Developing an integrated structural modelling workflow

Emma Howley[1*] and Randi Sundt Meyer[1] present a workflow and tools that integrate fault and horizon uncertainty modelling with structural modelling and 3D gridding to enable users to quantify uncertainty more effectively.

A fundamental problem in reservoir modelling today is the ability to create models – based on limited input data – that accurately represent the reality. Structural modelling is a key means of achieving this and yet, while a critical component of the reservoir modelling workflow accounting for the greatest uncertainty in terms of in-place reserves, it faces a variety of challenges and limitations.

Chief among these is the rise in more geologically complex reservoirs that often come with poor quality data and the inability of today's interpretation solutions to create a spatially accurate analysis of the field. Other challenges include the inability to input the inherent uncertainty of such fields directly into the interpretation and structural model for quantified risk analysis and improved decision-making.

The result is that decisions are often made with limited models and only best-case estimates of faults and horizons, with the interpreter having a weak understanding of potential errors or uncertainty in the interpretation. The result is an underestimating of the actual uncertainty in reservoir volumes.

This article aims to address these challenges and limitations through a new workflow and set of structural modelling tools. The workflow and tools integrate fault and horizon uncertainty modelling with structural modelling and 3D gridding to enable users to quantify uncertainty more effectively and acknowledge realistic uncertainties in the data via the building of geologically realistic scenarios.

The new workflow and tools will enable users to quantify uncertainty in their structural modelling and increase their confidence when it comes to crucial decisions on where to drill, what production strategies to adopt, and how to maximize oil and gas recovery. At a time of low oil prices, this is vital.

Structural modelling – the classic workflow

The structure of a field is one of the most critical components of the reservoir model accounting for the greatest uncertainty in terms of in-place reserves.

Structural modelling involves searching for a set of geologic surfaces (faults and horizons) that satisfy all available data (e.g., fault and horizon interpretation data, well picks, isochores, and zone logs) in a geologically consistent fashion.

It is the structural models generated that enable the construction of accurate reservoir models while leveraging all the information extracted from the seismic interpretation.

Structural models are used to generate grids for facies or petrophysical property modelling, forming a key element of the reservoir characterization workflow. The gridded 3D models provide crucial input to volume calculations, flow simulation and reservoir behaviour.

These fully integrated reservoir models can then be used directly for decision-making (data acquisition or well placement) or passed to reservoir engineers for simulation, history matching and production forecasts.

Current limitations

Despite their undoubted value in the reservoir modelling workflow, a number of challenges and limitations remain as to the value and implementation of structural modelling. These include the following:

- *A time-consuming workflow*. Many of today's structural modelling methodologies and tools are inflexible and cumbersome, making the incorporation of new data into the model a time-consuming and sometimes expensive process.
- *Uncertainty in input data*. Input data that goes into the reservoir model often comes with large uncertainties. Such uncertainties in static reservoir properties, for example (spatial description and volumes) are often difficult to quantify, particularly in frontier areas where there is little well control. This might include limited seismic resolution, poor constraints on velocities for depth conversion, and poor seismic quality. The result is that structural models are created using just approximate estimates of faults and horizons with the uncertainty within these interpretations neglected. This can lead to an underestimating of uncertainty in reservoir volumes as well as expensive and time-consuming manual-based processes.

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- *Conditioning the model to well data*. It is often necessary to condition the model to a lot of conflicting well data. This can be particularly problematic in cases with a lot of long, horizontal wells. The limited conditioning information in these horizontal wells and the lack of an automated update process means that the structural model does not always fit the well paths. Another matter of contention is the fitting of the grid to well picks. The process of modelling a grid from the structural model is an optimization process where ideal requirements are balanced. This means that grid cell faces do not always honour well picks exactly.
- *Uncertainty in the conceptual model*. Uncertainty in the conceptual model(s) also represents a significant challenge for interpreting and model building. Used as a basis for the interpretation and to define modelling parameters, the conceptual model can be one of the largest sources of uncertainty, particularly as it is currently hard to handle with any tool. By limiting the use of a conceptual model, this can limit the structural scenarios that may be considered in the reservoir model.
- *Representing complex structures*. Another key challenge is the ability to represent complex structures – thrust faults or salt domes, for example – while honouring stratigraphic relationships (depositional and erosional) and fault geometries. Any reservoir model that oversimplifies these obvious geological complexities is not going to deliver the vital information operators require for well planning and reservoir management.
- *A fragmented workflow*. Finally, there is the danger of fragmented workflows where the large inefficiencies created by having independent interpretation and modelling stages can lead to problems in creating a structural model where new data is left out of the reservoir model and errors are difficult to catch and correct. In this article, we show how the interpretation and modelling steps can be combined.

In summary, while the structure of a field is often one of the most critical components of the reservoir model, too often there are limitations to structural modelling causing a significant drain on the asset team and a source of uncertainty in the field model. The methodologies and tools described in this article are designed to address this.

The article objectives

The objective of this article is to introduce a new tightly integrated structural modelling workflow and a set of structural modelling tools that meet many of the challenges described above and provide input to the key questions on 'Where to drill, what production strategies to adopt, and how to maximize recovery?'

Key objectives of the article and the new workflow will be:

- To introduce enhanced structural modelling tools that acknowledge realistic uncertainties in the data.
- To negate any potential workflow bottlenecks through a faster and more efficient updating of the model's structural framework.
- To make it faster and easier for reservoir modellers to build geological scenarios, investigate the full effects of structural uncertainty, and increase confidence and understanding in reservoir decision-making.

The new workflow and structural uncertainty tools will allow users to make those crucial reservoir decisions with renewed confidence.

The workflow platform – model driven interpretation

There are a number of key elements of the new workflow that will be described below. These are fault uncertainty modelling; horizon uncertainty modelling; the satisfying of well data through conditioning to zone logs and the adjustment of the grid to match well picks; the application of volumetric sensitivity studies; the extraction of interval velocity maps; and new efficiency improvements such as multi-threading.

The main methodology behind this new workflow was described in a September 2013 *First Break* article (Leahy and Skorstad, 2013) and involves a geologically consistent structural model being created (and updated) every time the interpreter makes a measurement of a subsurface feature. We call this workflow 'Model Driven Interpretation'.

The fault and horizon surfaces created in this manner are the interpretation where the interpretation is not merely a collection of control points, but the integrated geological representation of a structural model satisfying those measurements.

Rather than creating one model with thousands of individual measurements, the new workflow can create as many models as required by estimating uncertainty in the interpreter's measurements. The software can then generate statistically significant models based on these probability distributions and provide immediate value to the geoscientist.

The interpretation is based on uncertainty information being collected and paired with an interpreted geologic feature (horizon, fault, etc.), creating an uncertainty envelope and thereby more accurately representing the limitations of the data and the interpreter's vision for the geologic structure. In this way, the new method shows what parts of the model are most uncertain by way of a larger uncertainty envelope. This can quickly indicate where more detailed investigation is needed and where new data may need to be acquired.

Users will also receive instant feedback on the consequences of a measurement with fewer points and clicks

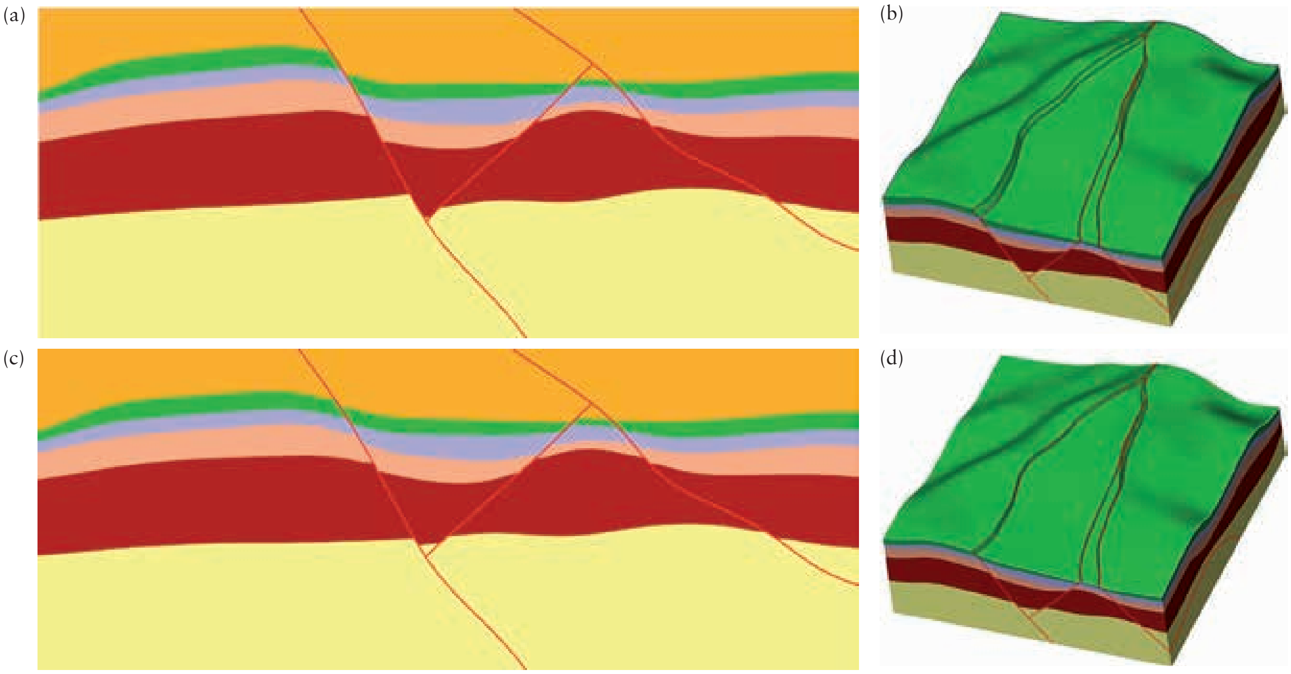

Figure 1 *Changes in fault throw created through an automatic worksflow (Georgsen et al. 2012).*

required to map a geologic feature. Through this, interpreters will be able to rapidly map the key features of the reservoir using a sparse representation and with fewer quality control phases.

Using Model Driven Interpretation as the cornerstone of this workflow, this article will examine how the workflow has been further developed and uncertainty better quantified. This has been achieved through fault and horizon uncertainty tools being integrated with structural modelling and 3D gridding. This enables users to quantify uncertainty more effectively via the building of geological scenarios and the acknowledging of realistic uncertainties in the data.

Fault uncertainty modelling

As part of the new workflow, fault uncertainty models can be built that correspond directly to the uncertainty in the input data.

Figure 1, for example, shows two realisations of possible fault throws where figure 1a and 1b have a larger throw on the two leftmost faults than the realisation shown in 1c and 1d. Since the fault uncertainty tool is integrated with structural modelling and 3D gridding tools, the user can now rapidly build these models in full to investigate the scenarios corresponding to the uncertainty in the input data.

Faults can also vary within the fault uncertainty envelope described in the previous section and can generate realistic structural scenarios with horizons also extrapolated to ensure realistic results. Figure 2 illustrates fault uncertainty envelopes and a map of reduced prediction error around wells.

Horizon uncertainty modelling

Horizon uncertainty modelling tools are also a key element of the new workflow, enabling the incorporation of realistic uncertainties into the horizon models by specifying uncertainties in the form of standard deviations for all input data used in the horizon modelling process.

Users are able to create horizons and zones based on uncertainty data and information derived from well picks, velocities, seismic travel times, and isochors. All these parameters acknowledge zone log information in order that long horizontal wells get correctly placed in the zones in which they belong. This eliminates tedious manual work while at the same time producing reproducible, easy to update, automated procedures.

The enabling of a user-specified uncertainty on the well picks also reduces the bull's eye effects in the resulting set of horizons as well as providing a measurement used to identify possible outliers and errors in the data. This gives the users extremely valuable feedback that can be used to evaluate the data quality.

The resulting horizons are all dependent on each other, such that an observation on one horizon also affects the neighbouring horizons ensuring a consistent, geologically valid result.

The set of horizons represent the most likely outcome based on the uncertainty in the input parameters whereby the user gets results that correspond to the actual data uncertainty that is traditionally neglected. In addition to the full set of horizons, the uncertainty in these can also be directly obtained. Figure 3 shows a map view where uncertainty is low around well picks and along well trajectories.

In addition to fault and horizon uncertainty modelling, new parameters are also exposed to the uncertainty workflow. These include parameters for modelling both fault sealing effects and for modelling fractures and provide the user with more control and flexibility for modelling uncertainties specific to individual projects.

The result of these uncertainty improvements is realistic structural scenarios, the correct placement of horizontal wells, improved volumetric sensitivities, and greater confidence in oil and gas volume calculations.

Conditioning to wells

The zone log and well picks are important input to any model but it has often been a challenge to accurately honour this uncertain and conflicting information at every stage of the reservoir modelling workflow.

Where long horizontal wells exist, it is often difficult to correctly condition the structural model to the zone logs due to the lack of conditioning information and the lack of an automated method. In the past, this has required tedious, manual-based work to update the model to correctly fit the zone log.

An important part of the Horizon Uncertainty modelling workflow is therefore the ability to fit the model to a well path by conditioning to the zone log automatically. This vastly speeds up the workflow making it repeatable and auditable in addition to reducing manual post-processing (See Figure 4).

The creation of a high-quality grid from a structural model typically requires the balancing of many constraints. As a result cell faces may not honour the well picks exactly and rather it is the cell corners that align with the input data. Although giving the best quality grid in terms of balancing all grid quality constraints, it may in some cases be more desirable that grid cell faces match the well picks.

To meet this challenge, the new workflow includes a new 'Adjust to Wells' tool that supports the calculation of residuals between the grid and well picks and adjusts the grid to exactly match the well picks. This generates models that accurately fit the data in addition to balancing external constraints.

Volumetric sensitivity studies

Moving faults or horizons can obviously change the volumes in place. With the new fault and horizon uncertainty tools, sensitivity studies are easy and straightforward to set up and

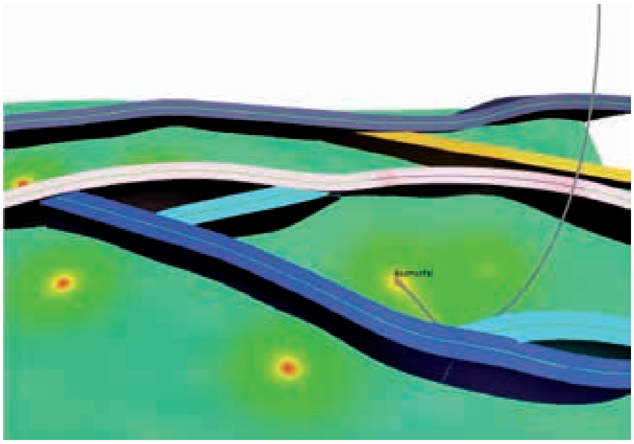

Figure 2 *Fault Uncertainty envelopes and a map of reduced prediction error around wells.*

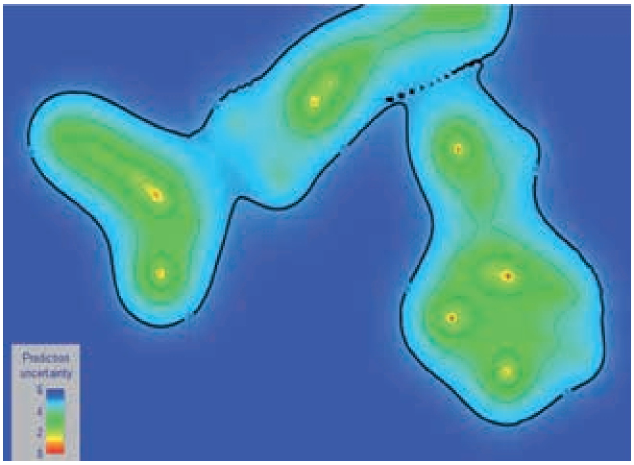

Figure 3 *Estimated horizon depth uncertainty.*

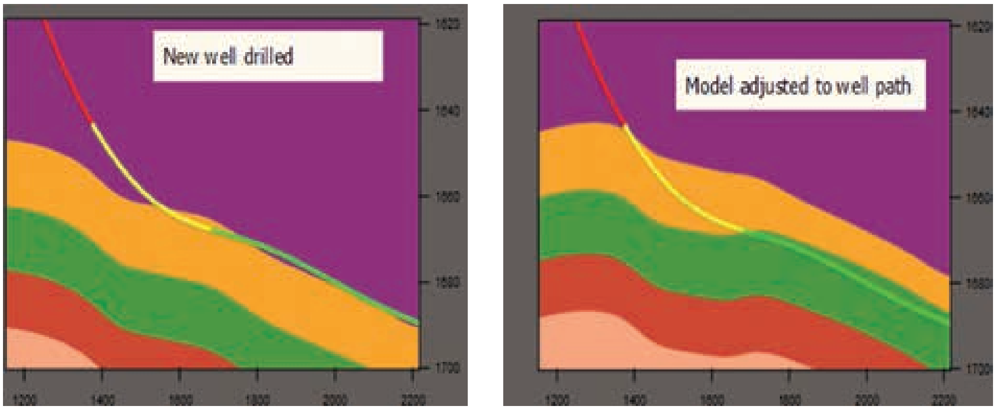

Figure 4 *Updating the model by condition to a new zone log.*

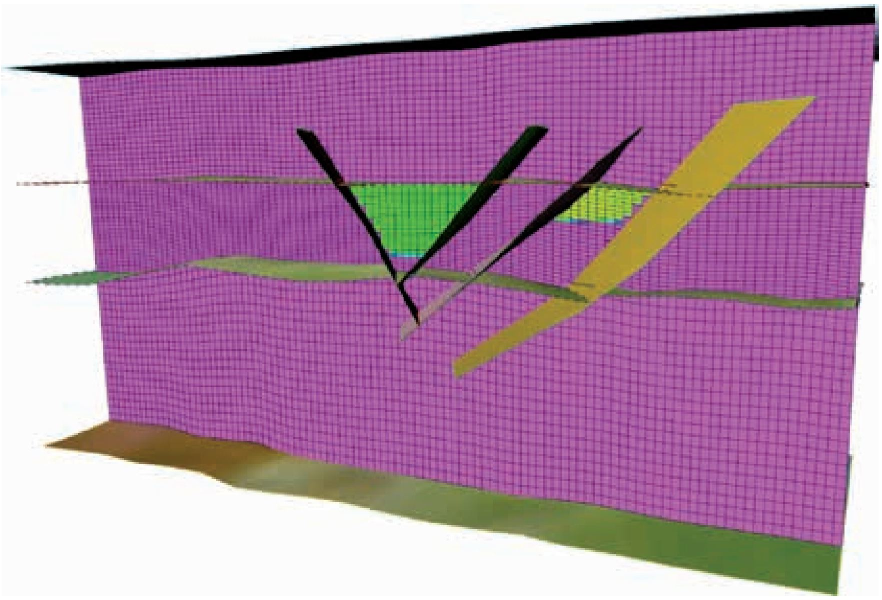

Figure 5 *The positions of the four faults are allowed to move laterally within a predefined fault uncertainty envelope. Differing contacts are illustrated in two segments.*

run. By using the new workflow concept, a range of different scenarios can be built and gridded by simply varying the input parameters and running the workflow.

Figure 5 shows an example where the positions of the four faults are allowed to move laterally within a predefined fault uncertainty envelope. The volumes of interest are bounded by these faults, a top surface and two contacts being different in the two segments of interest, allowing output for the total field or individual segments.

Figure 6 shows the volume distribution for the fault segments. Tornado charts can also be used to demonstrate the impact of the different uncertainty parameters. This can be used as a decision-support tool to account for the fault uncertainties so commonly neglected.

Extracting interval velocity maps

As previously mentioned, the new workflow builds on a Model Driven Interpretation methodology where uncertainty is captured during the interpretation process. One key element of the workflow is a new feature for extracting interval velocity maps.

Here, users can calculate average velocity maps between two horizons from a velocity model (see Figure 7) and interval velocity logs based on time-depth tables can be displayed as part of a well correlation view. The extracted maps can then be used to QC the velocity model, or as further modelling input to Horizon Uncertainty Modelling.

The use of multi-threading

As well as the focus on integrated fault and horizon uncertainty modelling, elements for improved efficiencies, usability and performance should be mentioned. Multi-threading plays a key role in enhancing the reservoir modelling workflow.

Multi-threading is the ability for computing to take place in parallel. This dramatically increases the efficiency of the model building process and helps to improve memory usage for large models.

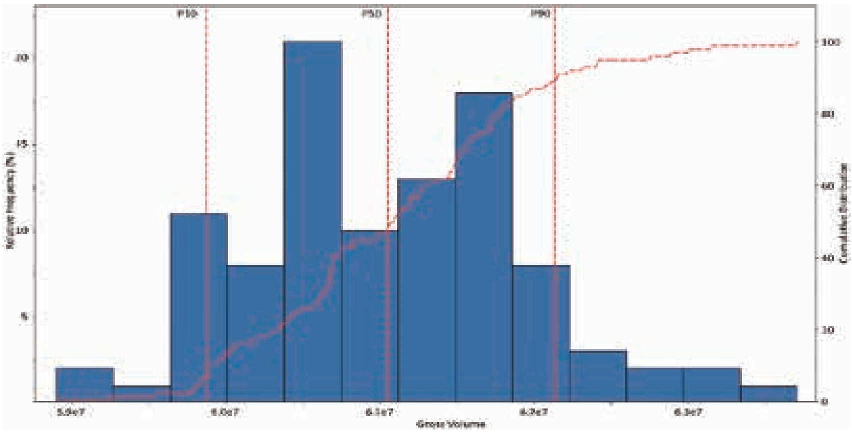

Figure 6 *Volume distribution in 100 simulations of fault location sensitivities.*

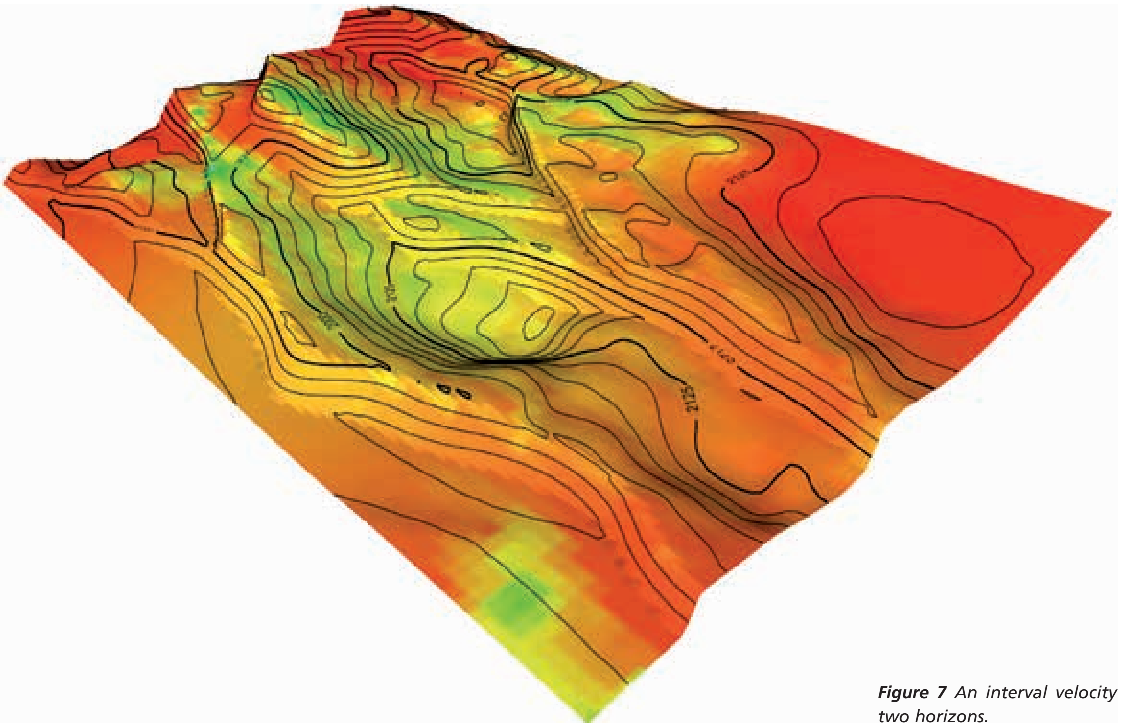

Figure 7 *An interval velocity calculated between two horizons.*

Multi-threading at various key points along the workflow, along with increased workflow automation, also allows users to make faster decisions and process more scenarios due to the multiple core processor architecture.

Conclusions

The key objectives of this article were to introduce a new workflow and set of structural modelling tools that acknowledge realistic uncertainties in the data; negate potential workflow bottlenecks and enable updating of the model's structural framework to be more efficient; and make it faster and easier for reservoir modellers to build geological scenarios and investigate the full effects of structural uncertainty.

Through an integrated and flexible Model Driven Interpretation workflow that integrates fault and horizon uncertainty tools with structural modelling and 3D gridding, we believe that we have achieved these objectives.

The result is a more effective quantification of uncertainty and increased operator confidence in crucial decisions such as where to drill, what production strategies to adopt, and how to maximize recovery.

References

Leahy, G. and Skorstad, A. [2013] Uncertainty in subsurface interpretation: a new workflow. *First* Break, 31 (9), 87-93.

Georgsen, F. Røe, P., Syversveen, A.R. and Lia, O. [2012] Fault displacement modelling using 3D vector fields. *Computational Geosciences*, 16, 247-259.