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Geological and geodetic constraints on the active deformation along the northern margin of the Hyblean Plateau (SE Sicily)

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ABSTRACT

A geologic and geodetic integrated analysis of the northern margin of the Hyblean Plateau (SE Sicily) has been carried out in order to test the relationship between the active deformation, recorded by GPS data, and the long-term tectonic evolution, reconstructed by the interpretation of structural and morphological data. Our study revealed the active growth of a large antiform, as a consequence of the positive tectonic inversion of the previous flexure, bordering the Hyblean Foreland. The deformation of Middle–Late Pleistocene marine terraces and the evolution of the drainage system are consistent with a progressive regional tilting of the entire eastern sector of the Hyblean Plateau (Siracusa Domain), representing the southern limb of the active antiform. The geometry of the Late Quaternary marine strandlines, compared with the results of analogue models, is compatible with the effects of the NW-ward propagation of a detachment fault at depth. The active deformation of the Hyblean region, coherent with the Nubia–Eurasia plate convergence, suggests to candidate the inverted tectonics at the northern border of the Hyblean Plateau as potential seismogenic sources of the area.

1. Introduction

The seismotectonics of SE Sicily, despite the huge amounts of studies, are still debated. Currently, two alternative models are considered in the Literature to explain the main seismicity. Several authors (e.g. Adam et al., 2000; Azzaro and Barbano, 2000; Bianca et al., 1999; Catalano et al., 2008a; Hirn et al., 1997; Monaco and Tortorici, 2000; Polonia et al., 2012; Scandone and Stucchi, 2000) referred the two major ($M \simeq 7$) historical events that struck the region (1169 and 1693 A.D.; Boschi et al., 1997) to off-shore faults at the African continental crust–Ionian Basin boundary (Malta Escarpment in Fig. 1). Conversely, other authors (Basili et al., 2008; Sirovich and Pettenati, 1999; Valensise and Pantosti, 2001) constrained the 1693 earthquake to on-shore active contractional structures bordering the northern margin of the Hyblean Plateau (Fig. 1).

In this paper, we discuss the results of integrated structural, morphological and geodetic studies across the inferred on-shore seismogenic sources of the northern border of the Hyblean Plateau. In our study we propose the comparison between the current deformation, obtained by the inversion of GPS data collected in a time-span of about 15 years, and the Late Quaternary deformation, provided by tectonic geomorphology combined with structural information. The geomorphological analyses included the study of the Late Quaternary marine terraces and of the drainage system. The structural analysis focused on geometry and kinematics of rejuvenated fault planes.

The study aims at providing new constraints on the mode and the intensity of the recent and active tectonic deformation as starting point for future modelling of the seismotectonics of one of the most relevant seismogenic region of the Mediterranean area.

2. Tectonic setting

The Hyblean Plateau, located on the south-eastern corner of Sicily, is a promontory of the Africa continental foreland (Pelagian Block in Fig. 1) that, during the Nubia–Eurasia collision, acted as a buoyant indenter deforming the frontal areas of the SE-verging allochthonous Maghrebian thrust belt (Fig. 1) (Ben Avraham and Grasso, 1990, 1991; Butler et al., 1992; Grasso et al., 1995; Lentini et al., 1994; Lickorish et al., 1999; Pedley and Grasso, 1991). To the east, the NNW Malta Escarpment separates the Hyblean Plateau from the Ionian Basin (Carbone et al., 1982; Finetti, 1982; Grasso and Lentini, 1982), probably overprinting the Mesozoic Africa–Ionian passive margin (Finetti, 1982; Scandone et al., 1981). The escarpment developed during Jurassic–Early Cretaceous Tethyan rifting (Robertson and Grasso, 1995) and was inverted into a hinge fault system with strike–slip component during the Eurasia–Nubia plate convergence (Casero et al., 1984; Fabbri et al., 1982; Reuther et al., 1993; Scandone et al., 1981). Following the emplacement of the orogenic belt onto the Hyblean Foreland, the

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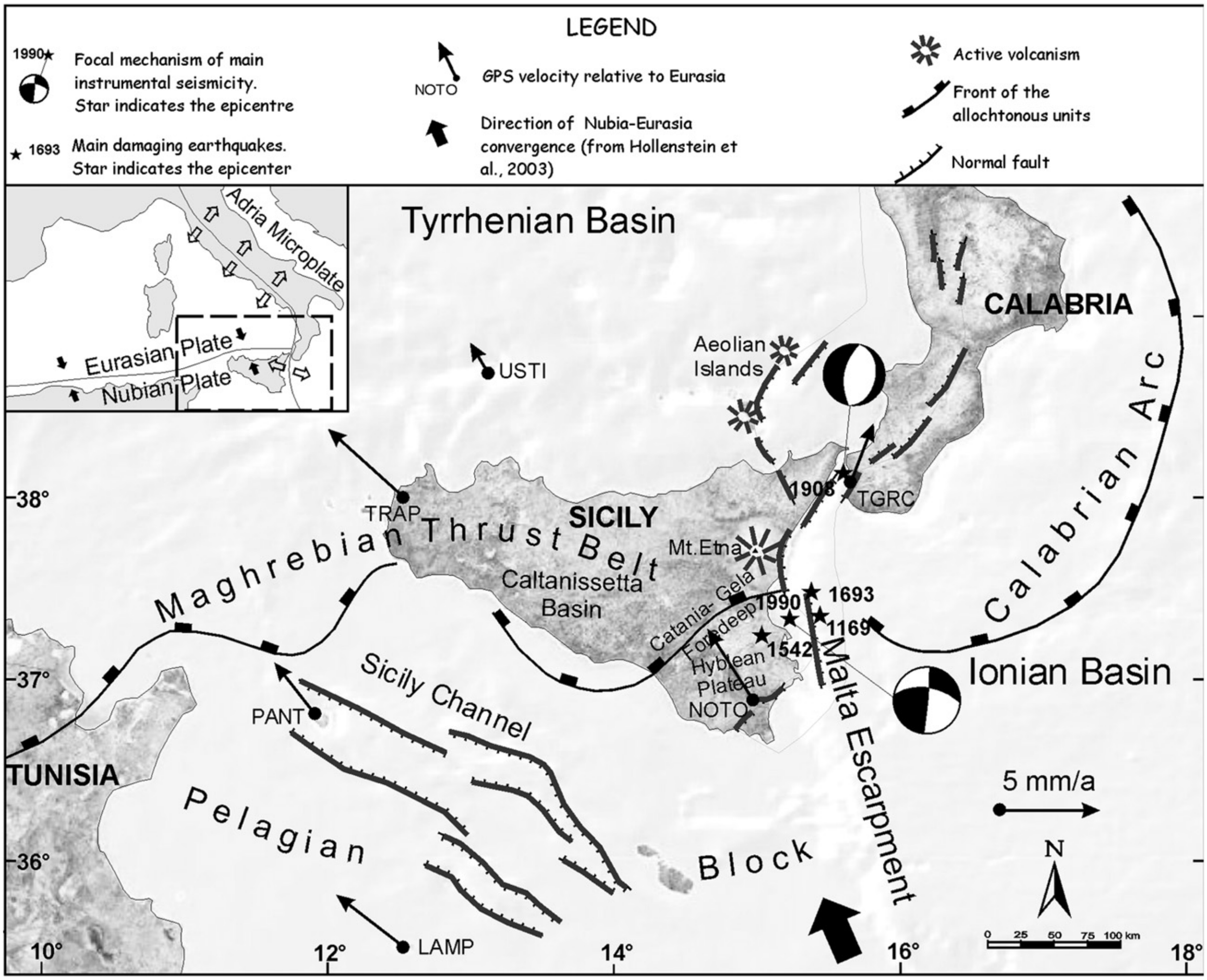

Fig. 1. Tectonic sketch map of the central Mediterranean from Tunisia to the Calabrian Arc, showing the main Quaternary fault belts and their relation with plate boundaries. The distribution of the volcanic districts is also evidenced. The inset describes the location of the Nubia–Eurasia convergent plate boundary and of the divergent western margin of Adria. Focal mechanisms are from Anderson and Jackson (1987) and Amato et al. (1995), epicentres of main damaging earthquakes are from Azzaro and Barbano (2000) and GPS velocities are from Hollenstein et al. (2003) and D'Agostino and Selvaggi (2004). After Catalano et al. (2008b) modified.

dextral motion accommodating the differential roll-back of the retreating Ionian slab was transferred from the Hyblean–Ionian boundary to the N–S oriented Scicli Line to the west (Fig. 2, Ben Avraham and Grasso, 1991; Grasso and Reuther, 1988; Grasso et al., 1990). In the interference zone between the two right-stepping dextral shear zones, the northern margin of the Hyblean Plateau collapsed to form the ENE–WSW trending Scordia–Lentini Basin (Ghisetti and Vezzani, 1980) (Fig. 2). A Calabrian to Ionian sedimentary succession (1.5 to 0.9 My), dominated by three carbonate units, developed around the shelf margin of this graben-generated embayment (Pedley et al., 2001). Towards the centre of the basin, the Lower Pleistocene carbonates pass laterally to deep-water pelagic marls and clays. The youngest terrains of the study area are represented by Middle–Upper Pleistocene marine terraces, including Milazzian (Ionian stage; <0.78 My; Cita, 2008) shallow water calcarenites and raised beaches. These unconformably cover the graben sediments, also extending out of the basin, where they overlie Lower Pleistocene subaerial basaltic flows and their pre-Quaternary substratum.

The Scordia–Lentini Basin has been recently interpreted as an half-graben related to a south-eastern dipping master fault (Catalano et al., 2010, 2011), whose hangingwall corresponds to the Siracusa Domain (**SD** in Fig. 2) (Catalano et al., 2008b). Several authors (Bousquet and Lanzafame, 2004; Catalano et al., 2010) observed a generalised positive tectonic inversion of the Scordia–Lentini extensional graben, coincident with the late contractional events at the front of the SE-verging Maghrebian thrust belt (Torelli et al., 1998)(Fig. 1). A still active NW–SE to NNW–SSE oriented regional compression, coherent with the direction of the Nubia–Eurasia convergence (Hollenstein et al., 2003; Serpelloni et al., 2007), is evidenced by both the focal mechanisms of the low Magnitude seismicity recorded in the Hyblean Plateau from 1994 to 2002 (Musumeci et al., 2005) and by in-situ stress measurements (Ragg et al., 1999).

3. Quaternary tectonics of the Scordia–Lentini Basin and the Siracusa domain

At the northern edge of the Hyblean Foreland (Fig. 2), N50-trending faults border the 12 km wide Scordia–Lentini Basin. The northern margin of the structural depression, splaying from the Scicli Line (Ghisetti and Vezzani, 1980), consists of the 40 km-long fault belt that borders the Sigona Grande–Primosole Horst (Figs. 2, 3a). The fault zone includes distinct N50 oriented, SE-dipping faults, showing lengths ranging from 5 to 15 km. Three main segments, which are distributed in a right-stepping en-echelon arrangement, can be recognised. To the south, the Scordia–Lentini Basin is bounded by a series of NW-dipping normal faults (Pedagaggi–Agnone System; Figs. 2, 3b) extending for about 27 km. This fault belt separates the basin from the eastern portion of the Hyblean Plateau, which is represented by the Siracusa Domain

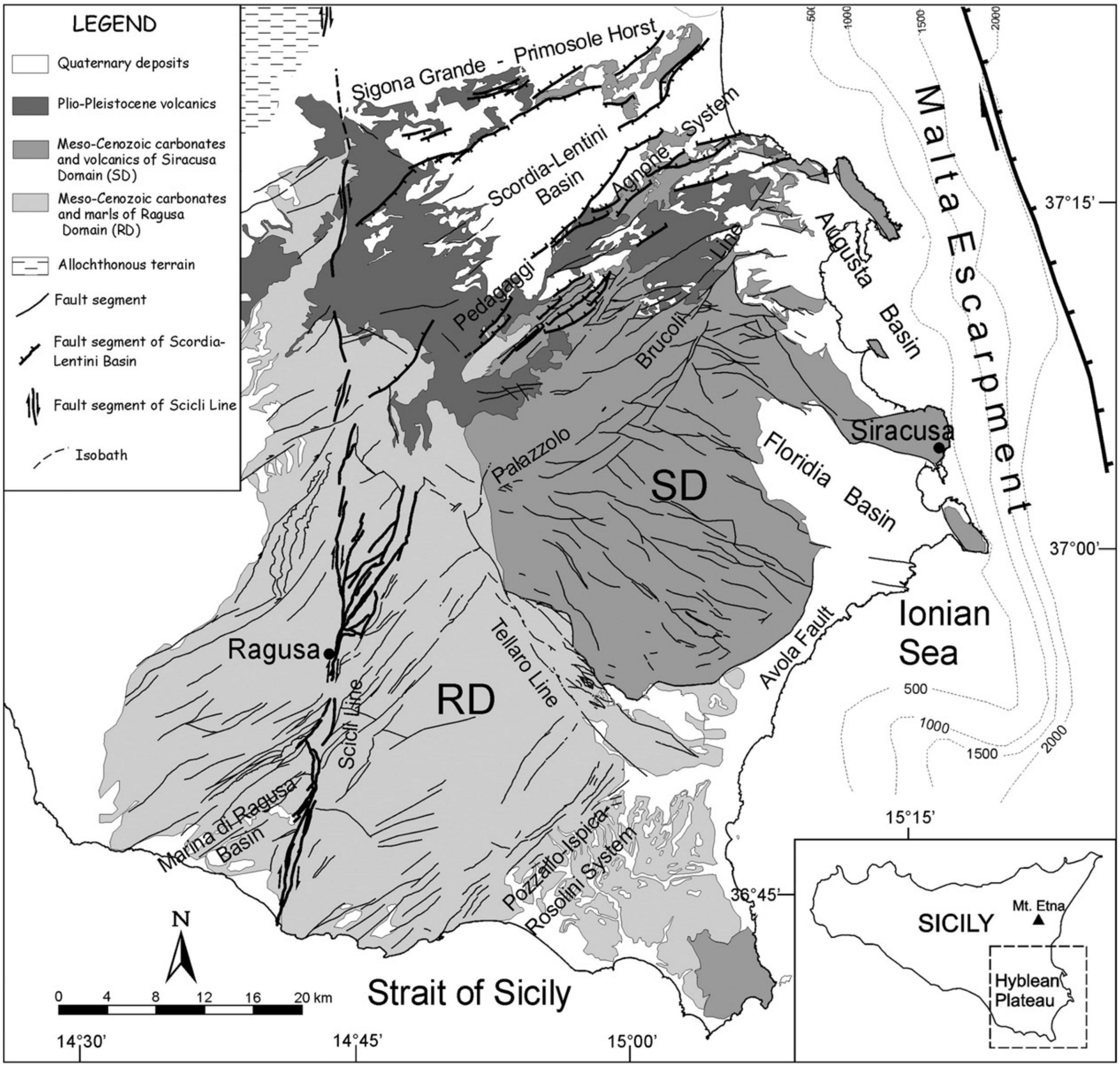

Fig. 2. Tectonic sketch map of the Hyblean Plateau (SE Sicily, see inset for location). In the figure, the border faults of the Scordia–Lentini Basin, the Scicli Line are evidenced. RD = Ragusa Domain; SD = Siracusa Domain. After Catalano et al. (2010) modified.

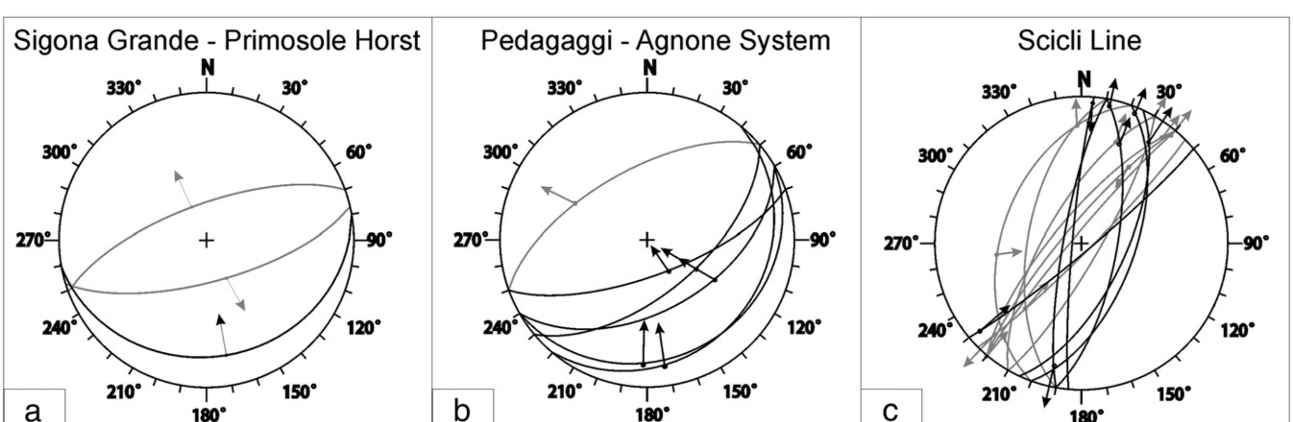

Fig. 3. Early Pleistocene vs. Middle-Late Pleistocene kinematics along the Sigona Grande–Primosole Horst (stereonet a), Pedagaggi–Agnone System (stereonet b) and Scicli Line (stereonet c) reported on the map of Fig. 2.

(Ghisetti and Vezzani, 1980). The northern sector of the Siracusa Domain is affected by NE–SW trending faults (e.g. Palazzolo–Brucoli Line; Fig. 2), while the southern one by NW–SE oriented extensional faults. They border the Augusta and the Floridia Basins (Fig. 2), where the Lower Quaternary succession (1.5–0.9 My) is collapsed along the Ionian coast (Catalano et al., 2011).

Along the northern margin of the Lower Pleistocene Scordia–Lentini Basin, several N70–80 oriented mesoscale fault planes show the imprinting of the change of the tectonic sense of motion from extensional to contractional (Catalano et al., 2006; Romagnoli et al., 2008) (Fig. 3a and b). The reactivated fault planes form a 5 km-long belt where Lower Pleistocene volcanic horizons overthrust, to the northwest, the Emilian calcarenites (1.5–1.2 My) that drape the Sigona Grande–Primosole Horst (Tortorici et al., 2006). The inverted tectonics also affect the southern margin of the Scordia–Lentini Basin (Bousquet and Lanzafame, 2004), where several N50°–70° oriented, SE-dipping (30°–40°) mesoscale reverse faults cut through the previous N60° oriented, NW-dipping Early Pleistocene extensional faults (Pedagaggi–Agnone System, Figs. 2 and 3b). Along this fault belt, two major reverse faults, each showing a length of about 6 km and dip of about 45°, have been recognised. The kinematic analyses of these fault planes constrain a prevalent NNW-directed compression (Fig. 3b). The NW-verging tectonic inversion of the extensional features is coherent with the change in the sense of motion, from right-lateral to left-lateral (Fig. 3c), along the Scicli Line (Fig. 2). This major fault displaces the deeply entrenched drainage system in the surroundings of Ragusa, showing evidence of very recent activity (Catalano et al., 2008a, 2008b).

4. Late Quaternary marine terracing and landscape evolution

The central portion of the Siracusa Domain of the Hyblean Plateau is capped by a summit low relief landscape, consisting of remnants of a mature drainage system now preserved at the divide of deeply entrenched river valleys. The distinct parts of this summit landscape

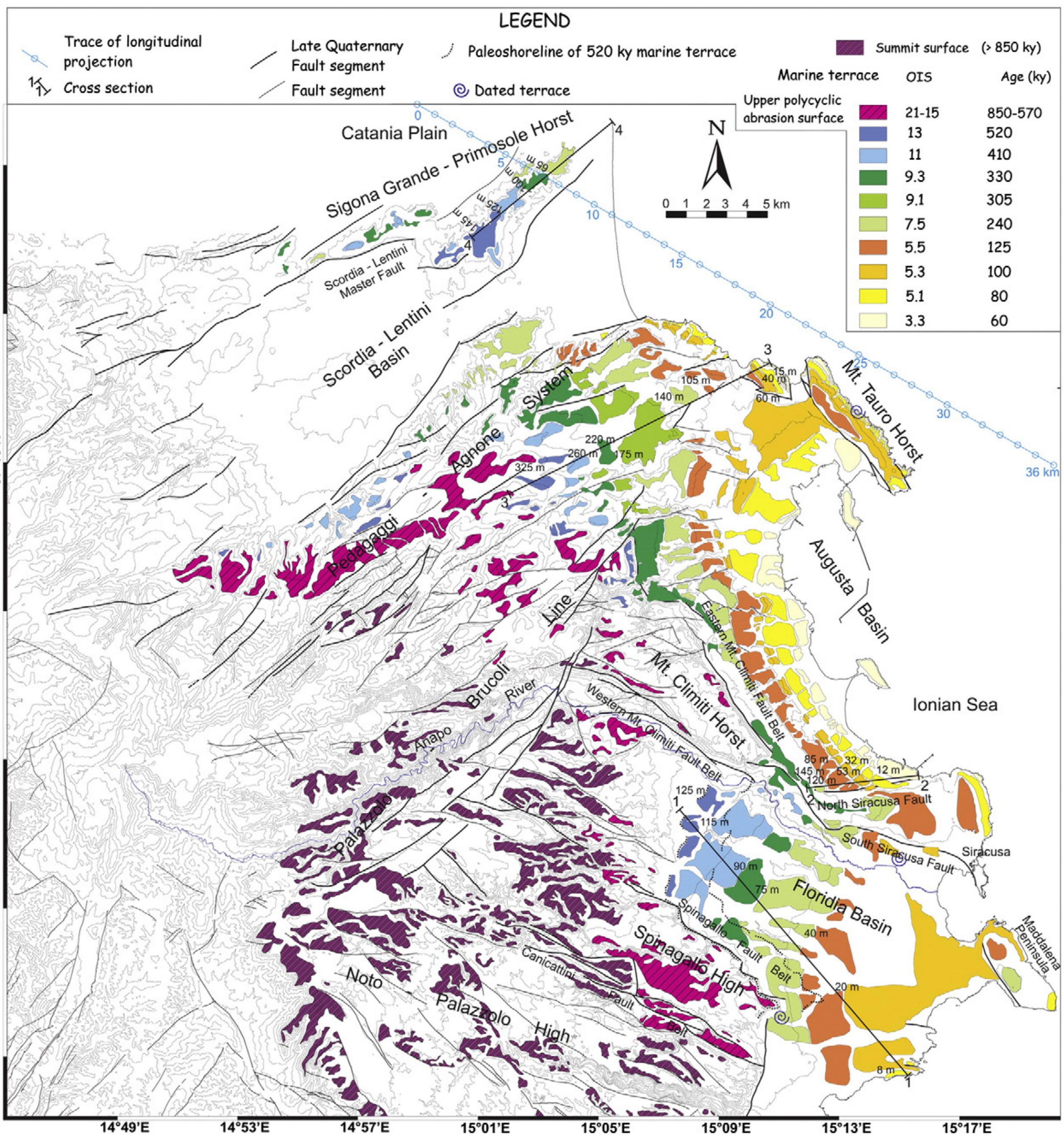

Fig. 4. Morphotectonic and structural map of the north-eastern sector of the Hyblean Plateau with distribution of Late Quaternary marine terraces and elevation of their relative paleoshorelines, measured along the Sections 1–4.

(maximum elevation of about 770 m. a.s.l.) outline, as a whole, an ESE-ward dipping surface (Fig. 4).

The summit surface is bordered, to the east and the north, by a wide polycyclic marine terrace (Fig. 4). This composite abrasion surface carves Upper Pliocene subaerial volcanics (Schmincke et al., 1997) and different levels of the Tertiary Hyblean carbonate succession. Along the margin facing the Scordia–Lentini Basin, the polycyclic abrasion platform rests upon the slope, 450 m higher than the top of the shallow water deposits onlapping onto the margins of the basin (aged 0.9 My, Pedley et al., 2001).

Several orders of marine terraces, distributed along the Ionian coast, from the Floridia Basin to the Scordia–Lentini Basin (Fig. 4; profiles 1–3 in Fig. 5), undercut the upper polycyclic surface. Along the Pedagaggi–Agnone System, the relics of the marine terraced surfaces are solely preserved on the upthrown conservative carbonate sequences, while they have been totally eroded within the basin. A flight of marine terraces has also been recognised on the Sigona Grande–Primosole Horst, at the northern margin of the Scordia–Lentini Graben (Fig. 4; profile 4 in Fig. 5).

The most significant section of the terraced marine features is exposed in the Floridia Basin, where 11 raised paleoshorelines have been recognised. Among these, 7 paleoshorelines undercut the upper polycyclic surface, bordering distinct orders of marine terraces (see profile 1 in Fig. 5). Along this section, 455 (±90) ky-old continental deposits, dated by isoleucine epimerization on rests of mammals (Bada et al., 1991; Bianca et al., 1999), infill a karst cave which developed along the 125 m-high notch-level. This paleoshoreline coincides with the inner-edge of the highest marine terrace undercutting the polycyclic surface. Moreover, the marine terrace, bordered by the 20 m high paleoshoreline, covers coarse-grained deposits bearing relics of 117 ky-old mammals, dated by Electron Spin Resonance method (ESR) (Rhodes, 1996). According to these data, the notch-level, pre-dating the continental deposits, should be referred to the Oxygen Isotope Stage (**OIS**) 13 (520 ky). Considering the elevation of the paleoshoreline, an averaged uplift-rate of about 0.25 mm/y results. Moreover, the terrace that carves the mammals relics can be assigned to the **OIS** 5.3 (100 ky), thus constraining an averaged uplift-rate of about 0.3 mm/y. The strandlines of the four intermediate marine terraces have been interpreted as the marine marks of the maximum transgression related to the 100 ky cyclicity of eustatism, from the **OIS** 11 (410 ka) to the **OIS** 5 (125 ky) (see profile 1 in Fig. 5). Considering the elevation of the distinct orders of the marine terraces, our correlation implies an uplift-rate, almost uniform in time, ranging between 0.26 and 0.35 mm/y. Assuming the uplift-rate remained constant also during the last 100 ky, the lower marine platform along the Floridia section, elevated at about 8 m a.s.l., can be assigned to the OIS 5.1 (80 ky).

Moving from the Floridia Basin (profile 1 in Fig. 5) to the northern edge of the Siracusa Domain (see profile 3 in Fig. 5), the two dated strandlines increase in elevation from 125 to 325 m and from 20 to 60 m a.s.l., respectively. They show, as well as the intermediate marine terraces, a well-defined north-westward divergence (Di Grande and Raimondo, 1982), which is coherent with the tilting of the summit surface (Fig. 4). In the Augusta section (profile 3 in Fig. 5), 9 distinct marine terraces undercut the upper polycyclic surface, for the appearance of two further raised platforms. The upper one is located between the terraces of the OIS 9 and 7. For its position, this platform has been interpreted as the marine mark of the OIS 9.1 (305 ky), immediately undercutting the terrace of the OIS 9.3 (330 ky). The lower platform of the Augusta section, undercutting the terrace of the OIS 5.1 (80 ky), has been correlated to the main transgression of the OIS 3 (60 ky).

Previous studies (Catalano et al., 2008b), assigned the inner-edge of the upper polycyclic marine terrace of the Siracusa Domain to the marine transgression of the OIS 21 (850 ky). Taking into account that the platform is modelled by almost 3 distinct paleoshorelines and that the outer-edge of the platform is undercut by the OIS 13 (520 ky) paleoshoreline, an age spanning from the OIS 15 (570 ky) to the OIS 21 (850 ky) can be confidently assigned to this polycyclic terrace. This would imply that the inner-edge of the upper marine abrasion surface is correlative with the top of the syn-tectonic deposits of the

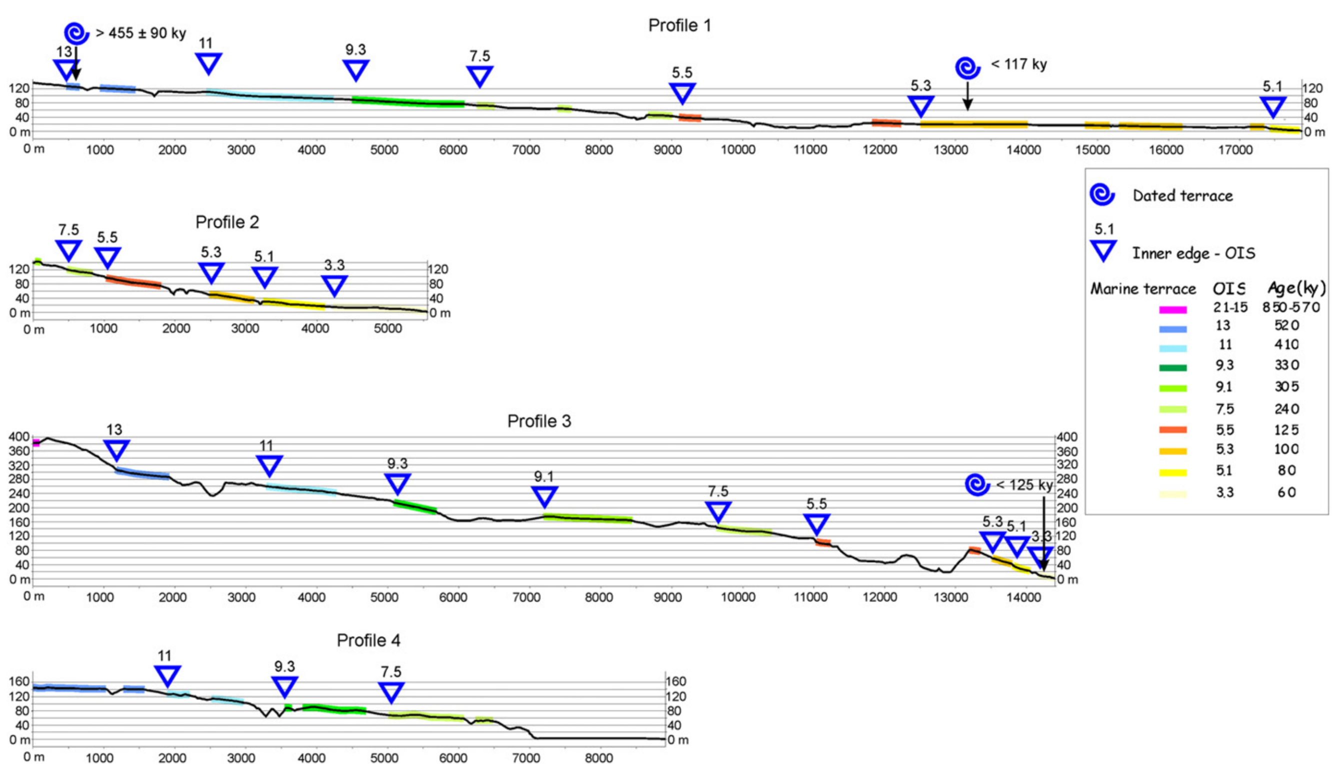

Fig. 5. Topographic profiles showing the distribution of the marine terraces along the Ionian coast of the Hyblean Plateau. The dated terraces and the inner edges of marine terraces associated to OISs are represented along the profiles. For the location of the profiles see Fig. 4.

Scordia–Lentini Basin, which thus represented the base-level of the Early Quaternary (>850 ky) summit fluvial landscape.

A different distribution of the Upper Quaternary marine strandlines characterises the northern margin of the Scordia–Lentini Basin (see profile 4 in Fig. 5). The flight of marine terraces, exposed along the Sigona Grande–Primosole Horst, at a maximum elevation of 145 m a.s.l., is composed of four orders of marine terraces, each one characterised by calcarenitic deposits assigned by Carbone et al. (1982, 2011) to the Milazzian, corresponding to the Ionian stage (0.78–0.13 My; Cita, 2008). The four terraces must be thus related to a pre-Tyrrhenian age and confined between the OISs 19 (780 ky) and 7 (240 ky). If related to the 100 ky cyclicity of eustatism, the marine platforms can be assigned to the four maximum transgression of OISs immediately pre-dating the Tyrrhenian, ranging from 13 (520 ky) to 7 (240 ky) (Fig. 4).

The flight of marine terraces contouring the Siracusa Domain has been incised by deeply entrenched river valleys (Fig. 6a). To the north, the main drainage axes, forming the upstream portion of the Anapo River valley, are parallel to the NE-oriented fault segments of the Palazzolo–Brucoli Line (see Figs. 4 and 6a). In this area, a clear asymmetry of the basin derives from the shifting of the Anapo River toward the south-eastern divide (Fig. 6a). The central portion of the Siracusa Domain, contoured by the inner-edge of the upper polycyclic surface, shows a dense sub-dendritic fluvial network. To the east, the area of the Floridia Basin is incised by a subparallel drainage pattern prevalently composed of ESE-directed streams. These have

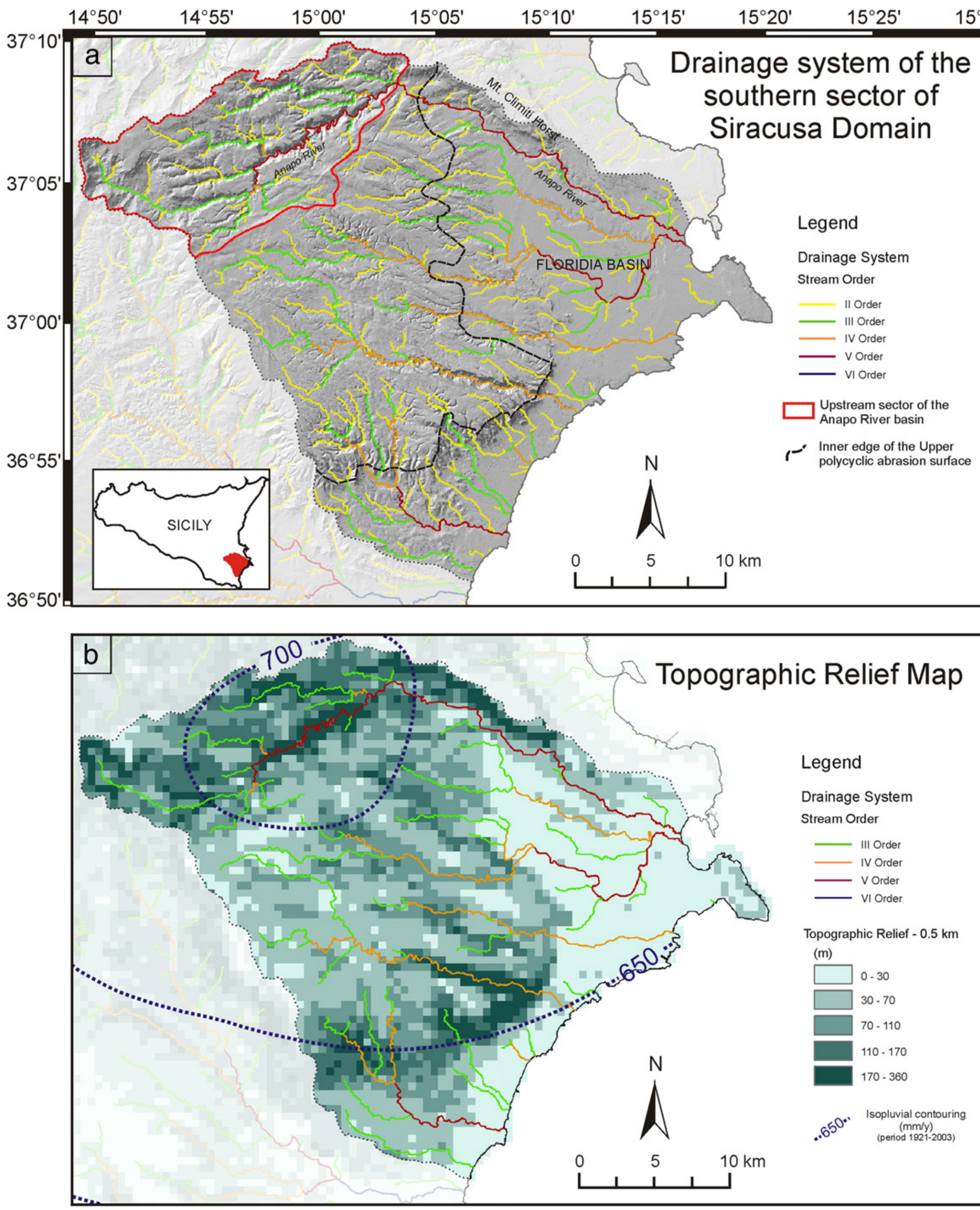

Fig. 6. Drainage system of the southern sector of Siracusa Domain. Streams from II to VI order, upstream sector of Anapo River basin and inner edge of upper polycyclic abrasion surface are represented (a); topographic relief map of the southern sector of Siracusa Domain showing the difference between the maximum and minimum elevation measured within a grid with 0.5 km-side length cells. Streams from III to VI order and average isopluvial contouring (1921–2003 time interval) are represented (b).

captured the NE-directed upstream segment of the Anapo River and large portions of the sub-dendritic pattern of the central sector of the Siracusa Domain. A morphometric picture of the region is summarised by a topographic relief map, obtained using a high-resolution Digital Elevation Model (Fig. 6b). To avoid the local effects due to lithological variability or to precipitations gradient, the map was confined to the areas of the monotonous carbonate plateau, showing almost homogeneous averaged annual precipitation rate. The relief was calculated as the difference between the maximum and minimum elevation measured within square cells of a reference grid. Changing the side length of the square cells (2, 1 and 0.5 km), the results are almost uniform, with a different detail on sampling the regional topography. The map that fits better the spacing of the main landscape features was obtained using 0.5 side length cells (Fig. 6b). The map evidences a wide high-relief region centred on the upstream portion of the Anapo River Valley, at the northern border of the investigated area. This zone also extends to part of the border of the Mt. Climiti Horst, where the relief is tapering to zero towards the ESE. A minor cluster of high relief, narrowing from the west to the east, is concentrated along the south-eastern margin of the plateau. Intermediate and low values characterise the entrenched valleys and the divides of the central portion of the plateau, respectively. The lowest estimations refer to the Floridia Basin area, to the ESE. The map clearly shows an increase of the relief from the ESE to the WNW, which is consistent with the tilting of the marine strandlines and the prevalent ESE-direction of the young subparallel drainage system, active during the emergence of the region.

5. GPS network and data processing

GPS surveys were performed since 1991, across the Scordia–Lentini Basin. In 1998 and 2000, the GPS network was extended on the eastern part of the Hyblean Plateau and of the Catania–Gela foredeep (Bonforte et al., 2002). More recently, GPS measurements were carried out again on October 14 and 15 2005, during the “EUROSOT 2005” Civil Defence seismic emergency simulation, on part of the same network measured during the 1998 and 2000 surveys. Differently from the previous surveys, 24-hour measurements sessions were carried out in 2005 on some vertices of the network (on those allowing a semi-permanent installation of instrumentation without risks). Just after the late 2005 survey, new benchmarks were installed to improve the network geometry and to solve some logistic problems, in order to allow semi-permanent installations on almost all vertices. A new survey was carried out on February 2006 measuring also those stations not surveyed in late 2005 and also the new benchmarks, in order to tie them to the old ones without losing the time series for the future. GPS data collected during the surveys were processed using Trimble Total Control software, introducing IGS final precise orbits and antenna calibration tables and keeping only fixed baselines solutions (with a ratio > 2 and rms < 2 cm), in order to achieve the maximum accuracy in the final position. The 2005–2006 measurements, due to the very short time span between them, were processed and adjusted as a unique campaign in order to achieve a stronger and more complete network solution. The measured networks were then adjusted in order to refer all station coordinates to the same frame. Following the approach used by Bonforte and Guglielmino (2008), data from ITRF stations were introduced into the processing in order to extend the network and to include and refer it to a global and well assessed reference frame; then, to isolate the local deformation from the overall plate motion affecting the entire area, the 2005–2006 survey results have been referred to the same reference frame of the 2000 one, by keeping fixed the coordinates of the external reference stations in the ITRF2000 frame at epoch 2000.4 (time of the previous survey) as reported in Bonforte et al. (2002). Station coordinates resulting from the 2000 and 2005–2006 surveys processing are then compared in order to calculate the displacements occurred during that time period. The measured displacements are normalized to velocities (expressed in mm/y), assuming a constant motion over the 5.6 year interval between the surveys. Compared with the 2-year interval analysed in Bonforte et al. (2002), the longer time period considered here allows investigating higher cumulative displacements. This should

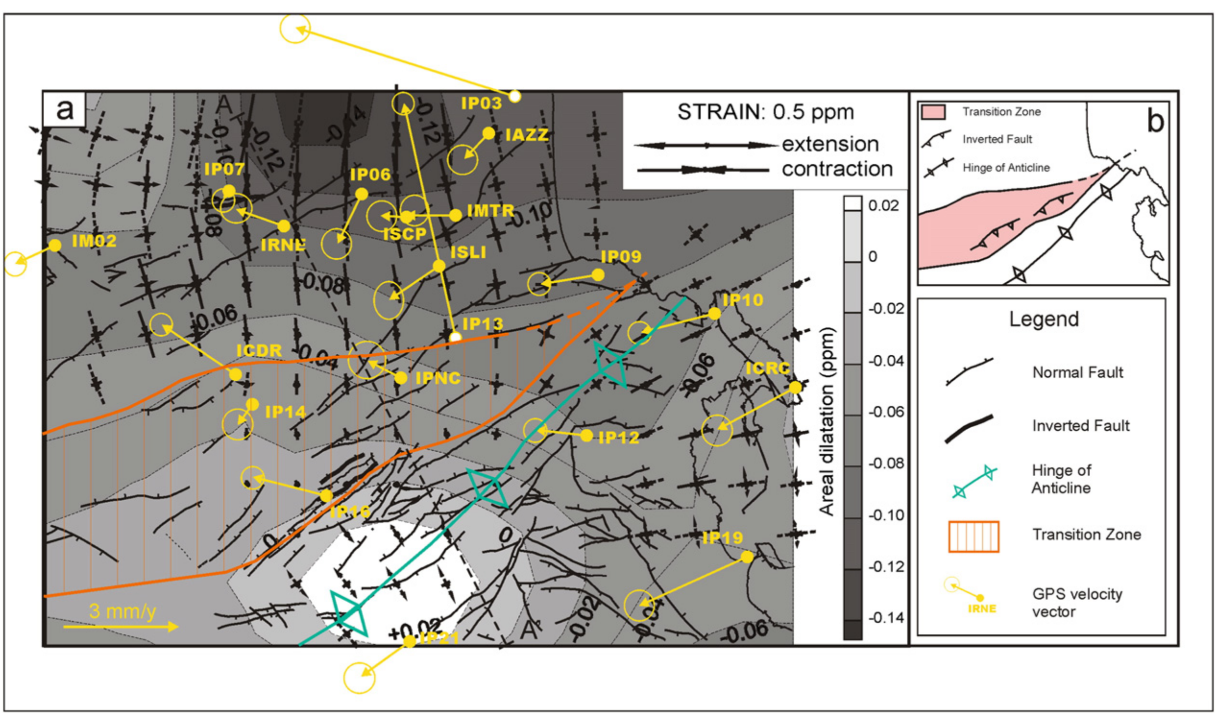

Fig. 7. Distribution of the strain tensor and areal dilatation contouring obtained by employing GPS station velocities on a regular grid over the area (a). A transition zone between extensional and contractional sectors and the hinge of anticline (also sketched in Fig. 7 b) are pictured. The GPS station horizontal velocities, shown in the frame, result by comparing the data of the 2000 and 2005–2006 surveys, with associates 2-sigma error ellipses.

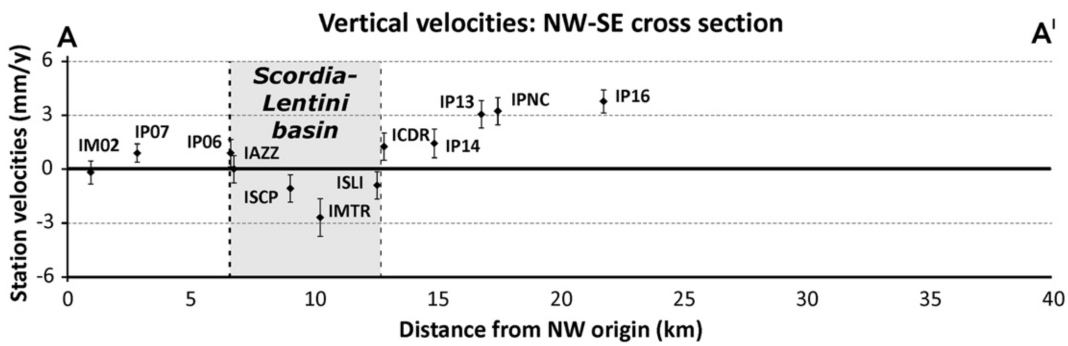

Fig. 8. GPS vertical velocities, with associated 2-sigma error bars, projected along a NW-SE section (A–A′ dashed line in Fig. 7a). The GPS data constrain the location of the active flexure of the northern border of the Siracusa Domain in an 8 km-narrow belt, including the southern margin of the Scordia–Lentini Basin.

also reduce the impact of instrumental errors on the measurements, improving the deformation/noise ratio and making the results more reliable.

6. GPS velocities and strain

The results of geodetic survey regarding the horizontal motions are summarised in Fig. 7a as arrows, with length proportional to the velocity according to the scale, and associated 2-sigma error ellipses. The measured velocities suggest a very slow deformation of the area, in the order of a few mm/y, except for the IP03 and IP13 station. The motion of these stations can reasonably be imputed to site effects, because they are not coherent with data from other surrounding stations.

Since all stations seem to be affected by a general slow westward component of motion with respect to the ITRF frame, to achieve a better information about the horizontal deformation affecting the northern part of the Hyblean Plateau, a calculation of the distribution of the 2-D strain was performed over the area covered by the GPS network by using the routine developed by Pesci and Teza (2007). This routine allows the strain tensor distribution to be calculated on a regular grid above a geodetic network, starting from station displacements. Since we are introducing station velocities, the results of the processing have to be intended as strain rates. We considered a 3 km regularly-spaced grid and the strain tensor was calculated for each node of this grid. The anomalous IP03 and IP13 velocities have been excluded from the calculation, due to the reasons previously explained and only the tensors on high and mid-significance nodes (according to the point distribution criteria established in Pesci and Teza, 2007) have been considered and reported. The results of this processing, expressed in terms of principal strain axes and contour of the areal dilatation (Fig. 7a), evidence that two distinct domains, characterised by different strain axes, can be recognised across the northern edge of the Hyblean Plateau. To the south of the Pedagaggi–Agnone System, a very low NNW–SSE extension, producing also a small positive areal dilatation, affects the uplifted areas of the Hyblean Plateau, while in the adjacent depressed areas of the Scordia–Lentini Basin, a more significant and northward-increasing N–S contraction, producing a negative areal dilatation can be detected. In general, the strain tensor analysis evidences a very low deformation rate of the area, with maximum values of about 0.2 microstrain/year. A discontinuity of the strain field can be recognized in the strain axes distribution, with the appearance of NNW–SSE oriented contractional axes north of the IP09-IP13-ICDR. This alignment coincides well with the southern border of the Scordia–Lentini Basin and reaches the Ionian coast, crossing the inverted southern margin of the depression (Fig. 7a and b).

A NW–SE cross section (AA′ on Figs. 7a; 8) is also reported, in order to look at the vertical motion effectively measured at each individual station, with the associated 2-sigma error bars. The plotted vertical velocities evidence the active uplifting of the northern edge of the plateau and of the Sigona Grande–Primosole Horst, with a subsidence concentrated in the intermediate Scordia–Lentini Basin. Vertical velocities and errors are, in general, higher than those reported by Serpelloni et al. (2013) using more continuous data from only permanent stations (values generally lower than 1 mm/y); however, the relative uplift of the central part of the plateau with respect to the southernmost NOT1 station is confirmed. Thanks to the higher density of the network considered in this paper, it is possible to highlight that all stations inside the Scordia–Lentini Basin (IMTR, ISLI and ISCP) show a slight relative subsidence (from −1 to −3 mm/y) while all surrounding ones show uplift (Fig. 8).

7. Discussion and conclusions

At the northern sector of the Hyblean Plateau, the geodetic data reveal an active deformation coherent with the Middle–Late Pleistocene to Holocene tectonic picture, outlined by the displacement of the marine terraces and by the pattern of the drainage system. The analysed deformation history represents the last phases of the flexural tectonics

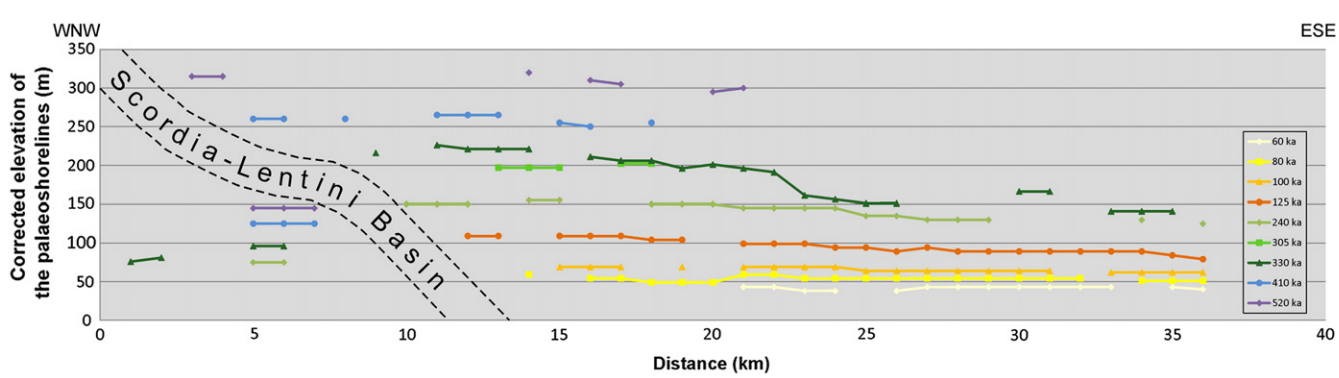

Fig. 9. Vertically projected profiles of the strandlines of the marine terraces of the Ionian coast along a WNW–ESE direction (for location see Fig. 4).

of the African foreland (Cogan et al., 1989; Elter et al., 2003; Schmincke et al., 1997) that during the Early Pleistocene caused the collapse of the forelimb of the Hyblean bulge, where the Scordia–Lentini extensional basin developed. Since 850 ky, the positive tectonic inversion of the basin (Catalano et al., 2011) was associated with a relative uplift of the eastern sectors of the Hyblean Plateau (Siracusa Domain) compared to the Scordia–Lentini Basin area. The uplift of the plateau, previously evidenced by Yellin-Dror et al. (1997) is recorded in the staircase of marine terracing and the dissection of the summit landscape, as reported in the present paper. The development of a set of northwestward divergent marine terraces, spanning in age from 850 ky to 60 ky, evidences an ESE tilting of the Siracusa Domain during the emergence of the region. The increase of the topographic relief towards the northern edge of the plateau also highlights this regional tilting. The river entrenchment beneath the summit landscape was in fact higher along the northern border than in the southern sector of the tilted block (Fig. 6a and b). This evidence is accompanied by the diffuse captures of the antecedent rejuvenated valleys, dissecting the summit landscape inland, by prevalent ESE directed consequent streams, incised within the flight of the marine terraces along the coastal slope. This evolution of the drainage system suggests that the regional scale tilting was active during the final river entrenchment. A model of the Late Quaternary deformation has been obtained projecting the strandlines of the marine terraces of the Ionian coast along a WNW–ESE oriented profile (Fig. 9), from Siracusa to the Sigona Grande–Primosole Horst. The profile was traced parallel to the consequent recent drainage pattern, which is assumed to be orthogonal to the axis of the regional tilting. The elevation of the projected strandlines has been preliminarily corrected taking into account the difference between their generative sea-levels and the present one. The profile clearly shows an impressive vertical displacement of the 520 to 330 ky-old paleoshorelines from the Siracusa Domain to the Sigona Grande-Primosole Horst, across the Scordia–Lentini Basin, which is associated with a divergence between the older (>240 ky) and the younger (240 to 60 ky) strandlines. This is mostly due to the deformation of the 330 ky-old marine terrace that depicts a gentle anticline which is interrupted by a sharp S-facing step, at a distance of about 16 km from the southern border of the graben (see projection at tract 20–25 km in Fig. 9). In the uplifted sector of the Siracusa Domain, the older marine platforms (410 and 520 ky) are almost parallel to the 330 ky-old strandline. On the contrary, the 240 ky-old strandline, which is downthrown of about 75 m across the Scordia–Lentini Basin (Fig. 9), together with the 125 ky-old terrace are only slightly dipping and converging towards the south. The youngest paleoshorelines, which have been totally cancelled both in the basin and in its northern margin, are almost horizontal in the Siracusa Domain. On the other hand, the GPS data reveal that active uplift of the Siracusa Domain is now associated with extensional deformation, centred on the northern border of the region, in contrast with a marked contractional and subsiding domain corresponding to the Scordia–Lentini Basin. Moreover, in the area of the basin, the inversion of GPS data evidence a NNW-directed compression that is consistent with the available stress in situ measurements (Ragg et al., 1999), and the seismogenic stress tensor reconstructed for the region (Musumeci et al., 2005). The geodetic data are also fitting well the kinematics measured along the Middle–Late Pleistocene reverse faults, which cut through the former extensional fault belts (e.g. Pedagaggi-Agnone System).Towards the south, the intensity of the contractional active deformation progressively decreases, switching into extension, across transition zone, including the inverted southern margin of the previous Scordia–Lentini Graben (Fig. 7). The GPS data thus constrain a permutation of the principal horizontal axis of the strain, from contractional to extensional, affecting the flank of an actively growing culmination. This behaviour can be explained as the surface expression of an extrados type of deformation, localised at the hinge zone of an active regional extent antiform that locally replaced the remote strain field. Therefore, the GPS data reveal a significant active doming along the northern border of the Siracusa Domain, in the same region where the antiformal folding was active in the period from 330 to 240 ky. The combination of morphological and geodetic data thus evidence that for discrete periods the long-term tectonic uplifting of the Siracusa Domain has been associated with active folding. Moreover, it is to be remarked that the deformation of the marine strandlines along the coast of the Siracusa Domain is comparable to that obtained by analogue models on the incremental deformation at the hangingwall of a detachment surface (Bernard et al., 2007). The long-term mode of deformation of the Siracusa Domain is thus compatible with the existence at depth of a low-angle SE dipping master fault that experienced Late Quaternary reverse motions, due to the regional positive tectonic inversion, responsible for the uplifting and the shortening within its hangingwall. The GPS data document significant accumulation of elastic deformation in the Siracusa Domain and in the adjacent region of the Scordia–Lentini that can be reasonably connected with motion along the master fault. This conclusion is relevant in terms of modelling the seismotectonics of the area and might be considered as a starting point for future investigation, necessarily supported by seismic data and detailed subsurface information to locate potential seismogenic sources associated with the deep-seated detachment.

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