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Research paper

Complementing coal seam gas facies modelling workflows with decompaction based processes

D. Shields*, F. Zhou, A. Buchannan, J. Esterle

School of Earth and Environmental Sciences, The University of Queensland, Australia

A R T I C L E I N F O

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A B S T R A C T

Differential compaction plays a key role in influencing the palaeogeographic organisation of many depositional systems. In the Jurassic Walloon Subgroup, Surat Basin, Eastern Australia, the process of compensational stacking contributes significantly to the complex coal layer architecture and is documented in mine exposure, borehole and seismic datasets. Despite this understanding, current best-practices do not formally consider the mechanics of compensational stacking when populating palaeogeography facies in coal seam gas (CSG) reservoir models. To address this limitation, a hybrid modelling workflow was developed in which numerical rules representing the process of differential compaction are used explicitly to condition an iterative workflow containing traditional geostatistical facies modelling algorithms. The workflow is facilitated by a newly developed open source plugin which allows grid decompaction in Schlumberger PETREL™ 2015. Application of the workflow was tested in a CSG production area containing closely spaced wellbores and a 3D seismic survey. In this area, facies models were constructed using both traditional geostatistical approaches and the newly developed hybrid methodology. Comparison of these models suggests that facies models constructed via unconstrained geostatistical approaches often result in unrepresentative realisations, inconsistent with coal seam architectures as observed in seismic and outcrop. The hybrid geostatistical-forward modelling approach developed during this study was better able to reproduce complex alluvial stacking patterns, particularly with respect to coal seam amalgamation, bifurcation and washout.

1. Introduction

Field-scale numerical earth models are useful in understanding the structure of geological systems and can be interrogated to predict reservoir behaviours in response to certain input conditions (Tipper, 2008). Within the CSG industry, these predictions often underpin techno-commercial subsurface activities including field development and reserve estimation. The predictive capability of these models relies, in part, on their ability to accurately represent the three-dimensional distribution of rock and fluid properties within a reservoir (Hosseinia et al., 2013). Depositional facies provide a representation of palaeogeography and are a principal control upon the spatial distribution of reservoir units, as well as the hydraulic connectivity within or between reservoirs (Eichhubl et al., 2004; Ayers, 2002). Recognizing this, most reservoir modelling workflows use palaeogeographic facies to guide the subsequent population of rock types and reservoir properties. While a variety of facies modelling methodologies exists, they can be generalised into two broad categories: 1) geostatistical approaches which honour statistical distributions and predefined spatial or temporal relationships and 2) stratigraphic forward modelling methods which populate facies using numerical rules intended to approximate geological processes.

Geostatistical approaches populate facies properties via pre-defined input distributions and spatial relationships sourced from analogues or empirical datasets. These methodologies employ a variety of geostatistical tools to generate spatial probability fields which are used to create stochastic realisations of the subsurface. Variogram models, describing the decay of correlation with offset, are one such geostatistical tool used commonly in pixel based facies population algorithms such as indicator kriging, sequential indicator simulation (SIS) or truncated Gaussian simulation (TGS) (Journel, 1983). Model outcomes generated using these techniques are statistically robust but may appear pixilated, failing to capture the true structure of the geological system they are intended to

* Corresponding author.
E-mail address: darenjshields@gmail.com (D. Shields).

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represent (Deutsch, 2006). Object based techniques such as Marked Point modelling populate physical entities of predefined shapes and sizes to represent geologically meaningful depositional sub-environments such as channels or lobes (Holden et al., 1998). Facies models constructed using object modelling can produce geologically meaningful outcomes; however sometimes these may be an overly idealised representation of a geological system and may not honour all input data (Seifert and Jensen, 2000). Multi-point statistics (MPS) was developed to reproduce more complex geological structures than can be rendered using traditional two-point statistics, without the use of idealised objects. In multipoint statistical workflows, the variogram model is replaced by a search mask which explores a pre-selected training image to describe higher order statistics (Silva and Deutsch, 2014). Once the spatial interactions between the training image facies are defined, a model can be constructed by applying these relationships to the observed dataset. Training images are conceptual models of the subsurface describing geological variability in three dimensions; however, given the uncertainty inherent to geological datasets the selection of an appropriate training image is often subjective (Comunian et al., 2012). Multipoint statistics succeeds in reproducing the complex spatial relationships inherent to many geological systems; however, model outcomes are highly dependent upon which training image is selected (Boisvert et al., 2007). Furthermore, while 2D training images are readily available (eg. digitised from aerial photos), 3D training images describing vertical stratigraphic relationships are more difficult to produce. These limitations may reduce the capability of models constructed using multipoint statistics to meaningfully represent geological stacking patterns. In general, geostatistical approaches are readily applicable and statistically robust; however, the resultant models may be biased based on the inputs, may not honour all input data or may result in geologically unrepresentative outcomes.

Process driven techniques, also termed stratigraphic forward modelling, populate facies using mathematically derived rules to approximate physical geological processes such as sediment dispersion, hydraulics and basin subsidence (Sacchi et al., 2016). Within the realm of stratigraphic forward modelling numerous mathematical approaches including geometric models, diffusion models, and hydraulic models have emerged and been tested in multiple basins (Huang et al., 2015). Stratigraphic forward modelling approaches are able to produce detailed sedimentary architectures; however, this methodology is rarely applied in industry field-scale modelling due to the approach's inability to strictly condition large input datasets. Despite limited direct application in reservoir-scale models, forward modelling approaches are commonly used to develop training images for subsequent use in multipoint statistics based modelling approaches (Straubhaar and Malinverni, 2014). This compound methodology leverages the geological realism achievable in stratigraphic forward modelling, with multipoint statistics' ability to strictly conditioning input datasets.

Both geostatistical and forward modelling methodologies have been previously applied to the Surat Basin (eg. Hamilton et al., 2014; Howell et al., 2013; Bianchi et al., 2015; Erriah et al., 2015; Zhang et al., 2014; Martin and Morris, 2015; Zhou et al., 2016). These earlier studies highlight the challenges in reproducing the complex stratigraphic architecture inherent to heterolithic coal bearing alluvial successions in numerical facies models. In these environments, a series of unique geological phenomena relating to the presence of organic facies result in complex reservoir structures including coal seam amalgamation, coal seam splitting and coal seam washout due to channel erosion. In the Walloon Subgroup (WSG) this complexity is further compounded by the thin, laterally discontinuous and heterolithic nature of WSG coal layers (Martin et al., 2013). Due to these challenges, existing reservoir modelling approaches struggle to capture the Walloon Subgroup's complex stratigraphic architecture and hence may poorly represent the structure of the CSG reservoirs contained therein. Considering the hierarchical nature of subsurface modelling workflows, should the stratigraphic complexity be insufficiently captured within the facies model, the distribution of reservoir units and the prediction of flow structures within or between reservoirs may be compromised in the resulting model.

In alluvial environments (Fig. 1), the process of compensational stacking contributes significantly to the complexity of coal layer architectures (Yago, 1996). Compensation is the tendency for sediment transport systems to occupy topographic lows which

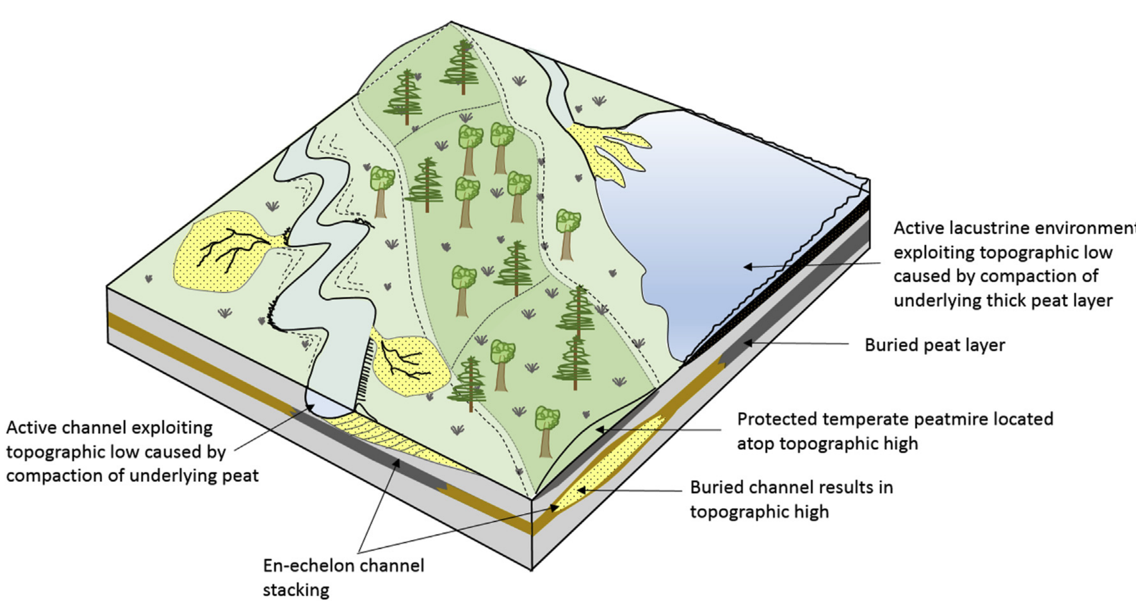

Fig. 1. Schematic of the WSG's depositional environment illustrating the influence of compensational stacking upon alluvial organisation. The location of active fluvial, lacustrine and peat forming environments is partially controlled by topographic variations expressed at the surface due to differential compaction driven compensational stacking.