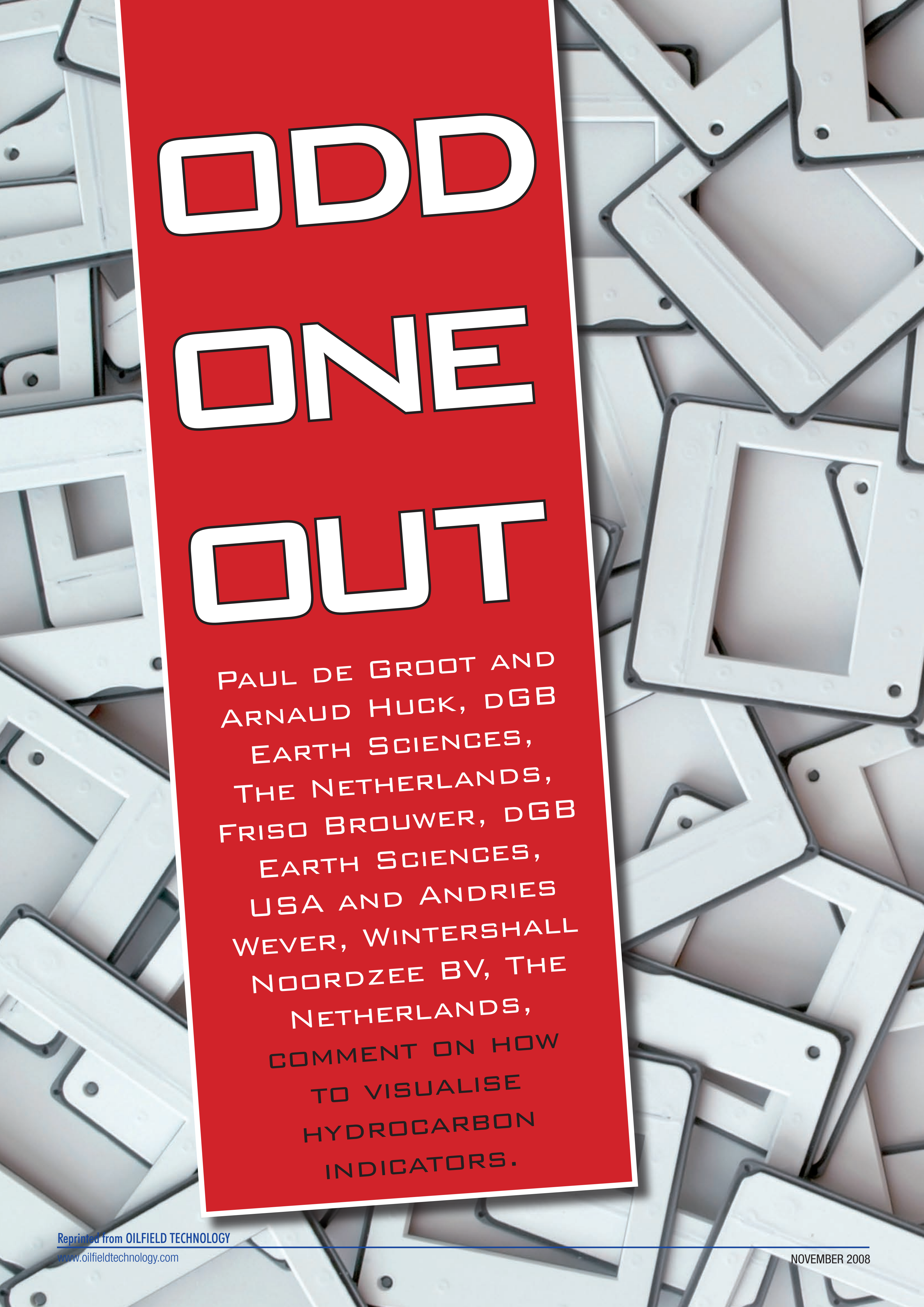

ODD ONE OUT

Paul de Groot and Arnaud Huck, dGB Earth Sciences, The Netherlands, Friso Brouwer, dGB Earth Sciences, USA and Andries Wever, Wintershall Noordzee BV, The Netherlands, comment on how to visualise hydrocarbon indicators.

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Direct hydrocarbon indicators (DHIs) are seismic anomalies caused by the presence of hydrocarbons. Examples of DHIs are seismic amplitude variations, flat spots, low frequency shadows, seismic chimneys and gas clouds. It is well known from theory and practice that certain attributes are sensitive to variations in fluid fill. In general, seismic amplitude, phase and frequency may change when hydrocarbons are present. Also angle and azimuthal variations can be expected as a function of fluid fill. In many cases DHIs are directly visible on (post stack) seismic data but to improve visibility and to enable spatial interpretation between DHIs and other elements of the petroleum system it is often preferred to transform the data to another domain. Such transformation can be easily done in most seismic interpretation packages by computing some kind of attribute. The problem arises from the multitude of potential attributes that can typically be calculated: which one to choose, how to evaluate this and what does it mean, where does it relate to? In OpendTect, the system used to generate the examples in this article, these problems are solved in three ways:

- ‘On the fly’ calculation of attributes in target zones which allows interactive testing by visual inspection of attributes and attribute parameters.
- Intelligently combining the information inherent in single attributes into meta attributes.
- Integration of these results into a 3D structural framework for spatial correlation, analysis and risking.

On the basis of examples the article first describes a few single attributes. Next it describes the process of creating meta attributes and shows how meta attributes can be used to create object ‘probability’ volumes. For example, to visualise seismic chimneys, which enables interpretation of fluid migration paths from seismic data. Then, the article gives an example of a new technique called common contour binning. Finally, all elements are integrated and visualised in the 3D model to understand their relation and meaning, and to exploit this for appropriate risk allocation.

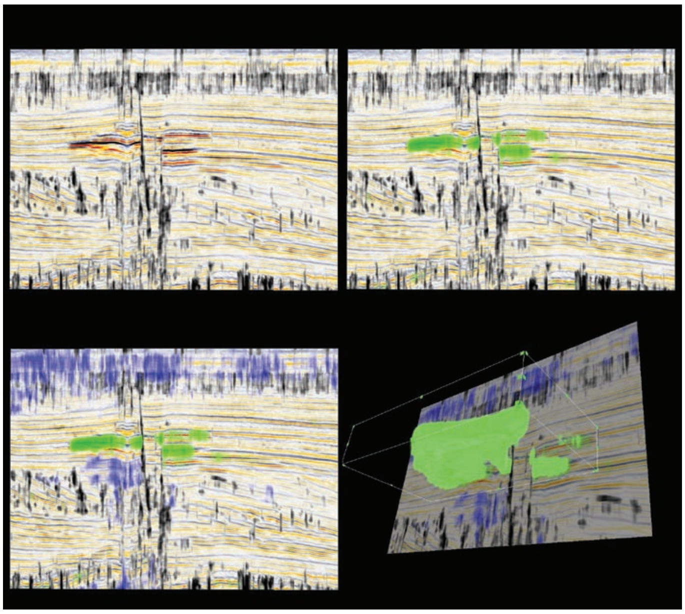


Figure 1. Top left, seismic combined with a discontinuity attribute (black) to highlight structure and trapping geometries. Top right, as before with rms amplitute attribute (green) to highlight bright spots that are indicative for hydrocarbon presence. Bottom left, a frequency ratio attribute indicates the presence of a low frequency shadow (LFS) below the left side bright spot (blue). Frequency ratio is independent from amplitude hence this attribute gives additonal support for hydrocarbon presence. Bottom right, the bright spot visualised with volume rendering of the rms amplitude attribute reveals the geometry of the anomaly.

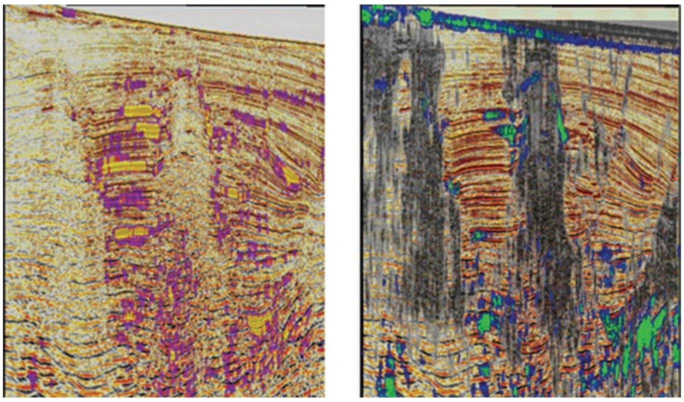


Figure 2. GOM meta attribute example. Left, seismic section with overlain energy attribute (yellow - purple). Right, seismic section with chimney probability meta attribute (grey) and low frequency energy attribute (green - blue). Chimneys indicate hydrocarbon migration, comparing energy and low frequency helps to discriminate between true and false (non hydrocarbon related anomalies).

Single attributes

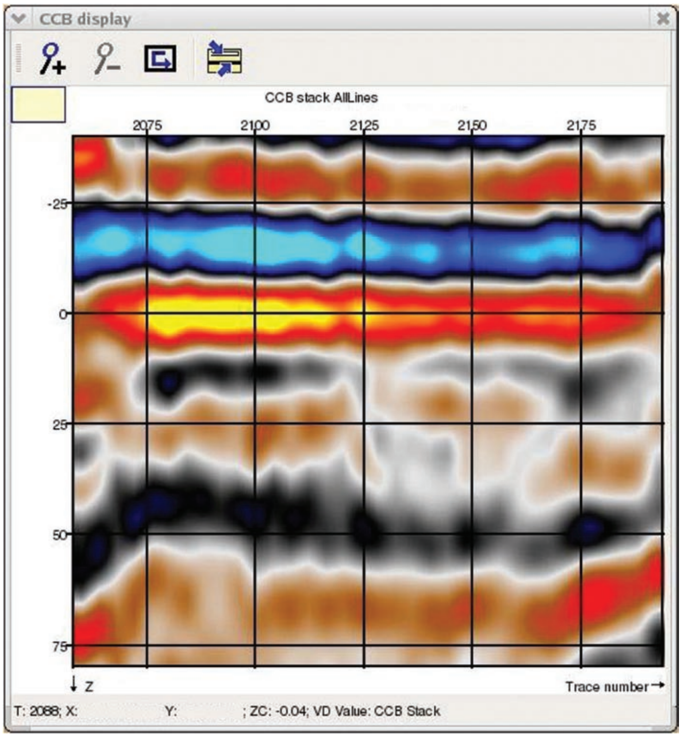
There are several indicators for hydrocarbon presence. Most used are amplitude and amplitude versus offset indications, reflection polarity and frequency behaviour.

- Amplitude and amplitude versus offset (AVO) behaviour. When hydrocarbons, especially light oil, condensate and gas, are present in the pore system of reservoir rocks this will generally lead to a decrease of acoustic impedance and Poisson ratio compared to the hydrocarbon free case. The magnitude and type of the amplitude/AVO response on the introduction of hydrocarbons is dependent on the rock and fluid properties in the reservoir rock as well as the embedding rocks. In general amplitude/AVO behaviour can be used to predict the presence, but not the saturation of hydrocarbons.
- Polarity. Polarity by itself is obviously not a unique hydrocarbon indicator, but it does support other hydrocarbon indicators. In some cases, especially when trying to discriminate hydrocarbon filled bright spots, or AVO type three from anomalous amplitudes due to hard streaks (such as poorly sorted sediments, sills, carbonate cemented sands) creating attributes that separate peak-trough reflections from trough-peak reflections sequences from through peak reflection sequences can be useful for weeding out false amplitude or AVO anomalies. This requires knowledge of the polarity of the source wavelet, which can be obtained from seismic processing, inversion processing, or by inspecting strong interference free reflections with known contrasts (e.g. seafloor, top of salt).
- Frequency effects. The article discriminates three types of frequency anomalies that are useful for indicating presence of hydrocarbons: high frequency attenuation (HFA), low frequency anomalies (LFA) and low frequency shadows (LFS).
    - HFA. HFAs are caused by a decrease in quality (Q) factor in reservoir rocks that are (partially) filled with gas or condensate. Decreased Q indicates higher dissipation of wave energy into heat, attenuation. This affects higher frequencies stronger than lower frequencies and is therefore best observed in attributes such as average frequency, or high frequency components of spectral decomposition. A potential pitfall is that dual phase systems (partial HC saturation) may exhibit the strongest attenuation.
    - LFA. Low frequency anomalies are often observed in the reflection signatures of hydrocarbon filled clean sands. The main mechanism is suspected to be interference patterns. Shaly sequences often consist of thinly interbedded layers with varying elastic properties, causing a high frequency geological reflectivity spectrum. In contrast, sandy deposits are often more homogenous, causing a low frequency geological reflectivity spectrum. The introduction of hydrocarbons in the sands causes the seismic velocity in the sand to decrease. This leads to a larger temporal thickness of the layers, often resulting in a lower frequency signature. A well known application is the sweetness attribute that combines LFA with amplitude anomalies. Sweetness is calculated as instantaneous amplitude divided by instantaneous frequency.
    - LFS. This refers to anomalous strong low frequency response below hydrocarbon filled reservoirs. This is mainly an empirical observation, without theoretical support. Proposed mechanisms include processing artifacts related to the presence of hydrocarbons and presence of internal multiples and/or converted waves immediately below the reservoir reflection.

None of these single attributes are unique or complete hydrocarbon indicators. In a typical study many attributes are calculated over the target zone and checked for anomalous behaviour by visual inspection. Figure 1 is an example of a seismic section and some of the attributes discussed above.

Meta attributes

One of the main advantages of single attributes is that they condense the information content and provide new views of the data, which may lead to new insights and better geologic interpretations. The problem with single attributes is that it is very easy to calculate hundreds of these and to become overwhelmed by the many different views. Many attributes carry overlapping information; hence produce similar images. But each view will be different and it will be difficult to choose the one that optimally represents the geologic feature of



T: 2068; X: Y: ; ZC: -0.04; VD Value: CCB Stack

Figure 3. CCB stack of a southern North Sea target. The CCB stack displays stacked seismic traces in a time window of -40 to +85 ms around the top reservoir horizon versus top reservoir depth (x axis) in m. From left to right (moving down dip) one can observe a decrease in amplitudes at 2136 m. This coincides with the confirmed gas/water contact.

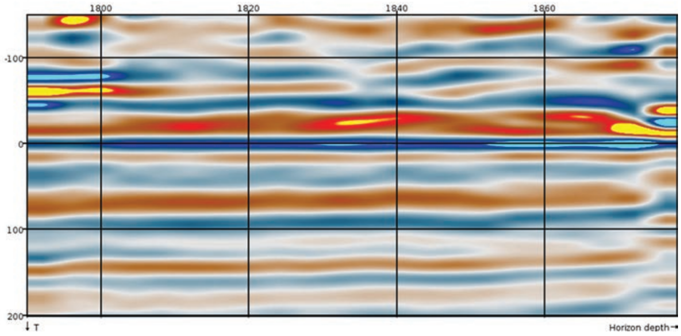


Figure 4. CCB stack for the Asian example. The CCB stack displays stacked seismic traces in a time window of -150 to +200 ms around the top reservoir horizon versus top reservoir depth (x axis) in m. From left to right (moving down dip) one observes that the amplitudes at time zero (top reservoir) increase in amplitude at 1800 m and at 1850 m. These changes are interpreted to mark the gas/oil contact and oil/water contact, respectively.

interest. Moreover, multiple attributes with complementary information for a complete view of the object of interest are often needed. For example, as stated before, a change in fluid fill may change the seismic response in amplitude, phase and frequency behaviour. Variations in these properties can be captured by e.g. energy, instantaneous phase and spectral decomposition attributes. If such attributes are combined in an intelligent way they create a meta attribute; an attribute that optimally combines the information content of the targeted geologic feature. Meta attributes can be created in various ways, e.g.:

- Using mathematical and logical manipulations.
- Creating a fingerprint from one or more input attributes at one or more locations of interest. The output indicates at every seismic position how similar (on a scale from 0 - 1) that position is as compared to the fingerprint. Fingerprints are used e.g. to map the extent of a suspected DHI from near, mid and far stack input attributes and to determine whether similar responses exist in undrilled prospects.
- Training a supervised neural network to recognise a targeted object. This technique differs from the fingerprint in two ways:
    - The user picks two sets of inputs (object and non-object, whereas the fingerprint only needs inputs for the object class to create the fingerprint).
    - It combines the input attributes in a non-linear manner (versus linear combination for the fingerprint), which gives greater separation power.

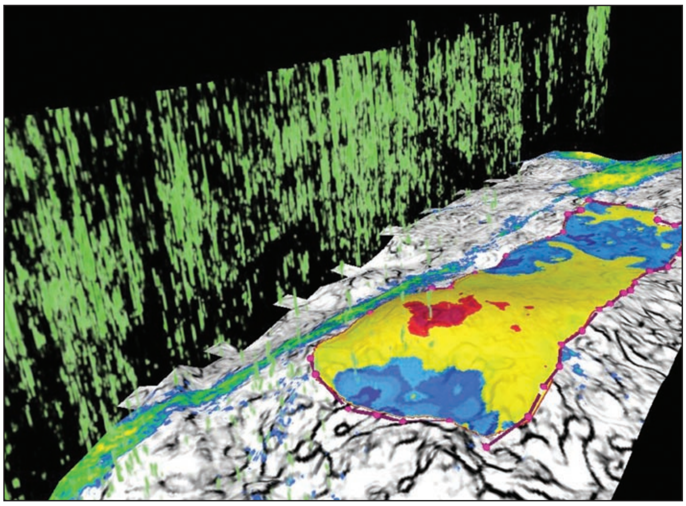


Figure 5. Top reservoir horizon with CCB stacked amplitude map (colours) and volume rendered seismic chimneys (green). Chimneys indicate vertical fluid migration occurs along the fault system. The absence of chimneys above the structure means one is dealing with a good quality top seal. The CCB amplitude map shows dimming to occur near the top (red - yellow, which is interpreted as the gas/oil contact) and dimming at a deeper level (blue - yellow contour meets the fault down dip of the structure; the chimney's indicate leakage. The blue - yellow contour is the interpreted oil/water contact). In Connolly's (2008) chimney classification scheme such configuration of chimneys and faults is highly prospective.

Figure 2 is an example of the neural network meta attribute technique that was used to highlight seismic chimneys. Seismic chimneys are vertical disturbances of the seismic response possibly caused by fluids migrating through the sequence. By transforming the seismic response to a seismic chimney cube it becomes feasible to study large and small disturbances in the context of fluid migration paths. Some applications of the chimney cube are: unravelling a basin's migration history, distinguishing between charged and non-charged prospects or sealing versus non-sealing faults, determining vertical migration of gas, identifying potential for over pressure, and detecting shallow gas and geohazards. Practically, chimney cubes can reveal where hydrocarbons originated, how they migrated into a prospect, and how they spilled or leaked from this prospect and created shallow gas, mud volcanoes or pockmarks at the sea bottom.[2] Connolly (2008) created a chimney classification scheme and compiled a catalogue with analogs that is used for prospect risking.

Common contour binning

Common contour binning (CCB) is used to detect subtle hydrocarbon related seismic anomalies and to pinpoint gas/water, gas/oil and oil/

water contacts.[1] CCB uses the power of stacking to enhance such anomalies. Consider a structure filled with hydrocarbons. All traces that penetrate the reservoir at the same depth will in principle sample the same hydrocarbon column length. The imprint of any hydrocarbon effect on the seismic response of these traces will therefore be similar. Stacking all traces along the same contour line can cause the hydrocarbon effect to stack up while stratigraphic variations and random noise are cancelled out.

CCB generates two outputs: first a CCB volume is produced that consists of traces stacked along contour lines that are redistributed along the same contour lines. In other words all traces along one contour line consist of identical traces that were produced by stacking all traces along that contour line. The second output is the CCB stack. This is a 2D section with stacked traces flattened along the mapped reference horizon. Figure 3 shows a CCB stack example of a typical southern North Sea deep target. The CCB stack shows a clear dimming below 2136 m, which coincides with the confirmed gas/water contact. On regular stacked seismic data however, no indication on the presence of a gas/water contact can be found.

3D integration and risking

The real benefit of DHI visualisation comes from integrating the results in a 3D visualisation environment where one can study spatial relationships between all elements of the petroleum system. The example shown here is from onshore Asia (Figures 4 and 5). A top reservoir horizon reveals a large anticlinal structure that is bounded down dip on one side by a large fault system. Chimney cube analysis shows that the fault is leaking. A polygon is drawn around the anticlinal structure outlining the area for the CCB analysis. Only traces inside the polygon that are positioned on the same contour line are stacked. The CCB stack shows amplitude variations at the target level in two steps (Figure 4). The first change occurs at contour depth 1800 m and the second at contour depth 1850 m.

The CCB volume shows the same amplitude changes in the structural context. Figure 5 shows the amplitude map at reservoir level extracted from the CCB volume. The low amplitude anomaly near the top of the structure (red) is probably associated with gas fill. The second amplitude change (yellow to blue) occurs at the depth of the expected spill point and is interpreted as the oil/water contact. The chimneys (green) in Figure 5 show that the structure is leaking down dip along the fault system. Analogs show that this type of chimney/structure configuration is highly prospective.[3]

Conclusion

The authors have described different techniques to visualise DHIs and have shown several examples. In general, application of these techniques increases geologic insight and facilitates the interpretability of the data. Especially when integrated in 3D the relation between the various elements can be investigated for an integrated assessment of the petroleum system. OT

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