G. DE GUIDI*, S. CATALANO*, C. MONACO*, L. TORTORICI* & A. DI STEFANO*

LONG - TERM EFFECTS OF LATE QUATERNARY NORMAL FAULTING IN SOUTHERN CALABRIA AND EASTERN SICILY

INDEX

ABSTRACT	"	79
RIASSUNTO	"	79
1. INTRODUCTION	"	81
2. TECTONIC SETTING	"	81
3. ACTIVE TECTONICS IN THE STRAITS OF MESSINA AREA	"	82
4. EVALUATION OF THE UPLIFT-RATE IN THE SOUTHERN SECTOR OF THE CALABRIAN ARC: METODOLOGY	"	83
5. EVALUATION OF THE REGIONAL UPLIFT-RATE IN THE CALABRIAN ARC	"	84
6. UPLIFT RATE ALONG THE RIFT ZONE	"	86
6.1. SOUTHERN CALABRIA	"	86
6.2. NORTHEASTERN SICILY	"	88
7. UPLIFT-RATE AND NORMAL FAULTING DEFORMATIONS	"	89
8. DISCUSSION AND CONCLUSION	"	89
REFERENCES	"	91

ABSTRACT

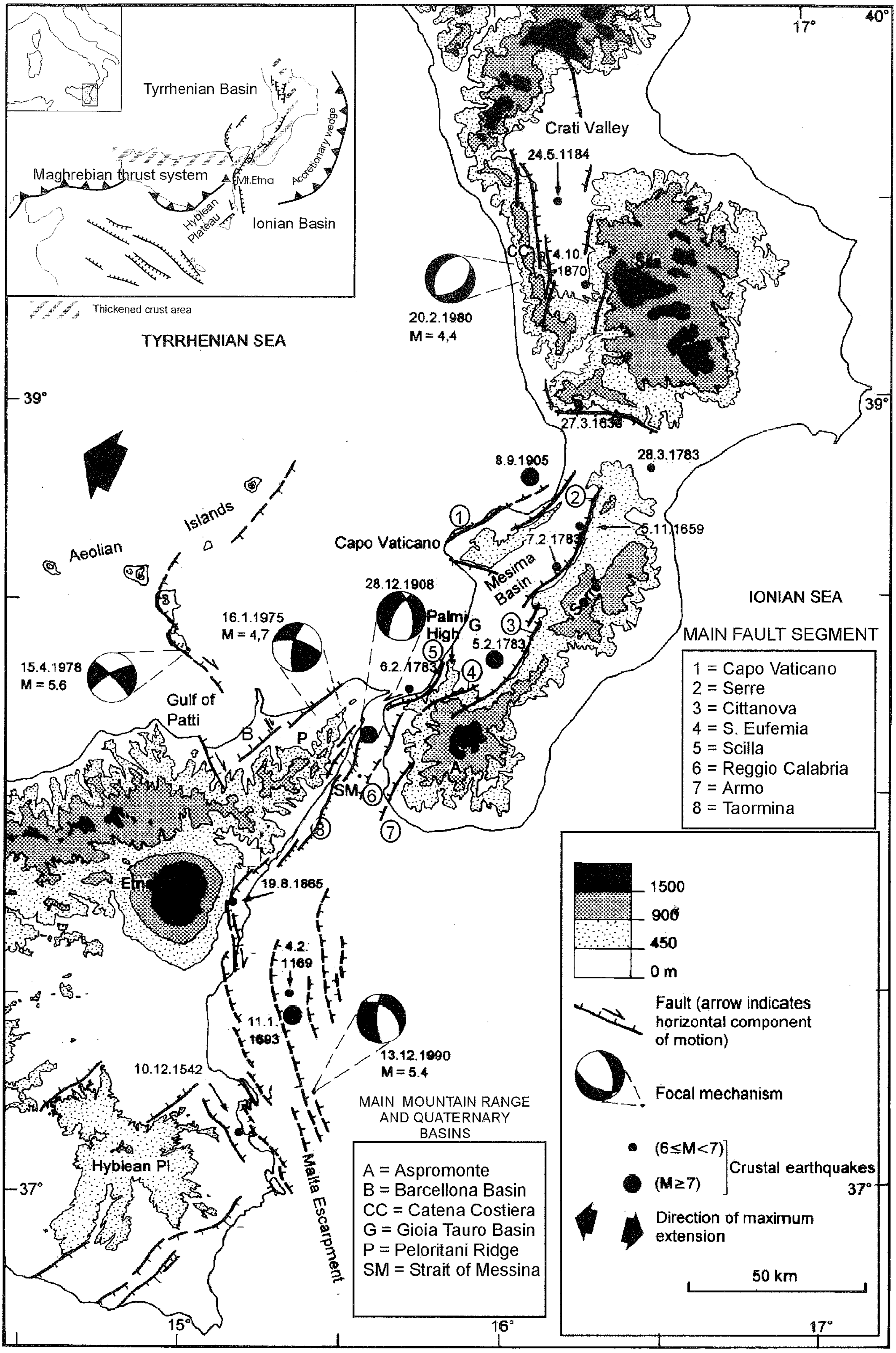
The Calabrian arc, located in the peri-Tyrrhenian collisional belt of Southern Italy, is characterised by intense post-collisional dynamics. These consist of a large scale uplifting of the mountain belt which is associated, since the Late Quaternary, with the active normal faulting, originating the "Siculo-Calabrian Rift Zone", from the Tyrrhenian side of Calabria to the Ionian coast of Sicily. In these regions, suffering an high level crustal seismicity, the effects of the two combined processes are well exposed in the Straits of Messina area, a major transfer zone which separates the southern Calabria and the northeastern Sicily branches of the rift. In the area, flights of Late Quaternary marine terraces are severely displaced along the coastal slopes by active normal faults. The difference in vertical displacement affecting the marine terraces on the footwalls and hangingwalls of the active faults allowed us to define the faulting-induced vertical motions partitioned vs. the time, with the resolution of the OIT stages curve. The performed analysis pointed out the occurrence, on the footwall of the active faults, of co-seismic and post-seismic vertical motions which superimposed, as additional component, to the uplift-rate recorded at a regional scale. Consequently, the onset of the normal faulting has been recorded by sudden increases in the vertical displacement-rate of the marine terraces. The different elevations of the paleoshorelines, in adjacent sites of the study area, clearly indicate a southward migration of the active faults, from the southern Calabria to the northeastern Sicily, through the Straits of Messina. Moreover, a variation vs. the time of the faulting-induced uplifting has been related to the variable displacement-rate recorded along the fault planes. The highest values of the two parameters occurred, from about 125 ka to 100 ka B.P., in the Southern Calabria side of the Straits of Messina. In this period, the normal faults propagated, almost instantaneously, along the Ionian coast of northeastern Sicily, from the Straits of Messina to Taormina, where a main change in the crustal reology occurs, at the southern end of the Calabrian arc.

In conclusion, the analysis of the long-term behaviour of the active faults in the Straits of Messina area pointed out some significant insights on the control of the crustal barriers on the evolution of a fault zone. The crustal barriers, geometrically evidenced by transfer zones, mechanically represent critical sites where the huge elastic strength to extension inhibits the fault propagation for long periods, directly influencing the recurrence of seismic events.

(*) Dipartimento di Scienze Geologiche, Università di Catania, Catania C.so Italia, 55 95129 CATANIA
Catalano@mbox.unict.it

RIASSUNTO

L'Arco Calabro rappresenta l'area soggetta ai maggiori effetti della dinamica post-collisionale che coinvolge la fascia orogenica peri-Tirrenica dell'Italia meridionale. Ciò è dovuto alla sovrapposizione di due processi principali rappresentati dal sollevamento a scala regionale del sistema orogenico e al concomitante processo di estensione crostale, responsabile di un elevato grado di sismicità, che ha dato origine al Rift Siculo-Calabro, esteso dalle aree tirreniche della Calabria fino alla costa ionica della Sicilia. Gli effetti della combinazione dei due processi dinamici in atto sono molto evidenti nella regione dello Stretto di Messina, dove le faglie attive della Calabria meridionale, immergenti verso il Mare Tirreno, si sovrappongono a quelle, immergenti verso il Mare Ionio, che controllano la costa dei Monti Peloritani, in Sicilia nord-orientale. Nell'area di interferenza tra i due sistemi di faglie si è originato lo Stretto di Messina, in corrispondenza di una barriera crostale determinata dalla presenza di una importante variazione di profondità della Moho. Nella zona dello Stretto di Messina i terrazzi marini tardo-quaternari hanno subìto notevoli tassi di sollevamento e sono stati soggetti a dislocazioni da parte di faglie normali attive. Una indagine geologico-strutturale e morfologica condotta sulle due sponde dello stretto ha permesso di valutare le differenze del sollevamento al letto e al tetto delle strutture attive, e di ricavare le componenti del sollevamento dovute alle deformazioni co-sismiche e post-sismiche, ripartite nel tempo, con la risoluzione dettata dalla curva degli stadi OIT. I risultati ottenuti evidenziano che le deformazioni indotte dalle deformazioni attive si manifestano con componenti addizionali al sollevamento regionale e, conseguentemente, che l'inizio dei processi di fagliazione è caratterizzato da un repentino aumento del tasso di sollevamento dell'area. Partendo da questi presupposti, l'analisi dell'elevazione dei terrazzi tardo-quaternari in differenti siti dell'area di studio ha messo in evidenza una propagazione delle faglie attive, a partire da 125 ka, dalla Calabria meridionale alla Sicilia nord-orientale, attraverso l'area dello Stretto di Messina. Inoltre la ripartizione nel tempo dei tassi di deformazione co-sismico e post-sismico, lungo le faglie attive, ha consentito di riconoscere che il massimo dei rilasci elastici è avvenuto in Calabria meridionale, a nord della barriera crostale, tra i 125 ed i 100 ka. In questo stesso periodo è stata registrata la propagazione istantanea delle faglie attive lungo un segmento discreto della costa ionica siciliana, fino all'area di Taormina, dove



Tyrrhenian Basin
Maghrebian thrust system
Mt.Etna
Accretionary wedge
Hyblean Plateau
Ionian Basin
Thickened crust area
TYRRHENIAN SEA
20.2.1980
M = 4,4
Crati Valley
24.5.1184
4.10.
1870
27.3.1638
28.3.1783
8.9.1905
5.11.1659
7.2.1783
Capo Vaticano
Aeolian
Islands
Mesima Basin
28.12.1908
Palmi High
G
5.2.1783
6.2.1783
16.1.1975
M = 4,7
15.4.1978
M = 5.6
Gulf of Patti
B
P
SM
A
Etna
19.8.1865
4.2.
1169
11.1.
1693
13.12.1990
M = 5.4
10.12.1542
Hyblean Pl.
Malta Escarpment
IONIAN SEA
MAIN FAULT SEGMENT
1 = Capo Vaticano
2 = Serre
3 = Cittanova
4 = S. Eufemia
5 = Scilla
6 = Reggio Calabria
7 = Armo
8 = Taormina
1500
900
450
0 m
Fault (arrow indicates horizontal component of motion)
Focal mechanism
(6≤M<7)
(M≥7)
Crustal earthquakes
Direction of maximum extension
50 km
MAIN MOUNTAIN RANGE AND QUATERNARY BASINS
A = Aspromonte
B = Barcellona Basin
CC = Catena Costiera
G = Gioia Tauro Basin
P = Peloritani Ridge
SM = Strait of Messina
39°
40°
37°
15°
16°
17°

una ulteriore barriera crostale è rappresentata dal margine meridionale dell'Arco Calabro. Nelle fasi successive dell'evoluzione, ad una diminuzione delle deformazioni co-sismiche e post-sismiche in Calabria meridionale sono corrisposti valori massimi di dislocazione verticale lungo le faglie ioniche della Sicilia nord-orientale, lungo un settore oggi marcato da un evidente gap sismico. Ciò implica che alla terminazione dell'arco Calabro sono prevedibili rilasci di notevoli quantità di energia, oggi assorbita elasticamente, su tempi di ritorno molto lunghi.

In conclusione i dati esposti rappresentano un esempio del ruolo esercitato in natura dalle barriere crostali, nell'evoluzione di una zona di faglia. Le barriere geometricamente sono evidenziate da zone di trasferimento ed esercitano una notevole e prolungata resistenza elastica alla deformazione, durante la quale la propagazione delle faglie attraverso la barriera è momentaneamente inibita, con dirette conseguenze sulle ricorrenze degli eventi sismici.

KEY WORDS: Structural analysis, geomorphic analysis, marine terraces, eustatism, uplifting, active faulting.

PAROLE CHIAVE: analisi strutturale, analisi morfologica, terrazzi marini, eustatismo, sollevamenti, faglie attive.

1. INTRODUCTION

The southern Calabria and the eastern Sicily are regions of the peri-Tyrrhenian collision belt of Southern Italy, characterised by intense post-collisional dynamics and high level crustal seismicity. In these sectors, a large scale uplifting of the mountain belt (WESTAWAY, 1993) has been combined, since the Late Quaternary, with the active faulting that originated the "Siculo-Calabrian rift zone" (Fig. 1) (MONACO *et al.*, 1997; MONACO & TORTORICI, 2000; BIANCA *et al.*, 1999; CATALANO & DE GUIDI, 2002).

The effects of the two interacting processes are well exposed in the Straits of Messina area, where the normal faults of the active rift zone, marked by well preserved fault scarps (MONACO & TORTORICI, 2000), dissect several strongly uplifted Quaternary marine terraces (WESTAWAY, 1993; MIYAUCHI *et al.*, 1994).

Starting from these evidences, structural and morphologic analyses has been carried out in the Straits of Messina area, in order to evaluate the variations of the uplift-rate in the region affected by the active faults. The analysis aims to stress out an high-resolution timing of the faulting-induced deformations recorded along the seismogenic faults, providing a reconstruction of the long-term behaviour of the active fault belt.

2. TECTONIC SETTING

The southern Calabria and the eastern Sicily represent the southern edge of the Calabrian arc. This consists of an arc-shaped segment of the peri-Tyrrhenian mountain belt, which was extruded onto the oceanic Ionian Basin (FINETTI, 1982) during the collision of the Sicily thrust belt with the African continental margin (Hyblean Plateau) (DEWEY *et al.*, 1989; BOCCALETTI *et al.*, 1990; BEN AVRAHAM *et al.*, 1990) (see inset of Fig. 1). The lateral escape of the arc, since the Late Miocene, has been constrained to the west by the E-W oriented active spreading in the Tyrrhenian Basin (SELLI & FABBRI, 1971; BOCCALETTI *et al.*, 1990) and to the east by the NW-ward subduction of the Ionian Basin (TORTORICI, 1983; BEN AVRAHAM *et al.*, 1990; FINETTI *et al.*, 1996). At the present, the Calabrian arc represents a thickened crust area (BOCCALETTI *et al.*, 1990; LOCARDI and NICOLICH, 1988) which is confined between a series of Plio-Pleistocene extensional basins, bordering the peri-tyrrhenian region, and a Neogene-Quaternary accretionary wedge, located in the outer edge of the arc (see inset of Fig. 1; GHISETTI & VEZZANI, 1982; BOCCALETTI *et al.*, 1990; FINETTI *et al.*, 1996).

During the Quaternary, a huge uplifting affected the Calabrian arc at a regional scale. Several authors (HEARTY *et al.*, 1986; WESTAWAY, 1993; MIYAUCHI *et al.*, 1994; CATALANO & CINQUE, 1995; TORTORICI *et al.*, 1995; CATALANO & DI STEFANO, 1997) estimated the averaged uplift-rate of the area, during the Late Quaternary, at about 1-1.1 mm/yr, pointing out the large-scale distribution of the process.

The emergence of the area was coupled, since the Middle Pleistocene, with the rifting processes which originated the "Siculo-Calabrian rift zone", the main neotectonic feature dominating the area (Fig. 2). Today, the "Siculo-Calabrian rift zone" extends from the Tyrrhenian side of the Calabrian arc to the African foreland, on the Ionian coast of Sicily, for a length of about 370 km (MONACO & TORTORICI, 2000). The southern Calabrian branch of the rift zone shows an half-graben geometry, composed of NNE-SSW oriented, west facing master fault zones, separating the uplifted Serre-Aspromonte Mountain range from the Tyrrhenian coast (Fig. 1). An opposite asymmetry characterises the northeastern Sicily branch of the extensional belt, which is represented by NNE-SSW trending, east facing, normal fault belt, controlling the Ionian coast of the Peloritani Mts. (Fig. 1) (MONACO *et al.*, 1997; CATALANO & DE GUIDI, 2002).

Between the two opposing sets of faults, an antithetic interference zone (GAWTHORPE & HURST, 1993), filled with Middle Pleistocene (300-200 ka) syn-tectonic clastic fans (Ghiaie di Messina Fm.; BADA *et al.*, 1991; BONFIGLIO, 1991; CATALANO & CINQUE, 1995; TORTORICI *et al.*, 1995; MONACO *et al.*, 1996), developed in the Straits of Messina region. This tranfer zone is located where the rift transversely crosses the previous collision belt and a main change in the crustal rheology occurs. According to several authors (PANZA *et al.*, 1980; NICOLICH, 1981; LOCARDI & NICOLICH, 1988), in fact, an upwarped semi-fluid mantle body, wedged between the subducting Ionian oceanic crust and the thinned sector of the continental crust of the Calabrian arc, pinches out beneath this region (Fig. 3)

The Straits of Messina has been affected, in the last centuries, by two main seismic events (1783; 1908), characterised by $M \geq 7$ (POSTPISCHL, 1985; BOSCHI *et al.*, 1995; 1997) (Figg. 1, 2). According to TORTORICI *et al.* (1995), the

Fig.1 - Seismotectonic map of Calabrian Arc and eastern Sicily showing the active faults (barbs on downthrown blocks) of the Siculo-Calabrian rift zone (the fault geometry is from MONACO *et al.*, 1997; BIANCA *et al.*, 1999; MONACO & TORTORICI, 2000). Crustal seismicity (H < 35 Km) since 1000 A.D. (POSTPISCHL, 1985; BOSCHI *et al.* 1995) and focal mechanism of historical earthquakes are from GASPARINI *et al.* (1982), CELLO *et al.* (1982) and ANDERSON & JACKSON (1987).
The inset shows the tectonic map of central Mediterranean area with location of the collision belt and the thickened crust area.

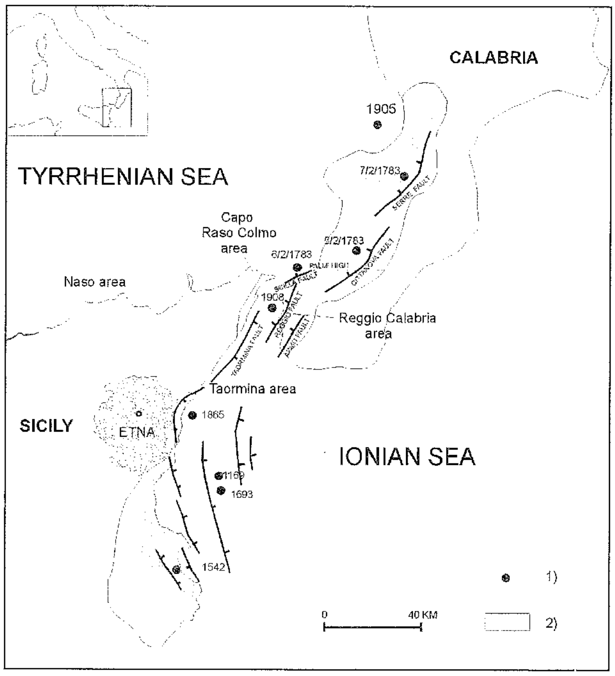


Fig. 2: Relationships between Quaternary faults of the Siculo-Calabrian rift zone and mesoseismal areas of the largest earthquakes (M≥6) of the Calabrian arc and eastern Sicily since 1000 A.D. (after CONTI, 1871; BARATTA, 1901 and 1910; BOSCHI *et al.*, 1995; 1997; BIANCA *et al.*, 1999).
The seismotectonic data evidence a clear "seimic gap" occurring along the Ionian faults of in the northeastern Sicily.
1) location of epicenters of the main historical crustal earthquakes; 2) mesoseismal areas of the largest earthquakes.

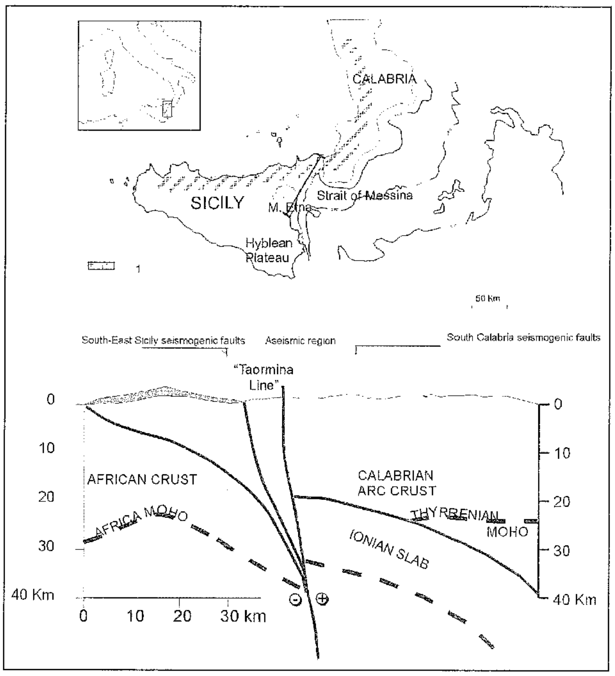


Fig. 3 - Crustal architecture of Eastern Sicily (after CATALANO & DE GUIDI, 2002, modified).
The transect (see the inset for the location) has been drawn on the basis of original geological data and the available geophysical information on the region (CRISTOFOLINI *et al.*, 1979; PANZA *et al.*, 1980; NICOLICH, 1981; LOCARDI & NICOLICH, 1988). In the cross section the highly deformed transition between the Calabrian arc and the African domain is imaged. The regional picture is dominated by a main oblique (dextral) shear zone (Taormina Line of GHISETTI & VEZZANI, 1982), separating the continental crust of the Calabrian arc, resting on the subducted Ionian domains, from the continental crust of the African foreland. In the transect, the upwarped melted mantle, intruded beneath the Calabrian arc crust and the Ionian slab is evidenced. On the transect, the projection of the seismogenic fault segments of southern Calabria and eastern Sicily and the aseismic area of the Peloritani Mountains are reported.

morphologic effects of these shocks have been recognised on very recent fault scarps, marking the NNE-SSW master faults, cutting the Calabrian side of the Straits.

The seismotectonic data outline a well-defined gap of the historical seismicity along the Ionian coast of the northeastern Sicily (STEWART *et al.*, 1997; MONACO & TORTORICI, 2000). This gap separates the Straits of Messina from the main seismogenic region (M ≤ 7) located on the southeastern Sicily branch of the rift (MONACO *et al.*, 1997; BIANCA *et al.*, 1999) (Fig. 2).

3. ACTIVE TECTONICS IN THE STRAITS OF MESSINA AREA

In the Straits of Messina area, an interference zone between the southern Calabria and the northeastern Sicily branches of the active "Siculo-Calabrian Rift Zone" occurs.

The southern Calabria branch mainly developed onshore, including, to the north, the NNE-SSW Serre and Cittanova faults and, to the south, three distinct fault segments, represented by the ENE-WSW Scilla Fault and the NNE-SSW Reggio Calabria and Armo faults (Fig. 2). This master fault zone controls the boundary of the main Plio-Pleistocene Mesima and Gioia Tauro Basins (Fig. 1).

The kinematic linkage between the different fault segments is suggested by the location of the seismic events, affecting the region, from the 1783 to the 1908. The 1783 seismic sequence (BARATTA, 1901), characterised by events with inferred 6.3<M<7.1 (POSTPISCHL, 1985; TORTORICI *et al.*, 1985; BOSCHI *et al.*, 1995, 1997) originated from ruptures along the fault zone, on a length of about 90 km, from the Mesima Basin to the Scilla Fault. The main first shock occurred on the Cittanova Fault and was followed by a seismic sequence (JACQUES *et al.*, 2001), which originated from releases, propagating both to the south, on the Scilla Fault, and to the north, on the Serre Fault. A secondary seismic event (M=5.7) originated, in the 1894, on the S. Eufemia fault segment, located in the relay ramp (Palmi High; Fig. 1), linking the Scilla and Cittanova faults. Finally, a further main shock (1908; M ≤ 7) affected the Reggio Calabria Fault, at the southern edge of the fault zone (MONACO & TORTORICI, 2000).

The Recent activity along the southern Calabria fault zone has been well recorded in the Late Quaternary landscape. The Cittanova Fault shows a very impressive 35 km-long scarp, which exhibits a composite profile, marked by three distinct sets of well developed triangular facets, respectively showing heights of about 400, 200-250 and 80-90 m. (TORTORICI *et al.*, 1995). Narrow V-shaped and «wine-glass» valleys, which developed during the last rejuvenation of the scarp, separate the lowest triangular facets.

The 600m-high and 20 km-long sea cliff, bounding the Palmi High, evidences the Scilla fault segment. Finally, to the south, the Reggio Calabria fault is marked by a 70-100 m high escarpment, showing 50-70m high triangular facets, distributed along the main mountain front bordering the adjacent coastal plain. To the south, the fault scarp seems to continue in the off-shore, for a length of about 10 Km (AMBROSETTI *et al.*, 1987). The Reggio Calabria fault offsets 125 ka-old sediments, which are unconformably covered by remnants of gently dipping alluvial fans of Wurmian age (DUMAS *et al.*, 1978), resting on the down-thrown block. These sediments progressively on-lap the fault scarp, showing effects of a syn-tectonic deposition, thus suggesting faulting activity during that period.

During the last destructive 1908 earthquake, a permanent subsidence of about 0.7 m affected the hanging-wall of the Reggio Calabria Fault, from Reggio Calabria to Scilla (BARATTA, 1910).

On the Sicily side of the Straits of Messina, a main fault zone is located along the Ionian coast ("Messina-Fiumefreddo System" of GHISETTI, 1979). This consists of a 40 km-long normal fault system, extending from the south of Messina to the Taormina region (BOSI *et al.*, 1983; SCANDONE *et al.*, 1991; SARTORI *et al.*, 1991). The geometry of the fault belt has been reconstructed, on the basis of a digital elaboration of the bathymetry of the sea-floor. The resulting map evidences the occurrence of three distinct, right stepping, NNE-SSW oriented scarps that, ranging in height from 200 to 150 m, obliquely dissect the continental slope. This submerged morphology fits well the distribution, along the coast, of sea-cliffs marked by trapezoidal and triangular facets (Fig 4).

Several morphologic features suggest a very recent activity along the fault zone. The most impressive evidence is represented by the four Holocene elevated notch-levels, preserved on the carbonate promontory of Taormina and Capo S.Alessio, on a distance of about 10 km. These hanging shorelines have been interpreted as the expression of repeated co-seismic displacements occurred during the last 5 ka (STEWART *et al.*, 1997).

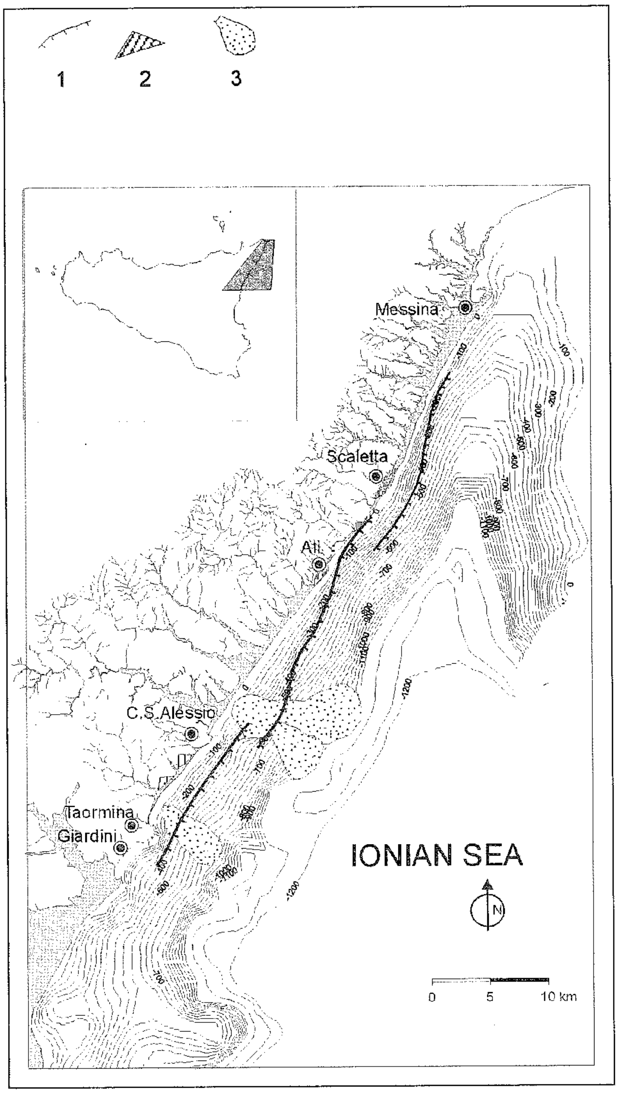


Fig. 4. - Geometry of the Messina-Fiumefreddo system in the Ionian off-shore of the Peloritani Mountains. The fault segments have been located at the base of scarps obliquely dissecting the continental slope, as evidenced in the bathymetry obtained by computer elaboration of the data reported in BOSI *et al.* (1983) and SCANDONE *et al.* (1991). The reconstructed fault pattern in the off-shore has been constrained also by the distribution of high sea-cliffs, showing well defined triangular and trapezoidal facets, that mark the near-shore prolongation of the faults. The reported bathymetry clearly shows also the location of the main clastic fans, facing the mouths of the principal rivers, displaced by the normal faults. 1) normal fault segments; 2) triangular and trapezoidal facets; 3) main clastic fans.

4. EVALUATION OF THE UPLIFT-RATE IN THE SOUTHERN SECTOR OF THE CALABRIAN ARC: METODOLOGY

In the uplifting regions, the elevation of the marine terraces, which developed during successive high-stands, indicate apparent fluctuations of the sea-level vs. the time wider than the eustatic changes, as consequence of the combination of the eustatism with the vertical motions of the lands.

In this case, the inner-edges of the marine terraces represent the marine marks of the maximum sea-level transgression, occurred during an highstand (BOSI *et al.*, 1996). Thus, the elevation of the inner-edges can be easily reproduced by the elevation of the eustatic peaks of a corrected eustatic curve (apparent eustatic curve) that, plotted in a time elevation diagram (m a.s.l./ka), takes in account the tectonic uplifting. The apparent eustatic curve can be obtained, following the suggestions expressed by several Authors (LAJOIE, 1986; CINQUE *et al.*, 1995; ARMIJO *et al.* 1996; BOSI *et al.*, 1996), plotting each eustatic peak of a reference eustatic curve at the elevation (m a.s.l.) attained by the correlative elevated inner-edge, because of vertical motion of the lands (Fig. 5). The relation intervening between age, elevation and, thus, the rate of vertical displacement of the different marine features are graphically imaged by the gradient of the curve in the diagram. This is better evidenced by plotting the TBL (Tectonic Behaviour of the Land)-curve (CINQUE *et al.*, 1995), that is the projection in the time of the Present-day elevation of the sea-level (Fig. 5). The TBL is represented by an horizontal line, in the case of stable lands, is an inclined straight line, in the case of uniform uplift-rate vs. the time and, finally, is a broken line, in the case of uplift-rate changing in the time.

The reconstruction of the apparent eustatic curve

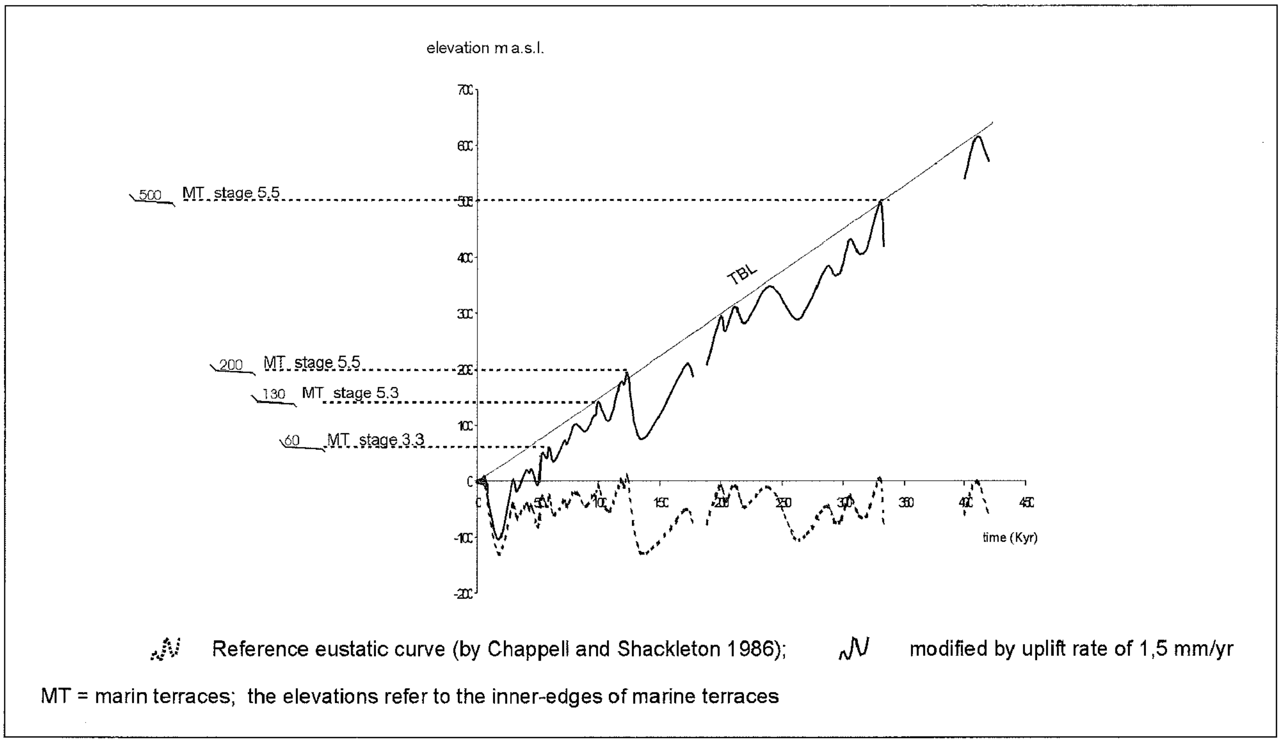


Fig. 5: - Time/elevation diagram showing an apparent eustatic curve deriving from the correction of a reference eustatic curve (Chappel and Shackleton, 1986) for an uplift-rate of the coast of 1.5 mm/yr.
The apparent eustatic curve reproduces the sea-level fluctuations vs. the time that actually occurred along the coast, because of the combination of eustatism and tectonic uplifting of land. In the reported example, the reconstruction of the apparent eustatic curve has been obtained by plotting the 9.3 (330 ka), 5.5 (125 ka), 5.3 (100 ka) and 3.3 (59 ka) eustatic peaks at the elevation attained by the correlative dated marine marks. The amount of the uplift-rate is graphically represented by the gradient of the corrected eustatic curve, that is better evidenced by plotting the TBL curve. In this case the TBL is a straight line, indicating an uplift-rate constant in the time.

requires one or more dated paleoshorelines for correlating the elevated marine marks and correlative high-stands. If exclusively based on dated marine marks, the apparent eustatic curves shows the variation of the net uplift-rate vs. the time, with the resolution of the eustatic changes (20 ka).

The apparent eustatic curves can, also, provide an indirect timing of the elevated marine features, if based on few chronological data. The reliability of the timing is demonstrated if all the elevated marine marks are fitting eustatic peaks of the curve, plotted on the basis of the inner-edges of the dated marine terraces. In the cases of good correspondence between the theoretical and morphological recorded sea-levels vs. the time, the uplift-rate variation vs. the time can be considered sufficiently constrained, as well as in the case of the curve based on dated paleoshorelines.

The apparent eustatic curves, for different sites of southern Calabria and eastern Sicily, have been reconstructed by data collected during geomorphic analysis carried out in order to detail the distribution of marine terraces and their relative inner- and outer-edges. The elevated marine features have been mapped over the whole area, using 1.10.000 scale topographic maps, 1:33.000 and 1:10.000 scale aerial photographs. This information was coupled by detailed field mapping carried out on the different sites we cited in the text. In these cases, the terraces have been mapped on 1:10.000 scale maps (contour elevation lines of 10 m) with an uncertain in the elevation of the inner-edges of ± 5 m. This uncertainty, basically, depends on the effects of erosional and depositional processes following the emergence of the terraces. The induced error is, however, negligible in the evaluation of the uplift-rate with the adopted time-resolution. The graphic restitution of the apparent eustatic curves (Fig. 5), deriving from the correction of the eustatic curve proposed in Chappel & Shackleton (1986), has been obtained using a computer software Mazzaglia, 1999) projected in the Catania University. The resulting time/elevation diagrams display the apparent eustatic curve for the time interval recorded by the marine terraces, indicating the predicted elevation of marine features referring to the different highstands. Their correspondence with elevated morphological features is indicated by dotted segments, marking the eustatic peaks.

The diagrams, also displays the age, expressed in terms of OIT substages (Bassinot *et al.,* 1994), of the elevated marine features, constraining the apparent eustatic curve, and the difference in elevation between the predicted and the morphological recorded strandlines. In the diagram are also reported the TBL curve indicating the uplift history of the area, which is also in term of absolute rate in the upper part of the screen. In the cases of uplift-rate changing in the time, the diagram displays the different rate of uplifting for each time-interval.

5. EVALUATION OF THE REGIONAL UPLIFT-RATE IN THE CALABRIAN ARC

The Late Quaternary uplift-rate, affecting the southern sectors of the Calabrian arc at regional scale, has been evaluated in the Capo Rasocolmo area, located along the Tyrrhenian coast to the north of Messina, in a region out of the influence of the normal faulting deformation.

The Capo Rasocolmo coastal range is characterised by the occurrence of several elevated wide wave-cut platforms, which are distributed from 450 to 35 m a.s.l.. The inner edges of the marine terraces have been recognised at

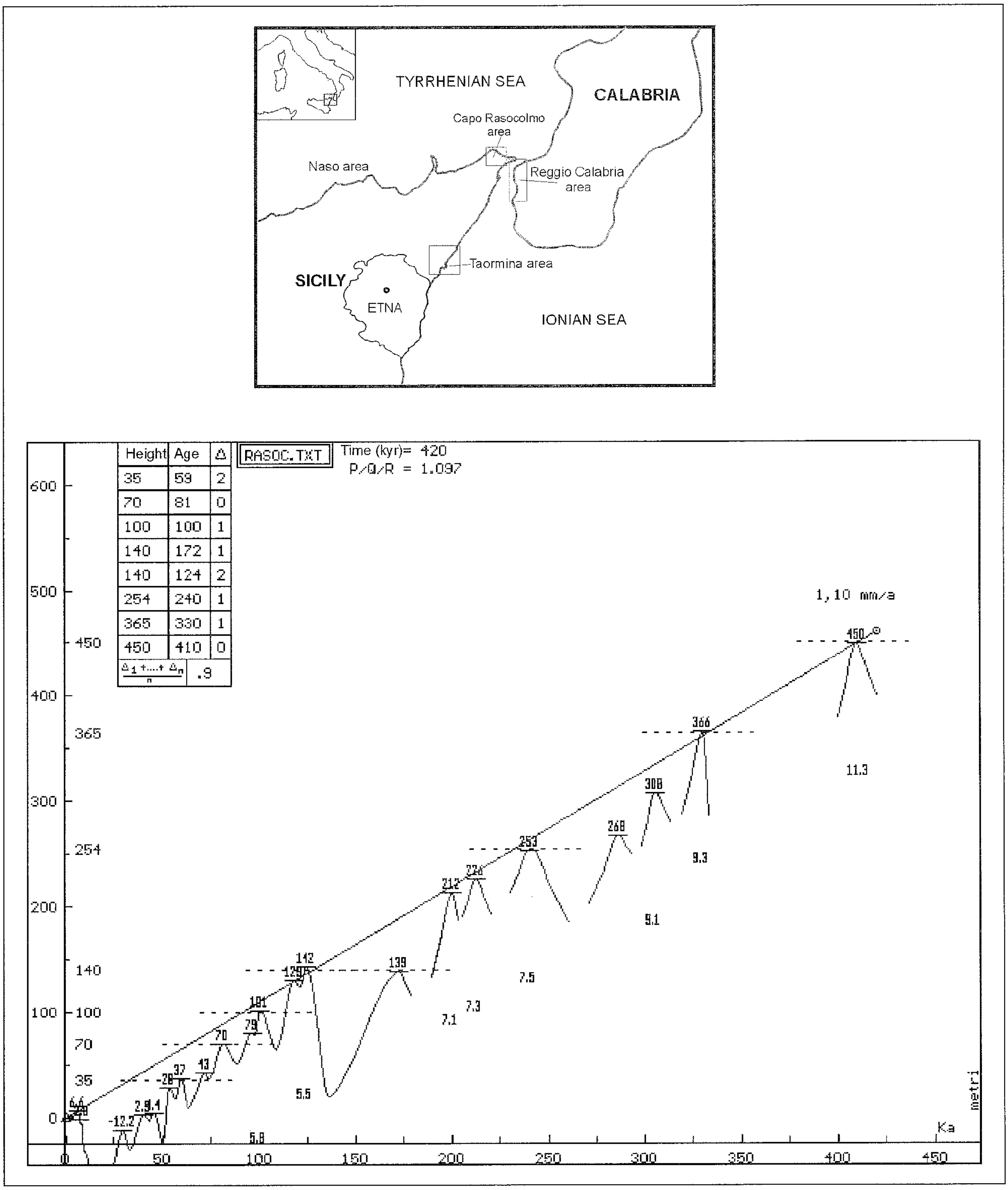


Fig. 6 – Apperent eustatic curve resulting from the elevation of the inner-edges of marine terraces in the Capo Rasocolmo area (see inset for the location).
The curve, corrected for an uplift-rate of about 1.1 mm/yr, on the basis of the elevation of the dated (BONFIGLIO & VIOLANTI, 1984) 125 ka inner-edges, displays the good fitting between the main transgressions of the 9, 7, 5 and 3 OIT stages with the recognised inner-edges. The elevation and the age of the marine terraces are tabelled on the upper left portion of the figure. The reconstructed uplift-history is represented by a straight TBL-curve (CINQUE *et al.*, 1995) indicating an uniform uplift-rate since 420 ka. The confidence of the results is constrained within an error of ± 0.03 mm/yr, deriving from the differences between the theoretical and actual elevations of the paleocoastlines, tabelled as Δ in the figure.

about 450 (I), 365 (II), 254 (III), 140 (IV) and, finally, 35 (V) m a.s.l.. Minor paleoshorelines, carving the 2 km-wide platform (IV), have been detected at about 100 m and 70 m a.s.l., respectively.

The apparent eustatic curve, reconstructed in the area (Fig. 6), has been constrained for a uplift-rate of about 1.1 mm/yr constant in the time, taking in account the elevation of the inner-edge of the 125-ka marine platform, displaced at about 140 m a.s.l. (Catalano & Cinque, 1995; Catalano & De Guidi, 2002). The result is a precise correlation, confined within an error of 2m, between the displaced strandlines with the elevation of the sea-level, predicted in the diagram, attained during the transgression of the OIT stages 11, 9, 7, 5 and 3. The two strandlines, carving the 125-ka platform, are fitting the eustatic peaks of the 5.3 and 5.1 OIT sub-stages, respectively.

This values is consistent with the available biostratigraphical data on terraced marine deposits, cropping out in the region (Bonfiglio & Violanti, 1984; Catalano & Di Stefano, 1997), indicating an uniform 1.1 mm/yr uplift-rate active since the 600 ka.

The long-term uplift-rate, calculated on the Tyrrhenian coast of Sicily, is also fitting the results about the Late Quaternary uplift-history reconstructed, at regional scale, by several Authors (Hearty *et al.*, 1986; Westaway, 1993; Miyauchi *et al.*, 1994), indicating values ranging from 1.1 to 0.8 mm/yr.

6. UPLIFT RATE ALONG THE RIFT ZONE

The evaluation of the Late Quaternary uplift-rate along the seismogenic fault belt of the Siculo-Calabrian Rift Zone has been stressed out in the Straits of Messina region, between the Villa S.Giovanni-Reggio Calabria area of southern Calabria, and along the Ionian coast of the Peloritani Mountains, in northeastern Sicily.

6.1. **Southern Calabria**

Southern Calabria is affected by the seismogenic Scilla and Reggio Calabria faults, responsible for the main shocks of the 1783 and 1908 seismic events, respectively. The area of interference between the two fault segments, pictured in Fig. 7, is located in the Villa S.Giovanni area. In this region, a flight of marine terraces is distributed across the faulted area. Terraced deposits, ranging in age from 100 to 60 ka (Balescu *et al.*, 1997), are differently displaced on the bridge between the two segments and on the footwall of Reggio Calabria fault. In the Villa S. Giovanni area, 60 ka-old deposits (3.3 OIT stage of Bassinot *et al.*, 1994) are related to a inner-edges located at about 40 m a.s.l., suggesting an averaged uplift-rate of about 1.15 mm/yr. On the footwall of the Reggio Calabria fault, terraced deposits of about 100 ka (5.3 OIT stage of Bassinot *et al.*, 1994) are bordered by an inner-edge displaced at about 130 m a.s.l., indicating an averaged uplift rate of about 1.5 mm/yr. A discrete increase of the vertical displacement-rate of the Late Quaternary marine deposits, thus, occurs as the active Reggio Calabria fault is crossed. In addition, a variation of the uplift-rate must be accounted, also, along the strike of the active structure, as the upthrown marine terraces are severely tilted towards the northern tip of the structure. These observations imply that the difference in the uplift-rate (0.35 mm/yr) recorded across the fault, can be confidently explained as the effect of an additional vertical-displacement rate, induced by slips along the faults, dramatically decreasing towards the tip.

In southern Calabria, the uplift rate of both the hangingwall and the footwall of the Reggio Calabria fault, partitioned vs. the time with the resolution of the OIT stages, has been graphically represented by the two apparent eustatic curves of Fig. 8. The two diagrams take in account the vertical displacement of the inner-edges of marine terraces, adopted as level data to identify the mean sea level during the different highstands.

In the Villa S.Giovanni area, in the hangingwall of the structure, the inner-edges of the marine platforms, ranging in age from 125 to 60 ka, are distributed from 200 to 40 m a.s.l. (Fig. 7). The deformed eustatic curve (Fig. 8a) indicates a main change in the uplift-rate, from 3.7 mm/yr to 1-1.1 mm/yr, which occurred at about 100 ka.

In the footwall of the fault, the apparent eustatic

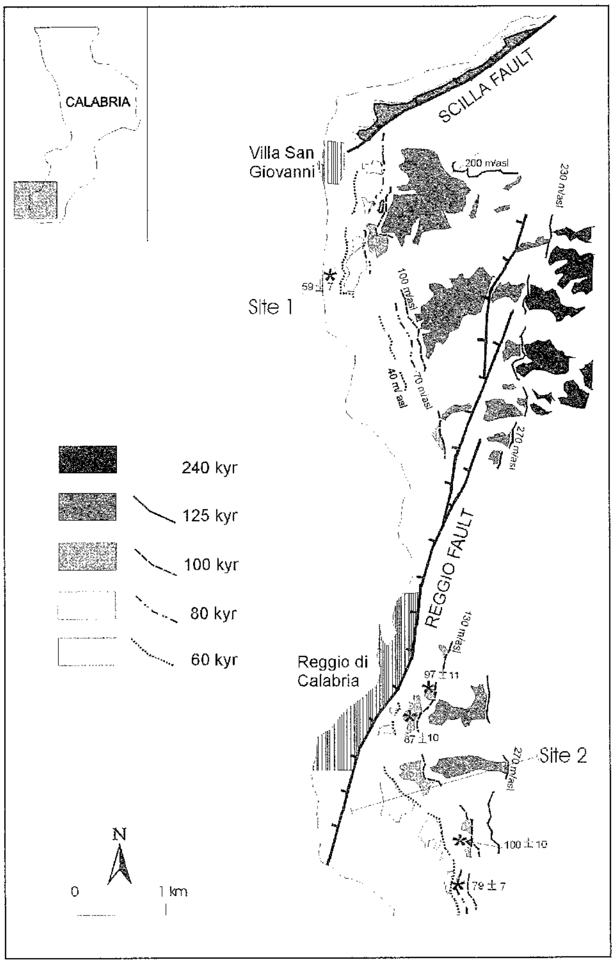
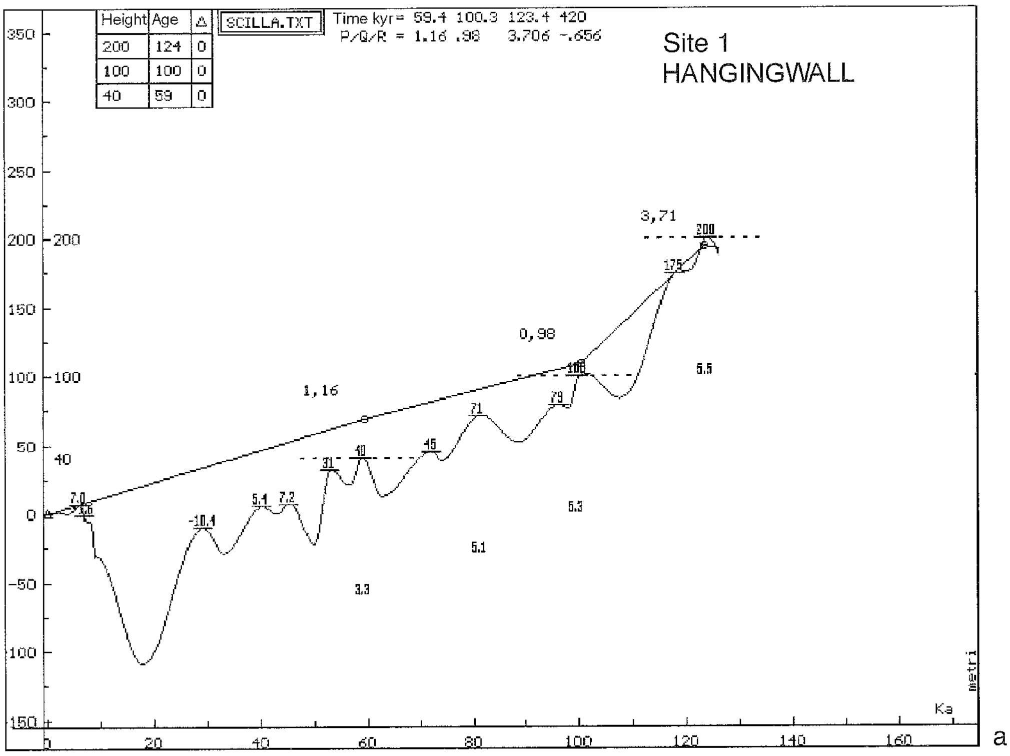


Fig. 7 – Late Quaternary marine terraces across the interference zone between the Scilla and the Reggio Faults, along the western coast of the southern Calabria (for the location see the inset).
The figure shows the distribution and the elevation a.s.l. of the marine abrasion platforms and their inner-edges ranging in age from 240 to 60 ka. The terraces dating have been based on the data from Balescu *et al.*, (1997) (stars indicate the sampled terraced deposits).



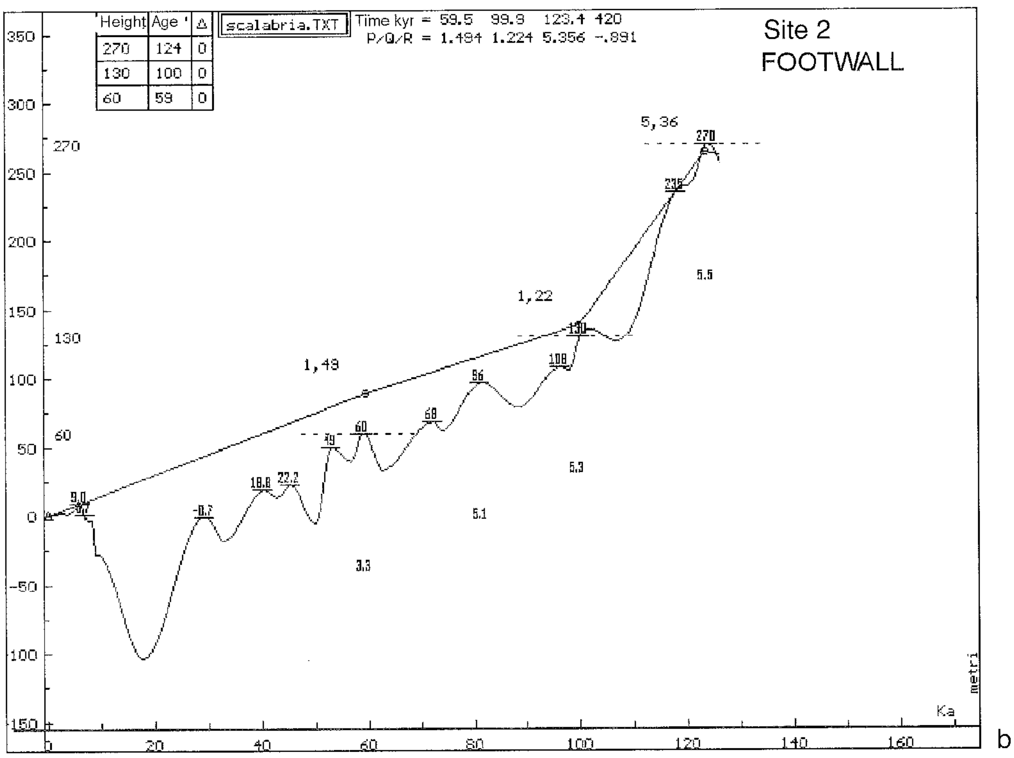


Fig. 8 - Apparent eustatic curves based on the elevation of the inner-edges of the marine terraces across the Reggio Faults (for the location see Fig. 7):

a) – apparent eustatic curve, referring to the hangingwall of the fault. The reconstructed uplift-history indicates two main changes, in the uplift-rate, from 3.7 mm/yr to 1 and from 1 to 1.1 mm/yr, which occurred at about 100 and 60 ka, respectively.

b) - apparent eustatic curve, related to the footwall. The curve indicates two well defined changes of the uplift-rate, from 5.4 to 1,2 and from 1.2 to 1.5, which, occurred at 100 and 60 ka respectively.

curve, reproducing the distribution of the Late Pleistocene marine terraces from 270 to 60 m a.s.l., indicates two well defined changes of the uplift-rate, from 5.4 to 1,2 mm/yr and from 1.2 to 1.5 mm/yr, which, occurred at 100 and 60 ka respectively (Fig 8b).

It is to remark that a very huge uplift-rate, from 3 to 5 times higher than the regional, affected both the footwall and the hangingwall of the Reggio Calabria Fault, during the 125-100 ka time interval. This period was followed by a sudden decrease of the vertical motions rates, falling down to values approximating the regional component.

6.2. **Northeastern Sicily**

The Ionian coast of north-eastern Sicily is located at the footwall of the faults of the Siculo-Calabrian riftzone (Fig. 2). It is characterised by the occurrence of several marine terraces, which are preserved on the main divides of a stepped slope, deeply incised by a consequent stream pattern.

The topographic profiles drawn across the divides show two main inflexion points, separating a gently inclined upper sector, a staircase-shaped intermediate segment and, finally, a very steep coastal slope (Fig. 9). The morphological evolution of the area started from the dissection of a low-energy continental landscape, which is now preserved in isolated relics (e.g. Monte Scuderi) at about 1250 m a.s.l..

In the upper gently inclined portion of the Ionian slope, relics of old landscapes, distributed at an elevation from 950 to 650 m a.s.l., form almost 4 distinct orders of erosion surfaces showing U-shaped valleys, infilled with continental deposits, which are slightly enclosed in levelled rounded crests. These morphologic features suggest that the mature low energy-relief landscapes derived by the complete replacement, in a continental environment near the erosion base-level, of pre-existing marine erosion surfaces, which were located at the elevation of the Present-day rounded crests. The development of this type of landscapes required a prolonged stability of the erosion base-level, suggesting very low uplift-rate.

The intermediate staircase-shaped sector of the slope is carved by wide terraces, which are referable to four distinct stages of marine abrasion. The inner-edges of these terraces have been recognised at elevations ranging from 615 to 230 m a.s.l.. The relics of these terraces still show the features of policyclic marine abrasion platforms, preserved beneath a veneer of continental deposits. Continental gravels, containing 200 ka-mammal fauna (*Hippopotamus pentlandi* and *Cervus siciliae*; SEGUENZA, 1900; 1902; BONFIGLIO, 1991; BADA ET AL., 1991), cover the terrace of Taormina, which is elevated at about 230 m a.s.l.. The development of these elevated surfaces can be referred to a short period of evolution in a continental environment, without any effect of fluvial erosion, which was followed by a deep entrenching of the fluvial streams. This second generation can be, thus, referred to a period of faster uplifting.

The lower part of the slope, which shows a very steep profile directly hanging on the coastline, is carved by several well-preserved marine abrasion platforms. The complete flight of terraces has been recognised in the Taormina area and comprises, at the top, the marine terrace that, undercutting the 200-ka continental deposits, is now displaced at about 180 m a.s.l., in the Taormina area, and at about 210 m a.s.l., in the Alì area. The lower terraces are represented by four main abrasion platforms, ranging in elevation from 130 to 20 m a.s.l., while clear marine-marks, such as small benches, characterise a strandline elevated at about 9 m a.s.l.. Sudden entrenching of the fluvial streams, preserving the elevated marine features by the deposition of alluvial horizons, must be invoked to explain the occurrence of this typology of terraces. This suggests their development under the condition of very high-rate of uplifting.

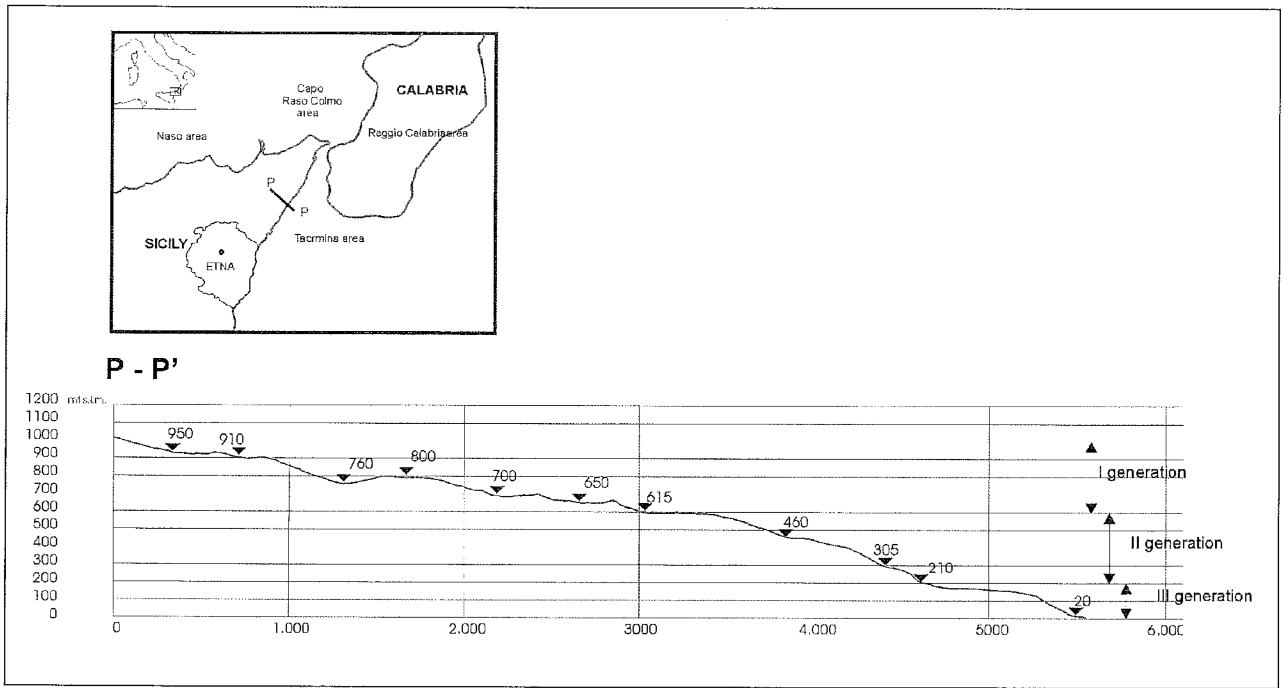


Fig. 9 – Topographic profile across the Ionian coast of north-eastern Sicily showing three generations of marine terraces.

At place, the Ionian coast of the Peloritani Mountains shows sea-cliffs, characterised by 150m-high triangular facets, replacing the terraced slope. Their location is on the near-shore prolongation of sub-marine scarps, ranging in height from 150 to 200 m, detected by a high-resolution digital elaboration of the local bathymetry (Fig. 4).

The distinctive morphologic features, characterising the three generations of terraces (Fig. 9), indicate the effects of, at least, two main changes in the uplift-rate during the emergence of the area. The youngest change in the uplift rate is well imaged in the time/elevation diagrams (Fig. 10), reproducing the apparent eustatic curve for the last 420 ka, reconstructed by the elevation of the inneredges of the Late Quaternary marine terraces, in different sites of measurement. The age of terraces has been constrained in the Taormina area, where the 200 ka-old continental deposits overhang the marine terraces younger than the OIT stage 7. The confidence of the results has been demonstrated by the coincidence of the main Late Quaternary high-stands with marine marks occurring at the elevation predicted in diagrams. The reconstructed apparent eustatic curves indicate a sudden increase of the vertical motion, from a rate of about 0.7-0.9 to a rate of 1.4-1.6 mm/yr, affecting, since 125 ka, a 40 km-long segment of the coast. The values of the final faster uplifting is consistent with those resulting from absolute dating of the Holocene notch-levels in the Taormina area (STEWART *et al.*, 1997). It is to note that the diagram reconstructed at the Briga site, in the surroundings of Messina, indicates an almost constant uplift-rate, ranging from 0.9 to 1.1 mm/yr, affecting the area in the whole considered time interval (420 ka to the Present). This same behaviour characterises the region to the south of the tip of the Taormina fault segment, in the Alcantara River Plain (CATALANO & DE GUIDI, 2002). The constant uplift-rate recorded at the northern and southern tips of the master fault zone, undoubtedly, indicate that the increase in the rate of vertical motions, during the last 125 ka, has been confined to the footwall of the Ionian active faults of the rift zone. The variation of uplift regime is, thus, to relate to contributions of the normal faulting deformation affecting the area.

7. UPLIFT-RATE AND NORMAL FAULTING DEFORMATION

The uplift-rates calculated along the rift zone consist of three main components: the regional and the two faulting-induced vertical motions, co-seismic and post-seismic, predicted by models (KING *et al.*, 1988). The three components add each other on the footwall of large seismogenic normal faults. Conversely, in the hangingwall of the structure opposite signs characterise the co-seismic and the post-seismic vertical motions, as the former results in an absolute subsidence of the downthrown block and the latter consist of a long-term uplift of a large sector centred on the fault (KING *et al.*, 1988). The effects of the three combined components have been recorded by the apparent eustatic curves (Fig. 8), reconstructed for the footwall and the hangingwall of the Reggio Calabria Fault. They point out a common behaviour of the uplift-rate, only differing in terms of the absolute value, exclusively depending on the difference in sign of the co-seismic components. These are connected to the slip-rate measured along the Reggio Calabria Fault which can be partitioned in the time, on the basis of the vertical-displacements of the successive Late Quaternary marine terraces. As the 125 ka, 100 ka and 60 ka marine terraces have been, respectively, displaced across the fault for 70, 30 and 20 m, slip-rates varying from 1.6 mm/yr, in the 125-100 ka interval, to 0.2-0.3 mm/yr, in the post-100 ka period can be evaluated. As the partition of the total slip-rate into hangingwall subsidence and footwall uplift is unknown, the total amount of the long-term component of the uplift can be only coarsely defined, considering that the two possible end-values in the range of variation are represented by the two diagrams of fig. 8. They actually stress out the variations in the time of the amount of the post-seismic rebounds, affecting the area, since the regional component of the uplift can be considered constant at about 1 mm/yr. The two diagrams, both, predict, for the 125-100 ka intervals, amounts of post-seismic releases anomalously high (from 1.7 to 2.7 times) with regard to the co-seismic motions. Moreover, in both the cases, a clear positive correlation exists between the amount of the co-seismic displacements and of the post-seismic deformations, relaxed on long term, as largely predicted by models. These evidences suggest the occurrence, in the earlier part of the Late Pleistocene, of huge releases of elastic deformation, associated with anomalously high post-seismic readjustments, concentrated along this sector of the fault belt.

The Tyrrhenian (5.5 OIT stage) represents a critical period also in the uplift-history of the Ionian coast of the north-eastern Sicily, as it is characterised by a sudden increase of the uplift rate due to normal faulting. The marine terraces formed before the 5.5 OIT stage have been vertically displaced at a rate ranging from 0.7 to 0.9 mm/yr, regularly increasing to the north (Fig. 10). On the footwall of the active faults, the higher vertical displacement-rate, occurred since the 125 ka, included both the regional and the fault induced, co-seismic and relaxed, components of vertical motions. A coarse evaluation of the total vertical displacement on the fault planes can be predicted taking into account the height of the triangular facets, marking the on-shore prolongation of the faults (150m) and the inferred height of the submerged fault scarps (200-150m). These values suggest that an averaged vertical displacement-rate, including the hangingwall subsidence and the footwall uplift, ranging from 1.6 to 1.2 mm/yr must be accounted in the last 125 ka.

8. DISCUSSION AND CONCLUSION

The performed analyses show that the vertical displacement-rate of the Late Quaternary marine deposits and platform abrasions recorded the evolution in the time of the faulting induced deformations, since they resulted as additional components of the uplift-rate. This is well shown by the distinctive long-term behaviour of the uplift processes which characterise the active rifting zone, where the vertical displacement-rate of the marine terraces has been rapidly changing both in the time and in the space. Conversely, an almost constant uplift-rate affected the areas out of the influence of the active normal fault deformations, where the vertical motions derived only by the regional scale dynam-

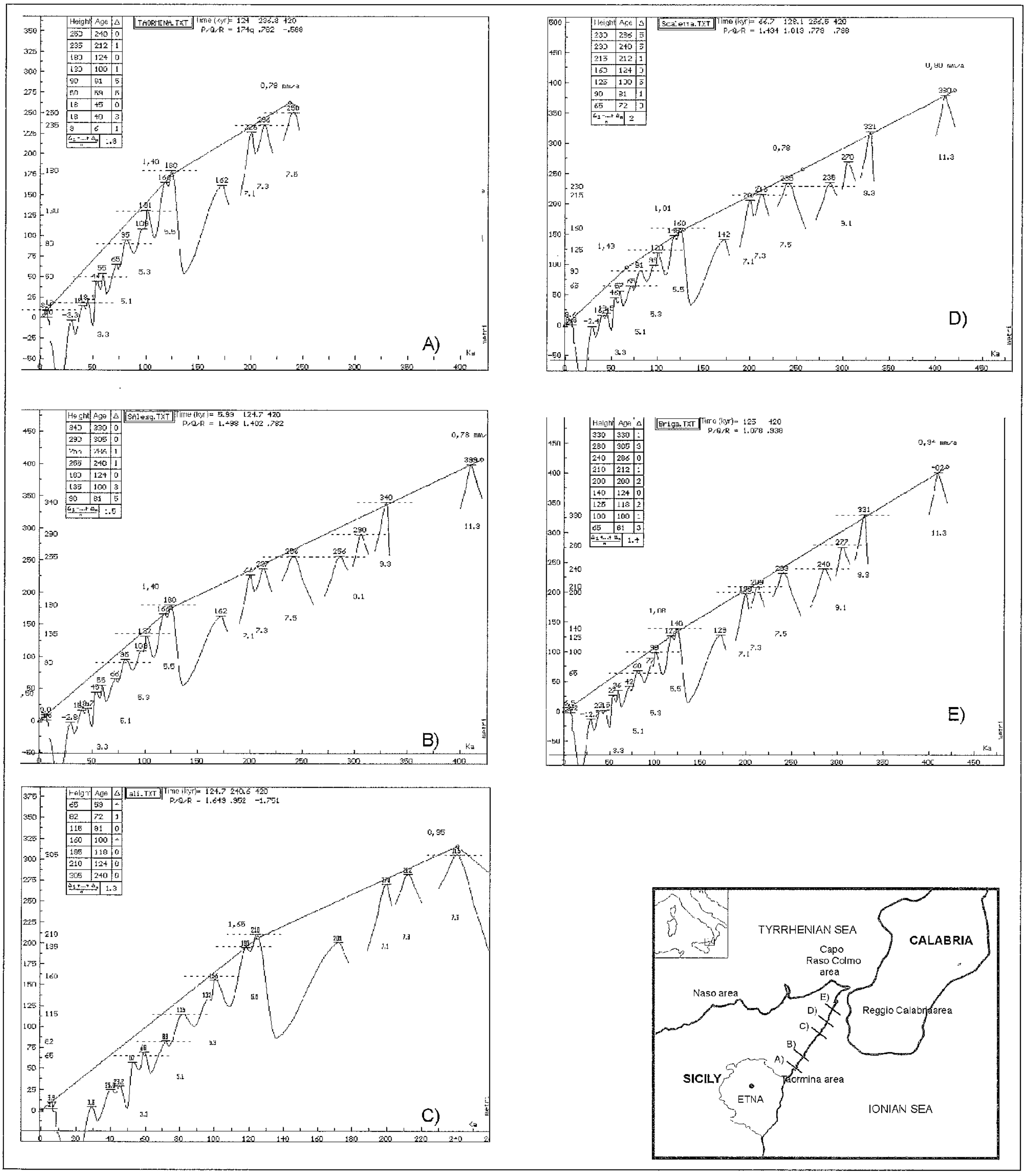


Fig. 10 – Apparent eustatic curves reconstructed by the elevation of the inner-edges of the Late Quaternary marine terraces, in different sites of north-eastern Sicily (for location see inset). The collected data have been adopted to reconstruct the uplift history during the last 420 ka. The diagrams point out a sudden increase of the rate in vertical motion, from a rate of about 0.8-0.9 to a rate of 1.4-1.6 mm/yr, characterising a 40 km-long segment of the coast, starting from 125 ka.
In the surroundings of Messina (Briga site) an almost constant uplift-rate, ranging from 0.9 to 1.1 mm/yr affected the area in the whole considered time interval (420 ka to the Present).

ics. The interference between the regional uplifting and the faulting-induced vertical motions has been clearly detected in the geomorphic evolution of the Ionian coast of Sicily, where a sudden increase of the uplift-rate occurred along the fault-controlled sectors of the coast, at about 125 ka. This evidence strongly indicates the propagation of the active faults of the rift zone in the area, long after the normal faulting affected the Southern Calabria, since 300 ka (MONACO & TORTORICI, 2000). The difference in age of the active faults, indicating the migration from southern Calabria to northeastern Sicily is, also, evident by comparison of the morphologic features of the fault scarps. Very high fault scarps, displaying different generation of triangular facets, characterise the southern Calabria. Lower scarps, showing a single generation of triangular and trapezoidal facets, occur in northeastern Sicily.

The propagation of the active faults in north-eastern Sicily was associated to a very high displacement-rate (1.6 mm/yr) and post-seismic elastic rebound (from 2.7 to 4.3 mm/yr) on the active faults affecting the southern Calabria, from 125 to 100 ka. This suggests the occurrence of anomalous high elastic deformation cumulated in the area, before that period.

The prolonged stop of the fault propagation, on the Calabrian side of the Straits, and the transient mechanic behaviour of the active faults of southern Calabria, during the time-interval 125-100 ka, can be related to the main crustal change occurring in the Straits of Messina region. The area, infact, represents the boundary zone between the thinned crust of the peri-Tyrrhenian belt and the thickened crust of the hinge-zone of the Calabrian arc (Fig. 2), which represents a crustal barrier exerting huge amount of elastic strength.

During the Late Pleistocene the releases of the elastic deformation along the Southern Calabria fault segments, likely, triggered the fault propagation on the Sicilian side of the Straits. The relation between the two processes is suggested by the sudden decrease of both the vertical displacement-rate and the post-seismic rebounds on the active faults of the southern Calabria, as the southward fault propagation, on the Ionian coast of Sicily, occurred.

It is also to remark that, during the final stage of the evolution of the rift zone, the highest displacement-rate has been evaluated on the northeastern Sicily, where a gap of the historical seismicity occurs. This evidence strongly suggests that, at the Present, the crustal barrier of the axial zone still exert a high elastic strength at the southern tip of the Taormina Fault, as the huge vertical-displacements must be accounted on very long periods of recurrence.

In conclusion, the analysis of the long-term behaviour of the active faults in the Straits of Messina area pointed out that the occurrence of crustal barrier influences the geometry, the mechanics of faulting and the fault propagation. Geometrically, a transfer zone evidences the crustal barrier that, from a mechanical point of view represents a transient strengthen area where huge elastic deformation is absorbed on long periods, directly influencing the recurrence of the seismic events. This reflects also on the fault propagation, which is temporary inhibited on the barriers as long as ruptures affecting discrete fault segments are triggered by the releases of elastic deformations cumulated during the stop of the propagation.

REFERENCES

AMBROSETTI W., BOSI C., CARRARO F., CIARANFI N., PANIZZA M., PAPANI G., VEZZANI L. & ZANFERRARI A. (1987) - *Neotectonic map of Italy*. Scale 1:500.000. C.N.R., Rome.

ARMIJO R., MEYER B., KING G.C.P., RIGO A. & PAPANASTASSIOU D. (1996) - *Quaternary evolution of the Corinth Rift and its implications for the Late Cenozoic evolution of the Aegean.* Geophys. J. Int., **126**, 11-53.

BADA J. L., BELLUOMINI G., BONFIGLIO L., BRANCA M., BURGIO E. & DELLITALA L. (1991) – *Isoleucine epimerization ages of Quaternary Mammals of Sicily.* Il Ouaternario, **4**, 49-54.

BALESCU S., DUMAS B., GUERMY P., LAMOTHE M., LHENAFF R. & RAFFY J. (1997) - *Thermoluminescence dating test of Pleistocene sediments from uplifted shorelines along the southwest coastline of the Calabrian peninsula (southern Italy).* Palaeo. Palaeo. Palaeo., **130**, 25-41.

BARATTA M. (1901) - *I terremoti d'Italia.* Arnoldo Forni Editore, Bologna.

BARATTA M. (1910) - *La catastrofe sismica calabro-messinese (28 Dicembre 1908).* Relazione alla Soc. Geogr. Ital.

BASSINOT F. C., LABEIRYE L.D., VINCENT E., QUIDELLEUR X., SHACKLETON N.J. & LANCELLOT Y. (1984) - *The astronomical theory of climate and the age of the Brunhes-Matuyama magnetic reversal.* Earth Plant.Sci. Lett., **126**, 91-108.

BEN AVRAHAM Z., BOCCALETTI M., CELLO G., GRASSO M., LENTINI F., TORELLI L. & TORTORICI L. (1990) - *Principali domini strutturali originatesi dalla collisione Neogenica-Quaternaria nel Mediterraneo centrale.* Mem. Soc. Geo. It., **45**, 453-462. 1

BIANCA M., MONACO C., TORTORICI L. & CERNOBORI L. (1999) - *Quaternary normal faulting in southeastern Sicily (Italy): a seismic source for the 1693 large earthquake.* Geophys. J. Int., **139**, 370-394.

BOCCALETTI M., NICOLICH R. & TORTORICI L. (1990) - *New data and hypothesis on the development of the tyrrhenian basin.* Paleogeog. Paleoclimat. Plaeoecol., **77**, 15-40.

BONFIGLIO L. (1991) - *Correlazione tra depositi a mammiferi, depositi marini, linee di costa e terrazzi medio e tardo-Pleistocenici nella Sicilia orientale.* Il Quaternario, **4**, 205-214.

BONFIGLIO L. & VIOLANTI D. (1984) – *Prima segnalazione di Tirreniano ed evoluzione pleistocenica del Capo Peloro (Sicilia nord-orientale).* Geogr. Fis. Dinam. Quat., **6**, 3-15

BOSCHI E., FERRARI G., GASPERINI P., GUIDOBONI E., SMRIGLIO G. & VALENSISE G. (1995) - *Catalogo dei forti terremoti in Italia dal 461 a.c. al 1980.* Istituto Nazionale di Geofisica, S.G.A., Roma.

BOSCHI E., GUIDOBONI E., FERRARI G., VALENSISE G. & GASPERINI P. (1997) - *Catalogo dei forti terremoti in Italia dal 461 a.c. al 1990.* Istituto Nazionale di Geofisica, S.G.A., Roma.

BOSI C., AMBROSETTI P., CARRARO F., CIARANFI N., PANIZZA M., PAPANI G., VEZZANI L. & ZANFERRARI A. (1983) - *Neotectonic map of Italy.* In: Progetto Finalizzato Geodinamica - CNR, Sheet 6

BOSI C., CAROBENE L. & SPOSATO A. (1996) - *Il ruolo dell'eustatismo nella evoluzione geologica nall'area mediterranea.* Mem. Soc. Geol. It., **51**, 363-382.

CATALANO S. & CINQUE A. (1995) - *Dati preliminari sull'evoluzione neotettonica dei Peloritani settentrionali (Sicilia nord-orientale) sulla base dei dati morfologici.* Studi Geol. Camerti, Vol. Spec. 1995/2, 113-123.

CATALANO S. & DE GUIDI G. (2002) – *Late quaternary uplift of north-eastern Sicily: relation with the active normal faulting deformation.* J. Geodynamics, in press.

CATALANO S. & DI STEFANO A. (1997) - *Sollevamento e tettogenesi Pleistocenica lungo il margine tirrenico dei Monti Peloritani: integrazione dei dati geomorfologici, strutturali e biostratigrafici.* Il Quaternario, **10**, 337-342.

CELLO G., GUERRA I., TORTORICI L., TURCO E. & SCARPA R. (1982) – *Geometry of the neotectonic stress field in southern Italy: geological and seismological evidence.* J. Struct. Geol., **4**, 385-393.

CRISTOFOLINI R., LENTINI F., PATANÈ G. & RASÀ R. (1979). *Integrazione dei dati geologici, geofisici e petrologici per la stesura di un profilo crostale in corrispondenza dell'Etna.* Mem. Soc. Geo. It., **98**, 239-247.

CHAPPEL J. & SHACKLETON N.J. (1986) - *Oxygen isotopes and sea level.* Nature, **324**, 137-140.

CINQUE A., DE PIPPO T. & ROMANO P. (1995) - *Coastal slope terracing and relative sea-level changes: deductions based on computer simulations.* Earth Surface Processes and Landforms, **20**, 87-103.

DEWEY J.F., HELMAN L.M., TURCO E., HUTTON D.W.H. & KNOTT S.D. (1989) - *Kinematics of the western Mediterranean.* Spec. Publs. Geol. Soc. London, **45**, 265-283.

DUMAS B., GUEREMY P., LHENAFF R. & RAFFY J. (1978) - *Relief et néotectonique de la facade orientale du detroit de Messine (Calabre, Italie).* Trav. R.C.P. CNRS, **461**, 105-125.

FINETTI I. (1982) - *Structure, stratigraphy and evolution of central Mediterranean.* Boll. Geof. Teor. Appl., **24**, 247-312.

FINETTI I., LENTINI F., CARBONE S., CATALANO S. & DEL BEN A. (1996) - *Il Sistema Appennino Meridionale-Arco Calabro-Sicilia nel Mediterraneo centrale: studio geologico-geofisico.* Mem. Soc. Geol. It., **115**, 529-559.

GASPARINI C., IANNACONE G., SCANDONE P. & SCARPA R. (1982) – *Seismotectonics of the Calabrian Arc.* Tectonophysics, **82**, 267-286.

GAWTHORPE R.L. & HURST J.M. (1993) - *Transfer zones in extensional basins: their structural style and influence on drainage development and stratigraphy.* Journal of the Geological Society, London, **150**, 1137-1152.

GHISETTI F. (1979) - *Evoluzione neotettonica dei principali sistemi di faglie della Calabria centrale.* Boll. Soc. Geol. It., **98**, 387-430.

GHISETTI F. & VEZZANI L. (1982) - *Different styles of deformation in the calabrian arc (southern italy): implications for a seismotectonic zoning.* Tectnonophysics, **85**, 149-165.

HEARTY P.J., BONFIGLIO L., VIOLANTI D. & SZABO B.J. (1986) - *Age of Late Quaternary marine deposits of Southern Italy determined by aminostratigraphy, fanual correlation, and uranium-series dating.* Riv. It. di Paleont. e Stratig., **92**, 149-164.

JACQUES E., MONACO C., TAPPONIER P., TORTORICI L., & WINTER T. (2001) - *Faulting and Earthquake triggering during the 1783 Calabria sequence.* Geophys. J. Int., **147**, 499-516.

KING G.C.P., STEIN R.S. & RUNDLE J.B. (1988) - *The growth of geological structures by repeated earthquakes. 1. Conceptual Framework.* J. Geophys. Res., **93**, 13307-13318.

LAJOIE K.R. (1986) - *Coastal Tectonics.* Studies in Geophysics, National Academy Press, Washington, 95-124.

LOCARDI E. & NICOLICH R. (1988) - *Geodinamica del Tirreno e dell'Appennino centro-meridionale: la nuova carta della moho.* Mem. Soc. Geol. It., **41**, 121-140.

MAZZAGLIA S. (1999) – *EUSTAT: un programma di simulazione per la valutazione dei tassi di sollevamento tardo quaternari.* Unpublished Thesis, Catania University, 1999.

MIYAUCHI T., DAI PRA G. & SYLOS LABINI S. (1994) - *Geochronology of Pleistocene marine terraces and regional tectonics in the tyrrhenian coast of south Calabria, Italy.* Il Quaternario, **7**, 17-34.

MONACO C., TORTORICI L., CERNOBORI L., NICOLICH R. & COSTA M. (1996) - *From collisional to rifted basins: an example from the southern Calabrian Arc (Italy).* Tectonophysics, **266**, 233-249.

MONACO C., TAPPONIER 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 tha Calabrian arc and eastern Sicily.* J. Geodynamics, **29**, 407-424.

NICOLICH R. (1981) - *Crustal Structures in the Italian peninsula and surroundings seas: a review of DSS data.* In: F.C. Wezel (ed.) - Sedimentary basins of Mediterranean margins Tecnoprint, Bologna, 3-17.

PANZA G.F., MUELLER S. & CALCAGNILE G. (1980) - *The gross features of the lithosphere-asthenosphere system in Europe from seismic surface wawes and body wawes.* Pure Appl. Geophys., **118**, 1209-1213

POSTPISCHL D. (1985) - *Catalogo dei terremoti italiani dall'anno 1000 al 1980.* CNR, P.F. Geodinamica, Graficcop Bologna.

SARTORI R., COLALONGO M.L., GABBIANELLI G., BONAZZI C., CARBONE S., CURZI P.V., EVANGELISTI D., GRASSO M., LENTINI F., ROSSI S. & SELLI L. (1991) - *Note stratigrafiche e tettoniche sul rise di Messina (Ionio nord-occidentale).* G. Geol., **53**, 49-64.

SCANDONE P., BIGI G., COSENTINI D., PAROTTO M. & SARTORI R. (1991) - *Structural model of Italy.* In: Progetto Finalizzato Geodinamica - CNR, Sheet 6.

SCANDONE P., CARROZZO M.T., LUZIO D., MARGIOTTA C. & QUARTA T. (1991) - *Gravity map of Italy.* Progetto Finalizzato Geodinamica - CNR, Sheet 3.

SELLI R. & FABBRI A. (1971) - *Tyrrhenian: a Pliocene deep-sea.* Rend. Atti Accad. Naz. Lincei., **50**, **5**, 580-592.

SHACKLETON N.J. & OPDYKE N.D. (1973) - *Oxygen isotope and paleo-magnetic stratigraphy of Equatorial Pacific core V28-238: Oxygen isotope temperature and ice volumes on a 105 year and 106 year time scale.* Quat. Res., **3**, 39-55.

STEWART I., CUNDY A., KERSHAW S. & FIRTH C. (1997) - *Holocene coastal uplift in prolongation of the Calabrian seismogenetic belt.* J. Geodynamics, **24**, 37-50.

TORTORICI L. (1983) - *Lineamenti geologico-strutturali dell'arco calabro-peloritano.* Rend. Soc. Ital. Min. Petr., **38**, 927-940.

TORTORICI L., TAPPONIER P. WINTER T. (1986) - *Faulting during the 1783 Calabria earthquakes and tectonics of the Messina Strait.* EOS Trans. Am. Geophys. Union, **67**, 1188.

TORTORICI L., MONACO C., TANSI C. & COCINA O. (1995) - *Recent and active tectonics in the Calabrian arc (Southern Italy).* Tectonophysics, **243**, 37-55.

WESTWAY R. (1993) - *Quaternary uplift of southern Italy*. J. Geophys. Res., **98**, 21741-21772.