Reservoir geology of the Utsira Sand in the southern Viking Graben area - a site for potential CO2 storage.

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Summary

Since October 1996 Statoil has started to inject CO_2 coming from the Sleipner Vest Field in the southern Viking Graben area into a saline aquifer at a depth of approximately 900 m. This is the first case of industrial scale CO_2 storage in the world (1 million tons per year). Careful monitoring of the behavior of the storage facility is hence required. To this end different time-lapse seismic surveys have been planned (presented in a companion paper: Brevik et al., this volume). In this paper the interpretation of the base survey acquired before injection is presented. The most likely pathways for CO_2 migration in the vicinity of the injection point have been indicated.

Introduction

The existing 3D seismic survey over the Sleipner field provided important insights into the local geology in the area immediately surrounding the injection site. Four key reflectors based on well logs have been interpreted, namely Top Pliocene Prograding unit, Intra-Pliocene Prograding Unit, Top Utsira Sand and Base Utsira Sand. These have also been picked on a more regional stratigraphical study of the reservoir (presented in a companion paper: Gregersen et al., this volume). The 3-D survey covers an area of approximately 24 x 33 km, calibrated by 11 (near) vertical exploration wells and 6 production wells. The correlation of the logs with the seismic data has been established through synthetic seismograms.

The Utsira sands

The Utsira Sand is of Miocene-Lower Pliocene age with a varying thickness around 200 m. Mounds at the base of the Utsira Sand were mapped and were interpreted as due to mud volcanism and mud diapirism that was active during deposition of the lower part of the Utsira Sand. The presence of these shale mounds induced compaction and subsidence anomalies, which led to depressions of the Utsira Sand and overlying units above the mud volcanoes. This can be observed in Figure 1. These depressions constitute local modifications of the general southward dip of the top Utsira Sand, including local domal and anticlinal structures, which probably act as traps and/or channels during CO_2 flow. A map view of the mud volcanoes in the area is shown in Figure 2.

Above the top of the Utsira Sand, separated by a ca. 5 m thick shale unit, occurs a westward thinning sand wedge whose areal distribution has been mapped. It is present above the injection site and disappears ca. 4.5 km west of it. Within the Utsira Sand, several (up to 14) thin (<1m) shale layers have been identified. Both the sand wedge and the intra-Utsira shale layers are expected to influence migration of CO_2.

The seal of the Utsira sands

The Pliocene shales of the cap rock can be subdivided into 2 units. The lower one, directly overlying the Utsira Sand includes at its base a shale drape that can be distinguished on a regional scale. This lower unit exhibits locally anomalously high amplitudes. The upper Pliocene prograding unit is characterized by irregular internal reflectors and frequently occurring very high amplitudes. The amplitude anomalies in these units might be due to isolated high-velocity lithologies, or alternatively to the presence of shallow gas.

Seismic attributes as indicators for shallow gas

Anomalously strong amplitudes occur occasionally within the lower part of the Pliocene shales and in the Utsira Sand and are abundant in the upper Pliocene shales (Figure 1). Most of the anomalies in the Utsira Sand were identified as probable artifacts (multiples), coinciding with the anomalies observed in the lower Pliocene. However, a small number of anomalies just below the Top Utsira as well as the anomalies in the Pliocene shales are considered to be real phenomena, which might be at least partially due to the presence of shallow gas. These anomalies seem in some cases to be linked to mud volcanoes by zones of weak amplitudes ('gas chimneys'). Many of the anomalies, however, can not be linked to features at the base of the Utsira Sand. By using interval attributes based on the amplitude of the seismic signal the occurrences of these anomalies have been successfully mapped.

Migration pathways of the CO_2

The time-depth conversion is a crucial point in the determination of the spill points of the different domal structures. For the 3D survey the time-depth conversion is based upon a velocity model derived from the (near-) vertical exploration wells. The relative error in depth at the Top Utsira Sand using this depth-conversion remains within 1.2 % (< 10 m).
The spill point of the dome above the injection site is difficult to determine, because two 'channels' leading away from the dome have nearly identical depth (Figure 3). CO_2 can thus migrate northward into a second dome, from where it can migrate westward into a large domal structure, or/and directly from the southern dome into this westward, large dome. This dome is then connected north-westward to a set of domal and anticlinal structures. Migration pathways through these structures and volume estimates have not yet been established.
Since the geometry of the intra-Utsira shale layers roughly follows the geometry of the top Utsira Sand (both being caused by differential compaction underneath), CO_2 should migrate underneath the shale layers towards the center of the dome defined by the top Utsira Sand, under which it is being injected. It is, thus, likely that it will reach the top Utsira Sand within that dome which will then be filled until its spill point. At this point we can not yet exclude migration of CO_2 into the sand wedge above the Utsira Sand.

Discussion and conclusions

Interpretation of the base survey has led to the most likely pathways for CO_2 migration in the vicinity of the injection point. The first time lapse seismic survey has been acquired in the second half of 1999. The results should provide answers to the so far speculative migration pathways. Important issues for further research using the monitoring results are the influence of the intra-shale layers within the Utsira Sand and the sealing efficacy of the overlying Pliocene shales.

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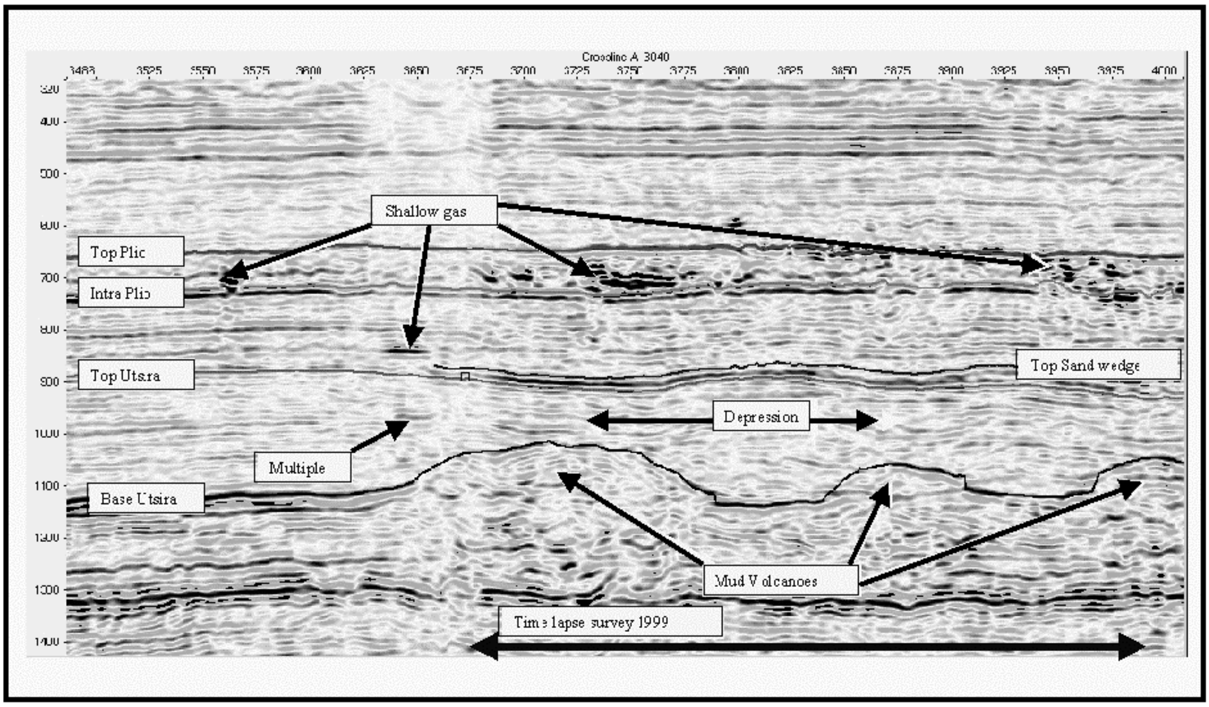

Figure 1: Crossline 3040 of the 3D survey. Note the mud volcanoes causing the depressions in the overlying Utsira Sand.

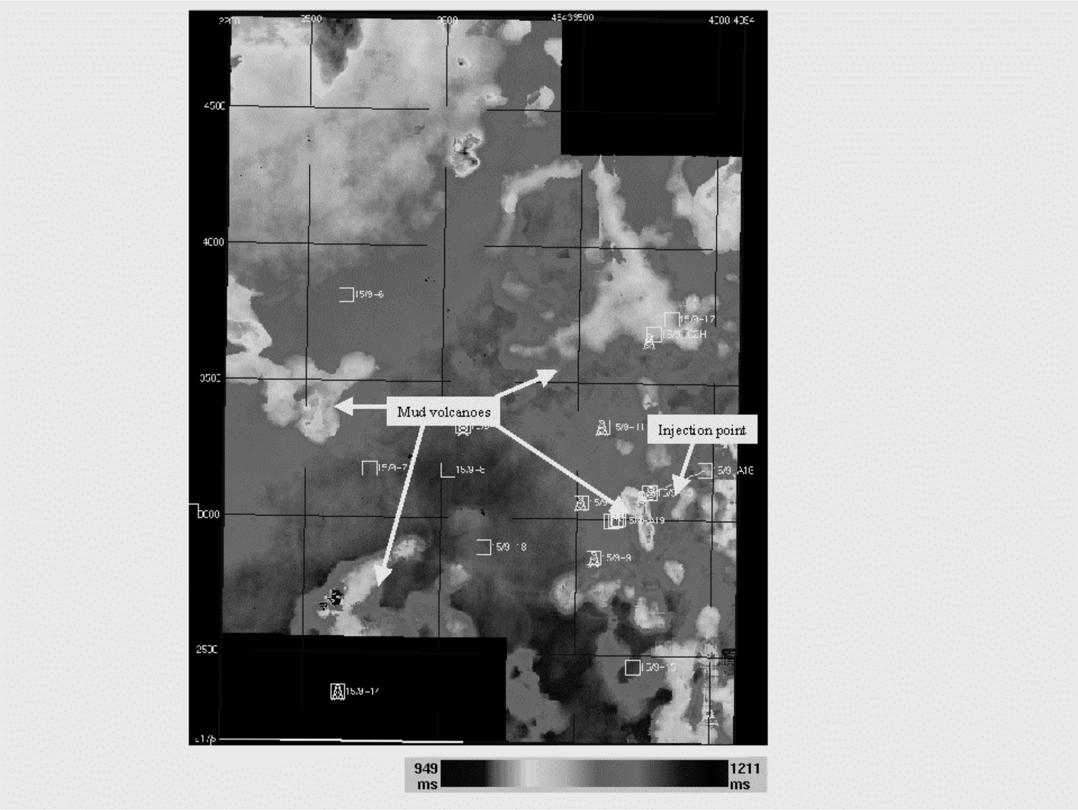

Figure 2: Map of the Base Utsira in TWT (ms) as covered by the 3D survey.

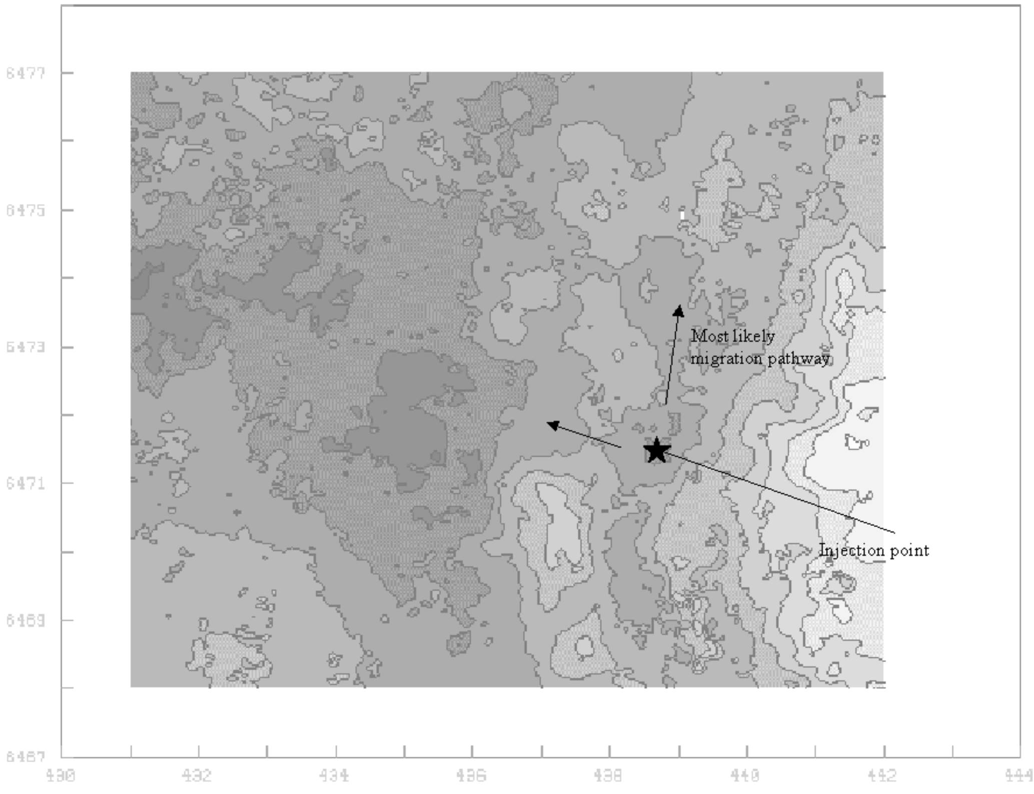

Figure 3: Depth map of the Top Utsira Sand around the injection point. The depths vary between 795 m (dark) and 900 m (light) with a contouring interval of 10 m.