Fluid migration path detection in seismic data, a valuable tool in oil and gas exploration

Herald Ligtenberg

Abstract

Understanding hydrocarbon migration in the subsurface is a key aspect of oil and gas exploration. It is well known that conventional 3D seismics contains information about hydrocarbon migration. A method has been developed to detect fluid migration paths semi-automatically, using assemblies of seismic attributes and neural networks.

The resulting seismic chimney cube yields valuable information about the origin of hydrocarbons, migration into prospects and leakage from prospects whereby features at or near the seabed are created. Also getting indications of over-pressured zones, sealing quality of faults and areas of active hydrocarbon expulsion are feasible. Such information is invaluable for basin modeling studies and for increased understanding of the petroleum system.

Unraveling the petroleum system is the key to exploration success. Recently Statoil explorationists introduced seismic chimney interpretation as a new tool to help unravel the petroleum system. Initially seismic chimneys were interpreted manually but this proved to be a difficult and labor intensive task. To facilitate this task a new seismic volume emerged: TheChimneyCube®. The volume highlights fluid migration paths in seismic data by combining various seismic attributes through neural network modeling. The method is used in conjunction with other geological and geophysical data, such as well logs, pressure data and other relevant information to confirm the observed structures. Chimney cubes have been processed and interpreted with success in many basins all over the world, a/o in the North Sea, Gulf of Mexico, Mediterranean and Niger delta.

The detection method uses an assembly of directive, multi-trace seismic attributes and supervised neural networks (Meldahl et al., 1998). The method can be applied for detecting fluid migration paths, but also for detecting faults, salt bodies and other seismic objects (Meldahl et al,, 2001). In this article I will focus on the detection and interpretation of fluid migration paths. First, the interpreter selects example locations inside interpreted gas chimneys as well as outside. For chimneys, these locations normally exhibit low energy, high variance of the local dip and low coherency (Fig. 1A). At the manually picked example locations the selected seismic attributes are calculated and given to a neural network, which will train itself to distinguish chimneys from non-chimneys. Finally, the trained neural network is applied to the seismic volume, creating a chimney "probability" volume (a so-called ChimneyCube), which is used for further interpretation (figure 1B).

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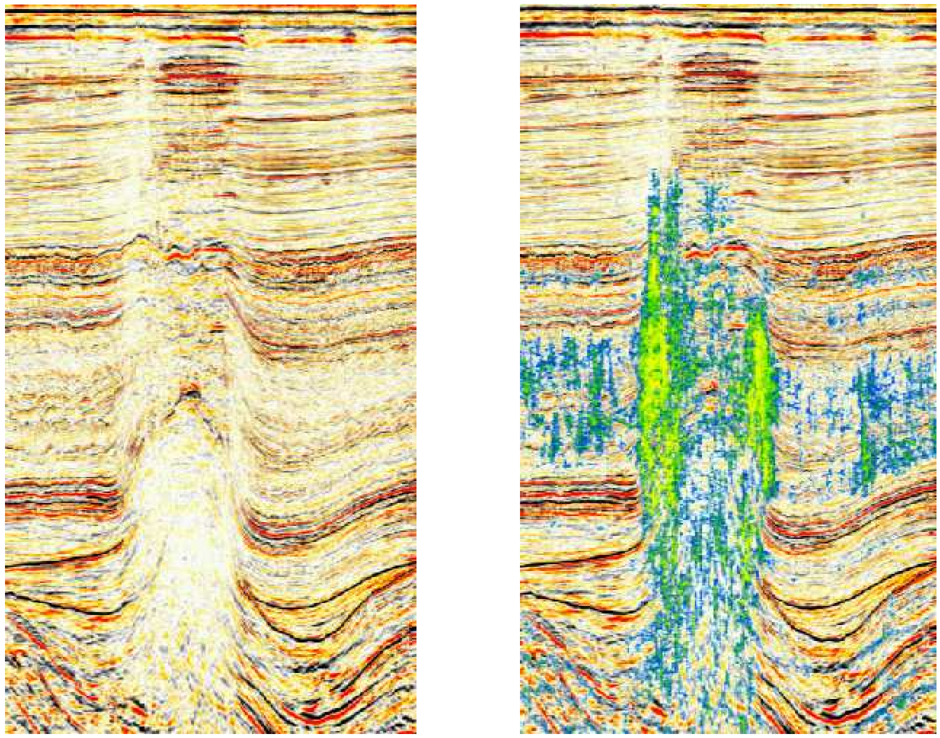

Figure 1. Original seismic section (left) and results of fluid migration path detection(TheChimneyCube) overlain on original seismic (right), indicating active hydrocarbon migration along flanks of a salt dome.

Prominent achievements from the analysis of fluid migration detection on seismic data are the determination of sealing quality of faults, detecting areas with active hydrocarbon expulsion, indication of possible charging of reservoirs and indication of possible spillage or leakage from these reservoirs.

In many basins hydrocarbon migration is fault-related. Surface maps show that faults associated with hydrocarbon seeps have a distinctive pock-marked character. The same pockmarked character can be observed in time-slices of *TheChimneyCube,* which may be associated with vertical fluid movement along the fault. Comparing *TheChimneyCube* data with structural data provides other diagnostics for distinguishing sealing and leaking faults. Overlays, like in figure 2, provide direct information on the sealing quality of each fault. The results show if faults are part of the fluid migration path or if they form a barrier and have good sealing quality (Ligtenberg & Connolly, 2003).

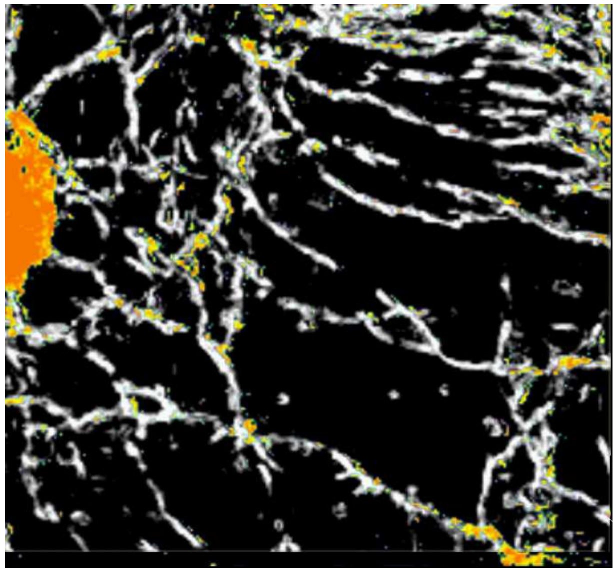

Figure 2. Chimney probability (in yellow) is overlain on top of fault pattern, indicating sealing and leaking faults.

Areas interpreted as locations of active hydrocarbon expulsion are enhanced by the fluid migration path detection. Strong activity is seen in areas where known source rocks have reached maturity level where generation and expulsion of hydrocarbons takes place (Ligtenberg & Thomsen, 2003).

Fluid migration detection results show the spatial relationship between source rock and reservoir and leakage from reservoirs. In conjunction with other structural and reservoir-property information the geological interpretations can be validated. An example of such an interpretation is given in figure 3. In the deeper section a salt dome is highlighted in lightblue. Along its flanks we see a red cloud with high amplitudes, corresponding to a deep reservoir. The shallow red cloud of high amplitudes is interpreted to represent a hydrocarbon-charged reservoir. Chimneys (in yellow) surrounding the salt dome indicate upward fluid migration from the deeper reservoir. The high density of shallower chimneys indicates charging of the shallow reservoir. Chimneys are visible up to the seabed (brown) where it has developed a small mud volcano, generated by transport of sediments, fluid and/or gas to the sea floor.

In some cases the gas reaches the sea floor and creates characteristic mud volcanoes or pockmarks. In other cases the gas does not reach the sea floor, but develops shallow gas zones that form a significant hazard for offshore activities. These shallow gas zones may be difficult to distinguish on seismic data, but can be detected with the described method for fluid migration detection (Aminzadeh et al., 2002).

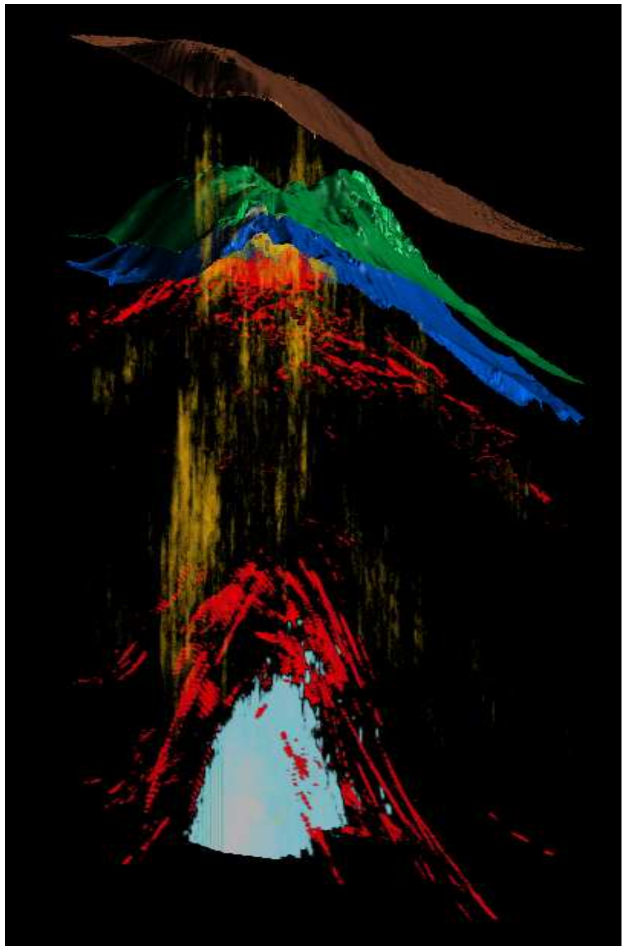

Figure 3. Fluid migration paths (in yellow) indicate migration from deep reservoir (red) along flanks of salt dome to shallow reservoir (red) and leakage from shallow reservoir to the sea floor. Courtesy Roar Heggland, Statoil.

Recently, the detection of fluid migration paths in seismic data has been used with success in a basin modeling study. To construct a basin model many assumptions have to be made. ChimneyCube results can provide relevant information, such as better estimations of the hydraulic properties of faults, locate areas of high overpressure, knowledge on outlines of petroleum kitchens and information on charge of reservoirs and leakage or spillage from reservoirs (Ligtenberg & Thomsen, 2003).

In summary, the detection of fluid migration paths in seismic data using chimney cube data has been proven a successful tool in the oil and gas exploration. Its application is manyfold, ranging from fault permeability analysis to charge/no-charge information on potential reservoirs, detection of geo-hazards and contribution to basin modeling studies.

For more information on the technique and interprations, please contact me at: herald@dgb.nl

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