Marine and Petroleum Geology 91 (2018) 576–585

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Research paper

Slope-fan depositional architecture from high-resolution forward stratigraphic models

Nicolas Hawie[a,*], Jacob A. Covault[b], Dallas Dunlap[b], Zoltán Sylvester[b]

[a] Beicip Franlab, Rueil-Malmaison, France
[b] Bureau of Economic Geology, Jackson School of Geoscience, The University of Texas at Austin, Austin, TX, USA

ARTICLE INFO

Keywords:
Submarine fan
Stratigraphic model
Deep-water
Channel
Lobe
Compensational stacking

ABSTRACT

Submarine fans in tectonically active continental-slope basins are targets of petroleum exploration and production. These slope fans commonly comprise compensationally stacked sandy and muddy architectural elements, including mass-transport deposits, weakly confined to distributary channel-and-lobe deposits, and leveed-channel deposits. The lateral continuity and vertical connectivity of these architectural elements are important uncertainties in reservoir characterization that influence fluid-flow behavior during hydrocarbon production. Here, we use a simple forward stratigraphic model to simulate the stratigraphic patterns and illuminate the likely distribution of fine-scale, sub-seismic heterogeneity in a slope fan. We used published seismic-reflection horizons from the tectonically active Columbus basin, offshore Trinidad, to define the top and base of a Pleistocene submarine fan. We then simulated the stratigraphic evolution of the slope fan with a series of DionisosFlow™ forward stratigraphic models. All variables were kept constant during the simulations in order to test the hypothesis that the autogenic evolution of the surface topography alone, as a result of erosion and deposition, can produce compensational-stacking patterns common in submarine fans. A reference-case model is similar to the thickness trend of published isochron maps of the Trinidad slope fan. The reference-case model also produced patterns of compensational stacking. Varying the time step impacts the heterogeneity of the model. Shorter time steps are characterized by less sediment accumulation, which results in less sediment diversion during the subsequent time step, more gradual migration of channel deposits, shorter offset distances of depocenters, and shorter length-scale heterogeneity compared to longer time steps. Thus, a key characteristic of slope-fan deposits is autogenic compensational stacking, without any external forcing, which governs heterogeneity in these reservoirs. Furthermore, our results suggest that relatively simple diffusion-based models can produce realistic compensation patterns and future work will be focused on higher-resolution model calibration to seismic-reflection data and the influence of input variables on heterogeneity of channel-and-lobe deposits of slope fans.

1. Introduction

Submarine fans are depositional sinks of continental-margin sediment-routing systems, where they host stratigraphic archives of Earth history and environmental changes (Clift and Gaedicke, 2002; Fildani and Normark, 2004; Covault et al., 2010, 2011; Fildani et al., 2016). Submarine fans are also important reservoirs of natural resources (Pettingill and Weimer, 2002). Early models characterized submarine fans as laterally extensive sheets in cross section with radial- or cone-like depositional morphologies in map view across unconfined basin floors of low relief and with gentle gradients (e.g., Shepard and Emery, 1941; Dill et al., 1954; Menard, 1955; Heezen et al., 1959; Bouma et al., 1985) (Fig. 1). However, receiving-basin geometry and tectonic deformation can influence the organization of sandy and muddy architectural elements of submarine fans (Piper and Normark, 2001). For example, tectonically active slope basins and stepped slopes with abrupt changes in gradient commonly consist of ponded mass-transport deposits overlain by weakly confined to distributary channel-and-lobe deposits, which transition to perched, downstream-thinning wedges comprising leveed-channel deposits (Beaubouef and Friedmann, 2000; Brami et al., 2000; Beaubouef et al., 2003; Prather, 2003) (Fig. 1); although, mass-transport deposits and leveed channels are not always present (e.g., Jobe et al., 2017). Such tectonically active slopes are targets of petroleum exploration and production (e.g., the slope basins and stepped slopes of the Gulf of Mexico and the Niger Delta; Damuth, 1994; Pirmez et al., 2000; Sullivan et al., 2004; Prather, 2003; Rowan et al., 2004; Adeogba et al., 2005; Deptuck et al., 2012; Sylvester et al., 2012).

* Corresponding author.
E-mail address: nicolas.hawie@beicip.com (N. Hawie).

https://doi.org/10.1016/j.marpetgeo.2017.12.033
Received 30 July 2017; Received in revised form 20 December 2017; Accepted 26 December 2017
Available online 02 February 2018

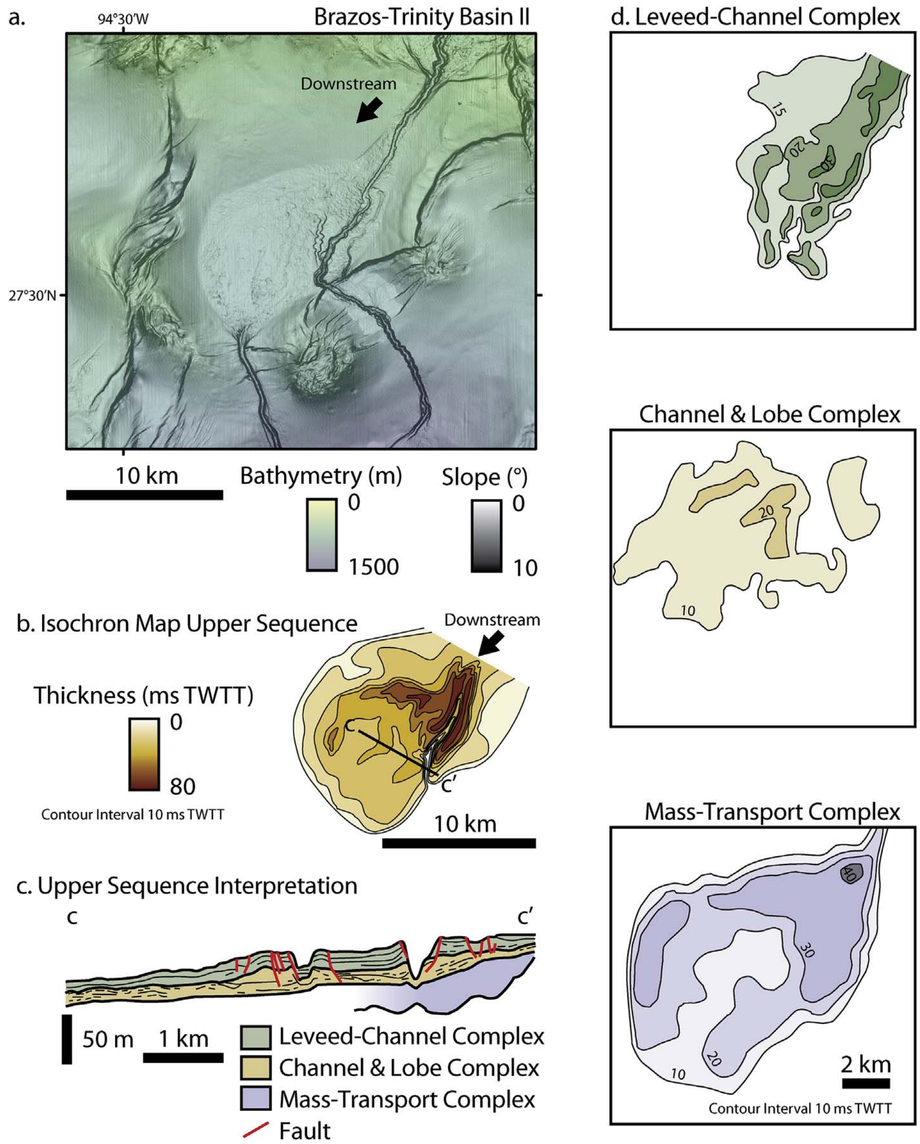

Fig. 1. Example of Brazos-Trinity Basin II slope-fan depositional architecture. a. Co-rendered bathymetry and slope of Basin II from the BOEM Northern Gulf of Mexico Deepwater Bathymetry Grid from 3D Seismic (https://www.boem.gov/Gulf-of-Mexico-Deepwater-Bathymetry/). b. Isochron map of the Upper Sequence. c. Upper Sequence stratigraphic architecture. d. Isochron maps of mass-transport complex, distributary channel-lobe complex, and leveed-channel complex of the Upper Sequence. Parts b-d modified from Beaubouef and Friedmann (2000).

Models of slope-fan stratigraphic architecture and evolution are predominantly based on insights from shallow-subsurface three-dimensional (3-D) seismic-reflection data (up to ~200 Hz peak frequency), with limited core penetrations (e.g., Beaubouef et al., 2003). These datasets can constrain the 3-D geometry of packages of strata as thin as several to tens of meters in the subsurface, but they lack the depth of penetration and deep-time perspective of conventional industry seismic-reflection data (e.g., generally < 40 Hz peak frequency; Normark et al., 1993; Prather et al., 2012). Moreover, core calibration is limited and does not provide a strong 3-D lithologic control, which can be of importance to the spatial variation in properties in oil and gas reservoirs (i.e., heterogeneity; Lake and Jensen, 1989). These datasets provide insights into the compensational stacking of architectural elements and the stratigraphic evolution from ponded to perched fan deposits. However, an important uncertainty is the lateral continuity and vertical connectivity of sandy and muddy architectural elements at higher resolution. These architectural elements control the static and dynamic connectivity of slope-fan reservoirs and influence fluid-flow behavior during hydrocarbon production (e.g., Glenton et al., 2013; Sutton et al., 2013).

Deptuck et al. (2008) used high-resolution 2-D seismic-reflection profiles (900–7000 Hz frequencies) and piston cores to investigate the causes of heterogeneity in Pleistocene submarine fans offshore East Corsica. This work provided new details of the hierarchical levels of compensational stacking of deposits: individual beds stack to form lobe architectural elements, which stack to form more composite submarine fans. However, the high-resolution 2-D imagery of the Pleistocene deposits offshore East Corsica lacks the 3-D perspective of fan geometry. Physical experiments provide high temporal- and spatial-resolution insights into the morphodynamic processes of sediment-gravity flows and fans (e.g., Spinewine et al., 2009; Hoyal et al., 2011, 2014; Fernandez et al., 2014; Hamilton et al., 2015; Postma et al., 2016); however, these studies lack the long-term ($> 10^3$ yr) perspective of stratigraphic evolution and the complexity of field-scale depositional elements. Nevertheless, physical experiments offer the opportunity to constrain fundamental processes that operate in slope depositional environments when combined with other approaches, such as 3-D seismic-stratigraphic interpretation and forward stratigraphic