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Seismic Characteristics of Gas Migration Structures on the North Atlantic Margin Imaged by High-resolution 3D Seismic

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SUMMARY

Dedicated Fluids and Fluid Flow.
We have acquired high-resolution P-Cable 3D data on five sites in the North Atlantic revealing a variety of different fluid migration characteristics. Both the Vestnesa and Nyegga areas offshore Svalbard and mid-Norway are characterized by pockmarks and vertical pipe structures. Gas hydrates are present in these areas and a layer of free gas is trapped beneath the gas hydrate stability zone. Kilometer-sized mud volcanoes have been imaged in the Gulf of Cadiz (Mercator Mud Volcano) and on the western Barents Sea margin (Haakon Mosby Mud Volcano) showing a circular crater with chaotic infill surrounded by inward dipping reflections. The Barents Sea contains large accumulations of shallow gas. We have acquired data from two sites were shallow gas and gas hydrates are interpreted. However, no vertical pipe structures are identified in the imaged regions. The surveys show that high-resolution 3D seismic data are very useful for mapping shallow gas and gas hydrates, for increased offshore safety, and for understanding of fluid flow processes.

Introduction

As deep sediments containing organic matter heats up, methane gas is produced and pore pressure increases. Sufficient pressure build-up can cause fracturing of the sediments and gas will migrate towards the surface in these fracture structures. Methane gas might also migrate towards the surface through existing cracks and pores in the sediments. With the right geological conditions gas will accumulate in pockets closer to the seafloor. In deep marine areas with the right pressure and temperature conditions, methane gas often accumulate in the shallow sediments as gas hydrates. Hydrate filled sediments often have low permeability so free gas is commonly trapped beneath the gas hydrate stability zone (GHSZ).

Methane gas is constantly migrating to the seafloor and out in the water column. Pathways for this gas can be seen on the seafloor as pockmarks or mud volcanoes. Pockmarks are the seafloor termination of vertical cylindrical fracture structures caused by pressurized gas escaping to the seafloor. These pockmarks are often signs of prior gas migration events but some are still active. Mud volcanoes are found both on and offshore. They normally erupt periodically, but often large quantities of hydrocarbons are released between the eruptions as well.

Shallow gas and gas hydrates are potential hazards for the petroleum industry. Blowout accidents caused by drilling in shallow gas pockets or ground failure due to melting gas hydrates are often worst-case scenarios that are crucial to avoid. In some cases shallow gas and gas hydrates are also seen as a potential resource. Several countries are investigating the possibility to exploit both gas hydrates and shallow gas, and also the possibility to store CO_2 in shallow reservoirs.

Both to reduce potential shallow gas and gas hydrates drilling hazards, and to increase the possibility to be able to exploit these potential resources, a good understanding of the gas migration processes is needed. We have acquired high-resolution 3D seismic data on five sites in the North Atlantic with both migration structures such as pockmarks and mud volcanoes and sites with gas hydrates and shallow gas (Figure 1). The high-resolution 3D seismic data are acquired using the P-Cable system in water depths ranging from 300 to 1300 meters.

Data and Method

The P-Cable system provide 3D seismic data ideal for imaging of shallow gas, gas hydrates and gas migration structures. The data resolution far exceeds that of conventional 3D data and is comparable with high-resolution 2D data with the added benefit of three-dimensional structural control. The system consists of a seismic cable towed perpendicular to a vessels streaming direction (Figure 2). This cable contains communication control units and navigation hardware and is the key component in the P-Cable system. In a normal configuration 8 to 24 streamers with 6.25 to 12.5 meters spacing are attached to this cable. The P-Cable development started in 2001 by Volcanic Basin Petroleum Research and National Oceanography Center in Southampton in collaboration with University of Tromsø. The current generation of the P-Cable system is developed by P-Cable 3D Seismic AS and Geometrics Inc. (see www.geometrics.com/p-cable).

P-Cable data from Haakon Mosby Mud Volcano (HMMV), Nyegga, Vestnesa, and the Barents Sea were acquired in collaboration with the University of Tromsø on their vessel M/V Jan Mayen in 2005, 2007, 2008, 2009 and 2010. The P-Cable data from the Mercator Mud Volcano were acquired in collaboration with National Oceanography Centre in Southampton in 2006.

Results

Pockmarks and vertical pipe structures are clear evidence of events where gas has migrated to the seafloor. Gas hydrates are often present in areas where these migration structures are found. A layer of gas hydrates reduces the permeability of the sediments causing pressure build up underneath the GHSZ. Both the Nyegga and Vestnesa area has a large density of pockmarks and vertical pipe structures (Figure 3). In both areas gas hydrates are present and there is a strong bottom-simulating reflector indicating free gas trapped underneath the hydrate layer (Bünz et al., 2003; Petersen et al., 2010). The Nyegga area is located at 600 to 1200 meter water depth on the northern flank of the Storegga slide. The pipe structures in the area provide evidence for three episodes of gas migration to the seafloor (Plaza-Faverola et al., 2011). During the intensive surveying no gas flares have been observed in the area indicating subdued gas seepage compared to previous episodes. The Vestnesa area is located at 1300 meter water depth west of Svalbard. Gas flares are observed on echo sounder data near the survey area indicating that some of the migration structures are still active.

In some areas migrating gas accumulate in the shallow sediments. In both of the two survey areas in the west Barents Sea, large accumulations of shallow gas are mapped. The seafloor in both areas is characterized by up to 15 meter deep iceberg plough marks formed during the Plio-/Pleistocene ice age. A major regional unconformity, URU, separates the glacial sediments from the underlying dipping Tertiary sediments. There are minor gas hydrates in the area.

Mud volcanoes are sites of rapid but possibly intermittent fluid and methane flow to the seafloor. In the North Atlantic Ocean they are mostly found in the Gulf of Cadiz region. The Mercator Mud Volcano (MMV) is located west of the Gibraltar Strait. The 3D seismic data indicate that the MMV is situated on an anticline that has been uplifted for a prolonged period of time (Figure 4). The location of the Haakon Mosby Mud Volcano (HMMV) at 1250 meter water depth on the continental slope west in the Barents Sea is more unusual. It is located within a 300,000-year-old slide on the Bear Island Fan. Methane is leaking from the crater and a 300 meter wide and up to 600 meter high gas flare is seen on echo sounder data.

Conclusion

The P-Cable system has proven to be a very useful tool for imaging of gas migration features. Vertical pipe structures in the Nyegga and Vestnesa areas are imaged in very high detail giving useful information on gas migration in these areas. Data from the MMV and HMMV has provided useful information on both the internal and external structure of mud volcanoes. The seismic data indicate that the MMV is situated on an anticline that has been uplifted for a prolonged period of time. Data from the HMMV shows that the sediment layers surrounding the volcano is deformed and are dipping towards the central pipe. P-Cable data has been acquired in the Barents Sea where large accumulations of shallow gas are present. Detailed maps of this gas are interpreted from the seismic data.

Acknowledgement

The Vestnesa, Barents Sea and Nyegga data were acquired by the University of Tromsø with support from the GANS project. The Barents Sea survey received additional support from Lundin Petroleum. The MMV and HMMV surveys were supported by the HERMES project and acquired by National Oceanography Centre in Southampton and University of Tromsø respectively. The P-Cable technology is patented (Planke and Berndt, 2003).

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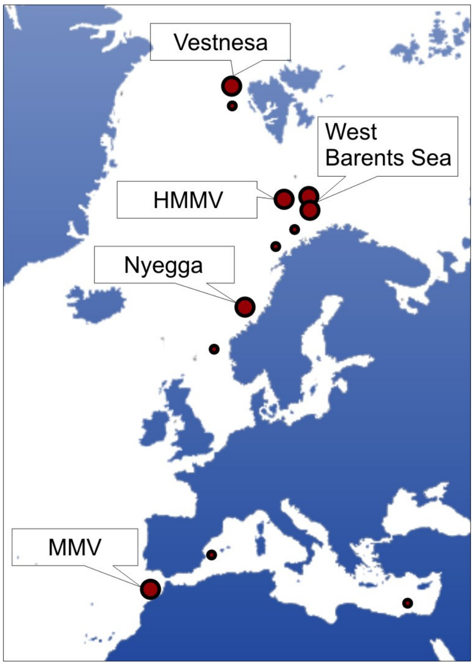

Figure 1 *High-resolution 3D seismic survey areas in the North Atlantic Ocean.*

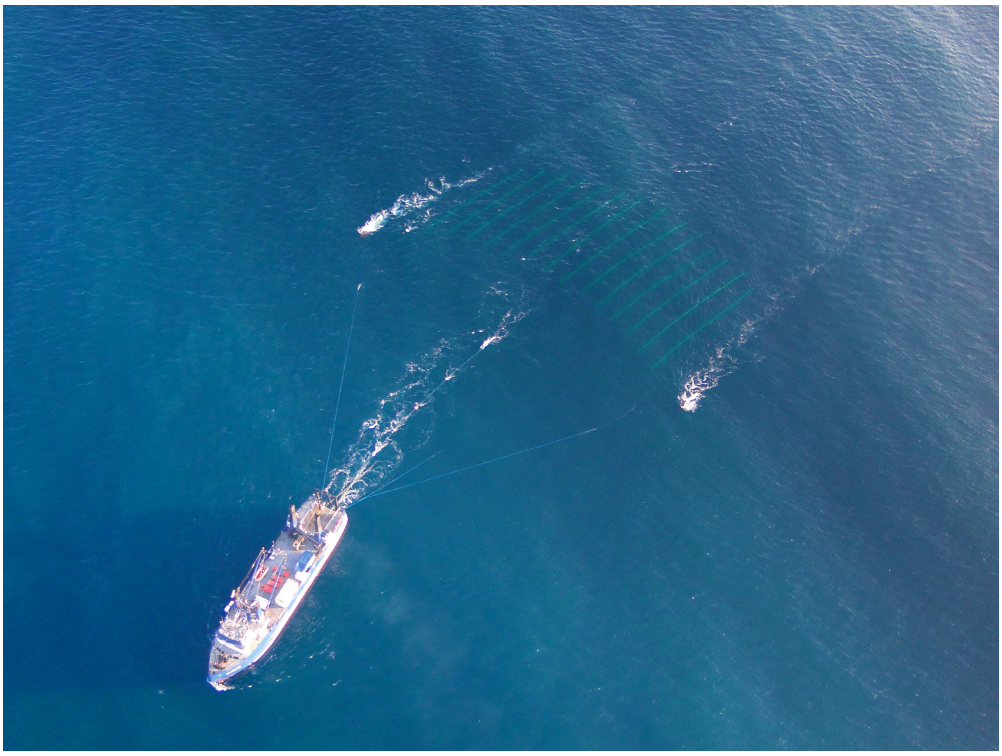

Figure 2 *P-Cable acquisition offshore California. 14 streamer system, 50 meter long streamers with 6.25 meters spacing.*

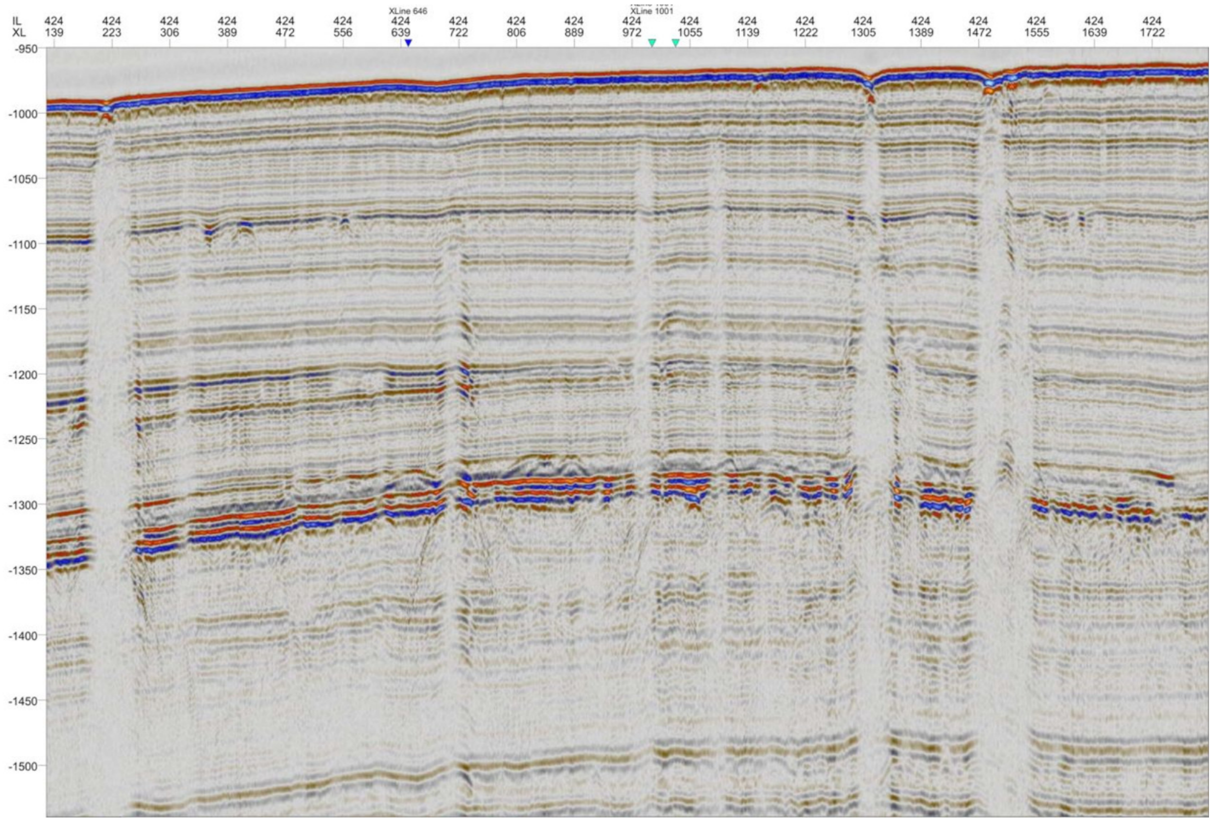

Figure 3 *Vertical pipe structures and pockmarks from the Nyegga area on the northern flank of the Storegga slide. High amplitude reflections at 1.2 s represent free gas beneath a gas hydrate layer.*

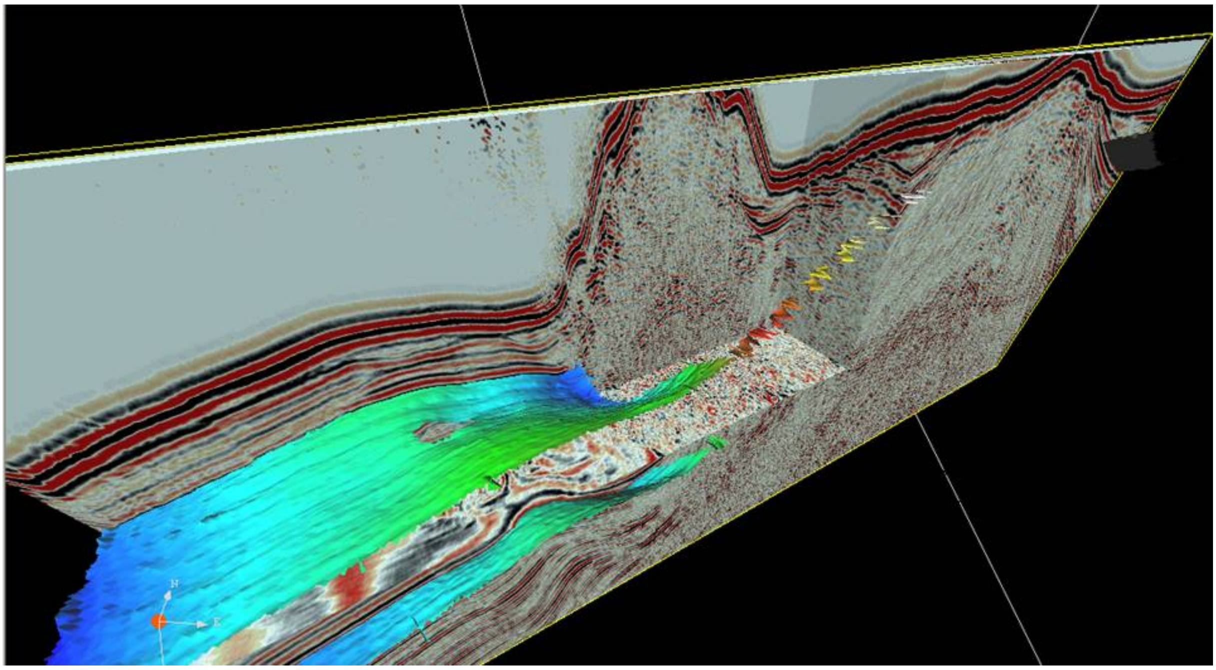

Figure 4 *P-Cable data showing the structure of the Mercator Mud Volcano.*