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Research paper

3D seismic analysis investigating the relationship between stratigraphic architecture and structural activity in the intra-cratonic Cooper and Eromanga basins, Australia

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A B S T R A C T

This research uses four three-dimensional (3D) seismic surveys located in Australia's largest onshore hydrocarbon province, the intra-cratonic Cooper and Eromanga basins, to present an approach that extracts important structural and stratigraphic information from geophysical data that can then be used to define the tectonostratigraphic evolution of subsurface provinces. The methodology consists of: (1) analysing isopach maps; (2) cross-section interpretation of stratigraphic features, erosional surfaces, and faults; and (3) constraining the evolution of fault activity. Most faults within this province are basement-involved with high dip angles. The primary fault set is NE-SW striking, with secondary sets striking N-S, E-W and NW-SE. These high angle faults most likely developed as normal faults before being reactivated by five of the six major tectonic events. Field scale NW-SE strike-slip faults are prolific and can often be overlooked due to the low seismic resolution. A close relationship between on-lapping features and present-day structural highs was found during each of the major structural events, particularly within hydrocarbon-rich Permian stratigraphy, inferring that present-day structures were present throughout basin development and intermittently reactivated. Significant stratal-package thinning, and a high presence of on-lapping features, were associated with regional basement-involved faults, particularly along the Gidgealpa-Merrimelia-Innamincka and Murteree-Nappacoongee ridges. Initial structural trap development occurred during the early Permian, but was most significant during the Late Triassic. Hydrocarbon accumulations were unaffected by structural growth after the critical moment in the petroleum system (90 Ma), as the final period of fault activity was during the Late Cretaceous. This research constrains the tectonostratigraphic evolution of the intra-cratonic Cooper and Eromanga basins, while detailing an approach that extracts and analyses important structural and stratigraphic information from geophysical data, where outcrop is not accessible.

1. Introduction

Structural and stratigraphic studies are often accompanied by hard data measured directly from outcrop (e.g. Lacombe et al., 2007, 2009; Amrouch, 2010; Amrouch et al., 2010a, 2010b, 2011; Beaudoin et al., 2012, 2014; Lin and Yamashita, 2013; Arboit et al., 2015, 2017; Burgin et al., 2018); however, this is difficult in regions that are entirely subsurface. For such provinces, wellbore core and geophysical data analysis are the only means of obtaining important structural and stratigraphic information and can be equally as representative as direct measurements from outcrop (e.g. Cartwright et al., 1998; Wiprut and Zoback, 2000; Manzi et al., 2015; Szalaiová et al., 2015; Kulikowski et al., 2017; Kulikowski and Amrouch, 2017; Ryan et al., 2017). Three-dimensional (3D) seismic surveys covering the subsurface Cooper and Eromanga (Cooper-Eromanga) basins (Fig. 1), Australia, are used as a case study for this work to present a methodological approach for constraining the relative timing of structural activity through the interpretation and analysis of the present-day stratigraphic architecture of the region. Development of accurate 3D tectonic and stratigraphic models are fundamental to gain a better understanding of the evolution of subsurface provinces, as they: (1) present the influence of structural growth, or subsidence, on the depositional patterns within a basin; (2) assist in constraining the periods of structural movement, fault reactivation and timing of structural trap development; (3) can be used to develop hydrocarbon migration pathway and accumulation models; (4) constrain the preferred location of sediment deposition through time; and (5) assist in the exploration and development of hydrocarbons.

The structural and stratigraphic complexity of the Cooper-Eromanga

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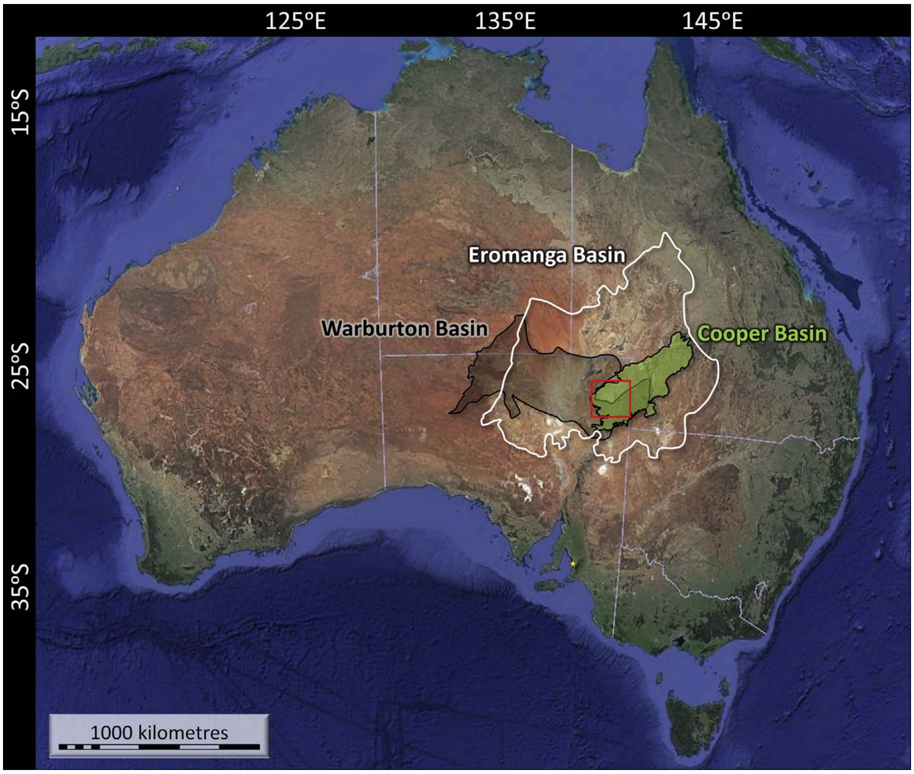

Fig. 1. Location of the Cambrian to Silurian Warburton, Permian to Triassic Cooper and Jurassic to Cretaceous Eromanga basins, Australia (Kulikowski et al., 2016a). Study area shown in red. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Basin (Fig. 1) has been conjectural since its first commercial hydrocarbon discovery in 1963 (Gravestock and Jensen-Schmidt, 1998). The majority of hydrocarbons in this province are reservoired within Permian fluvial sediments with exploration companies currently exploring for stratigraphic traps that have a close association with paleo-structural highs (Fig. 2) (Gravestock et al., 1998). Although significant research has been made to better understand the evolution of this basin (Kantsler et al., 1984; Kuang, 1985; Apak et al., 1997; Sun, 1997; Kulikowski and Amrouch, 2017), the intricate relationship between fault movement and the stratigraphic architecture remains poorly defined, and is in part due to a conservative approach when drawing conclusions from old, poor resolution and sparse two-dimensional (2D) seismic lines that were not time-to-depth converted. The difficulty of interpreting old and poor resolution 2D seismic data within the Cooper-Eromanga Basin is showcased in the transition between fault models, alternating between interpretations of extensive normal faulting (Gatehouse, 1986; Gravestock and Jensen-Schmidt, 1998), to interpreting the same structures as reverse faults (Sun, 1997), and to relatively more recent models that accept the presence of strike-slip features amongst inverted faults (Kuang, 1985; Apak et al., 1997; Grant-Wooley et al., 2014; Kulikowski and Amrouch, 2017; Kulikowski et al., 2017).

This study uses four 3D seismic surveys, located along major structural features, to define the tectonostratigraphic evolution of the intra-cratonic Cooper-Eromanga Basin (Fig. 3). Seismic data was depth converted, re-processed into incoherency volumes, interpreted for faults, stratigraphically interpreted, and divided into key stratal-units to create isopach maps. Cross-sections are interpreted through each of the 3D seismic surveys to constrain the timing and distribution of stratigraphic features related to structural growth, and to define the distribution and geometry of faults. To improve the accuracy of fault interpretation and assist in determining the depth of fault termination, seismic incoherency analysis is incorporated into the methodology and extracted along four key seismic reflector surfaces. The results are presented for seven hydrocarbon producing field to ensure minor details are not overlooked and to make it simple for readers to access data. The results are also discussed in a basin-wide context through time to provide regional relationships between structural growth and the distribution of stratigraphic features within hydrocarbon-rich stratal-units. The six structural events are finally linked to their influence on sediment deposition, erosion, and the timing of structural and stratigraphic trap development.

The structurally complex Cooper-Eromanga Basin has been affected by numerous regional tectonic events (Alice Springs: 450-300 Ma; Mid-Permian: 290-270 Ma; Daralingie: 258 Ma; Hunter-Bowen: 245-190 Ma; Late Cretaceous: 95-65 Ma; and Paleogene: 33-23 Ma) and undergone local stages of compression and flexural relaxation, which has developed a tectonostratigraphic architecture that is difficult to determine (Kulikowski and Amrouch, 2017). The difficulty is further compounded by the absence of outcrop and the previous use of poor resolution and sparse 2D seismic data (Kuang, 1985; Apak et al., 1997; Gravestock and Jensen-Schmidt, 1998). The uncertainty of seismic interpretation below the thick Permian coal measures enhances the difficulty of stratigraphic interpretation. Results from this study provide insights into the intricate relationship between structural movement, sediment deposition, and structural trap development that can be used for future hydrocarbon exploration and development programs and highlights the benefit of such studies to subsurface provinces where measurable outcrop is not available.

2. Geological setting

The Late Carboniferous to Middle Triassic Cooper Basin is a structurally complex intra-cratonic basin that is separated by unconformities to the overlying Jurassic to Cretaceous Eromanga Basin, and the underlying Cambrian to Silurian Warburton Basin (basement) (Fig. 2) (Kantsler et al., 1984; Bradshaw, 1993; Apak et al., 1997; Gravestock and Jensen-Schmidt, 1998; Kulikowski et al., 2016a, 2016b; Kulikowski, 2017). Understanding the evolution of this province has proven a difficult task, with early works providing contradicting results (Kantsler et al., 1984; Kuang, 1985; Bradshaw, 1993; Apak et al., 1997; Sun, 1997; Gravestock and Jensen-Schmidt, 1998), which was largely