Geogr. Fis. Dinam. Quat.
36 (2013), 289-302, 10 figg., 1 tab.

DOI 10.4461/GFDQ.2013.36.23

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AGE AND STATISTICAL PROPERTIES OF THE SUMMIT PALAEOSURFACE OF SOUTHERN ITALY

ABSTRACT: SCHIATTARELLA M., GIANO S.I., GIOIA D.,MARTINO M. & NICO G., *Age and statistical properties of the summit palaeosurface of southern Italy*. (IT ISSN 0391-9838, 2013).

Age constrains and statistical properties of the summit palaeosurface of the south-Apennine chain - Calabrian Arc have been investigated with the aims of refining its use as a morphotectonic marker and distinguishing climate and tectonic contributions in landscape evolution. The tops of the mountains of southern Italy are often featured by erosional flat landforms representing the remnants of a wide palaeosurface attributed to the late Pliocene - Quaternary boundary. Apatite fission-track analyses collected in the last years furnished new chronological constrains in terms of its absolute age: this kind of data has been here used in combination with geology and morphotectonics to better define its evolution. On this basis, we infer that both the cooling event and the erosion land surface now preserved at the top of the relief are evidence of the same episode of exhumation. It is worthy to note that the AFT cluster is comprised between 2 and 3 Ma, as well as mid-Pliocene sediments are the youngest deposit involved in the ancient planation process. Curiously, also the new interpretation of these data in the key of land surface dating suggests that the transition period between the late Pliocene and the early Pleistocene represents the time-span in which the summit palaeosurface developed. Such a regional feature was displaced by the 1.8 Ma regional tectonic stage.

Maps of palaeosurfaces derived by geomorphological survey have been compared to those constructed by identifying pixels on the SRTM DEM on the base of their current altitude and slope. The Sila Massif (Calabrian Arc) and the Campania-Lucania segment of the southern Italian Apennines, characterized by quite different geological settings, are chosen as test sites. The statistical properties of the palaeosurface remnants are here interpreted in terms of a common climate-driven fluvial erosion process and different tectonic activities in the two study areas.

KEY WORDS: Tectonic geomorphology, Geomorphometry, Land surface dating, Fluvial dissection, Long-term landscape evolution, Southern Italy.

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RIASSUNTO: SCHIATTARELLA M., GIANO S.I., GIOIA D.,MARTINO M. & NICO G., *Età e proprietà statistiche della paleosuperficie sommitale dell'Italia meridionale*. (IT ISSN 0391-9838, 2013).

La sommità dei rilievi appenninici è spesso caratterizzata da lembi di superfici di spianamento di importanza regionale attribuite ad un intervallo temporale corrispondente al passaggio Pliocene-Quaternario. In questo lavoro vengono definiti i vincoli cronologici e le proprietà statistiche della superficie di spianamento sommitale dell'Appennino meridionale («Paleosuperficie» *Auctt.*) e dell'Arco Calabro, allo scopo di renderne sempre più affidabile il suo utilizzo come *marker* morfotettonico. Le caratteristiche di un simile elemento relitto possono, inoltre, costituire nel loro insieme un riferimento sostanziale per discriminare il contributo tettonico da quello climatico nella successiva opera di dissecazione e rimodellamento del paesaggio fisico dell'Italia meridionale.

I dati ottenuti in anni recenti dall'analisi di tracce di fissione in apatite (AFT) hanno fornito migliori vincoli in termini di età assoluta. Il loro uso in combinazione con le informazioni di cronologia relativa (di natura geologica e morfostratigrafica) ha permesso di ipotizzare che gli eventi di raffreddamento responsabili del *cluster* più recente di età ricavate dalle tracce di fissione e l'inizio del modellamento della paleosuperficie siano espressione dello stesso processo esumativo della catena orogenica. Poiché l'addensamento di dati AFT è compreso tra 2 e 3 Ma, e i depositi mediopliocenici rappresentano i sedimenti più giovani coinvolti nel processo di spianamento della superficie sommitale, la genesi della stessa si può collocare ancora nell'intervallo temporale compreso tra il Pliocene superiore ed il Pleistocene inferiore, seppur in riferimento alla nuova scala geocronologica del Quaternario. La paleosuperficie è tettonicamente dislocata a scala regionale a 1.8 Ma.

La comparazione tra carte delle superfici erosionali, ricavate da rilievi di terreno ed analisi di aerofoto, con omologa cartografia automatica estratta da SRTM DEM ha permesso di validare quest'ultima e di utilizzare pertanto i modelli digitali di terreno come sorgente di dati topografici e statistici relativi all'oggetto di questo studio, con particolare riferimento al segmento campano-lucano dell'Appennino e al massiccio della Sila in Calabria, caratterizzati come noto da differenti assetti geologici e geomorfologici. Le differenze nelle proprietà statistiche dei lembi relitti di paleosuperfici appartenenti ai due domini sono state interpretate come dovute a differente attività tettonica nelle due aree, in termini per esempio di spaziatura delle faglie principali, consumatasi tuttavia sotto un comune fattore di controllo climatico che ha pilotato la dissezione dei paleopaesaggi ad opera della rete drenante.

TERMINI CHIAVE: Geomorfologia tettonica, Geomorfometria, Datazione di una superficie, Dissezione fluviale, Evoluzione a lungo termine del paesaggio, Italia meridionale.

AIMS AND METHODS

In the last decade, there has been a rise of interest on the role of climate changes in landscape evolution (Whipple & *alii*, 1999; Bonnet & Crave, 2003; Burbank & *alii*, 2003; Whipple, 2009). On the other hand, long-term landscape evolution reflects the interaction and feedback among tectonics, erosion and climate (Willett, 1999; Willett & Brandon, 2002; Wobus & *alii*, 2003; Schiattarella & *alii*, 2006; Bishop, 2007). In tectonically active areas characterized by a complex morpho-structural evolution, both relict and active landforms coexist as a result of exogenic vs. endogenic processes. Ancient landforms such as palaeolandsurfaces represent non-equilibrium features (cf. Bracken & Wainwright, 2006) resulting by surface uplift and subsequent degradation due to erosion. The analysis of these geomorphological features is used to assess the relationships among tectonics, surface processes and climate fluctuations during the geological past. The term palaeosurface denotes any identifiable surface of demonstrable antiquity, often characterized by gentle topography represented by relics of an ancient erosional land surface, that evolved in response to particular combination of geomorphological processes (Widdowson, 1997; Bonow & *alii*, 2006). The physical correlation of discrete remnants of palaeosurfaces allows to recognize extension and morphology of such ancient planation surfaces related to a former base level of the erosion (i.e. not in accordance with present morpho-climatic conditions), and they are identified in terms of attitude (i.e. characterized by little slope angles, not exceeding few degrees) and on the grounds of several markers of geomorphic processes acting in the past.

The reconstruction and dating of ancient land surface can provide useful information on morphotectonic evolution, whereas the nature of subsequent modifications by changing erosional and weathering regimes can reveal key aspects of subsequent environmental change (Borger, 1997; Schoenbohm & *alii*, 2004). Hung land surfaces (i.e. terraced surfaces suspended with regard to the present-day thalwegs) are also markers of regional-scale neotectonic deformation and provide information on the rate and timing of uplift and erosion (Schiattarella & *alii*, 2006; Martino & *alii*, 2009). Recently, the relation between morphotectonic features and the fractal dimension of topography of Taiwan has been explored as well (Sung & Chen, 2004). It has been found that the fractal morphology may reflect some subtle changes in topographic properties of a landscape sculpted by surface processes, which in turn are influenced by tectonic activities. This property is perhaps more diffused than reported in that paper, because a fractal behaviour was also found in studies of coastal and fluvial features (Rigon & *alii*, 1994; Turcotte, 1999; De Pippo & *alii*, 2004; Rinaldo & *alii*, 2006). The Hack's law relating the upstream length and the total drainage area at a given location is another evidence of fractal geometry in fluvial landforms. These statistical properties of river basins are irrespective of age even if real drainage basins evolve on a long-term time-scale. Furthermore, it was reported that the fractal dimension of the drainage network can also provide a method for assessing the degree of tectonic control on the geometry of fluvial networks (Del Monte & *alii*, 1999).

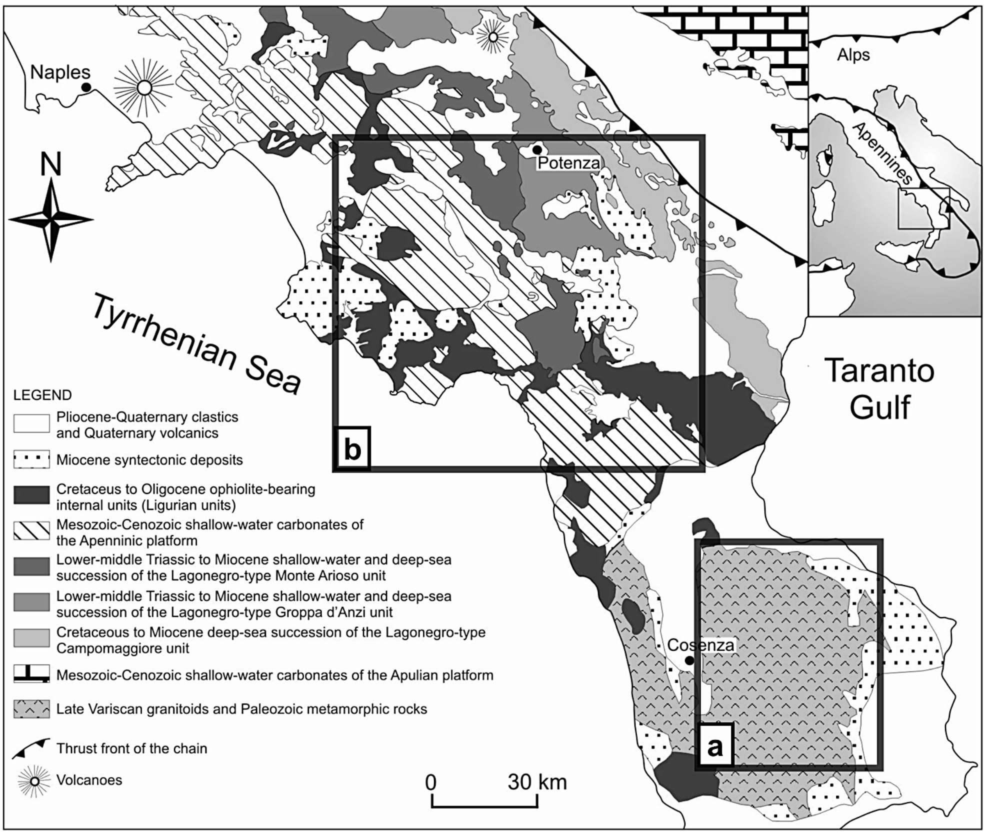
The purpose of this study is to better define the age of the summit palaeosurface of the southern Italian Apennines (i.e. «Paleosuperficie» *Auctt.*) by both morphostratigraphic and AFTA dating methods. A similar approach has been recently used also by Japsen & *alii* (2009), but for an area located on a passive continental margin (West Greenland). In addition, we aim to investigate the statistical properties and the modalities of the «fragmentation» processes of the south-Italian palaeosurface (i.e. the physical separation due to fault displacement and/or fluvial dissection) which led to the present-day arrangement of its morphological relics. Such a result may help to recognize regions with different tectonic histories and/or to emphasize the eventual role of other control factors. To this end, the morphometric properties of palaeosurfaces are extracted from a Digital Elevation Model (DEM) and maps of palaeosurfaces automatically derived using a recently published methodology (Martino & *alii*, 2009). The DEM used in this study is obtained by the Shuttle Radar Topography Mission (SRTM). In order to check the fit of the DEM-extracted flat surfaces with the real landforms related to erosional palaeosurfaces, the regional-scale automatic cartography has been compared with the geomorphological maps and schemes present in the literature relative to southern Italy and, overall, with a survey-derived map of land surfaces. To this aim, a local scale test-site (Mount Marzano - Maddalena Mts ridge) has been chosen to perform a more detailed comparison with the computer-aided cartography. In any case, a good correspondence between traditionally mapped and DEM-extracted land surfaces has been verified (cf. par. *Identification and age of palaeosurfaces*).

The statistical analysis of the properties of land surfaces of southern Italy has been carried out choosing two quite different test areas, but roughly characterized by the same climatic environment. The Sila Massif (Calabrian Arc) is the southernmost test area. It is characterized by wide and old land surfaces, at least Pliocene in age, probably inherited by pre-Tortonian flat landscape formed at sea level and weathered under tropical conditions (Scarciglia & *alii*, 2005). During Quaternary times, the Sila Massif underwent a generalized uplift without internal block faulting. Consequently, the summit palaeolandscape of this area is loosely fragmented by recent tectonics and scarcely dissected by fluvial erosion (Molin & *alii*, 2004). The Campania-Lucania segment of the southern Apennines is much more morphologically articulated, due to the more closely spaced Quaternary faulting, associated with a higher and more pervasive fluvial dissection.

REGIONAL OUTLINES

The southern Apennines are a northeast-verging fold-and-thrust belt (fig. 1), built on the western border of the African-Apulian plate from late Oligocene - early Miocene times. From Langhian-Tortonian times, the thrust front

FIG. 1 - Geological map of the Campania-Lucania Apennine (a) and northern Calabria (b), southern Italy. In the inset on the top right: regional localization (modified after Martino & *alii*, 2009).



moved progressively toward the east, as documented by the age of syntectonic deposits (Pescatore & *alii*, 1999, and references therein). Thrusting in the frontal sector of the chain was followed by back-arc extension, responsible for the Tyrrhenian sea opening (Malinverno & Ryan, 1986). Starting from the Tortonian, the orogen underwent low-angle extension which led to the exhumation of its non-metamorphic core complex constituted of Mesozoic Lagonegro-type pelagic units (Schiattarella & *alii*, 2003, 2006). Transpressional to transtensional tectonics was responsible for the Pliocene to early Pleistocene evolution of the south-Apennine chain, whereas high-angle extensional faulting took place in mid-Pleistocene times in the axial zone of the chain (Schiattarella, 1998).

The belt is mainly composed of shallow-water and deep-sea sedimentary covers, deriving from Mesozoic-Cenozoic circum-Tethyan domains, covered by Neogene-Pleistocene foredeep and satellite-basin deposits. It is strongly uplifted and fragmented by late Pliocene to Quaternary faulting and morphologically articulated by the presence of longitudinal and transversal fault-bounded basins. The main orientations of these high-angle strike-slip and normal faults are N120±10°, N150±10° and N50±20.

The belt tops are frequently characterized by remnants of an ancient flat landscape, uplifted and dismembered by Quaternary fault activity. Consequently, the erosional land surfaces are arranged in several superimposed levels (Schiattarella & *alii*, 2003, 2006). The regional uplift hung the ancient erosional base level to which this palaeolandscape was related, triggering new morphoevolutionary stages. As a consequence of the former erosional stages, the paleosurfaces are low-relief and high-altitude relict geomorphological features (Schiattarella & *alii*, 2003, 2006).

The Calabrian arc, which from a geographic point of view represents the southern continuation of the Apennines (fig. 1), is made of crystalline metamorphic units thrust on the Mesozoic African-Apulian carbonate domains, locally outcropping in tectonic windows. Its Neogene tectonic transport is toward the southeast and the thrust front in offshore (i.e. in the Ionian Sea). The Calabrian arc is partly characterized by flat-topped mountains as well, especially in the Sila Massif, where the top palaeolandscape is deeply affected by tropical-type weathering (Guzzetta, 1974; Scarciglia & *alii*, 2005). The arc is strongly articulated in longitudinal and transversal horst and graben structures (Ghisetti & Vezzani, 1981), which are genetically related to high-angle faults mainly oriented in WNW-ESE and N-S directions.

IDENTIFICATION AND AGE OF PALAEOSURFACES

Geomorphological and chronological constraints on palaeosurface dating

Long-term landscape evolution of an orogen results from the interaction between tectonic and geomorphological processes, largely controlled by regional uplift, fault activity and climate changes. The morphostructural evolution of the southern Apennines is characterized by stages of tectonic uplift and fault activity alternated with periods in which sculpture of erosional surfaces and deposition of sedimentary bodies took place in several intermontane basins. Both flat land surfaces and the tops of the alluvial deposits are related to the different past base levels. In the different catchment basins and surrounding ranges, three or four generations of erosional land surfaces, carved in both Mesozoic-Cenozoic bedrock and Pliocene-Quaternary clastic sediments of the basin infill, are normally recognized (Schiattarella & *alii*, 2003; Boenzi & *alii*, 2004; Gioia & *alii*, 2011). The highest land surfaces (summit palaeosurface, or S1 after Schiattarella & *alii*, 2003) represent the morphological remnants of a regional planated landscape. They unconformably cut across tilted Mesozoic-Cenozoic shallow-water limestones and coeval basinal formations and lower-middle Pliocene marine sediments outcropping along the Campania-Lucania segment of the southern Apennines. Apatite fission-track data from rocks belonging to different tectonic units of the axial zone of the southern Apennines (Aldega & *alii*, 2005; Mazzoli & *alii*, 2008) indicate a concordant final cooling age of ca 2.5-2.6 Ma (average value, Schiattarella & *alii*, 2009; Gioia & *alii*, 2011), suggesting a widespread exhumation during the late Pliocene. This relatively young exhumation is likely related to erosional denudation rather than tectonics (i.e. low-angle extension, as suggested by other authors for older stages, see Schiattarella & *alii*, 2006), thus implying a late Pliocene stage widely affected by intense exogenetic processes. It can be argued that such a regional denudation could be related to the summit palaeosurface morphogenesis. The attribution of those features to the late Pliocene is strengthened by the presence of lower-middle Pliocene clastic deposits outcropping at the top of the Maddalena Mts (Schiattarella & *alii*, 2003) and in the Mt. Marzano area, involved in the planation of the palaeosurface.

Based on the assumption that the regional uplift and fault activity related to the tectonic stage responsible for the morphological de-activation of that ancient land surface created the accommodation space for continental infill of the intermontane catchments, the regional correlation of the stratigraphic successions from different basins can provide chronological constraints to better identify the age of the first significant vertical movements (fig. 2). This vertical motion is responsible for the geomorphological de-activation of the palaeosurface and its uplift, whereas pervasive faulting and fluvial erosion are accountable for its subsequent fragmentation (Martino & *alii*, 2009).

According to all these evidences, it is possible to assign a late Pliocene age to the oldest palaeosurface (i.e. S1 after Schiattarella & *alii*, 2003) of the Alburni and Mt. Marzano massifs, generally found above 1100 m a.s.l.. The S2 erosional land surfaces (Schiattarella & *alii*, 2003) frequently represent dislocated remnants of the oldest one and their chronological attribution at the early Pleistocene is corroborated by the presence of lower Pleistocene fluvial deposits in many basins of the axial zone, morphologically inserted in such flat surfaces. The S3 erosional surfaces have been used to morpho-stratigraphically correlate the clastic infill of the different basins (Schiattarella & *alii*, 2003; Boenzi & *alii*, 2004); as a matter of fact, the S3 land surfaces often cut both bedrock and Pleistocene fluvio-lacustrine deposits along the axis of the entire Campania-Lucania orogenic segment. Several key-data produced about the radiometric ages of the fluvial-lacustrine deposits (Karner & *alii*, 1999; Di Leo & *alii*, 2009) allowed us to well-constrained the genesis and de-activation of the S3 surfaces, that can be reasonably referred to the early Pleistocene-middle Pleistocene time-span (fig. 2).

Apatite fission-track analysis (AFTA) furnished additional data concerning the time and rates of cooling related to exhumation in the uppermost part of the crust (i.e. below the 110°C isotherm). Thermal histories of rocks belonging to different tectonic units of the southern Apennines (Aldega & *alii*, 2005; Mazzoli & *alii*, 2008) have been used in combination with geology and morphotectonic analysis to define both the amounts and timing of denudation and/or uplift. An absolute chronology may be defined by combining the onset and duration of cooling events estimated from AFTA with stratigraphical data (i.e. hiatuses in the stratigraphy, age of the syntectonic basins) and the formation of erosional surfaces on a regional scale. Being the onset of the cooling episode determined from apatite fission-track data in agreement with the relative timing for the formation of the regional palaeosurface in the southern Apennines, we infer that both the cooling event and the erosion land surface are evidence of the same episode of exhumation. A similar approach has been recently used in different tectonic setting and geodynamic contexts (Gunnell, 1998; Schoenbohm & *alii*, 2004; Bonow & *alii*, 2006; Japsen & *alii*, 2006).

The youngest AFT cluster chracterizing the axial zone of the southern Apennines is comprised between 2 and 3 Ma (fig. 3), as well as mid-Pliocene sediments are the youngest deposit involved in the ancient planation process. Curiously, also the new interpretation of these data in the key of land surface dating suggests that the transition period between the late Pliocene and the early Pleistocene represents the time-span in which the summit palaeosurface developed. Such a regional feature was firstly displaced by the 1.8 Ma tectonic stage, so generating polygenic surfaces re-shaped by fluvial and karst processes, in turn faulted and hung with regard to the erosion base level at about 1.2 Ma («Emilian» tectonic stage).

Geomorphological vs. automatic mapping of the south-Apennine palaeosurfaces

Morphometric analysis of palaeosurfaces was performed by using an altimetric dataset derived by the interferometric data acquired during the SRTM mission. The 11-day spaceborne mission SRTM, was realized in 2000 with the aim of producing a global high resolution DEM of the Earth surface, covering 80% of whole lands between 60° N and 56° S, using the radar interferometry technique (Rabus & *alii*, 2003). The main advantage of SRTM digital topographic maps is to meet requirements for a homoge-

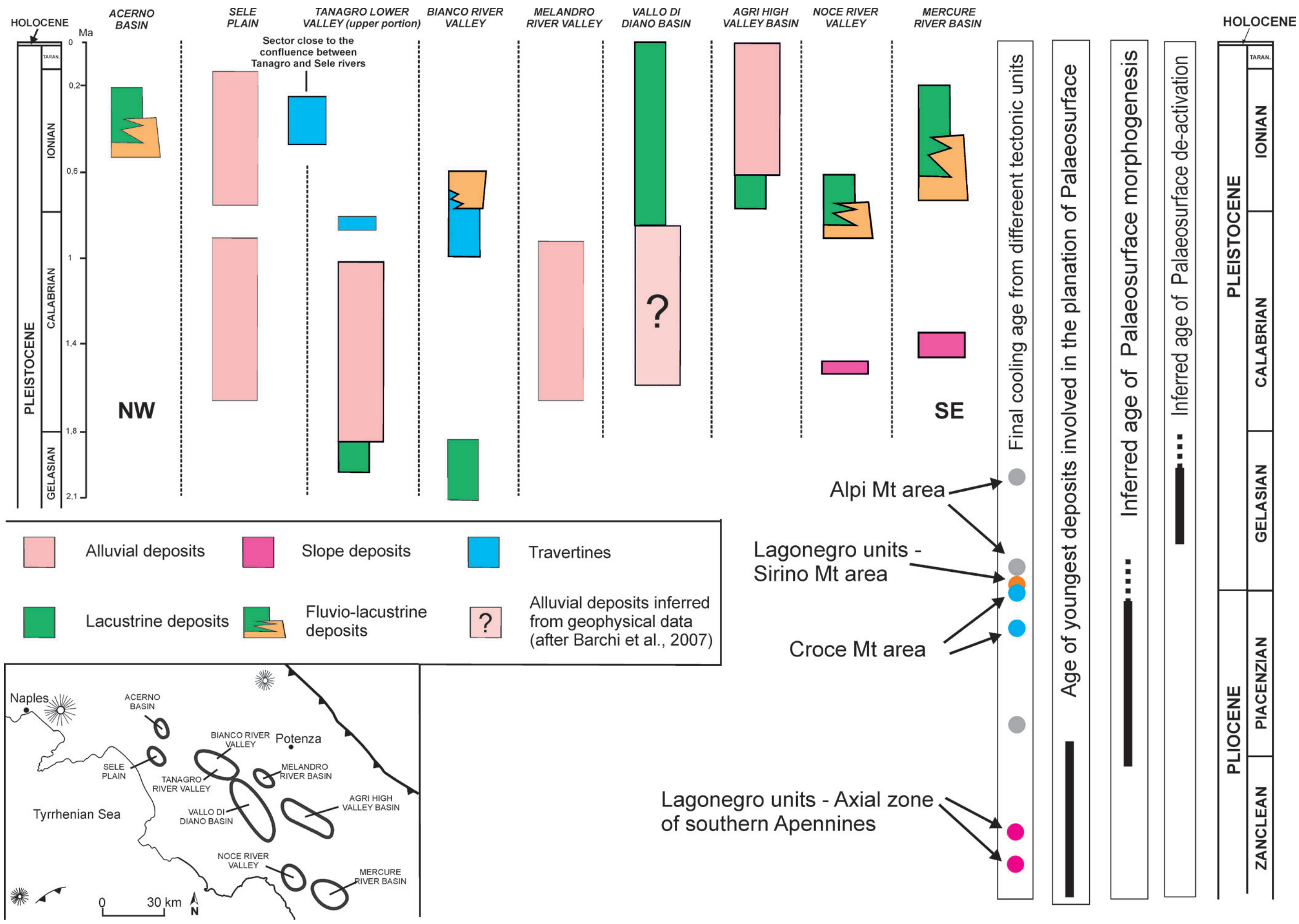


FIG. 2 - Stratigraphic successions from different basins of the axial zone of the southern Apennines, AFT data and chronological constraints on the age of the summit paleosurface (modified after Gioia et al., 2011a). Data sources: Capaldi & *alii* (1988), Munno & *alii* (2001), Porreca & Mattei (2012), for the Acerno basin; Cinque & *alii* (1988), Amato & *alii* (1991), Caiazzo & *alii* (1992), Magliulo & *alii* (2006), for the Sele plain and upper valley; Buccino & *alii* (1978), Amato & *alii* (1992), Ascione & *alii* (1992b), Gioia & *alii* (2011b), for the Tanagro and Bianco rivers (Auletta basin); Lippman Provansal (1987), Santangelo (1991), Giano & Martino (2003), Martino & Schiattarella (2006), Di Leo & *alii* (2011), for the Melandro basin; Santangelo (1991), Ascione & *alii* (1992a), Karner & *alii* (1999), Barchi & *alii* (2007), Di Leo & *alii* (2009), Villani & Pierdominici (2010), Giano & *alii* (2012), for the Vallo di Diano and Sanza basins; Di Niro & *alii* (1992), Di Niro & Giano (1995), Giano & *alii* (2000), Zembo & *alii* (2009), Giano (2011), for the Val d'Agri River valley; La Rocca & Santangelo (1991), for the Noce basin; Bousquet & Gueremy (1968), Schiattarella & *alii* (1994), Marra (1998), Schiattarella (1998), Gioia & Schiattarella (2006), for the Mercure basin.

neous reliable DEM fulfilling DTED-2 specifications (Bhang & *alii*, 2007). That of global high resolution DEMs is an active field in the research community working on radar interferometry. Recently the TanDEM-X spaceborne mission was planned by the German Space Agency to generate world-wide, consistent, high-precision Digital Elevation Models corresponding to the DTED-3 standard. The SRTM DEM used in this study has a m spatial grid and a 16 m absolute vertical accuracy (Bhang & *alii*, 2007).

The map of palaeosurfaces has been derived by identifying pixels with an altitude above 800 m a.s.l. and a slope below 6 degrees. These values characterize palaeosurfaces in southern Apennines and may change in regions having a different tectonic history. Each palaeosurface of this binary map was identified by means of algorithms based on an iterative local search and its geometrical characteristics (area, perimeter, orientations) were computed (Martino & *alii*, 2009).

In order to verify and refine such a DEM-based approach, a sufficiently wide area has been chosen as a test-site. In this 250 km^2-large area, palaeosurfaces have been mapped by both automatic and traditional (i.e. geomorphological-cartographic) methods: data comparison showed that the overlap of the land surfaces placed above 800 m a.s.l. is suitable for this study (cf. figs. 4 and 5). A similar process has been repeated on a regional scale, based on the remarkable literature on these topics (Di Niro & Giano, 1995; Amato & *alii*, 2003; Ascione & *alii*, 2003; Schiattarella & *alii*, 2003; Boenzi & *alii*, 2004; Molin & *alii*, 2004; Gioia & Schiattarella, 2006, 2010; Martino & Schiattarella, 2006; Putignano & Schiattarella, 2008), revealing a good fit also in this case.

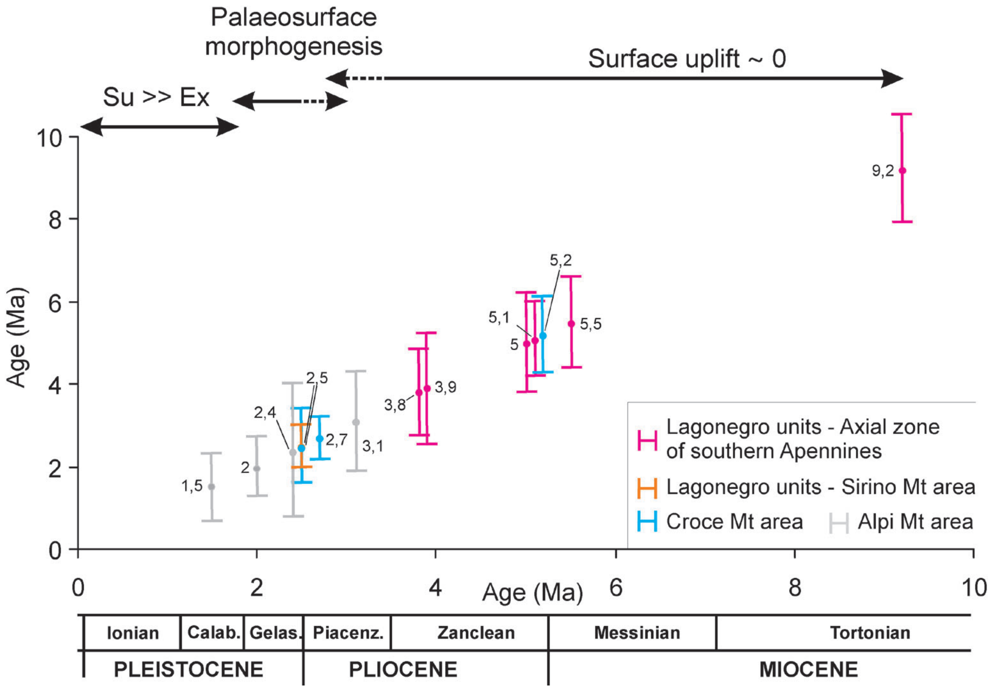


FIG. 3 - AFT ages from the southern Apennines (after Aldega & *alii*, 2005, and Mazzoli & *alii*, 2008). It should be noted that the younger cluster groups cooling ages included in the 2.4-2.7 Ma range (in turn comprised in the wider 3.9-1.5 Ma set) and may represent the exhumation episode linked to the relatively fast planation of the chain during the Pliocene-Pleistocene transition, whereas the older clusters (at about 5 and 9 Ma) have to be attributed to tectonic denudation phenomena (i.e. low-angle extension) leading to the genesis of the non metamorphic «core complex» of the southern Apennines (Schiattarella & *alii*, 2003, 2006; Invernizzi & *alii*, 2008; Mazzoli & *alii*, 2008).

It is useful to note that the most part of the high-altitude flat land surfaces are identified as erosional features cutting old, conservative, structurally complex, and variously tilted rocky successions; only a few amount of sub-horizontal surfaces above an altitude of 800 m a.s.l. can be ascribed to relatively small depositional features, such as stratigraphical tops of Quaternary undeformed sediments of different nature (karstic infill and limno-palustrine deposits in many cases). For this reason, one can conclude that synoptic or statistical comparisons between mapped and DEM-extracted morphological elements of the physical landscape are almost totally based on the real taxonomic similarity of the confronted categories.

Statistical analysis of morphological elements

The number of palaeosurface remnants extracted by the DEMs of the Sila Massif and of the Campania-Lucania segment of the southern Apennines are, respectively, 3804 and 5864. All these elements have an area larger than 0.01 km^2. The cumulative frequency distributions of their spatial extensions, derived by counting the number of remnants with an extension larger than a given value A, are plotted in figure 6. These distributions flatten out for areas smaller than about 0.06 km^2. It is worth noting that this change in distributions occurs at values larger than the minimal spatial resolution of the dataset, given by the spatial extension of each pixel corresponding to $8.1 \cdot 10^3$ m^2. Thus, it does not appear to be an artifact due a lack of completeness of the dataset. For spatial extensions in the range from Exp(11.5) m^2 (≅ 0.10 km^2) to Exp(13) m^2 (≅ 0.44 km^2), the frequency distributions in the Campania-Lucania Apennine (hereafter CLA) and Sila Massif (hereafter SM) are both characterized by a power law with an exponent of approximately –1.2, that is $N(area > A) \cong A^{-1.21}$. The Pearson coefficient of linear correlation is 0.92 corresponding to a goodness-of-fit exceeding 95%. The spatial extension of palaeosurfaces follows a power law also for values larger than Exp(13) m^2 (≅ 0.44 km^2), even if power law coefficients are different in this range. It has been estimated a coefficient equal to 1.56 in CLA and to 0.69 in SM. In both cases, the Pearson coefficient of linear correlation is 0.92 corresponding to a goodness-of-fit exceeding 95%. Table 1 summarizes the properties of power laws characterizing the cumulative frequency distributions of palaeosurfaces spatial extension in CLA (and its subdomains Maddalena Ridge, Pollino-Lauria-Orsomarso Mts, and Cilento region) and SM. The fragmentation index of palaeosurfaces can be defined as:

$$I_{fr} = \frac{A_{pal}}{N_{pal} \cdot A_{tot}}$$

where A_{pal} and N_{pal} are, respectively, the total area and the number of palaeosurface remnants, and A_{tot} is the surface area of the whole studied region.

TABLE 1 - Properties of power laws characterizing the cumulative frequency distributions of palaeosurfaces from the study areas

Study area	A_{ps}/A_{tot}	n_{ps}	I_f
Campania-Lucania Apennine	0.0085	5568	$1.97 \cdot 10^{-6}$
Maddalena Ridge	0.0217	1158	$18.7 \cdot 10^{-6}$
Pollino-Lauria-Orsomarso Mts	0.0174	1410	$12.3 \cdot 10^{-6}$
Cilento region	0.0189	767	$24.7 \cdot 10^{-6}$
Sila Massif	0.0962	3805	$25.3 \cdot 10^{-6}$

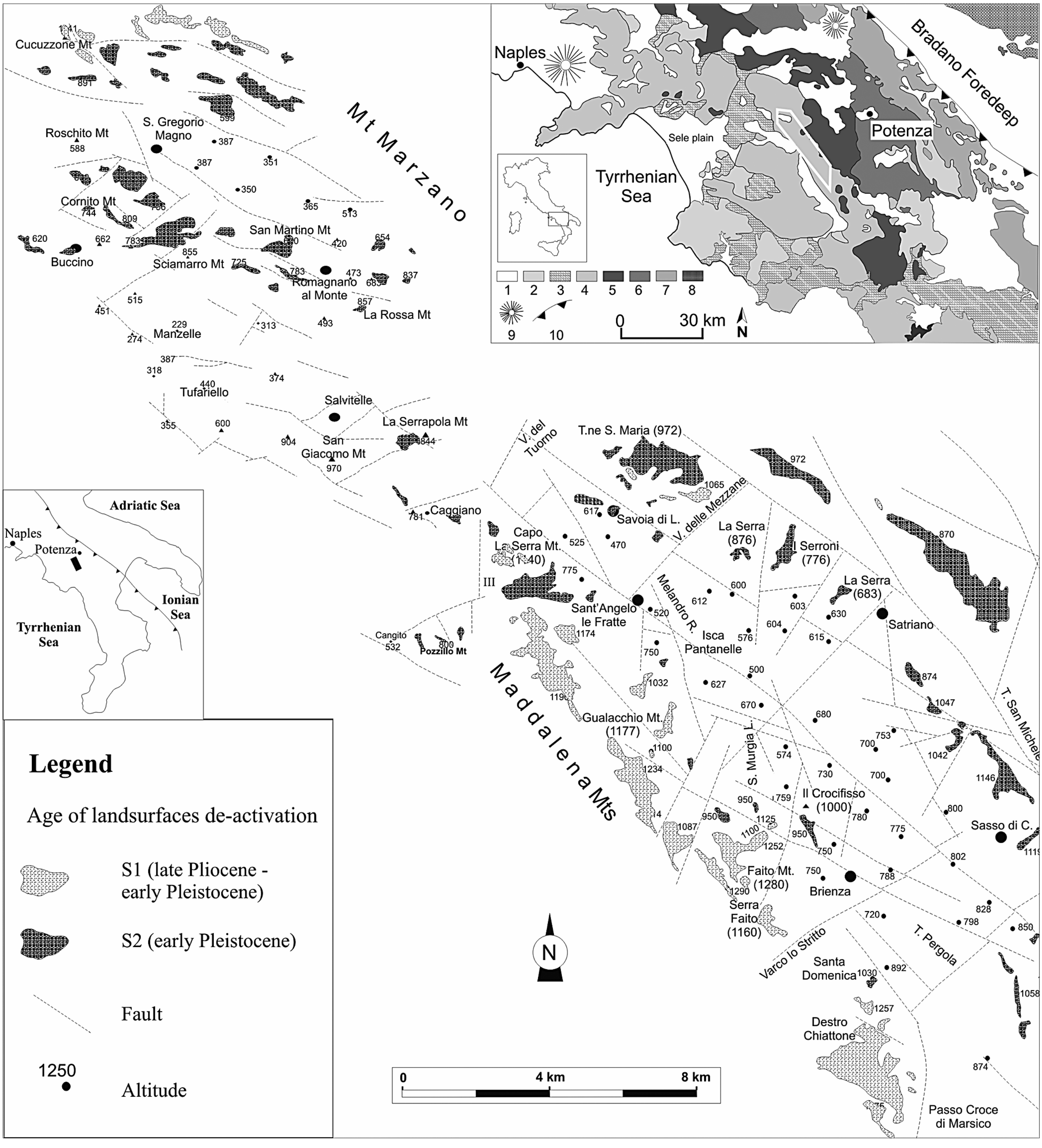


FIG. 4 - Morphostructural map showing the plano-altimetric arrangement of the erosional land surfaces from the test-area of the southern Apennines. Rectangular box: geological sketch map of the southern Apennines (modified from Pescatore & *alii*, 1999). The test-area are represented into white box. Legend: 1) Pliocene to Quaternary clastic deposits and volcanic products; 2) Miocene syntectonic deposits; 3) Cretaceous to Oligocene ophiolite-bearing internal units; 4) Mesozoic-Cenozoic shallow-water carbonates of the Apennines platform; 5) lower-middle Triassic to Miocene shallow-water and deep-sea successions of the Lagonegro-type Monte Arioso unit; 6) Mesozoic to Miocene deep-sea successions of the Lagonegro-type Groppa d'Anzi unit; 7) Cretaceous to Miocene deep-sea successions of the Lagonegro-type Campomaggiore unit; 8) Mesozoic-Cenozoic shallow-water carbonates of the Apulian platform; 9) Volcanoes; 10) thrust front of the chain.

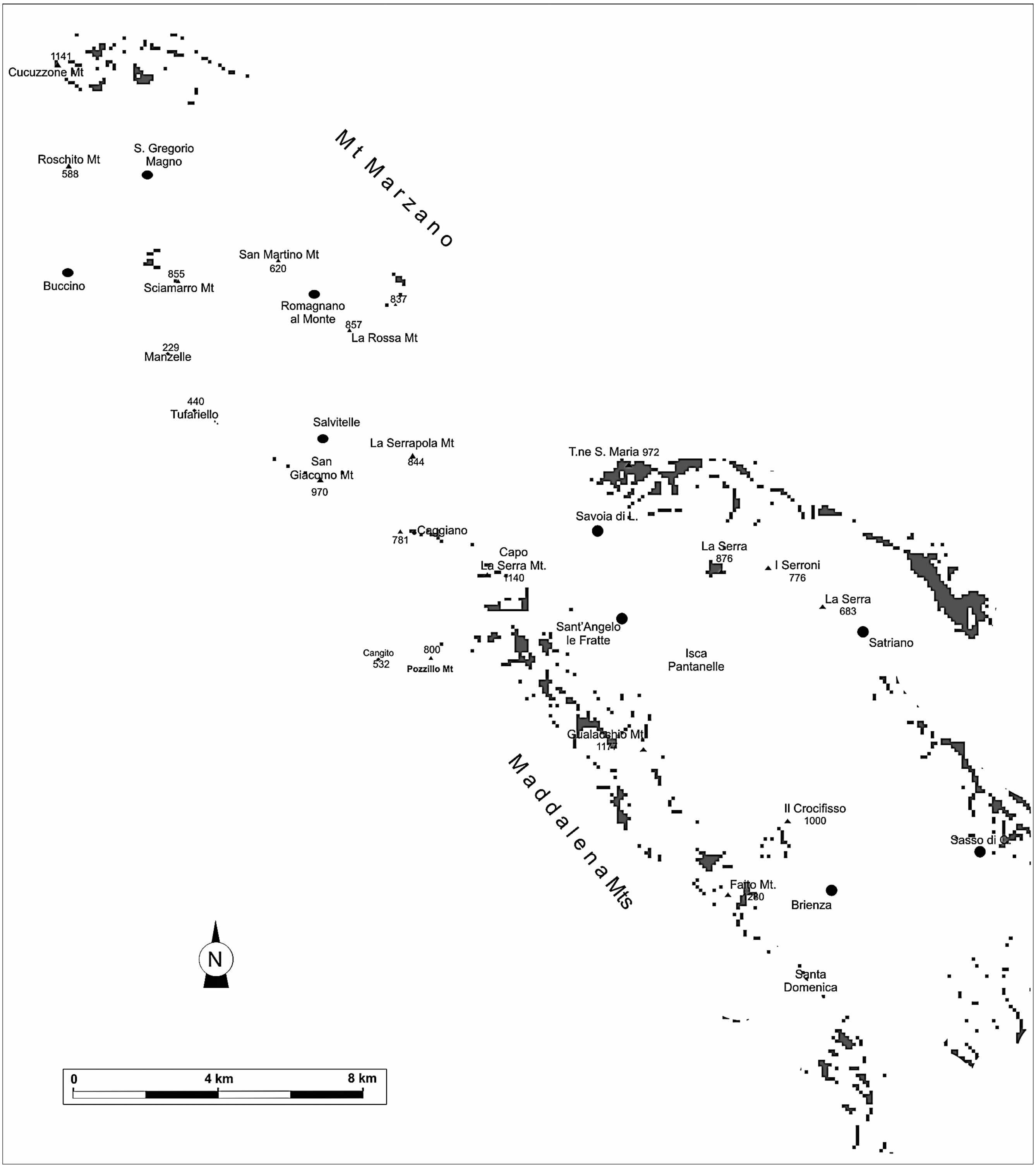
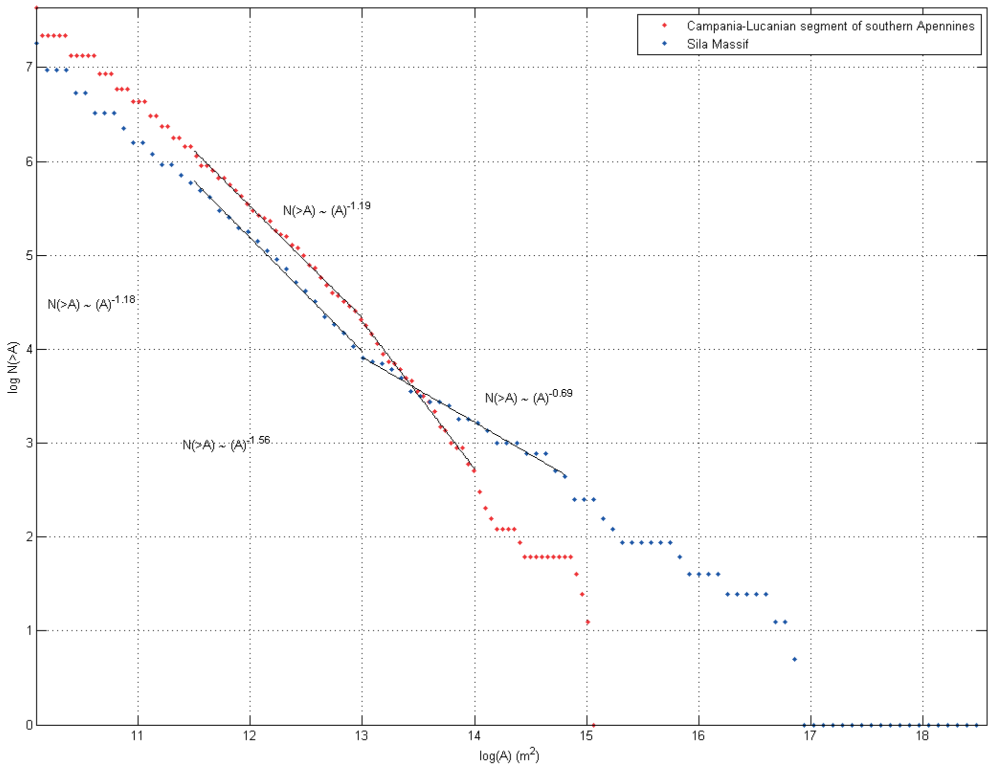


FIG. 5 - DEM-extracted erosional land surfaces from the test area of the southern Apennines with an altitude above 800 m a.s.l. and a slope below 6 degrees.

Low values for the fragmentation index indicate a larger breaking-up of palaeosurfaces. Hence, results in table 1 have shown that the fragmentation process has been more intense in the Maddalena Ridge and Pollino-Lauria-Orsomarso Mts than in the Cilento region and Sila Massif.

The threshold between the regions of validity of the two power laws in each dataset is estimated to be 0.44 km^2. Departure from linearity for spatial extensions larger than Exp(14) m^2 ($\cong$ 1.2 km^2) in CLA and Exp(15) m^2 ($\cong$ 3.27 km^2) in SM can be attributed to undersampling ar-

FIG. 6 - Cumulative frequency distributions related to the palaeosurfaces of the two test areas located at an altitude above 1000 m a.s.l.



tifacts. This result suggests the existence of the sub-populations in the dataset of palaeosurfaces identified in both geographical areas, as confirmed by a simple quantile-quantile analysis. Such analysis is used to determine whether two samples come from the same statistical distribution. If this is the case, samples lie along a strait line. Figure 7 reports the quantile-quantile plot of CLA vs. SM datasets. The spatial extension of palaeosurfaces are given

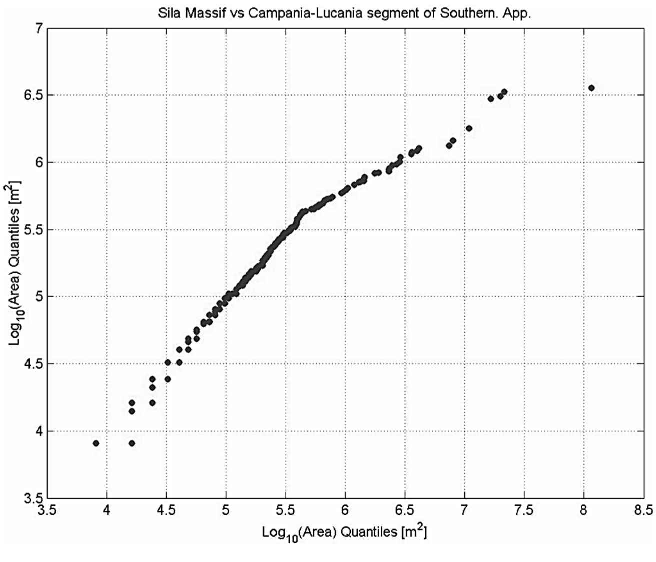


FIG. 7 - Quantile-quantile plots of palaeosurfaces areas of Sila Massif vs. Campania-Lucania segment.

in logarithmic units. The plot shows a linear behaviour with a clear knee between 5.6 and 5.7, corresponding to a range between 0.4 and 0.5 km^2. This means that two sub-populations are present in both datasets. Smaller palaeosurfaces (before the knee) follow the same distribution in both the SM and CLA. On the contrary, larger palaeosurfaces (after the knee) belong to a different population. In other words, the sub-population identified before the knee in SM and CLA traces the same distribution which is different from the common distribution followed by the sub-populations after the knee.

A closer analysis of the geometric properties of land surface elements is furnished by diagrams in figures 8 and 9 (CLA and SM, respectively). Each palaeosurface is represented as a point whose polar coordinates are given by its spatial extension and orientation. The orientation is computed as the angle between the x-axis and the major axis of the ellipse having the same second-moment as the shape of palaeosurface on the binary map. In both figures, a belt composed of palaeosurfaces with small extension and random orientation can be recognized. Beyond a polar distance of 5.7 on a logarithmic scale, corresponding to about 0.5 km^2, there are only a few palaeosurfaces. They have a large extension and a well defined orientation. The Sila Massif (fig. 9) shows less elements of such large remnants than the Campania-Lucania segment of southern Apennines (fig. 8). It is worth of note that the directions of the large palaeosurfaces correspond to the strikes of the main faults of the orogenic chain.

Although the fragmentation processes of the summit paleosurface – and, more in general, of the three or four

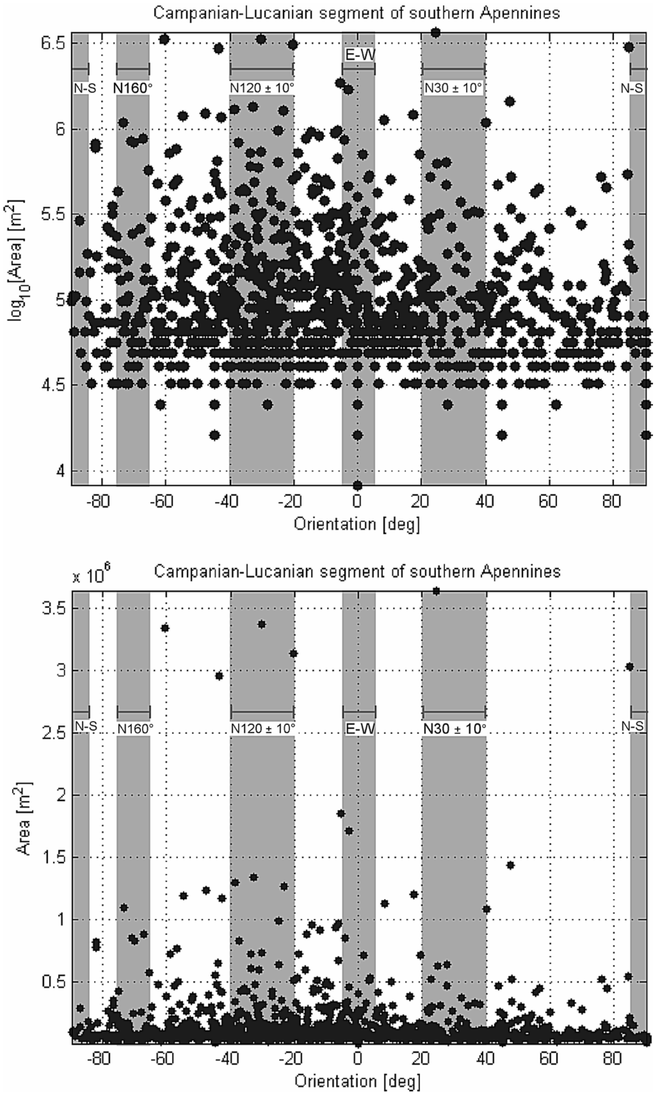


FIG. 8 - Representation of extension and orientation of palaeosurfaces in the Campania-Lucania segment: (top) areas are on a logarithmic scale; (bottom) areas are on a linear scale.

main land surface orders featuring the southern Italian Apennines – seem to be largely linked to the Quaternary tectonic activity (mainly block faulting), also the role of the fluvial dissection due to not tectonically controlled streams has to be taken into account. Further, both paleosurface remnants and hydrographic networks show power law distributions and fractal dimensions, so remarking the link between the fragmentation process and the fluvial net evolution. Anyway, to test the behaviour of the hydrographic nets from the study area, five catchments of southern Italy have been examined from a quantitative point of view. In particular, the statistical properties of the fluvial networks have been stressed using a number of streams vs. hierarchical order diagram. The hierarchical channel arrangement has been also computed with the aim to appreciate the role of geological and morpho-structural peculiarities on a catchment scale. Amazingly, the hierarchical properties of the drainage network appears to be very similar in all the basins (fig. 10), although the single catchments are characterized by very contrasting geological settings and quite different geomorphological features. This property can be interpreted as a result of the scarce sensitivity of the drainage systems to the litho-structural control whereas it seems remarkable the super-regional climate influence.

Interpretation of DEM-extracted data

The non linearity of the quantile-quantile plot (fig. 7) indicates that smaller and larger palaeosurfaces do not come from the same probability distribution in both the Sila Massif anf the Campania-Lucania segment of southern Apennines. Futhermore, the analysis of the cumulative

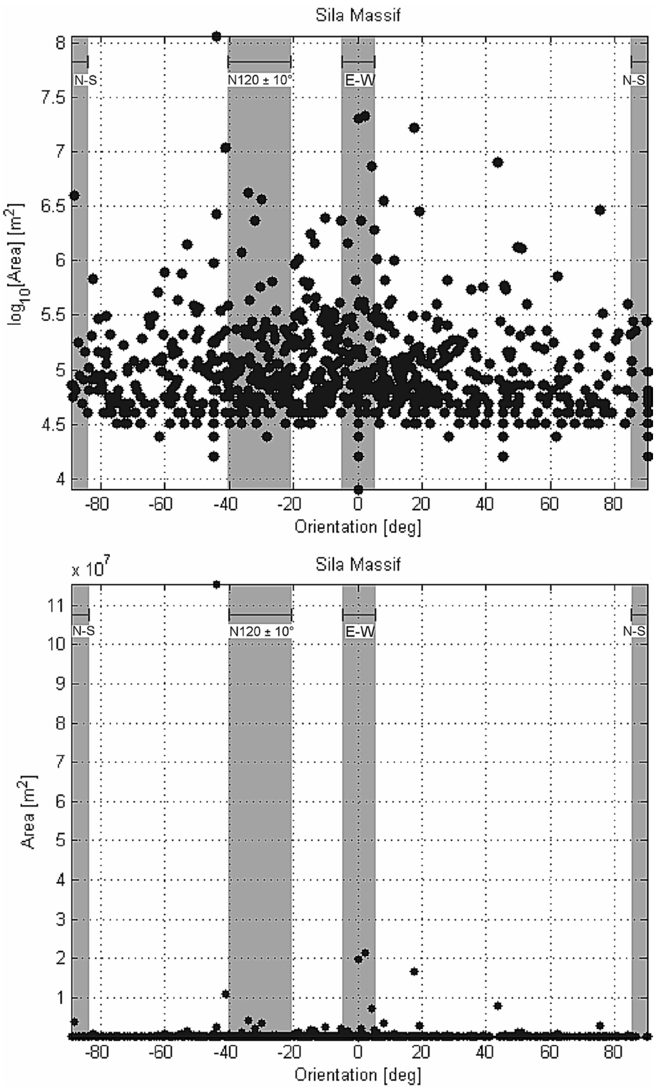
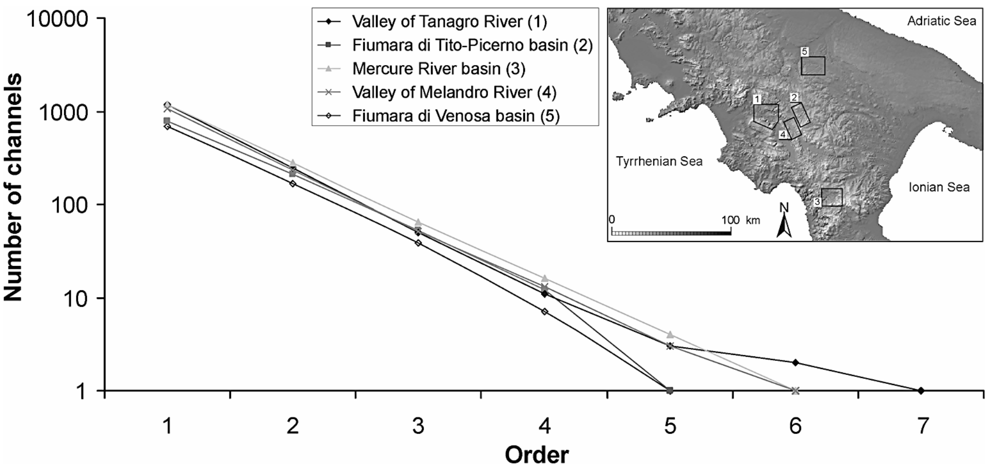


FIG. 9 - Representation of extension and orientation of palaeosurfaces in the Sila Massif: (top) areas are on a logarithmic scale; (bottom) areas are on a linear scale.

FIG. 10 - Plot of the number of channels for each hierarchic orders in five basins of the southern Apennines.



area frequency distributions put in evidence the existence of two populations of palaeosurfaces in the two study areas. In both cases the threshold between the two populations was found to be about Exp(13) m^2 ($\cong$ 0.44 km^2).

The close agreement between the slope of best fitting straight lines to frequency distributions before the above threshold could be explained in terms of a common surface segmentation genesis, probably related to a common climate-driven erosion. This result shows an unexpected agreement with the representation of the hierarchic arrangement of several drainage basins of the southern Apennines (fig. 10). Such basins show different tectonic structures, lithological characters, and morphostructural features (Schiattarella & *alii*, 2003, 2006, 2008): all these factors do not influence significantly the distribution of the number of channels per hierarchical order, which can be therefore considered an invariant parameter (except for the number of high order streams of some basins, depending on the different size of the catchments). One can conclude that climate is a prominent control factor of the hierarchical arrangements of the fluvial nets draining the axial zone of the chain. Indeed, the analysis of the hierarchical properties of the drainage network seems to confirm that climate-driven fluvial erosion processes have mainly controlled the fragmentation of the palaeosurfaces. On the other hand, the good correspondence between the directions of the large palaeosurfaces and the strikes of the main faults of the chain suggests that the first stage of palaeosurfaces fragmentation is related to the activity of the faults.

As time flows, erosion-induced fragmentation increases the number of small-area surfaces and reduces the average area of fragmented surfaces. Hence, the time evolution of erosion effects, producing smaller and smaller surfaces, increases the slope of the left part of figure 6 and possibly displaces the border towards large area values.

Both the slope and border depend on the elapsed time measured from the starting of erosion, on the climatic factor intensity and, of course, on the surface geology. The of figure 6 could be useful to extract information about past climatic environment and climatic changes. Beyond this threshold value, the cumulative area-frequency curves of the two datasets remarkably differ. In the Sila Massif a Hurst coefficient H < 0.5 has been found denoting a greater randomess with respect to the Campania-Lucania segment where H > 0.5. This different behavior could be related to the different tectonic activity in the study areas. Both studies area, even if characterized by different tectonic histories, experienced the same erosion-induced fragmentation as expected being all areas studied in this work included in a narrow range of latitude and hence characterized by the same climatic environment.

FINAL REMARKS

Apatite fission track analysis on rocks belonging to different tectonic units of the axial zone of the southern Apennines indicates a concordant middle to late Pliocene final cooling age of ca 2.5-2.6 My (fig. 3). Although the geothermal gradient is poorly constrained and the exhumation rates can be affected by errors, the values of the exhumation rates are significantly higher than estimated denudation and uplift rates. An exhumation rate of about 1.6 mm/yr for the last 3 My can be in fact inferred from thermochronometry, remarking the existence of past erosional processes faster than the recent and present-day exogenic dismantling, whose velocities have been obtained by our palaeotopographic reconstruction (Schiattarella & *alii*, 2008; Gioia & *alii*, 2011). Tectonic denudation processes has been accounted for the exhumation of Mesozoic core of the chain during older periods (from late Miocene to early-middle Pliocene) of the orogenic evolution (Schiattarella & *alii*, 2003, 2006), but they seem not suitable for the time interval here considered.

Regarding the genesis of the summit palaeolandscape, an attempt of morpho-stratigraphic correlation of many remnants has been done on a regional scale. The reconstruction of the original land surface palaeomorphology allowed to infer a probable origin at the sea level by marine erosion (Martino & Schiattarella, 2006). Such a genetic process is compatible with the very fast rates of the palaeosurface morphogenesis. Marine erosion linked to eustatic rising can be taken in consideration as an efficient mechanism of planation on a regional scale, able to sculpture huge flat landscapes and to dismantle large volumes of rocks. It is probable that AFT data cluster at 2.5-2.6 My could really represent the age of formation of the palaeosurface of the southern Apennines: in such a case, the higher denudation rates may be due to the rapid dismantling of shaly units (e.g. Liguride units, i.e. ophiolite-bearing «internal» units, Sicilide units, mainly composed of deep-sea polychrome clay, and Miocene Flysch units) which tectonically or stratigraphically covered the Campania-Lucania carbonate platform.

A quantitative analysis of an interferometric SRTM DEM for the identification of the statistical properties of southern Italy palaeosurfaces has been here presented. The analysis concerned two study areas characterized by the same present-day climate environment and similar palaeo-climate conditions, but featured by quite different tectonic settings: the Campania-Lucania Apennines and the Sila Massif in southern Italy. The cumulative frequency distribution of palaeosurfaces as well as a quantile-quantile analysis show the existence of two populations in both study areas. The threshold area value between the two populations is about 400 squared meters. Below this value, the surface fragmentation process has the same scaling properties in both datasets. Above this threshold value the two cumulative frequency distributions differ. The representation of palaeosurfaces in a polar diagram in terms of their extension and orientation clearly discriminate a set of a few palaeosurfaces with an area larger than 500 squared meters and well defined orientations from a cloud of uniformly distributed palaeosurfaces having small area and random orientation.

These properties are interpreted in terms of a common climate-driven fluvial erosion process and different tectonic activities in the two study areas. Neotectonic behaviour is expressed by an uniform block uplift in the Sila Massif, with a major kinematic role of the fault-bounded borders, whereas the Quaternary activity of the dense fault network of the Campania-Lucania Apennines assign to this sector of the chain a strong non-homogeneity of the uplift pattern.

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(Ms. received 1 November 2012; accepted 1 May 2013)