Use of spatial, frequency and curvature attributes for reservoir, fluid and contact predictions

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Summary

Integrating subtle attributes and 3D visualization can provide new exploration opportunities in a very mature area such as the Dutch Southern North Sea. Structure-oriented filtering techniques and Common Contour Binning (CCB) facilitate mapping and highlight subtle amplitude effects caused by fluid contacts. Cross-verification against other attributes such as curvature and frequency result in multiple, mutually supportive indicators for reservoir, fluid type and fluid contact, yielding better de-risking of prospects.

Introduction

The Southern North Sea has been explored for hydrocarbons since the sixties, and has proven a very prolific basin. With the ongoing maturation of the basin, additional reserves are mainly found in deeper and/or subtle traps as well as in reservoirs with higher reservoir quality risk. A series of techniques and suite of seismic attributes can be used to further develop geological and play concepts, uncovering previously overlooked reserves and yielding more accurate risking on economically marginal plays.

To support the exploration effort and to help reduce risks associated with prospects, a series of techniques and workflows have been developed, and applied on an ‘as needed’ basis. These techniques range from the use of frequency attributes such as spectral decomposition, spatial attributes such as various kinds of spatial filtering and advanced amplitude analysis; and the use of curvature attributes, most of them backed-up by forward modeling. Workflows are designed to be complementary, providing independent information. Any of these technologies as stand-alone only produces partial, non-unique indication, which is not sufficient for de-risking. This is due to a number of reasons: 1) attributes are non-unique (i.e. curvature can highlight faults, flexures and channels); 2) their response is very weak (i.e. deep patchy amplitudes), and 3) multiple criteria need to be satisfied for successful de-risking (fracture porosity can relate to curvature, HC presence to flat spots and/or CCB amplitudes). If a number of techniques are combined and all indicators are consistent, they prove to be a very powerful tool in reducing risk.

Regional geology

The southern Broad Fourteens basin, located in the Dutch North Sea, is an inverted rift basin and is on its fringes characterized by very rapidly changing geology (see figure 1). Large-scale regional horst-and-graben faulted systems are present and form the traps for the most prolific plays in the area: the Triassic clastics of the Main Bundsandstein Subgroup (including the Solling formation) and the Permian carbonates and clastics of the Z3 Platten Dolomites and Slochteren sandstones.

High-resolution 3D seismic data was acquired in 2005 with 6 km cables, and processed through Kirchhoff pre-stack time migration. Parameters for acquisition and processing had been optimized to image both the medium-depth Triassic clastic and deep Permian carbonate and clastic targets, as well as steeply dipping strata.

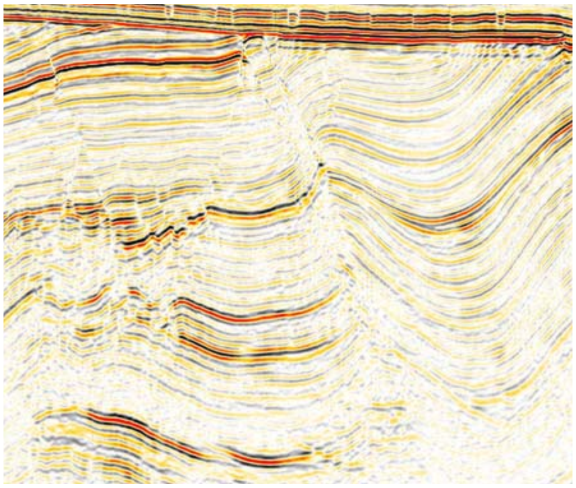


Figure 1: a typical horst-and-graben setting with steeply dipping sediments is characteristic for the Broad Fourteens basin.

Amplitudes

Forward modeling predicts amplitude effects for most of the reservoirs encountered in this area, ranging from obvious effects (brightening in most Triassic intervals in the presence of hydrocarbons and/or better reservoir) to very subtle (subtle brightening for Rotliegend gas intervals). However, interpretation of seismic amplitudes is not trivial for a number of reasons:

- Large scale faulting and steep dips complicate reliable amplitude preservation
- Complex overburdens, partly involving salt, can distort the signal

These two effects cause patchy amplitude patterns that are difficult of tie to fluid contacts, especially on the deep levels. Moreover, the presence of stacked reservoirs complicates the interpretation of the seismic signal, especially in quantitative terms. Therefore the analysis of amplitudes in their conventional domains is not always reliable and more advanced techniques and workflows are needed.

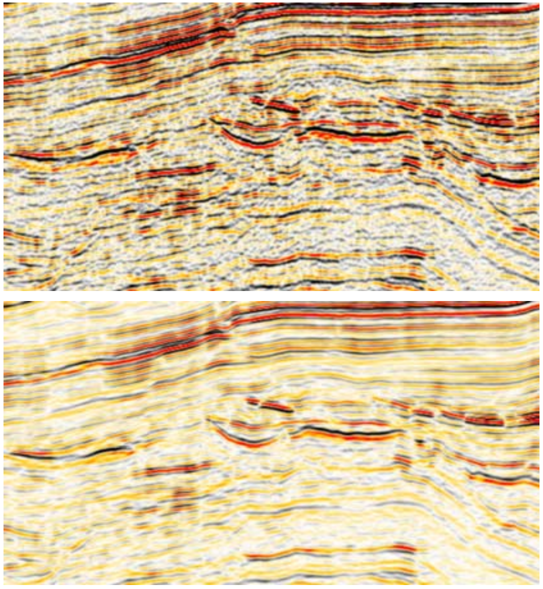


Figure 2a (above), raw data and 2b (below): the same data with (conventional) structure-steered spatial filtering applied, improving continuity of reflectors.

Spatial filtering and attributes

Spatial filtering is a well-known technique to average seismic traces in the x-y direction. It is particularly suitable in areas suffering poor signal-to-noise, or in areas where imaging is not perfect. Depending on how the filtering is applied, certain features can be selectively highlighted:

- filtering in the x-y direction in the global plane of strata can improve continuity of reflections (structure oriented filtering, Hoecker et al, 2002), improving data for structural interpretation and increasing quality on other attributes created from the filtered seismic (figure 2)
- filtering in the x-y direction horizontally (where geology is dipping) can highlight fluid induced flat events
- filtering along picked events or horizons perpendicular to local dip (CCB) can highlight subtle structure conformable amplitude effects on this event normally not visible (figure 3)

The first technique focuses on the structural definition of an area, as illustrated in figure 2a and 2b. Comparing the images it is obvious that spatial filtering improves lateral continuity of reflections and can improve the delineation of faults. However, as filtering is applied along the seismic event in all directions, amplitudes are averaged in all directions, including the dip direction. This means that structure conformable amplitude effects such as those caused by a fluid contact are altered due to smearing effects in the dip direction.

The second technique can highlight subtle flat spots due to fluid contacts using a horizontally oriented filter. Dipping events representing non-horizontal geology are destructively averaged. True horizontal events such as fluid induced flat spots are constructively averaged. In this way, structural effects of the flat-spot are highlighted. Obviously this filter works best in areas with a non-horizontal geology i.e. contrast between signal and background, working on depth data where fluid-contacts should be flat.

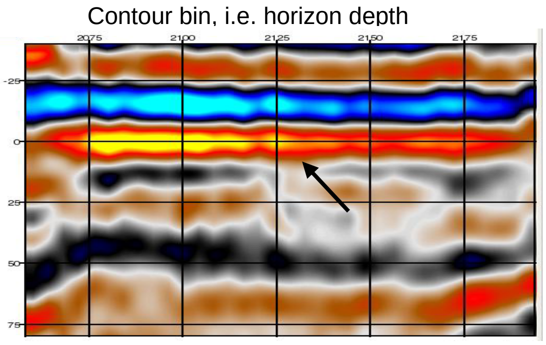


Figure 3: Display of CCB; the vertical axis presents relative time to picked event, the horizontal axis (in time) shows true vertical position. The amplitude roll-off on the image at 2126 ms has been confirmed as the gas-water contact.

The last technique focuses on highlighting very subtle amplitude effects, caused by this fluid contact. It is designed to detect amplitude changes on the structural reflector due to changes in fluid phase having a common down-dip limit. Conventional approaches use cross-plotting of amplitude versus depth maps (Haan et al, 2001) which highlight the amplitude change at a certain depth. However, this approach discards the additional geologic information of conformable strata above and below the target horizon. Therefore, in this approach, the seismic data are averaged along small contour intervals defined by the top structure map, hence the name “Common Contour Binning”. This approach will not only average-out local signal-to-noise problems as well as overburden effects; it also improves the representation of geologically conformable events around the target horizon. Such an image can either be used to quickly evaluate the possible presence of a structure conformable amplitude anomaly on the target horizon, as demonstrated in figure 3. If this is visualized and analyzed

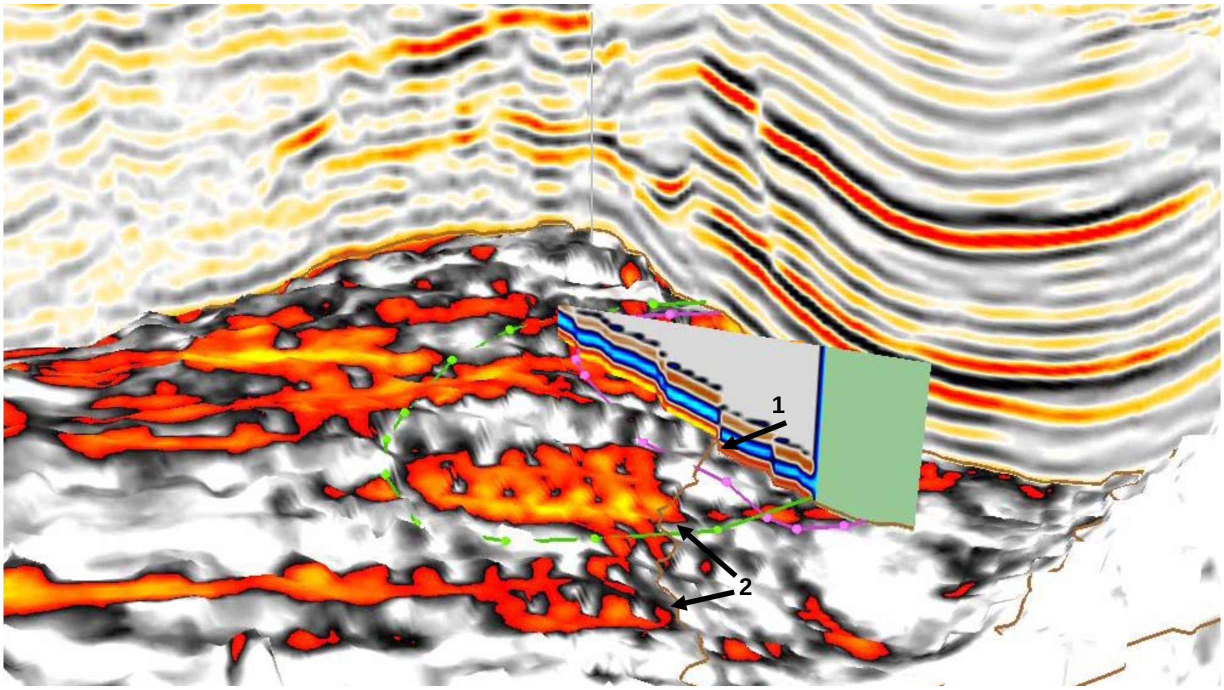


Figure 4: Same CCB as figure 3, projected on 3D random line perpendicular to the structure. The green polygon indicates the area in which data was binned. At the position of arrow 1, the amplitude roll-off indicates the (confirmed) GWC; the contact is indicated on the instantaneous amplitude map with the thin brown line. Only now it becomes evident that the patchy amplitudes (arrows 2), affected by acquisition footprint and picking problems, are cut-off by the contact. Seismic in the background is raw seismic (upper left side of image) and structure-oriented filtered (right).

in 3D, it can sometimes directly be linked to very subtle structure conformable amplitude anomalies in map view, that might be linked to a local spill-point, a leaking fault, or to very subtle similarity changes due to the contact. Alternatively it can represent the hydrocarbon column the top seal can hold, or demonstrate undercharge of the structure. An example is given in figure 4.

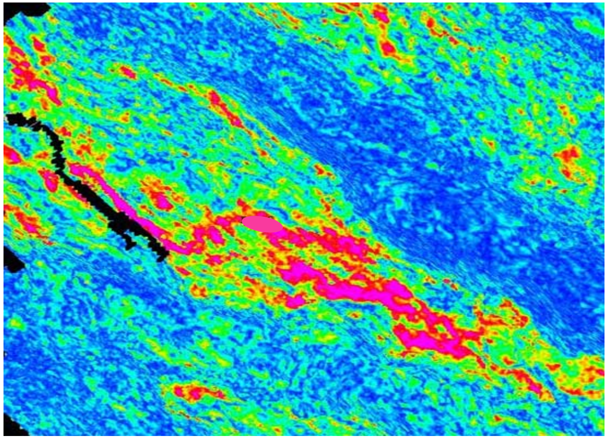
Frequency attributes

Welsh et al (2008) experimented with the use of spectral attributes as hydrocarbon indicator (Castagna et al, 2003; Li et al, 2005). It has been demonstrated in many studies that changes in fluid phase can causes measurable frequency effects. However there are other geological and seismic effects that cause frequency variations (e.g. tuning, attenuation, wave-field effects due to complex overburden settings). In Welsh' study on this same data set he shows promising results in the sense that very interesting local correlations between spectral effects and fields/dry wells can be found (figure 5a). However a block wide correlation with the well results shows that only attribute anomalies depending on frequency effects are insufficient as HC indictor in de-risking prospects. The conclusion is that spectral indictors should be used in conjunction with other attributes.

Curvature attributes

Curvature is a measure of the amount of bending in seismic events (Roberts 2001). The attribute is independent of the amplitude and frequency indicators discussed earlier. Again interpretation of curvature is non-unique. In a first iteration, we can attribute high curvature values to structural features such as synforms and antiforms, flexures and faults, as well as to sedimentary features such as differential compaction, erosional scours, and to other causes (Chopra et al, 2005). Next, the interpretation in this particular setting is based on the expectation that curvature correlates with increased fracture density. Increased fracture density would potentially lead to increased fracture related permeability necessary to sustain good reservoir performance (see figure 5b).

However, high curvature might also have negative correlations: For example upward continuous curvature (fractures) might increase top-seal risk; broad curvature zones near faults might increase fault-seal risk; increase water circulation due to fracturing might promote illitization, decreasing permeability. Also, varying seismic data quality might affect the curvature attribute.



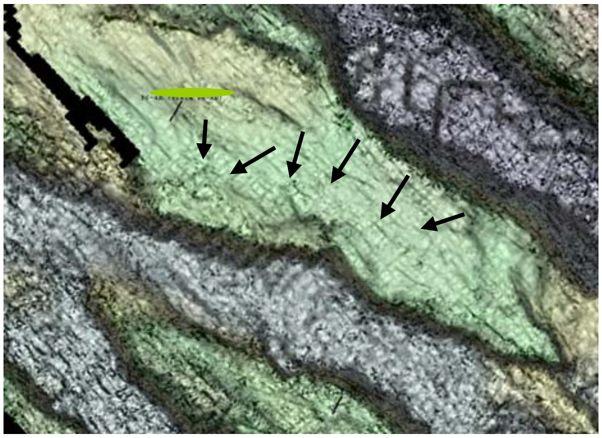


Figure 5a (left): Low frequency horizon slice 150ms beneath a known gas accumulation. There is a rough correlation between the high amplitude low frequency anomaly and the extent of gas field (from Welsh et al).

Figure 5b (right): Curvature horizon slice over the same area as figure 5a, but through the reservoir itself. It now becomes evident that the areas with possible higher fracture density (arrows) coincide with the frequency anomaly at the deeper level.

The initial interpretation of curvature shows anomalous signatures at the main producing Platten unit, which is dependent on fracture permeability for flow. A number of non-flowing wells at Platten and Bunter reservoir levels can be explained using geological reasoning based on observed curvature. However these interpretations are often only dependent on subtle changes in the curvature attribute. As such, the interpretation is subjective in nature and it remains an open question how to apply curvature in a robust predictive fashion in this difficult play.

Integration

As shown, each individual attribute can provide significant information related to the petroleum system. In this complex seismo-geological environment no single attribute will be a play-maker. However, interpreting multiple attributes and combining results significantly reduced uncertainty in reservoir prediction. A simple integration would be to define positive attribute responses in combination with a ‘the more, the better’ approach, reducing risk. However, this is a flawed approach, since 1) often it is not precisely clear what a positive attribute response is, and 2) the play will only be as strong as its weakest indicator. For example a brightening effect is produced when a water bearing sand becomes gas-filled; yet in general bright spots produced by gas-fills at shallow depth will be more visible than those at deeper depth. Curvature can indicate reservoir permeability and/or seal risk, depending on subtle variations. An effective way to integrate multiple attributes is to explain the responses of all attributes from a common likely geological scenario, acknowledging possible artifacts relating to seismic acquisition and processing. This geological scenario should be constrained by outside (hard and soft) information such as basin models, wells, stress history. This scenario should always be calibrated to nearby thoroughly investigated drilled analogues. If the likely geological scenario explains all attribute responses and is consistent with outside data, we have significantly reduced risk of prospects or reservoir risk for development projects.

Conclusions

It has been demonstrated that spatial filtering, spectral and curvature analysis as well as amplitude evaluations can be integrated and used together to highlight and exploit very subtle events, which are hardly discernable and would otherwise not be detected. Only when visualized in 3D, the correlation of the various attributes to the structural shape becomes clear.

Structure-oriented seismic filtering facilitates mapping whereas CCB can highlight very subtle amplitude effects caused by fluid contacts. Visualizing in 3D and correlation to structural attributes such as curvature, and other hydrocarbon related attributes such as frequency anomalies completes the understanding. In this way, very subtle indications that are not independently conclusive can be integrated to support each other.

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EDITED REFERENCES

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