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Slope channel sedimentary processes and stratigraphic stacking, Cretaceous Tres Pasos Formation slope system, Chilean Patagonia

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ABSTRACT

The Cretaceous Tres Pasos Formation of southern Chile records a slope system characterized by >800 m of paleo-bathymetric relief. Channel deposits are exposed in an outcrop 2.5 km long by 125 m thick and are located in proximity to the toe of a slope clinoform. Exquisite exposures of channel strata offer a unique opportunity for high-resolution analyses of channel stacking patterns and provide insight into the evolution of conduits that transport sediment from continents to the deep ocean.

Eighteen slope channels, or channel elements, are present in the strata studied. They are 6–15 m thick and comprised of stacked turbiditic sedimentation units. Channel fills are characterized by a gradational transition from amalgamated sandstone-rich facies in the channel axes to thinly interbedded sandstone and siltstone at the channel margins over distances of 10–30 m. These elements are generally considered to be ~300 m wide and were formed by punctuated periods of incision and sedimentary bypass, followed by in-filling by collapsing turbidity currents. Out-of-channel deposits consist primarily of fine-grained facies, which are typically covered by vegetation in the study area.

The channel strata of the mapped portion of the Tres Pasos Formation can be grouped into three channel complexes 25–70 m thick. Complexes are differentiated based on the preservation of siltstone-dominated deposits (bypass drapes and channel margin), which persist across the entire outcrop belt and coincide with shifts in channel stacking pattern. The oldest four channel elements (channel complex 1) are characterized by the highest lateral offsets, relative to one another. These are interpreted to record the most unconfined channel-stacking pattern present. As the channel system evolved (channel complexes 2 and 3), channel elements began to stack on top of one another, due to the increased confinement imparted on the slope channel system. The amount of vertical offset between successive channel elements preserves the record of channel aggradation as well as erosional degradation. The greatest vertical offset observed is associated with the oldest channels; as the system matured, vertical offset decreased. This decrease in vertical offset is coincident with the decrease in lateral offset of channels. The lateral offset decrease is attributed to establishment of constructional confinement and is the consequence of increased focusing of successive channel-initiating gravity flows. As confinement establishes, channels are predisposed toward underfilled conditions upon abandonment. The capture of channel-initiating currents along channel abandonment relief fairways focused incision and resulted in increased erosion and decreased vertical offset. The consequence of these conditions is an upward increase in channel element amalgamation.

The organized stacking of slope channels observed in the Tres Pasos Formation is comparable to that of seismically imaged channel-levee or entrenched slope valley systems. By analogy to these 3-dimentionally constrained systems, a portion of the poorly exposed out-of-channel facies in the Tres Pasos Formation is attributed to aggradational internal levee deposits. The facies insight derived from the studied outcrop provides insight into analogous hydrocarbon-bearing units from numerous continental margins.

1. Introduction

Slope channel deposits represent some of the most significant deep-water hydrocarbon reservoirs currently being explored for along continental margins (e.g., Kolla et al., 2001; Abreu et al., 2003; Deptuck et al., 2003, 2007; Posamentier and Kolla, 2003; Prather,

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2003; Samuel et al., 2003; Saller et al., 2004; Schwenk et al., 2005; Mayall et al., 2006; Porter et al., 2006; Gee et al., 2007; Cross et al., 2009). This significance has not only fostered inquiry into the facies characteristics, size, shape and stratigraphic evolution of channel bodies, but has also encouraged investigation into the poorly understood depositional processes that transport sediments into the deep sea (e.g., Peakall et al., 2000; Abreu et al., 2003; Keevil et al., 2006; Nakajima et al., 2009; Gamberi and Marani, 2011; McHargue et al., 2011; Sylvester et al., 2011; Fildani et al., 2013; Stevenson et al., in this issue).

Unlike many channelized sedimentary environments, direct observation of sedimentary processes in the deep oceans is particularly difficult (e.g., Smith et al., 2005; Paull et al., 2010). Instead, synthetic systems using flume tank experiments and numerical modeling have been used to replicate the processes of erosion and deposition along continental slopes (e.g., Imran et al., 1998; Kane et al., 2008; Straub et al., 2011). A variety of techniques have also been used to acquire imagery of modern continental slope environments at increasingly higher resolution, which provide insight into some of the conditions for sediment transport into deep ocean basins (Normark et al., 2009; Babonneau et al., 2010; Paull et al., 2010; Maier et al., 2011). High-resolution seismic reflection surveys have also provided insight into slope channel systems by yielding vivid three-dimensional images of subsurface deposits. These surveys allow specific morphologic features and coarse scale architectural complexities to be identified and represent an ideal opportunity to study turbidite systems as they evolve through space and time (Stelting et al., 1985; Deptuck et al., 2003, 2007; Hubbard et al., 2009). Each approach has limitations in its perspective and resolution; however these can be overcome, in part, with fine-scale observations collected from well-preserved outcrops of ancient deep-water, slope channel deposits (e.g., Gardner et al., 2003; Beaubouef, 2004; Kane et al., 2009; Pyles et al., 2010; Jobe et al., 2010; Hodgson et al., 2011; Arnott et al., in this issue; Callow et al., 2013).

This study is focused on an exceptionally exposed outcrop of the Late Cretaceous Tres Pasos Formation in southern Chile, which consists of strata deposited toward the toe of a high-relief (>800 m) basin margin (Fig. 1A; Hubbard et al., 2010). A primary objective of this study is to dissect the stratal hierarchy and deduce sedimentary processes responsible for slope channel evolution, as recorded in the deposits of eighteen stacked channel elements that are two- to three-dimensionally exposed in outcrop (Fig. 2). The scale of the stratigraphic features exposed in the outcrop belt fosters direct comparison to analogous slope channel units imaged seismically. Demonstrating the utility of the outcrop as an analog for deep-water deposits in the subsurface is a secondary objective of this work.

2. Background geology

The Magallanes foreland basin is located in southeastern Chilean Patagonia, developed along the western margin of South America in response to the initiation and uplift of the Andean fold-thrust belt (Fig. 1B; Dalziel et al., 1974; Wilson, 1991; Fildani and Hessler, 2005; Fosdick et al., 2011). The narrow basin was filled axially from north to south with sediments sourced predominantly from the orogenic belt (Katz, 1963; Fildani et al., 2003; Romans et al., 2010, 2011). The strata of interest, the Late Cretaceous Tres Pasos Formation,

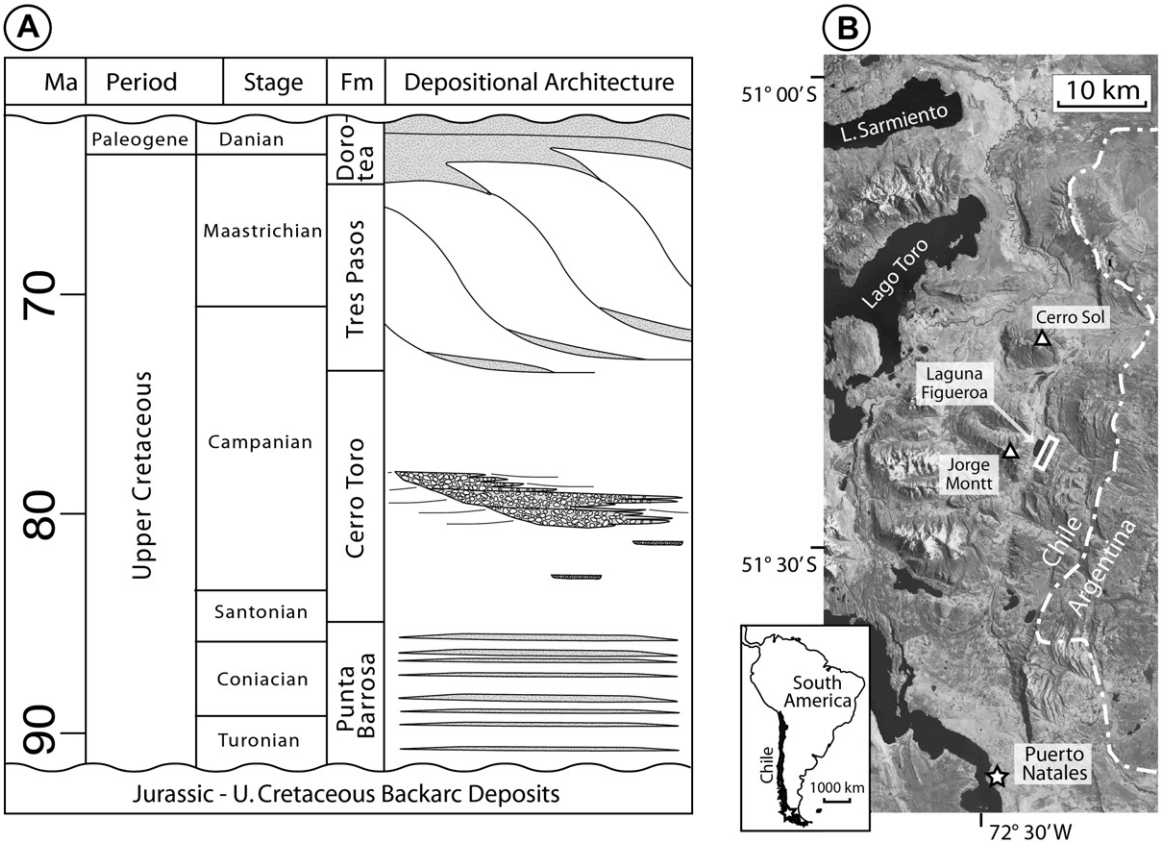

Figure 1. (A) Magallanes foreland basin stratigraphy (from Hubbard et al., 2010). Bathyal conditions persisted during deposition of the Punta Barrosa and Cerro Toro Formations. The Tres Pasos and Dorotea Formations record the progradational in-filling of the Cretaceous foredeep. Slope channel sandstones deposited at the base of a high relief (>800 m) slope, part of the Tres Pasos Formation, are the focus of this study. (B) Study area overview. The Tres Pasos slope channel strata of interest are present in the area highlighted, adjacent to Laguna Figueroa. Inset map of South America shows the location of the regional satellite image featured (star).