Shallow Gas Offshore Netherlands

The Role of Faulting and Implications for CO_2 Storage

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1. Background

Shallow gas within Pliocene–Pleistocene aged deposits in the North Sea has been well documented (Figure 1.1). Gas largely accumulates in structural traps above salt domes. Such traps are often cut by faults, formed by extensional stresses in the rocks above the upwelling Zechstein Group evaporites. Many shallow gas accumulations are coincident with these faults, leading to speculation that faults have acted as conduits for upward hydrocarbon migration from depth. The source of the gas remains a topic of debate, with indications suggesting both shallow biogenic and deeper thermogenic sources.

Here we assess the nature of several fault-associated shallow gas accumulations in the Netherlands sector of the North Sea, in order to investigate the role that faulting may have played in the migration of thermogenic hydrocarbons from depth. The results are used to discuss the implications for storing carbon dioxide elsewhere in the North Sea. Study of faults showing evidence for fluid leakage is useful while appraising potential storage sites for which fluid dynamic data is unavailable.

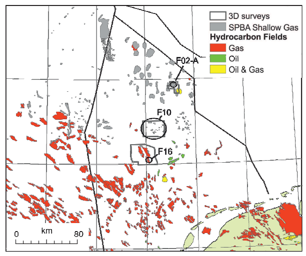


Figure 1.1. Location of hydrocarbon fields and shallow gas accumulations in the Southern North Sea.

2. Methodology

Shallow gas is imaged on seismic reflection data as high amplitude anomalies (Figure 2.1). 3D seismic over three areas of the Dutch offshore have been obtained in order to map the shallow gas accumulations and their associations to underlying hydrocarbon fields, gas-prone source rocks and potential migration pathways such as faults. Commonality in the history and geometry of the interpreted faults can provide an empirical indication of certain characteristics that should be considered carefully while assessing fault-risk for storage activities in the North Sea.

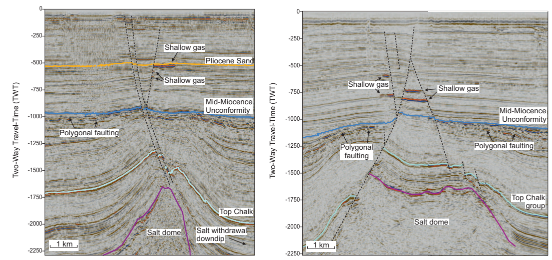


Figure 2.1. Seismic cross-sections showing seismic anomalies associated with faulting above salt domes.

3. Case studies

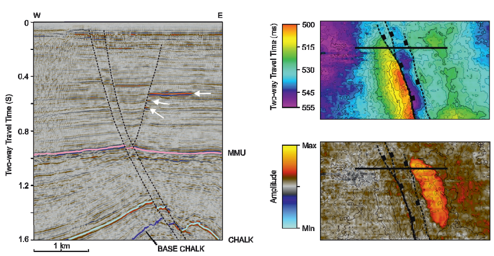


Figure 3.1. Seismic reflection section showing the nature of the shallow gas accumulations in Block F16 (white arrows), depth map (TWT) and amplitude map of the uppermost (largest) gas-bearing horizon.

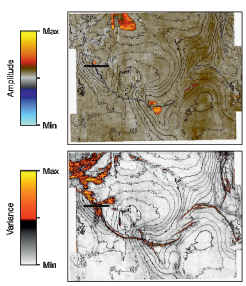
Two case studies occur in areas where Carboniferous source rocks are located, and are adjacent to salt withdrawal areas where thicknesses of the Zechstein Group evaporites are vastly reduced or absent.

The shallow gas accumulations in Block F16 (Figure 3.1) overlie the F16-P gas field (Rotliegend). An extensional fault system above an upwelling salt structure controls the extent of the shallow gas. Three separate layers within the Upper North Sea Group are saturated with observable volumes of gas, with amplitude anomalies abutting the footwall block of a fault antithetic to the main fault. The subtle TWT structure does not appear to be completely filled, and the footwall block of the main fault, in which a prominent closure exists is devoid of amplitude increase.

Several anomalies are observed at various horizons within the Upper North Sea Group in Block F10 (Figure 3.2). Many of these seem to be associated with an anastomising fault system bounding a mini-basin to the north, developed as a result of salt movement. Nearby fields include Carboniferous, Rotliegend and Jurassic (oil-prone) reservoirs, suggesting that both Carboniferous and Jurassic source rocks exist in the area. Amplitude anomalies and gas clouds associated with the faults suggests the role of faulting as migration conduits. Some of the gas accumulations occur in the vicinity of fault intersections and relay ramps.

The faults in both cases dip at angles close to 60° above the Mid-Miocene Unconformity (MMU), implying that they would be optimally oriented for failure if normal-faulting stress conditions prevail. Fault dip angles are shallower beneath the MMU.

Figure 3.2. Seismic amplitude and variance maps over selected gas-bearing horizon in Block F10, highlighting faults, bright spots and disrupted seismic signal indicative of gas clouds.



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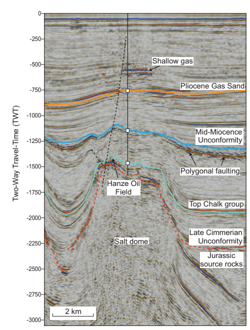
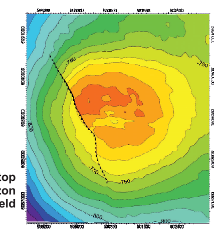


The F02-A Pliocene gas field overlies the Cretaceous Hanze oil field, where oil is sourced from the Jurassic Posidonia Shale. Both the shallow gas and deeper oil accumulation are productive. They are linked by a single fault (Figures 3.3 & 3.4). A number of smaller stacked amplitude anomalies are also seen in younger sediments above the Pliocene gas field.

Figure 3.3. Seismic section over F02-A and Hanze fields showing relationship between shallow gas, faulting and deeper thermogenic hydrocarbons

Figure 3.4. Depth map to top of Pliocene gas sand horizon F02-A field



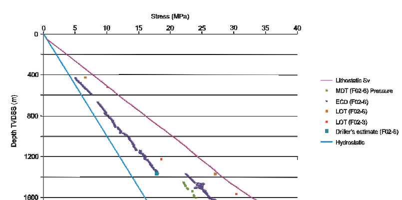


Figure 3.5. Pressure and stress profiles F02-A gas field. Overpressures of >7 MPa exist below the MMU.

Characterisation of the stress field using available well data (Figure 3.5) supports the notion that normal stress or strike-slip stress conditions prevail and that the fault may be close to being critically-stressed due to the orientation of the fault and the presence of overpressure beneath the MMU. The co-location of a critically-stressed fault and shallow gas above deeper hydrocarbon accumulations and source rocks imply that the fault could have provided a conduit for gas from depth.

4. Conclusions

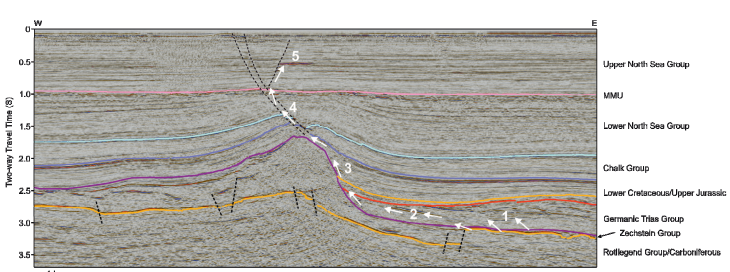


Figure 4.1. Example of potential migration pathway for thermogenic gas. 1) Gas migrates from Carboniferous via Rotliegend to Germanic Trias Group. 2) Up-dip migration towards salt dome/diapir. 3) Vertical migration along deformed strata at salt-dome edge. 4) Migration to Cenozoic via fault networks. 5) Accumulation in unconsolidated sandstone reservoirs. Note a lack of gas accumulation to the west of the faults.

Observations from seismic reflection data suggest that hydrocarbons are leaking from depth via fault networks above salt domes. Evidence suggests that the fault linking the F02-A gas field with the deeper Hanze Oil field may be critically-stressed, and might have provided the mechanism by which the F02-A structure was charged. Further evidence that the fault network is conductive to fluids include published observations of mixed biogenic and degraded thermogenic gases in seabed sediments overlying a nearby Jurassic gas condensate field.

Reduction of the effective stress due to overpressure would result in a higher probability of slip below the MMU. The top of the overpressured zone appears to coincide with a zone of intensely deformed strata affected by polygonal faulting directly beneath the unconformity. Above the MMU where normal hydrostatic pressures prevail, the fault dip of 60° is consistent with optimally oriented faults for slip in a normal faulting stress regime.

As illustrated in Figure 4.1, the faults studied may form part of migration pathways for hydrocarbons from depth, as the shallow gas accumulations overly areas where the Zechstein group is considerably thinned due to salt withdrawal, or as in the case of the F02-A field, directly overlie hydrocarbon accumulations and source rocks.

Despite the ongoing debate over the source of shallow gas offshore Netherlands, the observation that critically-stressed faults over salt domes exhibiting evidence for relatively recent movement occur coincidently with accumulations of shallow gas is important in terms of characterising risks associated with storage of supercritical CO_2 in the subsurface. The case studies identified here could prove useful in providing analogues for sites where injected CO_2 is expected to encounter similar faults cutting the reservoir and caprock, or as an indication of likely conduits towards the shallow subsurface in the event of site integrity failure.

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