Shallow Gas Offshore Netherlands
The Role of Faulting and Implications for CO2 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 Zachterikum Group evaporites. Many shallow gas accumulations are coincident with these faults, suggesting that faults have acted as conduits for upward hydrocarbon migration from depth. The source of the gas remains a topic of debate, with suggestions ranging from thermogenic to bacterial, 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 assessing potential storage areas for which fluid dynamic data is unavailable.

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. Commonly in the history and geometry of the interpreted faults can provide an empirical indication of certain characteristics that should be considered carefully when assessing fault risk for storage activities in the North Sea.

3. Case studies

Two case studies occur in areas where Carboniferous source rocks are exposed, and are adjacent to salt withdrawal areas where thicknesses of the Zachterikum 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 bracketed 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 extensional fault system bordering a mini-basin to the west and defining its southern boundary. Additional evidence points to a potential connection between shallow gas accumulations and Carboniferous, Rotliegend and Jurassic (oil-prone) reservoirs, suggesting that both Carboniferous and Jurassic source rocks exist within the area. Amplitude anomalies and gas clouds associated with the faults suggest 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.

4. Conclusions

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 indication was seen. Other evidence that the fault network identified to fluids include published observations of mixed biogenic and degraded thermogenic gases in watered sediments overlying a nearby Jurassic gas condensed 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 internally deformed shales 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 occur over areas where the Zachterikum Group is considered thinned due to salt withdrawal, or as in the case of the F02-A field, directly overlying hydrocarbon accumulations and source rocks.

During the ongoing debates over the source of shallow gas offshore Netherlands, the observation that critically-stressed faults over salt domes providing evidence for relatively recent movement occurs coincident with accumulations of shallow gas is intriguing, and could form part of a larger picture of the migration and storage of carbon dioxide from depth. Understanding these stress cycles identified here could prove useful in providing analogues for sites where injected CO2 is expected to encounter similar faults. The fault network identified in the F02-A field might act as conduits towards the shallow subsurface in the event of site integrity failure.

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

Figure 3.1. Seismic reflection section showing the nature of the shallow gas accumulations in Block F16 (white arrows). Two-Way Travel-Time (TWT) and amplitude maps of the uppermost largest gas-bearing horizon.

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.

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 shallow gas and horizon F02-A field.

Figure 3.5. Pressure and stress profiles F02-A gas field. Overpressures of 17 MPa exist below the MMU.

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