Detection and mechanisms

Natural gas migration to the near-surface environment as an analogue to potential leakage of CO$_2$

In most of the world’s hydrocarbon basins some migration of natural gas to the surface can be observed. This naturally occurring migration and seepage of gas through the subsurface to the near-surface environment can be considered as a natural analogue to the potential leakage of CO$_2$ from future subsurface storage sites. Although the chemical composition of natural gas (mainly consisting of CH$_4$) differs from CO$_2$, the physical behaviour is similar. Gas accumulated in or moving through the shallow subsurface can be detected with geophysical monitoring techniques. In seismic and acoustic datasets the presence of gas may result in a variety of expressions.

The interpretation of such expressions, or geophysical anomalies, as features related to gas can be confirmed by the examination of geochemical anomalies. In order to study the applicability of offshore geochemical monitoring techniques a number of obvious seismic and acoustic anomalies were selected for seabed sediment sampling and subsequent chemical analysis of the gas contained by the sediments. TNO and Statoil collaborated in this research project in the scope of the EC supported NASCENT project. These results were presented at the GHGT-7 Conference in Vancouver.

Nigerian continental slope

3D seismic data from the Nigerian continental slope show indications of fluid flow to the seabed through faults. Amplitude anomalies, indicating shallow gas accumulations, are concentrated around faults. Figure 1 shows a seabed azimuth map from 3D seismic data. Pockmarks (seafloor craters resulting from venting of gas or fluids) and mud volcanoes can be seen along faults. Seabed samples taken at the location of some faults and mud volcanoes proved to contain hydrocarbons, thus confirming seepage all the way to the seabed.

Norwegian North Sea

Through the use of 3D seismic data, various seismic attributes have been applied to map features associated with gas escape, like pockmarks, amplitude anomalies, mud volcanoes and carbonate build-ups. Observations of such features at different (but not all) subsurface horizons, indicate that gas escape through the seabed takes place during limited periods in geologic time. A method developed recently (using neural network-based software) to detect gas chimneys has been applied to different 3D data volumes from the Norwegian North Sea (Figure 2, 3 and 4). The results show that many chimneys are located at faults and fractures and, as such, indicate faults that are, or have been, working as fluid migration pathways. Faults can let through large amounts of fluids in short periods. Some chimneys do not seem to be related to faults. Such chimneys are believed to represent a much slower fluid migration process.

Figure 1  Azimuth map of the seafloor reflector from 3D seismic data showing the presence of pockmarks on the seabed, often aligned along fault lines (Nigerian continental slope). The pockmarks are probably caused by gas escape through the faults. Courtesy Statoil
In the Netherlands part of the Southern North Sea a variety of seismic and acoustic anomalies assumed to be related to the occurrence of shallow gas were observed. Some of these features were selected for a marine sampling campaign in the summer of 2002.

**Pockmarks**

A good example of a seafloor pockmark was found in the Dutch licence block A11. Figure 5 shows a multi-beam echo image of the seafloor that clearly indicates the crater-like depression. Maximum depth of the crater is about 2 m. Six shallow sediment cores were collected in 2002 (core lengths are up to 3.4 m). The methane concentrations measured in the headspace gas of the sediment samples are plotted. The highest CH₄ concentration (122.6 ppm) is found in the core from the very centre of the feature. This value is significantly higher than background values. It is remarkable that the location of the anomaly almost coincides with that of a smaller ‘unit pockmark’. Unit pockmarks are smaller features just a few metres in diameter that occur within the larger feature. They probably represent the most recent sites of venting. At distances of only a few dozen metres from anomalies concentrations can be as low as background values.

**Active gas vents seen as plumes in the water column**

In the northernmost part of the Netherlands sector of the Southern North Sea a number of shallow Plio-Pleistocene gas fields were discovered in the 1980s by drilling clear bright spots (seismic anomalies). The gas field in licence blocks B10 & B13 is one example (Figure 6a). The field is obviously leaking hydrocarbons (almost pure methane) into the shallow subsurface and into the water column.
This can be observed on high frequency acoustic profiles such as the XStar profiles acquired by TNO in 2002 (Figure 6b). Gas plumes are visible in the water column. Methane concentrations as high as 10,395 ppm were found close to one of the gas vents and confirm the acoustic anomalies. The fact that close to the strongest acoustic anomaly the methane concentrations are as low as 39 ppm suggests that the lateral variation in concentrations and fluxes is high. A standard 2D seismic profile (from 1987) running across the field (Figure 6c) shows the leaking gas reservoir as a bright spots and also shows shallow enhanced reflectors in the shallowest sediments over the field. The gas saturation in this shallow realm is not laterally continuous. The central patch of shallow enhanced reflectors coincides with the location of the strongest plume of Figure 6b.

Seismic chimneys

Figures 7 and 8 represent two seismic profiles from Dutch licence block F3, again both show gas accumulations at Plio-Pleistocene levels as bright spots. Like B13, block F3 is also leaking from its Plio-Pleistocene gas sands. But this time the expression on 3D seismic data is that of a gas chimney (Figure 7). The chimney is immediately adjacent to a fault, which may have provided a migration pathway for the gas. Methane concentrations in the sediment samples were only slightly elevated. Figure 8 shows a leaking fault system. At various levels where the faults intersect with highly porous layers gas is (temporarily?) trapped as small gas pockets, visible on the seismic data as small bright spots. Also visible on this profile is another bright spot that is not associated with any expressions of leakage.

Figure 6a Plio-Pleistocene gas field in licence blocks B10 and B13. The locations are shown of three exploration wells, four Xstar high frequency acoustic profiles (orange lines), gas plumes observed on those profiles (red circles), five vibrocores (blue triangles) with the CH\textsubscript{4} concentrations in the headspace gas annotated and a 13 km portion of a seismic profile across the field (green line)

Figure 6b About 2 km long portion of the E-W running high resolution XStar profile across two of the core sites. Penetration depth of this high frequency data is about 12 m. Gas plumes in the water column are clearly visible

Figure 5 Multi-beam echo image of the seafloor showing a seafloor pockmark associated with gas venting. Methane concentrations in seabed sediment samples are highest in the centre of the pockmark

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Figure 5 Multi-beam echo image of the seafloor showing a seafloor pockmark associated with gas venting. Methane concentrations in seabed sediment samples are highest in the centre of the pockmark
Conclusions

Migration of natural gas to the near-surface environment can have different expressions on seismic and acoustic data, depending on both local circumstances and types of surveys and data. Migration and leakage can be detected or monitored using the right geophysical and geochemical techniques. It is always advisable to verify the interpretations of geophysical anomalies using geochemical monitoring. Preferential migration and leakage through faults and fractures is found to be a widespread mechanism.

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Figure 6c  About 13 km long portion of 2D seismic profile SNST87-03 from 1987 showing the bright spot corresponding to the gas reservoir and patches of shallow enhanced reflectors in the shallowest sediments visible, indicating gas saturation. The red arrow indicates the location of the strongest gas plume anomaly observed on the XStar profile.

Figure 7  A shallow gas chimney visible on 3D seismic data as a seismic anomaly with higher amplitudes and lower reflector continuity in comparison to the surrounding sediments. The chimney is an expression of methane leakage from underlying Plio-Pleistocene gas sands.

Figure 8  A fault system that appears to be leaking. Bright spots indicate small gas pockets along the faults wherever the faults intersect with highly porous layers.

CO₂ Storage

TNO Built Environment and Geosciences
Geological Survey of the Netherlands is the central geoscience centre in the Netherlands for information and research to promote the sustainable management and use of the subsurface and its natural resources.

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