THE UTSIRA SAND, CENTRAL NORTH SEA – AN ASSESSMENT OF ITS POTENTIAL FOR REGIONAL CO_2 DISPOSAL

R.A. CHADWICK[1], S. HOLLOWAY[1], G.A. KIRBY[1] , U. GREGERSEN[2], P.N. JOHANNESSEN[2]
[1] British Geological Survey (BGS) [2]Geological Survey of Denmark and Greenland (GEUS)

ABSTRACT
The Utsira Sand is a saline reservoir beneath the central and northern North Sea. With an area of more than 2.6×10^4 km^2, and an estimated pore volume of 5.5×10^{11} m^3, its regional extent renders it potentially suitable for large-scale, multi-site disposal of CO_2.

The reservoir sand comprises a basinally-restricted deposit of Mio-Pliocene age, lying within the thick Cenozoic post-rift succession of the North Sea Basin at depths between about 550 and 1500 m. It occupies two distinct depositional basins which are likely to be in poor hydraulic contact. Sleipner currently injects CO_2 into the southern depocentre, close to where the reservoir attains its greatest thickness of about 300m. The succession overlying the reservoir is rather variable, but principally comprises prograding sediment wedges of Pliocene age. These are dominantly shaly in the basin centre but tend to coarsen into a sandier facies both upwards and towards the basin margins. In the Sleipner area a shale drape forms the caprock to the reservoir, separating it from the overlying prograding wedges. The shale drape extends well beyond the area currently, or predicted to be occupied by the injected CO_2, and seems to be providing an effective seal at the present time.

For putative injection sites over much of the reservoir area, assuming a dominant gravity drive, the top reservoir topography would tend to favour CO_2 migration towards the UK sector, beneath a complex caprock of both basin-restricted and prograding shale-sand deposits. In the north and east of the northern depocentre however (more than 200 km north of Sleipner), the preferred migration direction would be to the east or northeast, towards Norway.

INTRODUCTION
CO_2 separated from natural gas produced from the Sleipner West field is being injected into the Utsira Sand, a regional aquifer beneath the North Sea. The ongoing SACS (Saline Aquifer CO_2 Storage) project aims to monitor and predict the migration of the CO_2, and to assess the regional storage potential of the Utsira Sand.

This paper presents a preliminary analysis of the regional aspects of the Utsira Sand based on the interpretation of nearly 14000 line kilometres of 2-D seismic data and over 300 wells (Figs. 1 and 2).

SEQUENCE STRATIGRAPHICAL FRAMEWORK OF THE UTSIRA SAND
The Utsira Formation (Isaksen & Tonstad 1989, Gregersen et al. 1997) is of late Miocene to early Pliocene age. It comprises a main sandy unit but also, in some areas, shaly strata. This lithostratigraphical definition is not well-suited to a detailed interpretation of the reservoir system. Instead, seismic sequence stratigraphy has been used to divide the reservoir / caprock system into separate depositional units. The main storage reservoir, here termed the Utsira Sand, corresponds to the sandy part of the Utsira Formation, as proven in the wells around Sleipner (Lothe & Zweigel 1999). It forms a stratigraphically distinct depositional unit occupying the central part of the North Sea Basin, close to, but mostly east of the UK/Norway median line. It has an elongate depositional

extent, stretching some 450 km from north to south and typically 40 - 90 km from west to east (Fig. 3).

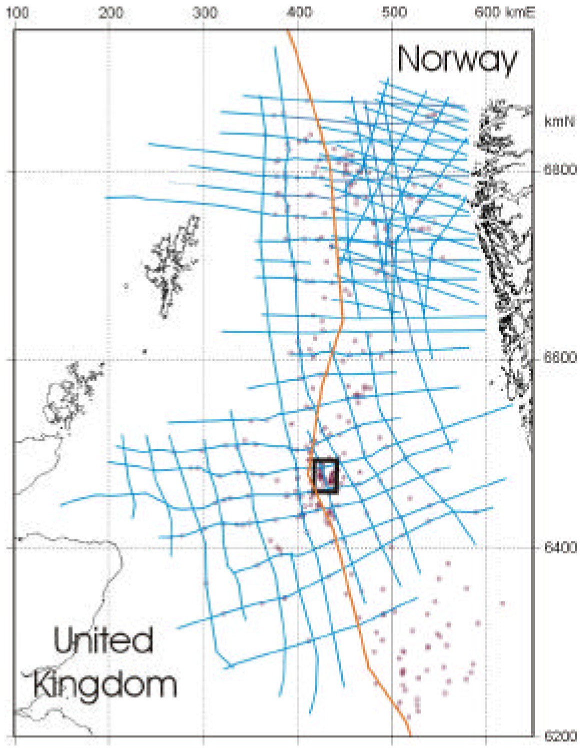

Figure 1 Location of seismic and well data. Note also UK/Norway median line (brown) and Sleipner 3D seismic survey ST98M11 (black rectangle).

Seismically the Utsira Sand is most clearly distinguishable from surrounding units in the south, around Sleipner. Here it comprises a tabular, basin-restricted unit, well-imaged on seismic reflection data and characterised by low ?-ray values on geophysical logs (Figs. 2 and 4a). From a depositional point of view, it is interpreted as a basinal lowstand deposit (turbidite or other mass-flow), sandwiched between prograding highstand units. The Utsira Sand overlies a mixed sand-shale succession of Miocene age and is overlain by thick prograding wedges of Pliocene age. At its eastern edge the Utsira Sand onlaps and pinches out against an unconformity, here termed the mid-Miocene onlap surface. Its western edge is less well imaged on the seismic data, but appears to involve onlap against older, sandy wedges. To the south the Utsira Sand deepens and passes into a thick, dominantly shale, succession. The internal structure of the reservoir is quite complex, particularly towards its base, where shale diapirism of the underlying unit produces severe local deformation (Lothe & Zweigel 1999).

Farther north the lowstand succession is more complex. The Utsira Sand comprises just one of a stacked succession of stratigraphically distinct basin-restricted units, of variable lithology. The eastern margin of the sand is generally well-imaged as an onlap/pinchout, but north of 6750 kmN, the current interpretation is less certain. Patches of Utsira Sand, possibly disconnected from the main reservoir, extend farther east (updip) to within about 300 m of the seabed. The western margin of the reservoir is also difficult to map with certainty, but it appears to pinchout beneath similar basin-restricted units. At its northern limit the reservoir narrows and deepens markedly, appearing to occupy a north-trending channel. In this area much of the Utsira Sand is overlain by flat-lying basin-restricted units, similar in morphology to the shale drape of the southern depocentre. Locally in the east, west-dipping prograding wedges of Pliocene age, form the reservoir caprock.

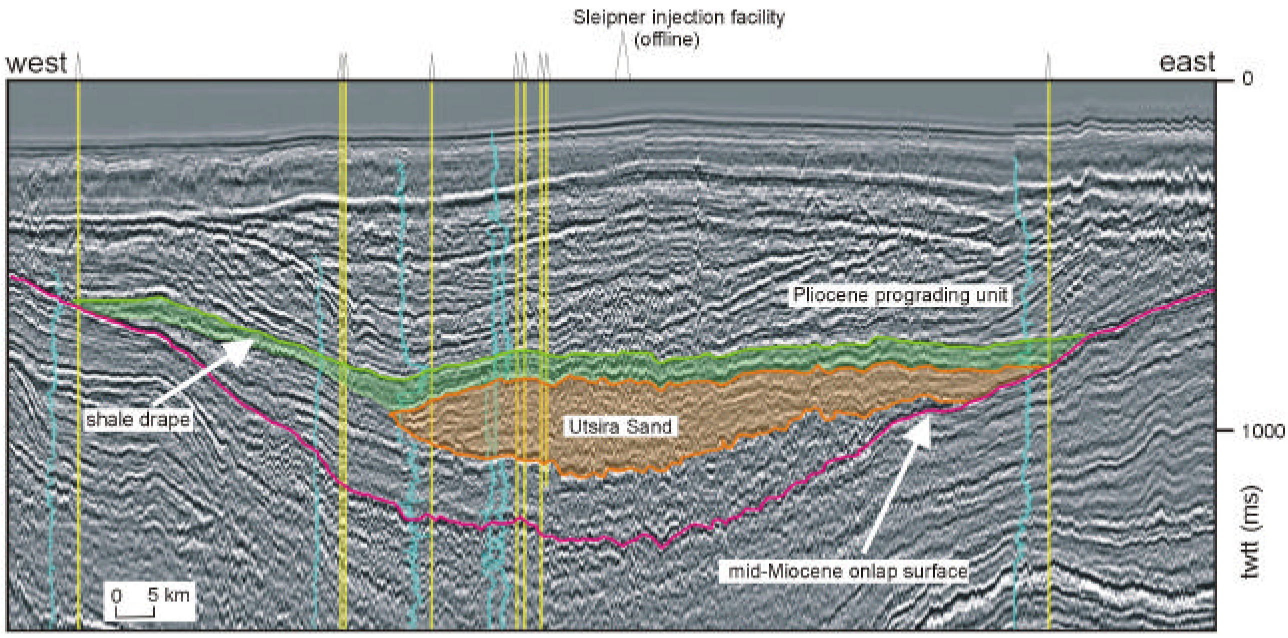

Figure 2 Regional seismic line through the southern part of the Utsira Sand, close to Sleipner. Well profiles show ?-log traces. Seismic data courtesy of Schlumberger Geco-Prakla.

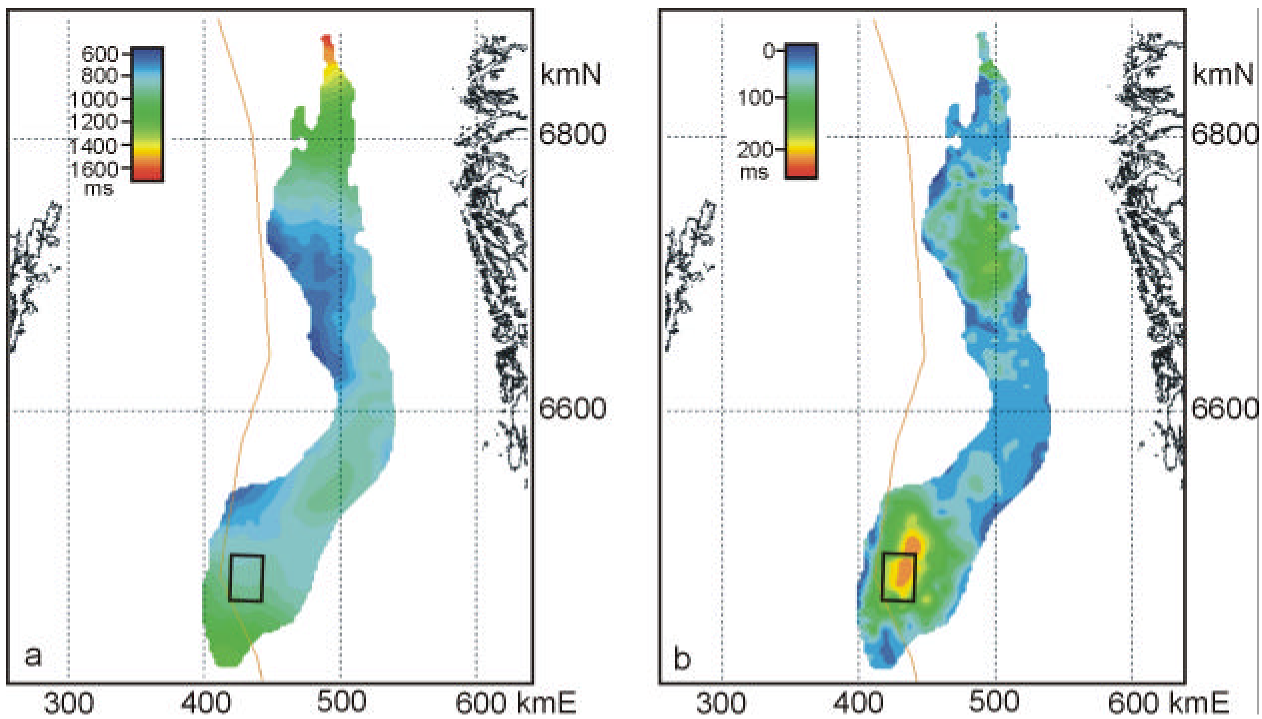

Figure 3 Maps of the main Utsira Sand a) two-way travel-time map to top reservoir b) two-way travel-time reservoir isochore map. Black rectangle denotes Sleipner 3D seismic survey ST98M11.

RESERVOIR/CAPROCK ASPECTS

The Utsira Sand

Regional seismic mapping indicates that the Utsira Sand covers an area of about 2.6 x 10^4 km^2, occupying two distinct depositional basins (Fig. 3) separated by a saddle where the reservoir is thin, narrow and of uncertain lithology. The hydraulic continuity of the two depocentres is therefore uncertain, but it is unlikely to be particularly good. In the southern depocentre the top of the sand lies between 650 ms two-way travel-time (~ 600 m depth) and 1200 ms (~1150 m), the reservoir reaching a maximum thickness of about 270 ms (~ 300 m). In the northern depocentre the reservoir top lies between 600 and 1700 ms (550 - 1500 m depth), with a maximum reservoir thickness of about 180 ms (200 m). [N.B. the velocity 'push-down' effect of the deep water Norwegian Trench means that, in the far northeast, the reservoir is somewhat shallower than the two-way travel-times would suggest].

Sleipner lies within the southern depocentre. Here the reservoir is dominantly sandy, with minor shale stringers. Macroscopic and microscopic analysis of core and cuttings samples show an almost uncemented, friable, fine to medium-grained sand, moderately to well sorted, with occasional coarse grains (Holloway et al. 2000). The grains are predominantly angular to sub-angular and consist primarily of quartz with some feldspar and shell fragments. Small amounts of sheet silicates occur, commonly as a thin coating on the sand grains. X-ray diffraction work indicates these are mainly smectite with minor illite and chlorite. Limited scanning electron microscope evidence suggests that some smectite morphologies are indicative of authigenic development. The core material shows no visible layering or preferred orientation of minerals. This may signify a high energy depositional environment (e.g. turbiditic), but alternatively, may be due to bioturbation.

Data from the Sleipner area suggest that the porosity of the Utsira Sand is high. Microscopic modal analysis of thin sections gives porosities generally in the range 27% to 30%; geophysical log porosities are slightly higher, between 30 and 40%. Porosity information from the northern depocentre is currently sparse however. Assuming a whole reservoir average porosity of 25%, the total pore volume of the Utsira Sand is estimated at 5.5×10^{11} m^3, roughly equally distributed between the two depocentres.

The caprock

Above the southern reservoir depocentre the thickness and lithology of the caprock varies on a regional scale. In the Sleipner area, a unit lying immediately above the Utsira Sand is interpreted as a shale drape (Fig. 2), the continuity and lithology of which is expected to be of key importance to the integrity of the seal (see below). Above this, Pliocene prograding wedges dip into the basin from both west and east (Fig. 2). These tend to coarsen both upwards and marginward into a sandy facies in their prograding parts, but are dominantly shaly in the basin centre, around Sleipner.

Above the northern depocentre the caprock mainly comprises basin-restricted tabular units. These appear to be similar in origin to the shale drape of the southern depocentre, though their lithology may be more variable. At shallower depths Pliocene prograding units are dominantly shaly in the basin centre, but more sandy above the eastern part of the Utsira reservoir.

The shale drape

The shale drape may be of key importance to the current Sleipner injection operation. It has the form of a tabular, basin-restricted unit, some 50 – 100 m thick, lying immediately above the Utsira Sand (Fig. 4a). It overlaps the reservoir to east and west, pinching out against the mid-Miocene onlap surface (Figs. 2 and 4b). Northwards it passes into the Pliocene prograding system, consistent with being a composite body formed by the overlapping distal bottom-sets of the Pliocene prograding wedges. No core samples exist, but drill cuttings from the Sleipner area indicate a grey mudstone with a high proportion of clay minerals. Analysis of geophysical logs indicates shale volumes of at least 80% (Fig. 4a). These results are consistent with the time-lapse seismic data (Arts et al. this volume) which suggest that the shale drape is currently providing an effective seal.

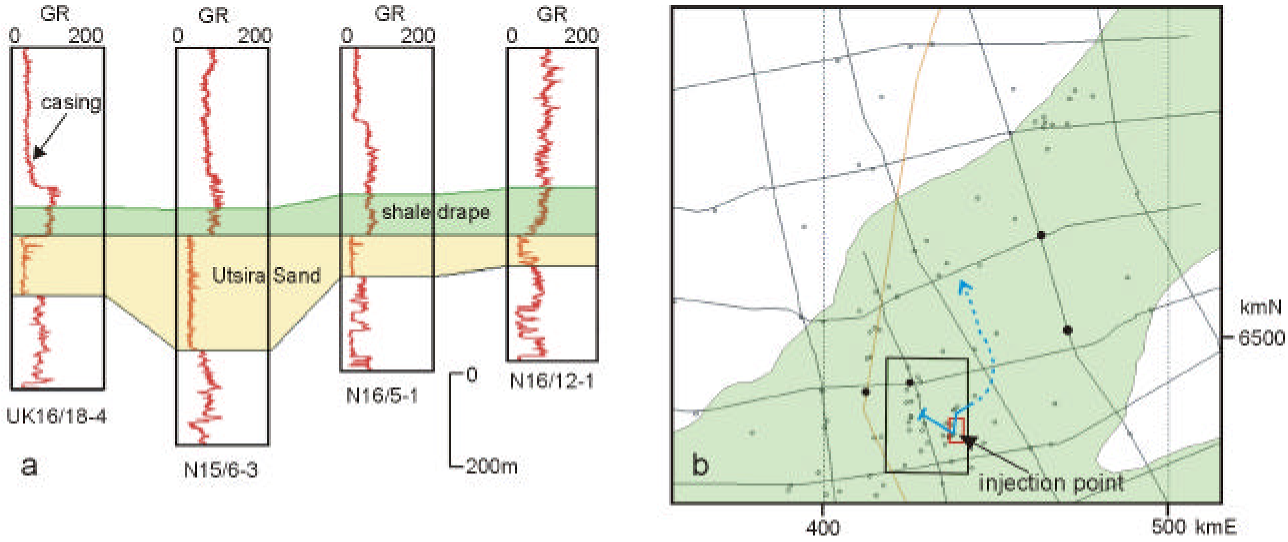

Figure 4 a) Detail of the shale drape from ?-ray logs in the Sleipner area b) Approximate extent of the shale drape (green shading) and predicted CO_2 migration trends (solid blue from Zweigel et al. this volume; dashed blue from this study). Black and red rectangles denote ST98M11 and 1999 3D seismic surveys respectively. Wells in Fig. 4a emboldened.

DISCUSSION

Comparison with both current and predicted migration trends suggests that CO_2 injected at Sleipner should remain beneath the shale drape for a considerable length of time. Zweigel et al. (this volume) present two possible migration scenarios for 20 Mt of injected CO_2. If the CO_2 were trapped at the base of the shale drape, it would probably migrate to the northwest and travel not more than 12 km from the injection point. An alternative scenario, whereby CO_2 migrates into a thin sand wedge just above the base of the shale drape, predicts initial northward migration, turning northeastwards to the edge of the ST98M11 survey. Our regional mapping suggests that the migration pathway would then deviate back northwards, beneath the main part of the shale drape (Fig. 4b), and still be effectively isolated from the overlying Pliocene prograding wedges.

On a more regional scale, in the southern depocentre, the top reservoir surface dips generally to the south or southeast. For putative injection points within the western half of the Utsira reservoir, assuming a gravity drive, migration towards the UK sector would therefore be the most likely outcome. The same holds true for the southern part of the northern depocentre. In the most northerly part of the reservoir however, beneath the Norwegian Trench, migration paths are likely to be eastward.

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