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Confined to unconfined: Anatomy of a base of slope succession, Karoo Basin, South Africa

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ABSTRACT

Two contemporaneous weakly confined deepwater systems form Unit B of the Permian Laingsburg Formation are sufficiently well-exposed to allow investigation of the down dip passage from channelized base of slope to distributive deposits over a 25 km dip section, with strike control over some 20 km. A high resolution stratigraphy was established over a 1200 m strike section in the proximal Skeiding locality and extended regionally at a coarser scale. Analysis indicates that Unit B comprises 3 depositional sequences which, at a regional scale, thin towards the N and E. The lowstand systems tract of sequence 1 comprises weakly confined high-aspect ratio, vertically stacked channels cut into a basal frontal lobe system, and are overlain by a regionally correlated condensed hemipelagic mudstone interval (combined TST/HST) that shows evidence of remobilisation in up-dip areas The LST of sequence 2 includes two superimposed channel complexes of different styles that become deeply entrenched 5 km down dip and pass basinward into tabular, distributive lobe sandstones. Sequence 3 is marked by a regional 100 m thick levee complex related to a lower slope channel system and marks a basinward shift in facies. Channel fills in the lowstand systems tracts of all 3 sequences commonly include a thin drape of mudstone-clast conglomerate over the basal erosion surface, onlapped by thin-bedded sandstones with tractional structures that exhibit a characteristic axis to off-axis transition in facies. These deposits accumulated during periods of sediment bypass and are overlain by amalgamated structureless sandstones which thin from the axis into characteristic wings that extend laterally up to 200 m. Levees are absent in the lower two sequences and flows appear to have been only weakly confined by basal erosional keels. The resultant succession is extremely sandstone rich (90%), a much higher percentage than in underlying basin floor fan and overlying slope channel-levee complexes. The levee deposits of sequence 3 are much less sandy (30%), consistent with a more proximal, slope setting. In the 1400 m thick Karoo deepwater succession the base of slope channel sandstones of Unit B represent the maximum sandstone content and connectivity, which has predictive implications for hydrocarbon reservoir development in weakly confined deepwater channel systems.

1. Introduction

Submarine slope-channel complexes present challenging targets for geological investigation, particularly in the subsurface, where sedimentary facies of similar character but differing stratigraphic age may be juxtaposed. Sonar images of modern submarine slopes and high-resolution 3-D seismic studies of Palaeogene and Neogene equivalents show that down-slope profiles of submarine slope channel systems are commonly dominated by erosional processes on the upper-slope and depositional processes in base-of-slope to basin floor settings (e.g. Mayall and Stewart, 2000; Kolla et al., 2001; Babonneau et al., 2002; Sprague et al., 2002; Samuel et al., 2003; Posamentier and Mutti, 2003). Depositional architecture reflects this transition in process, showing a general trend of upper slope valleys with incisional confinement, passing down slope through channel/levee complexes to unconfined distributive systems on the basin floor (e.g., Gerber et al., 2009; Mayall et al., 2010; Covault et al., 2011). This interplay between erosion and deposition has a significant impact on architectural style, stacking patterns and sedimentary facies distribution with position along the slope profile (Macauley and Hubbard, 2012). Analysis of 3-D reflection seismic datasets has also revealed depositional architectures transitional

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between channel confined and unconfined in base of slope settings, thought to represent a 'weakly confined' variant (Brami et al., 2000). However, examples of the sub-seismic regional character of such base-of-slope weakly confined systems have not been documented in as much detail.

This paper presents the detailed regional analysis of a well exposed succession in an interpreted base-of-slope to basin floor submarine setting. It extends the original work of Grecula (2000) and Grecula et al. (2003a,b) on the up dip part of the Unit B (Laingsburg Formation) system to a more system-scale interpretation. Stratigraphy is established at Skeiding, the most proximal preserved part of the system, where Unit B is >95% sandstone and is extended across strike over some 20 km and down-slope by 25 km. Investigation of basin scale controls is conducted through the mapping of depositional architecture and associated sedimentary facies over this area. Unit B is compared to the overlying Unit C system, interpreted as a slope deposit (Hodgson et al., 2011; Di Celma et al., 2011), which shows much greater variability in sedimentary facies, sandstone percentage, and architecture. This paper will show the temporal evolution of channel types (aspect ratios and stacking patterns) and the characteristics of infilling strata developed at the initially base-of-slope setting at Skeiding as basinward progradation of the Unit B system continued. Down-slope correlatives of the Skeiding channels will be used to show the resultant regional scale distribution of deepwater depositional architecture.

2. Regional geology and stratigraphy

The Karoo Basin lies inboard of the Cape Fold Belt (CFB), which locally comprises two limbs, the N–S trending Cederberg Branch and the E–W trending Swartberg Branch (Fig. 1). Most authors have considered that the Karoo Basin developed as a retroarc foreland basin with subsidence solely due to loading by the CFB (e.g. Johnson, 1991; Visser, 1993; Cole, 1992; Veevers et al., 1994; Catuneanu et al., 1998). However, more recent work suggests that the fold belt was not emergent at the time of deep-water sand deposition in the SW Karoo. Petrographic and geochemical studies of the turbidites suggest little or no contribution from the CFB (Johnson, 1991), the majority of input instead coming from a granitic source proposed to be the Northern Patagonian Massif (Van Lente, 2004). This indicates a transport distance of at least 600 km across western Gondwana (Van Lente, 2004; King, 2005). This interpretation implies that the foreland basin was not active until the Triassic and that during Ecca Group time a slow rate of long wavelength uniform subsidence was due to dynamic topography effects related to subduction (Tankard et al., 2009).

The SW Karoo Basin is sub-divided into the Laingsburg and the Tanqua depocentres (Fig. 1). Deepwater fill of the Laingsburg depocentre comprises the 1400 m thick Ecca Group which is subdivided into the basal, mudstone-prone Prince Albert and Whitehill Formations and the ash-rich Collingham Formation. These are overlain by the distal basin-floor Vischkuil Formation (mudstone-prone turbidites and mass transport deposits; Van Der Merwe et al., 2009, 2010) and then a proximal basin floor (Units A and B of the Laingsburg Formation; Sixsmith et al., 2004; Grecula et al., 2003a) through slope deposits (Units C–G of the Fort Brown Formation; Figueiredo et al., 2010; Hodgson et al., 2011 Brunt et al., 2012; also see Fig. 2). The overlying deltaic (Waterford Formation) and fluvial (Abrahamskraal Formation, Beaufort Group) successions mark continued progradation of the sedimentary system to the north and east during the late Permian/early Triassic.

Continued deposition and tectonic loading during orogenesis of the Cape Fold Belt (Fig. 1A) caused deposits of the Laingsburg depocentre to be buried to a depth of approximately 7 km (Rowsell and De Swardt, 1976; Van Lente, 2004). This post-depositional deformation also led to 25% tectonic shortening across the Swartberg range, decreasing in intensity from south to north through the Laingsburg depocentre (King, 2005) and is marked by a series of open east–west trending folds that plunge gently (but variably) towards the east. These folds include (from south to north) the Baviaans syncline, Faberskraal anticline, Zoutkloof syncline and Heuningberg anticline (Fig. 1B). The sandstone units are exposed as a series of prominent topographic ridges separated by fine-grained units forming valleys. Unit B is well exposed for over 15 km from the nose of the Baviaans syncline eastwards along the northern and southern limbs, and similarly on the limbs of the Zoutkloof and Heuningberg folds further to the north, providing both down dip and across strike control over 350 km^2 (Fig. 1).

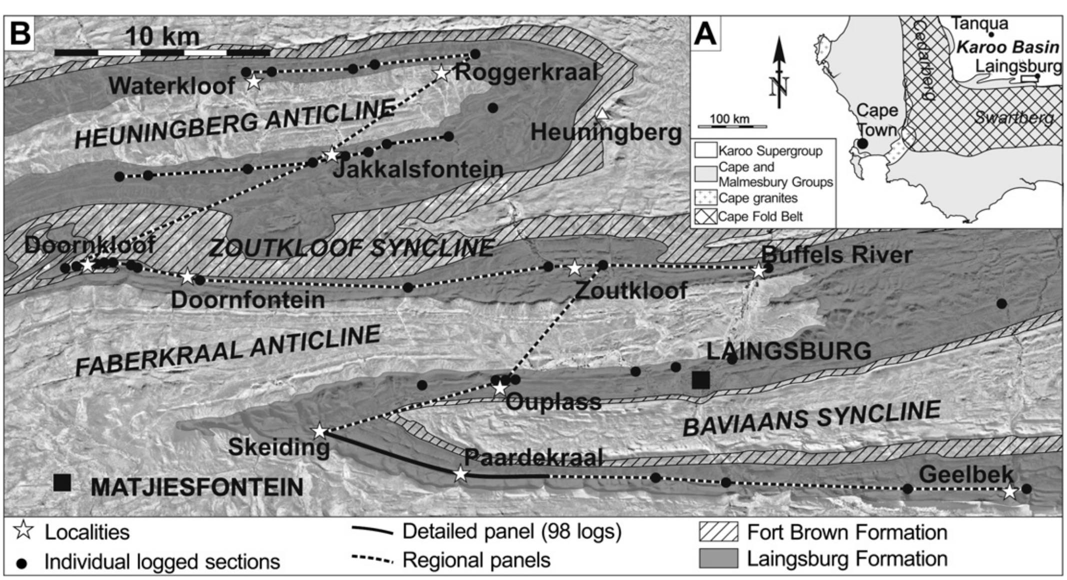

Figure 1. (A) Summary of the geology of the Western Cape region. The field area is identified by a rectangle to the SW of Laingsburg town. (B) Location map of the Laingsburg area derived from a mosaic of orthorectified aerial photographs and superimposed with a map of the Laingsburg Formation and overlying Fort Brown and Waterford Formations. The individual stratigraphic units of the Laingsburg Formation form a series of ridges that trace out the post-depositional folds. The positions of logged sections and key localities are indicated. Aerial photographs reproduced with the permission of the Chief Directorate: Surveys and Mapping (South Africa).