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Vertical Hydrocarbon Migration at the Nigerian Continental Slope: Applications of Seismic Mapping Techniques.

Summary

By the use of 3D seismic data, simple techniques, using various seismic attributes, may be applied to map features associated with fluid flow, like pockmarks, amplitude anomalies, mud volcanoes and carbonate build-ups. A method designed for detection of gas chimneys, showing up in 3D seismic data as columnar disturbances, has been applied on 3D data from different parts of the world. The results show that chimneys in many cases are located at faults and fractures. Clusters of chimneys are observed in areas where oil and gas discoveries have been made. These chimneys are believed to result from hydrocarbon migration through faults between source rocks and the seabed. Reservoirs located vertically above such hydrocarbon migration pathways may get charged.

Seismic data from the Nigerian continental slope show indications of fluid flow to the seabed through faults. Amplitude anomalies, indicating shallow gas accumulations, are located at faults. Numerous pockmarks can be seen along seabed fault lines, and mud volcanoes, recent and ancient, are located at faults. Seabed samples taken at locations of faults and mud volcanoes contained hydrocarbons. Gas hydrates were present in a sample taken from a mud volcanoe.

Introduction

Vertical hydrocarbon migration can not be observed directly in seismic data, and it is not well understood how to distinguish between migration of free gas, and migration of gas-saturated water releasing gas as a result of a drop in the pressure, or oil. Due to capillary resistance, hydrocarbons can not move through shales unless there is an open fracture or an open fault. Water can move through shales and release gas, if it is gas saturated and there is a sufficient drop in pressure, see Bjørkum et al., 1998. This may give rise to chimneys that are not associated with faults. These chimneys are frequently seen in seismic data. Seismic data also have the potential to show indications on fluid flow through faults. Whether the flow is gas saturated water, free gas or oil, is not known, but the fluid flow indicators tell that the faults are, or have been, open for fluid migration and, as such, they represent the most likely vertical migration pathways for hydrocarbons. Features that can be seen in seismic data and which can be associated with fluid flow, gas seepage or gas accumulations, are chimneys (columnar disturbances), pockmarks, mound structures (carbonate build-ups, diapirs or mud volcanoes), and amplitude anomalies (gas accumulations). The presence of features associated with gas seepage at different stratigraphic levels, indicates different periods of fluid migration.

Mapping

When 3D seismic data is available, gas seepage features can be imaged by mapping the horizons showing such features and generate dip – or azimuth maps. Horizon amplitude or volume amplitude maps may be used to map possible gas accumulations.
To map chimneys, a method is available for detection of chimneys in 3D seismic data using neural networks (Heggland et al., 2000, Meldahl et al., 2001). This method has successfully been applied in different areas to reveal vertical hydrocarbon migration pathways (Aminzadeh et al., 2001 and 2002). The output is named chimney cube, see Figure 1.

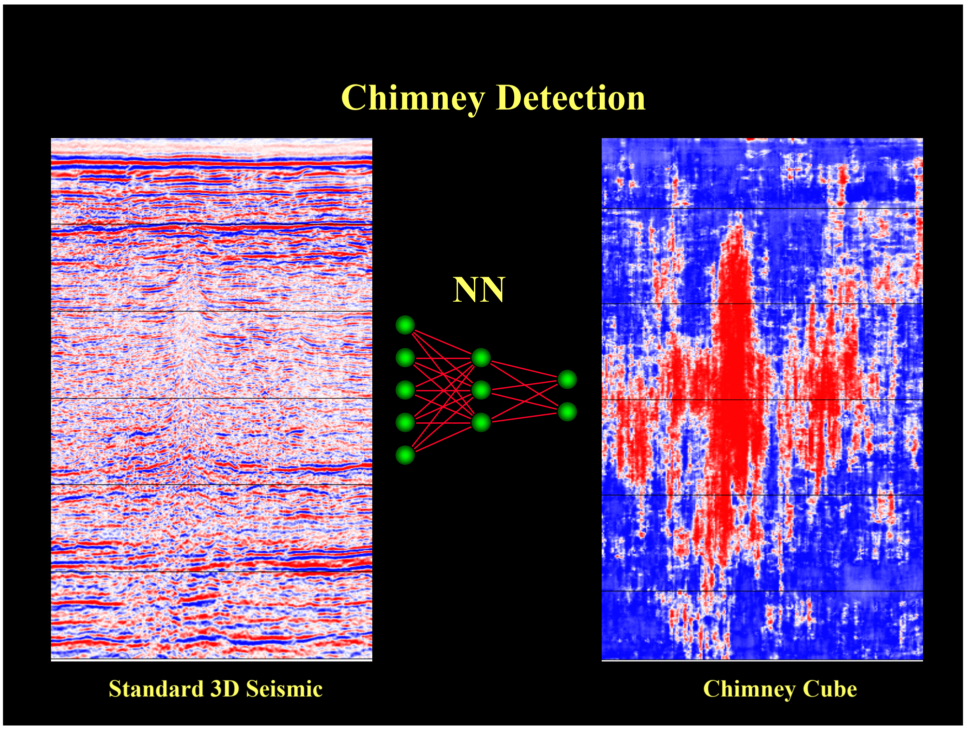

Figure 1. 3D seismic section before (left) and after chimney detection (right).

Case histories

Mapping of fluid flow indicators may help to distinguish between charged and dry reservoirs. Many examples show a higher density of chimneys and high amplitude anomalies in the vicinity of hydrocarbon charged reservoirs than in the surrounding area. In some cases they form a halo around the reservoir. Chimneys and high amplitude anomalies are frequently

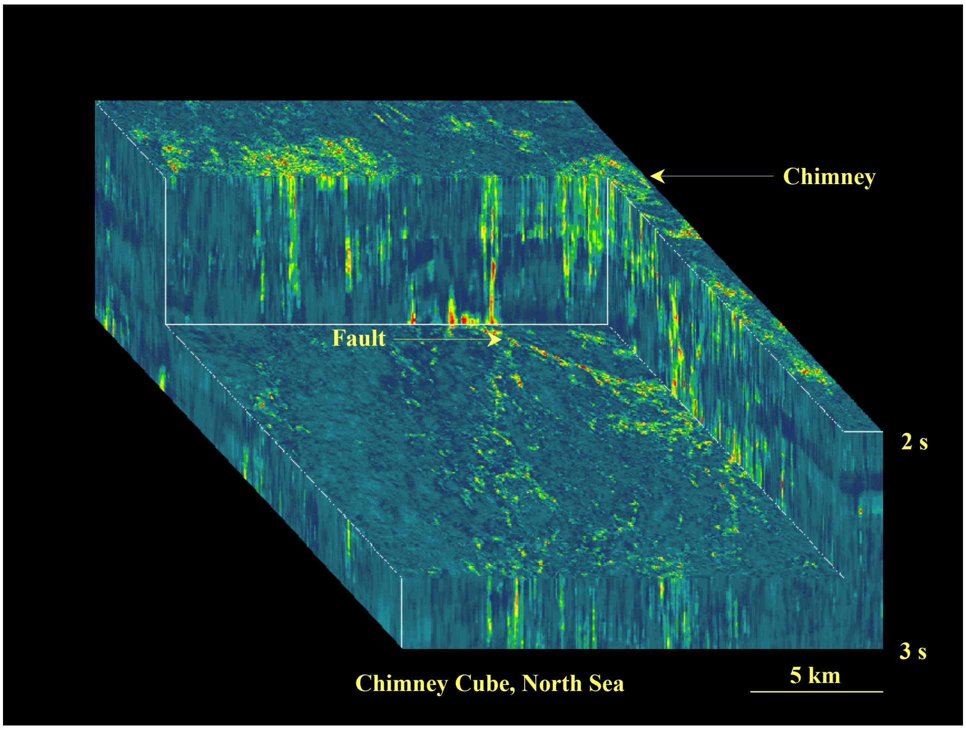

Figure 2. Chimney cube showing chimneys connected to faults.

observed to be located along faults, and in many cases they can indicate which reservoirs that are likely to have been charged, or which ones that have the highest risk of being dry due to lack of hydrocarbon charge or due to leakage (seal failure). The chimney detection method may also pick up steep faults, showing the relationship between chimneys and faults in the same cube, see Figure 2.

Nigerian continental slope

3D data from the Nigerian continental slope show several indications on fluid migration through faults. Figure 3 shows an azimuth map of the 3D seabed reflector. The water depth varies from approx. 300 m in the NE to 800 m in the SW. Pockmarks are visible along seabed fault lines indicating fluid flow through the faults. Mud volcanoes also seem to be associated with the faults. Rapid sedimentation and slumping of unconsolidated sediments along with high gas content in the sediments is believed to have caused the generation of the mud volcanoes. See also Damuth, 1994, Cohen and McClay, 1996, and Graue, 2000.

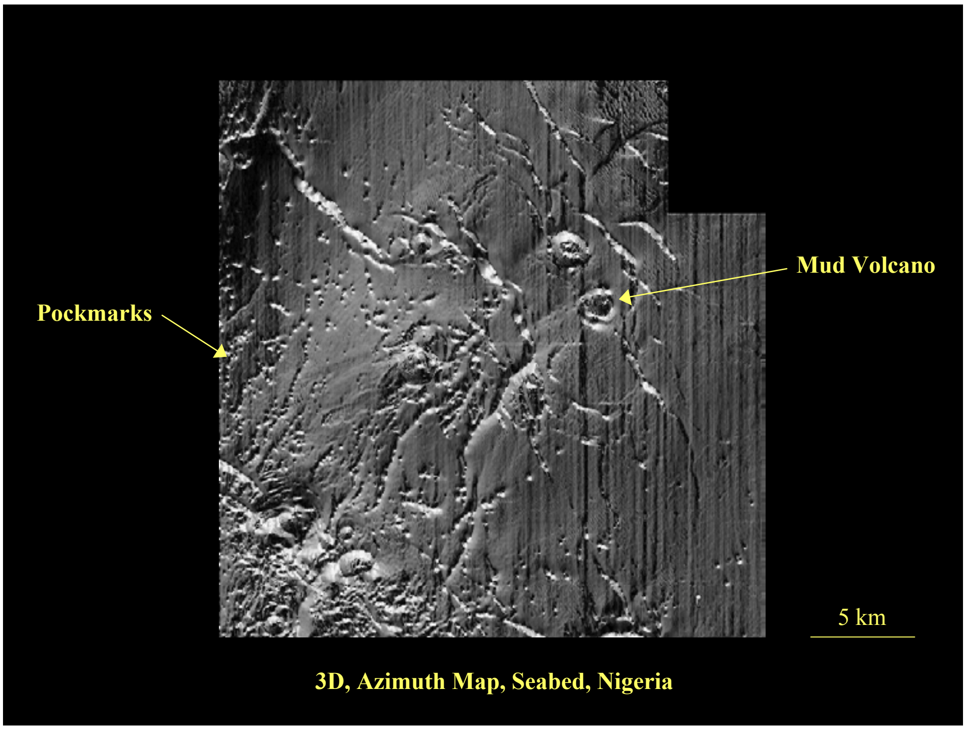

Figure 3. Azimuth map of the 3D seabed reflector showing faults, pockmarks and mud volcanoes.

High amplitude anomalies located at faults indicate gas charge of sands through the faults. Figure 4 shows a possible gas charged sand which has been segmented by two faults. The volume amplitude map on the right covers a time interval large enough to include the three high amplitude reflectors present in the seismic section on the left.
(From Heggland and Nygaard, 1998).

During a site survey in this area, seabed samples were taken. Samples taken at fault locations showed contents of methane. Samples taken at the mud volcanoes showed contents of methane and heavier hydrocarbons, and samples taken at the undisturbed seabed showed no contents of hydrocarbons. In another part of the Nigerian continental slope, similar fluid flow features have been observed. In one sample from a mud volcanoe in that area, a piece of gas

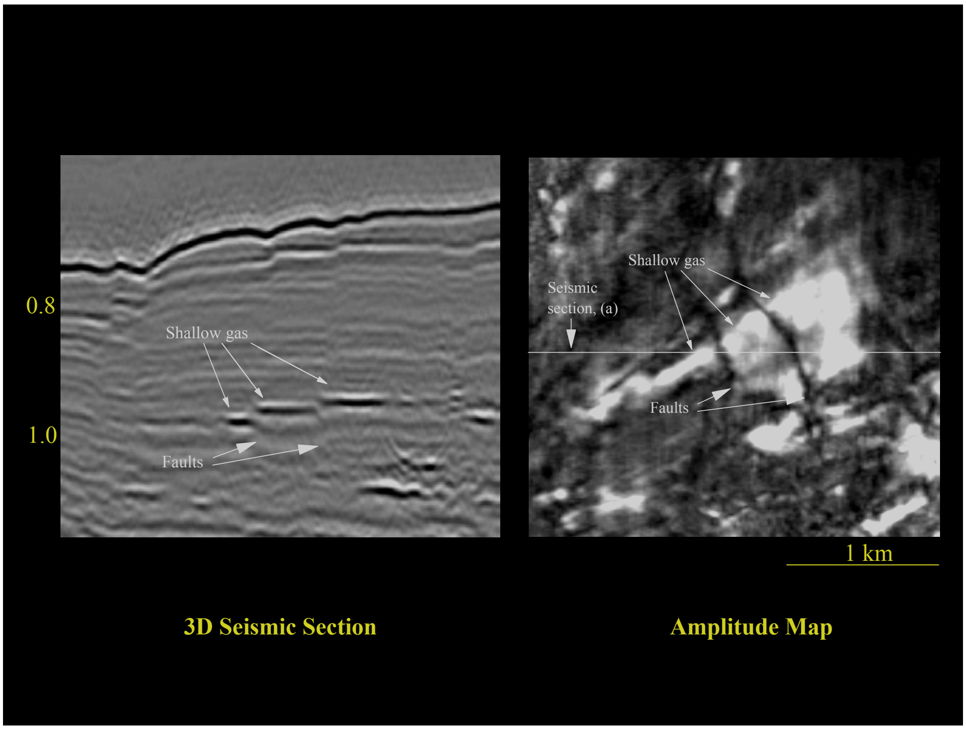

Figure 4. Possible sand segmented by faults. The sand is believed to be charged by gas migrating up the faults.

hydrates was present. Presence of gas hydrates in deep water Nigeria has been described by Hovland and Gallagher, 1994.

Conclusions

Seismic indications of fluid flow through faults show the most likely vertical hydrocarbon migration pathways. A complete mapping showing the spacial distribution of these pathways in relation to possible sources and prospects, may indicate whether the prospects have the potential to be charged or not.

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