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Evidence of active subsidence at Basiluzzo island (Aeolian islands, southern Italy) inferred from a Roman age wharf

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A B S T R A C T

The Aeolian Arc (Southern Tyrrhenian Sea, Italy) is one of the most active volcanic areas of the Mediterranean basin, affected by volcanic/hydrothermal and seismic activity. Ancient populations settled this region since historical times, building coastal installations which currently are valuable archaeological indicators of relative sea level changes and vertical land movements. In this study we show and discuss data on the relative sea level change estimated from a submerged wharf of Roman age dated between 50 B.C. and 50 A.D., located at Basiluzzo Island. This structure has been studied through marine surveys and archaeological interpretations and is presently located at a corrected depth of -4.10 ± 0.2 m. We explain this submergence by a cumulative effect of the relative sea level change caused by the regional glacio-hydro-isostatic signal, active since the end of the last glacial maximum, and the local volcano-tectonic land subsidence. Finally, a total subsidence rate of 2.05 ± 0.1 mm/yr^{-1}, with a volcano-tectonic contribution of 1.43 ± 0.1 mm/yr^{-1} for the last 2 ka BP, is inferred from the comparison against the latest predicted sea level curve for the Southern Tyrrhenian Sea, suggesting new evaluations of the volcano-tectonic hazard for this area of the Aeolian islands.

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1. Introduction

Coastal settlements and ports constructed in antiquity along the coasts of the Mediterranean provide important insights into reconstructions of historical sea-level changes during past millennia (Schmiedt et al., 1972; Flemming and Webb, 1986; Lambeck et al., 2004a, 2004b). Despite the large number of archaeological remains in this region, only those that are well preserved can be used to obtain precise information on their former relationship to sea level (Auriemma and Solinas, 2009; Lambeck et al., 2010). During the last decade, new studies integrated altimetry observations in coastal archaeological sites such as villas, harbors, piers and fish tanks of Roman age, with geological data and geophysical modeling. Results allowed the temporal and spatial reconstruction of the values and trends of the relative sea level changes and vertical land movements at specific sites (Paskoff et al., 1981; Lambeck et al., 2004b; Anzidei et al., 2011a, b; Mourtzas, 2012).

Recent studies have shown that the relative sea level changes observed along the coasts of the Mediterranean Sea depends on the sum of eustatic, glacio-hydro-isostatic and tectonic (including volcanic) signals, according to the following equation (Lambeck and Purcell, 2005):

$$\Delta\xi_{rsl}(\varphi,t) = \Delta\xi_{esl}(t) + \Delta\xi_{I}(\varphi,t) + \Delta\xi_{T}(\varphi,t) \quad (1)$$

Where, $\Delta\zeta_{rsl}(\varphi,t)$ is the observed change of sea surface relative to land at a location φ and time *t*, compared to its present position. The first term is the eustatic change $\Delta\zeta_{esl}(t)$; the second term $\Delta\zeta_{I}(\varphi,t)$ is the glacio-hydro-isostatic contribution and the last term $\Delta\zeta_{T}(\varphi,t)$ is the tectonic contribution (including volcanic and other disturbances) for active areas. The $\Delta\zeta_{esl}$ is mainly driven by climate changes and is time-dependent, while $\Delta\zeta_{I}$ and $\Delta\zeta_{T}$ are functions of position φ and time *t*, that can vary with location (φ).

The glacio-hydro-isostatic signal acting in the Mediterranean basin after the Last Glacial Maximum (LGM), has been recently predicted and compared with direct observational data in deforming zones (Lambeck et al., 2010, 2011). The results provided new insights on the relationships between sea level change and vertical land motion, because most maritime archaeological sites are currently submerged or emerged (Antonioli et al., 2007; Anzidei et al., 2013).

With the aim to estimate the vertical tectonic contribution to the observed relative sea level change in the volcanic arc of the

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Aeolian Islands, we investigated a submerged structure located at Basiluzzo Island. This small island, as well as the others of the Aeolian archipelago, has been settled since pre-historical times, and during the Roman time they become a crossroad of the maritime commercial ways toward Sicily and northern Africa (Kapitan, 1958; Bernabò-Brea and Cavalier, 1985; Bernabò Brea, 1985; Bound, 1992; Todesco, 1996; Zagami, 1993; http://www.regione.sicilia.it/beniculturali/).

Between 50 B.C. and 50 A.D., a large villa was built on Basiluzzo Island, supplied with a maritime structure located at Punta Levante. We used this well preserved structure as an archaeological indicator of the intervening relative sea level change and land subsidence over the last 2 ka, being submerged at an average depth of 3.20 ± 0.2 m. Here, we show and discuss surveys and results, in order to discriminate between the multiple responsible factors contributing to the observed relative sea level change.

2. Tectonic setting

The Aeolian Archipelago consists of seven major islands (Alicudi, Filicudi, Salina, Lipari, Panarea, Vulcano, and Stromboli) and some seamounts that form a Quaternary volcanic arc in the Southern Tyrrhenian Sea due to the opening of the back-arc Tyrrhenian basin. The volcanic arc extends for about 200 km along the inner side to the Peloritano-Calabrian orogenic belt and delimits the southern boundary of the Marsili basin (Barberi et al., 1973, 1974)(Fig 1a).

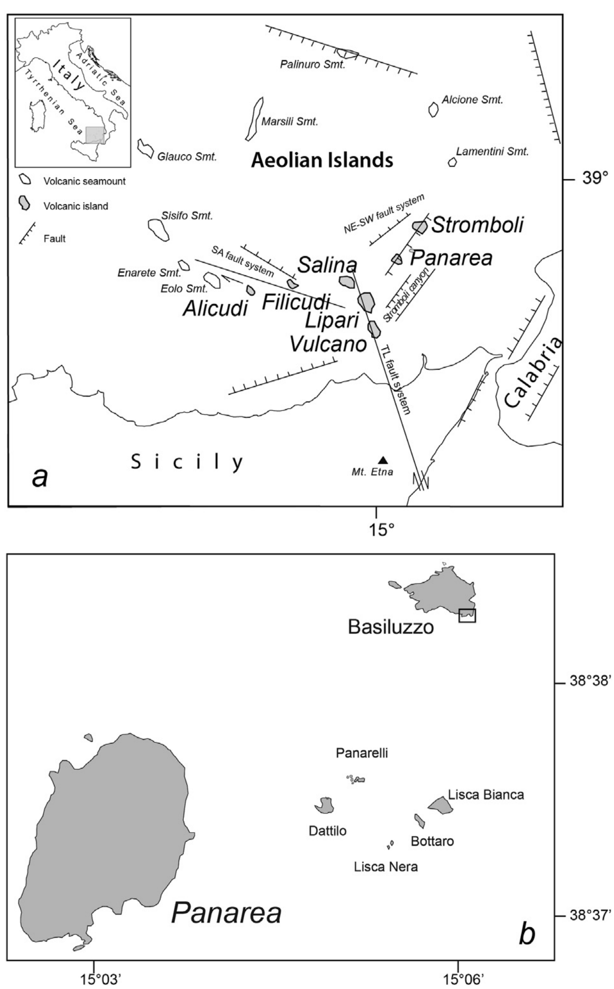

Fig. 1. a) Tectonic sketch of the Aeolian island; b) the Panarea archipelago. The square is the location of the Roman Age wharf located at Basiluzzo island.

The archipelago displays a complex geological setting and the islands belong to three main sectors (Falsaperla et al., 1999; De Astis et al., 2003): *a)*the extinct western sector characterized by CA (Calc-Alkaline) and HKCA (High PotassiumCalc-alkaline) magmas dated 1.3 to 0.05 Ma (Tranne et al., 2002b). It includes the islands of Alicudi, Filicudi and Sisifo Seamount, lying along a WNW–ESE right lateral fault system; *b)* the active central sector is formed by the NNW–SSE trending islands of Salina, Lipari and Vulcano. They are located along a northwest-southeast trending tectonic lineament, namely the Tindari – Giardini-Letoianni fault system, which extends in southern Sicily (Esposito et al., 2010; Serpelloni et al., 2010) (Fig. 1a). The volcanic activity started at ~400 ka BP and is still active at Lipari (the last eruption are dated at 580 AD) and Vulcano (last eruption in 1880–90 AD) (Tranne et al., 2002a), with magmas of CA, HKCA, and shoshonitic affinity. *c)* the active eastern sector, which includes Panarea and Stromboli islands and the Lamentini, Alcione and Palinuro seamounts. Volcanic activity started at ~800 ka (De Astis et al., 2003) and is still persistent at Stromboli whereas episodic gas eruptions occur at Panarea (Anzidei et al., 2005; Esposito et al., 2006; Monecke et al., 2012). This sector, which is located along a NE–SW trending extensional fault system (Gabbianelli et al., 1993; De Astis et al., 2003), includes the emergent part of the submarine stratovolcano of Panarea, which is higher than 2000 m and 20 km wide (Gabbianelli et al., 1990; Gamberi et al., 1997) and comprises the islets of Basiluzzo, Dattilo, Panarelli, Lisca Bianca, Bottaro, Lisca Nera and Le Formiche (Fig. 1b).

Geological and geo-chronological studies revealed the existence of two main volcanic stages in the Aeolian Archipelago: the older stage developed in Pleistocene time when the islands of Alicudi, Filicudi, part of Panarea and Salina and the northwest side of Lipari were produced. During the more recent stage (late Pleistocene–Holocene), the islands of Salina, Lipari, and Panarea were entirely formed and the magmatic activity concentrated in the still active volcanoes of Vulcano and Stromboli (Beccaluva et al., 1985; Gillot, 1987).

Frequent volcanic eruptions and seismic events were reported both in the main islands and offshore during the last 2000 years (SGA, 1996; Boschi et al., 1997; Esposito et al., 2006; Monecke et al., 2012). Besides the volcanic activity, the Aeolian islands are nowadays characterized by deep to shallow seismicity and ground deformation (Guidoboni, 1994; Hollenstein et al., 2003; Chiarabba et al., 2005; Serpelloni et al., 2005, 2010, 2013; Esposito et al., 2010). Particularly, gravimetric data revealed the existence of a positive local gravimetric anomaly between Basiluzzo and Panarea Island (Gabbianelli et al., 1990, 1993; Cocchi et al., 2008).

3. Basiluzzo Island

The island of Basiluzzo belongs to the Panarea volcanic complex, which also includes Panarea Island and the surroundings islets of Dattilo, Panarelli, Lisca Bianca, Bottaro, and Lisca Nera (Fig. 1b). Volcanic activity at Panarea complex started about 150 ka BP (Calanchi et al., 1999). It is mainly characterized by the emplacement of lava domes, plugs, and lava flows, which are high-K calcalkaline andesites to dacite and rhyolites (Calanchi et al., 1999, 2002), while pyroclastic deposits are subordinate. According to Lucchi et al. (2003), the eruptive history is divided into six successive eruptive epochs with periods of volcanic activity separated by quiescence stages. During the last 100 ka, volcanic activity was characterized by the emplacement of the endogenous dome of Basiluzzo (54 ± 8 ka) and of two pumiceous pyroclastic layers. Widespread pyroclastic deposits of external provenance (Punta Torrione Lithosome*)* were emplaced at Panarea and surrounding islets during several discrete eruptive events that occurred between about 70 and 8 ka BP (Lucchi et al., 2003). Some other tephras of external provenance are intercalated within these

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