Time Domain 3D VSP Processing as a Step Before 3D PSDM

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In nearly all cases within the seismic data processing industry, 3D Prestack Depth Migration (PSDM) of surface land and marine seismic data is preceded in the processing flow by time domain imaging steps. The time-domain steps include iterative NMO velocity analysis, residual statics and often 3D Prestack Time Migration (PSTM). The value of the time-domain steps is that source and receiver statics can be determined and a spatially variant 3D velocity field can be determined and later used in 3D PSDM steps.

We have found that high quality 2D and 3D VSP PSDM results can be obtained by following the same time-then-depth process that is used in surface seismic data. Time-domain processing of 2D VSP and 3D VSP data is achieved by first applying upward continuation of the VSP data to effectively transform the VSP data into surface seismic data. The upward-continued VSP data can then be treated as surface seismic data, hence allowing computation of surface-consistent residual statics and development of a spatially variant time-domain stacking velocity field through NMO analysis. Then, in a process identical to that used in surface seismic data processing, PSDM can be applied to the upward-continued VSP dataset. By this procedure the same benefits of time-domain residual statics and velocity analysis can be realized for 2D VSP and 3D VSP data.

Introduction

The geometry of 3D VSP data acquisition has multiple seismic source points at the earth's surface and seismic receivers at depth in the borehole. This geometry lacks the common mid-point assumption inherent in surface seismic data and therefore precludes direct application of hyperbolic NMO analysis that is central to time-domain analysis of surface seismic data. The lack of an obvious time-domain processing analog for 3D VSP data commonly leads to direct application of 3D Prestack Depth Migration (PSDM) using the native 3D VSP geometry of seismic sources at the earth's surface and geophones at depth in the borehole.

Generation of a high quality 3D VSP image directly from 3D PSDM requires prior resolution of surface source statics and an accurate migration velocity field. Unfortunately 3D PSDM does not generally contribute to residual statics analysis and PSDM migration velocity analysis normally requires input from earlier time-domain steps or other independent method of velocity determination. It is for these same reasons that we see the nearly uniform use of time-domain processing prior to PSDM in surface seismic data processing.

An alternative to direct application of PSDM to 3D VSP data is to first transform VSP data into an approximation of surface seismic data via upward continuation (Fuller, et al., 2008). The upward continued data can be treated and processed as surface seismic data thus allowing iterative spatially-variant velocity analysis and surface consistent residual statics, both of which contribute to maximum frequency content and structurally-correct reflection images. Following time-domain data processing, transformed 3D VSP data can be passed through the normal process of PSDM.

Method

Earlier publications show that upward continuation of VSP data simulates surface seismic data and allows iterative time-domain velocity analysis, residual statics analysis, and produces reflection images with higher frequency than surface seismic data (Fuller, et. Al., 2008, Van Dok, et. Al., 2012). The point of this abstract is to discuss that a next logical step in reflection imaging with VSP data treated in the time domain would be to apply Prestack Depth Migration. In this way we can obtain whatever benefits are to be realized from PSDM of VSP data while also realizing the benefits of iterative data-driven NMO analysis and residual statics.

Examples

The images shown below are time (PSTM) and depth domain (PSDM) VSP reflection images of the same horizontal and approximately vertical location. The images were both treated with the time-domain processing discussed above that includes iterative velocity and residual statics analysis. The results are similar in character and resolution.

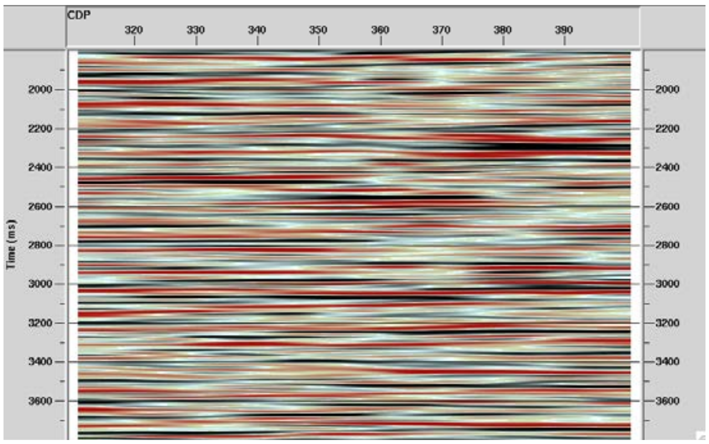

Figure 1. Time Domain Image. This image is a PSTM image from VSP data.

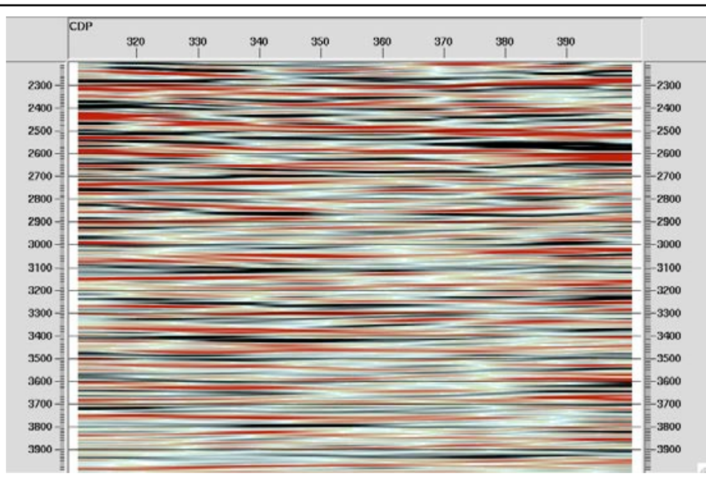

Figure 2. Depth Domain Image. This image is a PSDM image from the same VSP data used to generate the image in Figure 1.

Results and Conclusions

The well-understood and effective methods of processing surface seismic data through PSDM include the initial phase of time-domain processing that includes iterative velocity analysis and residual statics. It has already been shown that VSP data can be transformed to simulate surface seismic data via the upward continuation process and that VSP data can also benefit from iterative time-domain velocity and residual statics. Hence, the benefits of time domain velocity and residual statics analysis can be extended to apply to PSDM of VSP data rather than going directly to PSDM as is often done in generating reflection images from 2D VSP and 3D VSP data.

References

Fuller, B., Sterling, M., and Van Dok, R., 2008, Time Domain 2D VSP and 3D VSP Processing, Expanded Abstracts, 2008 SEG convention.

Van Dok, R., Fuller, B., Walter, L., Wojcik, E., and Reagan, J., 2012, Just-in-Time Well Trajectory Imaging Using Borehole Seismic to Guide the Horizontal Drill Bit: Haynesville Case Study, Expanded Abstracts, 2012 SEG Convention