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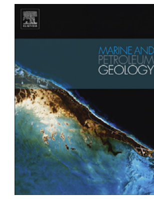

Research paper

Using sea-floor morphometrics to constrain stratigraphic models of sinuous submarine channel systems

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A B S T R A C T

Constructing geologically accurate reservoir models of deep-water strata is challenging due to the reliance on incomplete or limited resolution datasets. Connecting areas of high-certainty across areas where data is sparse or non-existent (e.g., between wellbores) is difficult and requires numerous interpretations and assumptions. In this study, morphometric data from the Lucia Chica Channel System, offshore California, provides high-resolution 3-D information that is used to constrain correlation and characterization of ancient submarine channel fill deposits.

A statistical relationship between cross-sectional asymmetry and planform morphology in sinuous submarine channels is determined from bathymetric data. Submarine channel cross-sectional asymmetry was quantified by calculating the ratio between the distance from the inner bend margin to the thalweg by the entire channel width. This metric was calculated for 243 cross-sections, from 27 channel bends ranging in sinuosity from 1.0 to 3.0. Three distinct channel geometries are classified based on their thalweg position; normal asymmetrical, symmetrical and inverse asymmetrical. Straight channel segments (sinuosities 1.0–1.05) exhibit the most symmetrical cross-sectional morphologies. Low (sinuosities 1.05–1.2) and high sinuosity (sinuosities >1.2) channel bends exhibit maximum cross-sectional asymmetries at bend apexes, with symmetrical cross-sectional morphologies at inflection points. As expected, asymmetry values systematically increase from straight to high sinuosity channel segments; however, the most significant increase occurs at the threshold from straight to low sinuosity channel segments, which suggests that even minor deviation from straight channels promotes development of asymmetrical cross-sectional morphologies. Defined relationships are utilized to inform correlation of channelform surfaces between two well-exposed outcrops of a sinuous deep-water channel system that are ~1 km apart (Cretaceous Tres Pasos Formation, southern Chile). The developed methodology can be applied in the subsurface to model realistic channelform sedimentary bodies guided by channel planform interpretations from limited-resolution 3-D seismic data, augmented by well data.

1. Introduction

Submarine channel systems are important conveyers of sediment from shallow- to deep-marine settings (Normark, 1970; Mutti and Normark, 1987; Kolla et al., 2001; Deptuck et al., 2003; Mayall et al., 2006; Gee et al., 2007; Covault et al., 2012; Sylvester et al., 2012). The deposits of ancient submarine channels contain significant volumes of hydrocarbon resources, and extensive subsurface data collection, along with enhanced visualization techniques over the past three decades, have improved our understanding of these depositional systems (Pirmez et al., 2000; Abreu et al., 2003; Samuel et al., 2003; Mayall et al., 2006; Deptuck et al., 2007; Kolla et al., 2007; Sylvester et al., 2011). Building accurate 3-D models of submarine channel strata for use in paleoenvironment interpretation and reservoir modeling is difficult as a result of incomplete datasets. For example, outcrops offer high-resolution perspectives of stratigraphy, but exposures are inherently discontinuous as a result of larger-scale geology (e.g., fold-thrust belt segmentation) and cover (e.g., vegetation). Therefore, constraining stratigraphic architecture of channelized sedimentary bodies amongst outcrop locations commonly requires interpretations and

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assumptions about length-scales and geometries of distinct lithofacies (e.g., Pyles et al., 2010; Pringle et al., 2010; Moody et al., 2012; Macauley and Hubbard, 2013). Subsurface datasets are more continuous, but are typically integrated across a range of disconnected scales, from centimeter-scale core analysis to interpretation of decameter-scale seismic reflection data (Abreu et al., 2003; Posamentier and Kolla, 2003; Deptuck et al., 2003; De Ruig and Hubbard, 2006; Cross et al., 2009). Constraining stratigraphic architecture of reservoir bodies is difficult because features such as individual slope channel fills commonly fall between the resolution of core and seismic datasets.

Morphologic data from fluvial channels, such as meander wavelength, sinuosity, and channel width-to-depth ratio, have been compiled for decades (e.g., Leopold and Wolman, 1960; Brice, 1974; Hickin, 1974; Hickin and Nanson, 1975; Hudson and Kesel, 2000). Quantitative analyses of geometries in submarine channel systems have been of more recent interest, emphasizing metrics that were developed for analyzing fluvial systems (cf. Flood and Damuth, 1987; Clark et al., 1992; Clark and Pickering, 1996; Kolla et al., 2001, 2007; Wynn et al., 2007). These studies of submarine channels, however, lack the detailed characterization of cross-sectional channel morphologies and their relationship to channel sinuosity. This important information provides constraints for reconstructing the shape of channel bodies in the stratigraphic record. The magnitude of cross-sectional asymmetry is presumed to be proportional to the magnitude of sinuosity (e.g., Peakall et al., 2000; Abreu et al., 2003; Deptuck et al., 2007). This relationship is recognized based on composite channelforms described from stratigraphic data (Fig. 1; cf. Posamentier and Kolla, 2003; Dixon, 2003; Deptuck et al., 2003, 2007; Mayall et al., 2006; Pyles, 2008; Jobe et al., 2015); however, it has not been statistically demonstrated from morphologic information constrained by bathymetric data.

In this study we derive mathematical relationships between sinuous slope channel planform morphology and cross-sectional geometry using high-resolution bathymetric data from the Lucia Chica Channel System (LCCS), offshore central California. The results are used to condition channel body geometries between disconnected outcrop exposures of slope strata in Chilean Patagonia (Cretaceous Tres Pasos Formation). This analysis will highlight the implications of utilizing geomorphic surfaces in the interpretation of the stratigraphic record and help shed light on formative channel processes on the slope. The developed workflow can also be applied in order to inform the shape and spatial relationships of channel bodies in reservoir models constrained by limited well penetrations and seismic data.

2. Sinuous deep-water channels

Submarine channels extend from the shelf edge to the deep-sea along continental slopes, and are common to water depths from 1 to 4 km (cf. Deptuck et al., 2003; Gee et al., 2007; Wynn et al., 2007). Many channels are represented by negative relief expressions on the seafloor that are produced and later modified by sediment density flow events (Mutti, 1977; Mutti and Normark, 1987). The geomorphic features are typically a long-term conduit through

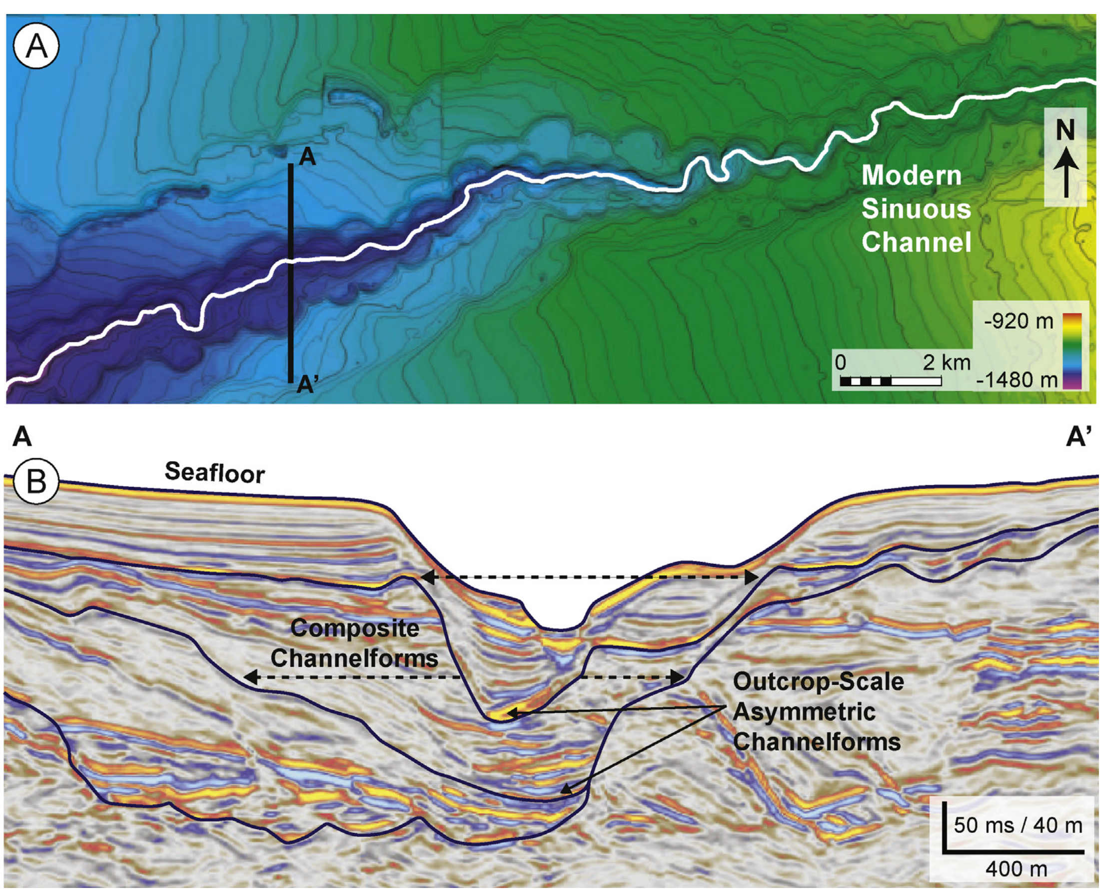

Fig. 1. Example of a sinuous deep-water slope channel from the Niger Delta Slope. (A) Sea-floor bathymetry map illustrating the sinuous nature of the modern slope channel (Modified from Jobe et al., 2015). (B) Seismic cross-section illustrating large composite asymmetrical channelforms that contain smaller (outcrop scale) asymmetrical channel fills. Cross-section location illustrated in Part A (Modified from Jobe et al., 2015).