Analysis of *in situ* stress and fault reactivation potential for a major candidate storage aquifer

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ABSTRACT

Within the Moray Firth, the Lower Cretaceous Captain Sandstone has been proposed as a prospective storage reservoir, with storage potential in depleting hydrocarbon fields, and more significantly, within the greater saline aquifer. Previous simulation studies of CO_2 injection into the Captain Sandstone aquifer suggest storage capacities in the range 358 to 2495 Mt over a range of sensitivity scenarios. Storage at this scale will introduce the risk of fault reactivation as a consequence of elevated reservoir pressures. The transmissibility of previously stable faults may be enhanced due to reactivation, increasing the risk of CO_2 migration from the storage reservoir.

By studying both the geometry of faults and the contemporary stress field affecting the basin, it is possible to resolve the shear and normal stresses acting on faults which cut the reservoir formation and extend into the overburden towards the seabed, and to determine which faults (or parts of faults) are most susceptible to becoming reactivated under elevated pressure conditions. In order to do so, detailed knowledge of the pore pressure conditions at depth and the magnitude and orientations of the principal stresses are required, as are the properties of the faults themselves. Such an analysis is presented here at the basin-scale, focusing on the Captain Sandstone of the Inner Moray Firth Basin.

Information pertaining to the stress conditions at depth are either directly measurable or may be inferred from data acquired in hydrocarbon wells. Pore fluid pressure data over the Lower Cretaceous sandstones suggest a 'normal' hydrostatic pressure gradient of ~10 MPa/km. The vertical stress magnitude (Sv), or overburden stress, is generally considered to be one of the principal stresses, and a stress profile has been obtained by integrating density log measurements from exploration wells. Borehole breakout analysis has been performed in order to determine the orientation of the maximum and minimum horizontal stresses (SHmax and Shmin respectively). While borehole breakouts were identified using downhole ultrasonic televiewer and electrical borehole image logs, no drilling-induced tensile fractures were observed over the logged intervals. The breakout analysis yielded a consistent orientation of SHmax in a NE–SW direction (29–42°) across the study area, somewhat oblique to the dominant structural grain of the Inner Moray Firth Basin.

The magnitudes of the horizontal stresses are more uncertain, but a reasonable linear least principal stress profile has been derived using available leak-off test data from the area of interest. Shmin is taken to be the minimum principal stress because reported values are all lower

than Sv, meaning the stress state is consistent with either normal faulting or strike-slip faulting stress regimes. As measurements of SHmax are unavailable, the possible SHmax magnitudes were constrained by the frictional strength of faults optimally oriented for failure. The occurrence of borehole breakouts and absence of drilling-induced tensile fractures were used to further constrain the possible SHmax magnitudes, providing end-member potential values.

The pore pressure and stress gradients derived from the analyses of well bore data, enabled the *in situ* stresses to be resolved onto the faults using a 3D geological model of the Captain Sandstone and its overburden. Several stress field cases were considered with varying magnitudes of SHmax. Slip Tendency (Ts), the ratio of shear to normal stress, was calculated for each of the faults cutting the area of interest, and used to identify particular areas where fault orientations are close to being critically stressed, and therefore most susceptible to becoming reactivated (Fig 1.). Over the different stress scenarios the risk of reactivating the faults appears to be highly variable depending on the particular stress conditions imposed. Pore fluid pressure increases required to cause reactivation of the faults ranges from as low as several kPa to more than 20 MPa across the scenarios.

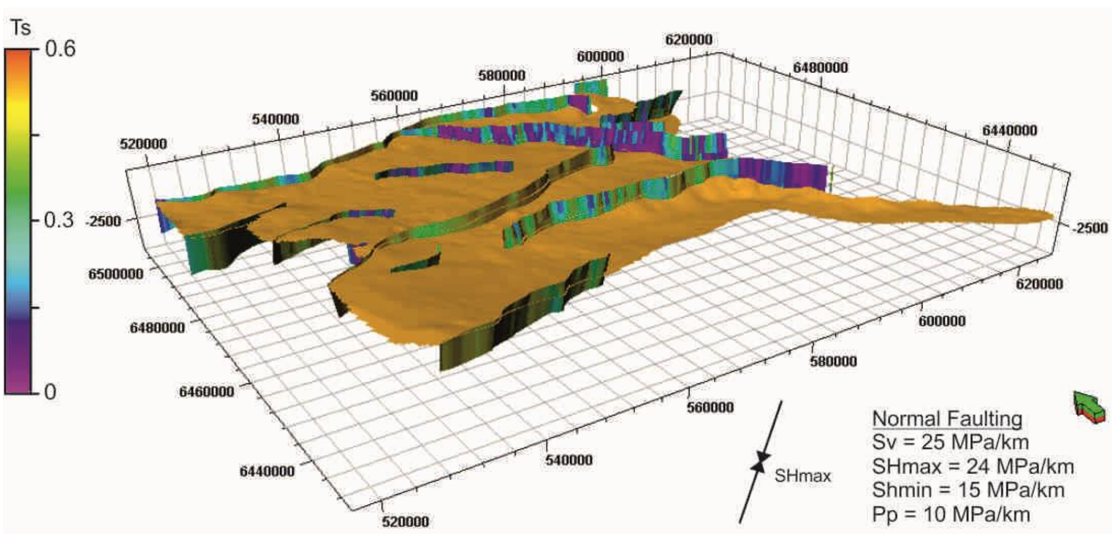

Fig 1. Fault model colored by slip tendency values for one of the stress magnitude cases. Higher slip tendency values highlight faults that are closer to being critically stressed. Surface shown is the top Captain Sandstone.

This study illustrates a workflow for assessing the containment risk posed by faults mapped at the basin scale, which will be useful as an initial assessment prior to detailed site-specific studies. The results may be helpful in refining initial storage capacity estimates, as particular areas where faults may pose a greater containment risk can be identified. Some areas of uncertainty are highlighted, such as rock strength, which would need to be explored during the appraisal process for a specific site. A reduction in the parameter uncertainty would likely rule-out some of the more conservative end-member cases presented.