Marine and Petroleum Geology 44 (2013) 196–216

Contents lists available at SciVerse ScienceDirect

Marine and Petroleum Geology

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

The role of tectonics and mass-transport complex emplacement on upper slope stratigraphic evolution: A 3D seismic case study from offshore Angola

Kehinde Olafiranye [a,*], Christopher A.-L. Jackson [a], David M. Hodgson [b]

[a] Department of Earth Sciences and Engineering, Prince Consort Road, Imperial College, London SW7 2BP, UK
[b] School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK

ARTICLE INFO

Article history:
Received 20 August 2012
Received in revised form
7 February 2013
Accepted 18 February 2013
Available online 7 March 2013

Keywords:
Seismic facies
Mass Transport Deposits
Grade
Kinematic indicators
Offshore Angola

ABSTRACT

Three dimensional seismic-reflection data of the mid-Pliocene-to-Holocene upper slope succession, offshore Angola, provide an opportunity to constrain the stratigraphic context, distribution, external morphology and internal strain within mass-transport deposits (MTDs). These data also allow an assessment of the impact that erosion and relief associated with MTDs have on upper slope stratigraphy and depositional patterns, and the role that MTDs play in achieving 'grade' on submarine slopes. The study area is dissected by a series of NW-SE-striking, thin-skinned, salt-detached normal faults, which bound a slope-perpendicular, intra-slope horst that divides the study area into two depocentres. Three main seismic packages and their six constituent units have been mapped across the study area and reveal that, during the initial stages of deposition, a series of MTDs were emplaced, the thickness and distribution of which are controlled by the intra-slope horst. Substantial volumes of substrate were removed and entrained into the parent flow, and significant and irregular relief (150 m) was developed along MTDs upper surface. This MTD-richpackage is interpreted to document a time when the slope was above grade, degradational processes dominated and sediment was trapped on the upper slope due to tectonic accommodation. Subsequent deposition was from either turbidity currents or and suspension fallout, at a time when the slope had begun to achieve 'grade' and depositional processes dominated. The associated depositional units display only minimal thickness variations with respect to the intra-slope horst, which had been 'healed' by this time; however, the unit displays pronounced and abrupt changes in thickness due to infilling of relief at the top of the preceding MTDs. The uppermost strata document a time when the slope was at grade and constructional process (i.e. aggradation and progradation) dominated. Deposition at this time was characterised by progradation of a mudstone-dominated, gullied slope system. This study highlights the role that tectonically- and mass transport-driven changes in bathymetry can have on upper slope accommodation and sediment dispersal. From a hydrocarbon exploration perspective this is critical, because tectonic and depositional accommodation provide a mechanism for capturing and trapping clastic sediments in an upper slope setting, which is otherwise typically associated with coarse-grained sediment bypass.

1. Introduction

Accommodation on submarine slopes is the gap between the sediment surface (the background slope surface) and the equilibrium profile (the slope profile of no net erosion or deposition) (Pirmez et al., 2000; Kneller, 2003). The equilibrium profile can be perturbed by changes in submarine slope bathymetry through time and space (Fig. 1). For example, faulting and folding (e.g. Bryant et al., 1991; Hodgson and Haughton, 2004; Kane, 2012), and the flow of salt and mud (e.g. Hodgson et al., 1992; Prather et al., 1998; Prather, 2000, 2003; Steffens et al., 2003) can lead to the formation of intra-slope bathymetric relief and disturbance of the grade of the slope (Fig. 1). A graded slope is typically characterised by a smooth, possibly sigmoidal, shelf-to-basin profile, which contrasts with the more irregular profiles that commonly characterise out-of-grade or above-grade slopes (e.g. O'Grady et al., 2000, 2001; Smith, 2004;

* Corresponding author. Present address: Shell Petroleum Development Company of Nigeria Limited, P.O. Box 263, Port Harcourt, PH, Rivers State, Nigeria. Tel.: +234 8039401808.
E-mail addresses: kehinde.olafiranye@shell.com, k.olafiranye09@imperial.ac.uk (K. Olafiranye).

0264-8172/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpetgeo.2013.02.016

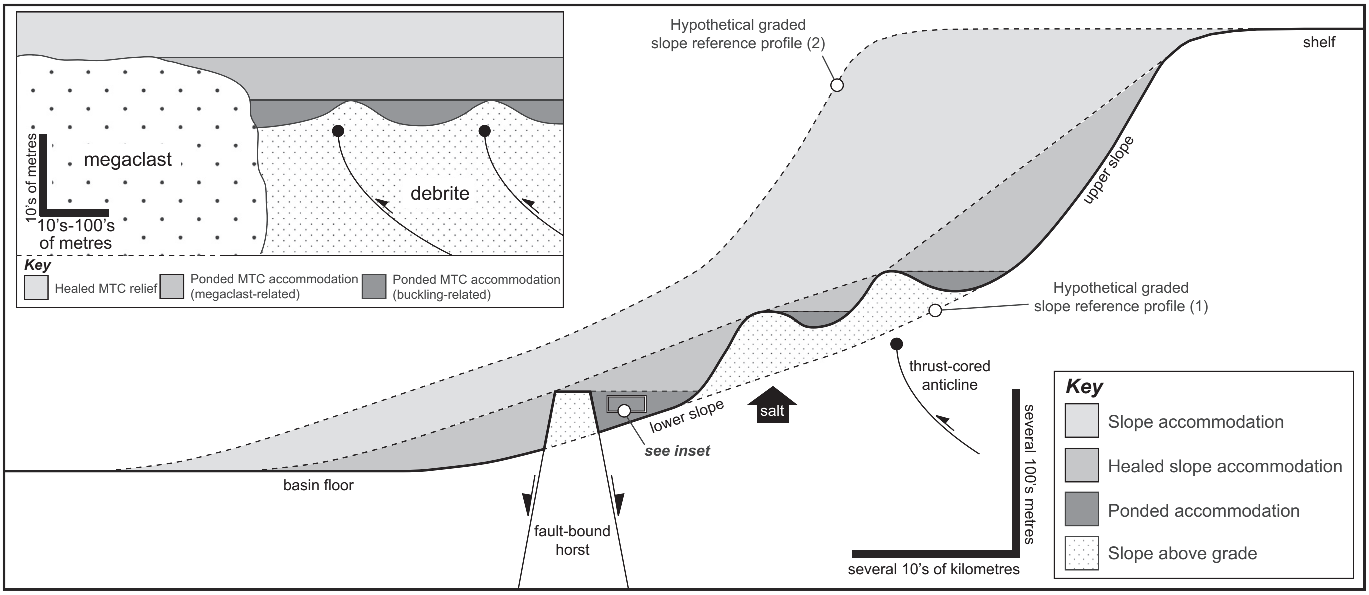

Figure 1. (a) Schematic cross-section illustrating the styles of accommodation developed on continental margins. Note the development of ponded accommodation on the slope due to normal faulting, salt flow and thrusting, which are all types of 'tectonic accommodation'. Modified from Prather (2003) and Steffens et al. (2003). The inset diagram illustrates the styles of accommodation (i.e. depositional accommodation) that can develop due to the emplacement of mass-transport deposits (MTDs). In this case, relief and accommodation can form in response to the emplacement of 'megaclasts' (left-hand side of diagram) or deposit 'buckling' (right-hand side of diagram), which may be related to shortening of the deposit during abrupt flow freezing. Modified from Armitage et al. (2009) and Jackson and Johnson (2009).

Prather, 2003; Steffens et al., 2003; Pyles et al., 2011). MTDs may typically form at the base of an out-of-grade slope, as the system evolves towards equilibrium; slope progradation by accretion may then occur. When a slope is significantly above 'grade' a series of predominantly erosional or 'degradational' processes may act to eventually return it to a condition of 'grade'; conversely, when a slope is below grade, depositional (i.e. progradational or aggradational) processes occur and return the slope to a graded profile (e.g. Ross et al., 1994, 1995; Prather, 2003; Steffens et al., 2003; Pyles et al., 2011). Changes in slope grade and equilibrium profile can therefore markedly influence the location and number of sediment fairways, the storage and dispersal patterns of sediment on the slope, and the behaviour of submarine sediment gravity flows (Haughton, 1994; Prather et al., 1998; Kneller and McCaffrey, 1999; Prather, 2000, 2003; Bouma, 2004; Hodgson and Haughton, 2004; Smith, 2004; Adeogba et al., 2005; Kane, 2012; Hodgson et al., 2011; Moscardelli et al., 2012). From the point-of-view of hydrocarbon exploration and production, changes in slope accommodation directly influences the potential for sand-prone reservoir facies to be deposited in upper slope settings, which are typically associated with coarse-grained sediment bypass.

The role of primary depositional relief on controlling accommodation development on submarine slopes is less well understood. Primary depositional relief on submarine slopes is typically related to the deposition of mounded sedimentary bodies or the transport of large clasts in mass-transport deposits (MTDs) (see inset in Fig. 1). Data from high-resolution, near-seabed, acoustic reflection profiles (e.g. Hampton et al., 1996; Piper et al., 1997), industry-standard seismic-reflection datasets (e.g. Collot et al., 2001; Deptuck et al., 2003; Faulkenberry, 2004; Moscardelli et al., 2006; Frey-Martinez et al., 2006; Moscardelli and Wood, 2008; Ashabranner et al., 2010; Mosher et al., 2010; Alves and Cartwright, 2009; Gamberi et al., 2011; Amerman et al., 2011; Cossey, 2011; Dykstra et al., 2011), and outcrop studies (e.g. Pickering and Corregidor, 2000; Pickering and Corregidor, 2005; Amerman et al., 2007; Armitage et al., 2009; Jackson and Johnson, 2009; Van der Merwe et al., 2009; Butler and McCaffery, 2010) have acknowledged the role that MTD-related depositional and erosional relief may have on local intra-slope and basin floor accommodation. However, the styles of relief associated with MTD-related accommodation, their three-dimensional form and areal extent, and their impact on subsequent sediment dispersal patterns remain poorly constrained. Furthermore, it is not clear over what timescales MTD-related accommodation may impact the stratigraphic development of deep-water successions. These uncertainties partly reflect the limited extent and two-dimensional nature of the majority of outcrops, and the lack of subsurface datasets that have used high-quality, 3D seismic reflection data.

This study focuses on the Mid-Pliocene-to-Holocene upper slope succession in Block 4, offshore Angola (Figs. 2 and 3). We aim to: (i) characterise and interpret the seismic facies present in this deep-water succession; (ii) describe and interpret the controls on the external morphology and distribution of MTDs at any one stratigraphic level; (iii) establish the overall stratigraphic context of multiple MTDs and assess the role of the associated sediment gravity-flows in achieving grade on submarine slopes; (iv) document the geometry, scale and distribution of structures at the base of, within and at the top of the MTDs, and relate these to the initiation, translation and emplacement of these deposits; and (v) assess the impact of tectonic structures, and depositional and erosional relief associated with the emplacement of MTDs, on the stratigraphic architecture of the upper slope and subsequent sediment dispersal.

2. Geological setting

During the Jurassic and Early Cretaceous, a series of rift basins formed along the West African margin in response to basement-involved, upper crustal extension. The Lower Congo Basin, which lies between 7°30′S and 7°45′S, is one of these basins (Fig. 2a). After the main period of rifting, the West African passive margin underwent thermally-induced subsidence during the Late Cretaceous to Tertiary. However, the presence of a thick, early Cretaceous-age evaporite layer (Loeme Formation) and westward tilting of the