P. MOLIN*, F. DRAMIS* & E. LUPIA PALMIERI**

THE PLIOCENE-QUATERNARY UPLIFT OF THE IONIAN NORTHERN CALABRIA COASTAL BELT BETWEEN CORIGLIANO CALABRO AND CAPO TRIONTO

INDEX

ABSTRACT

A model of the Plio-Pleistocene evolution of the northern Calabria Peri-ionian sector, between Corigliano and Capo Trionto, is proposed on the basis of morphological and sedimentary analysis. The main morphological features are gently undulated surfaces on the Sila Massif summits, five orders of fluvial terraces (Qt_1, Qt_2, Qt_3, Qt_4, and Qt_5) located in the watersheds of the hilly coastal belt, and structural scarps of a NW-SE trending extensional fault system, which separates the Sila Massif from the hilly coastal belt.

The northern slope of the Sila Massif is underlain by outcrops of Paleozoic granite and schist, whereas the coastal belt to the North is underlain by upper Pliocene–lower Pleistocene sand, clay and conglomerate. These sediments are unconformably overlain by middle and upper Pleistocene conglomerate and sand deposits. Sedimentary features suggest that the middle and upper Pleistocene sediments were deposited in a fan–delta and alluvial plain environment. These deposits are associated with five orders of terraces thought to be coincident with climatic/eustatic changes responsible for cyclic occurrence of stream aggradation/incision and marine erosion. Rock uplift and subsequent incision produces the accommodation space to preserve these deposits. Correlating the marine erosion surfaces with marine terraces found in neighboring areas, it has been possible to relate the 7, 5e, 5c, 5a, and 1 isotopic stages to the Qt_1, Qt_2, Qt_3, Qt_4, and Qt_5 orders respectively and to calculate a mean uplift rate of ~1 mm/yr.

On the basis of the above mentioned morphological and geological features a hypothesis of evolutionary model is proposed. Before the upper Pliocene a slow emergence occurred producing, together with arid or semi-arid climate conditions, a landscape probably dominated by areal erosion. During upper Pliocene and lower Pleistocene extensional tectonic structures began to displace the previous landscape, separating the emerging area from a subsiding marine basin. Then the uplift began to affect the subsiding basin too and, during middle-upper Pleistocene and Holocene, the uplift together with climatic/eustatic variations caused the formation and preservation of the terrace sequence.

RIASSUNTO

Sulla base di osservazioni geomorfologiche e sedimentologiche viene proposto un modello dell'evoluzione Plio-Pleistocenica del settore peri-ionico della Calabria settentrionale compreso tra il paese di Corigliano e Capo Trionto.

Le caratteristiche morfologiche principali dell'area studiata sono rappresentate da superfici gentilmente ondulate localizzate sulle regioni apicali del Massiccio della Sila, cinque ordini di superfici terrazzate (Qt_1, Qt_2, Qt_3, Qt_4 e Qt_5) presenti sulla porzione degli spartiacque ubicata nella fascia collinare costiera, scarpate strutturali di un sistema di taglio estensionale che, orientato NW-SE, divide il massiccio silano dalla fascia costiera collinare.

Nell'area esaminata affiorano, sul versante settentrionale della Sila, graniti e scisti paleozoici, mentre, nella fascia collinare costiera, argille, sabbie e conglomerati depostisi dal Pliocene superiore al Pleistocene inferiore. Il tetto di tali sedimenti è tagliato da una superficie d'erosione su cui poggiano depositi conglomeratico-sabbiosi pleistocenici che costituiscono il corpo delle superfici terrazzate. In base ai caratteri sedimentologici, si ritiene che questi depositi si siano deposti in ambiente di delta-conoide e di piana alluvionale. I cambiamenti climatici ed eustatici hanno provocato cicli di incisione ed aggradazione fluviale ed erosione marina che hanno prodotto morfologie terrazzate, la cui preservazione è avvenuta grazie al sollevamento che interessa l'area. Correlando la superficie di abrasione marina che sottende i depositi di delta-conoide e di piana alluvionale con i terrazzi marini studiati nelle aree limitrofe, è stato possibile riferire gli stadi isotopici 7, 5e, 5c, 5a e 1 ai terrazzi Qt_1, Qt_2, Qt_3, Qt_4 e Qt_5 rispettivamente e calcolare un tasso medio di sollevamento di ~1 mm/anno.

Sulla base dei dati raccolti e delle considerazioni fatte è stato possibile ipotizzare il seguente modello evolutivo dell'area. Prima del Pliocene superiore si è verificata la lenta emersione di un rilievo che, in concomitanza con condizioni climatiche aride o semiaride, origina bassi rilievi e ampie valli. Durante il Pliocene superiore e il Pleistocene inferiore si attiva una tettonica estensionale che divide il rilievo in lenta emersione da un bacino marino in subsidenza. Quindi il sollevamento inizia ad interessare anche il bacino e dal Pleistocene medio variazioni climatiche ed eustatiche unite al sollevamento provocano la formazione e la conservazione dei terrazzi studiati.

KEY WORDS: uplift, Northern Calabria, fan-delta, climatic changes, Plio-Pleistocene

PAROLE CHIAVE: sollevamento, Calabria settentrionale, delta-conoidi, variazioni climatiche, Plio-Pleistocene

1. INTRODUCTION

The Apennines are a fold and thrust mountain belt

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characterized by active shortening in the external Adriatic zone and by Pliocene-Quaternary extension in the Tyrrhenian flank (Royden *et al.*, 1987; Patacca *et al.*, 1992; Lavecchia *et al.*, 1994). Convergence began in the early Miocene and the arc has swung south-eastwards to its current location as a results of the retreating action of the subduction zone between the European and the African-Adriatic plates (Malinverno & Ryan, 1986; Royden *et al.*, 1987; Gueguen *et al.*, 1998; Cavinato & De Celles, 1999). In this process the back-arc extension of the Balearic sea shifted some European continental crust blocks (Sardinia, Corsica, Calabria) to the south and, successively, one of them (Calabria) was rotated to the south-east by the opening of the Tyrrhenian sea (Malinverno & Ryan, 1986; Patacca *et al.*, 1992; Royden, 1993; Moretti & Guerra, 1997).

The migration and extension of the Apennines arc has been associated with a slow emergence of the accretionary wedge since late Miocene-lower Pliocene and a stronger large scale uplift since Pleistocene (Demangeot, 1972; Ambrosetti *et al.*, 1982; Brancaccio & Cinque, 1988; Cinque, 1992; Dramis, 1992; Thomson, 1994; Calamita *et al.*, 1999; Coltorti & Pieruccini, 2000).

The southern portion of the Apennines chain, the Calabria arc, is underlain by European pre-alpine plutonic and metamorphic rocks, continental and oceanic metamorphic rocks overthrusted on the forearc fold and thrust belt that involved Mesozoic sedimentary rocks of the African-Adriatic margin (Ogniben, 1973; Amodio-Morelli *et al.*, 1976; Dietrich, 1976; Lanzafame *et al.*, 1979; Boccaletti *et al.*, 1984; Critelli, 1990).

The Calabria region is affected by one of the highest uplift rate of the Apenninic chain (Ricchetti & Ricchetti, 1991), by shallow and deep seismicity and by active tectonics (Gasparini *et al.*, 1982; Tortorici *et al.*, 1995; Moretti & Guerra, 1997; Monaco & Tortorici, 2000).

The aim of this paper is the reconstruction of the Plio-Pleistocene uplift of northern Calabria. To understand this phenomenon, a field survey and an air-photos interpretation of the Ionian coastal belt and of the Sila Massif northern flank has been performed. This study has been focused on the morpho-tectonics and on the Plio-Pleistocene stratigraphy of the area to point out features that are the main keys to figure out the uplift and its rate. Finally a conceptual model of the recent evolution of the ionian portion of the northern Calabria will be proposed.

2. GEOLOGICAL SETTING

The northern portion of the Calabrian arc, is characterized mainly by the exposure of the Hercynian crystalline basament and of the Meso-Cenozoic sedimentary rocks (Ogniben, 1973; Amodio-Morelli *et al.*, 1976). Since Tortonian, northern Calabria has been deformed by NW-SE and N-S extensional tectonics and locally by compressive structures (Moussat *et al.*, 1986; Moretti, 1993; Tortorici *et al.*, 1995; Moretti & Guerra, 1997). The activity of extensional tectonics caused the formation of subsiding basins where the so-called “Complesso postorogenico” laid down (Ogniben, 1973). The “Complesso postorogenico” (Ogniben, 1973) is formed by several continental/marine sedimentary cycles that covered the paleozoic and mesozoic rock-types in a transgressive way (Ogniben, 1973; Amodio-Morelli *et al.*, 1976; Ortolani *et al.*, 1979; Romeo & Tortorici, 1980; Carobene & Damiani, 1985; Colella, 1995; Argentieri *et al.*, 1998). The clasts of this deposits are mainly made up of plutonic and metamorphic rocks of Sila (Panizza, 1966; Vezzani, 1968; Di Nocera *et al.*, 1974; Ortolani *et al.*, 1979; Romeo & Tortorici, 1980; Carobene & Damiani, 1985; Colella *et al.*, 1987; Moretti, 1993).

At the end of the lower Pleistocene, a broad regional uplift affected northern Calabria (Ciaranfi *et al.*, 1983; Colella *et al.*, 1987; Tortorici *et al.*, 1995; Moretti & Guerra, 1997). This vertical movement has been ascribed to post-orogenesis isostasy (Ogniben, 1973; Del Ben, 1993), to crustal doming caused by the tyrrhenian rifting (Bousquet, 1973), to isostasy caused by the break off and the detachment of the sinking ionian slab from upper lithosphere (Moretti, 1993), to the formation of a bulge caused by the slab reaching of the more resisting to penetration portion of the mantle (Moretti & Guerra, 1997), or to the overriding plate rebound cause by the detachment from the subducting slab (Gvirtzman & Nur, 1999).

The study area is located along the ionian coast of the northern Calabria, between Corigliano and Capo Trionto (Fig. 1). This area, including the northern slope of the Sila Massif and the underlying coastal plain, is mainly characterized by the outcrops of the Sila Paleozoic granite and schist southward (“Unità di Longobucco”, Amodio-Morelli *et al.*, 1973; “Falda dell’Aspromonte”, Ogniben, 1973) and of the sandy, clayey and conglomerate rocks of the “Ciclo tortoniano-infrapliocenico” (Ogniben, 1973) and of the “Ciclo suprapliocenico-pleistocenico” (Vezzani,

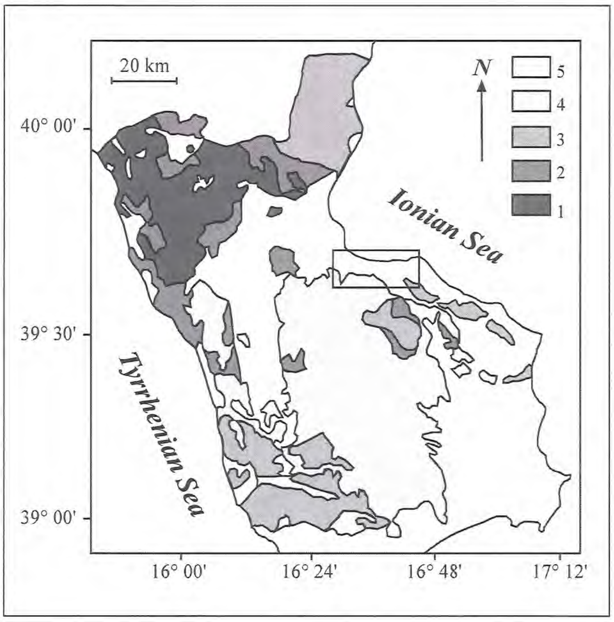

Fig. 1 - Sketch of the main rock-types cropping out in northern Calabria and location of the study area. 1) apenninic carbonatic units; 2) low-grade metamorphic units and ophiolites; 3) sedimentary, mainly flysch-type units; 4) intrusive and intermediate and high-grade metamorphic rocks of crustal alpine units; 5) sedimentary autochtonous units from Miocene to Holocene (from Sorriso-Valvo, 1993, modified).

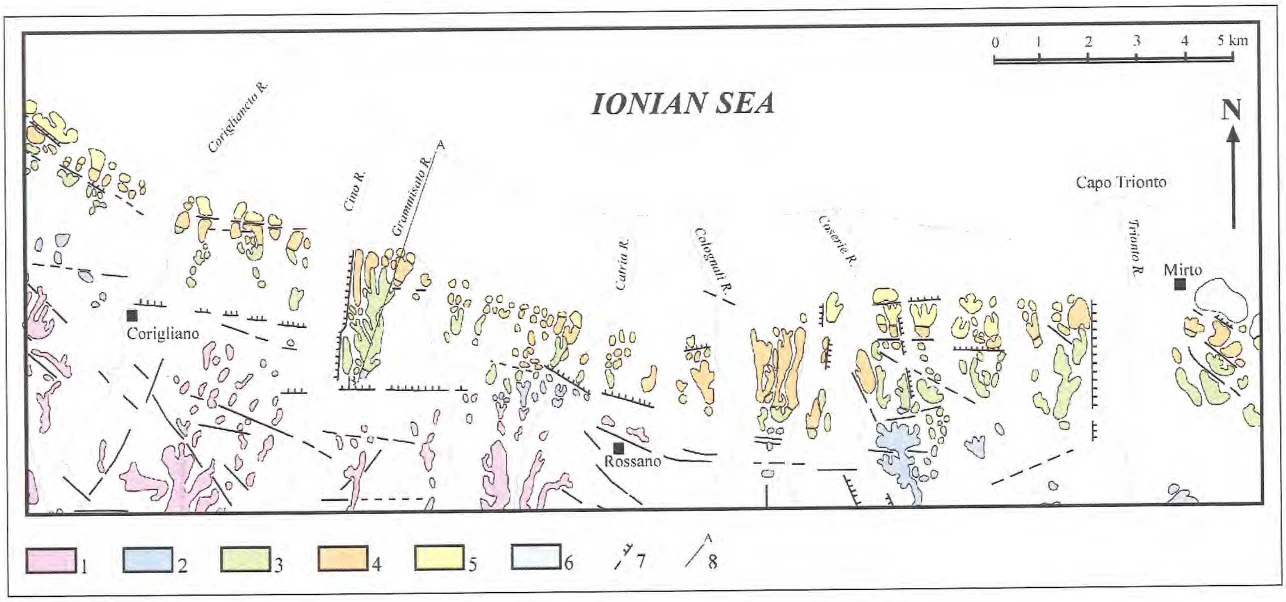

Fig. 2 - Sketch of the landforms that best describe the uplift in the study area. 1) gently undulated surfaces; 2) I order terraces (Qt_1); 3) II order terraces (Qt_2); 4) III order terraces (Qt_3); 5) IV order terraces (Qt_4); 6) V order terraces (Qt_5); 7) faults; 8) location of the cross section.

1968) northward. Middle and upper Pleistocene conglomerate and sand terraced deposits unconformably lie on the Neogene rocks (Vezzani, 1968; Ogniben, 1973; Critelli, 1990).

In the investigated area the main tectonic structures are NW-SE and WNW-ESE trending extensional fault systems that separates the Sila Paleozoic rocks from the Miocene-Present sediments cropping out seawards (Tortorici, 1981; Ciaranfi *et al.*, 1983; Moussat *et al.*, 1986; Knott & Turco, 1991; Sorriso-Valvo, 1993).

3. MAIN MORPHOLOGICAL FEATURES

Air-photo analysis and field survey have been performed to identify geomorphic elements whose genesis or present location can be indexed to quantify surface deformation. These geomorphic elements include upland surfaces, terrace treads, and tectonic scarps (Fig. 2).

In the northern flank of the Sila Massif, the upland surfaces of low relief occur on summits around 900 m down to a minimum elevation of 300-250 m. They are remnants of a old gentle undulated landscape characterized by wide valleys and gently rounded hills. The difference in elevation between the valley bottoms and the hill tops is less than 100 m and the slope percentage is mostly less than 20%. The upland surfaces are displaced by faults and delimited by present stream valleys slopes. These valleys are so deeply incised and characterized by narrow channels and very steep flanks that produce an abrupt change from the upland surfaces. These steep valley flanks are affected by landslides that, producing a slope retreating, are destroying progressively the old landscape together with the headward stream erosion. The present rivers channels are very narrow until they run in the deeply incised valleys of the northern flank of the Sila Massif, but they become wider, developing braided patterns, when the streams reach the hilly belt and the coastal plain.

In the hilly coastal belt below ~250 m five orders of terraces are located on the streams divides. Their treads are at the elevations of 125-230 m, 60-180 m, 35-110 m, 25-70 and 8-15 m above sea level and have been named respectively Qt_1, Qt_2, Qt_3, Qt_4, Qt_5. The terrace treads are gently seawards dipping flat surfaces but sometimes they are quite irregular because of fluvial dissection. The terraces Qt_1, Qt_2, and Qt_3 preserve wider treads.

Adjacent terrace treads are usually separated by a terrace riser scarp (Fig. 3) which defines their inner and outer edges. These scarps could be thought of relics of paleo-sea cliffs carved by the wave action or sometime by fluvial incision. At present the scarps are retreating because of mass movements and their bases could be covered by slope and/or alluvial deposits.

The lowest terrace surface (8-15 m a. s. l.) is present only close to Mirto (fig. 2), in the east side of Trionto River; there is no evidence of it westward. Its tread has an elevation of less than 2 m above the present Trionto River alluvial plain.

The Sila Massif and the hilly coastal belt are separat-

Fig. 3 - Treads of the Qt_2, Qt_3, and Qt_4 terraces located East of Corigliano. The treads are delimited by scarps, as indicated by the arrows.

Fig. 4 – E-W trending segment of the NW-SE extensional fault system. The stream erosion of the fault escarpment gives rise to triangular facets. The picture has been taken looking at east from the terraces located east of Cino River.

ed by a NW-SE trending extensional fault system, consisting in an array of WNW-ESE trending right-stepping fault segments. The extensional faults produced wide scarps which, crossed by incised rivers, form triangular facets (Fig. 4). The upper edges of the older terraces are usually in contact with the extensional fault scarps and sometime displaced by them.

Minor faults and joints displace the gently undulated surfaces, giving the divides a characteristic staircase profile and the terraces are affected by extensional structures that are oriented E-W or WNW-ESE and show displacements of 20-30 cm. Some N-S discontinuities are also present in the hilly belt.

4. UPPER PLIOCENE-PLEISTOCENE STRATIGRAPHY

The upper Pliocene-Pleistocene stratigraphic sequence outcropping in the hilly coastal belt comprises the sediments of the "Ciclo suprapliocenico-pleistocenico" (VEZZANI, 1968) underlying the middle and upper Pleistocene sand and conglomerate (VEZZANI, 1968; OGNIBEN, 1973; CRITELLI, 1990).

The sediments of the "Ciclo suprapliocenico-pleistocenico" (VEZZANI, 1968) are ascribed to a transgression and regression cycle. This cycle begin with the deposition of conglomerates characterized by randomly oriented subrounded polygenic clasts. The conglomerates are usually not cemented and can be clast- or matrix-supported depending on the variable amount of coarse sand matrix. The conglomerates are usually at the base of fossiliferous not cemented yellow-whitish sand (~100 m thick) which displays parallel and cross laminations (Fig. 5) and interbedded conglomeratic tongues and lens (Fig. 6). The sands underlie gray-yellowish silty fossiliferous clay containing sandy lens (~150 m thick). The clay usually underlies an erosion surface and locally sand that records the regression at the end of the sedimentary cycle. According to the fossils content, this sedimentary cycle has been referred to upper Pliocene-lower Pleistocene (VEZZANI, 1968; OGNIBEN, 1973).

Fig. 5 – Cross laminations in the upper Pliocene-lower Pleistocene sand of the "Ciclo suprapliocenico-pleistocenico" (VEZZANI, 1968). The pictures has been taken in a pit close to Corigliano.

In some localities, where the conglomerate and sand are in contact with the main fault scarps, they show clinoforms dipping ~15° northwards, i.e. towards the present coastline, testifying that coarse fluvial material supply to the marine basin.

Well rounded boulders (maximum diameter of 1 m) mixed with cobbles of 15 cm maximum diameter are sometimes located close to the main fault scarps. Similarly the lower sands of the "Ciclo suprapliocenico-pleistocenico" (VEZZANI, 1968) show beach sedimentary structures like cross laminations and bioturbations near the main faults. So both the boulders and the beach sedimentary structures testify littoral sedimentary environment close to the main tectonic structure that divided the Sila Massif from the hilly coastal belt.

The "Ciclo suprapliocenico-pleistocenico" (VEZZANI, 1968) sediments are cut by an marine erosion surface underlying the deposits that make up the terraces. These sediments are mainly partially open work conglomerate, characterized by poorly sorted, subangular to rounded clasts. The granulometry varies from sand size to 20-30 cm diameters and its abrupt changes produce lens and layers. Locally there are imbrications and no fossils have been found with the exception of some woody debris charcoal. A red silty matrix is sometimes present. The layers are subhorizontal or ~30° dipping towards the present coastline (Fig. 7). Some outcrops show clinostratification under subhorizontal layers suggesting the subhorizontal layers are

Fig. 6 – Interbedded conglomeratic tongues and lens in the upper Pliocene-lower Pleistocene sand of the "Ciclo suprapliocenico-pleistocenico" (VEZZANI, 1968). The conglomerate clasts are well rounded and sometimes imbricated.

Fig. 7 – Seaward dipping ~30° layers of the sediments making up the Qt1 terrace located east of the Cino River. These clinoforms are foreset units consistent with a fan-delta.

topset units, while the clinoforms are foreset units consistent with a delta architecture. These sedimentary features have been found in the Qt_1 and Qt_2 terraces, while only sub-horizontal layers characterized the others orders. Moreover, few of the youngest terraces display beach sedimentary structures like cross and flat laminations and bioturbations. So all the sedimentological characters and especially so deep foreset layers suggest a fan-delta depositional environment for the Qt_1 and Qt_2 terraces and an alluvial and/or coastal plain environment is consistent with the younger orders sedimentary features.

As above mentioned, the upper edges of the older terraces are in contact with the tectonic escarpments that separate the Sila Massif from the Pliocene-Pleistocene sediments of the hilly belt. Sometimes displaced remnants of the apical parts of the older fans are visible behind the scarps at an elevation of ~200 m a. s. l. Here the deposits are conglomerates showing sedimentary features very similar to the lower elevation ones, but the clasts can reach a 50 cm diameter and sand is scarce (Fig. 8).

Fig. 8 – Outcrop of Qt_1 located behind the north-facing Sila fault system, oriented NW-SE. The deposits are coarse conglomerates whose clasts can reach a 50 cm diameter.

5. AGE OF THE TERRACES AND UPLIFT RATE

In the study area, the tectonic uplift allows the preservation of the terrace sequence which deposits were referred generically to the middle and upper Pleistocene (VEZZANI, 1968; OGNIBEN, 1973; CRITELLI, 1990), but more precise dates are not available. With the purpose of dating them, it has been established a correlation with marine terraces in the neighboring areas.

Six or five orders of marine terraces have been found along the ionian coastline northwards (CUCCI & CINTI, 1998) and in the Crotone Peninsula southwards (GLIOZZI, 1988; COSENTINO *et al.*, 1989; PALMENTOLA *et al.*, 1990). These marine terraces have been referred to the isotopic stages 9, 7, 5e, 5c, 5a, and 1 according to paleontological, U-Th and aminoacid dating (BELLUOMINI *et al.*, 1986; DAI PRÀ & HEARTY, 1988; GLIOZZI, 1988; PALMENTOLA *et al.*, 1990; MAUZ & HASSLER, 2000). Since the elevation ranges of each order of these marine terraces show a good correspondence with the same order of the fluvial terraces in the study area, a correlation based on elevation criteria could be proposed. So according to this correlation, the Qt_1, Qt_2, Qt_3, Qt_4, and Qt_5 could be referred to 7, 5e, 5c, 5a, and 1 isotopic stages. To confirm this hypothesis and to calculate a relative uplift rate, the terrace orders elevations have been correlated to the glacio-eustatic curve. To establish this correlation it is necessary to point out a reliable indicator of the sea level highstand in the terraces. In fact, as mentioned

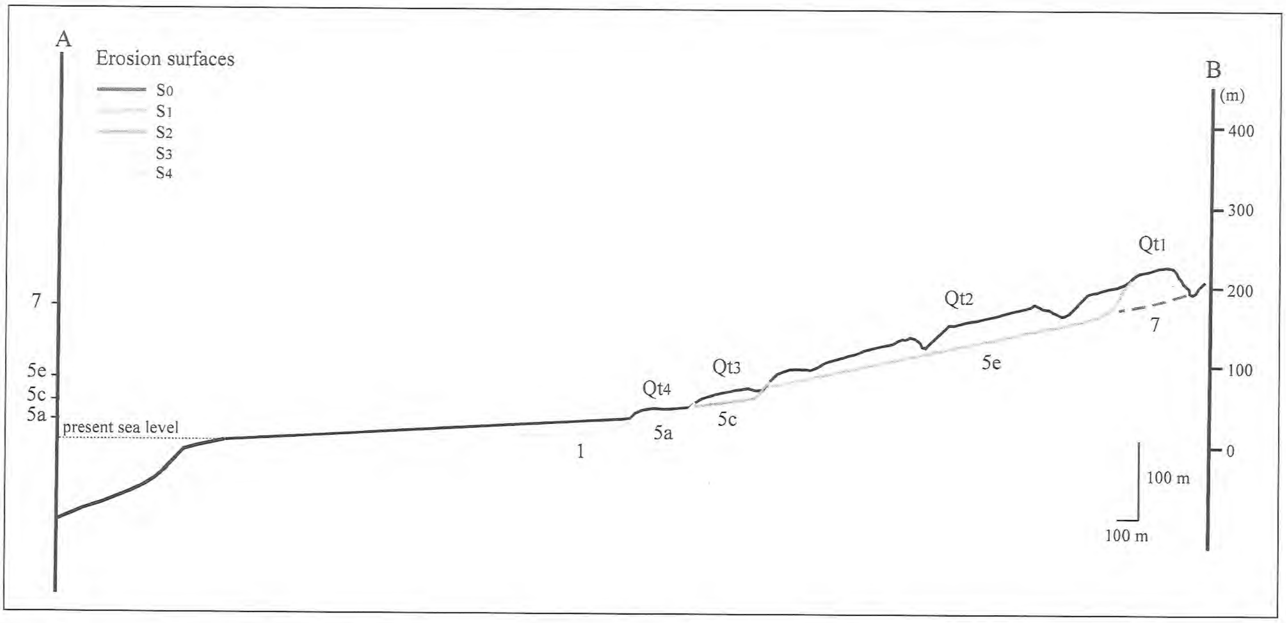

Fig. 9 – Cross section (see location in Fig. 2) showing the first four orders of terraces and the related strath named S_1, S_2, S_3, and S_4. Note the steep sea floor just in front of the shore. Left of the cross section, the projection of the intersection of the erosion surfaces with the terrace outer scarps have been reported to asses the difference in elevation between them and the present sea level.

above, the investigated terraces are mostly made up of alluvial and fan-delta deposits and the scarps separating the different orders are affected by slope processes, therefore the terrace inner edge can not be considered as indicator of highstand sea level. So, since the wave-cut platform is quite close to the sea level stand and it is mostly flat, its portion, that usually crops out at the bottom of the terrace scarp, could be used as rather reliable indicator of the sea level highstand. In fact, although the abrasion platform, that now is the terrace strath, was cut by the rising sea level, the portion that now crops out at the base of the terrace scarp is its upper part, i.e. the one cut by the sea level at its highest stand. So each strath and the deposits laying on it could be related to the same isotopic stage.

To obtain the most reliable correlation between terrace orders and glacio-eustatic curve, the method proposed by MERRITS & BULL (1989) has been used. So a longitudinal profile have been constructed along the divide, where the best preserved terraces are present (Fig. 9). This profile, located east of the Cino River (Fig. 2), shows the first four orders of terraces. An isotopic stage has been referred to each strath, according with the correlation between marine and fluvial terraces hypothesized before. The elevations of the intersection between the straths and the outer scarps of the terraces have been reported on the diagram of Fig. 10, where the glacio-eustatic sea level fluctuation curve is plotted. Since Qt_2, is the best preserved terrace and the corresponding marine terrace in the neighboring areas is the one that has been dated more precisely, its strath elevation has been projected to the 5e peak of the glacio-eustatic curve. Hypothesizing a costant uplift rate, the connection between the strath of the other terraces and the glacio-eustatic curve has been done just through parallel straight lines. Utilizing this method, a very good agreement results between the altitudes of the straths and some peaks of the glacio-eustatic curve. So the diagram of Fig. 10 confirms the correlation between Qt_2, Qt_3, Qt_4, and Qt_5 and 5e, 5c, 5a, and 1 isotopic stages. It also indicates that according to the hypothesis of a costant uplift rate, the Qt_1 could be correlated to the isotopic stage 9 and that the morphology and/or the deposits of the isotopic stage 7 are not preserved. On the contrary, the geomorphic setting of the terraces does not suggest the possibility of a complete erosion of a terrace order. Moreover, in the neighboring areas the marine terrace located at the Qt_1 elevation has been referred to the central peak of the isotopic stage 7. So these considerations suggest the hypothesis of a higher uplift rate before ~124 ka that could make reliable a connection between Qt_1 strath and 7a isotopic stage.

The obtained results could be use to evaluate the uplift rate of the study area. To calculate a reliable uplift rate, the intersection of the erosion surfaces with the terrace outer scarps have been projected out to the modern coastline to assess the difference in elevation between them and

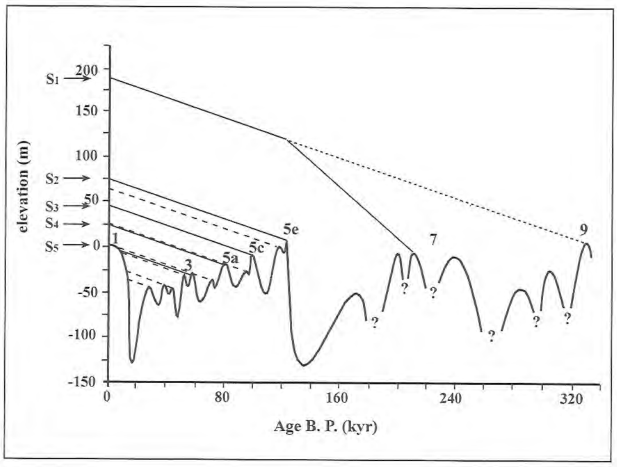

Fig. 10 – Diagram showing a possible correlation between the glacio-eustatic sea-level fluctuation curve and the erosion surface elevations. A costant uplift rate has been hypothesized in the last 124 kyr.

Strath	H_t (m)	S_t (m)	Isotopic stage	t (kyr)	U_t (m/kyr)
S_4	0	0	1	6	0
S_3	25	-19	5a	81	0.54
S_2	40	-9	5c	100	0.49
S_1	75	6	5e	124	0.56
S_0	190	-7	7a	212	0.93

TAB. 1 – Results of the calculation of the uplift rate of each terrace located east of Cino River. Ages (t) and altitudes of sea level at time t (S_t) are reported from references (MERRITS & BULL, 1989; CHAPPEL *et al.*, 1996; PILLANS *et al.*, 1998).

the present sea level (Fig. 9). Therefore the following formula has been used to compute the uplift rate:

$$U_t = (H_t - S_t) / t \qquad [1]$$

where U_t is the uplift rate at a certain time t, H_t is the elevation of the intersection of every erosion surface with the terrace outer scarp, S_t is the sea level elevation at time t relative at the present sea level, t is the age of the isotopic stages corresponding to each erosion surface (MERRITS & BULL, 1989; CHAPPEL *et al.*, 1996; PILLANS *et al.*, 1998). The results of the calculation are summarized in TAB. 1 and showed in the inferred uplift prediction diagram (Fig. 11), where the linear regression analysis indicates an uplift rate of 0.96 mm/yr.

To extend the results over a broader region, it has been hypothesized that the strath on which laid down the terrace deposits, always crop out at the bottoms of each terrace outer scarp (Fig. 12). So the elevation of the scarp bottom of every terrace has been computed considering an error of ±10 m. The linear regression analysis of these data in the inferred uplift prediction diagram in Fig. 13 indicates a mean uplift rate of 1.01 mm/yr.

Both the regression analysis results are very similar, suggesting an uplift rate of ~1 mm/yr m/ka and indicating a well defined decreasing trend. The obtained uplift rate is consistent with the ones calculated in the neighboring areas (GLIOZZI, 1988; COSENTINO *et al.*, 1989, PALMENTOLA *et al.*, 1990; WESTAWAY, 1993; CUCCI & CINTI, 1998), so it is possible to consider it quite reliable.

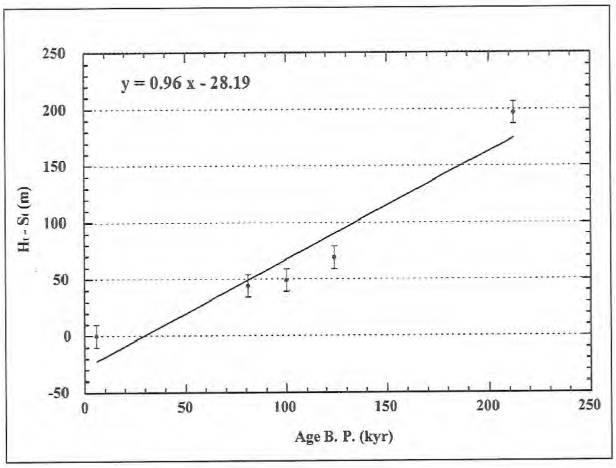

Fig. 11 – Computation of the inferred uplift rate utilizing data of Tab. 1. The linear regression analysis indicates an average uplift rate of 0.96 mm/yr.

6. EVOLUTIONARY MODEL OF THE AREA

The analysis of the morpho-tectonic features and of the Plio-Pleistocene stratigraphy of the study area, and the

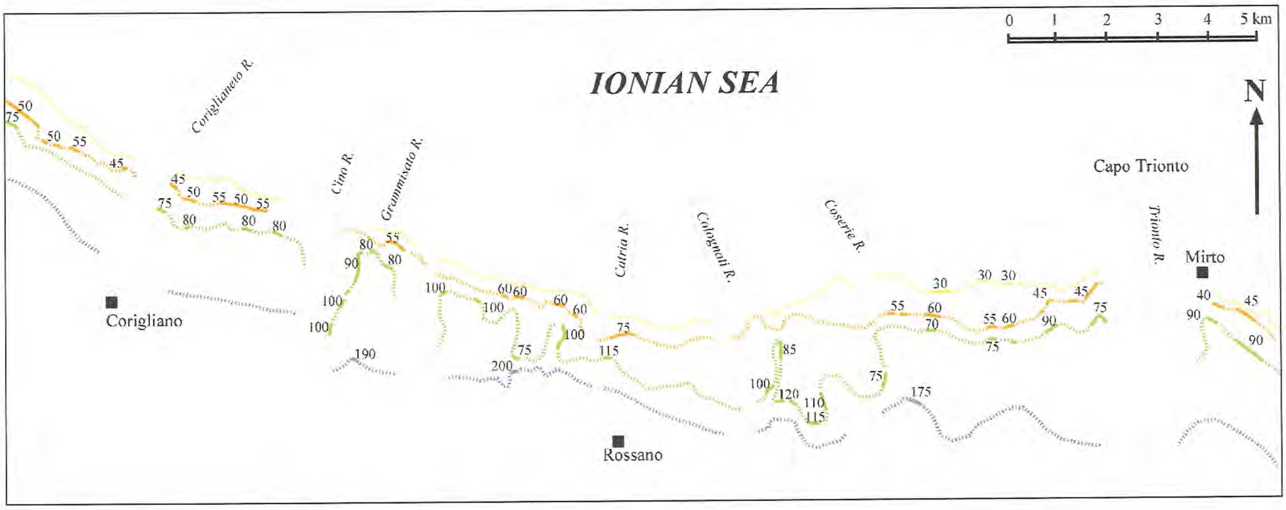

Fig. 12 – Map sketch of the bottoms of the terraces outer scarps. Every colour is related to the terrace order cut by the sea level surface (see Fig. 2), while the number is the elevation in meters above sea level of the scarp bottoms. The dotted lines indicate the hypothesized scarp bottoms that describe approximately the ancient coastlines. The ones relative to the Qt1 and Qt2 terrace orders have more sinuous course probably because the fan-deltas morphology influenced strongly the coastline trend.

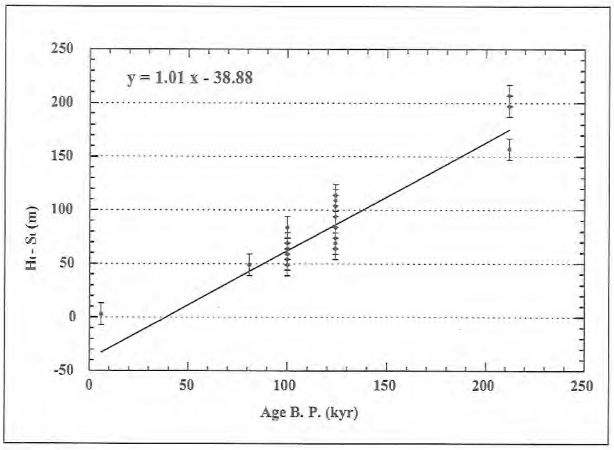

Fig. 13 – Computation of the inferred uplift rate utilizing the data of Fig. 13. The linear regression analysis indicates an average uplift rate of 1.01 mm/yr.

results of the correlation between the glacio-eustatic curve and the terrace orders speak to a landscape dominated by local tectonic structures, large scale vertical movements, and climatic changes.

The studied morphological features of the northern flank of the Sila Massif and of the hilly belt located at its bottom allow to identify the main stages of landscape evolution. The older stage is reported by the formation of a rolling landscape characterized by a quite stable relative base level. Probably it forms in conditions of low tectonic activity or of compensation between erosion and morphological effects of tectonics. Moreover arid or semi-arid climate could have contributed to the evolution of a landscape dominated by areal erosion processes.

Successively, a predominant linear erosion, that produce deeply incised valleys and formation and preservation of fan-delta and fluvial terraces, speak to an increase of tectonic activity and to climatic features that helps stream vertical incision. Fan-deltas, that are mostly basin-margin systems, are very sensitive to tectonically induced sea level changes (Gawthorpe & Colella, 1990; Postma, 1995). On the contrary fluvial systems are more tightly linked to climate and base level variations (Blum & Törnqvist, 2000). The climatic influence on the evolution of the study area landscape could be modeled in the following way. During warm periods, sea level is high and the lower reaches of streams, that drain the Sila Massif slope, are low gradient, braided channel. They aggrade slightly, but mostly they have reached a graded status in balance with sea level and upstream sediment supply. Falling into a cold glacial period, the sea level drop forces the streams to incise the floor of the Ionian Sea that is steeper than their gradient. This incision causes the formation of a knickpoint that, retreating upstream, induces incision up to the limit of sea level influence in the fluvial system (Summerfield, 1991; Schumm, 1993; Blum & Törnqvist, 2000). Then, the glacial climate induces a strong production of debris from poorly vegetated valley slopes, and large amounts of sediments are washed in the streams to fill the incised valleys. As the climate begins to warm, the sea level rises rapidly, cutting a wave-cut abrasion platform across the lowstand alluvial deposits and in the upper Pliocene-lower Pleistocene marine deposits. In the meantime, the large amounts of debris, produced in the previous cold period, rapidly aggrade the lower reaches of the rivers and form an alluvial/coastal plain through coalescent deltas. The alluvial/coastal plain deposits rapidly bury the abrasion platform cut by the rising sea level, making the strath and the deposits more or less isochronous. So the climatic/eustatic changes cause cyclic occurrence of stream aggradation/incision and marine erosion, but only the effects of several climatic/eustatic variations together with uplifting movement allow the formation and preservation of a sequence of terrace orders.

On the basis of the morphological and geological analysis results and of the model of terraces genesis, a hypothesis of a qualitative model of the study area evolution can be proposed. It is build up considering large scale vertical movement, extensional tectonics and climatic/eustatic changes as the main factors of the landscape developing.

In Miocene the Sila Massif exhumed because of syn- and post-orogenic extensional tectonics and of a contemporary increase of erosion rate (Thomson, 1994; Rossetti *et al.*, 2001). This increase of the erosion rate and the emersion of the study area is reported by Miocene fan, fan-delta and alluvial plain deposits found south-east of Rossano and southwards in the Crotone basin where they interfinger the deposits of the "Ciclo tortoniano-infrapliocenico" (Ogniben, 1973; Ciaranfi *et al.*, 1982; Moretti, 1993). The emersion was so slow and/or compensated by surface processes to originate a landscape whose topographic features speak to a stability of relative base level. The relics of this landscape are the rolling upland located at the summit of the Sila Massif.

During Middle Pliocene and lower Pleistocene, in the study area extensional structures, like the north-facing Sila Massif escarpment, separates the emerging relief from a subsiding marine basin where the "Ciclo suprapliocenico-Pleistocenico" (Vezzani, 1968) laid down. The huge thickness of these marine deposits suggests the basin subsidence were marked. The fault footwalls gave rise to marine cliffs at which bottom sand or gravel beach were present.

At the end of the lower Pleistocene the study area is affected by a regional uplift similarly to the rest of the Italian Peninsula (Vezzani, 1968; Tortorici, 1980, Tortorici, 1981; Ciaranfi *et al.*, 1983; Lanzafame & Tortorici, 1981; Boccaletti *et al.*, 1984; Colella *et al.*, 1987; Moretti, 1993; Tortorici *et al.*, 1995; Moretti & Guerra, 1997). This uplift, characterized by a rate higher than the previous vertical movements, affects the basin causing the end of the marine sedimentary cycle, and then the emergence and the partial erosion of its deposits.

Since middle Pleistocene the interaction between an uplift characterized by a rate of ~1 mm/yr, local tectonics, climate changes and relative glacio-eustatic changes produced a landscape dominated by a strong instability of the stream base level and by an increase of the vertical incision of river valleys. Moreover, at the bottom of Sila northern flank, the uplifting together with cycles of stream erosion/aggradation produced a sequence terraces. In particular until more or less 100 ka BP, during warm period, the stream aggradation made up coalescing fan–deltas beyond the main fault escarpment because of the abrupt change from the steep valleys slope to the marine basin. These fan-deltas, now corresponding to Qt_1 and Qt_2 terraces, are formed by the deposition of coarse material produced upstream during cold periods. Successively, the uplifting caused the progressive emergence of the "Ciclo suprapliocenico-Pleistocenico" (Vezzani, 1968) and made the river mouths being far from the mountain front. This made weaker the influence of the north-facing Sila fault activity and stronger the effect of the eustatic variations on the downstream reaches of the fluvial systems. So now, as modeled before, the cycles of stream aggradation/erosion linked to climate and sea level changes formed a coastal/alluvial plain, whose uplifted relics are Qt_3 and Qt_4 terraces.

In the Holocene the younger terrace Qt_5 and the present coastal plain form, feed by the load transported by streams in wintertime mostly during strong rain falls.

7. CONCLUSION

To reconstruct the Plio-Pleistocene uplift of northern Calabria, a field survey and an air-photos interpretation of the Sila Massif northern flank and of the Ionian coastal belt at its bottom has been performed. This study has been focused mainly on morpho-tectonics and the Plio-Pleistocene stratigraphy to point out features that are the main keys to figure out the uplift. The obtained results speak to a landscape dominated by surface processes that are strongly eroding the relief and by a vertical movement of ~1 mm/yr. Furthermore this landscape still preserves features that indicate that in the past the study area was affected by different geomorphic and tectonic conditions. So considering all the obtained results a conceptual model of the recent evolution of the Sila northern flank has been proposed. This model makes to distinguish some phases of landscape evolution.

Before upper Pliocene, the study area was affected by slow emergence that together with an arid or semi-arid climate conditions produced a rolling landscape. Its features suggest a base level stability caused by a low tectonic activity or by a compensation between tectonics and areal weathering processes.

During upper Pliocene-lower Pleistocene, the activity of the NW-SE trending extensional fault system separated the slowly uplifting relief from a subsiding marine basin.

At the end of lower Pleistocene-Present, the uplift became a larger scale movement affecting the marine basin too. The interaction of this regional uplift, that is characterized by a mean rate of ~1 mm/yr, with climatic/eustatic changes produced a relief affected by linear erosion and the formation and preservation of a sequence of terraces.

The obtained results evidence the importance of studying geomorphic elements whose genesis or present location can be used to quantify surface deformation. So the investigation of upland surfaces and terrace treads could provide information not only to evaluate local scale tectonic processes but also to reconstruct regional scale landscape evolution.

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