Assessing carbon dioxide storage integrity of an extensive saline aquifer formation; East Irish Sea Basin, UK

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ABSTRACT

Accurately determining the contemporary pore pressure and *in situ* stress conditions is critical to the safe planning and development of subsurface operations such as CO_2 storage. According to the UK storage capacity atlas, CO_2STORED (Bentham *et al*. 2014), the East Irish Sea Basin (EISB) has a significant storage capacity of nearly 4 Gt (P50) within saline aquifer parts of the Triassic-aged Ormskirk Sandstone Formation (OSF). The OSF is present over a significant part of the EISB, and where buried deeply enough to be considered for CO_2 storage is overlain by the Mercia Mudstone Group (MMG), a thick sequence comprising up to 3200 m of interbedded mudstones, siltstones and evaporites. As a result of Tertiary inversion, the Jurassic and younger succession is absent over most of the basin, and so the MMG represents the vast majority of the overburden succession. The presence of numerous gas accumulations, including the Morecambe South Gas Field with its ~400 m gas column, is testament to the sealing capacity of the MMG. Where halite formations within the MMG directly overly the OSF, the sealing capacity of the MMG is significantly increased.

Given the low permeability and high capillary entry pressure of the MMG (Armitage *et al*. 2015), the greatest risk to storage integrity in the OSF is likely to be from fracturing of the caprock or reactivation of pre-existing faults due to elevated pressures during CO_2 injection. In a recent re-assessment of the storage capacity in the OSF, pore pressure and *in situ* stress data were derived from hydrocarbon well data in order to calculate more accurately the Aquifer Seal Capacity (ASC), the pressure increase that could be permitted to occur without fracturing the caprock.

In order to characterize the effective *in situ* stresses, the long legacy of exploration and production well data from the EISB were consulted in order to extract; direct pore pressure measurements, estimates of the least principal stress magnitude (assumed to be the Minimum Horizontal Stress, S_{hmin}), and bulk density logs for calculation of the vertical (lithostatic) stress magnitude. Formation pressure was determined from Repeat Formation Tester (RFT), Modular Formation Dynamics Tester (MDT) and Formation Multi Tester (FMT) data, which show a pore pressure gradient of 0.0116 MPa/m in most wells. Wells in the Keys sub-Basin however are slightly underpressured compared to those in the rest of the EISB. The vertical stress calculated using integrated bulk density logs from 35 wells, indicates that although there is a relatively uniform trend, there is some variation across the EISB related to stratigraphic and structural relationships and burial history. The magnitude of S_{hmin} was estimated using formation leak-off tests. The minimum bound to the leak-off test data was used to determine a regionally-applicable

estimate of the fracture pressure. The orientation of the Maximum Horizontal Stress (S_{Hmax}) derived from analysis of borehole breakouts observed in borehole image logs, was found to be approximately NW–SE, consistent with regional models. As limited information was available from which to accurately calculate the magnitude of S_{Hmax}, frictional limits were used to determine an upper bound that cannot be exceeded without reactivating preferentially-oriented faults.

These data were used to calculate the maximum pressure increase that can be permitted to occur during storage in structural closures of the OSF, and the maximum CO_2 column heights that can be accumulated without fracturing the caprock. Of the six mapped closures where CO_2 would be stored in a supercritical state at the shallowest point, the column heights are limited by the relief of the structures rather than by fracture pressure limitations, and so there is a low risk of mechanical failure of the caprock by generation of new fractures. Column heights range from 113–752 m in the six structures.

To analyze the risk of fault reactivation, a regional *in situ* stress model derived from the well data is used to determine the orientations of pre-existing faults that are most likely to become reactivated under elevated pressure conditions. The most likely stress scenario considers a strike-slip faulting regime, where S_{hmin} and S_{Hmax} are respectively the least and maximum principal stresses, while the vertical stress is intermediate. Vertical faults striking at 30° to S_{Hmax} (122 or 182°) are most susceptible to reactivation, requiring pore pressure to increase by ~5 MPa at a depth of 800 m in order to trigger reactivation. Higher pore pressures of ~8–16 MPa would be required to cause reactivation of faults at distinctly different angles to the principal stress. Due to uncertainty regarding the magnitude of S_{Hmax}, these results consider an *in situ* stress model where faults penetrating the MMG and into the OSF are subjected to high differential pressures, and optimally oriented faults are therefore close to being critically-stressed. If the magnitude of S_{Hmax} is actually somewhat lower than this, the results presented will be conservative, representing a worst-case scenario.

The storage capacity in structural closures of the OSF in the EISB is not likely to be limited by the seal capacity of the MMG. Reactivation of pre-existing faults, optimally oriented with respect to the prevailing *in situ* stress field represent the most significant risk to storage integrity, however if pressure increase during injection is restricted to <5 MPa, there is little chance of reactivating pre-existing faults.

References

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