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Stratigraphic architecture and evolution of a deep-water slope channel-levee and overbank apron: The Upper Miocene Upper Mount Messenger Formation, Taranaki Basin

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ABSTRACT

This paper re-examines the Upper Miocene Upper Mount Messenger Formation, Taranaki Basin, to characterize its architecture and interpret its environmental evolution. Analysis of stratal architecture, lithofacies distributions, and paleotransport directions over the 250 m thick formation shows the outcrops provide a nearly dip parallel section displaying the lateral relationships between contemporaneous channel-levee and overbank depositional environments. At least five 30–40 m thick upward fining units are recognized in the north-central parts of the outcrop and are interpreted as large-scale overbank avulsion cycles. Each unit consists of thick- to medium-bedded predominantly planar laminated sandstone turbidites at the base that fine upward into thin- to very thin-bedded, planar laminated and ripple cross-laminated mud-rich turbidites. The units are traceable laterally over a distance exceeding 3 km where they are cut by channels that show basal mudstone draped by medium- to thin-bedded sandstone, and onlapped by thick-bedded planar laminated sandstone at the margin. The channels are separated by tapered packages of medium- to thin-bedded turbidites containing climbing-ripple cross-lamination interpreted as levees. The individual channel-levee and overbank avulsion cycles formed through four stages: 1) a channel avulsion spread sand into the overbank as an unconfined splay, 2) preferential scouring in one area of the splay led to development of a channel with small levees that prograded across the splay, 3) a deep incision followed by abandonment of the channel deposited a mud lining. Alternatively, the mud lining was formed during the first stage as the downdip portion of the channel was abandoned. 4) The channel filled at first by thick-bedded planar laminated and then by climbing-ripple cross-laminated sand. At this time, the growth of constructional levees progressively limited sand into the overbank. Ratios of Bouma division thicknesses calculated over a stratigraphic interval present a new method to distinguish deep-water depositional environments.

1. Introduction

Deep-water channel-levee and overbank depositional environments are important because of their fundamental role in sediment transport and distribution off the continental shelf as well as their potential for hydrocarbon reservoir development (Galloway, 1998; Beaubouef et al., 1999; Pyles et al., 2010). The broad architecture and overall geometries of channel-levee environments have been explored and described using 2D and 3D seismic and core data (e.g., Bouma et al., 1985; Beaubouef and Friedmann, 2000; Posamentier and Kolla, 2003; Deptuck et al., 2007; Pyles and Slatt, 2007); however, their fine-scale sedimentological complexity is known only from a limited number of outcrops (e.g., Walker, 1975; Elliott, 2000; Browne and Slatt, 2002; Campion et al., 2005a, 2005b; Rossen and Beaubouef, 2007; Browne et al., 2007; Hubbard et al., 2007; King et al., 2007; Pyles, 2008). Studies of channel-levee systems have led to an enhanced understanding of their large-scale geometries and how deep-water depositional environments are inter-related (e.g., Deptuck et al., 2003; Gardner et al., 2003; Posamentier and Kolla, 2003; Tomasso et al., 2006; Wynn et al., 2007). Understanding the sedimentary processes that sculpted the architecture of the depositional elements relies on data gathered at a cm-scale. There are few process-based outcrop studies that focus on both channel-levee and overbank environments (Hickson and Lowe, 2002) and even fewer are fine-grained (e.g.,

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Slatt et al., 1997, 1998; Browne et al., 2007; Di Celma et al., 2011). Coastal outcrops of the Upper Mount Messenger Formation provide a superb natural laboratory for studying deep-water channel-levee and overbank strata. The outcrops stretch for nearly six kilometers and reach 250 m in thickness, with strata that pervasively display sedimentary structures. Collectively, these outcrop attributes enable the investigation of contemporaneously active sedimentary processes operating in channel-levee and associated overbank environments. Recent hydrocarbon discoveries in Paleogene and Cretaceous source rocks (Stagpoole et al., 2004) motivate additional stratigraphic studies of these units.

Greater than two decades of study have led to volumes of literature on the Upper Mount Messenger Formation. Previous research has included regional geologic studies of the tectonics of and stratigraphic relationships among formations (Hay, 1967; Thrasher, 1989, 1990; King et al., 1993), sequence and stratigraphic architecture (King et al., 1994; Browne et al., 2000), sandstone petrography that led to an understanding of the sediment provenance (Martin, 1995a, 1995b), and stratigraphy and sedimentology of select parts of the formation with implications for petroleum reservoir geology (Browne et al., 1996; Hansen, 1996; Browne and Slatt, 1997, 2002; Slatt et al., 1998; Browne et al., 2007; King et al., 2007). Each of these stratigraphic studies described the lithofacies, stratigraphic architecture, and depositional environments represented by the formation. Overall, these studies concluded that the Upper Mount Messenger Formation was a slope fan composed of channel, levee, lobe, and overbank environments deposited in bathyal water depths near the base of a prograding continental slope characterized by high clastic influx. Key questions arising from these studies highlight the need for a process-based sedimentological study: what are the processes of sedimentation that define the lithofacies of the formation? How do these lithofacies systematically stack to form lithofacies associations? What is the nature of the cyclicity tied to lithofacies association development? This study incorporates and offers a new perspective from previous research in that it focuses on the complexity of sedimentation transport and depositional processes, paleotransport directions, and stratal surfaces at Pukearuhe Beach. Detailed sedimentological analysis has been integrated with stratigraphic and architectural data to develop a more detailed understanding of the lateral and vertical relationships among stratigraphic packages and evolution of the Upper Mount Messenger Formation. In this way, genetic relationships can be interpreted from the outcrops and used in a predictive manner in other fine-grained, deep-water depositional systems.

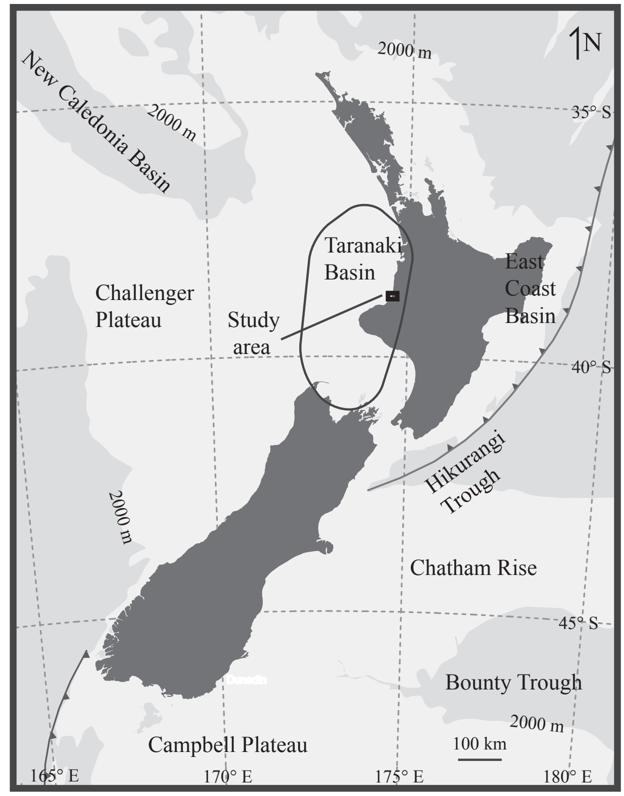

Figure 1. Bathymetric image of the New Zealand region, with major geographic provinces labeled and approximate area of the Taranaki Basin traced off the West Coast of the North Island. Figure modified from NIWA Taihoro Nukurangi maps, compiled from the NZ 250 m gridded bathymetric data set, CANZ (2008) and the Centenary Edition of the GEBCO Digital Atlas (2003).

2. Geologic setting

This study concentrates on the approximately 250 m thick Upper Mount Messenger Formation of the northeast Taranaki Basin (Fig. 1). The formation comprises a deep-water marine succession of siliciclastic and volcaniclastic deposits (Fig. 2) that forms part of a deep-water margin present in northeast Taranaki Basin during Late Miocene time. During Miocene time, sediment is thought to have been derived from the northern part of the South Island and western part of the North Island (King et al., 1993, King and Thrasher, 1996; Rotzien, 2013). Volcaniclastic materials were sourced from the active Mohakatino backarc to the north (Nodder et al., 1990a, 1990b; King and Thrasher, 1996).

The Mount Messenger Formation is divided into the lower and upper parts on the basis of bulk architectural fabrics, sedimentary structures, and location in the stratigraphic column (King et al., 1993). The lower part of the formation consists of thick-bedded packages of fine- to very fine-grained sandstone, medium- to thin-bedded sandstone and mudstone, volcaniclastic beds and thick packages of mudstone and mass transport units. In contrast, the upper part of the formation consists of thick- to thin-bedded sand-rich turbidites, thick packages of burrowed very thin-bedded muddy turbidites and rare conglomerates. These rocks of the Mount Messenger Formation represent a variety of submarine gravity flow deposits, including turbidites, debris flow deposits, and hemipelagic mudstone (Crundwell, 2004a, 2004b). The Mount Messenger Formation is overlain (and outcropping to the south) by slope deposits of siltstone, mudstone, and conglomerate of the Urenui Formation (King and Thrasher, 1996; King et al., 2007; Maier et al., 2010; Maier, 2012). The Mount Messenger Formation is generally underlain by the volcaniclastic basin floor turbidite and mass-transport deposits (MTD) of the Middle Miocene Mohakatino Formation that crops out to the north in the field area (King et al., 1993, King and Thrasher, 1996; Rotzien et al., 2012).

Previous workers have described the Upper Mount Messenger Formation as a series of coalescing channel-levee/overbank slope fan elements, forming an apron at or near the base of slope, fed by multiple point sources (King, 1988a, 1988b; Hansen, 1996; King et al., 1994; King and Thrasher, 1996; King, 2000a, 2000b; King and Browne, 2001; Browne and Slatt, 2002; King and Browne, 2004; Browne et al., 2005, 2007; Johansson, 2005; King et al., 2007). Planktic foraminifera and bolboform assemblages indicate the Upper Mount Messenger Formation was deposited in upper to mid-bathyal depths (Crundwell, 2004a, 2004b). At the basinwide-scale, King et al. (1994, 2007) have argued that the formation was deposited during an overall third-order Neogene regression, with fourth- and fifth-order relative sea level cycles superimposed on an overall lowstand systems tract. The 900 m thick stratigraphic succession from the Mount Messenger through Urenui Formation was