Small-strains and gentle uplift of the seabed: Modelling the regional geomechanical response to industrial-scale injection of carbon dioxide in the Bunter Sandstone

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Abstract

Several UK carbon storage licences target the Bunter Sandstone Formation in large anticlinal traps located in the Silverpit Basin area of the Southern North Sea. Whilst some of these traps are gas charged, current carbon storage projects are predominantly targeting water-wet saline aquifer structures. The Silverpit Basin area is bounded by a series of major faults and Zechstein salt walls, and no extensive internal pressure barriers are currently known. It can therefore be considered as a large hydraulically connected region isolated from surrounding aquifers, an interpretation supported by downhole pressure data. Furthermore, Bentham *et al*. (2017) used pressure depletion and recovery data from the Esmond gas field to infer good aquifer connectivity in the region, with a total connected pore volume of at least $1.8x10^{10}$ m^3.

Several previous studies have investigated the potential pressure response to injection in the Silverpit Basin area, suggesting that large-scale injection of carbon dioxide would result in elevated pressure across the region (Noy *et al*., 2012; Agada *et al*., 2017). These studies also invoke the role of a seabed subcrop of the Bunter Sandstone in allowing pressure relief through the displacement of brine to the water column (the carbon dioxide itself is contained within the intended structural traps). The subcrop occurs above a high-relief salt dome where Triassic rocks have been uplifted to the surface. While uncertainty exists related to the connectivity between the subcrop and the proposed injection sites at depth, to date no significant barriers to flow have been identified from regional seismic interpretation.

Previous studies have evaluated the geomechanical response of individual Bunter Sandstone structures for specific CO_2 storage development proposals (James *et al*. 2016; National Grid 2016; BP, 2021). However, site specific geomechanical models for CO_2 storage are generally concerned with whether the planned injection profile can be achieved without locally damaging the top seal. In an extensive hydraulically connected saline aquifer formation such as the Bunter Sandstone there are further considerations:

- What far-field stress changes are expected?
- Is induced seismicity likely to occur, either locally at the injection site, or further afield?
- Could reservoir dilation lead to excessive surface deformation?
- How will multiple storage sites interact with each other?
- Are there any regional monitoring considerations?

A regional geological model over the full extent of the Silverpit Basin area is used as the basis for a coupled flow and geomechanical modelling study to evaluate the geomechanical impact of industrial-scale CO_2 injection. The modelled injection scenario is taken from the Northern Endurance Partnership path to 10 Million Tonnes per annum (Phase 2) scenario outlined in BP (2022), which comprises injection into four distinct sites hosted in different structural closures. No water production for pressure relief is considered in this scenario. The modelling indicates that under the specified injection scenario, increasing pressure will generate only minor uplift and some minor elastic strain with no shear or tensile failure of the reservoir, top seal or overburden. Even under a conservative case with failure envelopes representative of optimally-oriented, cohesionless (weak) materials, no failure is observed in either the Bunter Sandstone or its top seals. A sensitivity run was also modelled which considered a reduction in horizontal permeability and reduced ratio of vertical to horizontal permeability. Despite higher pressure increases at the injection sites as a result of reduced injectivity,

the simulation mitigates the pressure increase through reduction of injection volumes to maintain pressure limits at the wells. Under current modelling assumptions therefore, the multi-store injection scenario is feasible without inducing significant strain or failure in the BSF or its top seal formations.

The effective stress changes are insufficient to induce fault reactivation at shallower far-field locations remote from the target structures. Alleviation of pressure via the seabed subcrop, along with control of injection well pressures are important factors that restrict unmitigated pressure increases in the model. Dilation of the Bunter Sandstone results in only modest uplift of the seabed (around 10 cm), concentrated at the injection sites where pressure increases are greatest. Regionally, a small amount of uplift occurs over a wide area, and is elevated above the Bunter closures. This may be because there is less overburden over the structural crests within which to accommodate the uplift via contractional strain.

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