Offset vector tile anisotropic tomography and PreSDM of the Hild OBC

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Abstract

In this work, we have performed model building and 3D PreSDM on P-wave data from a 3D OBC survey using offset vector tile (OVT) processing, wherein the velocity is estimated by a surface fitting non- sectored approach, characterising velocity in terms of a fast and slow direction, along with the azimuth of the fast axis. Using OVT VTI tomographic inversion permits us to thereby better resolve localized heterogeneity that is usually left unresolved when using a conventional non-OVT tomographic approach.

In addition to the OVT VTI tomography, we followed the 3D PreSDM model building and migration with an HTI azimuthal velocity analysis in an attempt to characterize any dominant fracture patters: in this case, no dominant patterns were found.

We compare the results with existing data showing how rigorous handling of azimuths better constrains the lateral velocity variations and results in a better focused image in the Jurassic, especially of steep fault planes.

Introduction

In conventional 3D seismic data processing, we can sort the data in a number of 3D common-offset volumes, each offset volume comprising a limited range of offsets. With single-boat acquisition, for example, even with a large number of towed cables, the range of azimuths for the majority of receivers is very limited, so this approach is generally justified. It is only at the head of the cable that we have a significant distribution of azimuths. Conversely, for OBC and some land acquisition configurations, we may have a sufficiently well distributed range of azimuths and offsets to be able to separate them during processing. In this case, in addition to a number of offset volumes, we will also have a significant number of azimuth classes. Hence, although the number of traces being processed may not be any higher, the number of volumes into which we sort the data, is dramatically increased.

One such sort-order for processing full-azimuth data is the offset-vector tile (OVT) configuration.

Once we no longer bin data across azimuth into just offset-classes, we open a whole range of possibilities for data processing and analysis. For example, for data binned only into offset classes, any 2D transform will tend to be degraded due to jitter between traces in the offset gathers due to conflicting arrival times resulting from slight ray-path travel time differences due to azimuthal variation. This type of jitter typically degrades velocity analysis, and coherent noise suppression processes.

In addition, once we have preserved the azimuth dimension of the data volumes, we can ascertain whether there are legitimate variations in velocity as a function of azimuth. This information can be invaluable for reservoir characterization, as it may be related to dominant fracture direction, and the degree of fracture openness. Further, the quality of a final migrated image can be improved, as by correctly dealing with any azimuthal variation, we will remove a class of smearing from the imaging procedure. This improvement arises as we take into account the azimuthal variation of velocity.

As a consequence of this less restrictive sort ordering, we need to have available a modified suite of software tools in order to exploit the additional dimension of information.

Performing non-sectored velocity analysis followed by VTI OVT tomography permits us to achieve greater resolution on localised heterogeneities in the overburden (Williams and Jenner, 2001; Jenner et al., 2001). Following this stage of the model building, which in this case involved three iterations of OVT VTI tomography, we progressed onto an HTI analysis of the data to ascertain if any geologically significant azimuthal velocity variation was present (Jenner, 2011).

Offset vector tile gathers

The notion of essentially single fold gathers, each with a very restricted range of offsets and azimuths, has been around for some time (e.g. Vermeer, 1990; 1998; Cary, 1999), but their adoption as an industry norm has been hitherto limited due to the expense of the acquisition required to provide them. The concept is quite simple, and extends our processing capabilities to preserving azimuth as well as offset in the pre-stack data ensembles and various processing steps.

Figure 1, adapted from Calvert et al., 2008, outlines the underlying principles. The offset vector tile ensembles only contain traces with a similar range of offsets and azimuths.

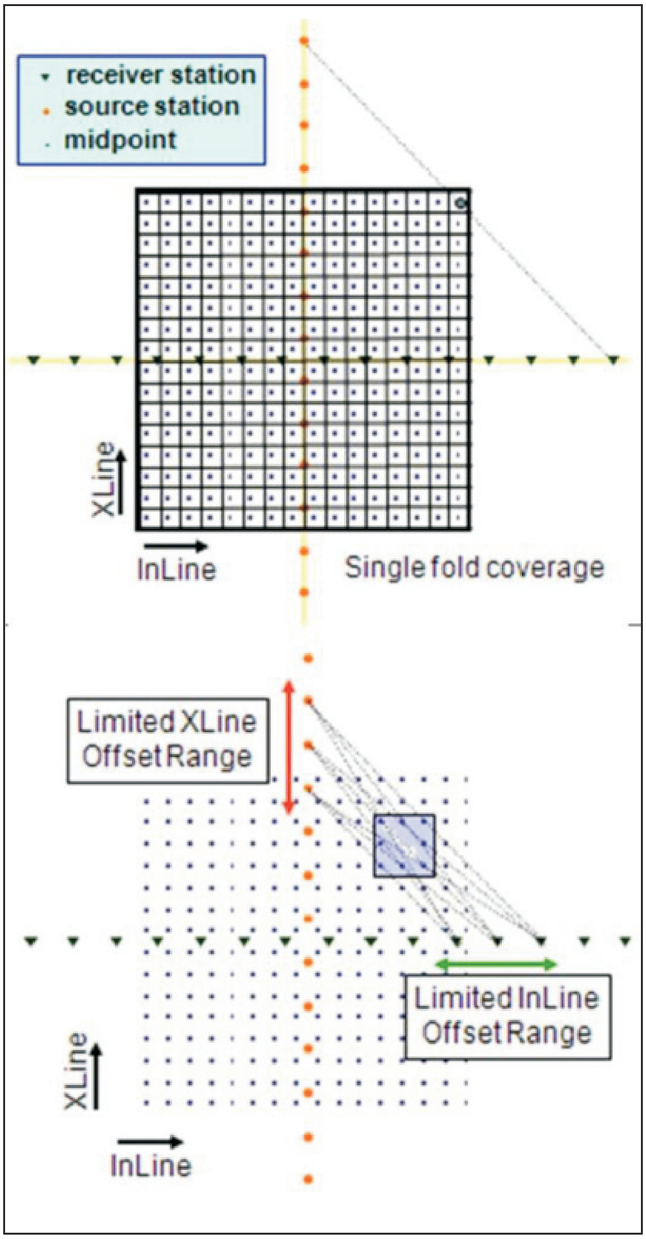

Fig. 1: (Adapted from Calvert et al., 2008) In a cross-spread geometry, traces for a given midpoint can be selected to give a specific offset-azimuth distribution. (a). Traces from a specified range of inline and crossline offsets are grouped into a common tile (cyan box), and if the tile size is chosen to match the source and receiver line spacing, the same tile from the cross-spread associated with the adjacent shot line will lie adjacent to the first tile. Collecting all the tiles from all the cross-spreads results in coverage of the full survey area with single fold data that has similar offsets and azimuths (b).

Rather than characterising the data in terms of offset and azimuth, we describe it in terms of the inline offset, and the corresponding crossline shot location. Figure 2a shows 2D slices through a subset of data from one inline and crossline location, and 2b shows a grouping of inline ensembles for a range of crosslines for this single location.

Offset vector tile residual velocity error picking

Using a smooth initial depth model for PreSDM, a continuous locally-coherent event autopicker is used to track residual moveout in the OVT gathers for a dense grid of picks. For OVT data, the autopicker performs non-sectored picking to produce measurements of the azimuth, and residual velocity-error fields for Vfast, and Vslow, as input to the tomography.

In other words, rather than fitting a 2D curve for a hyperbola or residual parabola, the technique fits a 3D surface at each time sample in the velocity analysis, determining the parameters describing a hyperboloid-of-revolution (Figure 3).

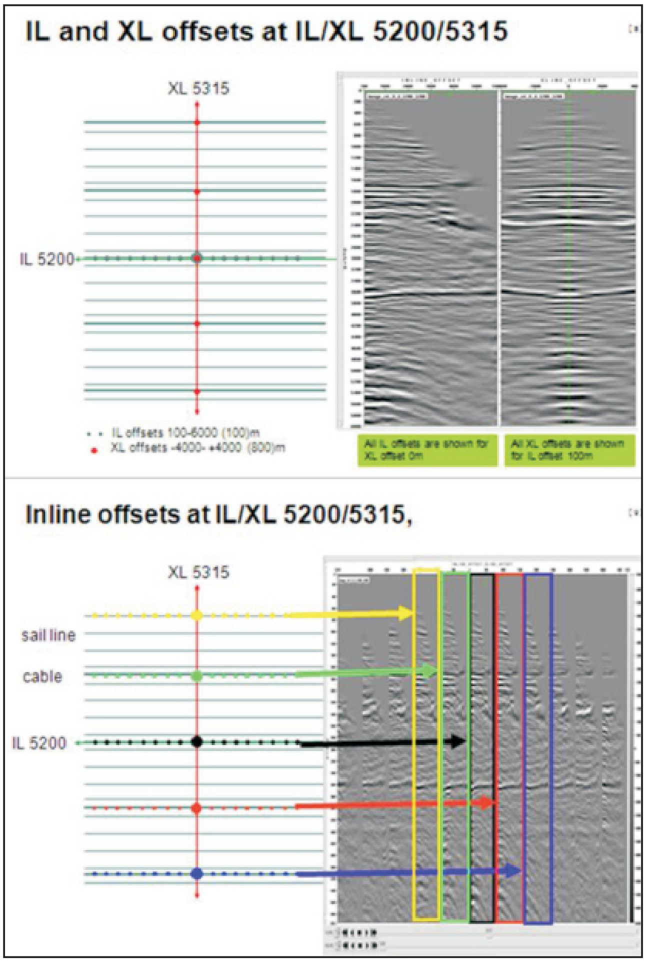

Fig. 2: For a group of inlines where the receivers are located, we can collect contributions at a given point for those receivers acquiring energy from a limited range of shot azimuths.

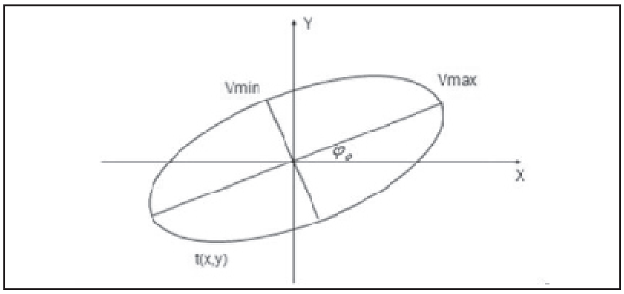

Fig. 3: Ellipticity of the migration velocity is assumed.

Offset vector tile tomography

Tomography updates the velocity model along raypaths, thereby taking into account the actual propagation path in the media. Conventional tomography measures velocity error at a CMP location for the available offset range, but having binned all azimuths into the same offset gather, hence no directional azimuthal dependence of velocity is retained (the VTI aspect is dealt with, but not azimuth itself). In the OVT approach, we preserve any observed azimuthal dependence on velocity, thus enabling the tomographic back- projection to better resolve localised overburden heterogeneities. The basic tomographic engine remains the same (all tomographic solvers back- propagate the observed error along ray paths) but for mono-azimuth tomography, we are essentially telling the solver that velocity error is the same for all azimuths at a given CMP location, which is an unnecessary restriction on its inherent abilities.

However, it should be stressed that our approach is not a full orthorhombic treatment of anisotropy: we separate the aspects of VTI and HTI. In the OVT VTI inversion, we assume that all observed error is due to local heterogeneity, and that there is in fact no true azimuthal component. Once a model has been built under this assumption, incorporating heterogeneities so as to explain any observed errors that fit the hypothesis, a second step in introduced, where we analyse the remaining error to ascertain if we have any consistent geologically plausible true azimuthal variation.

The study area

The Hild field straddles the UK-Norwegian border, with the main reservoir at about 4km depth comprising tilted Jurassic fault blocks. These are overlain by a complex Tertiary and Cretaceous overburden with gas charged zones causing rapid lateral velocity variations, as well as a thin high velocity chalk layer and anisotropic Lower Cretaceous units between the chalk and the main target. The field is covered with several vintages of 3D seismic data, including a three azimuth MAZ marine streamer survey, and a full azimuth OBC multicomponent survey.

The main problem in this area is the poor quality of seismic data, due primarily to: low impedance contrasts in the Pre-Cretaceous sequences, a large number of small faults, and minimal penetration of seismic energy below the Base Cretaceous level. Hence, the challenge is to improve imaging of the complex fault system at the Frigg (~1800-2000ms) and Upper Jurassic (~3200-3400ms) reservoir levels.

Results

Figure 4 shows the measured residual velocity error after a preliminary migration with the starting model. The fact that the velocity error in these two orthogonal directions is significantly different, is a clear indication that any mono-azimuth tomographic approach would be limited in correctly resolving this velocity error.

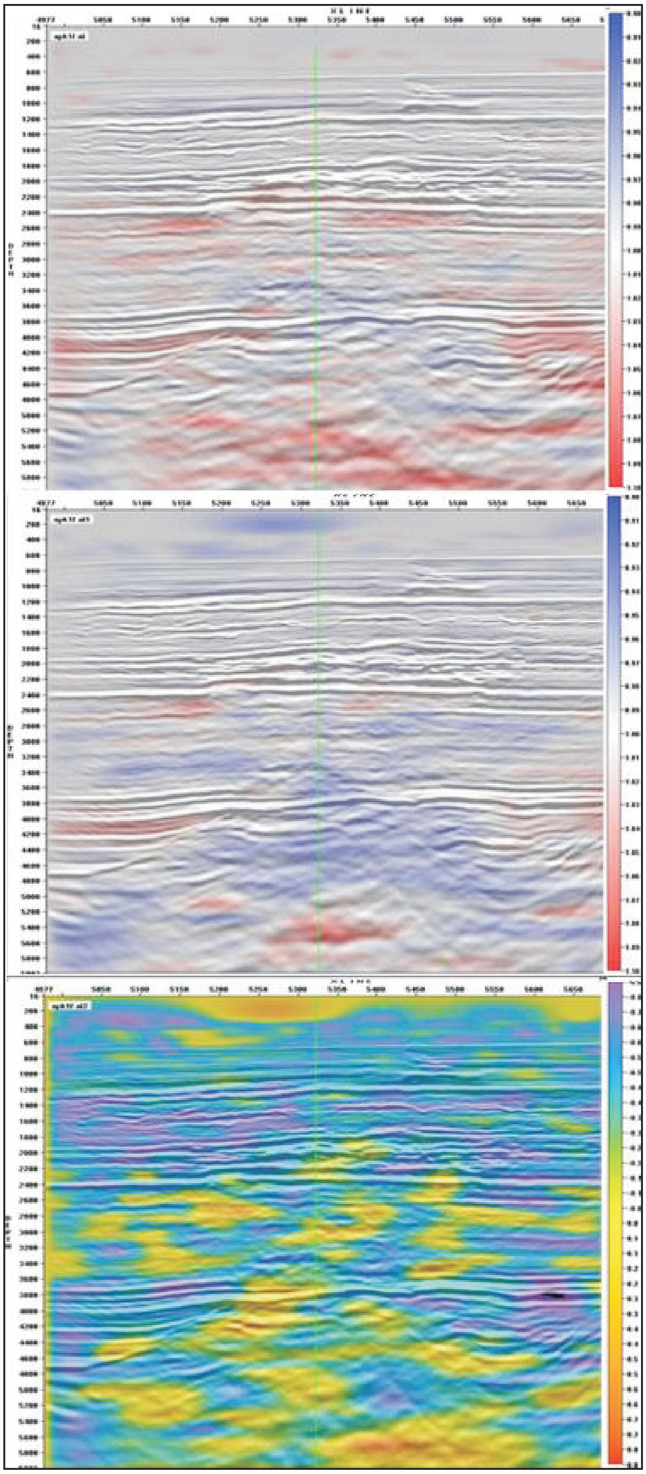

Fig. 4: Measured velocity errors for Vslow, Vfast, and the azimuth of the fast direction, for a single inline a) slow-direction velocity error, b) fast-direction velocity error, c) azimuth of the fast direction (radians). Here the velocity error is defined as the ratio between the current migration equivalent RMS velocity and that required to flatten the residual hyperboloid.

After three iterations of OVT VTI tomographic update, we obtained the images shown in Figure 5. Here a Kirchhoff PreSDM, applied to crossline offset zero, for a given inline, with the final velocity model overlay, is compared to an OVT migration with the original model. In this case, the original model was from a recent conventional anisotropic PreSDM project, so was a good starting point. Steep reservoir-bounding faults in the deep section are clearly better defined in the final results. Figure 6 shows gathers from this line demonstrating better overall gather flatness, especially in the shallow section, where small scale heterogeneities are better resolved. The gather displays also show the need for additional pre-migration processing, since most of the imaged energy at deep target level consists of high-amplitude, locally apex-shifted residual multiple.

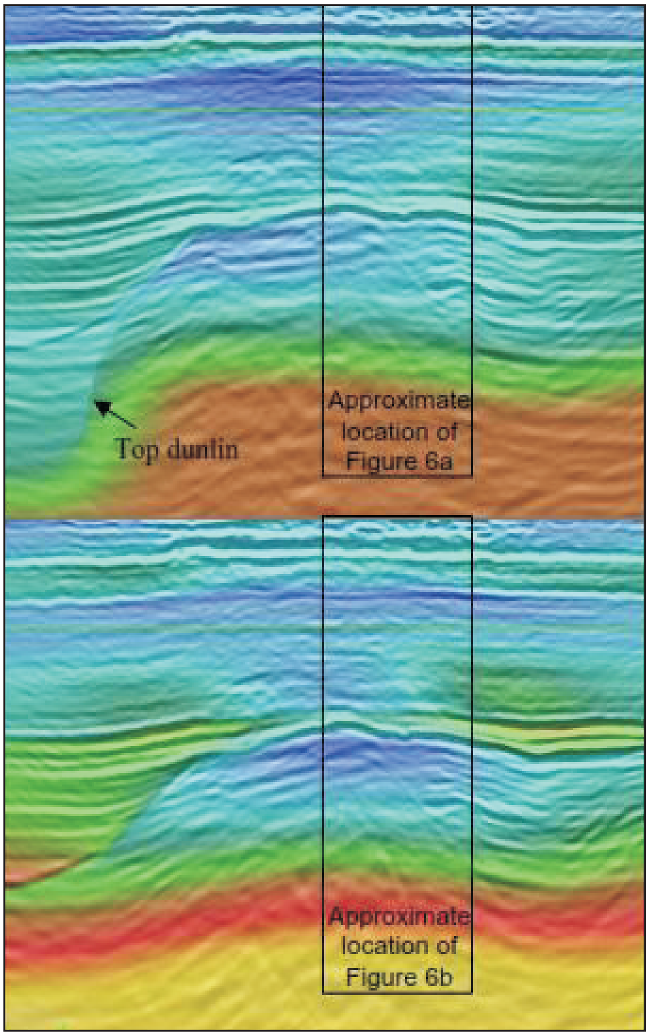

Fig. 5: Zoom on the deeper section with velocity overlay: a) OVT migration with initial model from previous study, and b) with the final model. The huge velocity difference between the models at target depth is a result of velocity updating and change in anisotropic layering. In the final model GXT have not used poorly constrained horizons such as top Dunlin.

Discussion

Tomographic inversion is itself not inherently limited to ignoring azimuthal variation in velocity error. It is only our pre-processing assumptions, and the binning of all data (across azimuth) into common offset bins, that imposes such a restriction. Performing OVT processing and preserving azimuth information requires handling of massively increased data volumes, but does offer the possibility of enhanced resolution of overburden heterogeneity, and better imaging of deep targets.

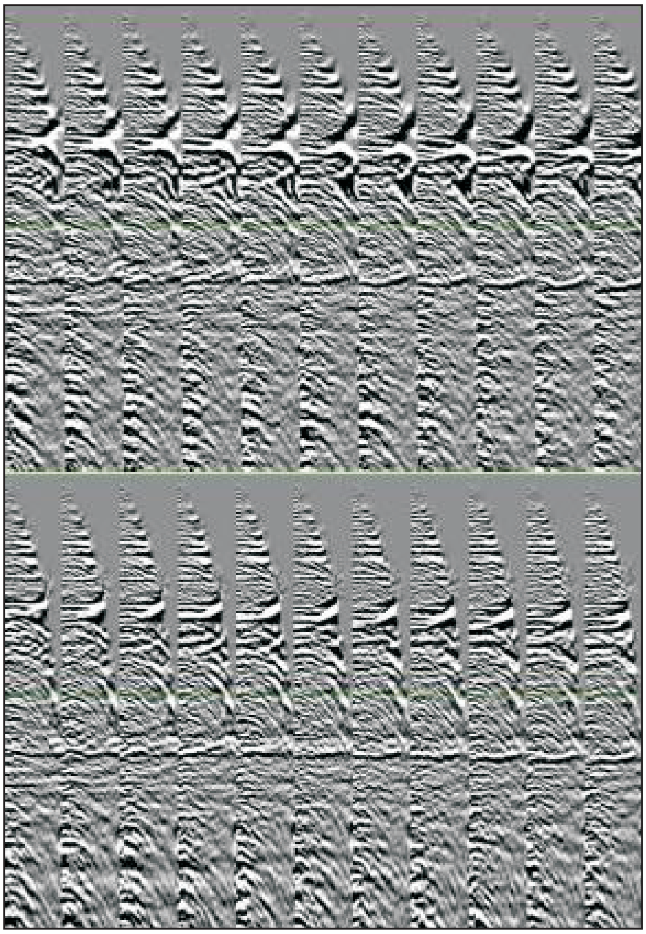

Fig. 6: CRP gathers from the inset shown in Figure 5, with the initial (a) and final (b) models. Overall gather flatness is improved, most notably in the shallow section as a result of GXTs model building and OVT tomography.

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