

Repeated bathymetric surveys as a fundamental tool to measure rapid seafloor variations in geologically-active areas: examples from Southern Italian coastlines.

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Abstract – Multibeam bathymetry has deeply changed our vision of the seafloor, allowing to map a large suite of landforms associated to oceanographic, sedimentary, volcanic and tectonic processes. Besides the advances in understanding the processes shaping the seafloor, these data represent a basic input both for a first assessment of marine geohazards and for planning more detailed studies. In this regard, the use of repeated bathymetric surveys in geologically-active areas is becoming a fundamental tool to evidence and monitor areas affected by rapid seafloor variations, whose genesis can be linked to active natural phenomena that otherwise would be often undetectable. In this paper, we show a review of examples from Southern Italy, where the application of such methodological approach allowed to monitor active erosive-depositional and volcanic processes.

I. INTRODUCTION

In the last few decades, advance in seafloor imagery systems (especially multibeam bathymetry) has enabled to extensively map the main morpho-bathymetric features of the Italian Seas from coastal to deep waters [1, 2, 3], providing an unprecedented view of oceanographic and geological processes shaping our seafloor [4, 5, 6, 7, 8]. A large spectrum of landforms associated to volcanic, tectonic and sedimentary features has been recognized. These data were often useful also for biological [9,10] and archeological studies [11], including paleo-landscape reconstruction [12].

Despite multibeam data can be used for several purposes, representing a basic information for any kind of more detailed seafloor observation and in-situ study, in the last years attention has been focused on the study of landforms that can be associated to marine geohazards, such as active canyon heads, tsunamigenic landslides, active faults and volcanism [13, 14, 15, 16]. In this regard, repeated bathymetric surveys represent a fundamental tool to monitor the morphological evolution of landforms associated to marine geohazards and more generally to

evidence rapid seafloor variations occurring in geologically-active areas [17, 18]. This is particularly evident for shallow-water areas, where the resolution of multibeam data increases exponentially along with the possible hazard associated to the geohazards-related features due to the proximity with the coastlines and the higher tsunamigenic potential.

The aim of this paper is to show a brief review of published examples on the use of repeated bathymetric surveys along geologically-active areas in southern Italy as well as to evidence possible uncertainties related to the correct interpretation of the measures provided by this methodological approach. Specifically, this latter point is dealt with in the next section.

II. DATA AND METHODS

Multibeam data used for this work have been acquired in the last 20 years from the University Sapienza of Rome and National Research Council (CNR) during several oceanographic cruises carried out aboard the R/V *Thetis*, *Urania* and *Minerval* (CNR), *Universitatis* (CONISMA, Inter-University Consortium for Marine Sciences) and small launch for shallow-water sectors (< -100 m). Data were acquired with different multibeam systems working at frequency, ranging from 50 to 455 kHz and coupled with DGPS (commonly at depths greater than 100 m) or RTK/PPK (coastal surveys in the first 100 m) data for spatial positioning. Repeated patch tests (i.e. ad-hoc sounding lines acquired for the calibration of the multibeam sensor) in areas close to the survey zone and daily sound speed profiles were acquired during the surveys. Data were processed with a non-standard procedure to ensure the maximum possible resolution for each bathymetric interval; for details on data acquisition and processing, refer to references [3 and 7]. The cleaned data were gridded to obtain Digital Elevation Models, having a cell-size variable from sub-metric in shallow-water (down to -100 m) up to 25 m in deep water (down to -2500 m). Vertical accuracy of bathymetric data has been roughly estimated at 0.1 m in shallow water and

several meters for deeper hydrographic data [7].

The methodology to monitor seafloor changes consists in computing the difference between two co-registered Digital Elevation Models obtained from repeat multibeam surveys. The resulting “residual map” quantifies the change in elevation between the two surveys, with positive values showing seafloor accretion (or deposition), negative values showing seafloor erosion, and null values showing unchanged surfaces. However, the correct interpretation of morphological changes and their use to compute mobilized volumes should be carefully checked. Several sources of errors can affect the accuracy of soundings, including geo-positioning techniques (GPS, DGPS, RTK, PPK), type of sonar system used (i.e., frequency and beam width), meteorological conditions, vessel configuration, tide and vessel draught, parameters of the water-column affecting sound velocity and its absorption, use of real-time sound velocity probe close to the transducer for beam-forming and ray-tracing, speed and overlapping between survey track lines, bottom detection algorithm, etc [7 and 19]. Moreover, it is fundamental a careful processing of multibeam data, able to recognize the type and variability of faults induced by the incorrect application of sound velocity profiles, instrumental offset, motion sensor parameters and delete the acoustic artifacts.

Once data have been correctly cleaned and residual maps generated, it is fundamental to check the results in areas presumably not affected by seafloor variations (for instance, bedrock outcrops). These areas represent a benchmark to constraint the error range of the residual maps and estimate the reliability of the data. Seafloor variations larger than this error range could be considered reliable and then linked to specific oceanographic or geological processes acting on the seafloor based on their overall shape, location and information retrievable from literature or web. It is also noteworthy that errors in the estimation of seafloor variations and associated volumetric computation are strongly dependent from the local seafloor morphology. Indeed, in the case of steep slope even a minimal lateral offset would result in substantial changes of the correct figure with respect to gently sloping areas.

III. RESULTS AND FINAL REMARKS

Several examples of repeated bathymetric surveys were carried out around some of the most active areas in the southern Italy, encompassing active insular volcanoes and canyon heads along tectonically-controlled margin.

As active insular volcanoes are concerned, the best example is represented by the morphological monitoring of the submarine part of Sciara del Fuoco depression (SdF, Fig. 1) at Stromboli Volcano in the last 15 years. The SdF is the last of four sector collapses that affected the NW flank of Stromboli in the last 13 ka [20 and 21]. This scar has acted as a main channel for the seaward transport of the large amount of volcanoclastic products produced by the persistent Strombolian activity at the summit craters

[21]. All this material has formed a steep volcanoclastic apron into the first -300 m, where a tsunamigenic submarine landslide occurred in 2002, representing the final stage of a complex eruption-driven instability process [22]. The extent and geometry of the tsunamigenic submarine failure were reconstructed only through the comparison of multibeam surveys carried out before and after the event [23]. This comparison also allowed to compute the volume mobilized from the 2002 slide, accounting for about $10 \times 10^6 \text{ m}^3$. This value was also a fundamental input for the numerical modelling of the related landslide-generated tsunami waves [23]. More interestingly, the successive bathy-morphological monitoring of this area [24] revealed a very rapid infilling of the 2002 scar, that was mostly sealed in 2007, only five years after the event. In addition, a new effusive eruption started in March 2007, forming a large lava delta within the 2002 scar. Repeated bathymetric surveys were realized during and after the 2007 eruption (Fig. 1), enabling to reconstruct the growth and evolution of the submarine part of the 2007 lava delta [18].

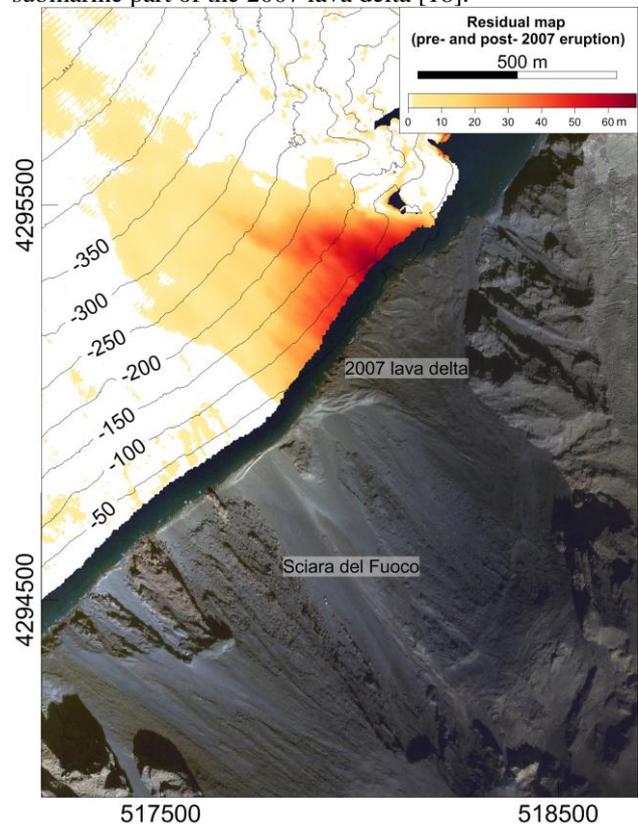


Fig 1. Aerial photo and isobaths (pre-2007 eruption, equidistance 50 m) of the Sciara del Fuoco depression at Stromboli. Residual map obtained as difference between multibeam bathymetries collected pre- and post- 2007 eruption is also shown, evidencing the accretion (up to 65m) of the seafloor due to the emplacement of the 2007 lava delta; for details see [18].

The residual map shows that the 2007 lava delta extended down to 600 m water depth, covered an area of $420 \times 10^3 \text{ m}^2$, with a maximum thickness of 65 m, accounting for an estimated volume of $\approx 7 \times 10^6 \text{ m}^3$, i.e.,

three times larger than its subaerial counterpart. Since the 2007 eruption, the evolution of the delta has been yearly monitored through bathymetric surveys, evidencing its overall dismantling through the occurrence of small mass-wasting processes (unpublished data).

As tectonically-controlled margins are concerned, repeated bathymetric surveys have been realized at the head of submarine canyons off Calabria coastline and in the Messina Strait (Fig. 2). These areas are characterized by narrow or totally lacking continental shelves and steep continental slopes, carved by several canyons, whose head often arrive up to some meters of depths, few tens of meters far from the coast [16]. Most part of the morphological variations can be associated to small landslides occurring at the head of the canyons [13, 17, 25, 26]. These landslides typically mobilize volume of several tens of thousands of cubic meters and are characterized by a retrogressive evolution, causing a landward retreat of the canyon head of several tens of meters (Fig. 2). In the Western Messina Strait, submarine landslides occurred during or shortly after the 2009 flash-flood, suggesting that the drained/undrained load exerted by the flash-flood generated hyperpycnal flows on the seafloor can be a plausible triggering mechanism for the development of small slope failures at the canyon head [13].

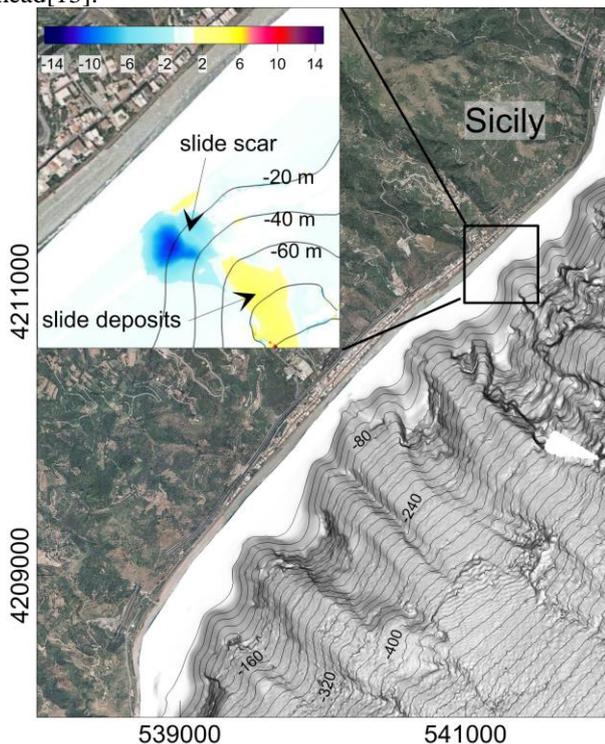


Fig 2. Aerial photo, shaded relief map and isobaths (equidistance 20 m) of the Western Messina Strait, where several submarine canyons carved the continental slope. The zoom in the upper left shows residual map obtained as difference between pre- and post- 2009 flash flood occurred in the area, where a retrogressive submarine landslide is recognizable at the canyon head; for details see [13].

By considering the proximity of these canyons at the

coast (few hundreds of meters, Fig. 2), it is evident that the morphological evolution of their head should be carefully monitored, because future retrogressive landslides could intersect the coastline, representing a main geohazard for the densely inhabited coastal sectors. The destructive potential of these processes has been, in fact, witnessed by two recent examples of tsunamigenic, retrogressive landslides occurred at the head of the Gioia Tauro (Calabria, Italy) and Var Canyons (Nice, France) in 1977 and 1979, respectively [27; 28]. Both landslides mobilized $5-10 \times 10^6 \text{ m}^3$ and produced several damages to the facing coastal infrastructures, i.e. the Gioia Tauro harbor (the main terminal for the Mediterranean transshipment) and the Nice Airport, respectively. Similarly, repeated bathymetric surveys carried out between 2005 and 2006 off Punta Alice (Ionian Calabria) showed a retrogressive submarine landslide occurred at the head of the Madonna del Mare Canyon [17]. The landslide caused a landward retreat of the canyon head of about 60 m and mobilized a volume of approximately $1 \times 10^6 \text{ m}^3$. The Punta Alice slide caused severe damage to the coastal chemical plant present in the area, showing its significance as geo-hazard for this coastal sector.

Summarizing, the above-mentioned examples highlight the need of repeated bathymetric surveys to monitor active natural phenomena in geologically-active areas that otherwise would remain undetectable. This is fundamental to assess their role as geohazards for surrounding submarine and coastal infrastructures, especially in strongly exploited areas such as the Southern Italy coastlines and more generally in the Mediterranean area. However, we remark that the results and interpretations arising from this methodological approach should be carefully checked, as seafloor variations can be affected by several sources of error, so hindering their reliability.

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REFERENCES

- [1] M.P.Marani, F.Gamberi, E.Bonatti "From Seafloor to Deep Mantle: Architecture of the Tyrrhenian Backarc Basin", Mem. Descr. Carta Geol. It., vol. XLIV, 216 pp., APAT, Rome, 2004
- [2] F.L.Chiocci, D.Ridente, "Regional-scale seafloor mapping and geohazard. The experience from the Italian project MaGIC (Marine Geohazards along the Italian Coasts). Marine Geophysical Research, 2011, vol. 32(1-2), pp. 13-23.
- [3] C.Romagnoli, D.Casalbore, G.Bortoluzzi, A. Bosman, F.L.Chiocci, F.D'Oriano, F.Gamberi, M.

- Ligi, M. Marani,). “Bathy-morphological setting of the Aeolian Islands” Geological Society, London, Memoirs, 2013, vol. 37, pp. 27-36; doi:10.1144/M37.4
- [4] M.Rebesco, R.C.Neagu, A.Cuppari, F.Muto, D.Accettella, R.Dominici, A.Cova, C.Romano, A.Caburlotto, “Morphobathymetric analysis and evidence of submarine mass movements in the western Gulf of Taranto (Calabria margin, Ionian Sea)” International Journal of Earth Sciences, 2009, vol. 98(4), pp.791.
- [5] D.Casalbore, C.Romagnoli, A.Bosman, F.L.Chiocci, “Large-scale seafloor waveforms on the flanks of insular volcanoes (Aeolian Archipelago, Italy), with inferences about their origin” Marine Geology, 2014, vol.355, pp.318-329.
- [6] D.Casalbore, D.Ridente, A.Bosman, F.L.Chiocci, Depositional and erosional bedforms in Late Pleistocene-Holocene pro-delta deposits of the Gulf of Patti (southern Tyrrhenian margin, Italy). Marine Geology, 2017, vol. 385, 216-227.
- [7] A.Bosman, D.Casalbore, M.Anzidei, F.Muccini, C.Carmisciano, F.L.Chiocci, “The first ultra-high resolution digital Terrain model of the shallow-water sector around Lipari Island (Aeolian Islands, Italy)” Annals of Geophysics, 2015, vol 58,2. <http://dx.doi.org/10.4401/ag-6746>.
- [8] R.Droghei, F.Falcini, D.Casalbore, E.Martorelli, R.Mosetti, G.Sannino, R.Santoleri, F.L. Chiocci. “The role of Internal Solitary Waves on deep-water sedimentary processes: the case of up-slope migrating sediment waves off the Messina Strait” Scientific reports, 2016, vol.6, 36376.
- [9] A.Savini, A.Vertino, F.Marchese, L.Beuck, A.Freiwald, “Mapping cold-water coral habitats at different scales within the Northern Ionian Sea (Central Mediterranean): an assessment of coral coverage and associated vulnerability” PloS one, 2014, vol 9(1), e87108.
- [10] M.Pierdomenico, E.Martorelli, C.Dominguez-Carrió, J.M.Gili, F.L.Chiocci, Seafloor characterization and benthic megafaunal distribution of an active submarine canyon and surrounding sectors: The case of Gioia Canyon (Southern Tyrrhenian Sea). Journal of Marine Systems, 2016, vol. 157, pp.101-117
- [11] M.Anzidei, A.Bosman, D.Casalbore, S.Tusa, R.La Rocca, “New insights on the subsidence of Lipari island (Aeolian islands, southern Italy) from the submerged Roman age pier at Marina Lunga” Quaternary International, 2016, vol 401, pp. 162-173. <http://dx.doi.org/10.1016/j.quaint>.
- [12] L.Abelli, M.V.Agosto, D.Casalbore, C.Romagnoli, A.Bosman, F.Antonioioli, M.Pierdomenico, A.Sposato, F.L.Chiocci, “Marine geological and archeological evidence of a possible pre-Neolithic site in Pantelleria Island, Central Mediterranean Sea”. In: Harff, J., Bailey, G., Lüth, F. (Eds.), Geology and Archaeology: Submerged Landscapes of the Continental Shelf, Geological Society, London, Special Publications, 2016, vol. 411. <http://dx.doi.org/10.1144/SP411.6>.
- [13] D.Casalbore, F.L.Chiocci, G.Scarascia Mugnozza, P.Tommasi, A.Sposato, “Flash-flood hyperpycnal flows generating shallow-water landslides at Fiumara mouths in Western Messina Straits (Italy)” Mar. Geophys. Res., 2011, vol. 32, pp. 257-271.
- [14] M.F. Loreto, U.Fracassi, A.Franzo, P. Del Negro, F. Zgur, L.Facchin, “Approaching the seismogenic source of the Calabria 8 September 1905 earthquake: New geophysical, geological and biochemical data from the S. Eufemia Gulf (S Italy)” Marine Geology, 2013, vol. 343, pp. 62-75.
- [15] D.Casalbore, C Romagnoli, A Pimentel, R Quartau, D Casas, G Ercilla, A Hipólito, A Sposato, FL Chiocci, “Volcanic, tectonic and mass-wasting processes offshore Terceira Island (Azores) revealed by high-resolution seafloor mapping” Bull Volcanol, 2015, vol.77:24. doi:10.1007/s00445-015-0905-3.
- [16] F.L.Chiocci, D.Casalbore “Unexpected fast rate of morphological evolution of geologically-active continental margins during Quaternary: Examples from selected areas in the Italian seas” Marine and Petroleum Geology, 2017, vol. 82, pp. 154-162.
- [17] D.Casalbore, A.Bosman, F.L Chiocci “Study of Recent Small-Scale Landslides in Geologically Active Marine Areas Through Repeated Multibeam Surveys: Examples from the Southern Italy” In: Yamada, Y., Kawamura, K., Ikehara, K., Ogawa, Y., Urgeles, R., Mosher, D., Strasser, M. (Eds.), Submarine Mass Movements and Their Consequences. Dordrecht: Springer, Netherlands, 2012, vol. 31, pp. 573–582. doi.org/10.1007/978-94-007-2162-3_51.
- [18] A.Bosman, D.Casalbore, C.Romagnoli, F.L. Chiocci “Formation of an ‘a’ā lava delta: insights from time-lapse multibeam bathymetry and direct observations during the Stromboli 2007 eruption. Bulletin of Volcanology” 2014, vol. 76 (7), 838. doi:10.1007/s00445-014-0838-2.
- [19] X.Lurton, J.M Augustin, A measurement quality factor for swath bathymetry sounders. IEEEJ. Ocean.Eng., 2010, vol. 35(4), pp. 852–862.
- [20] A.Tibaldi “Multiple sector collapses at Stromboli volcano, Italy: how they work. Bull Vulcanol”, 2001, vol. 63, pp.112–125.
- [21] C.Romagnoli, P.Kokelaar, D.Casalbore, F.L.Chiocci “Lateral collapses and active sedimentary processes on the northwestern flank of Stromboli volcano, Italy. Marine Geology, 2009, vol. 265, pp. 101–119.
- [22] F.L.Chiocci, C.Romagnoli, P.Tommasi, A. Bosman, “Stromboli 2002 tsunamigenic submarine slide: characteristics and possible failure mechanisms”. Journal Geophysical Research, 2008, vol. 113, B10102. doi:10.1029/2007JB005172.
- [23] S.Tinti, G.Pagnoni, F.Zaniboni. The landslides and tsunamis of the 30th of December 2002 in Stromboli

- analysed through numerical simulations. *Bulletin of Volcanology*, 2006, vol. 68(5), pp. 462-479.
- [24] F.L.Chiocci, C.Romagnoli, A.Bosman, “Morphologic resilience and depositional processes due to the rapid evolution of the submerged Sciara del Fuoco (Stromboli Island) after the December 2002 submarine slide and tsunami”. *Geomorphology* 2008, vol. 100(3 /4), pp. 356–365. doi:10.1016/j.geomorph. 2008.01.008.
- [25] A.Bosman, D.Casalbore, R.Dominici, “Cyclic Steps at the Head of Channelized Features Along the Calabrian Margin (Southern Tyrrhenian Sea, Italy)” In *Atlas of Bedforms in the Western Mediterranean* 2017, Springer International Publishing pp. 229-233. doi.org/10.1007/978-3-319-33940-5_35
- [26] D.Casalbore, A.Bosman, D.Ridente, F.L.Chiocci, Coastal and submarine landslides in the tectonically-active Tyrrhenian Calabrian Margin (Southern Italy): examples and geohazard implications. *Submarine Mass Movements and Their Consequences*. 2014, Springer International Publishing, pp. 261–269. doi.org/10.1007/978-3-319-00972-8_23
- [27] P.Colantoni, M.Gennesseaux, J.R.Vanney J.R., A.Ulzega, G.Melegari, A.Trombetta, “Processi dinamici del canyon sottomarino di Gioia Tauro (Mare Tirreno)”. *Giornale di Geologia*, 1992, vol3 (54/2), pp 199-213.
- [28] N.Sultan, B.Savoye, G.Jouet, D.Leynaud, P.Cochonat, P.Henry, S.Stegmann, Kopf, A., “Investigation of a possible submarine landslide at the Var delta front (Nice continental slope, southeast France)”. *Can. Geotechnical J.*, 2010, vol.47, pp.486-496.