

Stress state and stress path evaluation to address uncertainties in reservoir rock failure in CO₂ sequestration in deep saline aquifers: An experimental study of the Hawkesbury sandstone formation

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ABSTRACT

Injecting CO₂ into aquifer pore fluid (high salinity brine) in deep saline aquifers during the sequestration process causes the chemico-mineral structure to be altered through complex chemically-coupled mechanical deformations. This is as yet poorly understood in the field. The authors conducted a series of tri-axial strength tests on Hawkesbury sandstone under in-situ stress and temperature conditions to characterise the behaviour of reservoir rock upon exposure to super-critical CO₂ (ScCO₂) to determine this chemically-coupled mechanical behaviour.

According to the findings, injection of CO₂ into a brine-saturated reservoir rock mass may cause a considerable strength reduction, probably due to the rock's mineralogical alteration-induced mechanical weakening of grain contacts. This was confirmed by SEM analysis, according to which the mineral dissolution process upon exposure to ScCO₂ is significant, and considerable quartz and calcite dissolution were noticed in the tested samples. Importantly, this rock mineral dissolution may alter the reservoir's natural pore geometry. This eventually affects the effective stress patterns acting on the rock matrix. In addition, the slip tendency of brine + CO₂-reacted reservoir rock is increased with increasing injection pressure, revealing the fate of the resulting pore pressure-dominant effective stress field through the CO₂ injection process. The results were then incorporated in the effective stress field model. This model can be used to predict the possibility of mechanical failure of reservoir rock upon CO₂ injection into saline aquifers.

1. Introduction

CO₂ injection causes the existing effective stress field in deep saline aquifers to change during long-term CO₂ sequestration. This altered stress field may increase the stress carried by the load-bearing grain framework in the rock matrix, resulting in poro-elastic compaction and sudden collapse in the reservoir formation during the production process [1–4]. The CO₂ storage and monitoring processes in saline aquifers however remain little understood, particularly the physio-chemical reactions that occur in saline aquifers during the CO₂ storage process, which increase the risk of CO₂ leakage through the depleted reservoir formation after CO₂ injection. In-depth knowledge related to the mechanical behaviour of reservoir rock is therefore required to ensure the long-term integrity of the CO₂ sequestration process in saline aquifers.

Such in-depth knowledge cannot be gained without investigating the mechanical behaviour of natural aquifers (brine-saturated formations before injection) under in situ stress conditions. This has therefore been considered by several researchers [5–8]. Rathnaweera et al. [6]

investigated the mechanical behaviour of natural aquifers in the uni-axial stress environment, paying special attention to the salinity-dependent strength characteristics of reservoir rocks. However, the actual behaviour of aquifers cannot be understood by ignoring the effective stress effect. Therefore, the salinity-dependent strength variation of natural reservoir rock under confined stress condition was studied by Rathnaweera et al. [7]. Later in 2015, Rathnaweera et al. [8] studied the changes in CO₂ sequestration process-induced mechanical properties in saline aquifer reservoir rocks. Since CO₂ sequestration in deep saline aquifers is a long-term process, there is long-term geochemical interaction among the brine/CO₂ and the reservoir rock minerals. Therefore, Rathnaweera et al. [7] studied the mechanical property alterations which occur in long-term brine/CO₂-reacted Hawkesbury sandstone in an unconfined environment to investigate the influence of brine/CO₂/rock interaction on the mechanical behaviour of reservoir rock. This study revealed the significance of the brine/CO₂/rock interaction on reservoir rock strength. Although this study revealed the effect of brine/CO₂/rock mineral interaction on the mechanical

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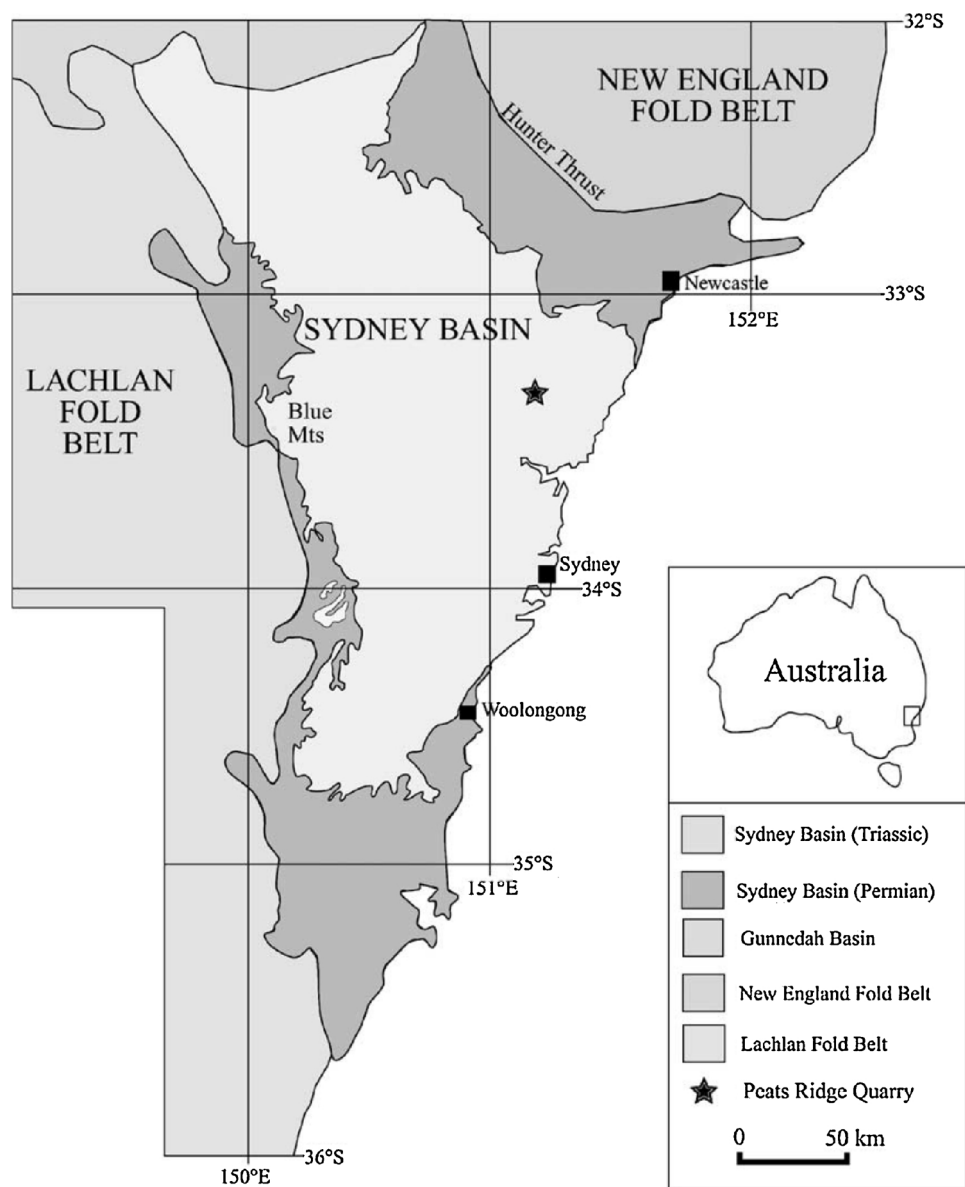


Fig. 1. Simplified geological map of the Sydney Basin, Australia [9].

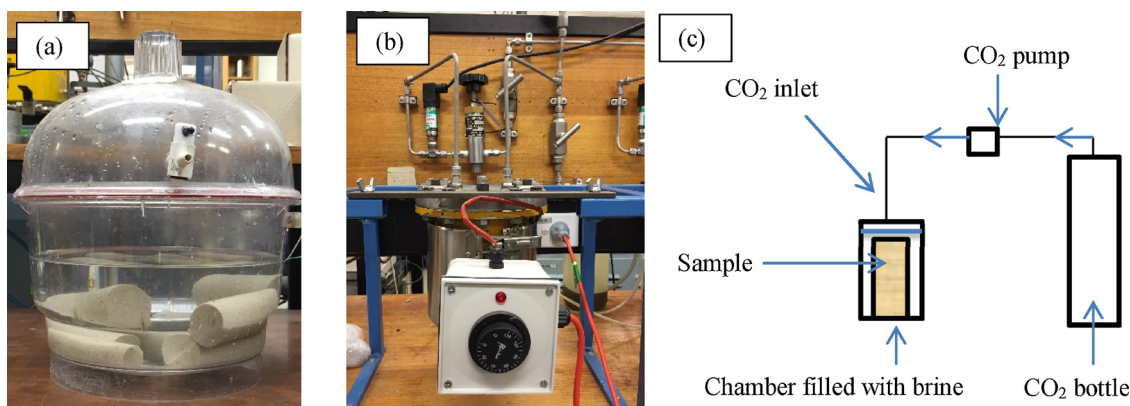


Fig. 2. (a) The set-up of desiccators used for brine-saturated samples (b) the set-up of saturation chambers used for brine + CO₂-reacted samples and (c) schematic diagrams of CO₂ reaction chamber.

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