CO_2 Storage Potential of the Eocene Tay Sandstone, Central North Sea

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

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1. Introduction

Carbon Capture and Storage (CCS) is crucial for low-carbon industry, climate mitigation and a sustainable energy future. The offshore capacity of the UK is substantial and has been estimated at 78 Gt of CO_2 in saline aquifers and hydrocarbon fields [1]. The early-mid Eocene Tay Sandstone Member of the Central North Sea (CNS) is a submarine-fan system and potential storage reservoir with a theoretical capacity of 123 Mt of CO_2 [1]. The Tay Sandstone comprises of 4 sequences, amalgamating into a fan complex 125 km long and 40 km wide at a minimum of 1500 m depth, striking NW-SE, hosting several hydrocarbon fields including Gannett A, B, D and Pict.

To better understand the storage potential and characteristics, the Tay Sandstone over Quadrant 21 has been interpreted using geophysical well logs and 3D seismic reflection data. Understanding the internal and external geometry of the sandstone as well as the lateral extent of the unit is essential when considering CO_2 vertical and horizontal fluid flow pathways and storage security.

2. Background

The early-mid Eocene aged Tay Sandstone Member is a submarine-fan system in the Central North Sea (Fig. 2.1). The fan rests on the regional Balder Tuff and is overlain by the thick mudstones of the Horda Formation (Fig. 2.2).

Four internal sequences make up the Tay Sandstone, reducing in size and clay influence with decreasing age. Each sequence separated by mudstones and a minor hiatus.

The Tay Sandstones were sourced from the Scottish Highlands via the Outer Moray Firth, with minor input from the southwest (possibly from the Southern Uplands) (Fig. 2.3).

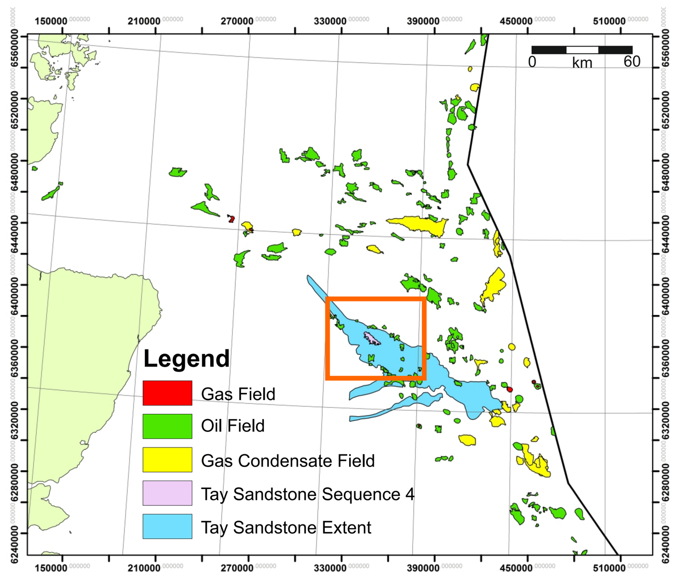
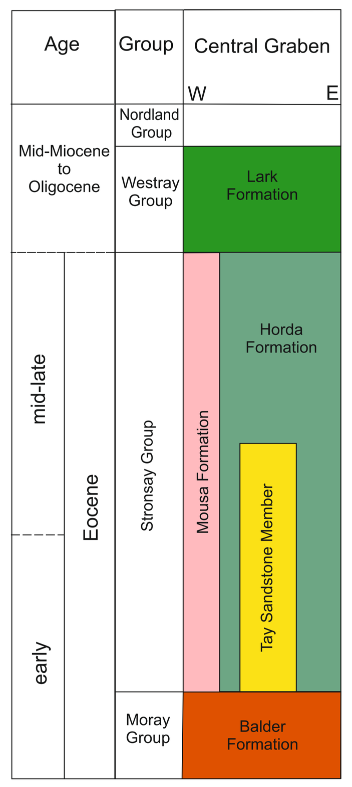


Figure 2.1. Location of UK hydrocarbon fields, the extent of the Tay Sandstone and the mapped sequence in the Central North Sea.



Oil at the Pict and some of the Gannet fields are in the Tay Sandstone proving the cap rock seal and suggesting good reservoir porosity and permeability.

The Tay Sandstone sits above other Cenozoic sandstones such as the Mey, Cromarty and Forties Members which overlie deeper Jurassic reservoirs. This offers the opportunity for stacked storage of Co_2 in the CNS.

Figure 2.2. A summary stratigraphic column for the Eocene of the Central North Sea. Including the Tay Sandstone Member and overlying mud-rich Horda Formation.[2]

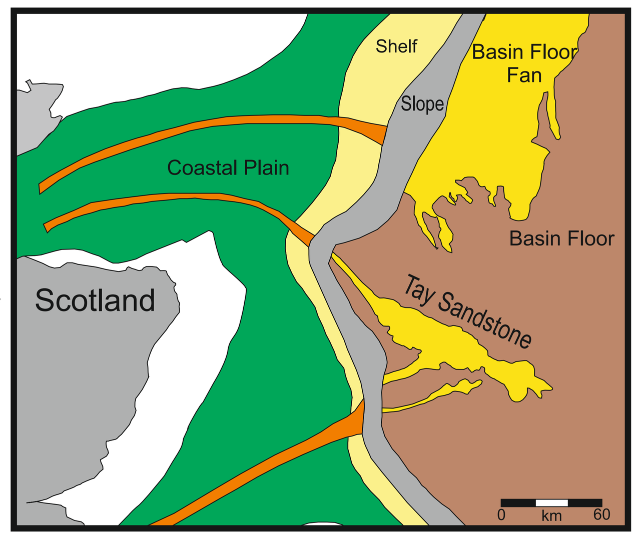


Figure 2.3. Early Eocene palaeogeography and depositional setting showing the extent of the submarine fans of the Tay Sandstone and Grid Sandstone members.[3]

3. Seismic Mapping

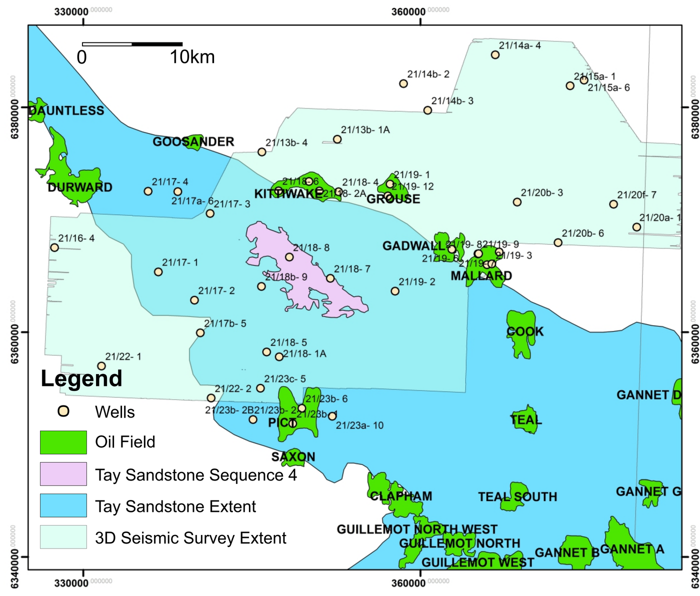


Figure 3.1. Location of the mapped Tay Sandstone sequence, with nearby wells, oil fields, and available 3D seismic coverage.

The 3D seismic volume used does not incorporate the whole extent of the large Tay Sandstone (Fig. 3.1). The fan strikes NW-SE across the seismic area, and is confirmed by numerous exploration wells.

The Top Tay Sandstone was mapped across the 3D seismic volume. The high amplitude horizon is clear below the thick homogenous Horda Formation. The Top Sele Formation represents the base of the Tay Sandstone Unit, as the Balder Tuff Formation is thin in this area and beneath seismic resolution.

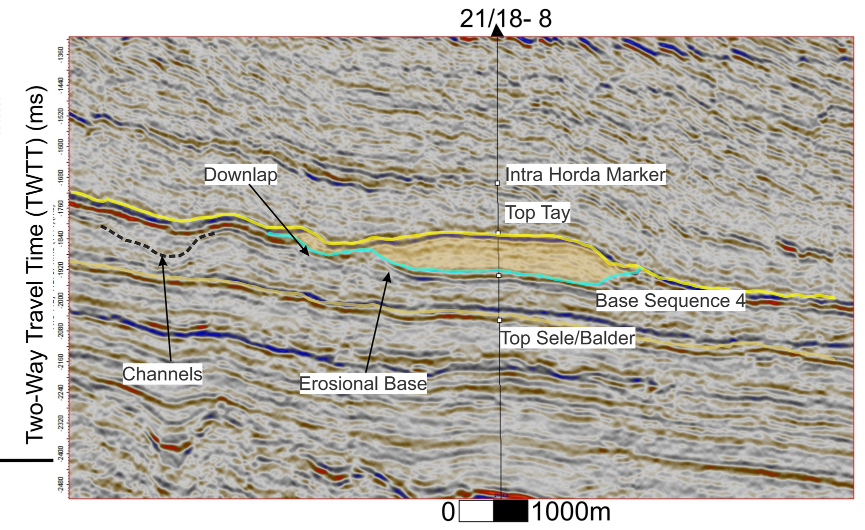


Figure 3.2. Seismic cross-section through sequence 4 showing the internal geometry of the sandstone

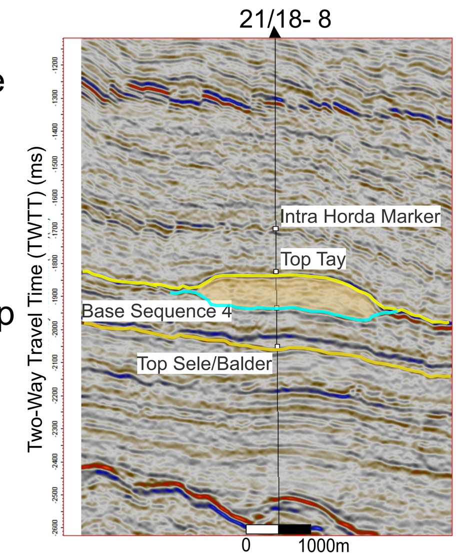


Figure 3.3. A perpendicular cross-section across sequence 4. Note the mounded geometry caused by differential compaction.

Internally sequences 1-3 are quiescent but complex, with channel systems and erosional surfaces (Fig. 3.2).

Sequence 4 has a distinctive mounded geometry (Fig. 3.3) with a mappable base, it is 12.8 km by 3.8 km with an average thickness of 97 m (Fig. 3.4). The mapped closure was depth converted using nearby well velocity data.

Sub-seismic thicknesses (<40 m) limit the range of the sequence, which could have more laterally extensive thin sandstones. Attribute analysis could help refine the margins of the sequence.

Tay Sandstone Sequence 4

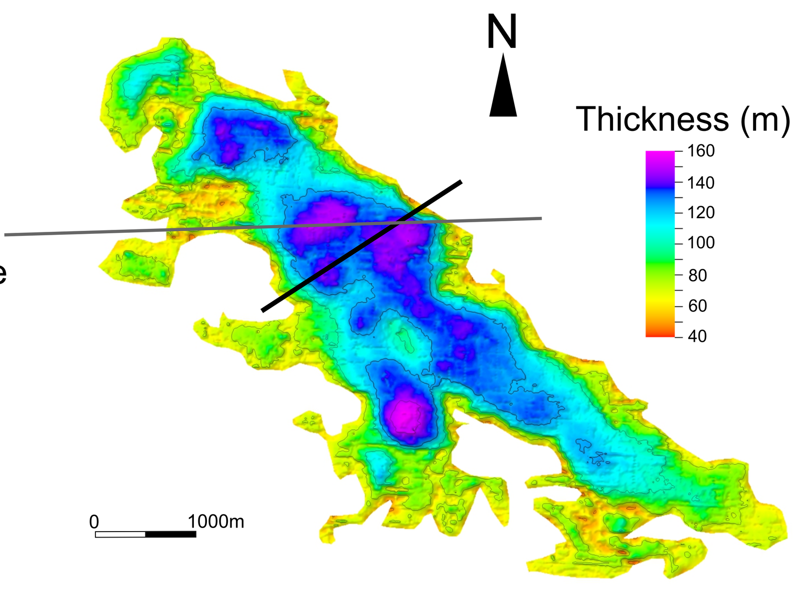


Figure 3.4. Thickness map for sequence 4, reaching 160 m at its thickest. Seismic resolution limits prevent mapping thinner than 40 m.

4. Well Information

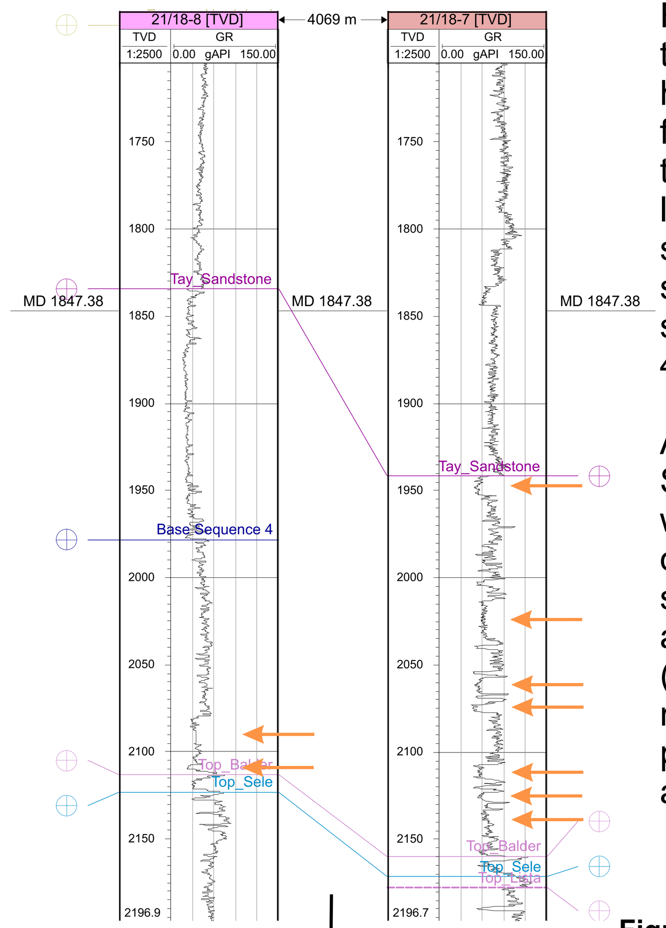


Figure 4.1. The gamma ray log in wells 21/18-7 and 21/18-8 showing the clear 'blocky' response of the sandstone

Fifteen wells within the extent of the seismic volume were used to help build the interpretation. The formation tops were taken from the exploration wells composite logs. Gamma ray traces clearly show the clean 'blocky' sandstones separated by thinner siltstones and mudstones (Fig. 4.1).

A few wells cored the Tay Sandstone, including well 21/17-2 which cored several metres of the overlying Horda Formation. The sandstone show visible porosity and are often poorly consolidated (Fig. 4.2). Core analysis has revealed very good reservoir properties with porosity of 30-39% and permeability of 2-11D

Figure 4.2. Core taken from sequence 3 in 21/17-2. A typical section of clean sandstones. With porosity up to 39% and permeability up to 11D.

5. Storage Potential

With 35% porosity, 5 D permeability and a net to gross of 0.8, sequence 4 of the Tay Sandstone has a high total pore volume of 927×10^6 m^3. The remaining three sequences of stacked channels and interbedded mudstones reduce in net to gross with age as mud has a greater influence in the early fan system. Nevertheless, the sandstone properties remain relatively consistent and are far more laterally extensive than the youngest sequence.

The value of 123Mt CO_2 quoted in the CO_2 storage online atlas CO_2Stored[3] is a rough estimate for the whole unit. Mapping undertaken and the pore volumes calculated will lead to a more accurate value of storage potential for this submarine-fan complex.

Several factors and risks still need considering when assessing this site for CO_2 storage:

- Pressure connection: dependent on whether the Tay Sandstone is an open or closed unit.
- Hydraulic connection with underlying Cenozoic sandstones (Forties, Cromarty, Mey).
- Modelling of migration pathways to stratigraphic traps.
- Connectivity between sequences within the Tay Sandstone.

6. References

[1]CO2Stored - Online CO2 Storage Atlas. www.co2stored.co.uk

[2]Knox, R. W. O. B., and Holloway, S., 1992, Lithostratigraphic nomenclature of the UK North Sea : vol. 1 Paleogene of the Central and Northern North Sea, Keyworth, British Geological Survey for the United Kingdom Offshore Operators Association.

[3]Jennette, D. C., Garfield, T., Mohrig, D., and Cayley, G., 2000. The interaction of shelf accommodation, sediment supply and sea level in controlling the facies, architecture and sequence stacking patterns of the Tay and Forties/Sele basin-floor fans, Central North Sea, in Proceedings Deep-water reservoirs of the world: Gulf Coast Section SEPM 20th Annual Research Conference 2000, SEPM, p. 402-421.

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Seismic data shown courtesy of CDA