USING DETECTION OF SEISMIC CHIMNEYS IN SEAL INTEGRITY ANALYSIS; A DISCUSSION BASED ON CASE HISTORIES

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Introduction

Gas chimneys are visible in seismic data as columnar disturbances. The gas chimneys are believed to be caused by free gas trapped in shales. For hydrocarbons to move upwards in a shale as free phase, there has to be an open fault, or a fracture, due to the capillary resistance in the shales. This can only occur as a result of overpressure in a reservoir, and the fault, or fracture, will be open for a time until the pressure has dropped (Bjørkum et al., 1998, Bjørkum and Nadeau, 1998). When free gas migrates through a fault, some gas is expected to move horizontally into the shale for a limited distance, i.e. in the order of 100 m, generating a “narrow” chimney. Gas may also be released from oil, or gas saturated water, moving through a fault, as a result of a drop in the pressure (seltzer- effect).

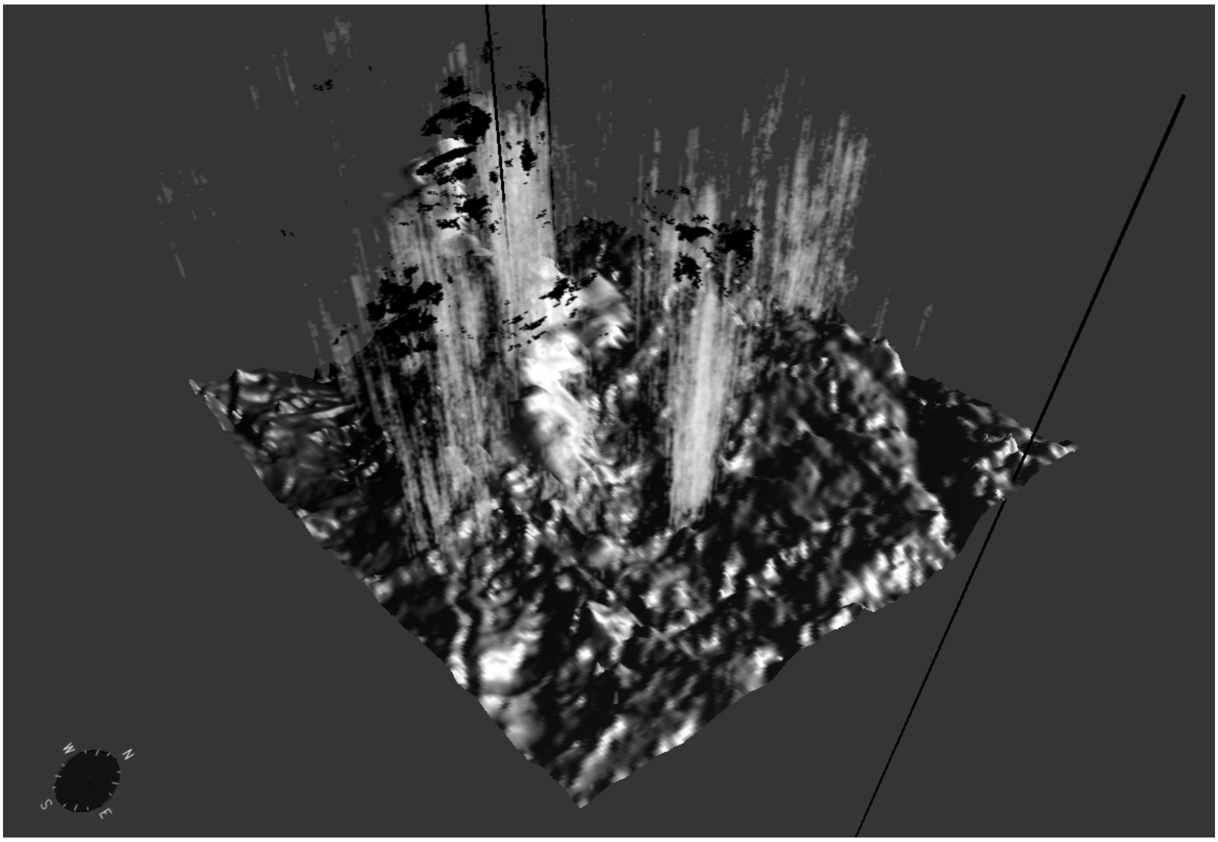

Figure 1. Visualization of gas chimneys from 3D seismic data, between top of Jurassic faults (at the dark surface) and the seabed. The smaller white structure in the middle represents the top of an Eocene oil and gas reservoir. The two wells penetrating this surface showed oil and gas columns. The third well (at the right) was dry. Amplitude anomalies (black) on top of chimneys indicate shallow gas accumulations, or alternatively, carbonate build-ups.

Water, as well as gas saturated water, is not exposed to capillary forces, and can move upwards through the shales. During the upward movement of water, gas may be released when the pressure drops. In this case the chimneys can get several hundred metres wide. In near surface and non consolidated clays, the buoyancy forces may overcome the capillary forces, and vertical migration of hydrocarbons may take place through the clays without having to migrate through a fault or a fracture. A number of 3D seismic examples show chimneys that are located at faults or fractures. In near surface sediments, where seismic data show no faults or fractures, chimneys may still be visible in the seismic data. In such a case the chimneys occupy a much larger space (i.e. several 100 metres wide) than at deeper levels.

In many cases high concentrations of gas chimneys are present in the area of hydrocarbon charged reservoirs. Figure 1 shows an interpretation example from the North Sea where an oil and gas charged reservoir is present.

Method

The diffuse character and often weak appearance of chimneys in seismic data, make them difficult to map, and in most cases they are visible in vertical seismic sections only, not on 3D seismic time slices and various attribute maps. To improve the identification of chimneys in seismic data and to make mapping more consistent and efficient, a method for detection of chimneys was proposed and developed in co-operation between Statoil and de Groot – Bril Earth Sciences (dGB) (Meldahl et al., 1998, 1999 and Heggland et al., 1999). The method and more interpretation examples are also described in Heggland et al., 2000, Meldahl et al., 2001, and Aminzadeh et al. 2001.

The method makes use of multi attribute calculations and a neural network. Multi-trace and multi-attribute calculations are performed on the input seismic data, in order to increase the contrast between the chimneys and the background. The different attributes that are input to the neural network are weighted according to their contribution to the contrasting of the chimneys. The attributes that give the highest contributions for the detection of seismic chimneys seem to be trace to trace similarity, energy (or absolute amplitude), which both generally are lower within chimneys than in the areas surrounding them, and the variance of the dip of seismic reflectors. The neural network is trained on attributes extracted at chimney and non-chimney example locations identified by the interpreter. After training, the network is applied to the entire data set. In the chimney detection process, multiple vertical attribute extraction windows are used. This enables the network to distinguish between chimneys, having a certain vertical extent, and other objects with similar attribute characteristics, but having a small vertical extent. The neural network finally makes a classification of the seismic samples into chimney and non-chimney samples. The output samples are given high values for chimney (high probability) and low values for non-chimney (low probability).

The method has been generalized for the detection of other seismic objects like faults and diapirs, in which the detection is steered along the main directions of extent of the actual seismic object (Tingdahl, K. M., 1999).

Results

The new method for detection of gas chimneys in seismic data makes it possible to achieve a much more consistent mapping as compared to standard manual mapping. The chimney detection has revealed chimneys lining up with faults, as well as with features associated with gas seepage (e.g. pockmarks, carbonate buildups, mud volcanoes), shallow gas and deeper hydrocarbon accumulations (Heggland et al., 2000, 2002, Aminzadeh et al., 2001, 2002). Possible hydrocarbon migration systems have been visualized by the seismic detection method in areas of proven oil and gas fields. The chimneys indicate fluid migration between source and reservoirs, between reservoirs (remigration), and between reservoirs and the seabed. As such, interpretation of detected chimneys can have significance in prospect evaluation. Observations of gas seepage features at different, but not all, subsurface horizons, indicate that gas seepage is not a continuous process, but takes place during limited periods in geologic time (Heggland, 1997, 1998). This may be related to periods of pressure release in deeper hydrocarbon charged reservoirs.

The presence of chimneys along faults or on top of structural closures, may indicate a “kind of” seal failure, in which case chimney (and fault) detection in 3D seismic data may have significance in fault-seal and top-seal integrity analysis. The disadvantage is that gas chimneys may not only be generated by free gas, or gas from oil, migrating through faults or fractures, but also by gas from water releasing gas (seltzer-effect) while moving up the faults or through the top seal. Future research may find ways to classify chimneys in seismic data, such that it can be possible to distinguish between cases when gas saturated water is the source of the gas chimneys, and cases when they are caused by free gas or oil. When chimneys have a large lateral extent and can not be related to faults, they are most likely caused by gas saturated water. The difficult case is when chimneys are associated with a fault or a fracture. In such a case, there is at present no way to tell from the seismic data whether it is gas saturated water, free gas or oil that is migrating upwards. The value of chimney detection and interpretation can be increased significantly by combining the results with various seabed data and well data, see for example O’Brien, 2002 .

Conclusions

Examples from detection of chimneys and faults show that chimneys are linked to faults and hydrocarbon reservoirs. The presence of chimneys may indicate which faults and which cap rocks that are leaking. A disadvantage is that there is no way at present to distinguish between chimneys in seismic data caused by upward movement of gas saturated water causing the seltzer-effect), or by vertical migration of free gas or oil. Future research may solve this by establishing a classification of chimneys in seismic data by using a combination of different data types.

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References

Bjørkum, P.A., Walderhaug, O. and Nadeau, P. (1998). Physical constraints on hydrocarbon leakage and trapping revisited, *Petroleum Geoscience*, Vol. 4 237-239.

Bjørkum, P.A. and Nadeau, P. (1998). Temperature Controlled Porosity/Permeability Reduction, Fluid Migration, and Petroleum Exploration in Sedimentary Basins, *APPEA Journal* 1998, Vol. 38, Part 1, 453–464.

Meldahl, P., R. Heggland, A.H. Bril and P.F.M. de Groot, 1998, Method of Seismic Body Recognition. Patent application GB 9819910.02.

Meldahl, P., R. Heggland, A.H. Bril and P.F.M. de Groot, 1999, The chimney cube, an example of semi-automated detection of seismic objects by directive attributes and neural networks: Part I; method, SEG 69th Annual Meeting, Houston, Oct. 31 - Nov. 5, Expanded Abstracts Vol. 1, pp 931 - 934.

Heggland, R., P. Meldahl, A.H. Bril and P.F.M. de Groot, 1999, The chimney cube, an example of semi-automated detection of seismic objects by directive attributes and neural networks: Part II;

interpretation, SEG 69th Annual Meeting, Houston, Oct. 31 - Nov. 5, Expanded Abstracts Vol. 1, pp 935 - 937.

Heggland, R., P. Meldahl, P. de Groot and F. Aminzadeh, 2000, Chimneys in the Gulf of Mexico, *The American Oil and Gas Reporter*, Feb. 2000, pp 78 - 83.

Meldahl, P., R. Heggland, A.H. Bril and P.F.M. de Groot. 2001, Identifying targets like faults and chimneys using multi-attributes and neural networks, *The Leading Edge*, May 2001.

Aminzadeh, F., T. Berge, P. de Groot and G. Valenti, 2001, Using Gas Chimneys as an Exploration Tool, *World Oil*, Part 1, May 2001, Part 2, June 2001.

De Groot, P.F.M., 1999a, Seismic Reservoir Characterisation Using Artificial Neural Networks, 19th Mintrop-Seminar, 16 – 18 May 1999, Münster, Germany.

De Groot, P.F.M., 1999b, Volume transformation by way of neural network mapping, 61st EAGE Conference, Helsinki, 7-11 June 1999.

Tingdahl, K.M., P. De Groot, R. Heggland, and H. Ligtenberg, 2001, Semi-automated object detection in 3-D seismic data, Offshore, Aug. 2001.

Heggland, R., 2002, Seismic Evidence of Vertical Fluid Migration Through Faults, applications of Chimney and Fault Detection, AAPG Hedberg Conference, Near-Surface Hydrocarbon Migration: Mechanisms and Seepage Rates, Vancouver, BC, Canada, April 7-10, 2002.

Heggland, R., 1997, Detection of Gas Migration from a Deep Source by the Use of Exploration 3D Seismic Data, *Marine Geology* 137, pp 41 - 47.

Heggland, R., 1998, Gas Seepage as an Indicator of Deeper Prospective Reservoirs. A Study Based on Exploration 3D Seismic Data, *Marine and Petroleum Geology* 15, pp 1 - 9.

O'Brien, G., 2002, The Yampi Shelf, Browse Basin, North-West Shelf, Australia: A test-bed for constraining hydrocarbon migration and seepage rates using a combination of 3D seismic data and multiple, independent remote sensing technologies, AAPG Hedberg Conference, Near-Surface Hydrocarbon Migration: Mechanisms and Seepage Rates, Vancouver, BC, Canada, April 7-10, 2002.