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Morphometric analysis in the offshore of the southern Taranto Gulf: unveiling the structures controlling the Late Pleistocene-Holocene bathymetric evolution

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The present study is focused on a morphometric analysis of high resolution multibeam data (10m, 5m and, locally, 2m resolution), that were acquired during the oceanographic TEATIOCA 2011 campaign along a sector of the Ionian margin of northern Calabria (Figs. 1a and 1b). The integration of morphometric analysis with sparker and chirp data allowed to unveil basic but robust information about: 1. hierarchy of the fault systems controlling the bathymetric evolution; 2. the interplay between tectonic and erosional processes in sea-floor modeling; 3. uplift rates; 4. tilting processes.

At the end of the Early Pleistocene, a tectonic change occurred in southern Italy (HIPPOLYTE *et alii*, 1994). At this time, NW-SE striking transpressional faults in the frontal part of the Apennines (Fig. 1a) were activated, as a consequence of the involvement of the foreland continental lithosphere in the collision (CATALANO *et alii*, 1993). Based on seismic reflection profiles and borehole data, DEL BEN *et alii* (2007) and FERRANTI *et alii* (2009) have shown that the on-land strike-slip fault zones continue off-shore and were active at least up to the Middle-Upper Pleistocene . Two major transpressive fault zones are known in the offshore: the Amendolara Fault (AMF) and the Spulico Basin Fault (SPBF), SW- and NE-verging, respectively (Fig. 1a). FERRANTI *et alii* (2009), through morphometric, structural and seismic data (Fig. 1a), proposed that compression is still ongoing.

In the Gulf of Taranto the Ionian slope is dominated by ridges and intervening basins which are the morphological expression of Pleistocene transpressive fault systems (DEL BEN *et alii*, 2007; FERRANTI *et alii*, 2009). The most prominent morphologic feature is the 45 km long, NW-SE Amendolara ridge characterized by three minor bathymetric highs: the Amendolara Bank (AMBK), the Rossano Bank (RBK) and the Cariati Bank (CBK) (Fig. 1a). In the northern sector, the Capo Spulico Ridge is a narrow E-W-trending crest. The AMBK is bordered by terraces and marine scarps that have a marked appearance in multibeam, sparker and chirp data (Fig. 1a).

The 10 m multibeam has been sampled at regular intervals of 1 km to generate 42 NE-SW cross profiles (Fig. 2a) which have been used to construct bathymetric swaths, illustrating changes in relief. To produce the swath, minimum, maximum and average depths have been compiled in an observation window 41 km long and 26 km wide. Such a window width insures that the maximum and

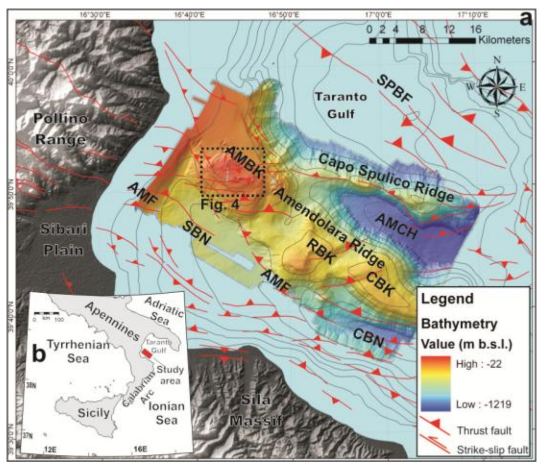

Fig. 1 – a) morpho-structural map of the southern Taranto Gulf. The multibeam data analyzed in this work for morphometric analysis are shown. Strike-slip faults in the Pollino range after Catalano et al. (1993). Offshore faults modified after FERRANTI et alii (2009). Faults: AMF, Amendolara Fault; SPBF, Spulico Basin Fault. AMBK, Amendolara Bank; RBK, Rossano Bank; CBK, Cariati Bank; SBN, Sibari Basin; CBN, Corigliano Basin; AMCH, Amendolara Channel; b) regional location of the study area.

the minimum elevations of the ridge and basins are captured. Bathymetric data were plotted against a NW-SE oriented section (A-B in Figs. 2a and 2b). Maximum and minimum elevation curves highlight a general southeastward deepening of bathymetry (Fig. 2b). A relief curve, derived by subtracting the maximum and the minimum elevations (Fig. 2b), reveals three areas (AMBK, RBK and CBK) where the sea-bed is relatively more incised in a way that is not immediately obvious from the smooth bathymetry alone. Such result is the submarine analogous to the regions of

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anomalously higher relief on-land, which are commonly coincident with sectors of active incision in response to rock uplift.

The profiles crossing the Amendolara Ridge evidence the presence of an overall northeastward tilt of the offshore area (Figs. 2c and 2d). Along the AMBK and the CBK a segment of the shelf area and a paleo-planation surface are evidently tilted northeastward with similar gradient of 17 m/km and 19 m/km, respectively (Figs. 2c and 2d). This tilting component is also evident in sparker profiles that illuminate Middle Pleistocene-Holocene seismo-stratigraphic sequences regularly dipping in the same direction. Superimposed on this deep rooted tectonic signal, the relief distribution highlight three areas interested by relatively higher uplift rates.

The rose diagrams of the azimuth distribution of slope gradient and channel flow direction (Figs. 3a and 3b) shows that they have both a maximum in a NE-SW direction (Figs. 3a and 3b). This supports the contention that the bathymetry is primarily controlled by NW-SE trending structures (AMF and SPBF, Fig. 1a).

In order to investigate the relative importance of the AMF and the SPBF in the bathymetric evolution we focus our attention on the semi-quantitative estimate of erosive processes affecting the slopes. First of all, we determined the Amendolara ridge and Capo Spulico Ridge

fronts sinuosity (f_s; Figs. 3c and 3d) as the ratio between the length of the ridge-front along the foot of the ridge at the pronounced break in slope and the straight line length of the ridge front (KELLER & PINTER, 1996). f_s is an index that reflects the balance between erosional forces that tend to cut an embayment into a front, and tectonic forces that tend to produce a straight front coincident with an active range-bounding fault. The relatively straight shape of the southward facing ridge-fronts (f_s from 1.01 to 1.12; Fig. 3c) points to active tectonic uplift. On the other hand, the northward facing range fronts (f_s from 1.34 to 2.30; Fig. 3c) are more irregular and probably shaped by erosional

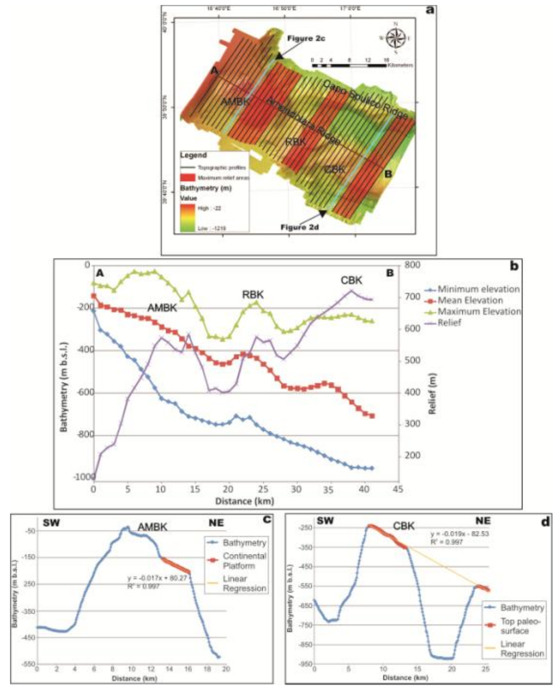

Fig. 2 – a) traces of the bathymetric profiles used to construct swath profiles (b); c – d) examples of bathymetric profiles (location in Fig. 2a).

processes. Furthermore, two ridge fronts are evident along the southern slope of the Cariati Bank (Fig. 3c). The more internal front (f_s: 1.12) is characterized by a more irregular shape than the southernmost front, which is conversely almost rectilinear (f_s: 1.01). We interpret the internal front as an earlier front linked to a structure no more active or interested by a decrease of the deformational rates,

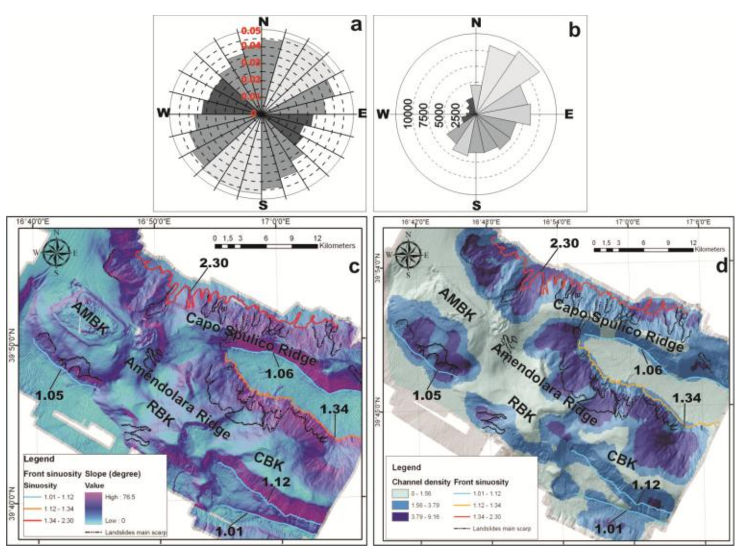

Fig. 3 – a-b) rose diagrams of the slope gradient (a) and of the channel flowing direction (b); c-d) morphologic maps showing landslide distributions, front sinuosity, slope degree (c) and channel density (d);

actually outpaced by erosional processes. The fresh appearance of southward facing ridge-fronts, as evidenced by the f_s index, suggests a more important role for the AMF in the recent morphological evolution of the area. This hypothesis is further supported by landslide distribution and the channel density map (Figs. 3c and 3d).

Based on multibeam, sparker and chirp data, 65 translational and rotational landslides were mapped; in figures 3c and 3d we report the distribution of the landslides main scarps in relation to slope (Fig. 3c) and channel density (Fig. 3d) maps. From figure 3c it is evident that slope acclivity is not the primary control of the landslide distribution. This is apparent if we look at the southern slope of the Capo Spulico Ridge and CBK which are characterized by the highest gradient and by the absence of gravitational processes (Fig. 3c). Landslides are almost totally localized on the northeastward slopes; we believe that this distribution is primarily linked to the northeastward tilt process that makes sediments prone to slide along north facing slopes.

One exception is represented by the AMBK southern flank were rational slides are probably related to the tectonic front activity.

Channel density was calculated as the ratio between the total channel length and the area of a circular cell with a radius of 100 m that encloses them. As already highlighted by landslide distribution and front sinuosity index, the northward facing slopes appear to be controlled by erosional processes. Probably, the mobilization of sediments through gravitational phenomena enhances the channel network development.

Summing up all the morphometric data, it is apparent that the AMF played a fundamental role in the recent bathymetric evolution of the area. The straight and regular southward facing slopes are linked to deformation and uplift rates outpacing erosional processes. On the other hand, the northeastward tilting process driven by slip on the AMF trigger gravitational and channelized erosion on the north facing slopes. The three higher relief areas highlighted by swath profiles reflects the AMF internal segmentation.

The only sector where an estimate of the uplift rates can be attempted is the AMBK where seven erosion marine terraces orders are preserved (Fig. 1c). In a first step terraces were identified by means of a statistical analysis of depth distribution along the AMBK top and the computation of a semi-logarithmic depth histogram. It is widely acknowledged that flat-lying morphological markers, such as marine terraces, show up as peaks in the depth histogram (PASSARO *et alii*, 2011). Inner margins (intersection point between abrasion platform and on-looking sea cliff) elevations were refined through a morphological analysis of multibeam data and, hence, corrected for the later Holocene cover draping the AMBK top through investigation of numerous chirp and sparker profiles (Fig. 1d). The eustatic origin of the terraces is supported by the absence of normal faults or landslides across the AMBK top. The absence of beach facies can be related to a later erosion by successive eustatic cycles and/or the disconnection between the AMBK and the sediment on-land sources. Furthermore, the several Low Stand System Tracts which were identified around the AMBK top were probably built up during eustatic low stands and emersion of the Bank as an island and the sub-

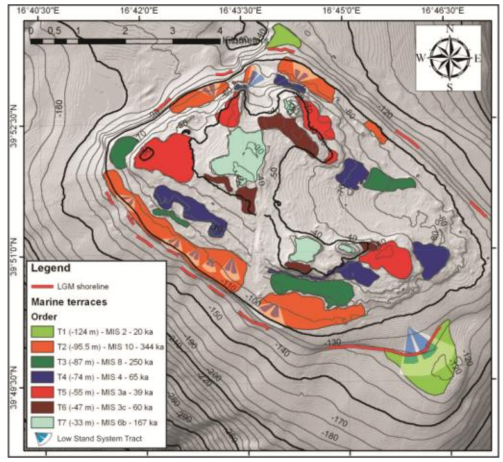

Fig. 4 – Morphologic map of Middle-Late Pleistocene marine terraces preserved on the top of the Amendolara Bank.

aerial erosion of eventually preserved beach facies. Because of the absence of direct chronological constraints, the terraces were dated indirectly by means of a trial and error approach. Uplift rates, ranging from -1 to 1 mm/a, were applied, with a 0.1 mm/a step, to theoretical marine terraces corresponding to the major glacial and interglacial cycles of the ~400 ka WAELBROECK *et alii* (2002) sea-level curve. We found that only an uplift rate of 0.1 mm/a fits the occurrence of the seven orders of eustatic terrace on the AMBK top. Both glacial and interglacial terraces are present: T1, MIS 2; T2, MIS 10; T3, MIS 8; T4, MIS 4; T5, MIS 3a, T6, MIS 3c; T7, MIS 6b.

By comparing the elevation of MIS 3c (~60 ka) terrace on the AMBK (T6, -47 m b.s.l., this work) and on the adjacent Pollino coast (T1 in SANTORO *et alii*, 2009, 16 m a.s.l.), we observe a decrease of the uplift rates from 0.8 mm/a to 0.1 mm/a in only 14.5 km. Therefore, it is apparent a strong NW-SE tilting component with a rate of 0.07 $m*km^{-1}*ka^{-1}$ in the last 60 ka. Differential uplift and eastward coastal tilting along the Ionian frontal sector of southern Apennines were already suggested by FERRANTI *et alii* (2009) to explain deep-seated slope gravitational deformation that deform marine terraces along the Taranto Gulf. Our analysis constitutes the first attempt to quantify this tectonic component. The sharp decrease in uplift rates could be explained by an eastward decrease of the regional southern Apennine uplift.

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