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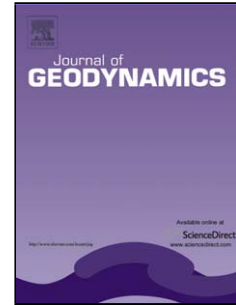
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Late Quaternary deformation on the island on Pantelleria: new constraints for the recent tectonic evolution of the Sicily Channel Rift (southern Italy).

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Abstract

Structural observations carried out on the volcanic island of Pantelleria show that the tectonic setting is dominated by NNE-trending normal faults and by NW-striking right-lateral strike-slip faults with normal component of motion controlled by a \approx N 100°E oriented extension. This mode of deformation also controls the development of the eruptive fissures, dykes and eruptive centres along NNE-SSW belts that may thus represent the surface response to crustal cracking with associated magma intrusions. Magmatic intrusions are also responsible for the impressive vertical deformations that affect during the Late Quaternary the south-eastern segment of the island and producing a large dome within the Pantelleria caldera complex. The results of the structural analysis carried out on the island of Pantelleria also improves the general knowledge on the Late Quaternary tectonics of the entire Sicily Channel. ESE-WNW directed extension, responsible for both the tectonic and volcano-tectonic features of the Pantelleria Island, also characterizes, at a greater scale, the entire channel as shown by available geodetic and seismological data. This mode of extension reactivates the older NW-SE trending fault segments bounding the tectonic troughs of the Channel as right-lateral strike slip faults and produces new NNE trending pure extensional features (normal faulting and cracking) that preferentially develop at the tip of the major strike-slip fault zones. We thus relate the Late Quaternary volcanism of the Pelagian Block magmatism to dilatational strain on

the NNE-striking extensional features that develop on the pre-existing stretched area and propagate throughout the entire continental crust linking the already up-welled mantle with the surface.

keywords: extensional tectonics; Quaternary; volcanism; Pantelleria island; southern Italy

1. Introduction

The island of Pantelleria, as for Linosa, represents the top of a large active composite Quaternary volcano belonging to the magmatic district of the Sicily Channel. Offshore geophysical and geological information (Calanchi et al., 1989; CNR, 1991; Grasso et al., 1993; Rotolo et al., 2006; Civile et al., 2008) show that the magmatic district of the Sicily Channel, which is part of the Pelagian Block (Burolet et al., 1978), includes several submerged volcanic edifices. Their distribution, that has been usually considered to have a NW-SE alignment, actually depicts, as a whole, a roughly N-S oriented belt crosscutting the entire channel from the surroundings of the island of Lampedusa, to the South, to the Graham Bank, to the North (Figure 1). N-S trend of the submarine volcanic centres is also recognizable at a local scale as shown by morphotectonic analyses carried out on detailed bathymetric maps of the Graham Bank area (Civile et al., 2008). The volcanism is mainly characterized by basic and poorly evolved products and only subordinately by evolved rocks exposed on the island of Pantelleria and dragged on a seamount located at about 30 km to the E (Rotolo et al., 2006). Magmatism displays alkaline, peralkaline and tholeiitic affinities and it has been related to the occurrence of extensional tectonics that, during Late Neogene-Quaternary times, caused the development of three major distinct tectonic depressions (Pantelleria, Linosa and Malta troughs). These features, from a morphological point of view, are defined by deep furrows with depths of about -1300 m, -1500 m and -1700 m in the Pantelleria, Linosa and Malta troughs, respectively (Morelli et al., 1975). Available seismic reflection lines (Finetti, 1984; Torelli et al., 1991; Finetti and Del Ben, 2005) show that these depressions, partially filled by Pliocene-Pleistocene turbidites reaching thicknesses of about 1000 m, 2000 m and 1500 m in the Pantelleria, Linosa and Malta basins, respectively (Colantoni, 1975; Maldonato and Stanley,

1977; Winnock, 1981; Calanchi et al., 1989), are bounded by NW-SE trending sub-vertical conjugate normal faults (Figure 1). The crustal stretching was associated with thinning of the African continental crust (Colombi et al., 1973; Boccaletti et al., 1984; Scarascia et al., 2000) that reaches thicknesses of 17-18 km beneath the Pantelleria and Linosa troughs (Finetti and Del Ben, 2005; Civile et al., 2008). These areas are also characterized by a relatively high heat-flow as high as 130 mW/m^2 (Della Vedova et al., 1995) and by positive Bouguer anomalies ranging between +40 and +80 mGal (Morelli et al., 1975). In order to explain the overall tectonic setting of the Sicily Channel in the framework of the geodynamic evolution of the central Mediterranean different models have been proposed. The structures of the Sicily Channel have been interpreted as an intraplate rift related to the NE directed displacement of the northern part of the Pelagian Block including Sicily, away from the Africa continent (Illies, 1981; Winnock, 1981; Beccaluva et al., 1983; Finetti, 1984; Corti et al., 2005). The tectonic depressions of the Sicily Channel have also been interpreted as large and discrete pull-apart basins involving deep crustal levels that developed in front of the Africa-Europe collisional belt within a large dextral wrench zone (Cello et al., 1985; Jongsma et al., 1985; Reuther and Eisbacher, 1985; Ben-Avraham et al., 1987; Boccaletti et al., 1987; Cello, 1987; Reuther, 1990; Finetti and Del Ben, 2005). A further interpretation is proposed by Argnani (1990) who suggests that the rifting is due to mantle convections developing during the rollback of the African lithosphere beneath the Tyrrhenian basin. In this paper we present new geological data from the Pantelleria Island based on structural analyses carried out on the different sets of structures affecting the volcanic products of the island and on morpho-structural investigation of the major volcano-tectonic features accompanied by a detailed levelling of the main Holocene raised palaeoshorelines. The collected data provide new constraints for defining the Late Quaternary kinematics of the major tectonic lineaments characterizing the Pantelleria Island in terms of the regional setting of this portion of the Pelagian Block and for evaluating the modes and the rates of the Holocene vertical deformation in order to test possible relations between tectonic deformation and volcanism.

2. Structural features of the Pantelleria Island

The island of Pantelleria consists entirely of volcanic rocks erupted from about 300 to 3 ka BP (Mahood and Hildreth, 1986). The volcanic products, grouped in distinct eruptive cycles (Civetta et al., 1988), are dominantly represented by acidic rocks, mainly peralkaline rhyolites (pantellerites) with subordinate trachytes and minor transitional basalts that crop out only in the north-western portion of the island (Civetta et al., 1984; 1988; Mahood and Hildreth, 1986). The volcanic activity of Pantelleria was mainly explosive and produced large volumes of ignimbrites and pyroclastics associated with the development of large volcano-tectonic collapses that, forming as a whole a caldera complex (*sensu* Cole et al., 2005), occur at present in the south-eastern portion of the island (Civetta et al., 1984; 1988). The most impressive ignibritic episode caused the emplacement, at about 45 ka BP, of the “Green Tuff” that drapes all the pre-existing volcanic features on the whole island and represents a well-defined stratigraphic key-horizon useful for defining the youngest volcanic activity of the island. An analysis of the most recent volcanics shows that the acidic products erupted in the south-eastern areas during the last 45 ka derive from the differentiation of primary basic magmas stored at a shallow-depth (3-4 km) chamber (Civetta et al., 1988). Its presence is also suggested by the thermal anomalies that characterize the island (Squarci et al., 1994). The most recent eruption of Pantelleria was submarine and occurred in 1891 about 5 km NW of the western coast of the island (Riccò, 1892; Washington, 1909). The structural setting of the island (Figure 2) is defined by different volcano-tectonic features and by tectonic structures mainly comprising fault segments and minor fracture systems that usually affect the entire volcanic succession.

2.1 Volcano-tectonic structures

The major volcano-tectonic features exposed on the island are represented by caldera rims, emission centres and dyke swarms. The most impressive feature is constituted by a caldera complex formed by two large nested calderas that developed on the south-eastern portion of the island (Figure 2). The oldest caldera, named La Vecchia Caldera by Mahood and Hildreth (1986) or Serra

Ghirlanda Caldera by Cello et al. (1985), is defined by a of 2 km-long remnant rim that, completely mantled by the \cong 45 ka-old Green Tuff, bounds to the west, with a maximum height of 100 m, the arc-shaped Serra Ghirlanda ridge. Volcanic horizons exposed on small sections along the southern coastal cliff of the island on relics of palaeo-escarpments attributed to La Vecchia caldera rims, constrains the age of this volcano-tectonic collapse to between 175 ka and 106 ka (Mahood and Hildreth, 1986). The more recent Zichidi Caldera (Cello et al., 1985), that corresponds to the Monastero Caldera of Cornette et al. (1983) and to the Cinque Denti Caldera of Mahood and Hildreth (1983), exhibits well developed rims that, extending more or less continuously, define a sub-circular subsided area located on the central portion of the island inside the older Serra Ghirlanda Caldera (Figure 2). The Zichidi Caldera rim is well preserved along the eastern side of Piano di Ghirlanda, along the Costa Zichidi and to the north of Bagno dell'Acqua from the Khartibucale ridge and Cala Cinque Denti. From Cala Cinque Denti to Piano di Ghirlanda the rim is buried beneath post-caldera volcanic products even if it is recognizable on the surface by the occurrence of small topographic ridges (e.g. on the Khaggiar pantelleritic lava flow) and/or by abrupt slope breaks (e.g. Cuddia Gadir-Cuddia Kamma-Tracino alignment) as the result of the infilling of the subsided floor related to dam effect of the caldera wall. To the northwest, the Zichidi Caldera is abruptly truncated by NE trending normal fault segments that run along the Monastero and the Zinedi escarpments (see below). The walls of the Zichidi Caldera reach maximum heights of 70-90 m at Piano di Ghirlanda and along the Khartibucale ridge and are carved on the oldest rocks of the island. The wall scarp is also partially mantled by thin layers of the \cong 45 ka-old Green Tuff that thicken outside the caldera rim (e.g. the airport area) and form a conspicuous intra-caldera filling as shown by a well drilled at Bagno dell'Acqua that penetrated this volcanic unit for at least 35 m (Villari, 1970). According to Mahood and Hildreth (1986), the Zichidi Caldera formed at \cong 45 ka during the eruption of the Green Tuff.

The eruptive centres of Pantelleria are represented by a large range of features. Cinder cones associated with basaltic eruptions are common in the north-western portion of the island

while pumice and lava cones and lava shields (Mahood and Hildreth, 1986), related to silicic magma eruptions, occur in the rest of the island. Eruptive centres that apparently spread all over the island actually depict NNE trending belts on the south-eastern part of the island and NW trending alignments, mainly located on the north-western sector. In place, they also develop along NNE-SSW trending eruptive fissures as on the north-western edge of Montagna Grande slope or on the south-easternmost part of the island along the Cuddioli di Dietro Isola ridge (Figure 2). Less impressive NW-SE trending fissures marked by aligned eruptive centres are also present in Contrada Caffefi. Assuming that each eruptive centre is fed by a sub-vertical dyke that develops perpendicular to the minor principal stress, to minimize the local magmatic field-effects related to the structure of the major volcano a statistical analysis of their surface density distribution has been performed to better define the regional tectonic regime (Figure 3). Considering that 100 eruptive centres have been mapped on the island, a grid with steps of 500 m along x-y coordinates was constructed using four overlapping series of circles with a surface equal to 1% of the total area of the island ($\cong 84 \text{ km}^2$). For each step, the density of the eruptive centres was calculated as the rate between the percent of the total number of the vent points occurring in the sample area and the percent of the sample area relative to the total surface of the island. Contour lines of distinct density values have been drawn showing the clustering areas of the eruptive centres. Contour lines depict a prominent NNE-SSW trending area that extends from coast to coast along the central portion of the island including most of vents of the island (Figure 3). It is characterized by a well-defined belt that extends to the Montagna Grande area and a lobe defined by a sub-maximum of density elongated from the northern border of Montagna Grande to Punta Gadir. A further NNE-SSW trending belt occurs to the southwest at Cuddioli Dietro Isola. In the area located between these two major belts, distinct scattered areas depicting, as a whole, a NNE trend are also recognizable. In the north-western part of the island contour lines indeed define a major sigmoidal shaped NW-SE trending belt accompanied by two lower density areas (Figure 3). The different areas defined by the contouring could be interpreted as the surface effect of sub-crustal magma-injection, thus implying

that the distinct belts of the island may represent the preferential zones where crustal cracking occurs. Considering that most of the described belts trend NNE-SSW, a WNW-ESE directed extension ($\approx N120^\circ E$) could be considered as the dominant mode of deformation of the island of Pantelleria. Following this line of evidence, the NW-SE trending belts occurring on the north-western part of the island could be consequently interpreted as the result of coalescent NNE-SSW trending cracks developing along a deep-seated NW-SE strike-slip zone with a left-stepping echelon array (Figure 3).

The volcanic rocks of the island are also intruded by dykes of a few cm to 10-15 m thickness, that are well exposed along the sea cliff of the island from the southeastern coast to Scauri village (Mahood and Hildreth, 1986). Dykes, mainly pantelleritic in composition, form local swarms and show a sub-vertical attitude trending roughly NNE-SSW thus indicating a N $100^\circ E$ oriented extension (Figure 4a).

2.2 Fault structures

The major faults exposed on Pantelleria Island are represented by NE and NW trending segments that affect all the products cropping out on the island (Figure 2). The NE-trending faults exhibit well developed steep and linear cumulative escarpments. The most important structure is the Zinedi fault (ZF), a roughly east-facing, 6 km-long segment crossing the whole island in its north-western sector. The ZF (Figure 2) extends from Punta Pozzolana to the NE, to Grotta Calda to the SW and separates the north-western part of the island, characterized by the occurrence of alkali-basalts effusion, from the south-eastern portion where only peralkaline products, ranging from pantellerites to trachytes, have been erupted. The ZF escarpment shows different heights along strike reaching a maximum value of ≈ 120 m on its north-eastern segment. Along the western border of Bagno dell'Acqua, the fault scarp truncates 130-190 ka-old lavas that are partially mantled by the 45-ka-old Green Tuff, which is, in turn displaced by about 20 m. In its central portion, the fault trace is buried by the ≈ 17 -ka-old pyroclastics while on the south-western edge it is characterized by a smoothed scarp overlapped by ≈ 14 -ka-old pantelleritic lava flows.

To the East the Monastero fault (MF) is a 2-km-long normal fault segment that affects the Zichidi caldera at Costa Monastero where it forms a 30-m-high escarpment that offsets the 47- ka-old lavas capped by the Green Tuff (Figure 2). The most impressive fault scarp of this system is represented by the Montagna Grande fault (MGF), a 3-km-long fault segment that bounds to the East the Montagna Grande massif with a 300-m-high escarpment (Figure 2). The MGF separates the 44-ka-old trachytes of Montagna Grande from the Monte Gibele trachytic lavas that flow along the fault scarp. Considering that the youngest lava flows of Monte Gibele have been dated at 28 ka, the entire fault scarp developed during 16 ka with a vertical uplift-rate of about 1.9 cm/a. This very high value suggests a volcano-tectonic origin associated with the emplacement of the trachytic body of Montagna Grande. Structural data collected on the cataclastic belts of these major structures show fault planes oriented between N170°E and N210°E, with slickenlines ranging from 65° to 90° thus documenting normal dip-slip kinematics (Figure 4b).

The NW trending fault system is represented by the Scauri Fault (SF), a roughly 5-km-long structure that mainly runs along the shore defining the south-western sea cliff of the island where the oldest products of the island (ages from \cong 320 to 80 ka) crop out, draped locally by the Green Tuff (Figure 2). In places, the fault zone is well exposed along the sea cliff showing clear negative flower geometries that suggest horizontal components of motion. Minor fault planes related to the major structure trend along N110°-145°E directions and show sub-horizontal slickenlines ranging from 10° to 30°, indicating right lateral motion (Figure 4b). Inversion of striated fault planes collected on NE and NW-striking major structures indicates that both systems are kinematically compatible with a E-W extension direction (Figure 4b).

2.3 Minor fractures

The volcanic products of the island of Pantelleria are pervasively affected by two main regional minor fracture sets characterized by a consistency of orientation. A statistic analysis of the total minor fracture measurements collected at selected sites shows that the dominant set affecting the products of the island is oriented along a roughly NNE-SSW direction with a mean direction of

N 15°E (Figure 4c). This set is constituted by sub-vertical systematic extensional joints characterized by spacing ranging from a few decimetres to 1 m; they are frequently represented by open fractures filled by secondary material and locally marked by fumarolic activity (Cello et al., 1985). In place, at both large and small scales, this set appears to be constituted by pairs of conjugate hybrid joints that define the dihedral angles containing the shortening and the extension directions. A statistical analysis of measurements carried out on 18 clearly exposed pairs of conjugate joints suggests an extension direction oriented N 105°E (Figure 4d). The minor fractures of the second set trend in a NW-SE direction with an average orientation of N 140° E and are characterized by metric spacing and lengths of several metres. Considering that right-lateral strike-slip fault segments extend in a NW-SE direction on the island, this minor fracture set has been interpreted as synthetic shear fractures associated with a dextral shear zone, being also kinematically compatible with a dominant roughly E-W directed extension.

3. Vertical deformation

The island of Pantelleria is affected by an intense vertical deformation, which caused a severe uplift of the wave-cut platforms and marine caves and notches carved at the base of the coastal cliffs of the island. Episodes of vigorous uplift have been reported also in historical times by Riccò (1892) who described an uplift of about 1 m of the north-eastern coast of the island before a shallow sub-marine eruption occurred in October 1891 about 5 km northwest of the island. In order to evaluate the extent of the uplift affecting Pantelleria we mapped in detail the distribution of marine platforms and palaeoshorelines occurring on the island (De Guidi and Monaco, 2008). These features have been recognized all over the coast of Pantelleria where they reach heights up to about 1.5 m along the southern coast (e.g. Scauri) and up to 4.5 m on the northern coastline thus indicating that the entire island in recent times, mostly during the Holocene, suffered a severe uplift. In particular, along the northern coast, from the village of Pantelleria to Punta Cortigliolo, three well-developed palaeoshorelines characterized by biogenic encrustations of calcareous algae,

vermetids and corals have been recognized at different elevations (Figure 5). ^{14}C age determinations carried out on several samples of biogenic material constrained the age of these distinct palaeoshorelines (De Guidi and Monaco, 2008). The lowest one (line a in Figure 5) shows an age of 197 ± 97 years BP (2 samples) whereas the intermediate one (line b in Figure 5) is characterized by ages ranging from 911 ± 37 years BP to 506 ± 21 years BP (8 samples) representing the period during which the palaeoshoreline developed. The uppermost palaeoshoreline (line c in Figure 5) is carved on the 5.5-ka-old Khaggiar pantelleritic lava flow (Mahood and Hildreth, 1986) and shows an age of 963 ± 87 years BP (2 samples) constraining the time interval during which this shoreline developed between about 5000 and about 1000 years BP. As a whole, these uplifted strandlines are also deformed into a large antiform with an axial trace almost perpendicular to the coastline and a hinge zone located around the central portion of the island that is characterized by the occurrence of the NNE trending eruptive belts (inset a in Figure 5). Along the antiform limbs, the palaeoshorelines dip with a convergent array and form steep ramps reaching at the antiformal crest the maximum elevation of 4.5, 3.1 and 1.3 m, respectively (Figure 5). Assuming that in the island uplift processes occurred as discrete episodes as documented by Riccò (1892) and strongly supported by overlapping ages for lines a and b, and that the growth of the biogenic encrustations on the palaeoshorelines developed continuously, three main episodes of uplift, characterized by values of 1.4, 1.8 and 1.3 m, can be thus estimated at about 900, 500 and 120 years BP. The high values of these repeated uplift episodes suggest that the vertical deformation acting in this portion of the island could be associated with magmatic processes active along the NNE trending eruptive belts occurring within the caldera complex of the central portion of the island. Along these zones, cracking processes could have been accompanied at shallow crustal levels by magma intrusion causing large scale inflation phenomena. These data apparently contrast with geodetic measurements (Bonaccorso and Mattia, 2000; Behncke et al., 2006) showing that the caldera complex of the island is at present affected by subsidence (about 11 cm from 1980 to 1996 AD). Considering that an analogous behavior characterized by uplift and subsidence has been detected

for the Campi Flegrei Caldera (Bellucci et al., 2006), we propose a similar mechanism for the Pantelleria caldera complex. In this view the subsidence should represent the typical background state of the area interrupted by discrete and faster uplift events related to magma intrusions. The result of the superimposed uniform subsidence and episodic uplift processes is thus represented, in the last 900 years, by a positive large vertical deformation resulting in the observed doming of the southeastern portion of the island.

4. Summary and discussion

Geological and structural analyses carried out on the island of Pantelleria point out that the main tectonic structures are represented by NNE trending dip-slip normal faults and by NW striking right-lateral strike-slip faults with normal component of motion. The major fault segments represent deep-seated structures (Behncke et al., 2006) that separate the southeastern portion of the island characterized by a shallow-depth magma reservoir (Civetta et al., 1988) from the northwestern sector where basaltic eruptions occurred. Minor structures are represented by two main regional fracture sets (NNE-SSW extensional and hybrid joints and NW-SE synthetic shear fractures) that pervasively affect the entire pile of volcanic products. The distribution of eruptive fissures, dykes and eruptive centres shows, as a whole, alignment along NNE-SSW belts thus suggesting that crustal cracking with associated magma intrusions has occurred with a similar trend. As a whole, the structural observations carried out on the island of Pantelleria emphasize that both the tectonic structures (faults and joints) and the volcano-tectonic features (eruptive fissures, eruptive centre distribution, dyke swarms, fumaroles) are all kinematically compatible and appear to have a common tectonic origin controlled by a $\approx N 105 \pm 15^\circ E$ directed extension. At a large-scale, this mode of deformation is compatible with the development of the roughly N-S oriented volcanic belt that extends from Linosa to the Graham Bank, thus implying that the entire region of the Sicily channel is affected by a regional ESE-WNW oriented extension. This regional extension is also suggested by geodetic data collected at permanent observation sites located on the African and

Sicilian shoulders of the channel (D'Agostino and Selvaggi, 2004). The African motion is well represented by data collected at the Lampedusa station (LAMP) which show a NW oriented convergence towards Europe (Figure 6). The motion of the Sicilian shoulder with respect to Europe is represented by data collected at the permanent sites of MILO, located on the westernmost sides of Sicily, and NOTO located on the Hyblean plateau, on the southeastern edge of the island. On the western side of the channel a roughly E-W extension direction is obtained, combining the different directions and rates between the velocity vectors of LAMP and MILO, the latter being clockwise rotated and characterized by a lower magnitude (Figure 6a). On the eastern portion of the channel, the combined velocity vector of LAMP and NOTO indicates indeed a NE-SW extension direction. Considering that between the two sites a major N10°E oriented left-lateral fault zone (Scicli line) accommodate about 1 mm/a (Catalano et al., 2008) the NE-SW extension in this portion of the Sicily Channel has to be re-oriented into an E-W direction (Figure 6a). This deformation pattern is also consistent with seismological data from strong earthquakes that have occurred in the Tunisia-Libya seismic zone (Westaway, 1990; 1991). Seismological information, based mainly on focal mechanisms of the strongest earthquakes (Sirte earthquake of April 19, 1935 and Tripoli earthquake of September 4, 1974) indicate in fact that the NW-SE trending regional faults affecting the Pelagian Block are characterized by a right lateral component of motion related to an oblique extension (oriented along \approx N 100°E direction) between Tunisia and Sicily (Westaway, 1990; 1991). Geodetic and seismological data together show, therefore, that the entire Sicily Channel experiences a regional Late Quaternary ESE-striking extension that is consistent with that which controls the Siculo Calabrian Rift Zone (SCRZ in Figure 6) along the Ionian coast of Sicily and the Tyrrhenian side of the Calabrian arc (Monaco et al., 1997; Monaco and Tortorici, 2000). We suggest that, at a larger scale, this extension direction may be considered as a second-order deformation process induced by first order Africa-Europe kinematics defined by a NNW convergence. The Late Quaternary extension reactivates the older crustal and/or lithospheric structures responsible for the crustal stretching of the Pelagian Block developed mainly during Late

Neogene-Early Quaternary rifting. Seismic reflection profiles across the Pantelleria trough (Torelli et al., 1991; Finetti and Del Ben, 2005; Civile et al., 2008) highlight, in fact, that the boundary master faults appear to be undoubtedly sealed by Late (?) Quaternary sediments well imaged along lines CS89-01 (see Fig. 5 in Torelli et al., 1991) and CROP MS25 (see Fig. 7 in Civile et al., 2008). This implies that the major NW-SE trending tectonic troughs of the Sicily Channel, with the associated mantle doming, fully developed during the Early Pliocene-Early Pleistocene as a consequence of a NE-SW oriented extension. We tentatively propose that during this stage the NE-SW oriented extension responsible for the rift process occurring in the Sicily Channel may represent the effect of the NW-SE directed impingement of the Africa continental crust (Pelagian Block) against the Maghrebian collisional belt. This caused the consequent lateral extrusion of the northeastern portion of the Pelagian Block towards weak segments of the continental margin represented by residual basin-areas (e.g. Caltanissetta Basin). Subsequently, since the Late Quaternary, the northeastward extrusion was locked and the NE-directed rift process ceased. The Sicily Channel is thus affected by a new extensional regime mainly related to the development of an incipient divergent margin. The Late Quaternary extension thus partially reactivates the NW-SE to E-W trending fault segments bounding the Pantelleria, Malta and Linosa troughs as right-lateral strike slip faults and produces new NNE trending pure extensional features (normal faulting and cracking) that preferentially develop at the tip of the major strike-slip fault zones (Figure 6b). The Late Quaternary volcanism of the Pelagian Block is thus confined along the NNE-striking younger extensional features that develop on the pre-existing stretched area and propagate throughout the entire continental crust therefore linking the already up-welled mantle with the surface.

The prominent magmatism of the island of Pantelleria, as well as the NNE-SSW trending volcanic belt of the Sicily Channel together with the occurrence of Mt. Etna volcano (Monaco et al., 1997), appears to be a consequence of crustal cracking related to the large-scale Late Quaternary extensional processes that govern the whole of southern Italy. This implies that magmatism is the result of a new, Late Quaternary tectonic extensional regime superimposed on the long-lived Late

Neogene-Early Quaternary rifting that originated the NW-SE trending troughs of the Sicily Channel. Magmatic processes are also responsible for the impressive vertical deformation that produced a large dome having maximum elevations located along the axis of the south-eastern portion of the island. During Late Holocene times, doming was the result of at least three distinct uplift events that inverted the uniform subsidence state likely associated with magma intrusions along NNE-SSW crustal cracks within the shallow-depth reservoir(s) of the south-eastern part of the island. The vertical deformations of Pantelleria also indicate a magmatic behavior similar to that described for the Campi Flegrei Caldera (Bellucci et al., 2006) thus implying that the island in the last 5 ka has been dominated by intrusion processes rather than eruptive activity.

References

- Argnani, A., 1990. The strait of Sicily rift zone: foreland deformation related to the evolution of a back-arc basin. *J. Geodyn.* 12, 311-331.
- Beccaluva, L., Rossi, P.L., Serri, G., 1983. Neogene to Recent volcanism of the southern Tyrrhenian-Sicilian area: implication for a geodynamic evolution of the Calabrian Arc. *Earth Evol. Sc.* 3, 222-238.
- Behncke, B., Berrino, G., Corrado, G., Velardita, R., 2006. Ground deformation and gravity changes on the Island of Pantelleria in the geodynamic framework of the Sicily Channel. *J. Volcanol. Geoth. Res.* 150, 146-162.
- Bellucci, F., Woo, J., Kilburn, C.R.J., Rolandi, G., 2006. Ground deformation at Campi Flegrei, Italy: implications for hazard assessment. In: Troise, C., De Natale, G., Kilburn, C.R.J. (Eds.), *Mechanism of activity and unrest at large calderas. Spec. Publ. 269. Geological Society, London*, pp.141-158.
- Ben-Avraham, Z., Nur, A., Cello, G., 1987. Active transcurrent fault system along the north African passive margin. *Tectonophysics* 141, 249-260.

- Bonaccorso, A., Mattia, M., 2000. Deflation acting on Pantelleria Island (Sicily Channel) inferred trough geodetic data. *Earth Planet. Sci. Lett.* 180, 91-101.
- Boccaletti, M., Nicolich, R., Tortorici, L., 1984. The Calabrian Arc and the Ionian Sea in the dynamic evolution of the Central Mediterranean. *Marine Geol.* 55, 219-245.
- Boccaletti, M., Cello, G., Tortorici, L., 1987. Transtensional tectonics in the Sicily Channel. *J. Struct. Geol.* 9, 869-876.
- Burollet, P.F., Mugniot, G.M., Sweeney, P., 1978. The Geology of the Pelagian block: the margins and basins off Southern Tunisia and Tripolitania. In: Nairn, A., Kanes, W., Stelhi, F.G. (Eds.), *The ocean basins and margins.* 4B, Plenum Press, New York, pp. 331-339.
- Calanchi, N., Colantoni, P., Rossi, P.L., Saitta, M., Serri, G., 1989. The Strait of Sicily continental rift system: physiography and petrochemistry of the submarine volcanic centres, *Marine Geol.* 87, 55-83.
- Catalano, S., De Guidi, G., Romagnoli, G., Torrisi, S., Tortorici, G., Tortorici, L., 2008. The migration of plate boundaries in SE Sicily: Influence on the large-scale kinematic model of the African promontory in southern Italy. *Tectonophysics* 449, 41-62, doi:10.1016/j.tecto.2007.12.003
- Cello, G., 1987. Structure and deformation processes in the Strait of Sicily “rift zone”. *Tectonophysics* 141, 237-247.
- Cello, G., Crisci, M., Marabini, S., Tortorici, L., 1985. Transtensive tectonics in the Strait of Sicily: structural and volcanological evidence from the Island of Pantelleria. *Tectonics* 4, 311-322.
- Civetta, L., Cornette, Y., Crisci, G., Gillot, P.Y., Orsi, G., Requejos, C.S., 1984. Geology, geochronology and chemical evolution of the Island of Pantelleria. *Geol. Magazine* 121, 541-668.
- Civetta, L., Cornette, Y., Gillot, P.Y., Orsi, G., 1988. The eruptive history of Pantelleria (Sicily Channel) in the last 50 ka. *Bull. Volcanol.* 50, 47-57.

- Civile, D., Lodolo, E., Tortorici, L., Lanzafame, G., Brancolini, G. 2008. Relationships between magmatism and tectonics in a continental rift: The Pantelleria Island region (Sicily Channel, Italy). *Marine Geol.* 251, 32-46, doi:10.1016/j.margeo.2008.01.009.
- Colantoni, P., 1975. Note di geologia marina sul Canale di Sicilia. *Giornale di Geologia* 15, 181-207.
- Cole, J.W., Milner, D.M., Spinks, K.D., 2005. Calderas and caldera structures: a review. *Earth Sc. Rev.* 69, 1-26.
- Colombi, B., Giese, P., Luongo, G., Morelli, C., Riuscetti, M., Scarascia, S., Schutte, K.G., Strowald, J., De Visintini, G., 1973. Preliminary report on the seismic refraction profile Gargano-Salerno-Palermo-Pantelleria. *Bollettino di Geofisica Teorica e Applicata* 59, 225-254.
- Consiglio Nazionale delle Ricerche, 1991. Structural Model of Italy and Gravity Map. Quaderni della Ricerca Scientifica 114, C.N.R., Roma.
- Cornette, Y., Crisci, G.M., Gillot, P.Y., Orsi, G., 1983. Recent volcanic history of Pantelleria : a new interpretation. *J. Volcanol. Geoth. Res.* 17, 361-373.
- Corti, G., Cuffaro, M., Doglioni, C., Innocenti, F., Manetti, P., 2006 Coexisting geodynamic processes in the Sicily Channel. In: Dilek, Y., Pavlides, S. (Eds), *Postcollisional Tectonics and Magmatism in the Mediterranean Region and Asia. Special Paper 409, Geological Society of America*, pp. 83-96.
- D'Agostino, N., Selvaggi, G., 2004. Crustal motion along the Eurasia-Nubia plate boundary in the Calabrian Arc and Sicily and active extension in the Messina Straits from GPS measurements. *J. Geophys. Res.* 109, B11402, doi: 10.1029/2004JB002998.
- De Guidi, G., Monaco, C., 2008. Late Holocene vertical deformation along the coast of Pantelleria Island (Sicily Channel, Italy). *Quaternary Int.* in press, doi:10.1016/j.quaint.2008.08.002.
- Della Vedova, B., Lucazeau, F., Pasquale, V., Pellis, G., Verdoya, M., 1995. Heat flow in the tectonic provinces crossed by the southern segment of the European Geotraverse. *Tectonophysics* 244, 57-74.

- Finetti, I.R., 1984. Geophysical study of the Sicily Channel rift zone. *Bollettino di Geofisica Teorica e Applicata* 26, 3-28.
- Finetti, I.R., Del Ben, A., 2005. Crustal Tectono-Stratigraphic Setting of the Pelagian Foreland from new CROP Seismic data. In: Finetti, I.R. (Ed.), *Crop Project: Deep Seismic Exploration of the Central Mediterranean and Italy. Atlases in Geoscience 1*, Elsevier, pp. 581-595.
- Grasso, M., Mazzoldi, G., Torelli, L., 1993. Structural and stratigraphic framework of the Tunisia shelf surrounding the islands of Lampedusa and Lampedusa (Pelagian Sea). In: Max, M. D., Colantoni, P. (Eds.), *Geological Development of the Sicilian-Tunisian Platform. Report Marine Science 58*, Unesco, Paris, pp. 65-70.
- Illies, J.H., 1981. Graben formation – the Maltese Islands – a case history. *Tectonophysics* 73, 151-168.
- Jongsma, D., Van Hinte, J.E., Woodside, J.M., 1985. Geologic structure and neotectonics of the North African continental margin south of Sicily. *Marine Petrol. Geol.* 2, 156-179.
- Mahood, G.A., Hildreth, E.W., 1983. Nested calderas and trap-door uplift at Pantelleria, Strait of Sicily. *Geology* 11, 722-726.
- Mahood, G.A., Hildreth, E.W., 1986. Geology of the peralkaline volcano at Pantelleria, Strait of Sicily. *Bull. Volcanol.* 48, 143-172.
- Maldonado, A., Stanley, D.I., 1977. Lithofacies as a function of depth in the Strait of Sicily. *Geology* 2, 111-117.
- Monaco, C., Tapponnier, P., Tortorici, L., Gillot, P.Y., 1997. Late Quaternary slip rates on the Acireale-Piedimonte normal faults and tectonic origin of Mt. Etna (Sicily), *Earth Planet. Sci. Lett.* 147, 125-139.
- Monaco, C., Tortorici, L., 2000. Active faulting in the Calabrian arc and eastern Sicily. *J. Geodynamics* 29, 407-424.
- Morelli, G., Gantar, C., Pisani, M., 1975. Bathymetry, gravity (and magnetism) in the Strait of Sicily and the Ionian Sea. *Bollettino di Geofisica Teorica e Applicata* 17, 39-58.

- Reuther, C.D., 1990. Strike-slip generated rifting and recent tectonic stresses on the African foreland (Central Mediterranean region). *Annales Tectonicae* 4, 120-130.
- Reuther, C.D., Eisbacher, G.H., 1985. Pantelleria rift-crustal extension in a convergent intraplate setting. *Geol. Rund.* 74, 585-597.
- Riccò, A., 1892. Terremoti, sollevamenti ed eruzione sottomarina a Pantelleria nella seconda metà dell'ottobre 1891. *Bollettino della Società Geografica Italiana* 11, 5-23.
- Rotolo, S. G., Castorina, F., Cellula, D., Pompilio, M., 2006. Petrology and Geochemistry of Submarine Volcanism in the Sicily Channel Rift. *J. Geol.* 114, 355–365,
- Scarascia, S., Cassinis, R., Lozej, A., Nebuloni, A., 2000. A seismic and gravimetric model of crustal structures across the Sicily Channel Rift zone. *Bollettino della Società Geologica Italiana* 119, 213-222.
- Squarci, P., Gianelli, S., Grassi, S., Mussi, M., D'Amore, F., 1994. Preliminary results of geothermal prospecting on the Island of Pantelleria (Italy). *Acta Volcanologica* 5, 117-123.
- Torelli, L., Zitellini, N., Argnani, A., Brancolini, G., De Cillia, C., Peis, D., Tricart, P., 1991. Sezione geologica crostale dall'avampaese pelagiano al bacino di retroarco tirrenico (Mediterraneo centrale). *Memorie della Società Geologica Italiana* 47, 385-399.
- Villari, L., 1970. Studio petrologico di alcuni campioni dei pozzi Bagno dell'Acqua e Gadir. *Rendiconti della Società Italiana di Mineralogia e Petrologia* 26, 353-376.
- Washington, H.S., 1909. The submarine eruption of 1831 and 1891 near Pantelleria. *Am. J. Sci.* 27, 131-150.
- Westaway, R., 1990. The Tripoli, Lybia, earthquake of September 4, 1974: implications for the active tectonics of the central Mediterranean. *Tectonics* 9, 231-248.
- Westaway, R., 1991. Continental extension on sets of parallel faults: observational evidence and theoretical models. In: Roberts, A.M., Yielding, G. (Eds.), *The geometry of normal faults*. Spec. Publ. 56. Geological Society, London, pp.143-169.

Winnock, E., 1981. Structure du Bloc Pelagien. In: Wezel, F.C. (Ed.), Sedimentary Basin of Mediterranean Margins. Tecnoprint, Bologna, pp. 445-464.

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Captions of figures

Figure 1. Schematic structural map of the Sicily Channel. PT: Pantelleria trough; MT: Malta trough; LT: Linosa trough; GB: Graham bank. Location of volcanic centres are from Calanchi et al. (1989), CNR (1991), Grasso et al. (1993), Rotolo et al. (2006) and Civile et al. (2008); Moho isobaths are from Finetti and Del Ben (2005).

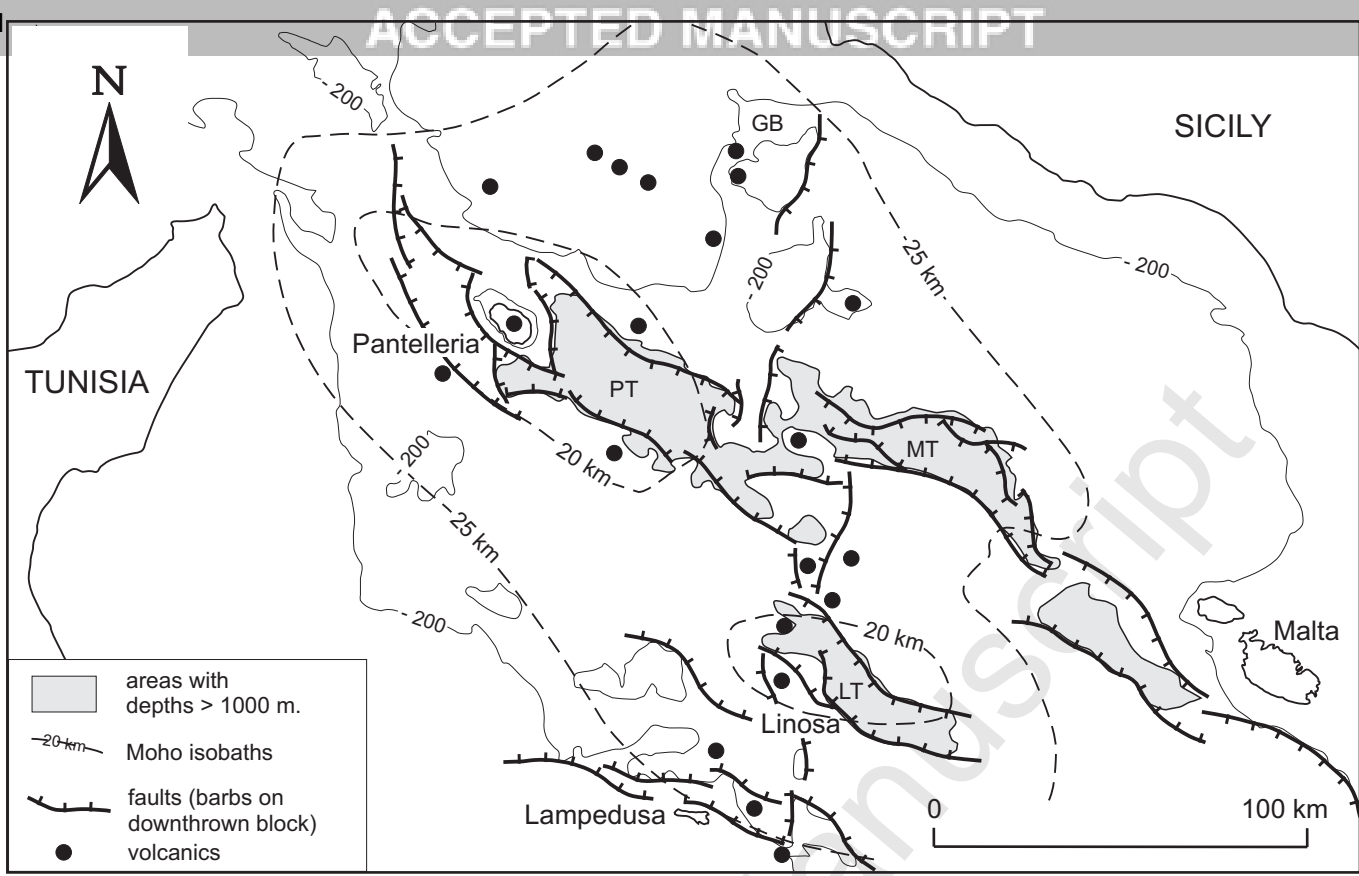
Figure 2. Structural map of the island of Pantelleria (modified from Civile et al., 2008). Digital elevation model has been generated on a geographic grid of 40 x 40 points per km² with elevation resolution at 10 m. Inset (a) shows a view from the SSE of the northwestern part of the island by a 3D prospective projection mode of 1:10.000 scale aerial photographs draped on digital elevation model.

Figure 3. Cartoon showing the surface density distribution of the eruptive centres occurring on the island of Pantelleria. On the map the major tectonic and volcano-tectonic features are also shown (for legend see Figure 2). Large arrows indicate the mean extension direction. Line A-B indicates the trace of the projection profile reported in Figure 5. Inset (a) shows kinematic interpretation of a discrete right-lateral strike-slip fault zone with associated en-echelon extensional fissures to suggest the possible relations between deep-seated structures and surface eruptive centres alignment.

Figure 4. Lower hemisphere equal area stereographic projections of the main structures affecting the volcanic products of the island of Pantelleria. Large arrows indicate the azimuth of the mean extension direction obtained from the analysis of distinct data sets. (a): pole density diagram showing the orientation of dykes; (b): attitude of major fault planes and associated slickenlines (thin arrows); (c): pole density diagram showing the orientation of regional joints sets; (d): pole density diagram showing the orientation of pairs of conjugate joints.

Figure 5. Vertical projected profiles of the elevations of the three Holocene palaeoshorelines (a to c) measured along the north-eastern coast of the island on a NE–SW direction (line A–B in Figure 3). Inset (a) shows the relations between doming and eruptive belts occurring in the island.

Figure 6. Structural sketch map showing the Late Quaternary deformation pattern of the Sicily Channel and surrounding areas. SCRZ indicates the Siculo Calabrian Rift Zone. Hatched areas indicate volcanics occurring within the Pelagian Block. Large arrows indicate the regional direction of extension as derived from structural data. Thin black arrows refer to the motion of the Africa (LAMP) and Sicily (NOTO and MILO) blocks in the Europe reference frame. The inset (a) shows the velocity diagrams indicating how the regional direction of extension acting in the Sicily Channel is the result of the relative motion between the Sicilian and Calabrian crustal blocks (data from D’Agostino and Selvaggi, 2004). Inset (b) illustrates the mode of deformation acting in the Sicily Channel and the relationships between faulting and magmatism.



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Figure 2

