International Journal of Greenhouse Gas Control 21 (2014) 33–48

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

Geomechanical behavior of Cambrian Mount Simon Sandstone reservoir lithofacies, Iowa Shelf, USA

Thomas Dewers[a,*], Pania Newell[b], Scott Broome[a], Jason Heath[a], Steve Bauer[a]

[a] Geomechanics Department, P.O. Box 5800, MS 0751, Albuquerque, NM 87185-0751, United States
[b] Mechanical Engineering Department, P.O. Box 5800, MS 0751, Albuquerque, NM 87185-0751, United States

ARTICLE INFO

Article history:
Received 5 April 2013
Received in revised form 7 November 2013
Accepted 14 November 2013
Available online 25 December 2013

Keywords:
Geomechanics
Sandstone
Mount Simon
Elasto-plasticity

ABSTRACT

The Mount Simon Sandstone (Mt. Simon), a basal Cambrian sandstone underlying much of Midwestern US, is a target for underground CO_2 storage and waste injection which requires an assessment of geomechanical behavior. The range of depositional environments yields a heterogeneous formation with varying porosity, permeability, and mechanical properties. Experimental deformational behavior of three distinct Mt. Simon lithofacies was examined via axisymmetric compressional testing of core samples. Initial yielding was confirmed with acoustic emissions in many tests and failure envelopes were determined for each lithofacies. Evolution of elastic moduli with stress and plastic strain was determined by use of unload–reload cycles, which permit separation of total measured strains into elastic and plastic strains. The Upper Mt. Simon lithofacies yields at higher shear stresses compared to two "Lower" lithofacies, with little modulus degradation with plastic strain. Lower Mt. Simon lithofacies are weaker and deform plastically with modulus degradation. This range in constitutive response is quantified with an elasto-plasticity model. Based on these results, Mount Simon Sandstone would likely deform elastically during CO_2 injection and storage, with large pore pressure increases (∼8–9 MPa above hydrostatic) predicted to initiate plastic yielding. Nonetheless, near-wellbore damage could result in weaker lithofacies during injection and/or brine extraction.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

The Cambrian Mt. Simon Sandstone is a broadly extending deep saline formation in the Midwestern United States that is being targeted for subsurface geologic storage of carbon dioxide, particularly in the Illinois (Leetaru and McBride, 2009; Bowen et al., 2011) and Michigan Basins (Barnes et al., 2009). Disposal injection of waste water associated with shale gas activities into the lower Mt. Simon in Ohio is thought to be responsible for induced seismicity, potentially from unmapped faults in the underlying Precambrian crystalline basement (Zoback and Gorelick, 2012; Zhang et al., 2013). Further, the Mt. Simon in the Illinois Basin and adjacent Iowa Shelf is used for underground storage of natural gas and has been investigated for its potential as an underground reservoir for compressed air energy storage (CAES). This paper examines the elastic–plastic deformational characteristics of three distinct lithofacies in the Mt. Simon that are relevant to the suitability of the Mt. Simon for storage for waste fluids and petroleum resources. Our experimental and modeling approach could be used in performance and risk assessment for other saline formation sandstone reservoirs for subsurface carbon storage.

Driven by the potential for CAES, several exploratory wells were drilled through the Mt. Simon into the underlying Precambrian at a small structural dome near Dallas Center, Iowa, adjacent to the Proterozoic Mid Continent Rift System. One of these, the Keith #1, was cored for a near-complete section of the Mt. Simon including much of the overlying Eau Claire Formation and the underlying Proterozoic "Red Clastics" (Fig. 1A–C). Select sub cores of three select lithofacies were subject to axisymmetric mechanical testing, and samples from each lithofacies were analyzed for porosity, permeability, and composition.

Rock mechanics testing for each lithofacies included one unconfined compression (UCS) test, a hydrostatic compression test, and two triaxial tests at different confining pressures. Results were analyzed in terms of elastic–plastic constitutive behavior associated with each lithofacies, including initial yield and failure surfaces. Unload–reload cycles in most tests allowed the tracking of elastic response post-yielding. A unique elastic–plastic constitutive model developed at Sandia National Laboratories (Brannon et al., 2009) was applied to experimental results up to failure. Essential aspects to describe Mt. Simon lithofacies behavior used in the model include non-associative plasticity, stress-invariant dependent failure, an elliptical cap surface capturing shear effects

* Corresponding author at: Sandia National Laboratories, P.O. Box 5800, MS 0751, Albuquerque, NM 87185, United States. Tel.: +1 505 845 0631; fax: +1 505 844 7354.
E-mail address: tdewers@sandia.gov (T. Dewers).

1750-5836/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijggc.2013.11.010

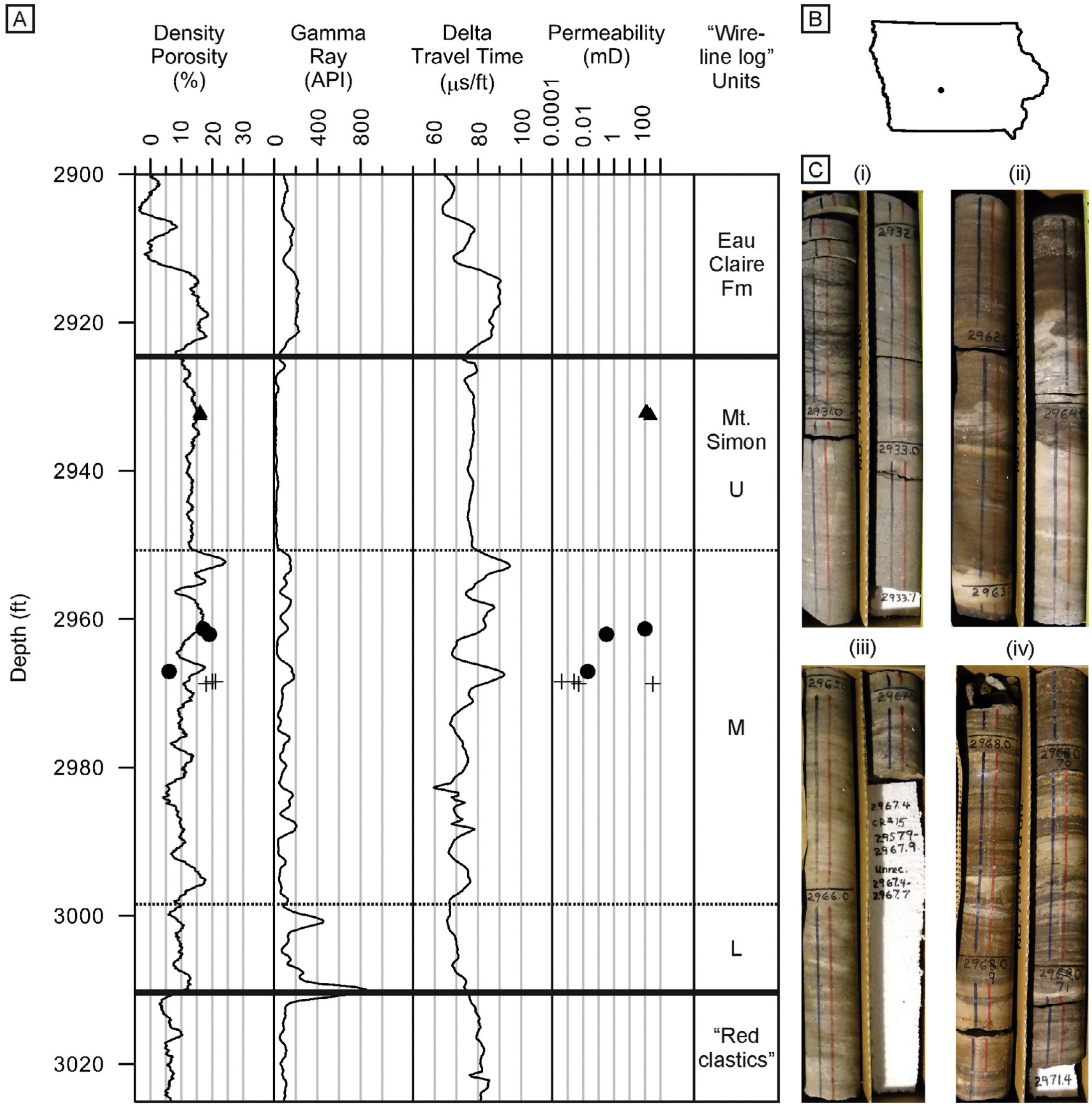

Fig. 1. (A) Wire-line logs, laboratory-measured porosity and permeability, and interpreted "wire-line-log" units for Keith #1 well. Triangle symbols denote the porosity and permeability measurements made on core from the upper portion of the Mount Simon Sandstone; circles and crosses represents distinct lithofacies of the middle Mount Simon Sandstone. All of the permeability and porosity measurements were performed on vertical plugs. (B) Map of Keith #1 well location in Dallas County, Iowa, USA. (C) Photos of core showing examples of lithofacies: (i) upper quartzose lithofacies which we term the 'I' lithofacies; (ii) heterolithic subarkosic-to-arkosic sandstone lithofacies (our 'II' lithofacies) and mudstone-bearing lithofacies (our 'III' lithofacies) with variable hematite cements; (iii) lithofacies that can be very coarse to conglomeratic with pebble-sized clasts; and (iv) very heterolithic facies of arkosic, subarkosic, and mudstone lithologies (mixtures of II and III and other lithofacies). Thin sections and cores for geomechanical tests fall within the depth ranges of (i)–(iv).

on pore collapse, kinematic and isotropic hardening, non linear elasticity and elastic–plastic coupling, among other features. Isotropic stress-dependent static elastic moduli agree within a factor of three with dynamic moduli determined from sonic well logs, and static and dynamic moduli (as well as seismic velocities) between lithofacies are linearly correlated. This correlation may permit application and upscaling of testing results to other reservoir-scale rock mechanics and fluid flow models of the Mt. Simon where wireline log or seismic information is available.

These results suggest that the Mount Simon Sandstone will likely behave elastically under most conditions relevant to geologic carbon storage, requiring relatively large excess fluid pressures to initiate plastic yielding and/or localized deformation. However, wellbore regions subject to large fluid pressure transients associated with CO_2 injection or brine withdrawal (e.g. as could be used to minimize fluid pressure build-up) could experience damaging deformation which could prove detrimental to wellbore performance.

2. Geologic background

The range and distribution of lithofacies in the Mt. Simon reflect deposition during the Upper Cambrian Sauk transgression (Sloss, 1963). The lower Mt. Simon was deposited by broad braided fluvial streams with possible dune fields (Fischietto, 2009; Bowen et al., 2011). Rising sea level produced a broad tidally influenced and widely bioturbated tidal flat sandstone facies associated with migrating barrier island sequences as demonstrated in the middle to upper portions of the Mt. Simon. Increasing sea level led to deposition of more muddy Mt. Simon facies and the marine carbonates and mudstones associated with the Eau Claire Formation, which is regarded as the regional caprock for carbon and gas storage (Person et al., 2010; Zhou et al., 2010).

Download English Version:

https://daneshyari.com/en/article/8091616

Download Persian Version:

https://daneshyari.com/article/8091616

Daneshyari.com