Potential Cyclic Steps in a Gully System of the Gulf of Palermo (Southern Tyrrhenian Sea)

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Abstract

Multibeam bathymetric data revealed the occurrence of a train of bedforms along a gully system in the Gulf of Palermo, southern Tyrrhenian Sea. The observed gullies, located in the westernmost sector of the Gulf of Palermo, incise the outer shelf at a depth of 120 m and converge at the Zafferano Canyon, connecting to the Palermo Basin at a depth of 1300 m. Bedforms develop along these gullies and along the thalweg of the canyon, displaying an average wavelength of 200 m, with maximum values of 340 m. Their gully floor location combined with their wave length, upslope asymmetry and crescent shape point to a possible cyclic step origin of these bedforms. Preliminary numerical modelling suggests that, assuming that these bedforms were formed by cyclic steps in turbidity currents, these flows might have been few meters thick and have had velocities in the range of 0.2–1.5 m/s.

Keywords

Cyclic steps • Gullies • Submarine canyons • Turbidity currents • Gulf of palermo • Tyrrhenian sea

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36.1 Introduction-Study Area

The submarine canyons of the Gulf of Palermo (northwestern Sicily, southern Tyrrhenian Sea) deeply carve the sedimentary sequence of the Palermo slope and basin system, most of them breaching the shelf margin, and extend to a depth of 1500 m, coinciding with the deepest area of the Palermo intraslope Basin (Lo Iacono et al. 2011, 2014). A train of bedforms occurs along a gully network in front of Cape Zafferano, in the easternmost sector of the gulf, where the continental shelf is no wider than 3 km (Fig. 36.1). The channel floor location of the bedforms, together with their wave length, crescent shape and upslope asymmetry, suggests that they might have developed as a result of a cyclic step process. In such a process, the downstream side of the bedform (the lee side of the bedform) is continuously eroded by a supercritical flow (Froude Number [Fr] > 1), while the flatter upstream side of the bedform is shaped by depositional subcritical flows (Fr < 1) (Parker 1996). This process leads to the formation of a series of asymmetrical upslope-migrating (often crescent-shaped) bedforms (Clarke et al. 2014). Similar bedforms have been observed in open slope environments (Migeon et al. 2000; Pratson et al. 2000; Hill et al. 2008; Urgeles et al. 2011) and more frequently along the thalweg of several submarine canyons and gullies (Fildani et al. 2006; Clark et al. 2014; Covault et al. 2014; Zhong et al. 2015) and could be interpreted as cyclic steps (Cartigny et al. 2011; Kostic 2011). Unfortunately, there are no available data to definitely confirm a cyclic step origin of the bedforms presented here, or even to proof their upslope migration over time. These bedforms are interpreted here as cyclic steps purely on the basis of their geometry and location. We aim to present their morphologic interpretation and in second instance to roughly estimate the main characteristics of the flow potentially responsible for their formation, applying an hydraulic flow model.

36.2 Methods

Swath-bathymetry multibeam (MB) data available for this study were acquired during two different oceanographic cruises in 2001 (CARG Project) and 2009 (MaGIC Project) (Chiocci and Ridente 2011). The MB system of the 2001 cruise was a Reson SeaBat 8111 generating 105 beams at a frequency of 100 kHz. The MB system of the 2009 cruise was a Reson SeaBat8160 generating 126 beams at a frequency of 50 kHz. The MB data were post-processed with the PDS-2000 system. Digital terrain models were produced with a footprint resolution of 20 m. For further details, see Lo Iacono et al. (2011, 2014). Global Mapper and Golden Software Surfer 9 were used to map the trains of bedforms and to calculate their main morphometric characteristics (Table 36.1). The bedform steepness has been defined as the step heights divided by the step lengths (h/L). The asymmetry index (AI) (Knaapen 2005) is defined as L2-L1/L, where L is the distance between two troughs, L1 is the distance between upslope trough and crest and L2 is the distance between the crest and the downslope trough. An AI > 0.02 indicates the presence of asymmetric bedforms. Negative AI values indicate a downslope asymmetry and positive AI values indicate an upslope asymmetry. The applied numerical model strongly simplifies the flows by averaging all flow parameters over the depth, by excluding any exchange of sediment in between the flow and the bed, and by limiting the downstream evolution of the flow to only include small variations as described in gradual varying flow theory. The numerical model uses an average grain size (medium sands) and the stoss and lee side slopes of observed bedforms as input data. The model runs several thousands of simulations for flows combining different discharges, Froude numbers and sediment concentrations. The synthetic bedform wavelengths and amplitudes predicted by these simulations are finally compared with the dimensions of the observed cyclic steps, and the most appropriate characteristics of their genetic flow are then fitted. More details on the model and its assumptions can be found in Cartigny et al. (2011).

36.3 Results-Discussion

The cyclic steps of the Gulf of Palermo were mapped in a depth range of 125–1050 m along a network of 9 gullies breaching the shelf-edge in front of Cape Zafferano, the eastern cape of the gulf (Figs. 36.1, 36.2). The gullies have an average width of 180 m and are up to 20 m deep. Some of the gullies display a smoothed and planed morphology of unclear origin within a depth range of 500–700 m (Fig. 36.2). The mapped bedforms have a wavelength ranging from 110 to 340 m and an amplitude ranging from 0.8 to 5 m. Their steepness ranges from 0.007 to 0.01, this last value corresponding to the most morphologically pronounced bedforms, where steeper lee (downslope) and stoss (upslope) sides occur (Fig. 36.3). These bedforms are also the most (upslope) asymmetric, with an AI of 0.27. The

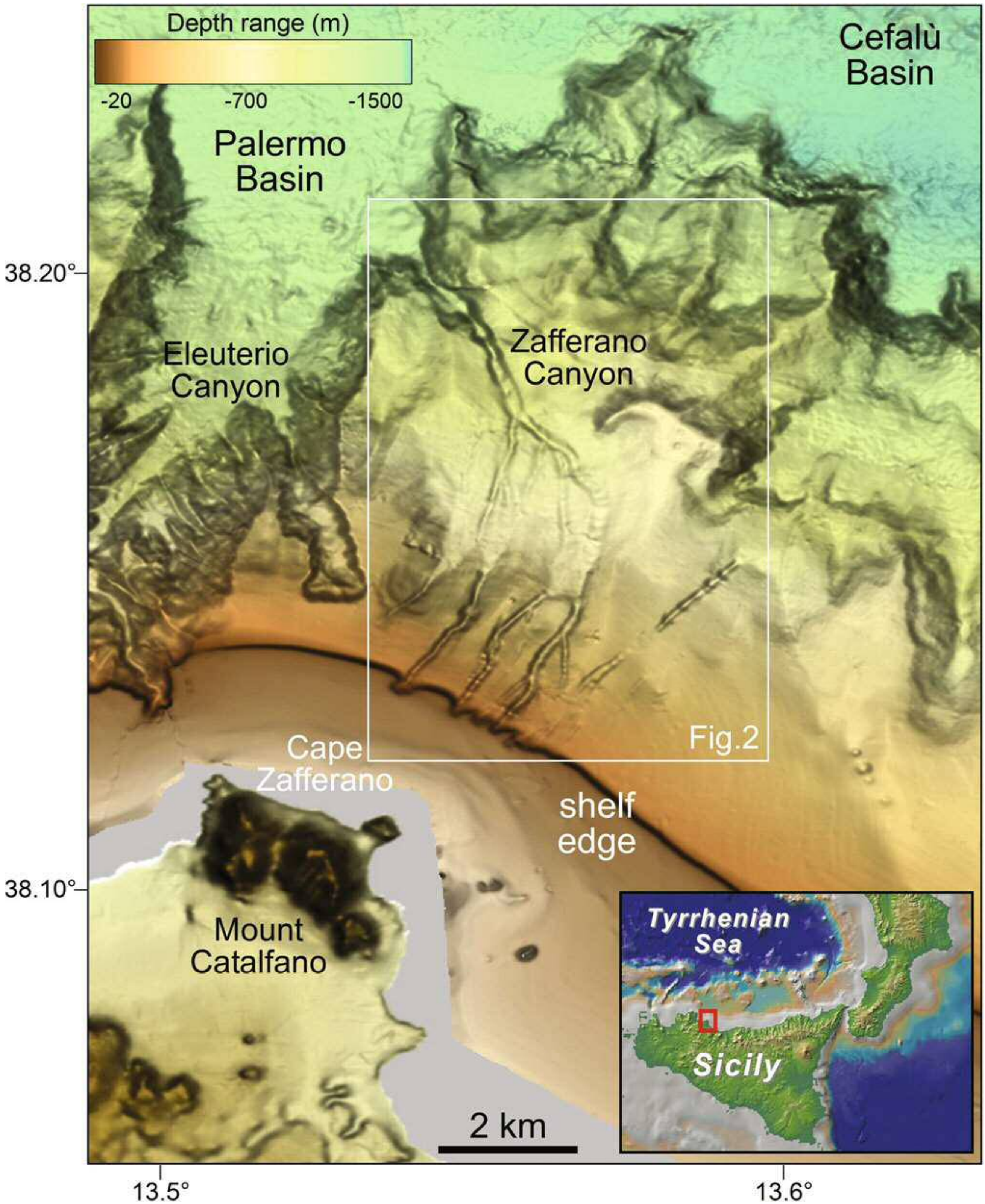


Fig. 36.1 Bathymetric model of the study area. Cape Zafferano is the eastern cape of the Gulf of Palermo

Table 36.1 Bedform characteristics of profile A–A′ in Fig. 36.3

Step #	Slope stoss side (m)	Slope lee side (–)	Length (m)	Amplitude (m)
Step 1	−0.008	0.164	224	5.8
Step 2	0.026	0.217	198	13.2
Step 3	0.003	0.110	249	3.1
Step 4	−0.038	0.063	286	5.0
Average	−0.004	0.138	239	6.8

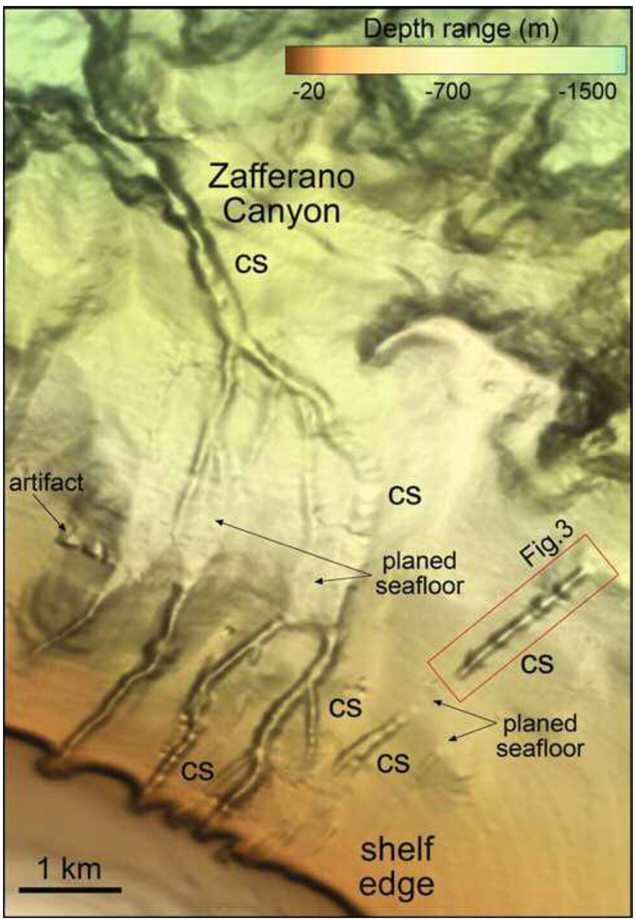


Fig. 36.2 Bathymetric model of the submarine gullies and of the Zafferano Canyon, where interpreted cyclic steps (*CS*) were mapped

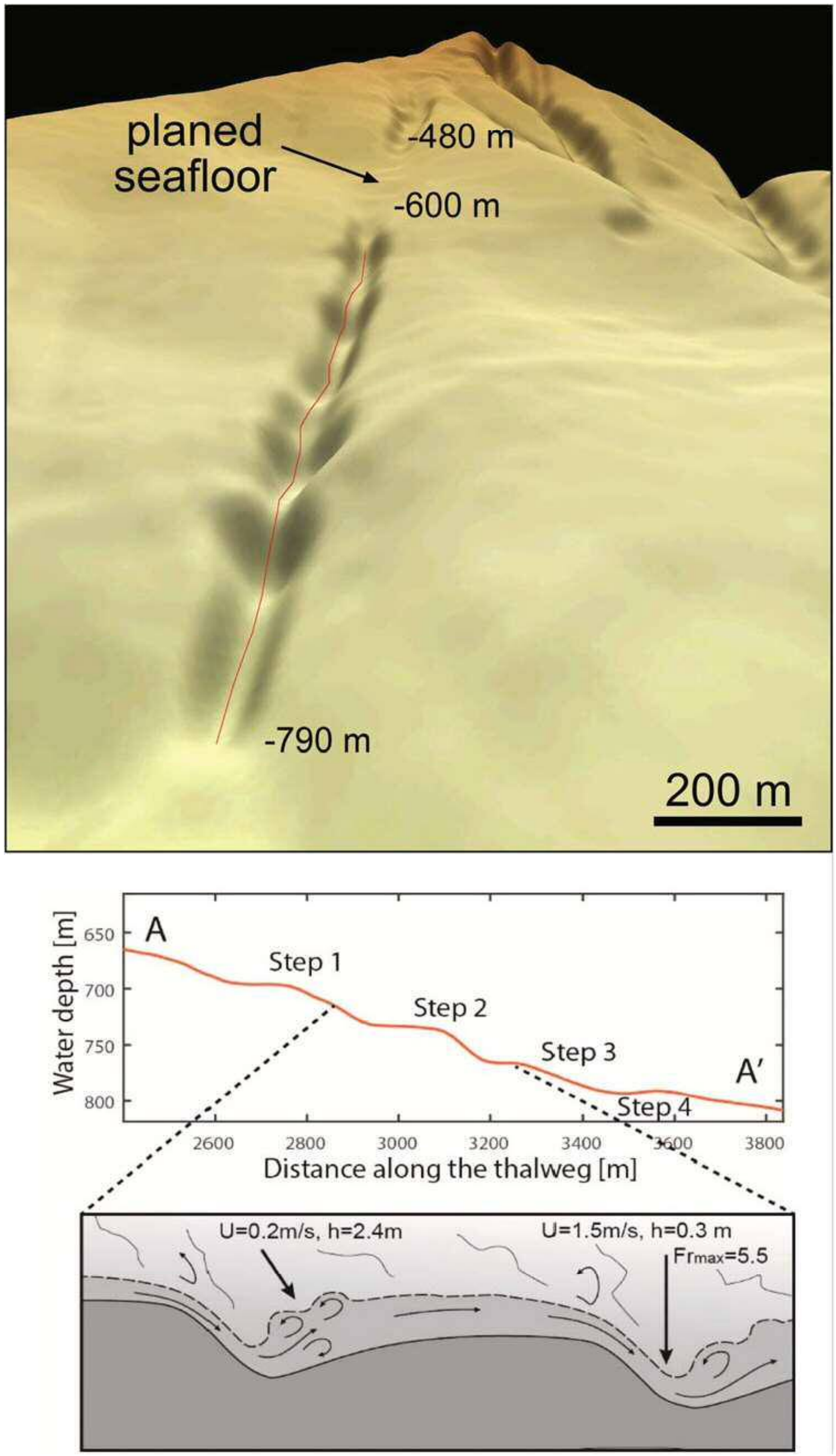
general slope gradient of the gullies along which the most asymmetric and steepest bedforms occur ranges from 7° to 10°.

Based on the assumption that the bedforms developed as a result of a cyclic step process, rough estimations of the turbidity currents which generated the cyclic steps can be made using a simple numerical model for a given range of flow characteristics. The bedforms of Cape Zafferano displaying a more pronounced morphology are here used as input for the model (Fig. 36.3). The average characteristics for the selected bedforms (700–800 m water depth) are summarized in Table 36.1. The model calculations indicate that the observed cyclic steps are likely generated by flows around 1 m thick, with average velocities of exceeding 1.0 m/s. The maximum velocities at the toe of the steep lee sides could reach values of ~1.5 m/s, whereas on the flatter stoss sides the flow reaches a maximum thickness exceeding 2 m combined with a minimum velocity of ~0.2 m/s (Fig. 36.3). As the model makes several assumptions to simplify the flow dynamics, it is necessary to point out that these values are only very rough estimates, and are fully dependent on our cyclic step interpretation.

The occurrence of the studied bedforms along the Capo Zafferano Canyon and associated gullies likely suggests intense turbidity current or a variation in morphology and grain size along these incisions compared to the other canyons mapped in the Gulf of Palermo, where bedforms are apparently absent. This observation fits with previous considerations describing the easternmost canyons and gullies of each gulf along the northwestern Sicilian margin as the most intensely subject to downslope turbidity flows (Lo Iacono et al. 2014).

The topography of the eastern Cape Zafferano and the corresponding decrease in the shelf width probably control the path of the along-shelf currents, which are diverted towards the canyon heads, promoting the creation of turbidity currents. Few insights are actually available about the age of the observed bedforms. The reduced steepness of most of the cyclic steps leads us to interpret these bedforms as no longer active and likely degraded in their height by sporadic diluted sedimentary flows and bioturbation processes.

Fig. 36.3 3D bathymetric model of the most pronounced cyclic steps in the area, where numerical models were applied to reconstruct the intensity (*U*) and thickness (*h*) of the corresponding turbidity currents (section A–A′)



36.4 Conclusions

Swath-bathymetry mapping along the Gulf of Palermo (southern Tyrrhenian) revealed the occurrence of trains of bedforms along a set of shelf incising gullies connected to the Zafferano Canyon. The observed bedforms are upslope asymmetric and display maximum lengths of 340 m. Based on their location and geometry, these bedforms are here interpreted as formed by cyclic step processes in turbidity currents. A preliminary and strongly simplified numerical reconstruction suggests that the flow controlling the development of such cyclic steps is a few meter thick (0.3–2.5 m) and might have reached peak velocities exceeding 1 m/s.

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