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High-resolution morpho-bathymetric imaging of the Messina Strait (Southern Italy). New insights on the 1908 earthquake and tsunami

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ABSTRACT

The 28 December, 1908 Reggio Calabria and Messina earthquake (named after the two most damaged cities on the coasts of Messina Strait) was one of the strongest (M_W 7.1) ever to occur in Italy, and was also followed by a tsunami that severely impacted the coasts of the Strait. Although there is general agreement that its epicentre is located offshore in the Messina Strait, the source fault has never been detected; a century-long question is therefore pending on the source of both the 1908 earthquake and tsunami. Within the ongoing debate on this subject, little attention has been given, so far, to morphological insights from high resolution bathymetric (multibeam) data, particularly as regarding the evidence of faults affecting the seafloor and the question of whether a submarine landslide may had been the cause of the tsunami. We aim to address this issue by presenting the results of a morpho-bathymetric study in the Messina Strait and surroundings, investigated by means of high-resolution swath bathymetry. The primary morpho-structural feature in this area is the axial channel of the Messina Canyon, towards which flow several tributary canyons that incise the steep continental slope on the Calabrian and Sicilian margins. These canyons carve deeply into a very narrow (almost lacking) continental shelf and merge laterally forming a continuous erosional margin rimming the Messina Strait. This giant, composite canyon environment is the locus of intense erosional and depositional processes that superimpose on active tectonic deformation, resulting in a complex geomorphology that hinders the distinction between tectonic and sedimentary features. Seafloor ruptures that may be linked to fault systems compatible with the source of the 1908 earthquake and tsunami could not be identified based from our morpho-bathymetric analysis; however, we provide evidence of several geomorphic features indicative of tectonic deformation in the Messina Strait, define the presence and distribution of submarine landslides, and evaluate their possible role as tsunami sources.

1. Introduction

Following the improvement of very high resolution acoustic techniques, during the past two decades, marine investigation of active offshore faults has become essential in assessing seismic hazard of coastal regions (e.g. Marlow et al., 2000; Pratt et al., 2003; Polonia et al., 2004; Cormier et al., 2006; Nodder et al., 2007; Chiocci et al., 2011). In the Mediterranean, with special reference to the Italian Peninsula, expanding the seismotectonic analysis to the offshore reveals significant implications because of the tectonically active settings that characterise the surrounding seas (e.g. Chiocci and Ridente, 2011). Offshore areas affected by tectonic deformation may fall within, or very close to, seismically active regions (e.g. Argnani and Bonazzi, 2005; Ferranti et al., 2008; Ridente et al., 2008; Di Bucci et al., 2009, 2010; Polonia et al., 2012; Loreto et al., 2013) or even lay marginally to main seismic belts (e.g. Ridente and Trincardi, 2006). Either of the above scenarios assumes special importance when these offshore sectors are next to coastal areas that have been hit by strong earthquakes and tsunami in historical (pre-instrumental) times, and for which the seismogenic fault and the tsunami source (the fault itself or a landslide) remain unknown or ambiguously defined.

Several of these cases are known in Italy (Fig. 1), the most relevant of which are: the M_W 6.7, 1627 Gargano earthquake and tsunami; the M_W 7.4, 1693 Catania earthquake and tsunami; the M_W 7.0, 1905 S. Eufemia earthquake and tsunami; and the M_W 7.1, 1908 Reggio Calabria and Messina earthquake and tsunami (e.g. Piatanesi and Tinti, 2002; Tinti and Armigliato, 2003; CPTI Working Group, 2004). With the exception of the Reggio Calabria and Messina 1908 event, located in the Messina Strait study area (Fig. 1), in all the other cases the epicentral area has been positioned on land based on, and perhaps biased by, macroseismic zonation (e.g. Fracassi et al., 2012). However, the identification of an offshore source for the 1908 earthquake has proved problematic, emphasizing how both the nature of the seismogenic fault and the offshore setting are such that well-resolved stratigraphic and structural evidence may be hindered.

Geologists and seismologists have debated on the sources of the 1908 earthquake and tsunami throughout the last century, with

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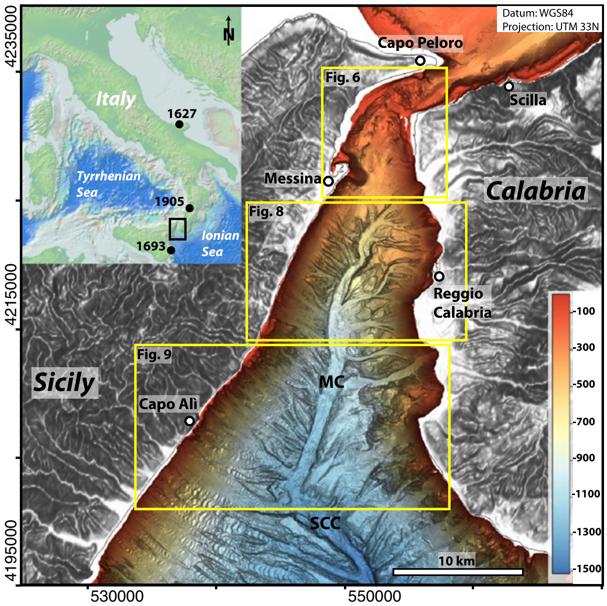

Fig. 1. The Messina Strait is the sea stretch between Calabria and Sicily with a narrow (~3–4 km) northern seaway between Capo Peloro and Scilla, and a wider (15–20 km) southern entrance. It is one among the several Italian coastal areas hit by strong earthquakes and tsunami in historical and recent time (other sites are indicated by black dots and year of occurrence in the upper left inset). The area is axially dissected by the Messina Canyon (MC), which intercepts the many tributary slope canyons and reaches depths >1300 m at its southern end. South of the Strait, the Messina Canyon is continued SE by the South Calabria Canyon (SCC), reaching depths >2500 m in the Ionian Sea abyssal plain.

mounting emphasis in recent years, due to the approaching of the centenary of the event (e.g. Bertolaso et al., 2008). However, within this renewed debate, little attention has been devoted to morpho-bathymetric analysis, especially concerning the question on whether a submarine landslide may have been the cause of the tsunami (e.g. Billi et al., 2008, 2009; Gerardi et al., 2008; Argnani et al., 2009b; Favalli et al., 2009). In order to fill this gap, we present a detailed morpho-bathymetric analysis based on multibeam data covering the Messina Strait (Fig. 1).

The results presented herein are limited by the lack of an ad hoc seismic dataset to complement the bathymetric data; indeed, compared to the importance of the 1908 event and the many existing uncertainties, screening of literature data has unveiled a relatively small amount of work aimed at investigating the possible offshore source of the 1908 earthquake and tsunami. This is probably due to the adverse morpho-stratigraphic setting in the Messina Strait (deep basin bounded by steep slopes, dominated by thick deposits of coarse-grained clastic sediment; i.e. Casalbore et al., 2011), as well as to the demanding navigation conditions (narrow seaway with intense currents and a dense network of commercial navigation routes). Despite the above limitation, our results allow some open questions to be addressed more effectively from a geomorphic perspective, as for instance:

1) Are there morphological features that can be interpreted as evidence of seafloor rupture?
2) Would any evidence of seafloor rupture and/or deformation allow the definition of a seismogenic fault compatible with source models of the 1908 earthquake?
3) Would any detectable fault display features (i.e. location, length and strike) compatible with the generation of the observed tsunami effects (documented in detail in the chronicles and reports of the time)?
4) Can we support or deny, as an alternative hypothesis, that a submarine landslide caused the tsunami?
5) Based on our results, can we assess the likelihood of the diverse hypotheses and models proposed by seismologists and geologists during the past decades?

More in general, our very high resolution morpho-bathymetric analysis provides a new and largely unexploited perspective for addressing the problem of the 1908 earthquake and tsunami sources, by this adding to the geological frame of the Messina Strait in the light of future seismotectonic investigation and geohazard assessment.

2. Background

2.1. Tectonic setting

The Messina Strait is part of the "Calabrian Arc" (Fig. 2), a terrain facing the Ionian Sea subduction zone (Royden et al., 1987; Faccenna et al., 2001; Pepe et al., 2010; Polonia et al., 2011, 2012; Doglioni et al., 2012) where westward subduction of the Ionian plate is marked by deep to intermediate (subcrustal) seismicity beneath the Tyrrhenian Sea (Giardini and Velonà, 1991; Selvaggi and Chiarabba, 1995). The roll-back of the crustal slab endorses the spreading of the southern Tyrrhenian Sea and related back-arc volcanism (Doglioni et al., 1999; Jenny et al., 2006; Nicolosi et al., 2006; Cuffaro et al., 2011), whereas slab detachment and consequent decrease in slab loading are considered responsible for the regional uplift of the Calabrian Arc (Westaway, 1993; Goes et al., 2004; Faccenna et al., 2005).

According to diverse data and methodologies, uplift has occurred at rates of ~1 mm/a at least since the Middle Pleistocene (e.g. Bordoni and Valensise, 1998; De Guidi et al., 2003; Ferranti et al., 2006), and is

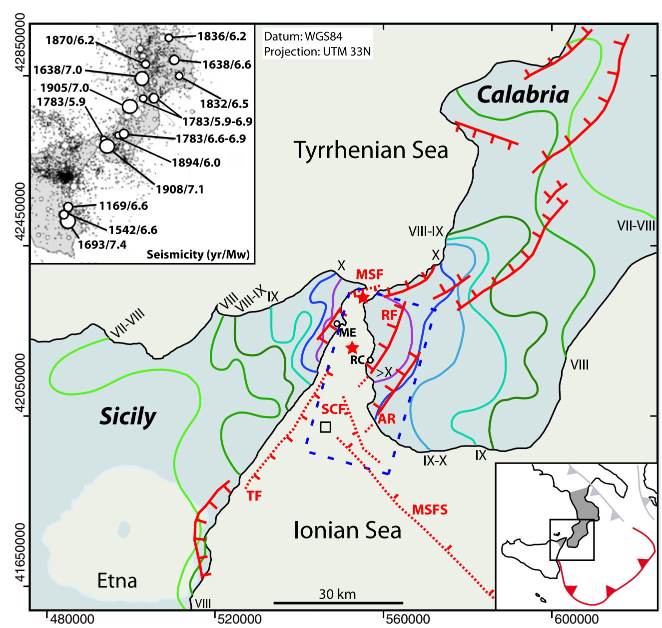

Fig. 2. Tectonic setting of the Messina Strait and Calabrian Arc (grey area in lower inset; front of Ionian subduction zone is also shown). NW-verging normal faults coincide with the main seismic belts (modified from Monaco and Tortorici, 2000), based on historical and instrumental data (upper left box; modified from Jenny et al., 2006). Stars indicate the two possible epicentres of the 1908 earthquake identified by Baratta (1910) after reconstructing macroseismic intensity zonation (lines with intensity values in roman numbers); the southern star also coincides with the epicentre proposed by recent authors (i.e. Neri et al., 2005), alternatively located further south (black square) by Rovida et al. (2011). Offshore faults (dotted lines) are reported in the literature based on the coastal termination of onshore faults (i.e. the Reggio Calabria and Armo Faults, RF and AF, respectively) or on coastal geomorphology (i.e. the Taormina Fault, TF); the South Calabria Fault (SCF) and the Messina Strait Fault (MSF) have been recognised on seismic profiles. The dashed rectangle images the fault plane at depth of a possible SE-verging blind master fault, as proposed by Bonini et al. (2011). South of Messina Strait, Polonia et al. (2012) indicate the presence of the transtensional Messina Straits Fault System (MSFS), at the NW end of a shear zone dissecting the Ionian accretionary prism.