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ORIGINAL PAPER

Pierpaolo Guarnieri

Plio-Quaternary segmentation of the south Tyrrhenian forearc basin

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Abstract The structural elements constituting the forearc basin of the Calabrian Arc–Sicily orogenic system are recognizable on land and in the Tyrrhenian offshore. The Plio–Pleistocene retreat of the Ionian subduction hinge, coeval with the roll-back of the Africa continental crust, leads to segmentation of the forearc basin and southeastward migration of the Calabrian Arc due to its higher degree of mobility compared to Sicily, where, on the contrary, continental collision takes place. The analysis of geological data collected in three areas of the orogenic belt and the integration with offshore geophysical data show evidence of two phases of subduction hinge retreat: (1) Late Pliocene–Early Pleistocene southeastward migration accompanied by the development of N120°E trending tear-faults and NE–SW-trending extensional systems, (2) Middle–Late Pleistocene SSE-ward migration with development of NNW–SSE-trending tear-faults and N70°E-trending collapse systems. The data presented here provide an innovative framework for the interpretation of this most seismically active area of the Mediterranean. In particular, in the Messina Strait area, the more recent N70°E lineaments could be associated with the faults that generated the 1783 Calabria earthquake and are coherent with the focal mechanism of the 1908 Messina earthquake, confirmed also by the analysis of frequency diagrams of the elongation directions of the isoseists.

Keywords Plio-Quaternary · South Tyrrhenian · Forearc basin · Calabrian Arc · Ionian subduction · Messina Strait

P. Guarnieri
Dipartimento di Scienze Geologiche
University of Catania
Corso Italia, 55-95129 Catania, Italy
E-mail: guarnier@unict.it
Tel.: +39-095-7195713
Fax: +39-095-7195712

Introduction

The geodynamic evolution of the Calabrian Arc-Tyrrhenian system is intimately related to the coexistence of extensional and compressive phenomena, which have led, from the Middle Miocene onward, to the structural arrangement of the Apenninic-Maghrebian Accretionary wedge of Sicily and Calabria and to the opening of the Tyrrhenian Basin (Finetti and Del Ben 1986). The geodynamic evoution is strongly controlled by the presence of lithospheric elements of different character, which are involved in the deformational front: the Sicilian sector characterized by continental crust (Africa Plate) separated by the Hyblean Escarpment from the Ionian Basin with oceanic crust (Fig. 1).

The north-westward subduction of the Ionian crust below the Calabrian Arc has brought the development of a complex backarc/forearc/trench system corresponding with the areas of oceanic crust and the development of wide foredeeps on the margin of the continental crust sector. Subduction, which is well recognized from the distribution of deep seismicity (Giardini and Veloná 1988), occurs in the form of slab sinking (Malinverno and Ryan 1986). Since the Late Tortonian, a phase of continental collision initiated in western Sicily, caused by the westward closure of the Ionian palaeobasin (Catalano et al. 1996; Lentini et al. 1996; Catalano et al. 2000; Del Ben and Guarnieri 2000; Guarnieri et al. 2002); on the contrary, a migration of the whole collisional system and thus the superposition in part onto the Ionian crust (Calabria) and in part onto the Africa crust (Sicily) is allowed by the presence of thinned crust toward east (Bianchi et al. 1987; Roure et al. 1990).

Within the forearc/backarc system, two main areas of sedimentations are recognized, which are characterized by different tectonic regimes and are separated from each other by a calc-alkaline volcanic arc. Due to the progressive retreat of the subduction hinge (Kastens et al. 1988), the elements constituting the forearc/back-

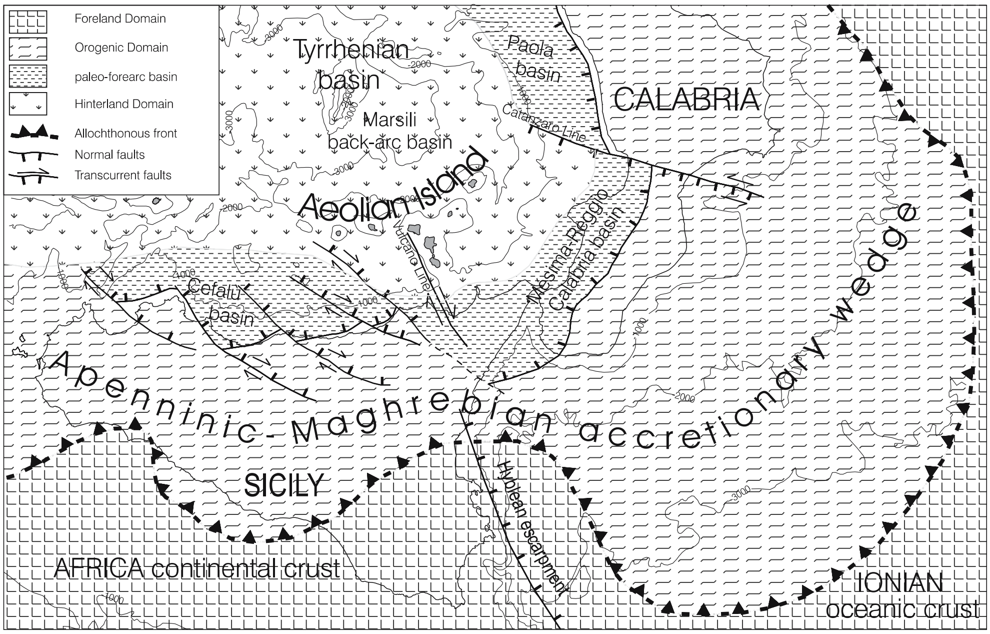


Fig. 1 Geodynamic scheme of the Calabrian Arc–Sicily and surrounding seas. The north-westward subduction of the Ionian crust below the Calabrian Arc is probably still active as testified by the presence of an active volcanic arc (Aeolian Island) and by the deep seismicity of the Tyrrhenian. In Sicily, along the northern sector, the presence of the Africa continental crust inhibits the subduction process with the activation of a dextral transcurrent junction since Late Tortonian up to Late Pleistocene (the South Tyrrhenian System of Finetti et al. 1996). In the hinterland areas, the backarc Tyrrhenian basin develops. The subduction hinge retreat caused the south-eastward migration of the Calabrian Arc

arc system were transferred southeastward to their present position (Fig. 1). This setting caused the curvature of the allochthonous front of the entire chain, and the approach along transcurrent faults of structural elements belonging to internal and external domains along the Tyrrhenian margin of Sicily.

Geodynamic setting

The orogenic belt of the central Mediterranean, which extends from northern Africa to the southern Italy across Sicily and the Calabrian Arc (Apenninic-Maghrebian Accretionary wedge), originated during the deformational history (Oligocene to Recent) that led to the complete closure of the Tethys ocean and part of the Ionian (Patacca and Scandone 1989; Roure et al. 1990; Lentini et al. 2002).

The first phase of convergence (Late Oligocene–Early Miocene) is linked to the westward subduction of the Tethys slab. On land, we recognised the tectonic units that constitutes an allochthonous wedge that form a regional duplex as part of the modern accretionary wedge.

The second phase of convergence (Middle Miocene–Recent) involved the Ionian palaeobasin characterized by oceanic crust. The north-westward subduction of this slab (still active) is conditioned by the crustal lineaments inherited from the Mesozoic palaeogeography which leads to the progressive collision of the crustal back-stop of the chain with the Africa margin in western Sicily (Guarnieri et al. 2002), and provoke a diachronous collision from west to east. This is expressed by the indentation of the continental margin and the formation of a dextral transcurrent junction (Finetti et al. 1996; Lentini et al. 2002; Guarnieri et al. 2002) oriented about NW–SE, which became active in the Late Tortonian in western Sicily and is still active in eastern Sicily.

Collision in the west is thus contemporaneous with subduction of the palaeo-Ionian oceanic crust to the east, a phenomenon to which the progressive opening of the Tyrrhenian backarc basin has been attributed (Fig. 1). The earliest evidence for extension in the Tyrrhenian stems from the Middle Miocene (Lentini et al. 1994), but oceanization, with the formation of new basaltic tholeiitic crust in the central part of the Tyrrhenian basin, started only in the Pliocene, contemporaneously with the formation of a submarine calc-alkaline volcanic arc (Yastrebov et al. 1988; Serri 1990; Beccaluva et al. 1994; Savelli 2000).

The Plio-Quaternary evolution of the southern Tyrrhenian margin was linked to the retreat of the Ionian subduction hinge (Scandone 1979; Malinverno and Ryan 1986; Kastens et al. 1988; Mascle et al. 1988; Patacca and Scandone 1989; Argnani 2000; Faccenna et al. 2001), which to the development of a remnant backarc basin (Vavilov basin), a new backarc basin with tholeiitic crust (Marsili basin) and a new calc-alkaline volcanic arc represented by the Aeolian Islands (Fig. 1).

The retreat of the Ionian subduction hinge occurred simultaneously with the roll-back of the Africa Plate (Guarnieri et al. 2002) and the Adriatic Plate (Doglioni et al. 1994). At the same time, a complex system of transcurrent/transtensive structures became active in Sicily, which brought the collapse of the Sicilian margin towards the Tyrrhenian, involving also the internal portion of the chain, that is, the forearc basin, in a geodynamic context located in the framework of the Tyrrhenian transtensional tectonics (Guarnieri et al. 2002). The recent earthquakes with reverse focal mechanisms, located in the Tyrrhenian sea, north of Sicily, probably indicate that in this part of Tyrrenian the strike-slip tectonics, linked to the migration of the Ionian subduction hinge is ceased and the overall tectonic regime is only related to a N–S convergence.

Geological and structural features

Outcrops of the Plio–Pleistocene deposits occur on the Tyrrhenian side of northern Calabria along the Crati Valley (Figs. 2/box-A, 3), within a N–S elongated depression that has been controlled, since the Late Pleistocene, by structures characterized by a prevalently normal component (Tortorici et al. 1995). The deposits of the Pleistocene cycle, which on the western side of the valley transgressively overlie the Messinian and Pliocene deposits, rest directly on the metamorphic basement on the eastern side, indicating an eastward migration of the sedimentation axis (Carobene and Damiani 1985). The basal portion of this stratigraphic interval consists of a thick sequence of conglomerates with pelitic intercalations of Middle Pliocene age, and are followed upsection by gray–green Late Pliocene marly clays, which in turn show a continuous passage into sands and sandstones of the Early Pleistocene. The topmost portion of the sequence is constituted by blue marly clays with a maximum thickness of 600 m, which are of Early Pleistocene age as well (Carta Geologica del Bacino del Crati 1975).

From a structural point of view, it is evident that the depression of the Crati Valley presents an asymmetric form, its western flank being bordered by structures cutting the deposits of the Early Pleistocene, while on the eastern flank the Early Pleistocene sands and sandstones directly overlie the units of the Sila massif (Fig. 2). The structures delimiting the western side of the depression locally show a compressive character, with high dipping planes that truncate the Early Pleistocene deposits and testify that the mechanism of the basin formation is related to the development of thrust-top basins linked to transpressive pressure ridges, and the major subsidence occurred right during the sedimentation of the Early Pleistocene blue marly clays (Cesarano et al. 2002) (Fig. 3). Late Pleistocene extensional tectonics (Tortorici et al. 1995) was thus superimposed on a pre-existing basin delineated in a collisional context with transpressive character.

The southern portion of the Calabrian Arc (Fig. 2) is characterized by a pile of basement nappes with remainders of the original Meso-Cenozoic cover that was deformed during the Oligocene to Early Miocene

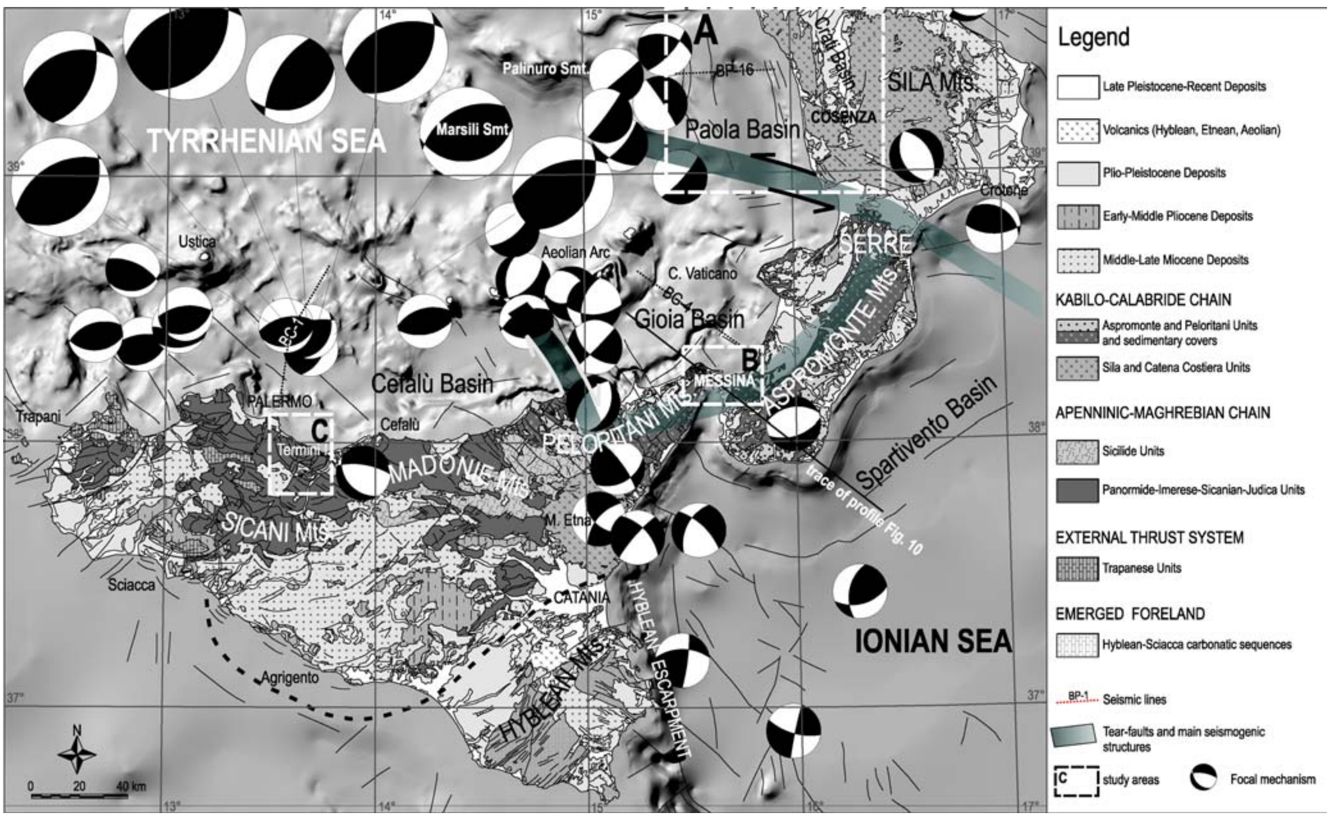


Fig. 2 Main structural lineaments of Sicily, Calabria, and the southern Tyrrhenian sea (modified after CNR-sheet n°6 1991). *Boxed areas* correspond to the offshore and onland sectors described in the next sections. Shaded relief of the marine areas derived by processing of contouring of the isobath map of CNR-sheet n°6 1991). The focal mechanisms are relative to the September 2002 seismic sequence, with exploded focal mechanisms of the main shock (Mw = 5.9) (modified after Pondrelli et al. 2004). The distribution of recent earthquakes indicates the presence of a predominant N–S convergent state, with reverse focal mechanisms, in the western part of the Tyrrhenian, and transcurrent/extensional mechanisms in the area confined between the two major tear-faults proposed in this work: the Vulcano Line and the Catanzaro Line

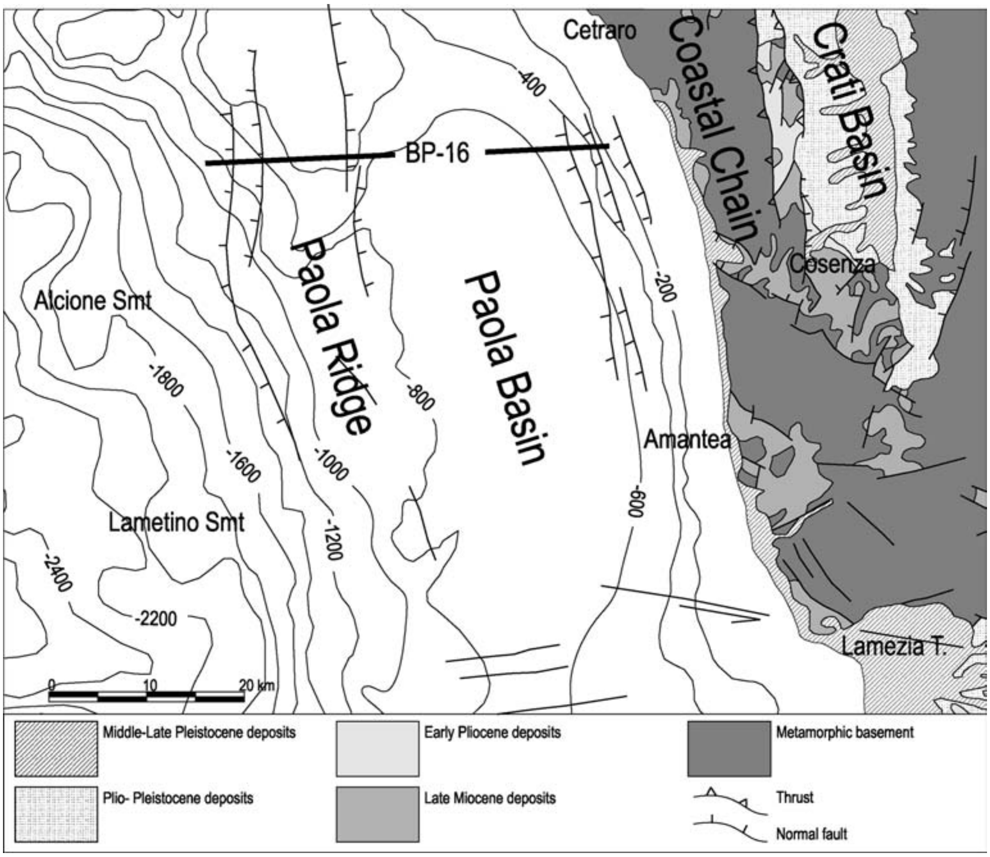


Fig. 3 Detailed geological data of the Crati Basin (northern Calabria) (modified from CNR-sheet n°6 1991; Cesarano et al. 2002). The western border of the Crati Valley is characterized by transpressive structures that are truncated by Late Pleistocene normal faults

(Ogniben 1973; Amodio-Morelli et al. 1976; Lentini and Vezzani 1978; Lentini et al. 1994). The Mèsima-Reggio Calabria Basin represents a wide depression generally oriented NE–SW, and confined south-eastward by the normal faults of the Aspromonte and westward by the Peloritani–Capo Vaticano Ridge (Fig. 2). This structural depression is characterized by a sedimentary sequence ranging from the Late Miocene to the Pleistocene. Although the deposits within the Mèsima trough and those of Reggio Calabria have undergone a different evolution, they share the same structural setting (Ghisetti 1981; Ghisetti and Vezzani 1981).

The Late Miocene to Early Pliocene deposits show a general unconformity at their base and rest directly upon the substratum, which is represented by both medium to high grade metamorphic rocks and Mesozoic sedimentary carbonate and Late Oligocene to Early Miocene terrigenous successions.

Deposition of the Early Pliocene *Trubi* Fm. was followed by a compressive tectonic event that led to the uplift of the Peloritani–Capo Vaticano Ridge with respect to the Mèsima-Reggio Calabria basin (Ghisetti 1981).

The Peloritani Ridge consists of a NE–SW elongated horst formed by the tectonic basement nappes of the Kabilo-Calabride Chain that tectonically overlie the Apenninic-Maghrebian Chain (Lentini et al. 1996). The Plio–Pleistocene sedimentation area is elongated parallel to the ridge of the Peloritani Mountains and dissected by NW-SE-oriented strike-slip faults that locally controlled its evolution (Di Stefano and Lentini 1995; Del Ben et al. 1996).

Next in the succession, above an unconformity, comes the Late Pliocene–Early Pleistocene sequence, with basal sands that pass laterally and upward into calcarenites, and into blue clays.

Since the Late Pliocene, the sedimentation appears to have been controlled by the presence of NE–SW-oriented fault systems, which separate the area of marine sedimentation from the sector corresponding to the Aspromonte, which was emergent since the Late Pliocene (Ghisetti 1981).

During the Middle Pleistocene, a deepening of some sectors of eastern Sicily and southern Calabria occurred, and are testified by the presence of sandy calcarenites on the Sicilian side and of marly sediments on the Calabrian side, both unconformably covering the substratum. It follows the deposition of a large amount of Gilbert-type fan delta sediments, the *Ghiaie e Sabbie di Messina* Fm., which is represented by submarine fan deposits controlled by the activity of normal faults (Fig. 4). These clastic deposits were interpreted as the product of ancient fluvial-deltaic systems fed from both the Peloritani Ridge and the Aspromonte with foreset geometries dipping toward the centre of the Messina Strait.

In the sector to the north of the city of Messina, to the north of the city of Reggio Calabria, the deposits of the *Ghiaie e Sabbie di Messina* Fm. have been dislocated

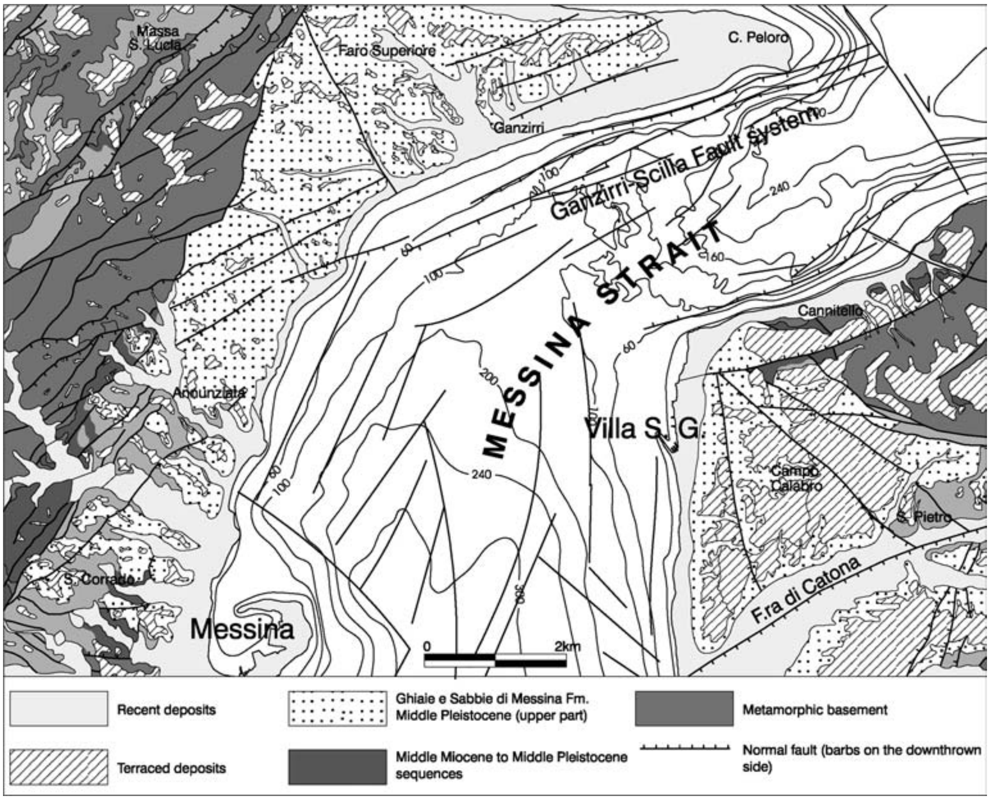


Fig. 4 Tectonic scheme of the Messina Strait area (after Guarnieri et al. 2004). This scheme pointed out to the distribution of the *Ghiaie e Sabbie di Messina* Fm. and the recent fault systems (Ganzirri-Scilla Fault system) that affected the whole area

by fault systems oriented ENE-WSW known as Ganzirri-Scilla fault system (Gargano 1994; Lentini 2000) (Fig. 4). This system of normal faults is oriented obliquely with respect to the preceding NE–SW-trending system that controlled the evolution of the basin. It is very likely that this fault system controls the Tyrrhenian coast line of Sicily in its northeastern portion, and represents one of the main alignments responsible for the recent deformation in the Messina Strait (Barbano et al. 1979; Del Ben et al. 1996) which make this area one of the most seismically active sectors (Valensise and Pantosti 2001).

In northwestern Sicily, along the coastal sector between Cefalù and Palermo (Fig. 2/box-C), the sedimentation of the Early Pliocene is represented by marly limestones that belong to the *Trubi* Fm. that unconformably rest upon the substratum represented by the tectonic units of the Apenninic-Maghrebian Chain, and locally overlie the Messinian evaporitic sequence. Above the Early Pliocene deposits, the Middle Pliocene calcarenites outcrops. These deposits are organised in northward prograding foresets that seal the transpressive structures and are themselves cut by transtensive faults that border the Tyrrhenian margin since the Late Pliocene (Fig. 5). Toward Cefalù, directly on a deep erosional surface cut into the *Trubi* Fm., rests the transgressive sequence of the Late Pliocene, which in turn is truncated by the abrasion surfaces of the Pleistocene marine terraces. This basin is structurally confined southward by the Caccamo Shear Zone, a Messinian–Early Pliocene dextral transpressive structure (Guarnieri et al. 1998; Del Ben and Guarnieri 2000; Guarnieri et al. 2002; Guarnieri 2004).

Morphostructural features of the forearc basin

The forearc is defined as the area that develops between an active volcanic arc and the external portion of the oceanic trough associated with that arc (Dickinson 1974; Karig and Sharman 1975; Seely 1979). Forearc basins do not always develop along convergent margins, and when they form they may have widths varying from 10 km to 200 km and extend over distances of many hundreds of kilometers parallel to the direction of the arc. The principal areas of sedimentation within a forearc are: trench, trench-slope basins, and forearc basins (Fig. 6). The forearc basin is confined internally by the back-stop of the chain, and toward its external portion by the accretionary wedge. The Colombia trench-accretionary complex-forearc basin represents a good example, which has developed along the western margin of South America and is characterized by a zone of active convergence, where the Nazca Plate is subducted underneath the Andean block. Figure 6 shows a line drawing of line MCS-1 within which it is possible to recognize the enormous thickness of the sediments (4.7 km) and the morphostructure of the forearc basin that shows a characteristic U-shape (Mountney and Westbrook 1997) with an internal margin that is represented by the backstop and its external margin being the accretionary wedge.

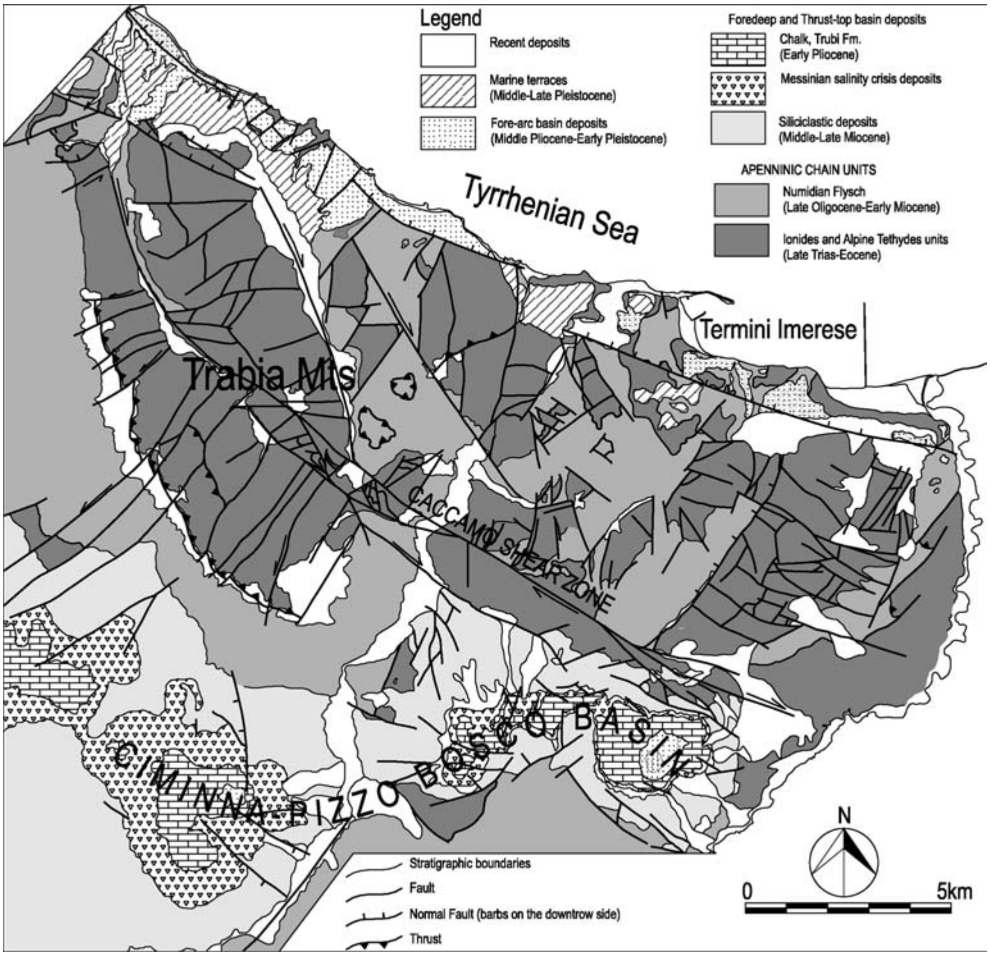
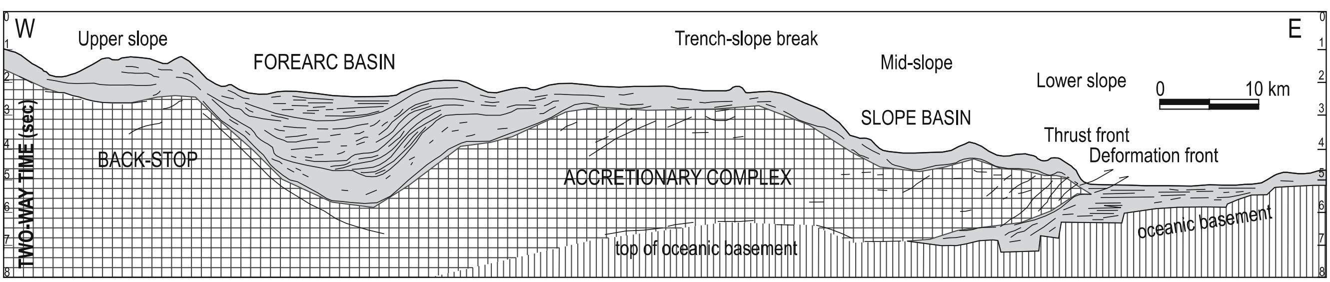


Fig. 5 Structural scheme of the Trabia-Termini Imerese Mountains (Guarnieri 2003). The Caccamo Shear Zone constitutes one of the main elements of the Late Miocene–Early Pliocene NW-SE-oriented dextral transpressive tectonics. The deposits of the Ciminna-Pizzo Bosco Basin are exposed within footwall synclines elongated parallel to the CSZ

The deep seismicity of the Tyrrhenian Sea testify the presence of a northward subduction slab (Giardini and Velonà 1991) (Fig. 7a), but the subduction process of the Ionian crust below the Calabrian Arc is quite complex due to the presence of continental crust (Africa to the south and Adria to the north) that collide against the back-stop of the entire orogenic system, since Late Tortonian. In particular, the absence of earthquakes up to 200 km below northern Calabria (Fig. 7b-dashed area) implies the presence of Tyrrhenian asthenosphere and the detachment of oceanic lithosphere deeper than 200 km. Figure 7c depicts the geodynamic setting along a lithospheric cross-section and the involvement of the Adria continental crust. The crustal structures below southern Calabria (Fig. 7d) are otherwise linked to a subducted lithosphere, while in the Sicilian side the collision between the orogenic back-stop and the Africa continental crust give rise to a transpressive collision with dextral movements (Fig. 7e).

In the southern Tyrrhenian basin, we analyze three seismic lines across the Paola Basin, the Gioia basin and the Cefalù basin (Fig. 2) presented in recent publications (Fabbri et al. 1981). In these seismic lines, it is possible

Fig. 6 Example for forearc architecture from the Colombia trench-accretionary complex-forearc basin, which has developed along the western margin of South America where the Nazca Plate is subducted underneath the Andean block. Line drawing of Line MCS-1 (from Mountney and Westbrook 1997)



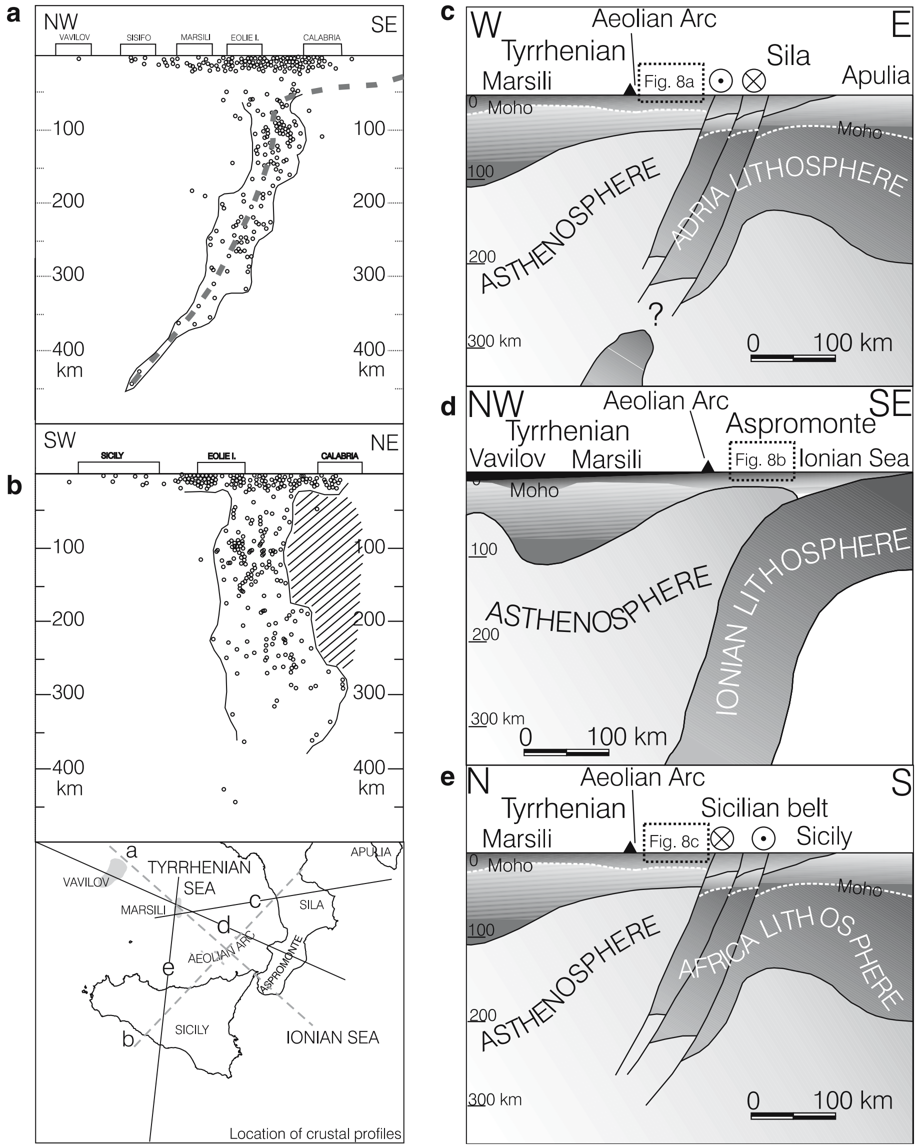


Fig. 7 **a** NW–SE cross-section from Tyrrhenian Sea to the Ionian Sea, the *circles* represent the foci of earthquakes of the deep seismicity of Tyrrhenian Sea (modified after Giardini and Velonà 1991), **b** SW–NE cross- section from Sicily to Calabria, below northern Calabria, is well visible the absence of seismicity (*dashed area*). **c** Lithospheric-scale cross- section of the Calabrian Arc–Tyrrhenian system (modied after Gvirtzman and Nur 2001), Tyrrhenian–Northern Calabria (Sila Mountains), the Ionian slab is probably detached and also indicated by the deep seismicity of the Tyrrhenian (Giardini and Velonà 1991) and the Adria lithosphere is involved, **d** Tyrrhenian–Southern Calabria (Aspromonte Mountains), the subduction of the Ionian lithosphere is still active, **e** Tyrrhenian–Sicilian belt, the presence of the Africa lithosphere inhibits the subduction process with the activation of a dextral transurrent junction since Late Tortonian up to Late Pleistocene. The *boxed areas* correspond to the seismic lines of figure 8

to recognize the morphostructural elements which in their entity constitute the paleo-forearc basin. Of the three basinal areas that make up the southern Tyrrhenian, the Paola Basin represents the one where the paleo-forearc is most completely recognizable (Fig. 8a).

The Paola Basin (Fig. 2/box-A) is a slope basin oriented parallel to the Tyrrhenian margin, in a NNW–SSE direction. To the west, this basin is confined by submarine volcanic edifices that show a similar alignment, while to the east it is bordered by a system of normal faults that separate it from the emerged sector of Calabria. Within the basin, two sectors are developed, which are separated by a NNW–SSE-oriented ridge (Paola Ridge) (Figs. 3 , 7a). The internal sector shows a slope that degrades progressively toward the volcanic arc and constitutes an intra-arc basin, while externally the forearc basin develops, represented by the U-shaped structural depression of the Paola Basin within which up to 2,500 m of Plio–Pleistocene deposits have been recognized. The present coast line appears to be controlled by normal fault systems, which run parallel to the axis of the basin and separate it from the Coastal Chain to the east (Fig. 3).

Differently from the Paola Basin, the Gioia Basin (Fig. 2/box-B) has no intermediate ridge but on the contrary constitutes an area whose characteristics are similar to the intra-arc sector, confined to the northwest by the volcanic arc (Aeolian Island), while its eastern margin consists of a ridge which is oriented NE–SW and has been indicated by some authors as C. Vaticano–C. Rasocolmo Ridge (Fabbri et al. 1981; Ghisetti and Vezzani 1981) (Fig. 8b). A great thickness of the Plio-Pleistocene sediments is present (2,500 m), and from a morphostructural point of view these characteristics are observed at least to as far as the Catanzaro Line to the south (Fig. 1) (Fabbri et al. 1982), whereas the U-shaped depression such as the one that characterizes the Paola Basin is absent.

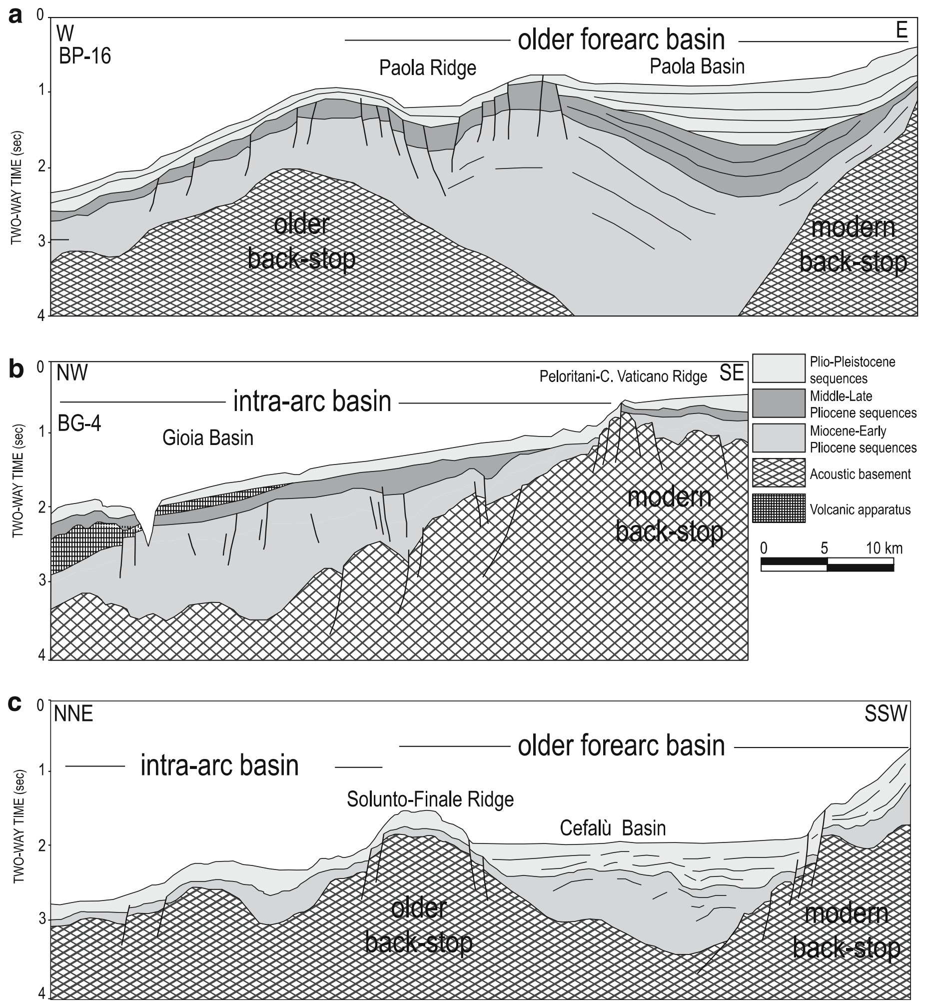


Fig. 8 **a** Line drawing of Line BP-16 (Fabbri et al. 1981). The reflector indicating the top of the acoustic basement delineates the characteristic form of a back-stop and the "U"-shaped depression corresponding to the forearc basin, linked to a compressive context until the Middle Pliocene, and with westward collapse starting in the Late Pliocene, **b** Line drawing of Line BG-4 (Fabbri et al. 1981). In this sector of the Tyrrhenian, the acoustic basement does not shows the morphostructure identified in the Line BP-16, while the basin appears confined toward SE by the Peloritani–Capo Vaticano Ridge, **c** Line drawing of Line BC-1 (Fabbri et al. 1981). The Solunto–Finale Ridge is constituted by a high of the acoustic basement, which could correspond to the morphostructure of the Paola Ridge, while the U-shaped Cefalù Basin can be seen as trending parallel to the Paola Basin. The scarp which degrades toward NNE from Solunto to the volcanic area would correspond to the intra-arc basin, and thus lie in the same position as the Gioia Basin

To the west, the Cefalù Basin is elongated parallel to the Solunto–Finale Ridge (Fig. 2), and confined to the south by a system of transtensive faults which became active from the Late Pliocene up to Late Pleistocene (Del Ben and Guarnieri 2000) and is linked to the NW–SE transurrent system (Finetti et al. 1996) that corresponds to the limit between the sectors under compression to the south and those in extension to the north, and thus represents the southern margin of the forearc basin system (Fig. 8c). The analysis of the public seismic lines of the Zone-G and the CROP-Mare lines (Finetti et al. 2005) has allowed the identification of several morphostructural elements that are seen to be associated with the thrust tectonics preceding the extensional Tyrrhenian tectonics (Del Ben and Guarnieri 2000). The morphostructural characteristics are represented by an intermediate ridge that separates an intra-arc basin, confined to the north by the volcanic arc (Aeolian Island) and to the south by the Solunto–Finale Ridge, which presently lies at a depth of about 600 m (Fig. 8c). To the south, the Cefalù Basin presents a characteristic U-shaped morphostructure similar to that described above for the Paola Basin, corresponding to the paleo-forearc basin. The sedimentary sequences that are present at the top of this ridge very probably correspond to the interval from the Late Pliocene to the Pleistocene and rest directly on the Messinian evaporites, which indicates that a probable emergence of the ridge occurred during the Middle Pliocene (Del Ben and Guarnieri 2000).

Discussion and conclusion

The interpretation of the offshore seismic lines has allowed to describe the basins composing the Tyrrhenian margin (Fabbri et al. 1982), such as the Cefalù Basin, the Gioia Basin, and the Paola Basin. These three basinal areas are presently situated between the northern Sicilian–Calabrian coast and the volcanic arc of the Aeolian Islands. The arrangement of these three areas correspond to a forearc basin, which probably developed between the Late Miocene and the Middle Pliocene (Fig. 9a). Since Late Oligocene in fact, the migration of the orogenic system was linked to the westward subduction of the Tethys, as testified by the remnants of the

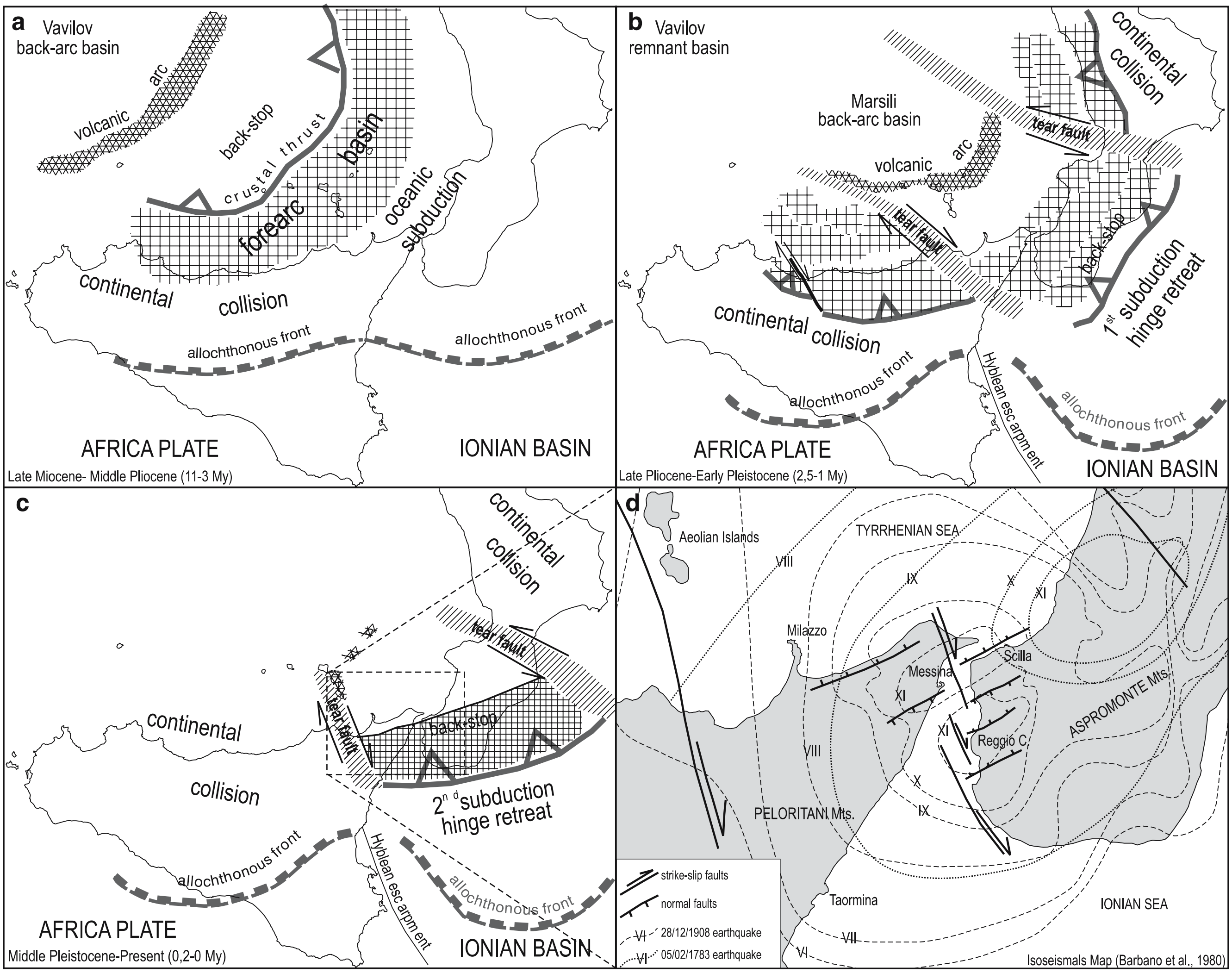


Fig. 9 **a** Late Miocene–Middle Pliocene retrodeformation has been realized considering that the back-stop in Sicily has been blocked after the Middle Pliocene, due to the continental collision with the Africa crust, **b** the roll-back of the Africa crust provokes the collapse of the Tyrrhenian margin and the uprise of out-of-sequence crustal thrusts, while the south-eastward retreat of the subduction hinge provokes the segmentation of the ancient back-stop, which is led by tear-faults, **c** the data derived from the analysis of the map of the magnetic basement (Arisi Rota and Fichera 1985) shows a trend at a depth of 9 km that is oriented N70°E in correspondence with the Ionian coast of Calabria, which might correspond to crustal thickening and thus to the formation of a new back-stop with associated NNW–SSE strike-slip faults and N70°E-oriented normal faults. These last fault systems are the surficial expression of the new phase of south-south-eastward retreat of the subduction hinge, **d** the elongation directions of the isoseists in the isoseismal map of the 1783 and 1908 earthquakes, highlights the correspondence between structures and seismicity

tectonic units outcropping on the Peloritani Mountains. (Fig. 2). This tectonic phase ceased in the Early Miocene (Amodio-Morelli 1976).

The stratigraphic characteristics and the deformational style observed in the analyzed sequences highlight a neat passage from accretion to extension between the Late Pliocene and the Early Pleistocene. The separation between the two systems of basins, compressive and extensional, is marked by a physiographic limit (Fig. 1) that is represented by normal faults with more than 1,000 m of vertical throw, and by the development of a U-shaped morphostructure that can be recognized on-land and along the entire southern margin of the Tyrrhenian. The evolution in space and time of the convergent system has brought the passage from a compressive tectonic regime in some sectors of the orogen to an extensional one. This structural setting furthermore coincides with the southeastward migration of the backarc system (Vavilov basin) with the development of a new backarc system (Marsili Basin) and the modern magmatism of the calc-alkaline volcanic arc of the Aeolian Islands (Fig. 1). In the view of many authors, this evolution corresponds with the retreat of the subduction hinge (Malinverno and Ryan 1986; Patacca and Scandone 1989) and with the roll-back of the African and Adriatic crust (Doglioni et al. 1994; Guarnieri et al. 2002). As an effect of the crustal roll-back, the sector containing the forearc basin collapsed from the Late Pliocene onward to form the present peri-Tyrrhenian margin. The three analyzed basins, however, do not

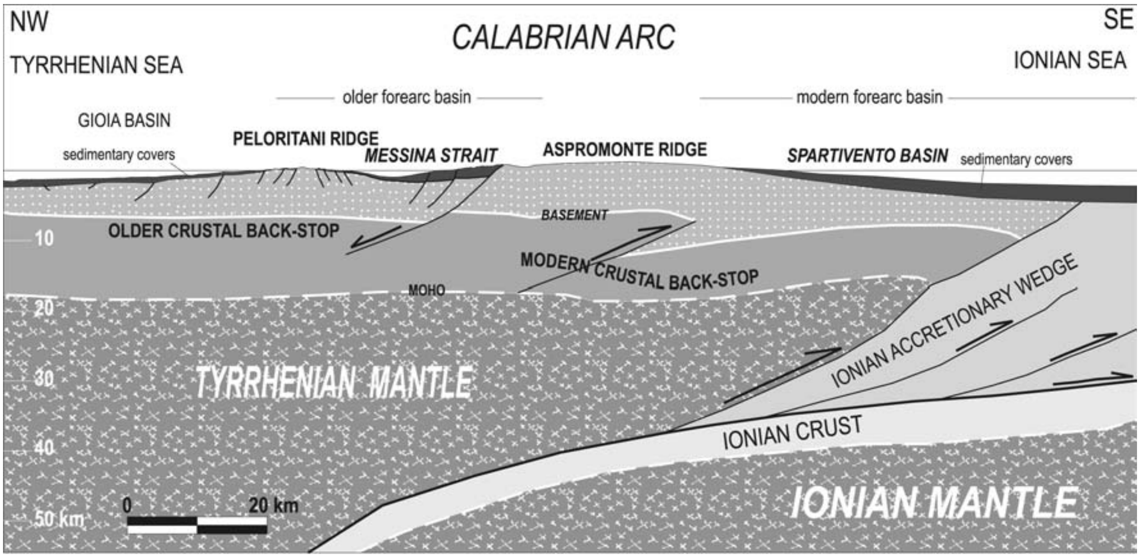


Fig. 10 NW–SE oriented crustal profile across the Calabrian Arc, from the Tyrrhenian to the Ionian Seas (modified after Guarnieri et al. 2004, using data from Cernobori et al. 1996 for the Ionian side). The Peloritani Ridge (belonging to the Mio-Pliocene back-stop) and the Messina Strait (the paleo-forearc basin) where uplifted after the Middle Pleistocene with the emplacement of a new back-stop structure linked to the last subduction hinge retreat. The Strait area is located within a surficial extensional zone due to a deep compressive deformation

correspond to the same morphostructures, but on the contrary, the depression of the Paola Basin corresponds to the depression of the Mèsima-Reggio Calabria and Cefalù Basins, since the retreat of the subduction hinge appears separated along tear-faults (Marani and Trua 2002) that provoke the segmentation of this forearc/backarc system (Fig. 9b). Since 200 ky onward (Fig. 9c), fault systems with an ENE-WSW-orientation (Ganzirri-Scilla Fault System) developed, which prevalently show dip-slip components and in some cases appear younger than the prevalently NE-trending structures of the Aspromonte and the Peloritani Mountains. This recent structural re-organization is parallel to the trends of the magnetic basement (Arisi Rota and Fichera 1985) that shows a culmination in correspondence with the southern coast of Calabria and with the trends of the compressive crustal structures (Cernobori et al. 1996).

The structures proposed in the present paper correspond to some of the main lineaments connected with the new deep-seated structural setting (Caccamo et al. 1996), which in turn are linked to a re-orientation of the direction of retreat of the subduction hinge from SE to SSE. The new setting provokes the formation of surficial extensional faults oriented ENE–WSW (GSF) (Fig. 4), and connected to compressive tectonics at depth (Fig. 9c). These structures could be associated with the lineaments responsible of the Calabria earthquake of 6 February 1783, whose submarine epicenter lay close to the town of Scilla (Barbano et al. 1979; Tortorici et al. 1995). As far as the NNW–SSE lineaments are concerned, besides trending parallel to the seismogenetic structures in the area of Patti (Vulcano Line, Fig. 1), these are coherent with the focal mechanism of the Messina earthquake of 28 December 1908; furthermore field evidence is confirmed by frequency diagrams of the directions of elongation of the isoseists of these earthquakes (Barbano et al. 1979) (Fig. 9d) and by the directions of elongation of the highest grade isoseists (Ghisetti 1981).

In conclusion, the Late Pliocene–Early Pleistocene southeastward migration is accompanied by the development of N120°E trending tear-faults and NE–SW-trending extensional systems, while the Middle–Late Pleistocene NNW–SSE-trending tear-faults and N70°E-trending collapse systems might represent the response to a SSE-ward retreat of the subduction hinge which leads to the structural re-organization of a new back-stop and a correspondent collapse behind it (Fig. 10).

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