



Integrating modern seafloor and outcrop data in the analysis of slope channel architecture and fill

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ABSTRACT

Submarine slope channels can form important hydrocarbon reservoirs, but reconstruction of their geometry is often problematic, reflecting the complex interplay of spatially and temporally varying erosional and aggradational processes. The morphology and character of slope channel fills are consequently studied via a number of different approaches that, relying on different potential resolutions, yield general conclusions but fail to capture the complexity of slope channel make up. The integration of observations from modern and ancient systems can allow inferences about a large range of slope channel attributes from the 3D distribution and the hierarchical significance of their constituent geomorphic elements, to their stratigraphy and their lithology. In this paper such an integration has been carried out using modern data from the southeastern Tyrrhenian Sea and outcrop examples from the Rosario Formation in Baja California. Both data-sets give the opportunity to study relatively straight slope channels in coarse-grained continental margin settings. The modern data consistently show a hierarchy of elements. Slope channels are composed of a channel belt and external levee wedge. Channel elements, internal levees, inter-channel bars and side-attached bars compose channel belts. Thalwegs, thalweg margin areas and interthalweg- and side attached bars compose channel elements. The degree of relief associated with the different hierarchical elements provides varying scales of flow confinement contributing to the stratigraphic architecture of the slope channels. In particular, the relief of internal levees, in the order of 10–20 m, prevents the lower, coarser-grained parts of flows from spreading over the entire channel belt.

Four types of channel element combinations are recognized. Type I has a sinuous thalweg associated with small scale laterally accreting deposits of coarse grain sediments; finer grained sediments are deposited in the overbank area marginal to the thalweg, in addition to coarse-grained scours fills. Type II has a straight thalweg with a complex scoured floor, flanked by side-attached bars. Type III is characterised by a straight thalweg and a fill mainly consisting of laterally accreted deposits, which are laterally and longitudinally extensive and show two scales of relief depending on the presence or absence of a thalweg margin area within the channel element. Type IV is relatively featureless and is characterised by sub-horizontal laterally continuous deposits that thin and coarsen in coincidence with an axial discontinuous low-relief thalweg or a wider depressed area.

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1. Introduction

Submarine slope channels are not only spectacular features of the modern seafloor, they can also form important hydrocarbon reservoirs (Wonham et al., 2000; Abreu et al., 2003; Weimer and Slatt, 2004; Mayall et al., 2006). Slope channels commonly have

complex erosional and aggradational morphologies, accordingly their fills are also complex; consequently they have been extensively studied using a variety of approaches, with differing resolution according to the aims and objectives of the study, and whether they are modern seafloor systems or ancient channels in the subsurface or at outcrop. The study of ancient slope channels at outcrop is vital in order to resolve the fine scale stratigraphy and lithology of slope channel fill; this affords a range of observational scale that cannot be matched by either subsurface and modern data (e.g., Kendrick, 2000; Mayall and Stewart, 2000; Hickson and Lowe,

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2002; Eschard et al., 2003; Beaubouef, 2004; Anderson et al., 2006; McHargue et al., 2011). However, outcrops, due to inherent exposure limitations, are not favourable for providing details of the planform and 3D geometry of the channel and its geomorphological elements. High resolution data from the modern seafloor can provide such planform and 3D insights into slope channel geomorphological elements (Normark et al., 1998; Demyttenaere et al., 2000; Fildani and Normark, 2004; Babonneau et al., 2010, 2002; Piper et al., 1999; Gervais et al., 2004; Gamberi and Marani, 2008; Maier et al., 2011, 2012) but generally lacks the lithological constraint of outcrop studies, particularly in coarse-grained systems where core recovery is poor. Sub-bottom profiles are also a useful tool in the integration of morphological and lithological data, but are also hindered by their resolution capability when coarse-grained deposits occur at the seafloor. Thus, in many cases, the stratigraphic architecture of the observed geomorphological elements within slope channels cannot be adequately imaged. One way of overcoming limitations in resolution and scale of observation of the different approaches is to integrate them. In particular, the merging of observations from modern and ancient systems can allow inference of the 3D distribution of geomorphological elements, their stratigraphic evolution and architecture, and their lithologic character.

As already pointed out in previous studies (Mutti and Normark, 1987, 1991, 2000; Normark et al., 1993; Piper and Normark, 2001), one of the main problems when integrating modern and outcrop data arises from the different scales of observation. The result is sometimes a comparison of elements with different hierarchical significance. A further issue involves the preservation potential of modern seafloor morphological elements; how much of what we see at the seafloor will survive the sum of the repeated episodes of erosion, bypass and deposition that characterises these channels? Another issue involves the recognition of key elements in the two different types of data, those in modern systems being defined largely by the external form of their upper surfaces and to a lesser extent by internal seismic reflection geometry (Normark et al., 1998; Fildani and Normark, 2004; Babonneau et al., 2010; Babonneau et al., 2002; Piper et al., 1999; Gamberi and Marani, 2008), whereas those in ancient systems are necessarily defined largely by their internal lithological architecture and preserved 2D cross-sectional geometry (Mayall and Stewart, 2000; Hickson and Lowe, 2002; Eschard et al., 2003; Beaubouef, 2004; Anderson et al., 2006; McHargue et al., 2011; Pyles et al., 2010).

In this paper, through the interpretation of multibeam seafloor morphology and CHIRP sub-bottom profiles (Fig. 1), we describe the geomorphological elements found within modern slope channels of the Tyrrhenian Sea, which are believed to have generally coarse-grained fills. We then describe some key outcrops from the Cretaceous Rosario Formation (Baja California, Mexico, Fig. 11), which demonstrate the complex coarse-grained fill of slope channels, which we consider broadly analogous to the Tyrrhenian Sea channels in terms both of grain-size range and slope setting. We demonstrate that the basic geomorphic elements present on the modern seafloor have their probable counterparts in the depositional bodies found in the outcrop system. From this analysis we derive a scheme for slope channel make up, which merges observations on the hierarchy of their component elements, their planform arrangement, and their stratigraphy and lithology.

2. Modern examples

2.1. Geological setting

The modern slope channels presented in this paper are from the northeastern Sicilian margin in the southeastern Tyrrhenian Sea

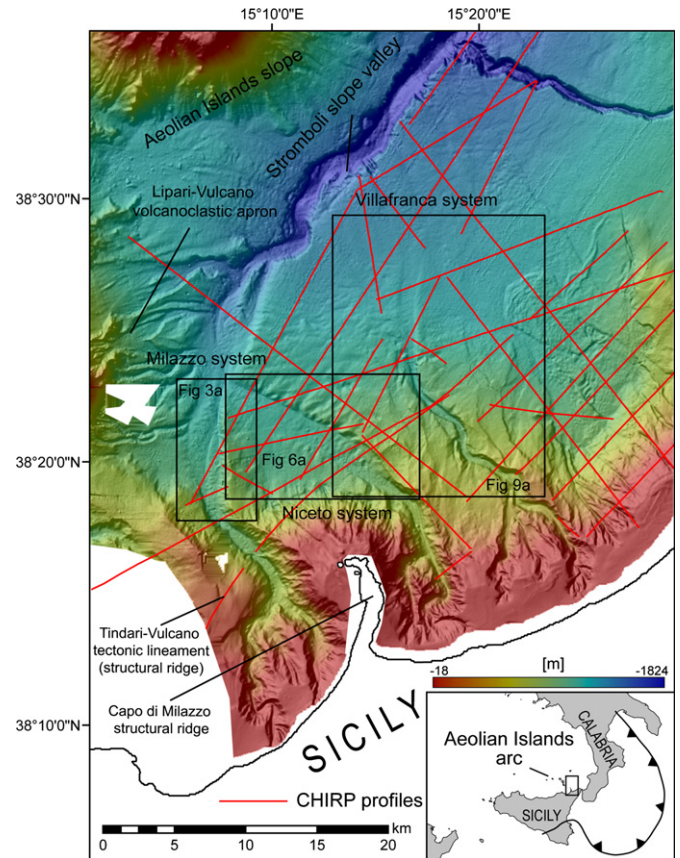


Figure 1. Shaded relief image from multibeam bathymetric data of the northeastern Sicilian margin in the SE Tyrrhenian Sea (see location in the lower left inset). The red lines are the traces of the available CHIRP profiles. The black boxes correspond with the areas detailed in the following figures. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(Fig. 1). The Sicilian margin developed behind the Apenninic-Maghrebic chain due to extensional tectonics, leading to the opening of the Tyrrhenian Sea back arc basin system (Kastens et al., 1988). The study area is still tectonically active on the adjacent mainland. On the Sicilian margin adjacent to the Capo di Milazzo structural ridge, the Milazzo and Niceto slope channels are tributaries to the Stromboli slope valley, which runs parallel to the slope, confined to the north by the Aeolian Island slope (Gamberi and Marani, 2006; Gamberi and Marani, 2007; Gamberi and Dalla Valle, 2009) (Fig. 1). Further East, the Villafranca slope channel is not connected with the Stromboli Valley, but spreads out on the lower slope into a transient fan, which does spill over into the Stromboli Valley (Gamberi and Rovere, 2011). Multibeam bathymetric data are available over the slope channels of the Sicilian margin. In addition, numerous CHIRP sub-bottom profiles have been acquired, which cross the slope channels in various places and provide details of their fill and architecture. Seafloor samples data are not directly available over the study area. However, box core samples (Tramontana et al., 1995) have collected sand to gravel-sized sediment within the axis of the Milazzo and Niceto slope channels confirming that they are coarse-grained systems. In addition, unpublished results of recent seafloor sampling (cruise MAGIC_ISMAR_0911; September 2011, box corer sampling) have shown that coarse grained sand to gravel are found in the floor of one of the channels of the depositional lobe fed by the Villafranca slope channel. The canyons that feed the Milazzo and the Niceto channels have their heads very close to the coastline (Fig. 1) and thus it is possible that they are presently active and regularly

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