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Inversion in depth?

An interesting idea, highlighted at the 2015 SEG Convention, was about carrying out seismic impedance inversion in the depth domain. "Inversion" refers to the transformation of seismic amplitude data into acoustic impedance data.

Impedance inversion has been conducted in the time domain for the last four decades. If it has to be carried out in depth, a few questions come to mind—what is so different about carrying out inversion in depth, rather than time, how does it help, and if it's important, why did we have to wait four decades to talk about it now? Let us address each question, with the last one first.

Why now? In the last two decades, rapid strides have been made in developing depth migration algorithms and procedures. We have now reached a stage, where post-stack or pre-stack depth migrated volumes are sought, whenever interpretation on seismic time volumes seems inadequate, or does not provide ready answers to some of the geological questions.

The computations required for depth imaging are way more than time migration, due to the iterative nature of the velocity revisions required. Computational costs have, gradually, become cheaper, which has resulted in advancements of algorithms from 2D to 3D, and then from post-stack to pre-stack applications. These days, large data volumes are stored and handled in the memory, which helps the processes run efficiently. Given an accurate velocity-depth model, depth migration overcomes velocity pull-up and push-down effects; enables calculation of more accurate volumetrics; and also improves vertical and lateral resolution by properly aligning events.

But how does this happen? Depth migration handles, better, the seismic signal wavefront bending caused by subsurface velocity contrasts, and thus repositions the reflection events with greater accuracy. The usual depth imaging process is to first construct an accurate subsurface velocity model in depth. This requires input from the seismic data, the available borehole data, the interpretation carried out for horizon picking and fault interpretation on the seismic, and the right workstation software tools to integrate all this information.

Another important input is accounting for anisotropy in subsurface rocks, i.e. variation of seismic velocity with direction of propagation. Shale formations exhibit a higher velocity, parallel to the bedding direction, than in a direction perpendicular to it. Similarly, dipping anisotropic effects arise from complex subsurface features seen in thrust belts or subsalt plays. The model's validity is checked by examining the depth-migrated gathers (pre-stack data) and the stacked response, where the gathers are expected to exhibit flat reflection events across all offsets, and the stacked response matches reasonably with the well data. It is sometimes difficult to determine a velocity model with accurate anisotropic parameters, and if the model used for depth migration is not optimum, the well ties are off, and so is lateral positioning of events.

To benefit from depth migration, past practices were to convert the depth migrated data into time, perform the impedance inversion in time, and then bring it back to the depth domain. Thus, the impedance inversion was performed in the time domain. The suggested difference, now, is to bypass the conversion of depth data into time and back, and perform the impedance inversion in the depth domain, itself.

The first step in impedance inversion, whether in time or depth domain, is the well-to-seismic data correlation, as it relates the data to stratigraphy and subsurface rock properties. The entity that links the seismic trace at the well site, and the reflection coefficient series constructed from the data, is the seismic wavelet. As stated above, processing involving wavelets has, traditionally, been done in the time domain. One reason is that the wavelet shape remains consistent in the time domain (though wavelet frequency decreases with time). In the depth domain, wavelet shape changes as velocity increases with depth, due to compaction, or otherwise.

When seismic data are converted to depth, the seismic wavelet undergoes a variable stretching that depends on the velocity. It gets stretched more in a high-velocity interval than a low-velocity interval. Also, because the velocity can vary spatially, depending on the geology, the seismic data in depth also can have the wavelet stretch varying spatially. For carrying out impedance inversion on post-stack seismic data in the depth domain, a simple approach would be to follow the procedure for seismic data in the time domain, and let the stretch effects be in there, however small or big. Of course, by choosing a narrow depth window, the depth of the variable stretch in the vertical direction can be minimized.

A few ways have been suggested to account for the variable spatial and temporal wavelet stretch. One is to replace the varying stretched wavelets in seismic depth data with an equivalent single-wavelet that is stretched in depth with a single velocity. Another approach overcomes the wavelet's estimation and its convolution in the depth domain by using a pseudo-depth transformation. As the impedance inversion in depth evolves, it establishes the accuracy of such techniques.

Thus, it is convenient to carry out the impedance inversion in depth directly. We can take advantage of the superior imaging of the reflection detail, as well as overcome the pitfalls of seismic data interpretation in time. The results demonstrated for impedance inversion in depth, in vendor presentations or some publications, look promising. Besides the post-stack inversion, the pre-stack inversion results also look superior. Hopefully, we will witness interesting developments in carrying out impedance inversion in depth, and the accurate interpretations that follow therefrom, in a quantitative way. WO

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