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An outcrop gamma ray study of the Tumblagooda Sandstone, Western Australia

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Abstract

Outcrop of the Tumblagooda Sandstone, Western Australia, is used to demonstrate the internal heterogeneity in ancient fluvial and deltaic systems and the potential difficulties for correlation and prediction of sandbody geometry in the subsurface. Twenty-two gamma ray (GR) logs were measured from a 50 m × 6.5 km coastal section in three facies associations (A–C) interpreted as braided river, overbank/interdistributary and distributary channel to distributary mouth deposits, respectively.

Five informal units are identified with the aid of the GR logs: Units 1–3 are braided river sandstones of Association A; Unit 4 overbank/interdistributary deposits of Association B (subdivided into 4a–4c); and Unit 5 is dominated by distributary channel sandstones of Association C.

The GR log profiles for the braided river deposits are smooth to ratty and highly variable in shape. Classic cylinder and bell profiles are present, as are funnel shapes. Lateral correlation based upon log character was impossible in Unit 1 (about 15 m thickness), even over short distances (i.e. 50 m). Despite layer-cake bedding, correlation was only possible in Units 2–3 (approx. 5 m thickness) by the field mapping of several sandstone benches and a regional pebbly marker (Gabba Gabba Member). Correlation for more than a kilometre based upon the log shape and lithology appears futile.

The GR log profile for the overbank/interdistributary deposits of Unit 4 resolves the metre to sub-metre scale interbeds of very-fine grained and coarser grained sandstones. These form sheet sand bodies that stack together as broadly coarsening-upward cycles, the GR character of which allows lateral correlation for a few hundred metres. These deposits occur at the same stratigraphic height as a distributary channel system to the south, which is approximately 2.5 km wide and belongs to Unit 5.

Unit 5 is composed of vertically stacked distributary channel sands and sheet-like sands that may represent distributary mouths. The channel systems were probably confined by sandy levees. The distributary channel systems and associated deposits are burrowed by *Skolithos* and have low total counts. However, stratigraphic correlation of these sand bodies was difficult due to discontinuous exposures. Nevertheless, several intensely bioturbated horizons appear to be traceable within Unit 5 and probably represent temporary delta abandonment and flooding.

These findings imply that in reservoir modelling of similar deposits caution must be taken not to over-interpret sedimentological models based upon well log character, especially on a limited data set. Stratigraphic correlation based upon sedimentary logs and GR is extremely difficult in the field and could be highly problematic in the subsurface, even in layer cake systems. However, contrary to first impressions, the inability to correlate between subsurface wells may in fact be a clue to a multi-storey, multi-lateral,

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braided river system. The internal heterogeneity described here is below the resolution of conventional well log data (approx. 30 cm), but resolvable on image log and core data. Deciphering the appropriate analogue data and semi-variograms to model and upscale the internal heterogeneity (of this outcrop and similar deposits) in three dimensions is a significant challenge.

Keywords: Outcrop analogue; Gamma ray; Braided River; Deltaic; Distributary channels; Overbank deposits; Bioturbation; Internal heterogeneity

1. Introduction

Gamma ray (GR) logging of outcrop is useful for the characterisation of reservoir analogues (Slatt et al., 1992, 2000) and to improve the understanding of subsurface well log correlations (Slatt et al., 1992). There are numerous reservoir analogue studies across the world that attempt to characterise outcrops in order to understand the reservoir architecture and rock properties of different depositional environments (e.g. Liu et al., 1996; Corbeanu et al., 2001; Jackson et al., 2003; Beaubouef, 2004; Yoshida et al., 2004). Oil companies interested in improved recovery from their portfolio of hydrocarbon fields typically sponsor this work. Data from such studies are generally used to improve 3D geological models of hydrocarbon reservoirs from similar environments (e.g. Ballin et al., 1997; Dalrymple, 2001; Pringle et al., 2004), as subsurface data are limited by well spacing and 3D seismic resolution. Engineers upscale these geological models for reservoir simulation in order to model fluid flow and plan for hydrocarbon extraction with the optimum design of production and injection wells (e.g. Andrews et al., 2004). The reservoir modelling process begins with a stratigraphic framework and a sedimentary facies model, which are calibrated to well and seismic data.

Gamma ray well logs are widely used to correlate and characterise hydrocarbon reservoirs, as they can provide invaluable information on the thickness, geometry, grain size, lithology and volume of shale in sedimentary formations. They are most useful when combined with core or image log data, biostratigraphic information and other well logs (Rider, 1996).

Outcrop GR logging with a hand held tool has become a widely used routine for stratigraphic analysis (Myers and Bristow, 1989; Slatt et al., 1992; Parkinson, 1996) for correlating between outcrops and documenting changes in log motifs that may be associated with variations in grain size and sedimentary environments (Myers and Bristow, 1989; Rider, 1990; Cant, 1992), and for the identification of parasequences and sequence stratigraphic analysis (Van Wagoner et al., 1990; Davies and Elliott, 1996; Ketzer et al., 2002). The usefulness of this technique is somewhat limited by the quality and amount of outcrop, the type of rocks, stratigraphic context, available biostratigraphic information, and the proximity of petroleum or other bores with GR logs. Spectral gamma-ray logs differentiate between potassium, uranium and thorium (K, U and Th) and aid in the identification of certain radioactive minerals such as K-feldspar, or heavy minerals (e.g. monazite), which may mislead log interpreters (Rider, 1990; Hurst, 1990). Outcrop gamma (total and spectral) data can been used in a variety of ways, for example: facies discrimination (Myers and Bristow, 1989; North and Boering, 1999); stratigraphic correlation (Myers and Bristow, 1989; Slatt et al., 2000); sequence stratigraphic interpretations (Van Wagoner et al., 1990; Davies and Elliott, 1996; George, 2000); clay mineralogy and palaeoclimate studies (Myers and Wignall, 1987; Ruffell et al., 2003); geochemical studies (Van Buchem et al., 1992; Svendsen and Hartley, 2001); stratabound ore-zone definition (Ruffell et al., 1998); structural correlations (Hadley et al., 2000); and to differentiate between faults and flooding surfaces (Ruffell et al., 2004). Spectral gamma ray data was measured in the Tumblagooda Sandstone, but the results will be discussed elsewhere.

This study documents the use of gamma ray logging to construct the stratigraphic framework, broad sedimentary facies, and internal architecture of a fluvial-marine transition in the uppermost part of the Tumblagooda Sandstone, south of Kalbarri in Western Australia (Fig. 1). The study area consists of 6.5 km of coastal cliff exposures up to 50 m in thickness, which trend along depositional strike. Despite laterally extensive sheet-like bedding in the Tumblagooda Sandstone, earlier workers have attested to the complexity of its internal architecture and sedimentary facies (e.g. Hocking, 1991; Trewin, 1993a), which are typical of braided river deposits (Miall, 1996). Our study is approximately at the scale of a moderately sized hydrocarbon reservoir in Australia such as the Tirrawarra Field, which is also a braided-river system (Williams and Wild, 1984; see discussion later). The advantage of the Tumblagooda outcrop is that it is possible to walk along many of the exposures and map the subseismic, stratigraphic