Impact of sequence stratigraphy on static and dynamic reservoir models: examples from the Precipice–Evergreen succession, Surat Basin, Queensland

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SUMMARY

CO_2 storage in the subsurface is a key aspect of climate mitigation. The UQ is investigating whether the Precipice Sandstone and Evergreen Formation in the Surat Basin, Queensland, are an appropriate reservoir-seal pair for the long-term storage of greenhouse gases. However, the Precipice-Evergreen succession remains poorly constrained from a paleo-depositional and stratigraphic standpoint. Studies have mostly applied lithostratigraphy for local correlation, and the understanding of time-stratigraphic relationships across the basin needs development. This has greatly hindered the capacity to construct robust reservoir models and is an active area of research.

We utilized core, wireline logs, seismic reflection surveys, and pressure data to compare the dynamic response to various CO_2-injection scenarios with contrasting stratigraphic architectures. A lithostratigraphic prediction of reservoir and seal intervals consisted of a layer-cake model of fluvio-deltaic deposits. The models suggest that reservoir layers are laterally well-connected with the gas plume primarily migrating parallel to bedding. In contrast, a sequence stratigraphic arrangement of facies resulted in a more complex architecture, where reservoir and non-reservoir strata cross-cut and intersect one another. The resulting models showed greater reservoir heterogeneity and potentially more complex fluid transmission pathways in both the lateral and vertical directions that could result in slower plume migration and more residual trapping. This is due to the fact that discontinuous mudstone intervals potentially baffle the CO_2 plume and may allow for more CO_2 trapping within the lower parts of Evergreen succession. The contrasting models show different geological realizations arising from the same dataset, interpreted in different ways than identify where there is uncertainty. They may highlight certain areas of the basin are more conducive to carbon storage than others.

Fluid flow is highly sensitive to the stratigraphic arrangement of reservoir and non-reservoir intervals. Refining static and dynamic models using sequence stratigraphy may result in a significant improvement in history matching. Modellers should carefully consider the implications of stratigraphic correlations during static model construction.

Key words: Precipice Sandstone, Evergreen Formation, Surat Basin, sequence stratigraphy, static reservoir models, dynamic reservoir models.

INTRODUCTION

Carbon capture and storage (CCS) shows considerable potential for climate mitigation, and especially to offset emissions from coal and gas fired power generation (Metz et al., 2005; IEA, 2008). Regional assessment of sedimentary basins in Queensland have identified the Surat Basin as being highly prospective for CCS because of the depth, favourable reservoir permeability, and the presence of quality reservoir-seal pairs (Bradshaw et al., 2011). The Jurassic Precipice Sandstone–Evergreen Formation interval is a major target for CCS investigation.

In order to investigate the dynamic storage capacity and subsurface fluid flow characteristics of potential CCS reservoirs, static geological models must first be produced and their essential elements incorporated into dynamic flow simulations. These properties include porosity and permeability, in addition to information about geological structure and layering. In areas of the basin where no well data exists, reservoir prediction is derived from conceptual geological models and a stratigraphic framework grounded in seismic data. The stratigraphic correlations, in particular, drive predictions of reservoir heterogeneity and interconnectedness in the vertical and lateral dimensions. However, there is more than one way to sub-divide the stratigraphy of a sedimentary succession. Lithostratigraphy, which uses lithological similarity between layers as a means of correlation has historically been used to subdivided strata. The basic lithostratigraphic unit is the Formation (Murphy and Salvador, 1998). More recently, the stratigraphic paradigm has shifted to facies-driven correlation of geological bodies using the theory and techniques of sequence stratigraphy. Sequence stratigraphy focuses on packaging rocks according to regional bounding surfaces, and uses the Sequence as the major unit (Catuneanu et al., 2011).

The stratigraphy of the Surat Basin has been examined by several workers in the past (e.g., Power and Devine, 1970; Exon, 1976; Exon and Burger, 1981; McKeller, 1998; Hoffmann *et al*., 2009; Totterdell *et al*., 2009; Ziolkowski *et al*., 2014; Wainman *et al*., 2015). However, a regional sequence stratigraphic framework remains elusive. The precise timing of deposition has been debated, resulting in an inconsistently applied stratal nomenclature (Figure 1; McKeller, 1998; Hoffmann *et al*., 2009; Ziolkowski *et al*., 2014). The Precipice–Evergreen interval lacks precise chronometric age dates, and age relationships have mostly been based on palynology. Sequence stratigraphy has been undertaken in the Surat Basin, incorporating varying datasets and with different resolutions (e.g., Wells *et al*., 1994; Hoffmann *et al*., 2009; Totterdell *et al*., 2009; Ziolkowski *et al*., 2014). Three "supersequences" were interpreted from the Surat Basin in Queensland and New South Wales by Hoffmann *et al.* (2009) and Totterdell *et al*. (2009). A higher resolution interpretation of the sequence stratigraphy was undertaken by Ziolkowski *et al.* (2014) that suggested the Precipice–Evergreen succession consists of 3 unconformity-bound sequences (Fig. 1).

This study aims to integrate geology (sedimentology and stratigraphy) with seismic, pressure data, and petrophysical core analysis to compare the dynamic response of reservoir models to various CO_2-injection scenarios with contrasting stratigraphic architectures. The impact of stratigraphic framework is important to assess, as it represents the large-scale organization of reservoir and non-reservoir geobodies that characterize static and dynamic models. Moreover, reservoir characteristics and the connectivity of reservoirs is predicted in areas of sparse data using the preferred stratigraphic model, and these happen to be the most prospective areas for CCS development.

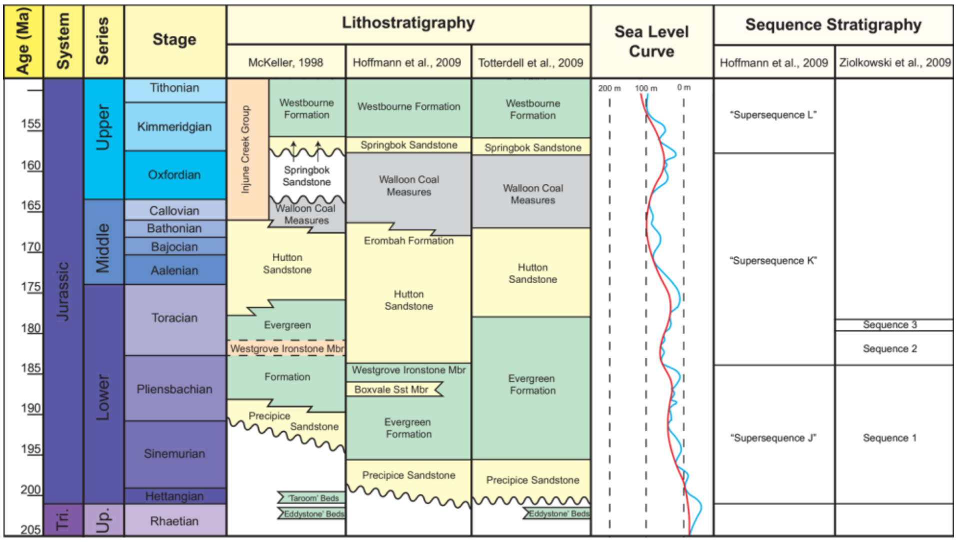

Figure 1 – Comparison of lithostratigraphic and sequence stratigraphic schemes used to characterize the Surat Basin stratigraphy accompanied by the global eustatic sea level curve (Haq *et al.* 1987).

DATASET AND METHODS

The geological and stratigraphic characterization of the Surat Basin was primarily based on five cored wells: Chinchilla 4, West Wandoan 1, Woleebee Creek GW4, Condabri MB9-H, and Reedy Creek MB3-H. An additional ~200 wells with wireline logs were incorporated with the core data and facilitated correlation of regional fences. Approximately 4000 2D seismic lines, and nine 3D seismic volumes were calibrated to core and logs with appropriate time-depth relationships. Key lines and volumes that pass through the cored wells were the main focus, but additional seismic data was also used. Seismic data was tied to wireline logs using synthetic seismograms created with the sonic and density logs.

Sedimentary facies were interpreted from core, and their respective "electro-facies" were identified in logs. Seismic reflectors were objectively identified from the data and their depths were constrained by comparing against core and synthetic seismograms. Seismic reflectors were traced laterally and truncations between reflectors were identified. The important regional surfaces interpreted from seismic, and tied to core, were traced across the basin using logs. Core data was also used to understand the core analysis-to-log relationship for each reservoir property.

Static reservoir models were built using Petrel and consisted of a stratigraphic framework, facies / electrofacies classification, as well as log property assignment – porosity, permeability, and net:gross. The scale of static models varied by location, from single well models in areas of very sparse data to more complex sector models incorporating several wells and 3D seismic in data-dense areas. Static reservoir models were exported for numerical simulation. Dynamic models used Petrel. Models were tested for sensitivity to the scale of gridding. The vertical resolution of gridding varied from 1 to 10 meters, whereas grids in the horizontal direction varied from 10 m (e.g. near wellbores) to 500 m. Dynamic models were first run using a previously defined lithostratigraphic stacking pattern of flow units, and these results were compared against models run using the updated sequence stratigraphic stacking pattern.

RESULTS AND INTERPRETATION

Single and multi-well flow simulations were run from a key part of the basin, the Managed Aquifer Recharge (MAR) area. The simulations were anchored to existing dynamic data to better calibrate the models. Using lithostratigraphy, models showed good continuous lateral communication of pressure and relatively homogeneous pressure build-up, indicating that reservoir sandstones (i.e., the Precipice Sandstone) are sheet-like. By contrast, using a sequence stratigraphic organization of facies with more complex lateral and vertical geometry of flow units, yielded dynamic models that showed anisotropic pressure build up, with significantly more lateral and vertical variation than in the lithostratigraphic scenario. We interpret this to be more representative of the complex geology, and our interpretations are supported by a better history-match. Heterolithic (interbedded sandstone and mudstone) "thief zones" had substantial impacts on fluid flow in the sequence models, but were negligible in the lithostratigraphic models. This is due to the fact that mudstone intervals baffle the CO_2 plume and add anisotropic complexity to the reservoir. The contrasting models show different geological realizations arising from the same dataset, interpreted in different ways.

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CONCLUSIONS

There are significant, demonstrable differences in dynamic flow simulations that relate directly to the interpretation of the stratigraphic arrangement of flow units. Lithostratigraphy tends to overestimate reservoir interconnectedness and intraformational seal continuity, because it does not capture the complexity of realistic facies distribution. A sequence stratigraphic interpretation of reservoir and seal distribution is a more geologically reasonable approach and leads to conservative static and dynamic models by improving the prediction of baffles and barriers to fluid flow. Future efforts to characterize reservoir-seal pairs for CCS should utilize sequence stratigraphy as the basis for model construction.

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