Fluid migration path detection and its application to basin modeling

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Abstract

Modelling Petroleum Systems in a basin with a high degree of confidence requires the ability to calibrate migration paths, hydrocarbon kitchens and all other factors that influence and make up the petroleum system. Often only limited information is available with respect to hydrocarbon migration. Therefore, the method for integrating detection of fluid migration paths in seismic data with 3D basin modelling is proven to be a new important contributor to the task of reducing exploration risk.

The detection method is using an assemblage of directive, multi-trace seismic attributes, neural network technology and the interpreter's insight to produce a 3D Chimney Cube. Structures in the seismic that are probable fluid migration paths are enhanced selectively while other features are muted. These results provide additional input and calibration information to basin modelling in a 3D volume. Especially information with respect to hydraulic properties of faults, location of possible overpressure zones, location of high and low permeability zones and indirectly about charge of reservoirs and leakage/spillage from these reservoirs into shallow gas pockets or to the sea floor are valuable for constraining the 3D basin model.

Besides providing information on hydrocarbon migration paths, the Chimney Cube appears to be detecting areas where hydrocarbons are actively being generated and expelled thus offering unprecedented constraint on basin modeling predictions concerning delineation of areas containing mature source rocks. Examples are provided to illustrate the value of integrating the fluid path detection with 3D basin modeling.

Introduction

The method to detect fluid migration paths in seismic data facilitates the identification and mapping of possible hydrocarbon migration pathways and aids in a better understanding of complex hydrocarbon migration systems. Studies have been carried out in which the chimney detection results have been integrated with basin modelling. A basin-wide study is currently being carried out in which the main attention is focused on a regional understanding of petroleum systems. Fluid migration path detection has been incorporated in this study and integrated with 3D basin modelling - a combination that has provided significant additional information that would otherwise not have been obtainable.

Method

The method to detect fluid migration paths in seismic data is using an assembly of directive, multi-trace seismic attributes and a multi-layer perceptron neural network (Meldahl et al., 1998 and 2001). The interpreter selects representative example locations of chimneys, which are characterized by low energy, (near-) vertical structures and noisy seismic character. Also example locations are selected that do not represent chimneys. Seismic attributes are calculated at these example locations and a supervised

neural network is trained based on the extracted attribute values to be able to distinguish between chimneys and non-chimneys.

The results outline probable fluid migration paths and have been used as additional input to a 3D basin model for calibrating the model and constraining model predictions. Based on the results, constraints are set for hydraulic properties of faults, formations and locally more intensely fractured zones. Additionally, the information on areas of active hydrocarbon expulsion in combination with the fluid migration paths provides important new insight for determining the lateral vertical extend of petroleum systems. The vertical features resulting from the detection processing allow for an interpretation of zones of higher vertical fluid flux. The significance of these zones can, once zones with salt effects or other types of regional disturbance have been removed, be related to either pressure systems and de-watering or hydrocarbon movement. When used for calibrating the basin model these zones are outlined in three dimensions and transferred to the 3D basin model and are given properties resulting in vertical fluid movement thus providing zones of vertical fluid transfer.

Results and analysis

The applications of the chimney detection results for basin modelling are manifold. An important contribution is to determine the sealing quality of faults (Ligtenberg & Connolly, 2003) and the ability to define the permeability factor for each fault. Figure 1 illustrates an example of sealing and permeable faults. In a West-Africa study the detection of fluid migration paths has significantly contributed in updating the basin model. For example, a fault was assumed to have only minor permeability. However, from chimney detection analysis this fault appeared to be an important pathway for hydrocarbons leaking from the reservoir (Figure 2) and an update of the basin model was required.

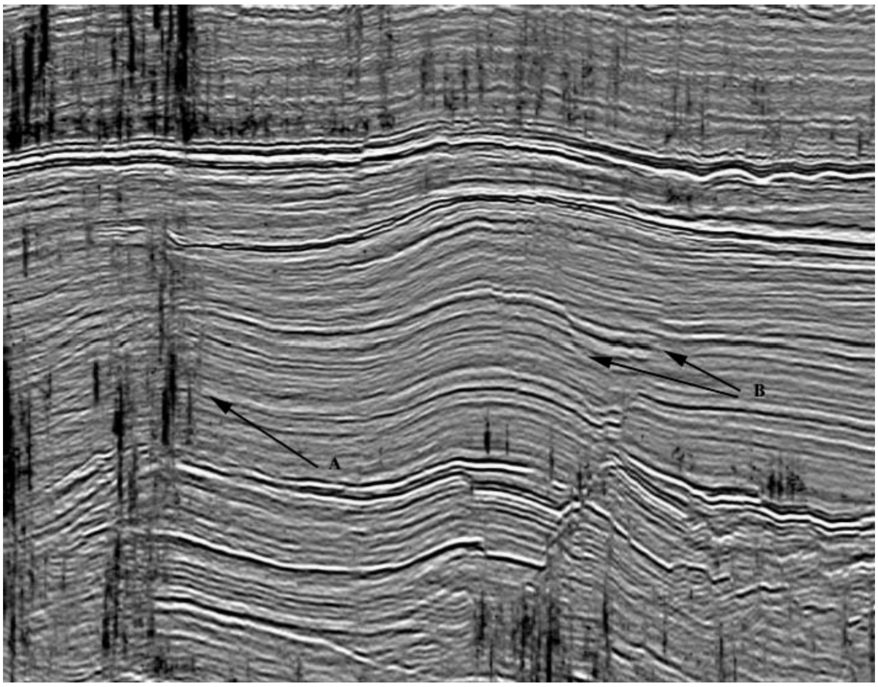

Figure 1. Fluid migration path detection as overlay on seismic, showing leaking (A) and sealing faults (B)

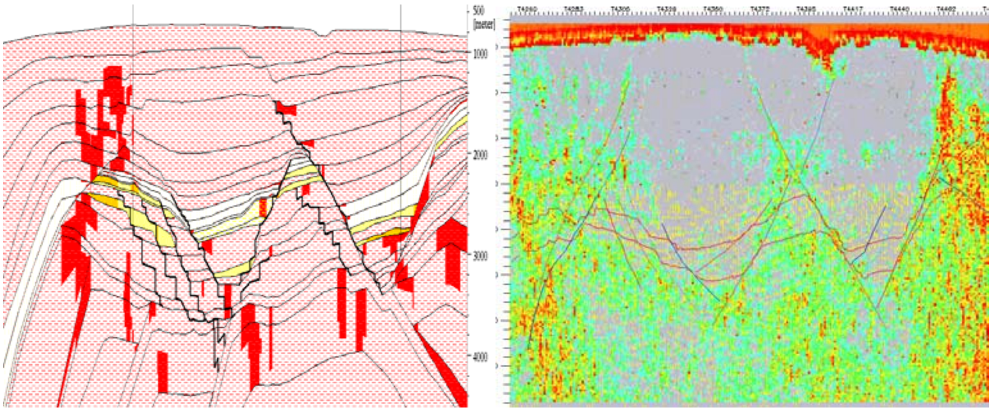

Figure 2. Old basin model (left) and chimney detection (right) showing clear indications for strong leakage along right fault and necessity for update of the old basin model

Similar observations can be used for evaluating the sealing capacity of the top seal of hydrocarbon accumulations. A pronounced chimney on top of a hydrocarbon accumulation indicates a leaking structure with subsequent differentiation of hydrocarbon components allowing for a better prediction of the expected hydrocarbon type (Sales, 1997).

Many areas exhibit polygonal faulting. These polygonal faults, because they are picked up in the detection method, can be interpreted as de-watering structures, i.e. vertical fluid migration effects. Variations in the intensity of chimney probability are observed in this Lower Tertiary (e.g. see top section of Figure 1). It is assumed that these areas with higher chimney density are higher overpressure zones and/or containing hydrocarbons. These higher overpressure zones in combination with possible chimneys are often associated with areas of locally more intensive faulting and higher strain (Aminzadeh and Connolly, 2002) and/or with internal variations as often seen for instance in the upper part of the North Sea Chalk.

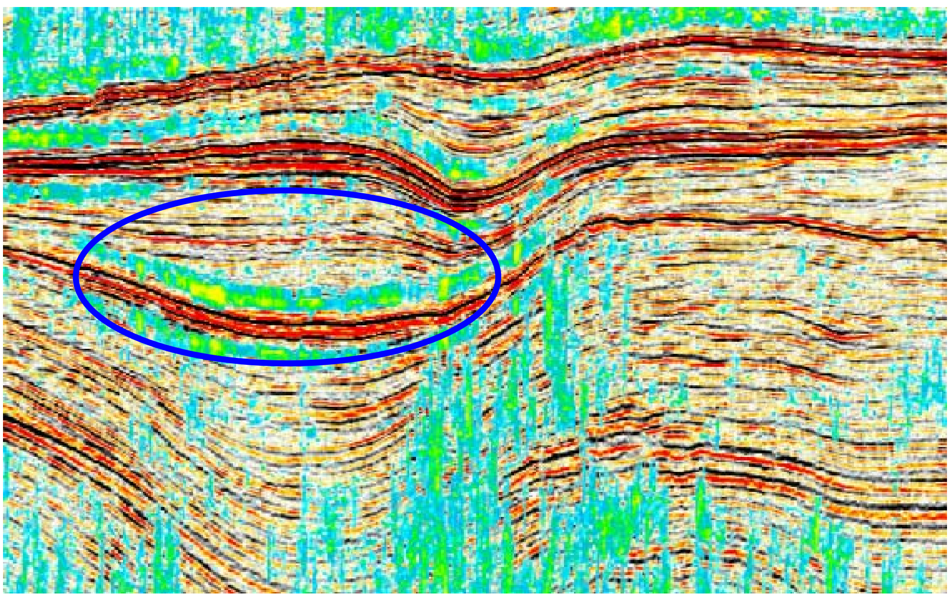

Figure 3. Fluid migration assumed to be active hydrocarbon expulsion

Areas interpreted as locations of active hydrocarbon expulsion are also picked up by the fluid migration path detection. Strong activity is seen in areas where known source rocks have reached a maturity level where generation and expulsion of hydrocarbons occurs (Figure 3). This type of information, when integrated with 3D basin modelling, increases the confidence level on model predictions. Chimney detection results add additional check on the outline of a kitchen area as well as a check on the presence of a source rock in areas where all other indicators point to sufficient maturity to generate and expel hydrocarbons.

Conclusions

The integration of fluid migration path detection and 3D basin modelling has been shown to be a valuable component in increasing the confidence level on model predictions and thereby contributing to lowering the overall exploration risk. It provides information to better estimate the hydraulic properties of faults (transmissibility), delineate zones of lower capillary entry pressures in formations allowing vertical fluid movement and outline probable fractured zones acting as zones of vertical fluid transfer. Areas of high overpressure are indicated and significant information is added to the prediction of probable charge to reservoirs and if leakage/spillage occurs. In general, the chimney detection highlights all types of fluid migration features. These also include enhanced imaging of areas in which active hydrocarbon expulsion takes place. Results derived from fluid migration path detection integrated with 3D basin modelling contribute significantly to an improved understanding of active petroleum systems in basins.

References

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