We SBT5 04

Evaluating the Gap between Seismic-scale and Well-scale Observations of Structure - A North Sea Case Study

R.M. Williams* (GeoTeric), E. Pascual-Cebrian (GeoSciences ltd), G. Paton (GeoTeric) & J.C. Gutmanis (GeoSciences ltd)

SUMMARY

Fault and fracture studies for reservoir characterisation have been an essential stage of prospect generation and field development from seismic data and well data respectively. Commonly well image logs are used to predict fracture intensity and orientation, or small scale faults from seismic interpretation are used. These results are then scaled up/down respectively and applied on a reservoir scale. The biggest ambiguity with either of these processes relates to scale. The aim of this study is to analyse the reliability of fracture trends between well and seismic data to improve fracture pattern identification and delineation in offshore Netherlands (Block E), Southern North Sea.

Two independent studies were performed, a well driven fracture analysis and a seismic driven fault analysis, and the two results were compared. The seismic fault study was undertaken using Cognitive Interpretation workflows to illustrate the potential of small scale faulting and fracture lineaments. The fracture study used image logs to identify fracture orientation and intensity. When the detailed multi-attribute analysis and well image logs analysis are compared a distinctive overlapping pattern in the faults/fractures begins to appear. Supporting the theory that the seismic to well gap is closer than ever before.

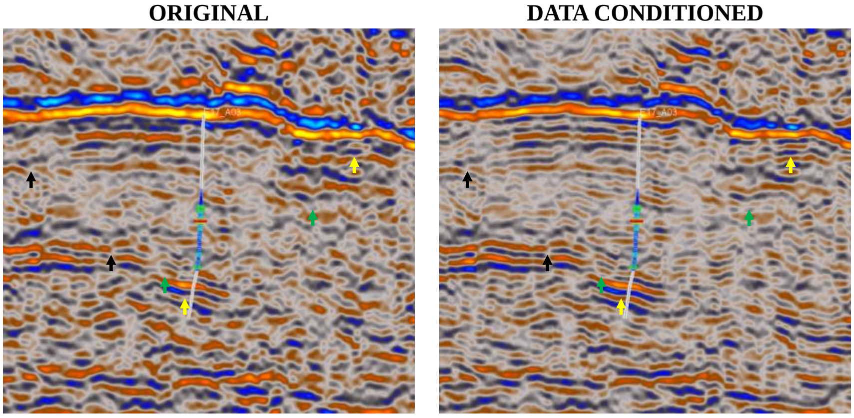
Introduction

Fault and fracture studies for reservoir characterisation have been an essential stage of prospect generation and field development from seismic data and well data respectively. Fracture studies often utilise image logs to predict fracture intensity, and orientation. These results are then scaled up and applied on a reservoir scale. A similar process is applied to small scale faults in seismic, which are downscaled to identify fracture networks for future well planning, in an attempt to bridge the seismic-to-well data gap. The biggest ambiguity with either of these processes relates to scale. The trends seen at the centimetre scale with image logs may or may not be similar to the trends identified by regional fault patterns.

The aim of this study is to analyse the reliability of fracture trends between well and seismic data to improve fracture pattern identification and delineation in offshore Netherlands (Block E), Southern North Sea. Two independent studies were performed, a well driven fracture analysis and a seismic driven fault analysis, and the two results were compared. The seismic fault study was undertaken using Cognitive Interpretation workflows to illustrate the potential of small scale faulting and fracture lineaments. The fracture study used image logs to identify fracture orientation and intensity. The two sets of results were analysed together to see whether there is overlap in the faults/fractures being identified and to identify whether modern seismic acquisition and interpretation techniques are able to bridge the well-to-seismic scale gap.

Method

The gas field E17A is located in Block E of the offshore Dutch sector of the Southern North Sea at the Cleaver Bank High, which is part of the Carboniferous Basin. The reservoir rocks are Carboniferous sandstones of the Hospital Ground Formation, which have been interpreted as fluvial deposits. The reservoir is a stratigraphic trap formed by an unconformity overlain by upper Permian mudstones and halite layers of the Upper Rotliegend Group (Silverpit Fm.), which act as seal. A 35km^2 seismic dataset located around well E17_A03 has been analysed in an attempt to identify small scale faulting and fracture trends. Data conditioning which includes noise cancellation and spectral enhancement was undertaken to improve reflector continuity and vertical resolution. This process provides an optimised volume to take forward for the seismic fault analysis (Figure 1).


ORIGINAL

DATA CONDITIONED

Figure 1 *Data conditioning helps improve the lateral continuity of reflectors (yellow arrows), and improve vertical resolution (green arrows) whilst preserving edge definition (black arrows).*

A suite of edge detection attributes were computed on the data conditioned volume to best highlight where the small scale structural elements can be identified. A multi-attribute based analysis was used whereby structural edges are detected by amplitude, phase and orientation discontinuities and coloured with Cyan, Magenta and Yellow colours respectively. When blended together, where one or more of the attributes has identified a structural discontinuity we see a blending of the associated attribute colours and where we see a strong response from all 3 attributes we see a black response. This allows the delicate fault response illustrated by different style of seismic discontinuities to be shown. By optimising this analysis for small scale structural features and correlating the results back against the seismic, it is possible to have a high level of confidence that what is being identified as a structural discontinuity is a true geological event.

The results of the CMY Blending are displayed as a single voxel thick fault plane where each voxel represents a confidence factor passed on by the contributions of attributes. The orientations of the detected fault planes were identified in a rose plot format so that the direction of the small scale fault patterns could be identified and directly compared to that of the fracture trends in the well study.

The image log analysis was undertaken with two types of logging tools. An Oil-Based MicroImager (OBMI) provided resistivity images between 3741-4074m MD, and an effective resolution of 1.2 inch. It only provided ~43% coverage of the wellbore, whereas the Ultrasonic Borehole Imager (UBI) provided amplitude and travel time images with complete coverage of the wellbore walls between 3745-4054m MD. The UBI has a vertical resolution that ranges between 0.2 to 0.4 inches. The sampling of fractures by a particular borehole trajectory is dependent on the relationship between the borehole orientation and the fracture orientations. This sampling bias is corrected for both fracture dip and dip azimuth frequencies using Terzaghi corrections (Terzaghi, 1965).

Naturally the well log imaging tools will produce a higher resolution in terms of small scale fractures and the seismic will demonstrate the large scale faults, but is it possible to see an overlap in the lower limits of the seismic resolution and the upper limits of the image log information where we are possibly seeing the same information?

Results

Image log fracture pick data is presented in Figure 2. The UBI image logs show a dominant set of fractures striking NNW-SSE (**Set 1**) and a broad cluster of fractures striking from NNE-SSW to NE-SW (**Set 2**); both fracture sets display features that can be interpreted as potentially open and mineralised fractures. The resistivity image log (OBMI) shows a broad cluster of fractures striking NNW-SSE (**Set 1**), a cluster with NE-SW strikes (**Set 2**), and a less developed set of fractures trending ESE-WNW (**Set 3**). Open and mineralised fractures are highly clustered and their distribution is a consequence of important lithomechanical control and proximity to faults. The highest peaks in fracture intensity are observed in sandstone layers near faults (e.g., fault at 3900m MD).

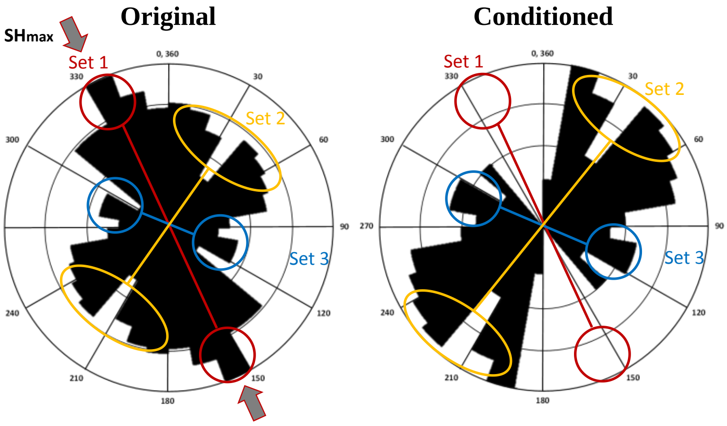


***Figure 2** The combined UBI and OBMI data input highlights 3 fracture sets. The NNW-SSE (Set 1) is sub-parallel to the modern day stress field. Both Set 2 and Set 3 are geological trends seen in the seismic (Figure 3).*

The maximum horizontal compressive stress (σHmax), inferred from borehole breakouts and axial fractures, is oriented NNW-SSE. Borehole stability studies from nearby gas fields indicate a normal faulting regime and generally low horizontal stress anisotropies within the Carboniferous. Since σHmax is sub-parallel to the dominant open fracture strike, NNW-SSE (**Set 1**), it may be suggested that these fractures are under extension. Consequently, they are better seen in the image logs because apertures are enhanced.

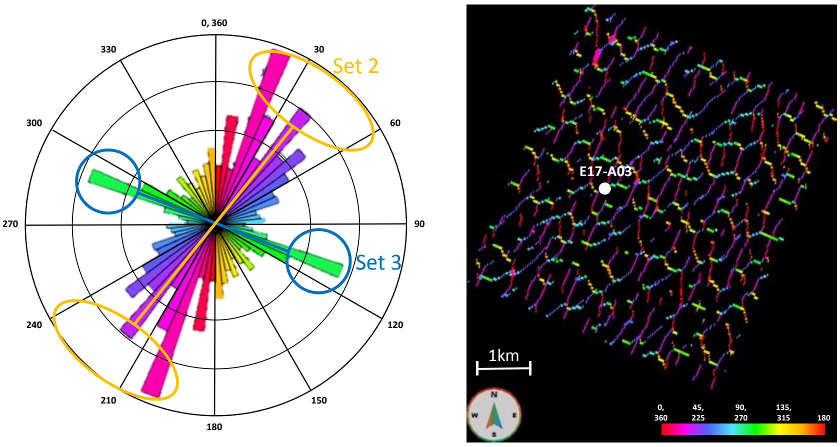


Figure 3 *The detected faults/fractures from the seismic input can be plotted according to their orientation and show a strong correlation with fracture Sets 2 (NNE-SSW) and Set 3 (*ESE-WNW).

The seismic analysis in its nature will include data on a much larger scale. To increase the accuracy of the analysis only detected faults that are located within the same vertical analysis window of the well logs was used. There was however a larger X and Y analysis window to increase the data samples within the area of interest. As with the well log study it is possible to identify a strong NE-SW striking event (**Set 2**) and a further ESE-WNW event (**Set 3**), indicating there is overlap between the analysis types (Figure 3). This correlation is observed when plotting the two fracture orientations against one another (Figure 4).

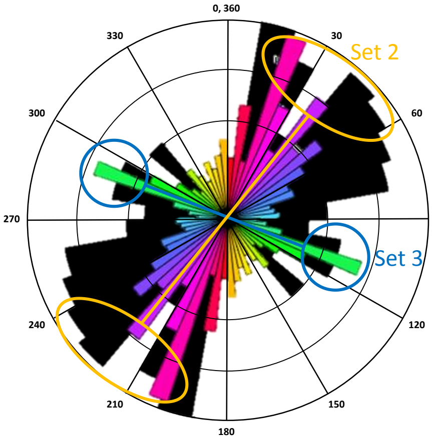


Figure 4 *When plotted against one another it is possible to see a strong correlation between Set 2 (NE-SW) and Set 3 (ESE-WNW) in the well data and in the seismic analysis.*

Bedding picks from image logs analysis show an easterly trend with shallow to moderate dip magnitudes (average 25°). Beds overlying the top Carboniferous unconformity have shallower dip magnitudes. Additionally, bed steepening is observed in the hanging wall of an easterly dipping fault located at 3900m MD.

The seismic detected faults have been embedded into the reflectivity data and compared directly to that of the well log results. Figure 5 highlights where the two sets coincide with one another and the alignment of well-based detected faults and seismic detected faults at 3900m MD. The fault detected in the well at 3900m MD is of a size that can bridge the gap between well and seismic data. Coupled with the earlier orientation based analysis in Figures 2, 3 & 4 it is possible to conclude that small scale seismic features can be correlated to large scale features within image logs.

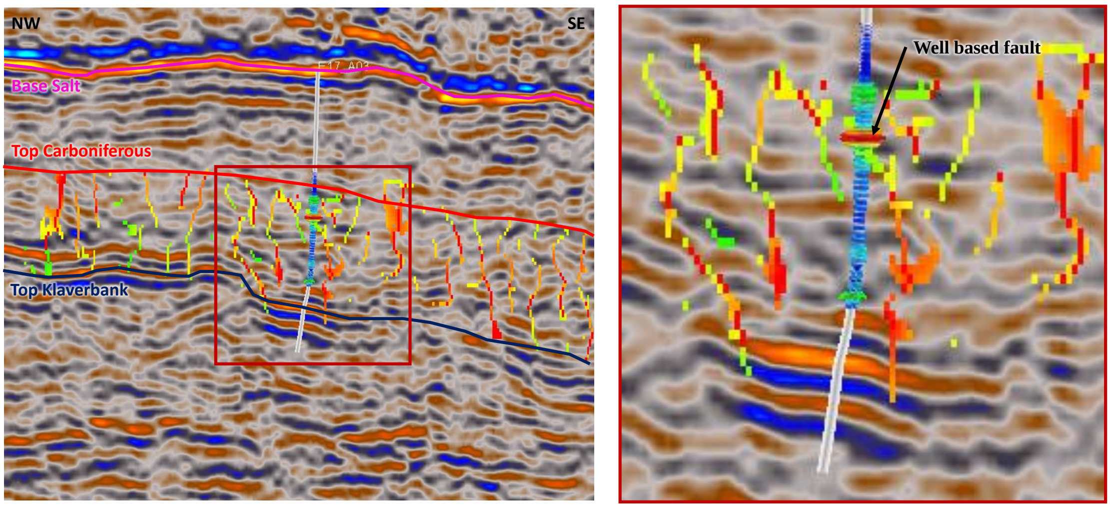


Figure 5 *The faults that are illustrated in Figure 3 can be imbedded into the reflectivity data to accurately identify where fractures are observed in both well and seismic data. The faults are displayed in confidence where blue is low fault confidence and red is high fault confidence. Both methods of interpretation identify a fault in the well at depth 3900 MD.*

Conclusions

The seismic-to-well data gap is an issue that has led to ambiguity within data modelling and reservoir interpretation, but with detailed multi-attribute analysis coupled with well image logs analysis it is possible to close the gap even further. Mapping of the structural lineament orientation in both the image logs and seismic data can be directly compared to identify the alignment of events. As shown here the fracture events in Set 2 and Set 3 from the well results compare well with the seismic lineaments, whereas Set 1 is not observed in the seismic. We interpret this to be because the *in situ* stress field is acting to dilate NNW-SSE fractures at the well scale, which are therefore seen in the well data. Direct comparison of the well log results can be undertaken to identify where faults interpreted in the image logs and the seismic overlap, thus increasing the interpreters' confidence in interpreting small scale structural events away from the well location. There will be events that are just too small for seismic surveys to identify, but where results in both seismic and well logs correlate we can have high confidence in identifying small scale faulting or fracture patterns. Using seismic analysis techniques where very small and subtle changes in the wavelet response are identified independently and then combined together have enabled us to get a very high resolution image of the fault/fracturing present in the area of interest. This is only possible to achieve with confidence when the seismic data quality is high enough, both in terms of the signal to noise ratio and the vertical resolution. By identifying individual changes in the seismic response, fractures that are not resolved can be detected and imaged so that we can identify features that are at the limit, or just below, seismic resolution. A single coherency attribute will only be able to identify the resolved breaks in the data, thus maintaining the scale gap between the seismic image and the well image, extracting the fractures from a multi-attribute CMY blend bridges this gap and gives increased confidence in the fault presence and orientation away from the well. In addition, the *in situ* stress conditions at the well and its impact on fractures seen in the image log (both natural and induced) must be considered.

Acknowledgements

We would like to thank GDF for the release of the data for this analysis to be undertaken. The seismic analysis was undertaken using GeoTeric and the image log and *in situ* stress analysis were undertaken using Techlog petrophysics software (Schlumberger).

References

Terzaghi, R.D. [1965] Sources of error in joint surveys. *Geotechnique*, **15**, 287-304.