FAULTING IN PROSPECTIVE CO_2 STORAGE SITES IN THE UK SOUTHERN NORTH SEA

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ABSTRACT

Post-depositional folding of Triassic strata, formed largely by the development of salt domes and pillows in the underlying Zechstein Group, led to the formation of numerous large anticlinal structures at the level of the Triassic aged Bunter Sandstone Formation (BSF). These structural closures, some of which have formed effective traps to natural gas, have been mapped across the UK Southern North Sea (SNS), and are currently of interest as potential prospects for the storage of anthropogenic CO_2.

During the development of the salt domes, the BSF and its caprock successions were subjected to extensional fault-forming stresses, particularly over the crests of the structures where CO_2 is envisaged to accumulate if storage is implemented. These faults pose a significant risk to the storage integrity of the BSF structures, and represent a key remaining uncertainty regarding the prospectivity of these sites for potential CO_2 storage. Here we examine the limitations these faults may pose to the storage integrity of the BSF.

Eight gas fields have produced, or are currently producing, Carboniferous-sourced gas from the BSF in the UK SNS. Of these, five fields are contained within simple periclines overlying salt domes or pillows, while the other three are anticlines associated with the inversion of faults located marginal to the area most affected by halokinesis. Seismically detectable faults cut the BSF and much of its overlying succession in at least four of the fields. They do not appear to constrain the level to which the structures were charged with natural gas, and they do not leak at the overpressures exerted by the gas columns. It is possible however, that injection induced overpressure could cause faults like these to reactivate due to a reduction of the effective stress, which could potentially compromise storage integrity. Similar faults have been shown to affect a large number of the non-gas bearing structures that are of interest for CO_2 storage, and sub-seismically resolvable fracturing is also likely to occur over their crests.

Although detailed pressure data is not readily available for the BSF outside of the producing gas fields, regional data suggests that the formation is normally pressured, with pore fluid pressures lying on a gradient of 10.07 MPa/km. The lithostatic pressure gradient is approximately 22.5 MPa/km, and 16.9 MPa/km is considered to be a conservative estimate of the fracture pressure in the basin, based on evidence from leak-off pressure (LOP) testing (Noy *et al*. 2012).

The orientation of the maximum horizontal stress over much of NW Europe is NNW-SSE; however following the assertions of Hillis & Nelson (2005), the *in-situ* stress regime may differ

between the de-coupled post-Zechstein succession in the centre of the SNS Basin and the regional stress field which prevails in the pre-Zechstein succession. This is thought to occur in the Central North Sea, where stress conditions in the Chalk Group of the Norwegian Ekofisk field (Teufel 1991) appear to relate to the geometry of the structure rather than to regional factors. Crestal fault geometries, along with a limited number of borehole breakout orientations suggest that a similar process occurs in the post-Zechstein succession of the UK SNS. We conclude that at least over the crests of the BSF structures, the stress conditions will be related to a locally controlled normal stress regime.

The pressure gradients described above have been used to provide input parameters to a simple geomechanical model assuming a Mohr-Coulomb failure criterion. Initial pressure in the model is considered to be hydrostatic, and the lithostatic pressure gradient is used to derive the highest principal stress. The LOP gradient is used to derive the minimum horizontal stress, while the magnitude of the maximum horizontal stress is considered to fall somewhere between the two. By increasing the pore fluid pressure incrementally to simulate the effect of CO_2 injection, it is possible to calculate the pore pressure rise that would cause the frictional failure of a pre-existing fault, if it is assumed to be optimally oriented with respect to the *in-situ* stress conditions. The result is the derivation of a fault-reactivation pressure gradient, which in the absence of site-specific data could be considered as a regionally applicable guide to the safe limiting pressure for CO_2 injection into a BSF structure in the UK SNS.

Simulation of CO_2 injection into twelve potential storage sites within part of the BSF, suggests that the modeled fault-failure pressure may be exceeded over the crests of several structures where the injected CO_2 is expected to accumulate. Simulations where CO_2 injection is limited by the fault-failure pressures are more likely to yield realistic estimates of the amount of CO_2 that can safely be stored without compromising the storage integrity of the structures through fault reactivation. However, it remains likely that optimally oriented faults and fractures lying outside the areas where CO_2 is likely to migrate, may reactivate due to the increased pore fluid pressures. This may result in a degree of pressure bleed-off into the overlying succession, which may in fact be beneficial for the storage of CO_2 in the BSF. An additional effect could be the occurrence of induced seismicity, the magnitude and effects of which are not quantified. In either case, even if pressure is maintained below the fault-failure pressure gradient everywhere across the model in order to reduce the risk of both leakage and induced seismicity, significant volumes of CO_2 may still be stored without necessitating the use of pressure control wells.

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