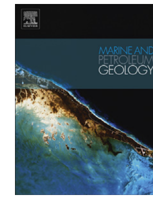
Marine and Petroleum Geology 54 (2014) 1–22

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo



Research paper

Evolution of a deep-water lobe system in the Neogene trench-slope setting of the East Coast Basin, New Zealand: Lobe stratigraphy and architecture in a weakly confined basin configuration

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A R T I C L E I N F O

Article history:
Received 20 July 2013
Received in revised form
25 November 2013
Accepted 16 February 2014
Available online 2 March 2014

Keywords:
East Coast Basin
New Zealand
Stratigraphic architecture
Trench-slope
Lobe complex
Slope basin
Slope healing
Deep-water

A B S T R A C T

This study presents a new depositional analysis of the stratigraphic architecture of a deep-water lobe system in a trench-slope basin setting by examining the upper Miocene Hikuwai sandstone and Mapiri Formation of the East Coast Basin (ECB) in the Tolaga Bay area, New Zealand. The Hikuwai sandstone is up to 385 m thick and is enveloped by the mud-rich middle and upper Mapiri Formation. Stratigraphic sections measured at centimeter-scale and high-resolution photo-panoramas were collected from sea-cliff exposures for stratigraphic and architectural analysis and definition of six lithofacies. The Hikuwai sandstone is interpreted to represent a succession of frontal lobe deposits that contain a distributary network of meter-scale erosional channels and scours on their surface. Lobe lithofacies depend on their proximity to the sediment source, and their proximity to a distributary channel and/or scour.

The late Miocene basin setting is interpreted to be a weakly to moderately confined trench-slope basin. The basin configuration controlled the development of the depositional system through elongate fault-controlled ridges that directed sediment dispersal pathways through longitudinal troughs. The basin filled from north to south in four phases: 1) lobe aggradation related to healed slope accommodation, 2) retrogradation and lateral migration of the system 3) back-stepping of the system upslope causing reduced confinement and allowing flows to become wider, longer, and thinner, and 4) shut off of sediment supply and mass wasting of the upper Mapiri Formation, representing either renewed fault movement or equilibration of the system to the regional slope profile.

This paper provides a detailed description of the internal structure of lobes in a trench-slope setting, and a depositional model that relates lobe lithofacies to the filling of healed slope accommodation. Therefore, this work presents an analog applicable for elongate basins, such as in the trench slope or settings with mud diapirism, where only seismic-scale or limited data is available.

1. Introduction

Near-seafloor studies of modern to very young deep-water intra-slope deposits have shown that their distribution and shape vary dramatically depending on the slope gradient, basin geometry and bathymetric features, and sediment supply (Prather et al., 1998; Beaubouef et al., 2003; Booth et al., 2003; Laursen and Normark, 2003; Smith, 2004; Adeogba et al., 2005; Li et al., 2012; Prather et al., 2012a). Although slope basins can contain significant accommodation and host important hydrocarbon reservoirs, the centimeter to meter scale character of their fill and internal structure is poorly understood due to limited sedimentological and stratigraphic data in modern sea-floor studies. This makes prediction of reservoir quality and connectivity particularly challenging in slope settings.

Intra-slope basins exhibit a range of morphologies depending on their tectonic setting. Smith (2004) identified three types of confined intraslope basins: (1) silled sub-basins that fully confine the flow, (2) partially silled basins with lateral escape paths, and (3) connected tortuous corridors that direct the flow basinward. Fill-and-spill depositional models for silled basins are well developed due to extensive studies in areas such as the Gulf of Mexico (Prather et al., 1998; Prather, 2000; Beaubouef and Friedmann, 2000; Prather et al., 2012a). Tortuous corridor basins can also be important reservoirs, and include regions such as the Niger Delta slope (Hooper et al., 2002; Steffens et al., 2003; Adeogba et al., 2005;

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http://dx.doi.org/10.1016/j.marpetgeo.2014.02.011
0264-8172/

Prather et al., 2012b) and offshore Brunei (Demyttenaere et al., 2000; Steffens et al., 2003) where mud diapirism and associated thrust faulting create mobile shale ridges separated by synclinal troughs (Wood et al., 2004). In addition to these basin settings, other elongate depressions on the slope, such as large submarine canyons, could also be considered as a type of tortuous corridor accommodation. Trench-slope basins, which also fall into the connected tortuous corridors category, are less well studied. The trench-slope is typically characterized by margin-parallel, fault-controlled ridges that direct sediment longitudinally through their troughs (Fig. 1; Underwood and Bachman, 1982). Modern studies in this setting have been conducted in Indonesia (the Sunda Fore-arc), the Aleutian trench (Alaska), the Japan trench, and offshore Columbia using seismic data sets and piston cores (Moore et al., 1982; Underwood and Norville, 1986; Okada, 1989; Vinnels et al., 2010). While these studies have demonstrated the importance of slope morphology in dictating flow pathways and regions of deposition, they lack the stratigraphic resolution to develop a depositional framework. A few studies have utilized outcrops to address stratigraphic development in the trench-slope (McCrory, 1995; Lomas, 1999; Bailleul et al., 2007), but most studies are limited due to intense deformation of ancient convergent margin deposits (Underwood and Moore, 1995). Additionally, trench-slope deposits are not commonly exposed in outcrop and therefore opportunities for study are limited. Therefore, this study provides a rare opportunity to investigate the detailed stratigraphic architecture associated with deposition in the trench-slope.

Deep-water deposits in trench-slope settings often have unusual shapes and dimensions due to the receiving basin configuration and evolution, which impacts the stratigraphy and architecture of the depositional elements. High-resolution seismic imagery has shown that deep-water lobe morphology is largely dependent on basin floor bathymetry (Gervais et al., 2006; Hay, 2012). Lobes are defined in this study as deposits where sediment gravity flows decelerate and deposit due to lack of confinement.

With improvements in near-surface imaging technology, a new understanding of lobe systems has emerged. Many lobes have a complex distributary network on their surface (Nelson et al., 1992; Twichell et al., 1992; Adeogba et al., 2005; Jegou et al., 2008; Prather et al., 2012b), and several terms have been applied to

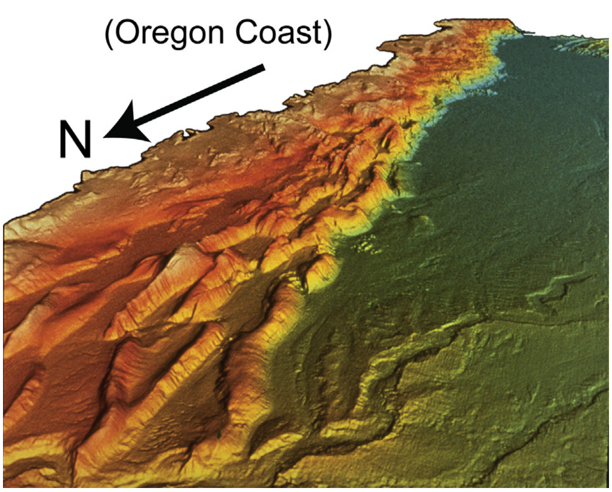

Figure 1. Compressional folds dominate the offshore Oregon convergent margin, creating a terraced slope with structurally defined tortuous corridors that direct sediment delivery pathways. Sediments partially bury the ridges due to ponding and slope healing. This setting is analogous to the present day convergent margin setting in the Wairarapa Region of the East Coast Basin, New Zealand (modified from Pratson and Haxby, 1996, Fig. 1E).

describe this type of distributive lobe system, including "braided" marine fan (Belderson et al., 1984), distributary channel–lobe complex (Beaubouef and Friedmann, 2000), scoured lobe (Piper et al., 1999; Abreu et al., 2006), and distributary lobe complex (Hay, 2012). This depositional element has been recognized in modern studies of fully to weakly confined basins where flows diverge then reconverge into a single channel (Adeogba et al., 2005; Prather et al., 2012b), or continue to diverge and thin as confinement and slope gradient is reduced (Hay, 2012). However, ancient deposits of distributive lobe systems are required to better quantify the dimensions of channelization and the character of its fill. In reservoir modeling, the extent of channelization and nature of the fill (i.e., mud-lined channels versus sand-on-sand contacts) within lobes will impact their connectivity (Snedden, 2013), and therefore it is important to understand their occurrence.

This study presents a new stratigraphic and architectural analysis for the Hikuwai sandstone, a fine-grained Miocene deep-water unit interpreted to represent a system of lobes in the trench-slope setting of the East Coast Basin (ECB), North Island, New Zealand (Fig. 2). The Hikuwai sandstone is relatively undeformed, and therefore provides an uncommon opportunity to investigate the lithofacies, internal architecture, and stratigraphic evolution of a deep-water system in the trench-slope setting. This study develops a lithofacies scheme for the Hikuwai sandstone and the overlying mud-rich upper Mapiri Formation based on sedimentological, stratigraphic, and architectural data. A conceptual model of lithofacies distribution within the lobe is developed based on high-resolution outcrop data, large-scale morphology data from analogous near-surface seismic images, and experimental and numerical modeling. The lobe model is used as a building block to create a four-phase depositional model of the turbidite system as it filled slope accommodation, and then is linked to pseudo-wells through the outcrop to show corresponding lithofacies stacking patterns in different regions of the basin. The high-resolution lithofacies scheme developed in this study can be applied to the basin-scale and is readily transferable for reservoir modeling in the trench-slope and other similarly structured basin settings, such as basins dominated by mud diapirism.

2. Geologic background

2.1. Geologic setting of the East Coast Basin

The ECB is a partly emergent forearc basin on the eastern side of the North Island, New Zealand (Fig. 2A). As part of a convergent margin setting, the basin is bordered by the Hikurangi trench to the east and by the Axial Ranges to the west. The basin formed around 23–25 Ma with the southward propagation of subduction along the Hikurangi trench (Ballance, 1976; Pettinga, 1982; Rait et al., 1991; Ballance, 1993). The ECB has a complex history including compressional and extensional tectonic regimes likely related to changes in plate configuration, the subduction of seamounts and rugose seafloor, and other subduction processes such as accretion and subduction erosion (Davey et al., 1986; Lewis and Pettinga, 1993; Chanier et al., 1999; Collot et al., 2001; Lewis et al., 2004). Offshore seismic-reflection data to the south in Hawke Bay reveal a complex history of deformation including a shortening phase during early–mid Miocene time, followed by basin extension in mid-Miocene time, and finally basin inversion beginning by Pliocene time (Barnes et al., 2002; Barnes and Nicol, 2004). Although most of the basin is still experiencing compression, the Raukumara region, which includes the study area, is currently undergoing extension (Nicol et al., 2007). The offshore region may provide some insights for controls on sediment accumulation and basin configuration during Miocene time in the Tolaga Bay area. Offshore