Sealing quality analysis of faults and formations by means of seismic attributes and neural networks

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Abstract

A seismic interpretation technique aimed at predicting effective seals and assessing the risk of seal failure is presented. The method integrates seismic chimney cubes, fault cubes, pressure information, well data and other relevant information. Chimney cubes reveal subtle vertical disturbances in the seismic response that can often be interpreted in terms of hydrocarbon migration paths. Linking chimneys to seepage-related features such as pock-marks and mud-volcanoes is an established way of calibrating the interpretation. Visually comparing time-slices through the chimney cube with slices thought the fault cube is the way to distinguish between sealing and leaking faults. This paper describes the methodology and shows various interpretation examples.

Introduction

Many exploration portfolio post mortems indicate that seal failures are the primary cause of dry holes. Seals with limited capacity and small column heights, incapable of holding sizeable hydrocarbon are often the reason for economic failure. For example, a recent post-well analysis on the UK Atlantic Margin (Loizou, 2003) revealed that 65 % of all recent wells were drilled at locations with poor traps and 9 % were at locations with fair traps. Main problems were poor seal quality, poor quality of reservoir and minor to no charge.

These post-mortems reflect the research foci of the seismic industry. Since the advent of 3D seismic technology, the primary focus of interpretive efforts has been to delineate structural geometry, soon followed by predicting reservoir presence and quality and fluid-type. The notion that seismic data also contains valuable information about hydrocarbon migration, hence seal and charge is still quite new (Heggland, 1998). The introduction of the seismic chimney cube (Meldahl et.al., 1998) was instrumental to the development of new interpretation techniques aimed at improved understanding of hydrocarbon systems.

Method

Seismic chimney cubes are derived from conventional 3D seismic volumes using a neural network-based pattern recognition technique. A human interpreter manually picks example locations of seismic chimneys as well as locations

representing non-chimneys. A training set for the neural network is constructed by extracting multiple attributes at each of the example locations. Application of the trained network yields the chimney cube, a volume in which amplitudes represent the chimney "probability" at each sample position. A chimney cube is just one example of the seismic object detection method developed by Meldahl et.al. (1998 and 2001). Dip-steering and neural network modelling are in this method used to combine multiple attributes into so-called meta-attributes that provide the optimal view for any target variable. Apart from chimney cubes the method is also frequently used to detect various other features such as faults, stratigraphic patterns and salt bodies.

Chimney cubes highlight subtle vertical disturbances in the seismic response. These disturbances are often caused by vertical movement of hydrocarbons. A small percentage of free gas or pressure-released gas trapped in the pores of the migration pathway is enough to change the acoustic response and leave a detectable trail in the seismic record. Interpretation of seismic chimney cubes to predict effective seals and to asses the risk of seal failure is not a trivial business. It involves studying the spatial relationship between chimneys, amplitude anomalies (DHI's), seepage-related seismic features (pock-marks, mud-volcanoes and carbonate build-ups), potential source rocks, traps and possible path-ways through fault systems. Other information, such as lithologies from wells, pressure maps, and basin models must be incorporated for a geologically sound interpretation.

Observations

- Faults

Overlays of chimney cube time-slices and fault cube slices is a powerful tool to distinguish sealing faults from leaking faults. In many case studies it has been observed that not all faults are visible on chimney cube slices. Often faults in one direction are visible (read leaking) whilst faults in another direction are not (Figure 1). Some faults are not leaking along their entire length but may have sections of low to no permeability. This may be related to variations in lithology along the fault, or to variations in pressure regime.

Many leaking faults show a characteristic pockmarked pattern of fluid migration on chimney cube time-slices. These seem to suggest fluid migration along faults in semi-regular spaced intervals, as long as no significant variations in lithology occur on either side of the fault. Diapirism-like behaviour of fluids is expected to occur along the faults. These 'regularly' spaced intervals are also observed at shallower level, at which pockmarks and circular carbonate build-ups in and above faults are often present in a semi-regular pattern. These carbonate build-ups are good indicators for possible hydrocarbon migration along faults, by which so-called HRDZ's (Hydrocarbon-Related Diagenetic Zones; Johnson, 2001) are formed by methane-related biogenetic processes (Hovland & Judd, 1988).

Chimney cube results in combination with fault structure can assist in the determination of the permeability factor for each fault. This technique has been

used successfully in several basin modelling studies (Ligtenberg & Thomsen, 2003), such as in the North Sea and offshore Nigeria.

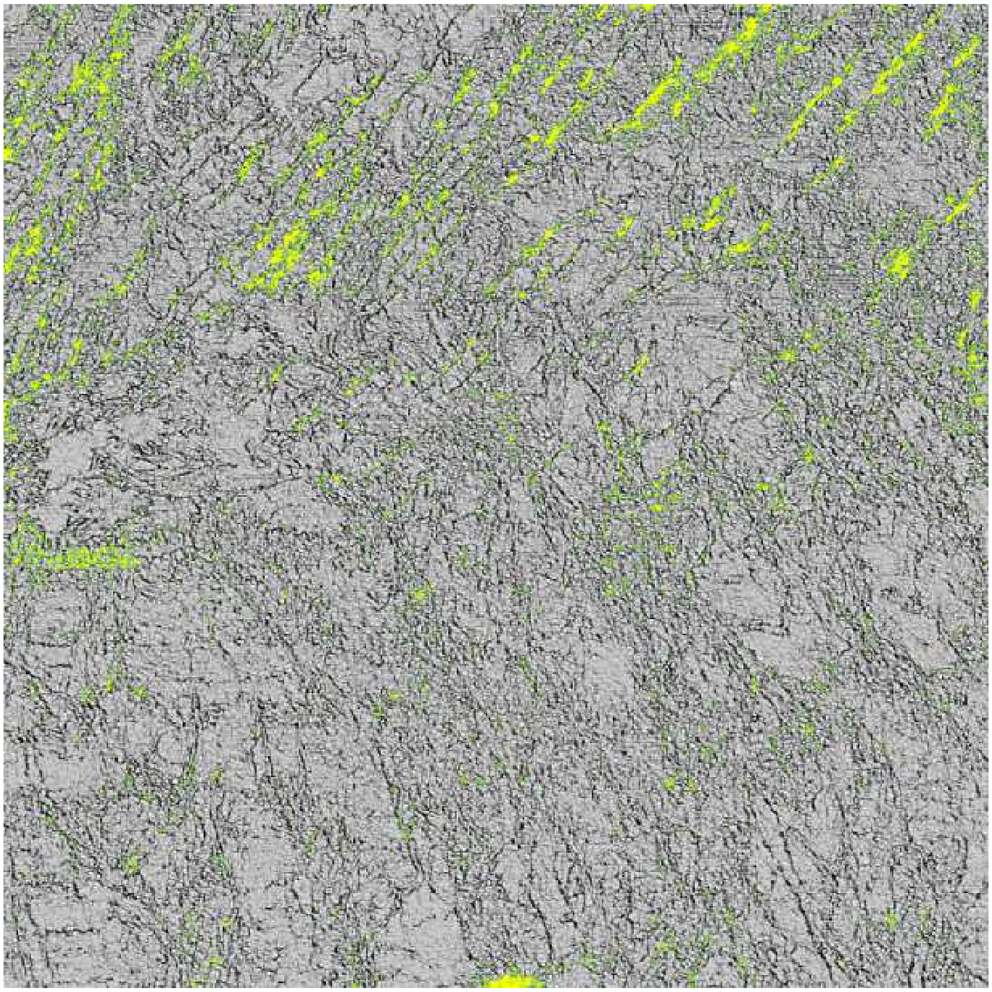

Figure 1. Fluid migration path detection (yellow) as overlay on fault structures, indicating leaking (ENE-WSW) and sealing faults (NNW-SSE)

- Top seals

Gas chimneys are usually caused by significant pressure gradients in the sub-surface and are often characterised by low seismic velocity and locally higher pressure. Combining fluid migration detection results with pressure data, it is possible to determine the optimum objective intervals for effective seal. This information can also be used to determine where abnormal pressure is breached, causing reservoir seal risk.

Seal failure is often associated with areas of locally more intense faulting and higher strain (Aminzadeh and Connolly, 2002) and/or with local lithological variations. Seismic attributes such as "Curvature", can indicate areas of locally more intense fracturing. These areas are sensitive for breaching, and may be

detected as such by combining the attribute information with fluid migration path interpretations.

Chimney cube results highlight zones of fluid migration, as well as possible over-pressured zones and shallow gas pockets. In addition, the reciprocal of the data indicates zones of good sealing quality by complete absence of any fluid migration features. Several studies in the Gulf of Mexico, offshore Nigeria and Mediterranean have confirmed these observations: zones of more intense fluid migration, overpressure and hydrocarbon accumulations are completely sealed off by impermeable layers. The only pathways for continued migration are faults and locally intensely deformed structures.

Fluid migration path detection is a very useful contributor in the analysis of seal strength and trap closure, because it highlights areas of breaching, locations of leakage and spill points. It can also assist in the prediction of expected hydrocarbon type, based on presence of gas chimneys and other hydrocarbon migration features, causing differentiation of hydrocarbon components (Sales, 1997).

Conclusions

The interpretation of fluid migration paths from seismic chimney cubes has proven to be a valuable tool in fault seal and top seal analysis. The sealing quality of faults can be determined when chimney cube results are used in combination with other relevant data such as fault maps, making it possible to distinguish leaking from sealing faults. In addition, the method provides information on the sealing quality of formations. In combination pressure maps and well information, detailed evaluations can be made of top seals.

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