



Introduction

Carbon Capture and Storage (CCS) is an emerging solution to current decarbonisation challenges, reducing atmospheric greenhouse gas emissions and supporting the transition to a low-carbon energy system. The deployment of this technology is essential to achieve the UK's legal target of Net Zero CO₂ emissions by 2050. The UK Continental Shelf (UKCS) in the Southern North Sea (SNS) has significant potential for large-scale offshore geological storage of CO₂. Abundant depleted gas fields, saline aquifers and existing subsurface datasets make this a highly favourable region for development (Fig. 1a & b). The primary storage targets include the Permian Rotliegend Group (Leman Sandstone Formation) and the Triassic Bunter Sandstone Formation, of which the former is regionally sealed by evaporites of the Upper Permian Zechstein Supergroup (Fig. 1c). The structural framework of the SNS predominantly reflects the reactivation of inherited Paleozoic basement structural fabrics during multiple phases of Mesozoic syn-sedimentary extension and later Cretaceous-Cenozoic uplift and inversion (Glennie, 1986; Grant et al., 2019).

The North Sea Transition Authority (NSTA) identified several offshore carbon storage licence areas in the south-western SNS through the 2022 and 2025 licensing rounds (Fig. 1a), however these are intersected by major basin-scale throughgoing fault systems, namely the Dowsing Fault Zone and the North and South Hewett faults (Fig. 1b; Cooke Yarborough and Smith, 2003). Despite the significance of these faults which offset key reservoir and seal units, their influence on reservoir connectivity remains poorly constrained at a semi-regional scale from a CCS perspective.

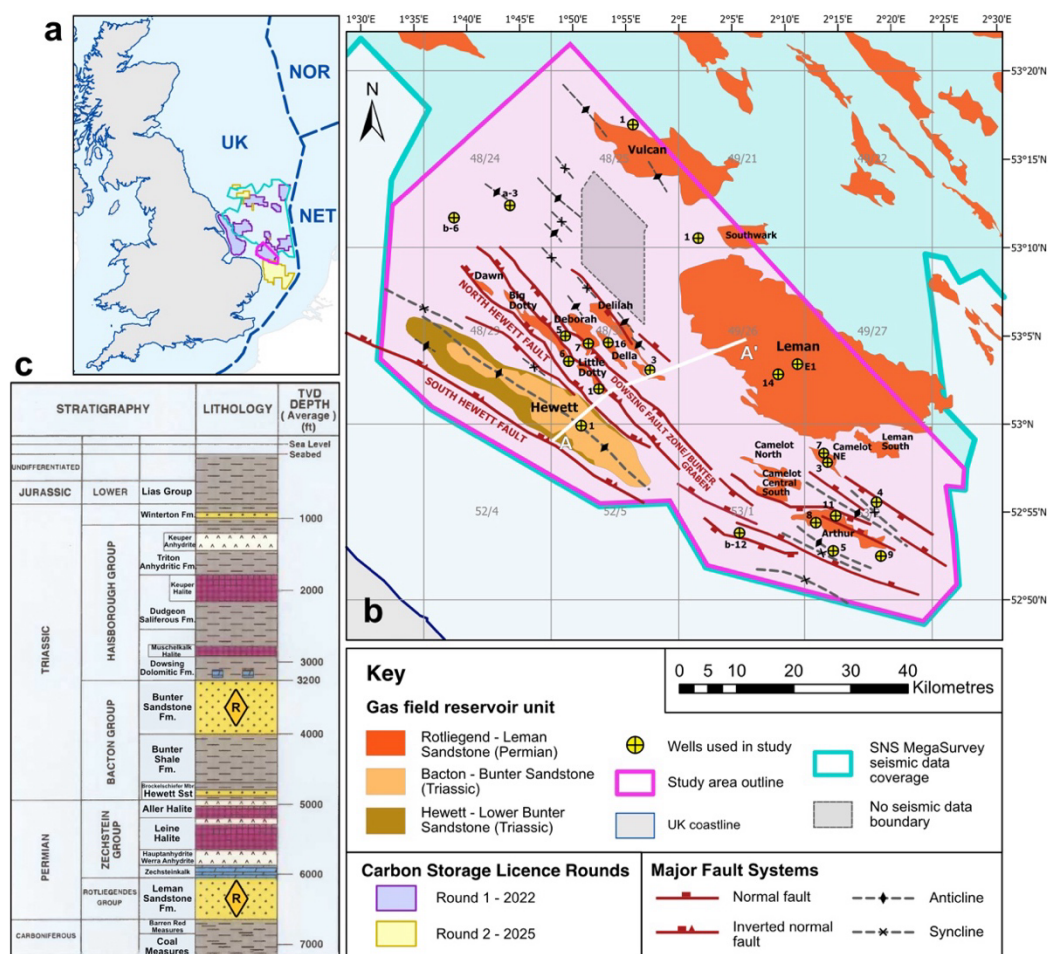


Figure 1 (a) Regional UK map with the Southern North Sea NSTA carbon storage licence rounds. (b) Study area showing the SNS MegaSurvey 3D seismic extent, wells used, gas fields coloured by reservoir unit and major fault systems. White line indicates seismic section A-A' (Fig. 2). (c) Stratigraphy of the Hewett Unit (modified after Cooke-Yarborough and Smith, 2003).



This raises uncertainty in how strongly reservoir compartmentalisation, fault sealing behaviour and pressure communication are controlled by fault architecture, especially where faults offset and interact with the regional Zechstein seal (Stewart et al., 1996). Assessing the suitability of specific carbon storage sites requires an understanding of whether these faults act as effective structural traps or as potential leakage pathways into overlying formations (Yielding et al., 1997; Holloway et al., 2006). This study applies detailed 3D seismic interpretation and structural analysis to major fault systems within emerging CCS licence areas in the SNS (Fig. 1b), characterising their geometry, kinematic evolution and connectivity. The aim is to evaluate how these faults developed through segment linkage and potential reactivation of inherited basement structures and to assess how vertical connectivity across the Zechstein seal influences long-term CO₂ storage security.

Methods

Interpretation was undertaken using a 1,880 km² subset of the NSTA SNS MegaSurvey 3D seismic dataset, comprising 44 merged, high-quality, reprocessed post-stack time-migrated seismic surveys, providing continuous vertical coverage from the seabed to the Carboniferous succession (around 2875 ms TWT). Well control utilised 24 wells from the UK National Data Repository, incorporating checkshot data, formation tops, and gamma ray, density and sonic logs for well ties and synthetic seismogram generation. Key stratigraphic horizons were mapped in two-way time, including Top and Base Chalk, Top Haisborough Group, Top and Base Bunter Sandstone, Top Zechstein, Top Rotliegend and Top Carboniferous. Horizons were manually picked every 20-40 crosslines, then infilled using autotracking with manual quality control. Major faults were interpreted manually, supported by seismic coherency extractions along time slices. Fault throw analysis was used to investigate throughgoing fault growth and linkage, while Allan-style juxtaposition analysis assessed reservoir connectivity and potential sealing behaviour of the Bunter Sandstone and Rotliegend reservoirs. Depth conversion was performed using a layered velocity model calibrated to well data, built to incorporate velocity and compaction variations in the overburden, with intervals defined by the key stratigraphic horizons from the seabed down to Top Carboniferous.

Findings

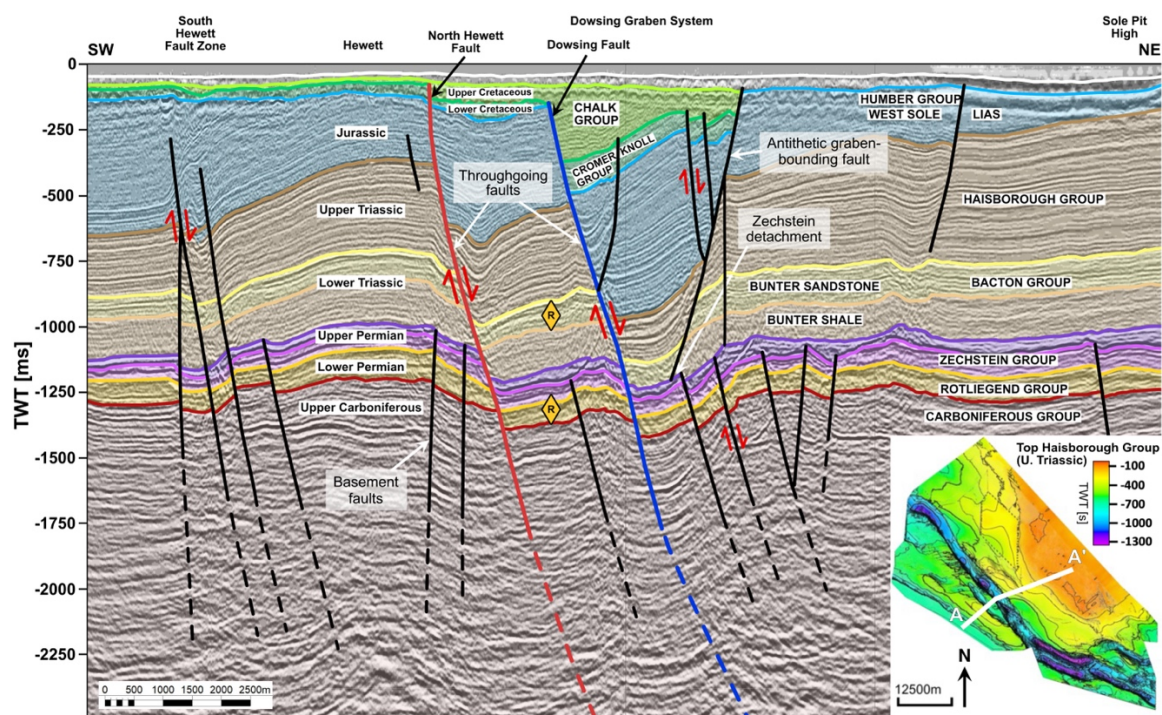


Figure 2 SW-NE interpreted seismic two-way time (TWT) section along line A-A'.



Dominant regional NW-SE structural trends across the SNS are defined by the Dowsing Fault Zone and the North-South Hewett fault system (Fig. 1b & 2). The North Hewett Fault laterally extends for approximately 20 km and the Dowsing Fault Zone for over 40 km, both exhibiting throughgoing or strongly coupled fault architecture over significant parts of their strike (over tens of kilometres) where they are interpreted to approximately 2600 ms TWT, around 5200 m depth (Fig. 2). The two fault systems show a planar geometry and are sub-parallel in map view, with approximately 3 km separation between, both steeply dipping to the north-east (65-75°) and offsetting stratigraphy from the Carboniferous to Cretaceous succession.

Throw analysis along-strike of the Dowsing Fault Zone, calculated between mapped stratigraphic horizons and displayed along the fault plane, shows significant displacement variability and decreasing throw towards fault tips (Fig. 3). It is characterised by multiple discrete throw maxima of up to 180-190 m, spaced around 5 km apart and separated by lower displacement zones. Throw maxima are interpreted as fault growth centres that accommodated the greatest displacement, while local minima indicate linkage between interacting segments or breached relay ramps (Peacock and Sanderson, 1994). This pattern is consistent with progressive linkage of initially offset smaller normal fault segments (Walsh and Watterson, 1987), involving relay ramp destruction as overstepping segments tilt to form a larger composite fault that offsets the Zechstein seal (Peacock and Sanderson, 1994; Stewart et al., 1996).

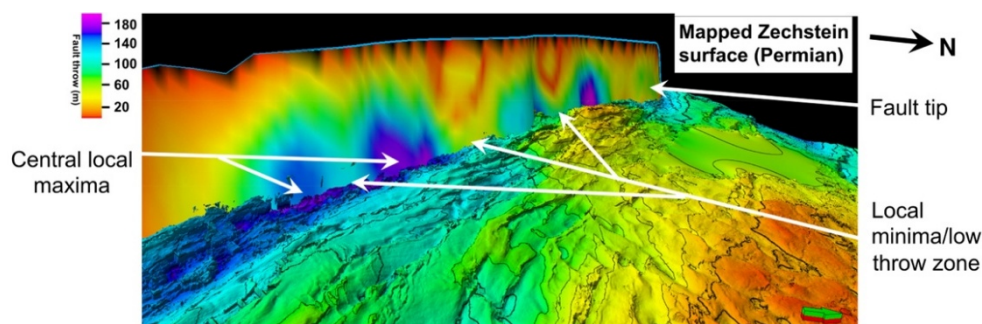


Figure 3 Fault throw distribution (m) along the Dowsing Fault plane displayed on a 3D structure map of a Zechstein surface.

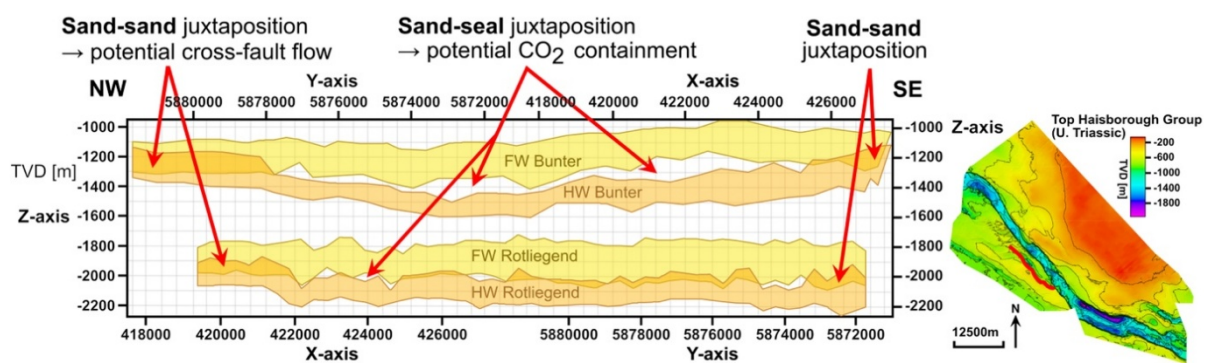


Figure 4 Allan-style juxtaposition diagram for the North Hewett Fault in depth (m), showing Bunter and Rotliegend reservoir relationships (fault outlined in red on inset map).

Allan-style juxtaposition analysis shows significant variations in reservoir connectivity along the North Hewett fault (Fig. 4). For the Bunter Sandstone, sand-seal juxtapositions against the Triassic Haisborough Group dominate over approximately 14 km, representing an increased probability of sealing, whereas localised reservoir-reservoir contacts near fault tips occur over approximately 6 km, representing potential leakage points and pressure communication. In contrast, Rotliegend connectivity is restricted to discrete fault segments but over approximately 5 km of the fault, Rotliegend-Zechstein juxtaposition potentially acts as a local side-seal to individual reservoir compartments, although trapping uncertainty at this level is higher. However, seal integrity also depends on fault-rock properties



and stress state (Yielding et al., 1997). In the Bunter Sandstone near the Hewett field, sealing potential is likely enhanced by the approximately 478 m thick clay-rich Haisborough Group, which may contribute shale-rich material to form fault rocks and reduce pressure communication even where the reservoir is self-juxtaposed, minimising the risk of CO₂ migration (Williams et al., 2014).

Conclusions

Integrated 3D seismic mapping and structural analysis show that the Dowsing Fault Zone (>40 km) and North Hewett Fault (around 20 km) form laterally extensive, steeply dipping fault systems that offset the Carboniferous-Cretaceous stratigraphy, indicating vertical connectivity across key reservoir-seal intervals. Throw analysis presents segmented profiles characterised by multiple throw maxima with concentrated displacement zones around 3.5 km wide, suggesting throughgoing faults likely developed through progressive linkage of these smaller fault segments. Juxtaposition analysis reinforces the significant along-strike variability in reservoir connectivity and sealing behaviour, including majority sand-seal juxtaposition of Bunter reservoir across approximately 14 km of the North Hewett Fault and Rotliegend sand-seal juxtaposition over around 5 km. These results indicate that throughgoing fault architecture strongly controls the likelihood of fault sealing and pressure communication, acting as effective traps over some strike segments, or potential fluid leakage pathways in others. This research provides an improved framework to evaluate the role of basin-scale fault systems in successful long-term CO₂ containment, with the aim to de-risk development within emerging UK CCS licence areas.

References

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