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Research paper

Sedimentary facies analysis, mineralogy and diagenesis of the Mesozoic aquifers of the central Perth Basin, Western Australia

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A B S T R A C T

Assessment and successful exploration for, and exploitation of, aquifers in the Perth Basin require knowledge of their petrophysical and sedimentological characteristics and geometries. This study provides a sedimentological and lithofacies analysis of core from the Mesozoic Yarragadee Formation, Cadda Formation, Cattamarra Coal Measures, Eneabba Formation and Lesueur Sandstone of Western Australia recovered from Pinjarra-1, Cockburn-1, Gingin-1 and Gingin-2 wells provide insights into changes in depositional environment over time and space in the central Perth Basin. In studied sections, nine different fluvial-dominated lithofacies have been identified in the Yarragadee Formation, Cadda Formation and Cattamarra Coal Measures that occur in similar proportions, whereas the Lesueur Sandstone is dominated by coarse-grained deposits of high energy fluvial systems. Vertical variation in lithofacies on the order of 10 cm to approximately 2 m vertical scale is observed in all formations and wells. Changes in the lithofacies, linked to local depositional environments, are probably associated with fluvial-alluvial to fluvio-deltaic systems that have complex 3D architecture, including braided and to probably meandering systems, and are affected by channel avulsion. Point counting and automated mineral analysis of thin sections of core showed detrital mineralogy dominated by monocrystalline quartz, with rare polycrystalline quartz, a moderate amount of alkali feldspar and very minor amounts of garnet, organic fragments, muscovite and biotite. These data show a lithofacies-dependence of the proportion of minerals, with little variation between equivalent lithofacies from different depths, formations or wells. Grain size and sorting, that have a first order control on porosity, are strongly lithofacies dependent. Individual lithofacies types show a trend of decreasing porosity with depth due to the increasing effects of compaction, quartz overgrowth cementation and authigenic clay mineral development. Lithofacies and depth are the main controls on permeability, and so lithofacies distribution exerts a key control on hydraulic behaviour.

1. Introduction

The Perth Basin (Fig. 1) has a deep (up to 15 km) and varied (Permian–Recent) sedimentary fill, including numerous unconfined and confined groundwater aquifers (Davidson, 1995; Harris, 1994; Playford et al., 1976; Davidson and Yu, 2006). Locally, some of these ‘aquifers’ are also important hydrocarbon reservoir units (Crostella and Backhouse, 2000), potential targets for ‘hot sedimentary aquifer’ geothermal exploration (Corbel et al., 2012; Timms et al., 2012; Reid et al., 2012; Delle Piane et al., 2013), or potential repositories for CO_2 storage (Causebrook et al., 2006; Stalker et al., 2013; Olierook et al., 2014a). The Triassic Lesueur Sandstone and Jurassic Yarragadee Formation (Fig. 1) are two of the most important aquifer units, with thicknesses of up to 2000 m, and subsurface depths between 50 and >2000 m, respectively. These units, therefore, form a substantial proportion of Perth's deep groundwater resources, and are key potential targets for shallow

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geothermal heat extraction. A predominantly fluvial origin has been inferred for the Lesueur Sandstone and Yarragadee Formation (Playford et al., 1976). However, significant spatial and temporal variations in sedimentary processes, porosity and permeability have been identified (McWhae et al., 1958; Johnson, 1965; Brownhill, 1966; Jones and Nicholls, 1966; Smith, 1967; Playford et al., 1976; Davidson, 1995; Delle Piane et al., 2013). The well completion reports only describe the sedimentology of each formation at a basic level (e.g., the Yarragadee Formation consists of sandstone and mudstone). A more detailed description of the sedimentology and depositional environment for these formations exists for sparse outcrops over 300 km away in the northern Perth Basin (Playford et al., 1976; Crostella and Backhouse, 2000). To date, a lithofacies analysis of these key stratigraphic units has not been undertaken in the central Perth Basin. This study aims to address the paucity of data on Mesozoic formations in the central Perth Basin through lithofacies and petrographic analyses of core data, having implications for aquifer/reservoir development.

Sedimentary depositional environments exert a primary control on lithologies and rock unit architecture. In turn, lithological variations at all scales, related to both deposition and diagenesis, exert a first order control on porosity and permeability. Previous investigations report wide ranges of key petrophysical properties such as porosity and permeability in the Mesozoic Perth Basin formations (Johnson, 1965; Brownhill, 1966; Jones and Nicholls, 1966; Smith, 1967; Delle Piane et al., 2013; Olierook et al., 2014a; Esteban et al., 2015). For example, the Yarragadee Formation penetrated by the Cockburn-1 well shows 6 orders of magnitude variation in permeability from 0.0022 to 1403 mD that does not have a straightforward relationship with depth. (Delle Piane et al., 2013). Knowledge of the porosity and permeability structure of target rocks is essential for modelling fluid flow in steady-state scenarios, yet the links between sedimentology, porosity and permeability had not been systematically examined. Improved understanding of lateral and vertical variations in depositional environments and their influence on lithological heterogeneity and sedimentary geometries are essential to better characterise flow variability and connectivity within the system. Examination of spatial and temporal changes in lithofacies is also pertinent to evaluating controls on changes in depositional environments during the Mesozoic evolution of the Perth Basin.

Mineralogy and porosity/permeability are key considerations for geothermal or hydrocarbon exploration, CO_2 capture and storage and aquifer management in the central Perth Basin (e.g. Crostella and Backhouse, 2000; Ghori, 2008; Varma et al., 2009; Reid et al., 2012; Ricard et al., 2012; Timms et al., 2012; Schilling et al., 2013; Stalker et al., 2013; Olierook et al., 2014a, 2014b; Esteban et al., 2015). Knowledge of grain size distribution and cements is vital for assessment of the physical integrity of potential reservoirs. An evaluation of the mineralogy of potential reservoirs and/or aquitards is necessary to understand possible fluid–rock reactions during fluid injection or extraction. Despite mineralogical variations being important for understanding siliciclastic sediment provenance, and via diagenetic alteration being linked to pore system evolution, siliciclastic component data is lacking for the central Perth Basin (Davidson, 1995). Furthermore, there are no previous studies of the diagenetic fabrics of the central Perth Basin, and their effects on porosity and permeability have not been assessed.

This study presents new data from sedimentary logging, lithofacies analysis and interpretation of the environment of deposition during the Mesozoic in the central Perth Basin based on core samples recovered from Pinjarra-1, Cockburn-1, Gingin-1 and Gingin-2 wells. New mineralogy data from rock samples from these sedimentary units are discussed in the context of lithofacies.

2. Geological background

The central onshore Perth Basin (Fig. 1) comprises an asymmetric graben known as the Dandaragan Trough, which is an axis-parallel sub-basin bound to the east by the N–S trending Darling Fault, and compartmentalised to the north and south by major oblique fault zones (Playford et al., 1976; Cockbain, 1990; Harris, 1994; Wilde and Nelson, 2001). The western margin of the Dandaragan Trough is taken to be the South Turtle Dove Ridge – an inverted half graben which separates the Dandaragan Trough from the offshore Vlaming sub-basin (Cockbain, 1990; Lockwood and Iasky, 2004). The Dandaragan Trough represents the deepest part of the Perth Basin where up to 15 km of sedimentary succession was deposited from the Permian to Recent (Cockbain, 1990; Frog Tech, 2005; Timms et al., 2012).

The depositional environment in the central Perth Basin was fluvial-dominated from the Permian to the Jurassic, with possible marine incursions, resulting in the sequential deposition of the Lesueur Sandstone, Eneabba Formation, Cattamarra Coal Measures, Cadda Formation and Yarragadee Formation (Fig. 1) (Crostella and Backhouse, 2000). These formations were deposited during the main rift phase of basin development as Greater India and Australia separated during the breakup of Gondwana (Harris, 1994). The long-lived predominantly fluviatile system in the central Perth Basin implies that sedimentary fill approximately kept track with rift-related accommodation space generation. The Dandaragan Trough–Mandurah Terrace has been partially compartmentalised by syn-rift faulting, and the drainage patterns during the Permian to Jurassic are unclear (Harris, 1994). Potential detrital source rocks include the Archaean to Proterozoic rocks of the Yilgarn Craton, the Leeuwin Block, the Albany Fraser belt, the East Antarctic Craton or Greater India (Sircombe and Freeman, 1999; Cawood and Nemchin, 2000; Kohn et al., 2002; Veevers et al., 2005).

The burial history of the central Perth Basin is not well understood. Average burial rates for the deepest parts of the Dandaragan Trough–Mandurah Terrace system (12 km) must have been approximately 40 m/Myr, assuming continuous linear burial rates since the Permian. However, actual burial rates could vary significantly from this value across the central Perth Basin due to unknown additional overburden prior to Valanginian uplift and erosion (formerly known as the Neocomian Unconformity), and differential subsidence related to local faulting. Apatite fission track data from the northern Yilgarn Craton suggests slow, continuous exhumation of the craton during the Early Permian through to Mid-Late Jurassic; considered to be due to removal of a sedimentary blanket rather than erosion of cratonic material (Weber et al., 2005). Vitrinite reflectance data from the Permian coal measures in the nearby Collie Basin (Fig. 1) indicate the presence of an extra ~1.4 km of sedimentary cover to achieve the inferred maximum burial temperatures of ~100 °C (Le Blanc Smith, 1993). However, it is unclear whether this inferred removal of overburden strata also applies to the onshore Perth Basin.

3. Summary of the stratigraphy of Pinjarra-1, Cockburn-1, Gingin-1 and Gingin-2

The locations of wells studied are indicated in Figure 1, with the depths of stratal unit boundaries given in Table 1. Formation boundaries are taken from well reports with Table 2 summarising the key palynomorphs used to discriminate age, listed by well and formation. The full fossil listing may be found in each of the well completion reports (Johnson, 1965; Brownhill, 1966; Jones and