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Mass-transport complex evolution in a tectonically active margin (Gioia Basin, Southeastern Tyrrhenian Sea)

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ABSTRACT

Along the southeastern Tyrrhenian Sea margin, the Gioia Basin formed as a result of extensional tectonics at the rear of the Maghrebian thrust belt. In the central part of the basin, mass-transport deposits represent up to 80% of its recent infill. The basin-wide Nicotera slump is the deepest mass-transport deposit present in the basin and was followed by sheet turbidite deposition. Above the turbidite package, a mass-transport complex (MTC) formed through the stacking of different mass-transport deposits due to repeated failures of the continental slope and of a base of slope channel levee wedge, which is still preserved in the western side of the basin. The Villafranca frontally-confined slide, a body mainly consisting of coherent blocks, represents the bulk of the MTC. The failure of the Villafranca slide was due to asymmetric loading of a permeable condensed horizon in the thinnest, distal lateral part of the channel levee wedge. The relatively large thickness of the Villafranca slide caused it to remain confined at its toe region. Smaller scale mass-transport deposits, a debris-flow sheet and a debris-flow lobe, followed the Villafranca slide and were sourced from the same headwall area. Their different run out and internal character are possibly a function of the lithology of the material involved in the collapse. A slab slide, characterized by little internal deformation and frontal contractional ridges, originated when seafloor instability propagated towards the north, causing clockwise rotation of a sediment wedge. Along the linear headwall of the slab slide, a localized upslope failure propagation is shown by a small scale re-entrant. The Sicilian margin, along which the Gioia Basin develops, is characterized by strong differential vertical movements due to ongoing extensional tectonics. The effects of both local and regional strong earthquakes are frequently felt in the area. Thus, slope oversteepening and earthquakes are suggested as the more likely causes for the observed repeated events of seafloor failure. In addition, an evolution of the MTC through larger slides controlled by the migration of uplift of the basin bounding submarine ridge, followed by smaller scale failures due to the consequent slope profile modification, is here advanced.

1. Introduction

Sediment instability and failure are important processes that substantially contribute to the evolution of many continental margins worldwide. Seismicity, slope oversteepening, sea level fluctuations, gas charging of sediments and rapid sediment accumulation are the main documented agents for seafloor instability and triggers for eventual sediment failure (Coleman and Prior, 1988; Hampton et al., 1996; Haq, 1998; Lee, 2009; Sultan et al., 2004). Where these processes are in action for long time spans, sediment failure can be a recurring process and single mass-transport deposits (MTDs) stack into composite depositional bodies referred to as mass-transport complexes (MTCs). Examples of mass-transport complexes are found in the Storegga area along the Norwegian margin (Bull et al., 2008; Micallef et al., 2009), in the southern Cretan Sea (Strozyk et al., 2009), in the Caribbean Plate Boundary Zone (Moscardelli et al., 2006), in the Israel continental margin (Frey-Martínez et al., 2005), in the river-fed Nile deep-sea turbidite system (Garziglia et al., 2008) and in the Mauritania offshore (Heinrich et al., 2008). In all these cases, single failure events give rise to the deposition of composite, displaced sediment masses, whose geometry and internal structure reflect different mechanisms of downslope transport and deposition. Traditionally, submarine downslope transport is classified on the basis of the geomorphology, the geometry and the internal structure of the associated deposit (Coleman and Prior, 1988; Dott, 1963; Mienert et al., 2003; Mulder and Cochonant, 1996; Nardin et al., 1979; Prior et al., 1984; Varnes, 1978). The early suggestion that landslides may evolve into different types of gravity flows, proposed by Middleton and Hampton (1976), has been recently substantiated by a wide number of studies (Martinsen, 1994; Moscardelli et al., 2006; Strachan, 2008; Tripsanas et al., 2008). Whereas many groupings and classification schemes have been proposed, it is now recognized that the processes

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of downslope sediment transport are part of a continuum, where one flow type may evolve into another or trigger other movements. Since submarine sediment failures are seldom directly observable, the attributes of mass-transport deposits are the only available information that can be used to understand the initiation and the evolution of slope failure. The morphology, geometry and internal deformation of mass-transport deposits are in fact a direct result of the failure type, the morphology of the seafloor prior to failure and of the facies of the involved sediment masses. Thus, through the characterization of the internal deformation and of the morphology of mass-transport deposits, it is possible to reconstruct a kinematic model for mass-transport deposit emplacement (e.g. Bull et al., 2008; Gee et al., 2006; Lucente and Pini, 2003).

This paper presents the characterization of mass-transport deposits in the Gioia Basin along the Sicilian and Calabrian continental margins through the integrated interpretation of high resolution multibeam bathymetry and seismic data. The aim of the study is to show the details of the internal structure of the different mass-transport deposits and to infer their failure and transport mechanisms. The single deposits that make up the mass-transport complex are identified and their mechanism of failure and emplacement are then distinguished. Moreover, an interpretation of the predisposing factors and triggering mechanisms for the observed repeated failure events is presented. Finally, an evolutionary model for MTC generation and internal make-up in tectonically active areas is advanced.

2. The study area

The Gioia Basin (SE Tyrrhenian Sea) is located along the northeastern Sicilian and the southern Calabrian margins and is bounded seaward by the Aeolian Islands (Fig. 1). It is the result of the tectonics, mainly through NE–SW oriented extensional faulting, that led to the opening of the Tyrrhenian back-arc basins (see Malinverno and Ryan, 1986; Patacca and Scandone, 1989). Extensional tectonics affected the Oligo–Miocene thrust sheets of the Kabilo–Calabride units (Lentini et al., 1994, 1995, 1996) and was accompanied by a complex system of transcurrent/transtensional structures (Guarnieri et al., 2002; Pepe et al., 2005).

A channel levee wedge formed by the Milazzo, Villafranca and Niceto channels is present in the western part of the Gioia Basin (Gamberi and Marani, 2006; Fig. 1). The Gioia–Mesima channel-canyon system is present in the northeastern part of the basin (Gamberi and Marani, 2006, 2008) and is a tributary of the Stromboli Valley, the axial drainage trunk of the Gioia Basin (Fig. 1). In the central part of the basin, the Acquarone Ridge is an elevated area, corresponding with a horst, formed during the extensional tectonics that originated the present-day setting of the margin (Fig. 1).

3. Geophysical data

Multibeam bathymetric data over the study area were acquired during two surveys carried out in 1996 and 1999 on board *R/V Gelendzhik* and *R/V Strakhov*, respectively, with a hull-mounted SIMRAD EM12 model (Fig. 1). The data were post-processed using the CARIS HIPS and SIPS software, with a standard procedure, including positioning and depth correction, manual and statistical cleaning of the data.

Alongside the multibeam data, single-channel seismic lines were acquired with an average spacing of 3 km, oriented parallel to the margin (Fig. 1). The source consisted of two synchronized air-guns operating with an energy of 70–100 bar. The active section of the streamer was 150-m-long. Shot interval was set to 8 s and the record length to 4 s. Vertical resolution is about 10 m. A regional reconnaissance grid consisting of both strike and dip lines acquired in 1973 by the former IGM-CNR institute aboard the *R/V Bannock* with a single-channel 30 kJ sparker system was also used (Fig. 1). Vertical resolution is about 30 m. CHIRP high resolution sub-bottom profiles (frequency ranging between 3 and 7 kHz) acquired in 2003 were also used, their vertical resolution is 0.5 m (Fig. 1).

4. Seismic statigraphy

In the Gioia Basin, marginal zone Messinian evaporites with thickness <100 ms are present above the acoustic basement (Fabbri and Curzi, 1979; Fabbri et al., 1981; Fig. 2b). A unit with seismic transparent facies, typical of the hemipelagic Trubi-like deposits of Early Pliocene age, follows (Fig. 2b). Successively, sheet turbidites of Middle to Upper Pliocene age were deposited exclusively in the depocenters created during the extensional tectonics (Gamberi and Marani, 2006; Fig. 2b).

The deposits from Upper Pliocene/Lower Pleistocene up to the Present, as defined by Gamberi and Marani (2006), are the subject of this study. They were divided into two units. The lower one has at its base the Nicotera slump followed upslope by sheet turbidites and by a channel levee wedge developed only in the western basin portion (Fig. 3b). The upper one is made up of a channel levee complex that spans the whole margin but considerably thins toward the east where it was affected by the failure contributing to the building of the MTC (Fig. 3b, c).

5. Results

5.1. The Nicotera slump

The Nicotera slump is consistently buried below a thick section of younger sediments (Figs. 2b and 3b) and therefore its characteristics have been reconstructed only through the analysis of seismic data. It is recognized as a transparent body with fairly uniform thickness of about 50 m that is present from the base of the slope to the distal basin area (Figs. 2a, 3b, 4 and 5). The Nicotera slump covers an area of 636 km^2 and its estimated volume is 30 km^3 (Fig. 2a). Its headwall is visible in Fig. 2b on the southwestern side of the Acquarone Ridge. In general the slump has a sheet-like geometry with a rather smooth upper surface (Fig. 5). A conspicuous reduction of the slump thickness occurs along the edge of a paleo high formed by a buried extensional fault on the continuation of the Acquarone Ridge (Figs. 2b and 4). The slump also thins gradually towards the West (Fig. 4). On the contrary, a thickening of the slump occurs in its northern part close to the slope of the Capo Vaticano Ridge; here the development of a rough upper surface, possibly related to folds, is apparent (Fig. 6). The slump also thickens in the distal portion of the basin where it is at present cut by the Stromboli Valley, but originally presumably onlapped against the southeastern slope of the Aeolian Islands (Fig. 2a, b).

5.2. The mass-transport complex (MTC)

5.2.1. The Villafranca slide

A large slide, up to about 300 m thick (in average 200 m thick), represents the basal thickest portion of the mass-transport complex present in the Gioia Basin (MTC in Fig. 2a, b). The Villafranca slide occupies an area of 230 km^2 and has an estimated volume of 46 km^3 (Fig. 7a, b). In the proximal part of the slide, the basal shear surface cuts down stratigraphy and originates two wide flat-bottom depressions interpreted as megascours (Fig. 3a, b). A ramp and flat geometry is present more distally (Fig. 5). Both the lateral margins of the mid-slide area are represented by a discontinuity that cuts up stratigraphy from the basal shear plane (Fig. 4). The western lateral margin of the Villafranca slide is not visible in the bathymetry since it is healed by successive deposits (Fig. 7a). The eastern lateral margin of the slide shows up in the bathymetry as a relatively continuous SE–NW