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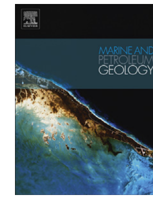

Research paper

Depositional canyon heads at the edge of narrow and tectonically steepened continental shelves: Comparing geomorphic elements, processes and facies in modern and outcrop examples

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ABSTRACT

Marine geology data show that canyon heads can be the site of depositional processes and furnish the details of the geometry of their geomorphic elements. Canyon heads are usually floored by sediment with a prevailing coarse-grained nature and their sampling is very difficult thus preventing the characterization of the facies of their infill. Lithological and facies information is however available through outcrop studies. In this paper, we integrate modern seafloor and outcrop data to characterize the architecture of depositional canyon heads in tectonically active continental margins with a narrow shelf. The modern examples are located along the northeastern Sicilian margin (Milazzo and Niceto canyon-head systems), whereas the ancient one, Pliocene in age, is located onshore, along the Ligurian coast (Ventimiglia canyon-head system). The modern Milazzo canyon head is located at the coastline and has a steep slope. The flanking deposits are equivalent to the oldest Gilbert delta foresets of the Ventimiglia canyon head as the delta progrades directly into the upper slope. A deeply entrenched channel and a large chute mark the mostly erosional area directly facing the mouths of the rivers that enter the Milazzo canyon head. Laterally, the upper part of the foresets slope is characterized by a bulge with swales and ridges topography. These geomorphic elements are interpreted to be formed by debris flows and turbidity currents as suggested by the upper part of the Ventimiglia foresets, where chaotic, massive or graded deposits are observed. The swales and ridges topography gradually disapper downslope; this area is dominated by turbulent processes due to flow expansion from a confined to a more unconfined setting. An high turbulent flow environment is also confirmed by the formation of plunge pools, due to hydraulic jump, at the foresets-toesets transition. Similar features in the outcrop are infilled by bedsets facies with grain-size coarser than the eroded surroundings. The modern Niceto canyon head is connected landwards to a delta system that stretches across a 1 km wide shelf. Channelized delta distributaries are similar to the topset strata of the youngest deltas of the Ventimiglia canyon head. Channels are up to 200 m wide and 50 m deep and show axial bedform trains confirming that large scale trough cross beds are an important facies of channel infill. Wave reworking in the upper part of the topsets is also suggested by both the modern and outcrop data.

Our work shows how the nature of the infill and the depositional processes at the canyon heads are dependent on the shelf width and can give hints on the degree of evolution of the canyon itself. In addition, our work shows how the location and character of river entry points is important in dictating lateral facies variations within canyon heads.

1. Introduction

Canyon heads are usually thought as retrogradational features where erosional processes prevail (Sherpard, 1981; Pratson et al., 1994; Pratson and Coakley, 1996; Piper and Normark, 2009). It is

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a common understanding that canyon heads with amphitheatre-shaped margins are formed by the headward migration of landslide scars and associated linear chutes and gullies with erosional processes extending upslope until eventually reaching the shelf break (Farre et al., 1983; Arbues et al., 2007; Dakin et al., 2013).

However, recent acquisition of high-resolution multibeam seafloor images, coupled with outcrop analogue data on canyonized shelves and upper slopes, show that depositional elements are also a common trait of canyon heads (Postma, 1984; Morris and Busby-Spera, 1988; Mellere et al., 2003; Breda et al., 2007, 2009). High-resolution data from the modern seafloor provide planform and 3D insights into canyon head geomorphological elements, but usually lacks lithological information, 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 hindered by their resolution capability when coarse-grained deposits occur at the seafloor. Thus, in many cases, the lithology and stratigraphic architecture of modern canyon heads remain elusive. The study of ancient successions is thus vital in order to resolve the fine scale stratigraphy and lithology of canyon head deposits. However, outcrops, due to inherent exposure limitations, are not favourable for providing details of the planform and 3D geometry of the canyon head infill.

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 lithological character (Mutti and Normark, 1987, 1991; Normark et al., 1993; Morris and Normark, 2000; Gamberi et al., 2013). In this paper, we integrate modern seafloor and outcrop data to define the architecture of canyon heads undergoing an infill phase. Both the moderns and ancient examples are located along the margins of the western Mediterranean Sea. The canyons developed during the Messinian salinity crisis (Hsü et al., 1973; Catalano et al., 1978; Cita and Ryan, 1978; Clauzon et al., 1996; Krijgsman et al 1999; Blanc, 2002; Duggen et al., 2003; Rouchy and Caruso, 2006; Garcia-Castellanos et al., 2009), when sea level in the Mediterranean basin fell approximately 2000 m. Thick evaporitic successions were deposited in the abyssal plain whereas the basin margins recorded deep entrenchments by river erosion. During the subsequent Pliocene sea-level rise, the river valleys were flooded and transformed into submarine canyons. Their heads, at the re-adjusted shelf-slope break, were gradually infilled by mass flow deposits and subsequently by coarse-grained shelf-edge delta systems (Breda et al., 2007, 2009; Carbone et al., 2011). During late Pleistocene and Holocene times, the newly created shelf and the canyonized upper slope underwent alternating processes of erosion and deposition caused by tectonic movements and eustatic fluctuations (Dallagiovanna et al., 2012; Gamberi et al., 2013, 2014).

The modern canyons surrounding the Milazzo Promontory, on the northern margin of Sicily, are imaged by multibeam and shallow high-resolution seismic and record the latest Pleistocene and Holocene infill. The outcrop analogue system is in Ventimiglia, along the coast at the border between Italy and France and records the earliest Pliocene phases of infill. In both locations, canyon heads are 4–7 km wide and are flanked by narrow and steep continental shelves. Where present, the shelf-edge is at maximum 1 km from the shoreline and locally the canyon heads indent the coastline. Both locations are subject to active tectonics due to the uplifting orogens at their back. On land, the uplifted Pliocene to Pleistocene deposits lie onboard from the present canyon heads and onlap with an angular unconformity the pre-Messinian strata. In both examples, canyons heads are connected with rivers presenting comparably small drainage basins, flanked by high relieves and with an highly fluctuating discharge. The studied deposits are coarse-grained, ranging from coarse and pebbly sandstone to cobble and boulder grade conglomerate. They are similar to many modern and ancient river-connected canyon head systems, like those developed along the California coast (Morris and Busby-Spera, 1988; Mutti et al., 2003; Normark et al., 2006; Romans et al., 2009), the western Iberian margin (Arzola et al., 2008), Almeria (Postma, 1984), Ainsa (Dakin et al., 2013; Arbues et al., 2007) and the Messinian Strait nearshore zone (Casalbore and Chiocci, 2017).

Our aim is to provide a detailed case history of the morphology and processes of these river-connected coarse-grained canyon head fills. Our study shows that deposition at canyon head is highly complex, with a range of sedimentary features and processes that reflect changes in downslope geometry and a transition from mass flow and slope failure to organized, segregated flows, with processes and geometries from purely erosive to depositional.

2. Methods

The study of the NE Sicilian margin has been carried out through multibeam bathymetry and CHIRP (compressed high-intensity radar pulse) sub-bottom profiles interpretation. Data have been acquired during various cruises carried out by ISMAR (Istituto di Scienze Marine – Consiglio Nazionale delle Ricerche) in the past fifteen years. High resolution bathymetric data were acquired during two cruises in the upper slope and shelf area, carried out on board R/V Mariagrazia in 2009 and 2010 using a hull-mounted Kongsberg EM3002D (300 kHz) and a pole-mounted Reson 7111 (100 kHz) multibeam system respectively. In 2011 some sectors of the outer shelf were re-mapped with a hull-mounted Kongsberg EM710 (70–100 kHz) multibeam system on board R/V Urania. All the multibeam data have been merged and post-processed using CARIS HIPS&SIPS software and a 5-m-resolution DTM was produced. The merged bathymetric data cover the shelf at depth higher than about 30 m and the upper slope. High resolution CHIRP seismic profiles were acquired on board R/V Mariagrazia and Urania with a hull-mounted Teledyne BENTHOS III CHIRP system having a frequency modulation between 2 and 20 kHz. The CHIRP profiles are spaced at an average interval of 200 m and have 0.5-m-vertical resolution. Cores are not available, thus sediment grain-size can only be inferred from the seismic facies on the Chirp profiles. Consequently, only a relative estimate is possible, since finer-grained sediments have low-amplitude reflections whereas coarser-grained sediments have strong reflections that often preclude further downsection penetration.

The study of the Ventimiglia outcrops has been performed using the conventional sedimentological fieldwork methods, including facies analysis, detailed logging and line-drawing of bedding architecture on outcrop photomosaics.

3. The modern north-eastern Sicily canyon heads

3.1. Geological setting

The study area is located along the NE Sicily margin surrounding Capo Milazzo (Fig. 1), outboard of the outcropping Peloritani orogenic wedge (Lentini et al., 1996). The region was widely affected by the extensional tectonics that led to the opening of the Tyrrhenian back-arc basins (Patacca and Scandone, 1989). As a result, NNE-SSW-trending normal faults and NW-SE-trending strike-slip faults give rise to the horst and graben structural setting of NE Sicily (Di Stefano and Lentini, 1995; Lentini et al., 2000). High regional uplift rates affect the NE Sicily area

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