) method.

The traveltime method

The traditional, or "traveltime", method of water velocity correction relies on comparison of zero-offset travel times from overlapping subsurface coverage of adjacent sail lines. First, water-bottom reflection times are picked from the seismic data. Then, the reflection times are analyzed along “crosslines,” i.e., lines of CMP bins perpendicular to the sail-line direction. The times are NMO-corrected to zero offset using velocities from velocity analysis of the traces in each sail-line crossline group. If the water bottom is dipping, the measured NMO velocity will be higher (Levin, 1971), but the effect of NMO will still be of removing offset dependence in the reflection times. The NMO velocity will also be dependent on the observed velocity, or the actual velocity experienced by the energy traveling from the sources to the detectors. A process similar to reflection residual statics then finds shifts to apply to each sail-line crossline group of data that will produce maximum alignment in those CMP bins where there are data from more than one sail line. The shifts represent changes in water velocity between the sail lines and may be used for a water velocity correction of the seismic data (MacKay, 2001).

Determining the shifts can be tricky. If there are no overlaps between sail lines, then there is nothing to align, and shifts cannot be determined. Commonly though, nearby crosslines of the same sail lines will have overlaps, and shifts from those crosslines may be interpolated to provide the missing shifts. A more difficult problem occurs in the presence of dip. It is not uncommon to have a 50-degree azimuthal difference between sail lines in overlap areas. Figure 1 shows the differences in time that occur in NMO-corrected (with a dip-affected velocity) reflection times when source-detector azimuth varies. Even at a small dip of 10 degrees, the figure shows over 5 ms of difference in NMO-corrected time at a 1300-m offset. One of the problems with traditional overlap-based methods is that these differences contaminate the results and lead to erroneous corrections.

The layer replacement method

The layer replacement method is different from other methods in that it bases all determinations on a physical model and simple, straight raypath geometry. Primarily, there is an implicit assumption that all reflection times in a common midpoint bin must be consistent with respect to three model parameters: the observed water velocity, the slanted-path zero-offset raypath through the water, and the geologic dip of the water bottom. Thus, for any trace in a survey, the water-bottom time may be found from these three components when given the trace’s source-to-detector offset, azimuth, and midpoint. The observed water velocity for a trace is constrained to be the same for all traces of the traditional method’s sail-line crossline group.

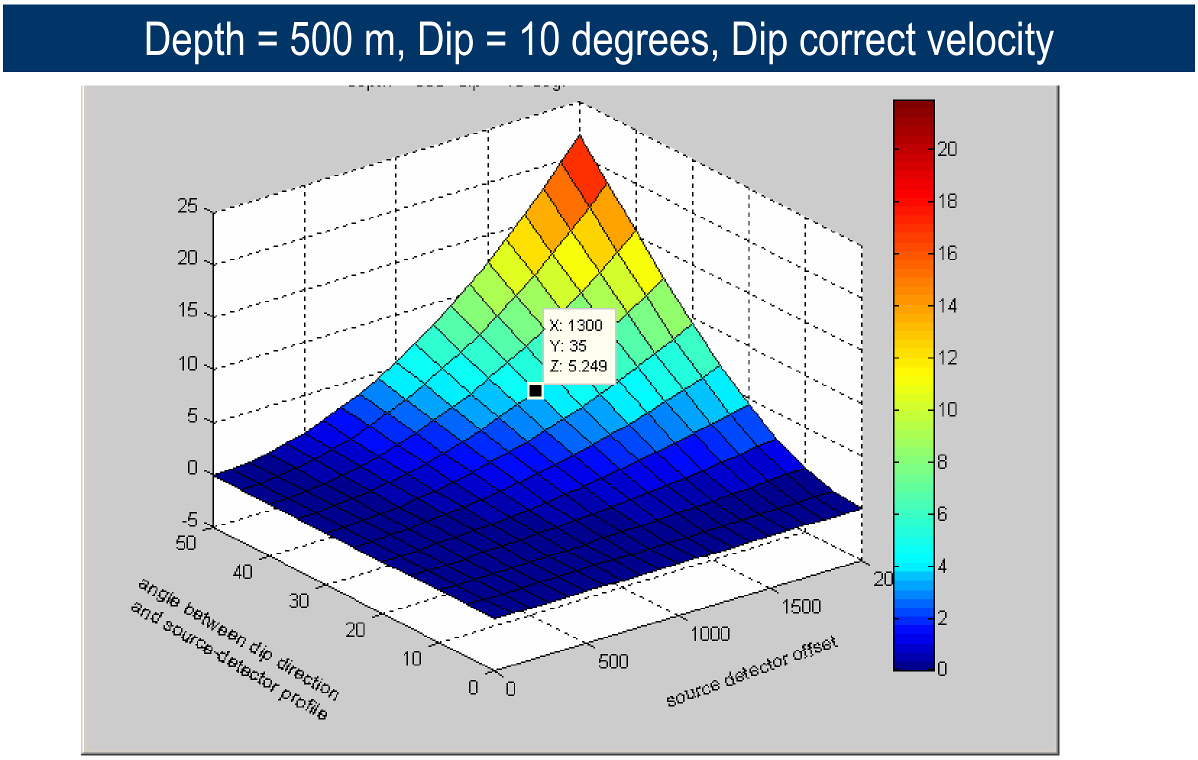

Figure 1: *Difference in NMO-corrected time (ms) for different azimuths and offsets for a dip of 10 degrees and zero-offset distance of 500 m.*

From this foundation, the layer replacement method finds the observed water velocity that, when layer replaced with a "replacement" velocity, explains the observed water-bottom reflection times. The method consists of iterative layer replacement, residual estimation of observed velocity, and dip estimation. By accounting for the geometry of the source-to-detector raypath, seafloor dip, and midpoint scatter within bins, the layer replacement method produces a robust estimate of the absolute observed water velocity as it varies along each sail line. After finding the observed velocity, it is a simple matter to calculate the zero-offset difference in water bottom reflection time between the observed and replacement velocities (delta-t) to use in applying MacKay's dynamic correction to the seismic data.

One interesting feature of the layer replacement method is that the true up-dip position of offset reflections in a CMP is ignored. A reflection point is positioned laterally by its source-detector midpoint falling in a CMP bin. Only the reflection times are adjusted to move down dip to the zero offset position at the centre of each CMP. For each CMP, the reflector is assumed to be a plane for all the traces in the CMP, even though, in reality, actual reflection points may be spread far if the dip is large. There is dichotomy in allowing the same true reflection point to be in different CMPs, and therefore, to have different zero-offset times. With local dip estimated from many CMPs in the surrounding area, the dip estimate appears to be quite stable and locally smooth; so in practice, the issue may not be that important.

Application

Figure 2 illustrates two problems that can occur when using the traveltime method. Compare the section with traveltime corrections (middle) with a stack with no corrections (top). First, although the method works well in flat areas such as in the left-most circle, in dipping areas, azimuth changes between sail lines and lack of redundancy leads to erroneous results. The circled areas highlight zones of transition between adjacent sail lines. The small jumps are about 5 ms in magnitude. In the area below the arrow, a structural feature makes some reflection times at the edge of the feature uncertain. Unfortunately, the edge is also an area of overlap of sail lines. Here, aligning the reflection times of the pre-stack data has pushed down the water bottom reflection. And although there is less structure in the water bottom reflection, there is an unrealistic look to the continuity and character of events below the water bottom. When there are many errors of this type, a processing geophysicist may try to resolve the problem by identifying and interpolating good corrections from flat areas, a manually intensive and time-consuming process. In contrast, processing with the same reflection times, the layer replacement method finds corrections that resolve the problems (bottom).

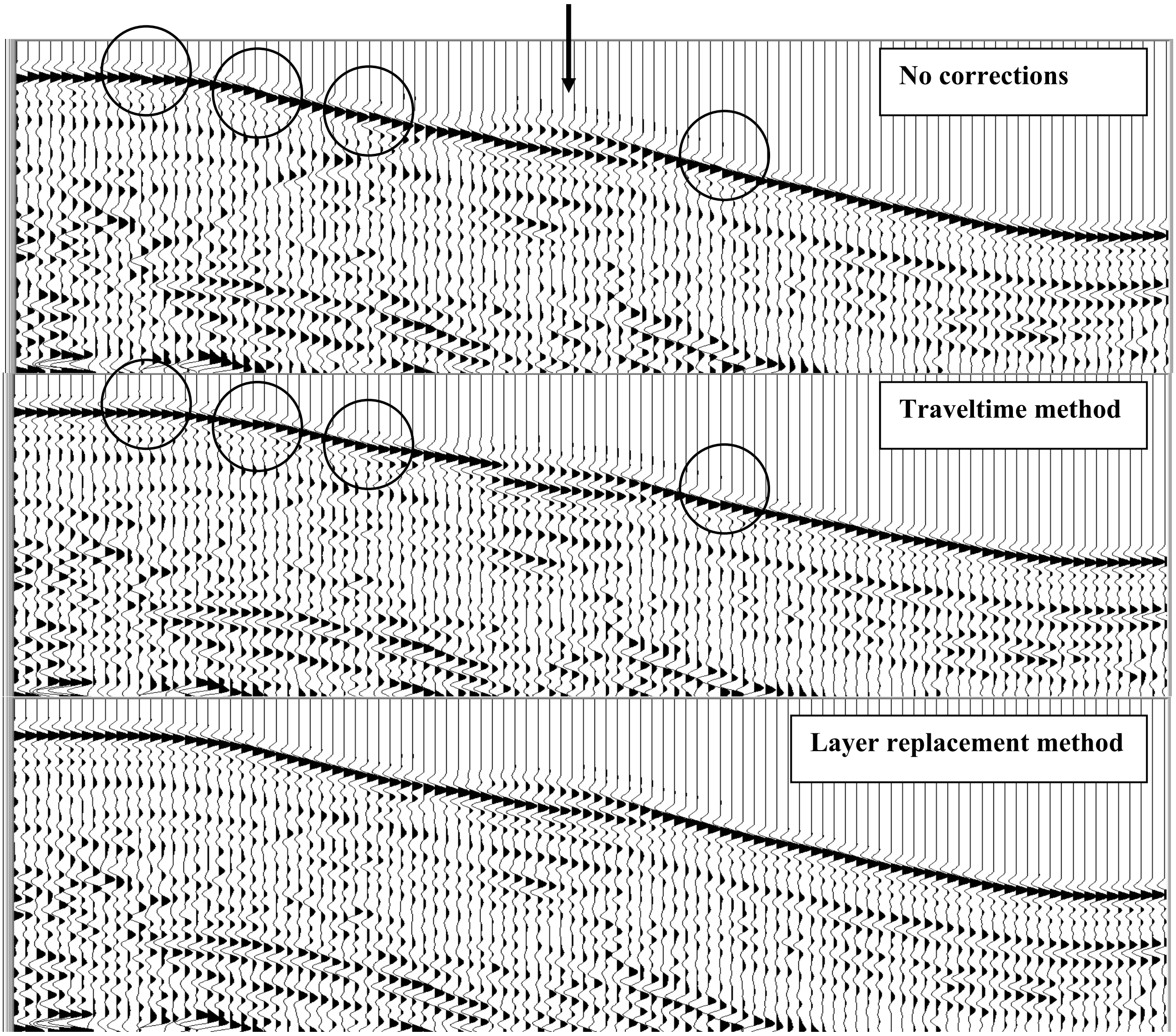

Figure 2: *The stack of the water bottom of a crossline section from a 3D survey illustrates some of the problems that lead to manual editing in the traveltime method. The stack without water velocity corrections (top) shows some joints where adjacent sail lines overlap in the crossline direction. The Traveltime method corrections applied without editing (middle). The layer replacement method (bottom) has resolved all jumps and discontinuities related to water velocity. (The two strong peaks at the water bottom below the arrow are about 30 ms apart.)*

Conclusion

A new, robust method of water velocity estimation is introduced here. The method finds the best estimate of the observed water layer velocity with which to replace observed water-bottom reflection times with reflection times that would have been observed with a water layer having the replacement velocity. The estimate of absolute water velocity may be used to determine water velocity corrections between sail lines and amongst surveys. The method is fully 3D and accounts for water-bottom dip and source-detector azimuth. Unlike "relative" methods, the layer replacement method uses overlapping coverage, but does not depend on it. Finally, the layer replacement method produces high quality results and efficient turnaround times.

Acknowledgements

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