Reducing Structural Uncertainties Through Anisotropic Prestack Depth Imaging: Examples from the Elgin/Franklin/Glenelg HP/HT Fields Area, Central North Sea

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Abstract

The Elgin/Franklin High-Pressure/High Temperature (HP/HT) fields lie in the Central Graben area of the North Sea UK sector approximately 240 km east of Aberdeen. The fields are the deepest production in the North Sea and represent the largest gas condensate development in the world with recoverable reserves estimated at over 700 million barrels equivalent. The reservoirs produce from the Jurassic Fulmar shallow marine- and Pentland fluvial- reservoirs at depths of 5100-5600 meters subsea. Production from these HP/HT reservoirs (1100 bar/200°C) started in March 2001 and flows over 200,000 boe/day from 12 wells.

For this type of producing environment, the stakes are high for understanding uncertainties related to imaging. Improved fault imaging translates not only to reduced uncertainties in bulk rock volumes and ultimately in-place volumes but also to an increased understanding of the static/dynamic behaviours of the fields through better imaging of internal faulting.

The application of various proprietary and contractor-based seismic depth processing since 1997 has allowed for a better understanding of structural configuration of the deep reservoirs. This rich processing history has provided the Total interpretation team with various processing volumes (isotropic PostSDM, anisotropic PostSDM, and most recently anisotropic PreSDM) to allow a more complete understanding of the uncertainties related to different imaging approaches.

Historically, the effects of anisotropy on vertical and lateral positioning were realized and a number of internal proprietary software were developed to quality control depth imaging processing. The 1998 Glenelg discovery southwest of Elgin Field was the focus for the initial Anisotropic PreSDM study which was later expanded to include the Elgin/Franklin fields area. This processing benefited from Total's internal QC tools and a combination of additional data (i.e. walkaway VSP profiles with different orientations, long-offset 2D seismic data, etc.) which provided an optimum mix to derive and verify the anisotropic parameters for the velocity model.

Overall, the new seismic showed significant improvement over the previous time- and depth-migrated datasets, reduced uncertainty on internal and bounding-fault positions, and allowed the observation of the vertical and spatial uncertainties attached to different migration approaches. This understanding of the variability in seismic imaging, and its effects on the reservoir parameters and structural configurations in depth, is used as an input to understand ranges of in-place volumes, the potential of near-field exploration, and future infill-drilling strategies.
Keywords
anisotropic prestack depth imaging, gas condensate, high-pressure/high-temperature, uncertainty

Geographical and Geological Setting of Study Area

The Elgin/Franklin High-Pressure/High Temperature (HP/HT) fields lie in the Central Graben area of the North Sea UK sector approximately 240 km east of Aberdeen. (Figure 1) The fields are the deepest production in the North Sea and represent the largest gas condensate development in the world with recoverable reserves estimated at over 700 million barrels equivalent. The reservoirs produce from the Jurassic Fulmar shallow marine- and Pentland fluvial- reservoirs at depths of 5100-5600 meters subsea. Production from these HP/HT reservoirs (1100 bar/200°C) started in March 2001 and flows over 200,000 boe/day from 12 wells.

Figure 2 is a structural elements map showing the current assets within Total’s Central Graben Asset and the surrounding fields: 1) the Elgin/Franklin fields which are producing assets, 2) Glenelg, which is an undeveloped discovery made in 1998 that is currently under study for development, and 3) West Franklin, which is an exploration prospect that was declared a discovery in July 2003. The green boundary represents the total output area of the anisotropic PreSDM processing which is 220 square kilometres. The red boundary represents the input data area corresponding to roughly 295 square kilometres.

Figure 3 shows a structural southwest-to-northeast cross-section across the area that gives a flavour of the structural complexities of the study area. This section covers West Franklin, Glenelg and Elgin and continues to the neighbouring Shearwater field that is operated by Shell Expro. The main reservoirs are the Fulmar and Pentland Jurassic sands (highlighted in blue shades) which were deposited over a series of Triassic “pods” (highlighted in pink) controlled by salt tectonics (Stuart & Clark, 1999 and Wonham, et al, 2002). The salt diapirism and withdrawal was quite active during the deposition and plays a major role in controlling structuration during not only the Jurassic but also later on during periods of inversion in the Late Cretaceous and Tertiary. The lack of quality of seismic imaging deeper in the section often makes it difficult to concur on the exact relation of the Jurassic fault elements, the salt, and the underlying Permian sediments.

Evolution and Uncertainty in Structural Mapping

The challenge for all seismic interpreters for field-scale evaluations is to integrate the available well and seismic datasets to evaluate the base-case rock volumes and the overall uncertainty attached to these volume estimates. Figure 4 shows the evolution of structural mapping at the Top Fulmar reservoir of Elgin Field from the initial round application in 1989 based on 2D seismic all the way until the latest interpretation performed in 2003 on the 3D anisotropic prestack depth migration (stretched-back-to-time).

The detail of each map is not important but more the evolution of the geometry of the field based on different seismic datasets, interpreters, and well data.

In combining all of the structural elements from the previous maps Figure 5, one can classify the evolution of structural mapping into two main periods:
- The first period, from 1984-1995, is based on 2D seismic and an early 3D seismic dataset over the field. The fault elements characterized by this period are coloured grey.
- The second period, from 1996 to today, is based on the 1996 3D seismic that was acquired over the entire Elgin/Franklin/Shearwater area (92 fold, 4600 meter streamer length). This is the acquisition that was used for all of the subsequent time and depth imaging processing that Total is using today and that will be presented in this paper.

Three main sets of interpreted fault elements from depth processing are shown in colour:
- The blue fault elements based on the 1997 Isotropic poststack depth migration (PostSDM)
- The red fault elements based on the 1998 Anisotropic PostSDM (picked in depth)
- The green fault elements based on the 1998 Anisotropic PostSDM (stretched-back-to-time) and vertically depth-converted using a layer-cake approach.

The overall message is that there is quite a bit of uncertainty in fault picking due to the different imaging quality among the various seismic datasets. However, the Anisotropic PreSDM migration provides the clearest imaging of both the field-bounding and intra-field faulting for structures in the study area and is used as the future base-case structural model for future geological and reservoir studies.

**Seismic Processing Issues:**
Anisotropy parameters were derived from various datasets (well data, long-offset seismic data and well seismic profiles in various azimuths over the study area to analyse any azimuthal component of anisotropy). Figure 6 shows the overall anisotropy profile derived for the overburden (Sea Level to Marl) in the study area. The strongest anisotropy was seen in the Lower Tertiary dewatered shales and the Hod-Marl chalk interval.

**Added Value of PreSDM Processing: Comparison of Raw PreSDM Stack with Previous Processing**

Two different seismic lines over Glenelg/Elgin and Franklin fields will be used to demonstrate the differences in quality between the existing time migration and depth migration products that are available to Total’s seismic interpreters.

The first line is Inline 1242 that runs southwest from the Glenelg structure to the Elgin structure and passes through the central panel where the discovery well and the 22/30c-G5 development well were drilled (Figure 7).

Figure 8a (no interpretation overlaid) and Figure 8b (with interpretation overlaid) compare the 1996 time-migration processing with the 1998 anisotropic PostSDM processing with potential interpretations on each dataset (red faults and horizons based on time migration, yellow faults and horizons based on anisotropic PostSDM). The lines pass through the 22/30c-G5 development well which is less than 200 meters from the above-mentioned discovery well.

Looking at the interpretations of the reservoir interval for Glenelg on the two different datasets, one can see that there is uncertainty on the main fault position and also on the
position/dip of the reservoir. These differences were the drivers for the PreSDM reprocessing project over the Glenelg structure.

Looking at the Elgin structure and overlaying the interpretation from the PostSDM processing over the time-migration processing, one can also see some uncertainty on the bounding faults which translates directly into uncertainty on the bulk-rock volumes.

In addition to the existing 1998 anisotropic PostSDM (with a simpler legacy velocity model and a phase-shift-plus-interpolation migration algorithm), Total performed a Kirchoff PostSDM using the 1996 time-stack with the detailed 2002 anisotropic PreSDM migration velocity model. Figure 9 shows the results of the two PostSDM processing (1998 below and 2002 vintage above). One can see strong differences in reflector continuity and apparent dips between the two datasets and various levels of residual multiple energy in each section (there is no demultiple applied to either dataset as compared with Figures 8a & 8b). There are also differing levels of imaging quality between the Glenelg main fault and the northern Elgin bounding fault which translates to varying degrees of interpretability on both datasets. Overall, this is a good example showing how differences in velocity models and migration algorithms can affect the quality of the imaging.

Lastly, Figure 10 compares the differences between the 2002 PreSDM (above) and the 2002 PostSDM (below). Over Glenelg, this particular line shows the continuity to be slightly better on the PostSDM than on the PreSDM due to the enhanced multiple energy on the PreSDM dataset (there is no demultiple processing applied to either line). However, the PreSDM data gives a much sharper image of the fault areas over the PostSDM data. Thus, one can see the overall added value of a PreSDM approach over the PostSDM approach.

If one looks at a magnified portion of the seismic line over Elgin Field and compares the various seismic datasets, one can see the differences in fault imaging. This variability, or uncertainty, can be related back to the composite structural elements map in Figure 5.

Figure 11 compares 1996 time migration with the 1998 anisotropic PostSDM. Both sections have a post-stack, horizon-based demultiple applied, and although there are slight differences in amplitude gain between the sections, the picking of faults with confidence on either dataset presents a challenge.

Figure 12A compares the two different anisotropic PostSDM processing using different velocity models and migration algorithms. The 1998 PostSDM on the left of this figure also has a post-stack, horizon-based demultiple applied as compared to the 2002 PostSDM with no demultiple applied. Figure 12B is the same comparison except with no demultiple applied to the 1998 PostSDM. It was actually seen in retrospect that while the strong demultiple aided reflector continuity in areas where the dips were quite strong (i.e. over the Glenelg structure), the demultiple actually degraded the overall image over the Elgin and Franklin fields where the reservoirs are sub parallel to the overlying multiple-generating layers. As a result, any post-stack, horizon-based demultiple on the PreSDM processing was carefully tested and applied to provide a balance between noise-elimination and signal enhancement. Finally, Figure 13 compares the 2002 PostSDM processing versus the 2002 PreSDM processing.

These figures clearly show the progressive improvement of the post-stack approach using more complex migration velocity models and ultimately the improvement of the prestack approach over the previous post-stack approaches. Figure 14 compares the 1998 anisotropic
PostSDM and the 2002 anisotropic PreSDM which demonstrates the clear improvement in the fault imaging from the prestack approach over the post-stack approach. As the 1998 PostSDM seismic dataset with the post-stack, horizon-based demultiple was the basis of the existing Elgin/Franklin geologic and reservoir models, future structural models based on the 2002 PreSDM seismic will result in less uncertainty in the horizon and fault picking.

Rather than comparing each seismic vintage as for Elgin Field, Inline 1550 over Franklin on Figure 15 shows (see location map in Figure 7) the differences between the Anisotropic PostSDM done in 1998 used to interpret the current structural picture and the 2002 PreSDM that will be used for the future structural framework for the fields. In general, there is better fault imaging with the PreSDM on the frontal and back faults which reduces picking uncertainty. Better horizon continuity in the reservoir interval on the PreSDM reduces uncertainty on picking and intra-reservoir faulting. Lastly, better imaging of the inversion structure and salt helps to understand the main mechanism controlling structure, reservoir distribution, and reservoir quality over the entire study area.

Quantifying Structural Uncertainties:

Total applies a proprietary software program to combine the following: 1) fluid contact uncertainties 2) horizon uncertainties based on picking and vertical depth conversion, and 3) fault picking uncertainties based on picking for poor data quality areas and for lateral movement depending on the different migration vintages. Figure 16 shows the Elgin Field with the main fault position uncertainties (displayed as vectors along fault plane) and the Top/Base Fulmar horizons with associated uncertainty (zero at well locations increasing away from wells).

Based on these uncertainties, three hundred (300) structural models were simulated. Gross-rock volumes (GRV) for the Fulmar reservoir were calculated for each of the simulations to understand the influence of each uncertainty on the overall probabilistic (GRV) distribution around the base-case GRV. The results of the simulations were sorted and different distributions were created (Figure 17).

The interpreter can also visualize the various realizations by choosing structural models that correspond to various quantiles along the distribution.

Figure 18 shows a 1998 PostSDM seismic line on Elgin with the base case fault positions in addition to a Q10 (pink) and a Q90 (green) fault position from the simulation results. Figure 19 shows the same line from the 2002 PreSDM processing which shows that fault picking uncertainty will be reduced and will result in a slightly more volumetrically optimistic fault picking for this displayed line.


It is interesting to analyse the historical evolution of GRV in relation to the well and seismic datasets that are available.

Figure 20 shows this evolution for Elgin Field and the Glenelg discovery. For Elgin on the right-hand side, there are approximately 6 geomodels that have been built based on various seismic processing and the well data that was available at the time. Each colour bar
represents the evolution of the GRV over time and the physical distribution of the GRV according to the Elgin compartments that were mapped.

From this evolution, one can make the following observations:
- The isotropic migration tended to over-migrate the flank of the structures, thus reducing the volumes of these areas as compared to the anisotropic model (-14% for Elgin).
- When anisotropy was introduced, the reduction in GRV from the isotropic migration was reversed.
- In looking at the Elgin East Panel where the majority of in-place hydrocarbons are located, there was a net –6% reduction in GRV in the ‘2002’ model compared with the previous 2000 model that was interpreted directly in depth on the Anisotropic PostSDM. There were also significant changes in structural interpretation for the south-east part of Elgin. This comparison was done using the same Base Case GWC in order to see only changes related to structural modifications of the interpretation.
- Looking at the total difference after integrating the change in the Base Case GWC for Elgin East (which was raised by 5 meters in the ‘2002’ model), there is a total overall reduction in GRV for Elgin East by around 8% (‘2002’ versus the ‘2000’ model).

Interestingly, despite all of these variations due to different seismic, interpretations and additional well data, the overall reduction in GRV from project sanction in 1995 to 2002 is only 7%. Work is in progress using the PreSDM data which will allow us to establish the definitive structural model for the future (2003 and beyond) for reservoir management and possible infill drilling.

For the Glenelg structure, most structural models until today were based on the 1996 time-migration and the 1998 Anisotropic Poststack Depth Migration picked in depth.

If one compares the differences between the 2000 model based on the time-migration and the 2003 structural model, the PreSDM has allowed the confirmation of two panels based on better fault imaging and horizon continuity. The results of this structural modification were then input into the development studies in order to determine the best way forward for this undeveloped discovery.

Conclusions:

The application of various proprietary and contractor-based seismic depth processing since 1997 has allowed for a better understanding of structural configuration of the deep reservoirs.

Overall, the new anisotropic PreSDM seismic has showed significant improvement over the previous time- and depth-migrated datasets. It has reduced uncertainty on internal and bounding-fault positions, and allowed the observation of the vertical and spatial uncertainties attached to different migration approaches. This understanding of the variability in seismic imaging, and its effect on the reservoir parameters and structural configurations in depth, has and is being used as an input to understand ranges of in-place volumes, the potential of near-field exploration, and future infill-drilling strategies.

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2002 PreSDM (No Demultiple)

2002 PostPDM (No Demultiple)

Glenelg

Elgin

Even Better Fault Imaging

Less continuity on PreSDM over Glenelg structure due to residual multiple energy

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Elgin Field – Internal and Field Limit Faulting

1998 PostSDM (Poststack Demultiple)  

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Fault Picking for Future Base Case Structural Model to be greatly reduced with PreSDM Seismic

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